

Growing Green Guide

**A guide to green roofs, walls and facades in
Melbourne and Victoria, Australia**

February 2014

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The project partners reserve the right to make changes to the guide at any time.

Foreword

by Sidonie Carpenter

Sidonie co-founded Green Roofs Australasia, the peak body for the green roof, wall and facade industry, in 2007. She was president of the association for almost four years and is currently the board member for Queensland. Sidonie has a landscape architecture practice in Brisbane.

Building one green roof will provide benefits for a small number of people and the local environment, but developing this *Growing Green Guide* provides the knowledge and confidence to implement innovative and good quality green roofs and walls for years to come. It is what the green roof and wall industry needs in able to plan, design and maintain quality green roof and wall systems throughout Australia.

Green Roofs Australasia was founded in 2007 as the industry body to promote and support the case for green roofs and walls. It is with the development of Australian guidelines such as the *Growing Green Guide* that we will see the industry grow and strengthen.

Cities around the world have found green roof support and development has strengthened following the publication of how-to guides like this.

Given the predicted impact that climate change and population growth will have on our urban environment, can we afford not to invest in these types of sustainable solutions? Green roofs and walls provide a wide range of environmental, economic and social benefits, both public and private. They can reduce urban heat loadings and stormwater run-off, increase the energy efficiency and liveability of buildings, provide a range of habitat outcomes and even produce food. These guidelines will help to develop an understanding of the technology and build knowledge about the benefits and methods of green roof/wall/facade design, construction and maintenance for all sectors of the industry.

The guidelines have been written for Melbourne and Victoria but much of this information has national and international relevance. The *Growing Green Guide* team has issued an open invitation to others to use the guidelines' contents to develop additional resources, or even produce a second version through their Creative Commons licensing.

This guide is only one of three main outputs developed by the *Growing Green Guide* project team – a policy options paper and feasibility study and design for four demonstration sites have also been completed. I encourage you to look at the *Growing Green Guide* website: www.growinggreenguide.org . Here you will find the comprehensive policy options paper for use by government and others in developing policies to encourage green roofs and walls and an opportunities assessment for demonstration green roof and wall sites in each partner council's municipality.

With these guidelines, I look forward to seeing the number of green roofs, walls and facades increase across Victoria and Australia, and I encourage you to read the sections that are relevant to you. While the publication of the guidelines marks the completion of the *Growing Green Guide* team's planned work, this is not the end of the *Growing Green Guide* project; it is the start of mainstreaming green roofs and walls into our built environment.

I congratulate the Inner Melbourne Action Plan (IMAP) councils of Melbourne, Port Phillip, Stonnington and Yarra, along with the State Government of Victoria and The University of Melbourne, on the delivery of this project and hope to see the guidelines further developed in coming years as we learn more about how these systems can deliver long term sustainable solutions across Australia.

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Preface

The *Growing Green Guide* ('the guide') has been developed with advice from industry experts and knowledge from academic research, to explain how to create high quality green roofs, walls and facades.

The development of the guide was supported by four inner Melbourne local governments through the Inner Melbourne Action Plan (the cities of Melbourne, Port Phillip, Yarra and Stonnington) and by the State Government of Victoria, through the Victorian Adaptation and Sustainability Partnership. The University of Melbourne is a project partner.

This guide is written for professionals who may be involved in the design, construction and maintenance of green roofs, walls and/or facades. It is also relevant to developers, homeowners, and local and state governments.

The guide is targeted at projects based in Melbourne and Victoria, Australia, but is also largely relevant for a wider geographic area.

The *Growing Green Guide* is released under a Creative Commons licence to encourage periodic updates and use of the information in a range of places.

Section 1 explains what green roofs, walls and facades are, why they are important and the potential benefits of these systems for Melbourne and Victoria. It also provides answers to some frequently asked questions.

Section 2 introduces some of the research that has been undertaken on green roofs, walls and facades to provide a more specific understanding of their potential benefits.

Section 3 was written in collaboration with industry experts to provide technical advice on the design, construction and maintenance of green roofs, walls and facades.

Section 4 highlights several existing green roofs, walls and facades in Melbourne and Victoria, as case studies. Each example provides a description of the project, its design and components used, maintenance, costs and results and reflections.



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Section 1

Introduction

Green roofs, walls and facades are becoming more common in cities across the globe. Growing numbers of Australians are realising the potential of these living systems to improve the quality of their built environment to provide social, aesthetic, environmental and economic benefits.

Like many other cities, Melbourne faces continued pressure from increasing urbanisation. Rapid population growth and urban development have transformed natural environments into areas of highly engineered infrastructure. Heat generation from cars, industry and commerce, coupled with the retention of the solar energy by buildings and paved surfaces, creates unnaturally warm city environments (known as urban heat islands). This can have negative effects on human health and wellbeing. The transition from the natural landscape to the built environment has also created large areas of impervious paved surfaces, creating problems such as loss of vegetation and habitat, increased surface run-off and flash flooding. Each of these issues is being exacerbated by an increasingly variable climate.

Collectively these issues present enormous environmental, economic and social challenges and require new ways of thinking to make our cities more liveable now, and into the future.

Many cities around the world recognise the importance of having green infrastructure; that is, natural landscape assets, including green spaces and water systems. Green infrastructure includes trees, parks, water sensitive urban design (such as wetlands and rain gardens) and green roofs, walls and facades.

Green roofs, walls and facades are appealing as a way of adding green infrastructure to a city because they can be included on new buildings or retrofitted onto existing buildings, and require little, if any, space at ground level. They are being used to compensate for the loss of urban greenery, and to provide localised cooling and aesthetic improvements in dense urban centres where there is insufficient space for other types of green infrastructure.

It is estimated that there are more than 50 green walls, more than 100 green roofs and hundreds of green facades across Melbourne. Yet there is limited Australian information about how to create and manage these types of green infrastructure. This guide provides technical advice on how to design, build and manage green roofs, walls and facades so they can provide multiple benefits over a long time span for building owners and the wider community.

Figure 1. Pressure builds over our cities, with the transition from natural landscapes to hard infrastructure, an increasingly variable climate and a growing population

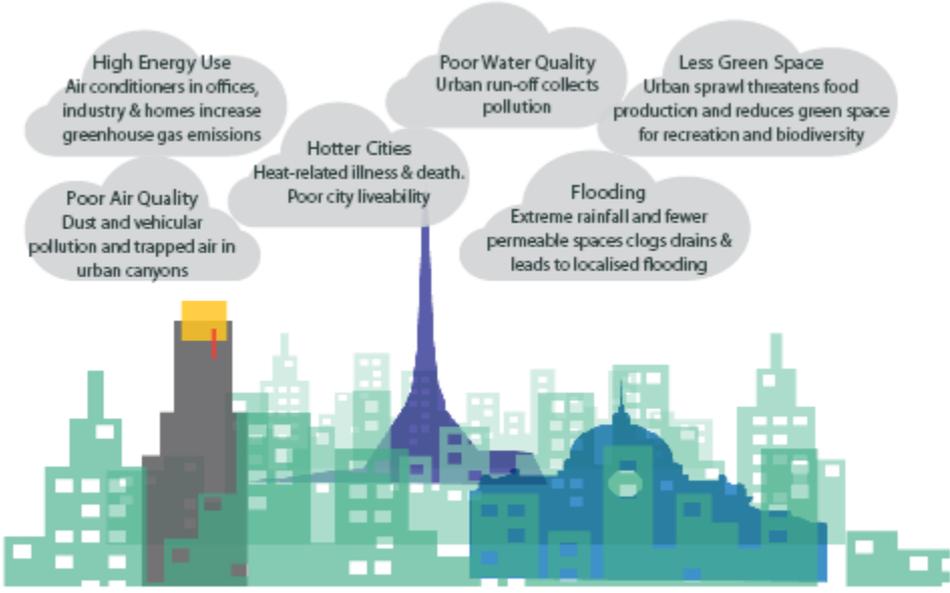
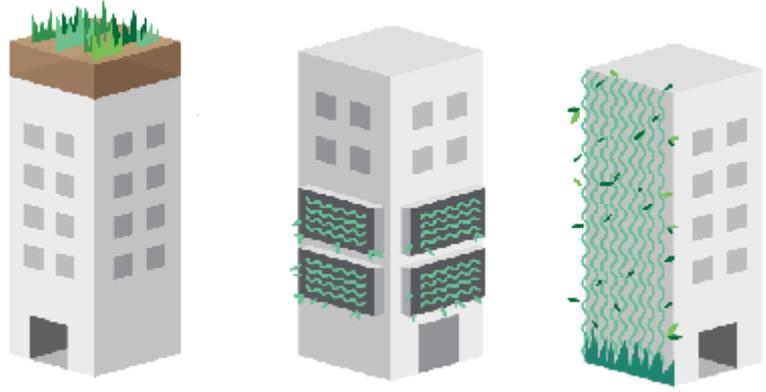


Figure 2. Vegetation can be added to a building as green roof, green wall or green facade



Definitions

Green roof

A vegetated landscape built up from a series of layers that are installed on a roof surface as ‘loose-laid’ or modular (that is, installed layer by layer on the roof or as pre-prepared layers in trays).

Green roofs are constructed for multiple reasons – as spaces for people to use, as architectural features, to add value to property or to achieve particular environmental benefits (for example, stormwater capture and retention, improved species diversity, insulation of a building against heat gain or loss).

Vegetation on green roofs is planted in a growing substrate (a specially designed soil substitution medium) that may range in depth from 50 mm to more than a metre, depending on the weight capacity of the building’s roof and the aims of the design.

Green roofs have traditionally been categorised as 'extensive' or 'intensive'.

Extensive green roofs are lightweight with a shallow layer of growing substrate of less than 200 mm deep, requiring minimal maintenance. They generally have lower water requirements and use small, low-growing plant species, particularly succulents. 'Ecoroofs' or 'brown roofs' are terms used to describe these extensive green roofs. Roofs that are designed and planted specifically to increase local plant diversity and provide habitat (food and shelter) for wildlife are known as 'biodiverse green roofs'.

Intensive green roofs are generally heavier, with a deeper layer of growing substrate, and support a wider variety of plant types. Because they can support a heavier weight, they are readily accessed by people. Intensive green roofs need more irrigation and maintenance than extensive roofs, and are highly engineered landscapes, often built directly on structures with considerable weight load capacity, such as car parks. 'Roof gardens' or 'podium roofs' are terms also used to describe these types of green roofs. 'Roof garden' is used particularly for sites where less space is dedicated to the vegetation and growing substrate and more to hard infrastructure such as decking.

Until quite recently, extensive green roofs were usually designed as lightweight installations that were not publicly accessible, while intensive green roofs were designed as amenity spaces for people. The boundaries between these types of roofs are now less distinct, and terms such as 'semi-intensive' or 'semi-extensive' are used to describe roofs that show elements of these major categories.

The International Green Roofs Association and other international green roof industry organisations use these distinct roof classifications. However, in this guide, green roofs are described in terms of their particular characteristics, such as depth of growing substrate. The authors of the guide consider that as each green roof is unique and may incorporate a mix of design elements, strict classification of types is no longer as helpful or relevant as it once was. Around the world, designers and their clients, and those who install and maintain green roofs, are exploring a range of creative solutions.

Green wall

A green wall is comprised of plants grown in supported vertical systems that are generally attached to an internal or external wall, although in some cases can be freestanding. Like many green roofs, green walls incorporate vegetation, growing medium, irrigation and drainage into a single system. Green walls differ from green facades in that they incorporate multiple 'containerised' plantings to create the vegetation cover rather than being reliant on fewer numbers of plants that climb and spread to provide cover. They are also known as 'living walls', 'bio-walls' or 'vertical gardens'.

Green walls provide an attractive design feature, but also add to building insulation by direct shading of the wall surface. They create cooler microclimates and improve local air quality, and provide the possibility of growing plants in locations that would not normally support vegetation. A wide range of plants is used on green walls, usually herbaceous, though some small shrubs can also be suitable. The provision of adequate light is an important consideration, particularly when planning an interior green wall, where artificial lighting may be necessary.

Many different proprietary green wall systems are available. Some are hydroponic and others use a growing substrate. Green wall structures vary from modular systems to sheet or board-based structures with felt pockets to contain and support plant life. All green walls require irrigation, often inclusive of fertiliser (fertigation). Fertigation solution can be re-used, but requires careful monitoring and management to ensure nutrients do not build up over multiple recirculation to damaging levels.

A well-designed green wall system will fulfil both design and functional aims by providing growing conditions suitable for the selected species, have a long lifespan, require minimal component replacement and have achievable demands for maintenance.

Green facade

A green facade is created by growing climbing plants up and across the facade of a building, either from plants grown in garden beds at its base, or by container planting installed at different levels across the building.

Climbing plants can attach directly to the surface of a building, or they can be supported on a structure independent of the building. The use of climbers that anchor themselves to a structure by twining stems or twining tendrils enables a green facade to be installed in front of solid walls or some other structure, to create a partition, privacy screen or sunshade. The degree of density of the facade coverage can be managed to suit the required function. For example, a facade designed to shade a building wall would ideally have greater foliage density than a screen installed near a window that is designed to allow at least partial views to the environment beyond the facade.

Green facades are often installed because they provide an attractive look to a building wall, or they may be used to block out a view, or to provide shade for a building. Green facades can create a cooler microclimate immediately adjacent to a building, primarily through direct shading of the building facade, but also from cooling from plant foliage (transpiration of water through the leaves), and evaporative loss of water from the growing medium. All climbing plants will provide some retention of stormwater, shading of the building, protection of its surface, and capture of airborne particulate matter and volatile gaseous pollutants. These benefits will be greater for evergreen species that retain foliage cover year-round.

For multi-level facades, particularly at height, wind can create significant problems for plant attachment. In these settings, twining climbers are preferred over plants that adhere directly to the building facade as the twining stems attach strongly around vertical and horizontal supports. Foliage may still be stripped under extreme wind conditions, so foliage type and size should be matched to the level of exposure and likely wind strengths at the site. In general, the higher the planting on a building, the more extreme the growing conditions are likely to be. Other factors of importance in multi-level facade design include planter box design (volume, substrate, drainage), maintenance access and irrigation system design.

The distinction between green walls and green facades is not always clear. As the design and use of plants on vertical surfaces expands, systems become harder to define. For instance, a 'hybrid living wall' system has been created in Adelaide that uses both green wall and green facade technologies. This blurring of definitions is akin to the already acknowledged difficulties in classifying green roof types, where new designs merge what were previously considered different categories.

Benefits of green roofs, walls and facades

There is a range of benefits, outlined below, that can potentially be provided by green roofs, walls and facades. Some provide benefits to the public at large and some only benefit the building owner or occupants. It is important to recognise that the following benefits are only realised if the roof, wall or facade is planned and constructed well and has the supporting management required to sustain it. **Section 3** of this guide discusses the importance of design in realising the intended outcomes from any project. **Section 2** provides the research evidence for these benefits.

Increased property prices and other benefits for building owners

Building owners and developers are increasingly installing green roofs, walls or facades to add a point of difference, increase commercial returns, provide visual appeal and turn a building into a local landmark. Most building owners in Melbourne ignore the potential of

large, leasable spaces on rooftops that can be transformed into versatile recreation, amenity or productive facilities, or commercial spaces for bars, restaurants or cafés.

While the construction of a green roof, wall or facade can be independent from the rest of a building project, involving specialists early in the construction timeline will help to minimise risks associated with design development. Importantly, early design discussions will help ensure that the roof, wall or facade can be planned and incorporated in other building aspects such as drainage, irrigation, lighting and weight loading.

Green roofs can lengthen the lifespan of a traditional roof surface. They protect a roof's waterproof membrane from solar radiation and add insulating materials (vegetation, substrate and other layers) to reduce severe temperature fluctuations on the roof surface.

Stormwater management

Green roofs absorb and retain rainwater and can be used to manage stormwater run-off in urban environments. They can also filter particulates and pollutants. Stormwater run-off can be reduced or slowed because it is stored in the substrate, used by or stored in the foliage, stems and roots of plants, and also evaporates directly from the substrate. Additional water storage capacity in green roof systems can be provided through incorporation of a water retentive layer or drainage layer at the base of the green roof.

Several factors influence the extent to which a green roof can reduce the volume of water run-off into the stormwater system, including depth and properties of the growing substrate, type of drainage layer used and roof slope. Plants and drainage systems are important considerations in the design of a green roof for stormwater management. Details on research supporting stormwater management are provided in [Section 2](#).

Improved thermal performance

A significant benefit of green roofs, walls and facades is the potential for reducing building heating and cooling requirements. Green walls and facades can reduce heat gain in summer by directly shading the building surface. Green roofs reduce heat transfer through the roof and ambient temperatures on the roof surface, improving the performance of heating, ventilation and air conditioning (HVAC) systems. While there is great potential to cool buildings, research data and the results of modelling studies vary greatly in relation to the extent of the difference in temperature and the energy savings that are predicted for buildings with green roofs versus conventional roofs (see [Section 2](#)).

Cooling a city – urban heat island effect

Hard surfaces in urban environments, such as concrete, brick, glass, asphalt and roofing, have a high thermal mass, collecting the sun's heat during the day and re-radiating it slowly back into the atmosphere. This contributes to a rise in ambient temperature in cities, creating large, stable masses of hot air (urban heat islands), especially during periods of calm, still weather.

Temperatures can be reduced by covering a roof or wall with a layer of vegetation that shades building materials which would otherwise absorb heat. Evapotranspiration provides cooling effects, as water is evaporated from the soil and plants and plants transpire by taking water in through roots and releasing it through leaves. Energy from the sun that would otherwise heat the roof or wall surface and increase ambient air temperatures is instead used in the evapotranspiration process, resulting in latent heat loss that lowers surrounding air temperatures. When green wall and facade plants are grown on a support system that leaves a gap between the wall and the planting, hot air moves up by convection through the space between the wall and the vegetation, providing passive cooling.

A city-wide strategy to implement green roofs, walls and facades could help mitigate some of the negative consequences of urban heat islands, and consideration should be given to appropriate plant selection and substrate depth to maximise cooling potential.

Creation and preservation of habitat and ecological biodiversity

Green roofs can contribute to and enhance biodiversity by providing new urban habitats and specific habitats for rare or important species of plants or animals. Green roofs can also provide a link or corridor across urban 'ecological deserts' and assist in migration of invertebrates and birds. Designing for biodiversity requires consideration early in concept development with regard to plant species, food sources, habitat values, access points and building heights.

Aesthetics, open space and urban food production

The liveability of cities is increasingly dependent on the availability of and access to green open space. Green roofs, walls and facades can increase amenity and provide opportunities for food production, recreation, relaxation or commercial ventures.

In dense, rapidly growing urban areas, the contribution of green roofs, walls and facades to overall green space should not be underestimated. In inner-city areas especially, most space is occupied by buildings and related infrastructure and the opportunities for new parks and gardens is extremely limited. Green roofs, walls and facades can be used for multi-level greenery designs that connect with ground level green spaces.

Cleaning the air

Green roofs, walls and facades can contribute to the removal of gaseous pollutants from the air, although their effectiveness varies with plant species and area of cover. Plants with a high foliage density or with textured leaf surfaces that trap small particles also assist in removing particulate pollution, through dry deposition on the foliage or through rain wash. On a larger scale, green roofs, walls and facades can help to reduce overall environmental heat gain (re-radiation of heat from building materials with high thermal mass), in turn improving air quality as less photochemical pollutants are produced at lower air temperatures.

In interior environments, plants have been shown to have a significant capacity to reduce volatile organic compounds from the air. Carpets and other soft furnishings and office equipment are common sources of these gaseous pollutants; inclusion of vegetation, such as a green wall, can help to improve the air quality of the indoor environment.

Next steps

Read the frequently asked questions and the rest of the guide to understand the details of green roof, wall or facade systems, or seek advice from a professional in the industry to learn more about approaches that may be suitable to achieve particular identified aims for your site.

Section 2 details some evidence of the benefits of green roofs, walls and facades. In **Section 3**, technical advice is provided on how to design, construct and maintain green roofs, walls and facades. Finally, **Section 4** provides detailed case studies of a selection of Victorian green roof, wall and facade projects to give practical examples of design, construction and maintenance.

Frequently asked questions

Do green roofs work on new and old buildings?

Yes. Green roofs can be fitted to a range of roof types. A new building can be constructed to accommodate the weight loading necessary for a green roof. Some existing buildings will have the capacity to support a green roof, or additional structural support can be retrofitted to support the required increase in loading. A structural engineer must be engaged to clarify details of building structure and weight loading capacity.

Can I green any building?

Most building surfaces have the potential for greening. Challenging sites such as those in deep shade or with low weight-loading capacity, and tall buildings or sites with limited access, require specialist engineering, design and technical input.

Can a tile roof be greened?

Yes, but it requires design expertise and specialised systems that are not yet widely available in Australia.

Is irrigation necessary for a green roof, wall or facade?

All green walls and most green facades and roofs, require irrigation. It is possible to install a green roof with no irrigation, but this will limit the range of plants that can be used successfully and the potential benefits of the roof (such as summer cooling or aesthetically pleasing views of leafy plants). Some green facades grown in garden bed settings may not need irrigation.

Can I have a green roof on a slope?

Yes, but steeper slopes present a challenge, and require specialised design solutions, including drainage boards and systems to help hold substrates and plants in place.

How much water do you need?

There is no one answer, as calculating the water needed to sustain a green roof, wall or facade depends on climate and environmental influences, the design and type of system used, and on the substrate and vegetation characteristics. Explore alternative sources of water for use in irrigation, such as harvested and recycled water, to minimise reliance on potable water. Many green walls rely heavily on irrigation and it is essential to establish that supply can meet demand.

Will plants 'overtake' the roof or wall?

Vegetation maintenance on a green roof is important and should be factored in during the design phase of the project. Selection of less vigorous plants (species with low biomass) or those that do not seed freely will help reduce maintenance requirements. Green walls can be designed to have an air gap between the back of the system and the wall, to provide air pruning of roots. Green facades will require pruning to manage size and maintain effective cover.

How much do green roofs, walls and facades cost?

Costs will vary significantly between sites and projects. The case studies in this guide indicate costs for a range of projects of varying complexity for comparative purposes. The key factors that influence costs are the size of the roof, wall or facade; the design and type of materials used in the roof (for example, structural reinforcement, volume of growing substrate and components used in the mix, plants, system components, hard surfaces and furniture, etc.); requirements for access; and the requirements for ongoing maintenance (including inputs for irrigation, weeding, pruning, fertiliser).

Green wall technologies offer notable variation in costs, with relatively cheap domestic green wall products suited to small-scale DIY (do-it-yourself) applications, through to large and

small-scale custom-designed commercial systems. Each presents a different level of refinement and security for long-term success.

Will the green roof leak and cause problems?

Any roof has the potential to leak. Well-constructed green roofs, walls and facades will not leak or cause other structural damage to the building. Correct installation of waterproofing is essential on roofs and some walls, and leak detection systems can minimise risks on green roofs. Waterproofing membranes can actually last much longer under green roofs because they are protected from damage by the elements by overlying layers.

What is the typical lifespan of a green roof, wall or facade?

The lifespan is directly related to the quality of the design, construction and maintenance, and in particular, the longevity of the system components. Some green roofs in Europe have been in place for more than 75 years and are still performing strongly. There are many examples of direct façade greening in Melbourne that have lasted for decades. The projected lifespan of green wall and facade technologies that are more recent entries into the market are less well understood.

Will construction of a green roof, wall or facade cause delays in the construction of my building?

Although a green roof, wall or facade should be considered an integral component of a building, its construction can usually be done independently from the rest of the build, so it poses little risk in causing delays. It is very important to include the installation specialists in early design discussions and associated construction project timelines to establish the most efficient construction timetable and ensure that drainage, irrigation and lighting are designed to include the green roof, wall or facade.

Can I have solar panels on a green roof?

Yes. There are examples of green roofs in Melbourne and other parts of the world where green roofs have solar panels installed above them.

How much pruning will be needed if I grow a green facade on my building walls?

Pruning is usually required once or twice a year, although this will depend on the vigour of the plant species and the growing conditions. Annual pruning is important to control growth and keep vegetation away from building fixtures (lighting, heating or cooling equipment, drains).

Could I just paint my roof white to achieve summer cooling?

Increasing roof reflectance through a 'white roof' is one way of reducing heat gain through the roof. However, a white roof will not capture and retain stormwater, provide aesthetic benefits or increase biodiversity values. Paint eventually degrades and requires maintenance. Most white roofs cannot help insulate the building in the winter months and will therefore only improve the building's energy efficiency in the heat but not the cold. A green roof can help a building's energy efficiency year round.

How do I know if my building has the capacity for a green roof?

An architect, engineer and green roof provider are needed to ascertain that a green roof can be installed on a new building. To retrofit a green roof on an older building, consultation with an architect and/or structural engineer is necessary to determine the load-bearing capacity of the structure. Consult with green roof, wall or facade providers to discuss design ideas and solutions for the site.

Are green roofs, walls and facades environmentally sustainable?

Design of the system is paramount to how well it contributes to broad sustainability goals, such as pollutant filtration, thermal insulation, providing habitat or localised cooling. By considering how you design, operate and maintain your system you can also ensure that the

materials and practices used are environmentally sustainable now, and in the long term. This process is called 'life-cycle analysis'. Recycled waste products could be used (from the building materials to substrate materials) or local products sourced rather than imported materials to reduce the energy used in these components. Some systems may require more water than others, but if that water is sourced from harvested stormwater or recycled water, it may be more sustainable than a low water-using system that uses potable water. Considered application of fertiliser is required to ensure there is no negative effect from polluted run-off from the site. Management of weeds and pests in the vegetation through a maintenance regime will also contribute to overall sustainability outcomes.

Section 2

Evidence-based benefits of green roofs, walls and facades

The following section examines the benefits of green roofs, walls and facades that have been established by research. In most cases, experimental testing and/or computer modelling based on experimental data are used. In this overview, green roofs receive the most coverage because more research has been undertaken about them and firm conclusions can be drawn. Research into the most effective uses of green walls and facades is underway in many parts of the world.

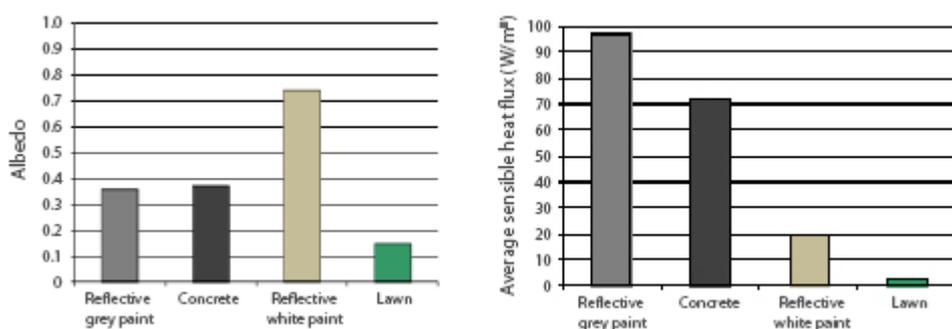
The information provided is from peer-reviewed scientific, architectural and engineering research journals, technical reports and books. References and links are provided to the original articles, although some of these are accessible only through journal subscriptions. Data used here have been summarised or re-plotted to demonstrate key points.

Reducing the energy budget of a building

Green roofs, walls and facades can reduce cooling and heating costs, by reducing heat gain or loss across the building surface.

Figure 3 shows the results of a study at Kobe University, Japan, where a green roof performed best out of four different roof treatments in reducing heat flux from the outside to the inside of the building. The roofs differed in albedo (the ability to reflect, rather than absorb, solar energy). A high albedo value means that more light is reflected and less is absorbed. A green roof planted with lawn grass had the lowest albedo, but was most effective at reducing heat flux into the building. Heat flux across the 'cool roof' treatment using reflective white paint was 10 times higher than for the green roof, although its albedo was almost five times greater. The sensible heat flux across the white roof surface is small because most solar radiation is reflected, and little is absorbed. Sensible heat flux across the green roof is small because of loss of latent heat through evaporation of water from plants and the growing substrate, even though the amount of solar radiation absorbed is high. Grey paint and concrete have similar reflectance, but heat flux with alternative cool roof paint (reflective grey) was greater than the bare concrete roof alone.

Figure 3. Albedo (ability to reflect solar radiation) and sensible heat flux under different roof treatments

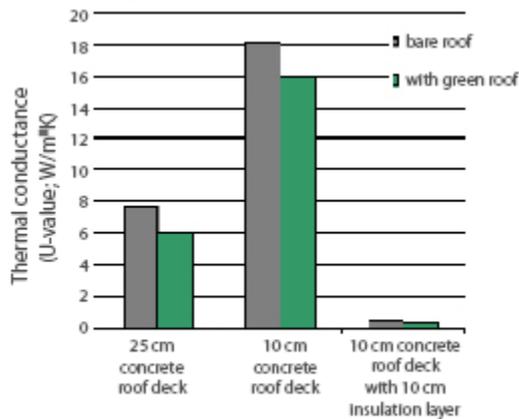


Source: Takebayashi H, Moriyama M (2007) Surface heat budget on green roof and high reflection roof for mitigation of urban heat island, *Building and Environment* 42: 2971-2979.

A green roof provides significant cooling benefits compared to an uninsulated bare roof, although the most effective cooling comes from inclusion of insulation under the roof. Modelling comparisons suggest that green roofs could be useful on poorly insulated

buildings to reduce the thermal conductance across the roof deck. Thermal conductance (U-value) is the inverse of the resistance to transfer of heat (R-value). A study conducted in Athens, Greece, modelled the effect of adding a green roof to concrete roofs of different construction. Figure 4 shows that a green roof lowers heat transfer across a 25 cm thick and a 10 cm thick uninsulated concrete roof.

Figure 4. Effect of a green roof on heat transfer (thermal conductance) modelled for different types of roof construction

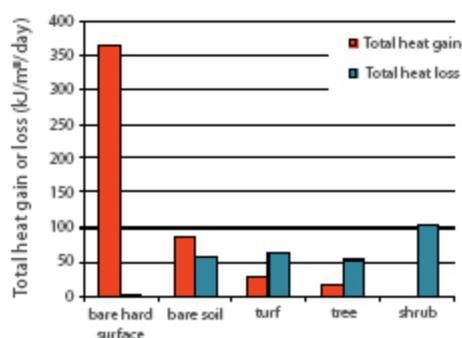


Source: Niachou A, Papakonstantinou K, Santamouris M, Tsangrassoulis A, Mihalakakou G, (2001) Analysis of the green roof thermal properties and investigation of its energy performance, *Energy and Buildings* 33: 719-729.

Insulation of a building translates into energy savings for both heating and cooling. In Melbourne, with a well insulated building, winter heating is likely to dominate total energy costs, although this will depend on heating and cooling set points preferred by the building's occupants. The R-value of an insulation material is a measure of its resistance to transfer of heat. Establishing the R-value offered by a green roof, wall or facade depends on a complex interaction of all the materials used, the depth of the growing substrate and the amount of water held in the substrate, as well as the plant selection, degree of coverage by plants and whether that coverage is present year-round. The following studies investigated the effect of green roofs compared to bare roofs on the thermal performance of buildings.

A study carried out in Singapore, comparing the effect of different vegetation types on a green roof with 40 cm deep soil, showed that heat gain was prevented, and heat loss was greatest under vegetation with the largest and densest foliage cover (*Raphis* palm used as a shrub) – see Figure 5. The bare hard roof surface accumulated and retained the most heat. Turf, and trees with an open canopy, provided less cooling benefit, with similar heat loss to that of bare soil. The reduction of heat gain and increased heat loss from soil, compared to the hard roof surface, is most likely due to evaporation of water held in the soil.

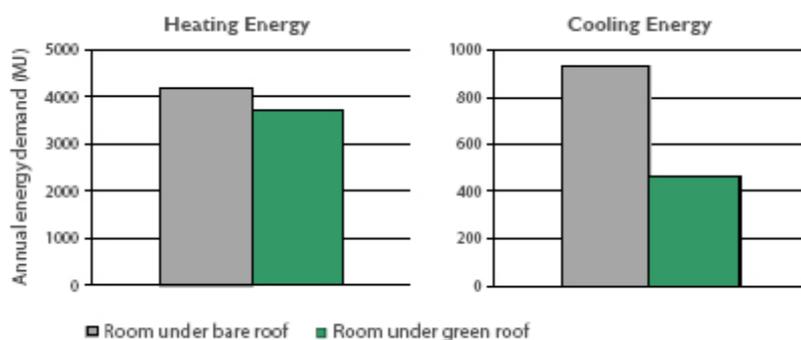
Figure 5. A comparison of thermal effects on a green roof under different types of vegetation cover



Source: Wong NH, Chen Y, Ong CL, Sia A, Investigation of thermal benefits of rooftop garden in the tropical environment, *Building and Environment* 38 (2003) 261-270.

Figure 6 shows the results of a study on energy demand under a green roof and bare roof in Melbourne. The building was described as having double brick external walls, a concrete slab floor and concrete roofs – no mention was made of ceiling insulation. Temperature measurements were made between September 2008 and July 2009, in a room with a conventional waterproofed concrete bare roof, and a room with a green roof installed over the roof deck. These measurements were used in a simulation to predict the effect of a green roof on annual energy costs. Parameters used in the model included cooling and heating set points of 24°C and 18°C respectively, and an assumption that the space was heated or cooled between 8 am and 6 pm. Results showed that cooling and heating costs for the room covered with a vegetated roof would be 50 per cent and 12 per cent lower respectively than for the same room with a conventional bare concrete roof. For a building constructed from less strongly insulating materials, although winter heating and summer cooling requirements would be higher, the green roof would achieve comparable energy savings.

Figure 6. Heating and cooling energy demand in a room under a bare roof and a green roof

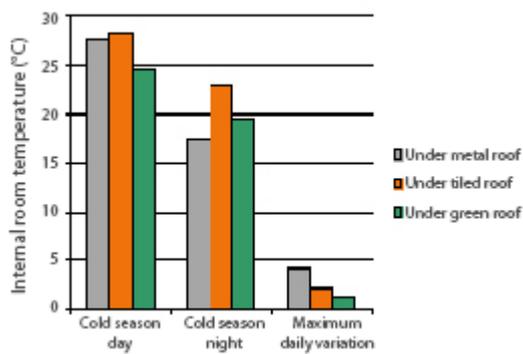


Source: Chen and Williams (2009) Green roofs as an adaptation to climate change: modelling the green roof at the Burnley campus, The University of Melbourne, Research Report for CSIRO Climate Adaptation Flagship.

One of the major benefits of the insulation provided by a green roof is the reduction of internal and external heat fluctuations. The stability of internal temperatures under a green roof is increased and contributes to thermal comfort year-round by preventing heat gain from the outside to inside in summer, and by reducing heat loss from inside to outside in winter. The construction of the roof deck and other building components plays a major role in determining the extent of heat gain or loss from a building.

Figure 7 shows the results of a study in Brazil that compared external roof temperatures with internal ceiling temperatures in a building with rooms covered by a green roof, metal roof or a ceramic tile roof. Measurements were made over a week in both warm and cold seasons. Heat flux was recorded between the three roof types and the internal surface of the ceiling inside each room, and internal air temperature was measured 1.5 m above the floor in the three rooms. The green roof was planted with a monoculture of a low-growing succulent herb (*Bulbine frutescens*) in a substrate 140 mm deep. The graph indicates that the room under the green roof showed the smallest variation in daily temperature during the day in the cold season: this was also the case during the warm season, with a maximum daily variation of 1.2°C.

Figure 7. Internal room temperatures under different roof types



Source: Parizotto S & Lamberts R (2011) Investigation of green roof thermal performance in a temperate climate: a case study of an experimental building in Florianópolis city, Southern Brazil, *Energy and Buildings* 43:1712-1722.

Green roof trials in Adelaide (June 2011-May 2012) compared two plots with 300 mm deep growing substrate to four plots with shallower, 125 mm thick substrate. Two of the shallow depth plots had a trafficable aluminium grating installed 150 mm above the surface of substrate to create an air gap. The aluminium grating treatment was tested to investigate the effect of shading of the vegetation. The substrates used were either a lightweight growing medium or a heavier substrate made from recycled brick and other inorganic materials. Temperature fluctuations of the underlying surface were smaller for the inorganic growing substrate with its higher thermal mass, than for the lightweight growing substrate. The variation in temperature across the entire day was halved with the aluminium grating installed over the substrate and vegetation. The grating created an increased insulation effect with a combination of shading, and from the creation of an unstirred air layer.

Source: Clay R, Wild N, Hopkins G, Goodwin C (2012) *Determining and understanding thermal characteristics of green roofs in the City of Adelaide*, Appendix 1 of Green Roof Trials Monitoring Report by Fifth Creek Studio for SA Government’s Building Innovation Fund and Aspen Development Fund No. 1.

Experimental studies on green walls and facades focus on the shading (and cooling) benefits that facade greening provides. Even though a broad range of factors influence how much shading a green facade offers (including the presence and type of a support structure, facade orientation and whether the climber is deciduous or evergreen), decreases in wall surface temperature of between 5°C and 10°C are common. The most useful assessments come from data collected throughout the year: in the future, longitudinal studies could provide additional value because outcomes are likely to change as the facade matures. To date, there is limited published data on thermal benefits from vertical greening in Australian conditions.

Table 1 shows the results of a Spanish study on green facades. Temperature measurements were made over a year on the north-east, south-east and south-west sides of a building in Golmés, Spain, that was covered with the deciduous climber *Wisteria sinensis* (Chinese Wisteria). The climber was grown on a steel mesh support system. Shading of the south-west face of the building provided the greatest cooling effect.

Table 1. Effect of a green facade on building thermal performance

Parameter measured	Outcome	Effect of the green facade
Difference in temperature in front of and behind the facade	1.4°C cooler in summer 3.8°C warmer in winter	Absorption of light and heat energy by foliage keeps the cavity temperature lower Facade support system creates a microclimate/unstirred air layer next to the wall even when stems are bare
Difference in surface temperature between bare wall and vegetated wall (summer)	Average bare wall temperature is 5.5°C higher Maximum temperature is 15.2°C higher	Full leaf cover provides effective shading and prevents heat gain by the building
Difference in relative humidity in front of and behind the facade	7% higher in summer 8% lower in winter	Evapotranspiration from leaves causes a local increase in humidity (and cooling) in summer which is not apparent when stems are bare

Source: Pérez G, Rincón L, Vila A, González JM, Cabeza LF (2011) Behaviour of green facades in Mediterranean Continental climate, *Energy Conversion and Management* 52:1861–1867.

Research undertaken in Adelaide investigated hybrid vertical greening systems that combine elements of green facades and living walls. Air temperature and solar radiation were measured in front of and behind the green facade. Although there was little reduction in air temperature in front of the green facade (relative to the air temperature in front of the adjacent bare brick wall), the wall surface temperature was considerably lower. The green facade wall surface temperature was 37 to 38°C, whereas the brick wall was 45.8°C.

Source: Hopkins G, Goodwin C, Milutinovic M, Andrew M (2012) *Post-construction monitoring report: Living wall system for multi-storey buildings in the Adelaide climate*. Prepared for the Government of South Australia.

Contribution to urban cooling

Concrete, bricks, glass and large areas of impervious paved footpaths and roads contribute to heat gain in urban areas. This, and the loss of shading and cooling from vegetation in high density urban development, contributes to the formation of urban heat islands: increased ambient temperatures that arise when warm stable air masses develop above cities, particularly during periods of calm weather and low wind speeds.

A modelling study conducted by CSIRO and the Nursery and Garden Industry of Australia investigated the likely effect of increasing vegetation cover in Melbourne’s Central Business District (CBD) on average summer daily maximum (ASDM) temperatures over the period of December through February. Remote sensing imagery from the 2009 summer was analysed, and showed that daytime land surface temperatures were significantly reduced by vegetation. An urban climate model was then used to predict urban temperature changes under different vegetation schemes for the 2009 climate, and for projected future climates in 2050 and 2090.

Comparisons were made using the CBD both in its present form as a reference (with respect to urban boundary and density of vegetation), and with increased densities of vegetation. Vegetation density was doubled at ground level, installed on green roofs, or both.

Green roof vegetation was 0.5 m high and covered 50 per cent of building rooftops completely. In all models, it was assumed that vegetation was irrigated, so that evapotranspiration rates did not vary significantly between different years. In the 2009 scenario, ASDM temperatures were reduced by 0.3°C by doubling the density of vegetation in the CBD, or by 0.4°C with green roofs. Increasing vegetation density both at ground level and with green roofs reduced ASDM temperatures by 0.7°C. In comparison, the creation of

large urban parklands reduced ASDM temperatures by 2°C. (Suburban areas were 0.5 to 0.7°C cooler than the CBD).

The same relative effect of vegetation on ASDM temperatures was predicted for 2050 and 2090. Green roofs, in conjunction with cooling from an increased density of street trees and park vegetation at ground level, could help to decrease urban temperatures, reduce summer heat stress and the peak electricity requirements for air conditioning.

Source: Chen D, Wang X, Khoo YB, Thatcher M, Lin BB, Ren Z, Wang C-H, Barnett G (2013) Assessment of Urban Heat Island and Mitigation by Urban Green Coverage, in *Mitigating climate change: the emerging face of modern cities*, Khare A, Beckman T (eds), Springer, Berlin, New York.

An Australian report outlines principles for choosing the green roofs, walls, facades, and other more traditional uses of vegetation to cool urban areas (collectively known as green infrastructure) for cooling of urban spaces in the Greater Melbourne area. The report is available at <http://www.vcccar.org.au/publications>

Source: Coutts A, Livesley S, Norton B, and Williams N (2013) *Urban Heat Island Report: Decision principles for the selection and placement of Green Infrastructure*, Victorian Centre for Climate Change Adaptation Research.

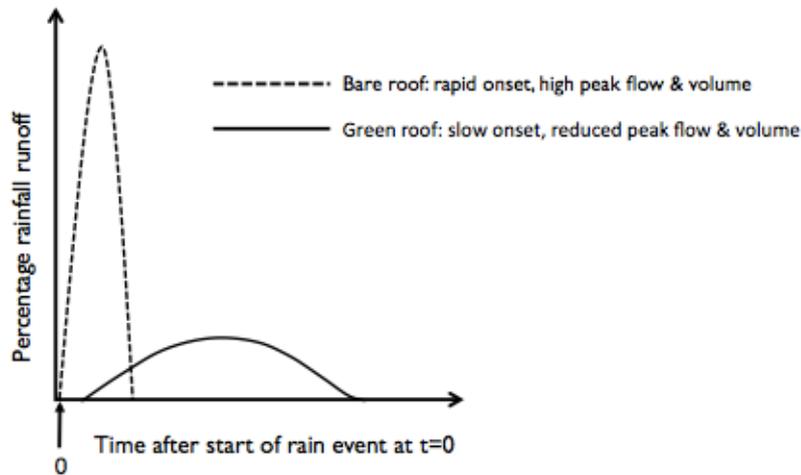
A 2005 study in Toronto, Canada modelled the effect of implementing green roofs on low-rise buildings with low slope and flat roofs of areas greater than 350 m², and concluded that green roofs, implemented as a city-wide strategy, could mitigate the heat island effect by reducing local ambient temperatures by 0.5 to 2°C. It was calculated that this could save Toronto homeowners and businesses CAN\$21 million annually by reducing the energy demand for mechanical cooling.

Source: Banting D, Doshi, H, Li J & Missios P, (2005) *Report on the environmental benefits and costs of green roof technology for the City of Toronto*, prepared for City of Toronto and Ontario Centres of Excellence – Earth and Environmental Technologies, Ryerson University, <<http://www.toronto.ca/greenroofs/pdf/executivesummary.pdf>>

Managing stormwater volume

Green roofs absorb and retain water and can be an effective strategy for reducing stormwater run-off in urban environments. When rain falls on a bare roof, run-off water flows into drains very rapidly. The rate of run-off depends on the slope of the roof as well as the volume of the rain event. When the rain stops, run-off continues until the roof is drained: any water remaining on the surface will evaporate. On a green roof, plants and growing substrate intercept rainfall. Some water will evaporate directly off plant foliage, but rain that falls directly onto the substrate, or drips off the foliage, percolates downwards. Some water is absorbed by substrate particles, and some drains down into underlying layers where it can be stored if these have the capacity to hold it (typically the drainage and protection/water retention layers). Excess water drains onto the roof and out into the stormwater system. So, on a green roof, both the time to onset and the time to peak flow of stormwater entry are delayed, and the overall time taken to drain the roof is increased, as shown in Figure 8. The overall volume of stormwater is reduced because of the retention by the substrate and other layers of the green roof.

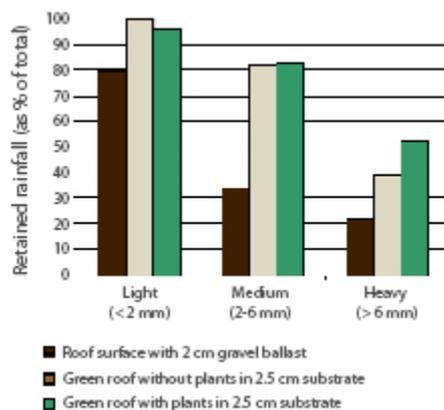
Figure 8. Theoretical graph comparing stormwater run-off from a bare roof and green roof



The advantage of using vegetation to manage stormwater run-off is that it increases the surface area available for rainfall capture, and thus helps slow the rate of entry and reduce the volume of stormwater. The height and spread of vegetation, as well as the type and diversity of species used affects how much rainfall plants can capture on their leaves, and how much water they release back into the environment through transpiration. Evaporation of water from the substrate also reduces the overall volume of stormwater.

Figure 9 shows data from an experimental green roof study in Michigan, USA, where rainfall retention was measured over 14 months. The three treatments were: a roof with gravel ballast only; an unplanted green roof; and a green roof planted with succulents (*Sedum* species). All roofs had a 2 per cent slope. Run-off was measured for rain events of different intensity. The green roof with plants retained the highest proportion of water from heavy rain events. For smaller rainfall volumes, the substrate-only roof was as effective as the green roof in retaining water. Both captured more water than the ballasted roof.

Figure 9. Rainfall retention under three roof treatments for rain events of different intensity

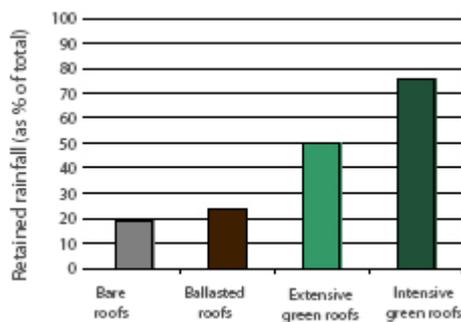


Source: Van Woert ND, Rowe DB, Andresen JA, Rugh CL, Fernandez RT, Xiao L (2005) Green roof stormwater retention: effects of roof surface, slope and media depth, *Journal of Environmental Quality* 34:1036-1044.

Note: When considering international research results, keep in mind climate differences to Australia. Many European and North American green roofs have very shallow substrates, such as the 2.5 cm deep substrates described in Figure 7. In Melbourne conditions, a minimum depth of 10 cm is recommended for a green roof substrate. Shallower substrates are likely to dry out too quickly, and plants will not survive.

Figure 10 shows the results of an analysis of published data on rainfall retention across a range of roof types. Data were analysed for five (5) bare roofs, eight (8) roofs covered with gravel ballast, 121 shallow (extensive) green roofs and 11 deeper substrate (intensive) green roofs, with average substrate depths of 0 mm, 50 mm, 100 mm and 210 mm respectively. Deeper substrate green roofs retained the most rainfall on average, with minimum and maximum retention of 65 per cent and 85 per cent respectively: for roofs with shallower substrates it was 27 per cent and 81 per cent.

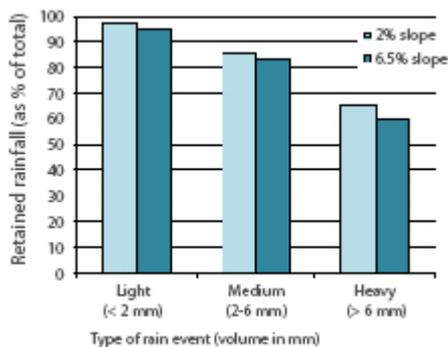
Figure 10. Rainfall retained by different types of green roofs



Source: Mentens J, Raes D, Hermy R (2006) Green roofs as a tool for solving the rainwater runoff problem in the urbanised 21st century? *Landscape and Urban Planning* 77:217-226.

Figure 11 shows how slope affects stormwater retention. Green roofs with 2 per cent and 6.5 per cent slopes were planted with succulents (*Sedum* species) in 4 cm deep growing substrate. Run-off was measured for rain events of different intensity. The difference in percentage run-off between the two slopes was greatest in heavy rain events, with the highest run-off observed from the more steeply sloped roof.

Figure 11. Rainfall retention on green roofs with different slopes



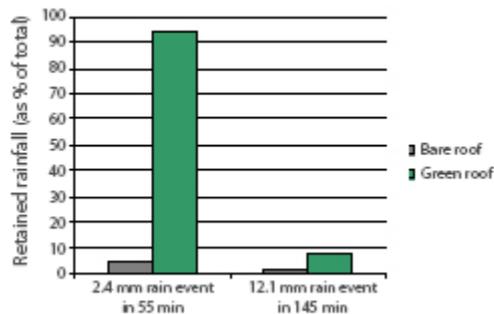
Source: Van Woert ND, Rowe DB, Andresen JA, Rugh CL, Fernandez RT, Xiao L (2005) Green roof stormwater retention: effects of roof surface, slope and media depth, *Journal of Environmental Quality* 34:1036-1044.

A green roof captures a higher percentage of rainfall during a light rain event than a heavy one. If the rain event is very small, there may not be any run-off from the green roof, especially if the substrate is dry. During intense rain events where a large volume of water is delivered in a short time, the substrate may not absorb all the rain that falls, even on a densely vegetated roof. In these situations, the vertical movement of water through the substrate dominates, although vegetated roofs usually still have lower run-off than bare

roofs. The run-off from intense or long rain events could be harvested and stored for irrigation.

Figure 12 shows how retention varies with different intensities of rainfall. Rainfall run-off was collected from a bare roof and a green roof with low growing herbaceous and succulent species planted in a growing substrate 10 cm deep. The green roof captures most of the volume of a small rain event. Although the green roof did not capture much of the rainfall from a more intense rain event, it did capture more than the bare roof.

Figure 12. Rainfall retention on a green roof under different rainfall scenarios



Source: Teemusk A, Mander Ü (2007) Rainwater runoff quantity and quality performance from a green roof: the effects of short-term events, *Ecological Engineering* 30:271-277.

Research examining four different green roofs in Auckland investigated rainfall retention in relation to substrate depth and composition. Peak flow per rainfall event from the green roofs was 62 per cent to 90 per cent less than run-off from a corresponding conventional roof. During winter, when plants are not actively using water from the substrate in transpiration, rainfall retention was reduced. It was found that water retention and peak flow are affected by the type of drainage layer used, and the horizontal distance that stormwater has to travel before it enters the perimeter gutter or point drains that lead off the roof. Increasing the distance to the drains, or using drainage layers that have some storage capacity (either granular aggregate or plastic cells with water-holding capacity), should increase the retention period on the roof.

Source: Fassmand-Beck E, Voyde E, Simcock R, Hong YS (2013) *4 Living roofs in 3 locations: Does configuration affect runoff mitigation?* Journal of Hydrology 490:11-20. See also Fassman-Beck EA and Simcock R (2013) *Living Roof Review and Design Recommendations for Stormwater Management*, prepared by Auckland UniServices for Auckland Council, Auckland Council Technical Report 2013/045.

Improving stormwater quality

In urban environments stormwater collected from surfaces at ground level is usually contaminated. Rainfall run-off carries a mix of litter, organic materials (plant material and animal droppings), dust and soil particles and chemical pollutants such as oils and fertilisers. In contrast, the quality of water arriving at stormwater drains from roofs is relatively high.

Data from two separate experiments (tables 2 and 3) show the improvement of the quality of run-off from green roofs relative to bare roofs. The higher concentration of nitrogen and phosphorus in run-off from the bare roof is most likely due to the wash down of contaminants in the first flush run-off after rain begins. The greater surface area for potential capture and storage of these contaminants on a green roof (on foliage, in the substrate) reduces the nutrient loading entering stormwater run-off. In Table 2, the green roof included mixed herbaceous perennials, including succulents, planted into 10.2 cm deep substrate held in modular boxes that were installed on a roof. In Table 3, succulent species were installed on a vegetated mat over 10 cm deep substrate.

Table 2. Comparison of nitrogen (N) and phosphorus (P) content in rainwater and run-off from bare roofs and green roofs (modular boxes)

Nutrient content	Total N (mg/l)	Total P (mg/l)
Rainfall	0.51	0.007
Bare roof run-off	0.896	0.197
Green roof run-off	0.49	0.043

Source: Gregoire BG, Clausen JC (2011) Effect of a modular extensive green roof on stormwater runoff and water quality, *Ecological Engineering* 37:963-969.

Table 3. Comparison of nitrogen (N) and phosphorus (P) content in rainwater and run-off from bare roofs and green roofs (vegetated mat)

Nutrient content	Total N (mg/l)	Total P (mg/l)
Rainfall	0.6 - 1.3	0.012 - 0.019
Bare roof run-off	1.4 - 2.6	0.102 - 0.104
Green roof run-off (vegetated mat)	1.2 - 2.1	0.026 - 0.09

Source: Teemusk A, Mander Ü (2007) Rainwater runoff quantity and quality performance from a green roof: the effects of short-term events, *Ecological Engineering* 30:271-277.

Most plants grown on a green roof require some fertiliser application for them to grow well in the long term, and leaching of nutrients into roof run-off will reduce water quality to some extent. The nutrients of greatest concern in run-off water quality are phosphorus and nitrogen: high levels of both cause algal blooms in waterways. However, relative to the amount of fertiliser initially applied to the roof, loss of nutrients into run-off can be small. The benefit of a large reduction in stormwater volume probably outweighs the cost of a small increase in nutrient loading. This should be considered in relation to stormwater quantity and quality requirements set by local water authorities.

The water quality from the outflow of green roof systems with shallow or deep substrates was studied over nine months on a rooftop in Adelaide. Controlled release fertiliser was applied at the same rate to both green roof types. Run-off from the green roof areas with deeper substrates was of higher quality than that off shallow substrates, lower total dissolved salts and electrical conductivity, and there were lower sediment levels. However, there was also a trend for elevated nitrogen (measured as nitrate) and phosphorus concentrations in run-off from green roofs with deep substrates: these nutrients are highly soluble so their appearance in run-off is expected, but given that fertiliser application was the same for both the shallow and deep substrates, it is noteworthy that the deeper substrate did not provide greater nutrient retention. Comparison of measured run-off quality against local, state and national water guidelines suggest that green roof run-off could be recycled for irrigation and other non-potable use. A [link](#) to the report is available from the Government of South Australia's Building Innovation Fund - ANZ House Green Roof Trials Stormwater Quality Monitoring.

Urban air quality

Many Australian and international studies show a link between poor air quality and adverse effects on human health. This is particularly evident for people prone to asthma and other respiratory conditions, and those with cardiovascular disease. A study by the Environmental Protection Authority, undertaken in Melbourne between 1991 and 1996, demonstrated an association between elevated nitrogen dioxide, carbon monoxide, ozone and particulate air

pollutants (such as smoke and dust) and mortality due to cardio-respiratory disease, including asthma. This association was strongest in warm weather, when ozone levels are high due to increased production at higher temperatures and stable weather conditions that reduce mixing of air.

As urban populations continue to grow, and even with improvements in quality of motor vehicle emissions, it is projected that the concentration of pollutants such as ozone and fine particulate matter (PM_{2.5}) will also rise. Management of pollution requires control of emission sources and measures that reduce the concentrations of pollutants in the atmosphere. Increasing the amount of vegetation in urban environments is one such measure: plant leaves absorb gaseous pollutants, while particulate matter can fall onto leaves or be washed onto them by rain, and ultimately into the growing medium, where it is degraded or stored.

Sources: EPA (2000) Melbourne Mortality Study: Effects of ambient air pollution on daily mortality in Melbourne 1991-1996, EPA publication 709; EPA (2013) Future Air Quality in Victoria – Final Report, EPA publication 1535.

The larger canopies of trees and shrubs offer the biggest surface area for pollution capture, suggesting that green roofs with deeper substrate, with the potential to carry a broad range of vegetation types, will be an effective approach to pollution management at height. However, as any increase in the surface area available to absorb or adsorb pollutants offers the potential for improvement of air quality, shallower green roofs, or walls and facades planted with herbaceous species may still provide significant benefit. The extent of pollutant capture will vary with the density of foliage cover, and the degree of complexity of the leaf surfaces.

In narrow city streets at ground level (urban canyons), green walls and facades offer the opportunity for improvement of urban air quality in narrow spaces, by increasing the area that is covered by vegetation and providing more potential surfaces for deposition of pollutants. Measures of pollution capture in urban canyons (and estimates from modelling studies) vary widely, as so many factors contribute to the outcome, including the dimensions of the urban canyon, and wind speeds through it. A study that modelled the effect of vegetation in London street canyons estimated a reduction of 15 per cent to 40 per cent for nitrogen dioxide and 23 per cent to 60 per cent for particulate matter concentrations, respectively, with the adoption of green walls in an urban canyon that was as wide as it was high.

Major findings are that significant reduction in both gaseous and particulate pollutants are achievable with vegetation on roofs and walls. This is achieved by direct capture of pollutants, and by reducing building heat gain and associated localised warming of the environment. All of these contribute to the creation of urban heat islands and the generation of photochemical smog.

Source: Pugh TAM, Mackenzie AR, Whyatt JD, Hewitt CN (2012) *Effectiveness of green infrastructure for improvement of air quality in urban street canyons*, Environmental Science and Technology 46:7692-7699.

Human health and wellbeing

During the Melbourne summer, the city often experiences several consecutive days of hot weather. This is subsequently associated with higher rates of illness and death: extreme high temperatures are an additional stress to people whose health may already be fragile, particularly the elderly. A report by the Victorian Department of Health quantified the increased incidence of heat-related illness and death during severe heat waves in January 2009. During this time, there were 62 per cent more deaths than would have been expected on average for this time of year, mostly in the 75 years or older age group. Keeping our buildings cooler through increased shading is likely to contribute to a reduction in the loss of human lives, and the demands on health services associated with extreme hot weather.

Source: Department of Health (2012) *January 2009 Heatwave in Victoria: an Assessment of Health Impacts*.

Vegetated environments are good for people. Traditional public parks and open spaces provide refreshment and restful views, space for recreation and cool areas of shade in summer, and community gardens offer opportunities for food production. These environments offer the potential for social interaction and community building. They are good for physical and psychological health and wellbeing and provide relief from the pressures of high-density living. Cost estimates of morbidity and mortality associated with the lack of access to green open space are not easy to dissect as there are usually concurrent, co-dependent factors that limit people's ability to engage with nature. Exposure to nature improves people's ability to focus, cope with stress, generate creative ideas, and decreases volatile, antisocial, behaviours.

Source: Townsend M, Weerasuriya R (2010) *Beyond Blue to Green: the benefits of contact with nature for mental health and well-being*, Beyond Blue Limited: Melbourne.

Cities are noisy places to live in: construction, vehicular traffic and the sounds of HVAC (heating, ventilation and air-conditioning) equipment are constant features of Melbourne's aural landscape. Modelling studies show that although green roofs provide some attenuation of noise, it is small: up to a maximum of 10 dB across most of the frequency ranges that have been tested. Tests on a range of green wall and facade systems in Singapore's HortPark revealed a similar outcome. So far, for green roofs, there is no evidence for increased sound absorption beyond a substrate depth of 20 cm (up to 40 cm). Any small decrease in the volume of outside noise is an additional, unsolicited benefit of a green roof, wall or facade. It has been suggested that the University of Tasmania's green roof was a significant factor in sound reduction emanating from its site, however the building had a number of other technologies installed to reduce sound transmission, so results cannot be attributed to the green roof alone.

Sources: Van Renterghem T, Botteldooren D (2008) *Numerical evaluation of sound propagating over green roofs*, Journal of Sound and Vibration 317:781-799; Wong NH, Tan AYK, Tan PY, Chang K, Wong NC (2010) *Acoustics evaluation of vertical greenery systems for building walls*, Building and Environment 45:411-420. Hopkins G, Goodwin C (2011), *Living Architecture*, CSIRO Publishing.

Property value

There is very little published research on the impacts of green roofs, walls or facades on property value. Research in Canada estimated that buildings with a recreational green roof achieve an 11 per cent increase in property value, and buildings with views onto green roofs have a 4.5 per cent increase in property value.

Source: Tomalty, R. & Komorowski, B. 2010, *The Monetary Value of the Soft Benefits of Green Roofs*, Smart Cities Research Services, <http://www.greenroofs.org/resources/Monetary_Value_of_Soft_Benefits_of_Green_Roofs.pdf>

Green roofs research at The University of Melbourne

Since 2008, researchers at The University of Melbourne's Burnley campus have undertaken research evaluating green roofs for Australian conditions, with a focus on plants, substrates, hydrology, energy use and environmental psychology.

Experiments on roofs and in controlled environments have quantified the performance of 56 different plants, including both Australian native and exotic species. For survival in the absence of irrigation, plants with low water use and high leaf succulence, such as *Sedum pachyphyllum* and *S. xrubrotinctum* proved to be the most successful. However, to reduce stormwater run-off from green roofs, plants also need to dry out substrates between rainfall events, a feature that low water use succulents are incapable of. This research showed that plants from specialised natural habitats similar to green roofs, such as rock outcrops, can balance high water use with high drought tolerance. The most successful species included *Dianella revoluta*, *Stypantra glauca* and *Lomandra spp.* An additional benefit was the

capacity of these plants to re-sprout following desiccation, further improving survival after drought.

The development and analysis of lightweight growing substrates, based on mineral and waste components, such as scoria, crushed roof-tiles and bottom ash (wastes from coal-powered electricity generation) has led to multiple green roof installations across Melbourne. This work also included testing and evaluating a wide range of substrate components and mixes, and investigating the use of water-retention additives in substrates, such as silicates, hydrogel and biochar. Of these, biochar was the most effective, resulting in lighter substrates that held more water and delaying the onset of permanent wilting in test plants by up to two days. This research also showed that the effectiveness of retention additives varied, depending on substrate and additive properties (for example, fine silicates were ineffective in coarse-textured substrates).

Hydrology research under natural rainfall conditions found that a 100 mm deep scoria substrate can reduce stormwater run-off in Melbourne by 43 per cent to 88 per cent, depending on the season. Further work evaluated the influence of three different substrates (bottom ash, roof tile and scoria) and succulent vegetation cover (planted vs. bare) on evapotranspiration and retention capacity under simulated rainfall conditions. The results showed that the effect of plant cover was influenced by season with greater evapotranspiration in spring. Planted modules also retained more rainfall than bare modules for medium and large rainfall events and overall the cumulative evapotranspiration was greatest from the bottom ash substrate (bare and planted) and significantly less in scoria.

Water retention also differed between substrate types, with scoria retaining at least 20 per cent less rainfall after large events than both bottom ash and roof tile substrates, probably due to lower evapotranspiration from scoria between rainfall events. Results of an energy study completed in 2009 showed that a 125 mm deep scoria substrate green roof reduced building energy use by 38 per cent on a summer day.

Environmental psychology research demonstrated that people prefer 'meadow-like' green roofs, dominated by green strappy or grass-like plants. The addition of flowers on the green roof further increased preference scores. Viewing this type of green roof was also found to improve concentration and could result in improved workplace productivity.

Section 3. Technical Guide

Chapter 1. Introduction

This *Technical Guide* provides advice on the factors that need to be considered to design, construct and maintain green roofs, walls and facades.

The *Growing Green Guide* is the first publication in Australia to collate such technical advice through independent agencies. It is likely that over time the industry will mature and have a body of research and experience that can be used to move from advice to technical standards that are directly relevant to Australian conditions.

Refer to the introductory section of this guide for definitions of green roofs, walls and facades. A glossary of other terms follows Appendix A at the end of this document.

Including this Introduction, the *Technical Guide* has been divided into eight chapters covering the following areas:

- Chapter 2. Site Analysis
- Chapter 3. Design and Planning
- Chapter 4. Building and Installation – General Advice
- Chapter 5. Building and Installation – Green Roofs
- Chapter 6. Building and Installation – Green Walls
- Chapter 7. Building and Installation – Green Facades
- Chapter 8. Maintenance
- Chapter 9. Conclusion

In Appendix A you will also find specific and detailed information about green roof growing substrates.

If, after reading this guide, it appears that green roofs, walls or facades are not suitable for a particular building, consider other greening options, from balcony plantings to backyard and nature-strip gardens. This guide does not cover these options, but many books and websites are dedicated to these opportunities.

This guide has been published under Creative Commons licencing as an invitation to others to adapt, update and improve the guidelines as new technology is developed and research improves our knowledge.

While it provides the key relevant information on this subject at its publication, for more detailed information and updates visit the *Growing Green Guide* website:
www.growinggreenguide.org

Chapter 2. Site Analysis

Before designing a green roof, wall or facade it is important to understand the characteristics of the site, as these factors will influence the feasibility and cost. This chapter explains how to evaluate a proposed location for a green roof, wall or facade. It is written for situations where there is an existing building on-site, however it can be adapted by those planning to construct a new building.

2.1 Climatic factors on-site

Climatic factors will vary with geographic location as well as with the site aspect and height and even from effects of surrounding buildings. It is important to understand the likely climate on-site in order to inform decisions about which plant species are suitable for the site. There are no hard and fast rules about what constitutes too much wind or shade or other factors; rather, these are environmental gradients (for example, low wind to high wind) and often the best approach is to estimate the worst case scenario for plant growth that is likely on-site, and design with that in mind.

- Wind – average wind speeds are greater at height than at ground level. Winds may be strong around the edges of buildings, or from the down draft caused by tall buildings. It is necessary to understand the likely wind load that a green roof, wall or facade will be subjected to, so that it can be built to withstand the forces. Wind at high elevation will also influence temperature, and wind has a direct dehydrating effect on vegetation, therefore influencing species selection and irrigation requirements. *See the Freshwater Place and Victorian Desalination Project green roof case studies in this guide to learn more about the challenges of wind.*
- Rainfall and irrigation – rainfall in Melbourne is generally not sufficient to support a green roof, wall or facade throughout the year. It is important to establish whether rainwater or another water source can be harvested from other areas on-site, and stored to supply an irrigation system. This will avoid or minimise the need to use potable water for irrigation. It is useful to carry out an irrigation water demand analysis, to estimate water needs.
- Solar radiation – light intensity tends to be greater at height than at ground level. At height there are fewer structures, no vegetation to absorb solar radiation and increased reflection from adjoining building and surfaces (such as glass and light-coloured walls). Conversely, there are some roofs and walls that may receive significantly less solar radiation, due to intense shading by nearby buildings. Shadowing and shading analysis can be used to assess areas of light and shade on a site and possible changes over the year (for example, at the equinox) and over time (for example, adjoining new building development).
- Temperature – in urban environments temperatures tend to increase with elevation, due to the increased thermal mass of built structures and the commensurate heat gain. Assessing the likely temperature range on a site is crucial in planting design, particularly in extreme temperature events. While cold temperatures are rarely a problem for vegetation in Melbourne, there can be localised green roof situations where this could be a factor in plant selection.
- Microclimate – enclosed spaces such as urban canyons can create their own microclimate where wind turbulence, pooling of pollution, humidity and temperature can be intensified. The localised climate of these areas will change the growing conditions for plants and needs to be considered when planning and designing green roofs and walls.

Climate and rooftop vegetable production

The Pop Up Patch is a subscriber-based edible gardening club, based on a car park roof behind Federation Square, in central Melbourne. The Little Veggie Patch Co. runs the garden and has to allow for the different climate that comes from being based on a roof. The concrete roof stores heat and the warmer temperatures mean that species that might not normally have been considered suitable for the area can grow. Some species that are usually annual begin acting like perennials. For instance, they have found that capsicums and chillies survive and continue to fruit through the winter months in this location. The warmer temperatures necessitate growing substrate with a high water-holding capacity. In addition, the winds at height dry the surface of the substrate, so drip irrigation underneath a layer of mulch is highly recommended.

2.2 Weight loading

The load bearing capacity of a building must be known before planning a green roof, wall or facade. A structural engineer's advice is essential to ensure comprehensive design development, based on the building's construction, condition and weight loading capacity.

For retrofitting a green roof, wall or facade, it is important to establish early whether the installation will meet the existing structural capacity of the building, or whether this will be modified to support the installation. In some instances, it is possible to strengthen an existing roof in strategic areas (and not across the whole roof) in order to achieve the design outcome while also minimising costs.

For a green roof, wall or facade, the loads that the building structure must support include:

- Dead load – the final constructed weight of all built elements and all components associated with the roof or wall assembly, including plants, growing substrate and any water held in the system
- Live load – the weight of people who will use the space, and of any mobile equipment that will be used periodically on the site, for example, maintenance (live load generally applies to green roofs, not facades or walls, however it would be appropriate on a vertical surface if a trafficable maintenance platform was built into the system)
- Transient load – moving, rolling or short-term loads, including wind and seismic activity

It is important to consider not just the weight of plants when planted but their weight at maturity, especially where shrubs and trees are proposed, as these are likely to be significantly heavier over time. The weight of saturated plants and substrate must also be included in the load assessment. Some example weight loadings of plants are provided in tables 4 and 5.

Damage to a wall can arise from wind forces, plant load, cable tension, and human access. This is particularly important where older walls are being used and where there is a large surface area of green facade (that is, wind uplift).

Table 4. Weight loadings for some representative climbing species

Green facade species	Weight loading (kg/m ²)
<i>Jasminum</i> (Jasmine), <i>Rosa</i> (Rose)	6-12
<i>Clematis</i> (Clematis), <i>Tropaeolum</i> (Flame Nasturtium)	3-12
<i>Vitis</i> (Ornamental Grape), <i>Ampelopsis</i> (Porcelain Vine)	12-26
<i>Lonicera</i> (Honeysuckle), <i>Actinidia</i> (Kolomitka), <i>Wisteria</i> (Wisteria)	10-26

Source: Jakob Rope Systems. Note: these are figures from the Northern Hemisphere, where the effective growing season is shorter than Australia's. Weight loadings are therefore likely to be an underestimate.

Table 5. Green roof vegetation weight loadings

Green roof vegetation type	Weight loading (kg/m²)
Low herbaceous (succulents and grasses)	10.2
Perennials and low shrubs up to 1.5 m	10.2-20.4
Turf	5.1
Shrubs up to 3 m	30.6
Small trees up to 6 m	40.8
Medium trees up to 10 m	61.2
Large trees up to 15 m	150

Source: FLL Guidelines

Some load-bearing capacities used in design of Melbourne green roofs and walls

The University of Melbourne's demonstration green roof is designed for use by visitors and staff. It is built on a heritage-listed brick building in Burnley. It has areas of deep and shallow substrate and is designed for a dead load of 300kg/m² and a live load of 300kg/m² on the decking and walkway mesh areas, and 150kg/m² on the planting area.

The Venny green roof has shallow substrates on two types of roof, the first roof is on shipping containers, and is designed for a dead load of 250kg /m² and live load of 100kg/m². The second trussed roof is designed for a dead load of 160kg/m² and a live load of 40kg/m².

The Triptych external green wall and the Telstra Conference Centre internal green wall are both designed for a dead load of 80kg/m².

2.3 Drainage

Sites for green roofs should be assessed for drainage. Check whether the site has primary and/or secondary drainage systems (illustrated in Figure 13).

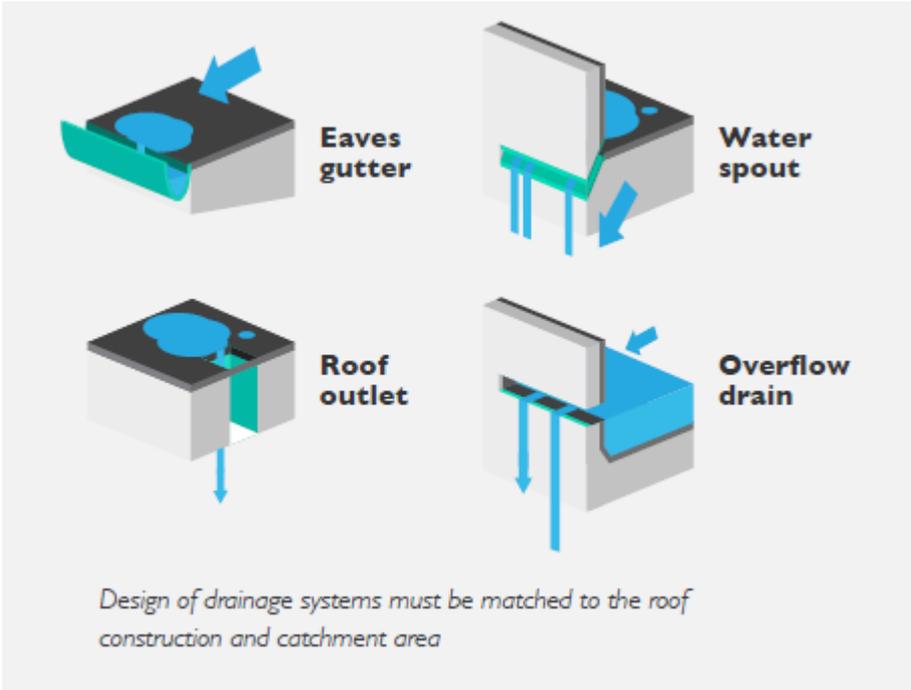
Primary roof drainage systems may use:

- box gutters (for near-flat roofs) or eaves gutters (for pitched roofs)
- simple waterspouts (also known as scuppers)
- outlets or box drains built into the roof

These are collector drains that are designed to flow when only partly full. Primary drainage systems are not designed to remove all of the water that falls on a roof during exceptionally heavy rain. A green roof may require a separately plumbed secondary drainage system, also known as the overflow relief system. For flat or nearly flat roofs, primary drains are located at the lowest point of the roof: flow of water into them is promoted by positive drainage.

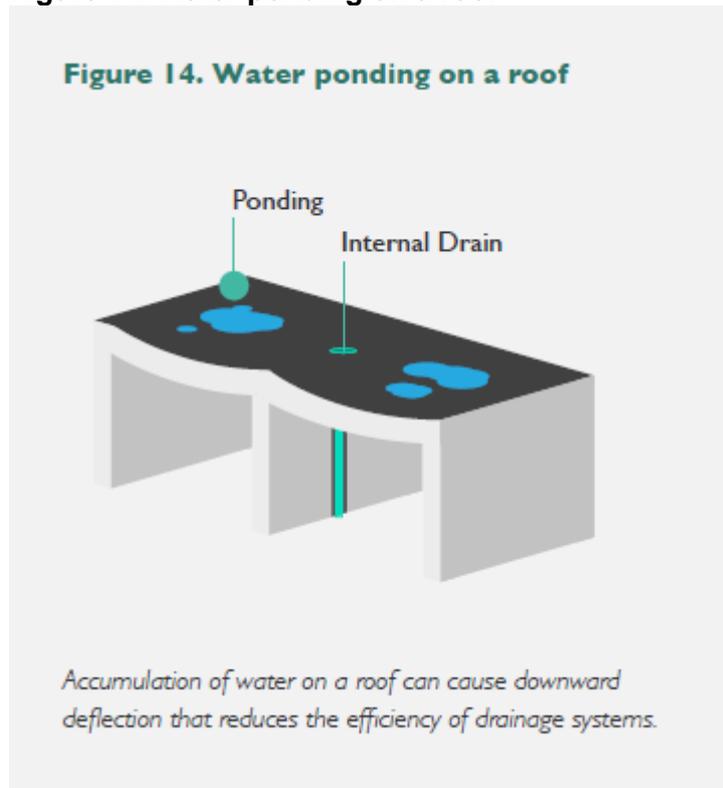
Secondary (overflow) drains are located at a higher point on the roof. These are designed to operate in a worst-case scenario where the primary drains are completely blocked and water builds up on the roof due to a torrential downpour of rain and/or a failure of the irrigation system to shut off. Overflow drains remove accumulated water to a depth that the roof can carry without becoming unstable, and ensure that the roof weight loading capacity is not exceeded. For roofs with a very low parapet, overflow drainage may be achieved simply by flow over the roof edges, if accumulation of water to this height fits within the roof's design weight loading. The need for overflow relief will be established by looking at existing performance of the drainage in conjunction with the historical data on rainfall intensity.

Figure 13. Different types of roof drains



Removal of water from any roof surface is assisted by some degree of pitch or slope. Even roofs that look flat have a gentle fall to promote movement of water into the roof drains, to prevent ponding. 'Ponding' refers to water that remains on a roof for extended periods after the end of the most recent rain event (Figure 14). Recurrent ponding can cause lasting downward deflection of the roof structure, which over time may reduce the efficiency of drainage and cause the roof to become unstable. A pitch of at least two per cent reduces the risk of ponding, and a steeper pitch means the roof will drain more quickly. Strengthening the roof construction to reduce deflection may be needed.

Figure 14. Water ponding on a roof



When assessing the site and planning for the design of a drainage system, consider:

- the amount of rainfall that lands directly on the site, and any that drains onto it from adjacent roofs or walls
- length of rainfall event – estimated from historical records and forecasts of future extreme rainfall events under a warmer climate
- the speed at which rainfall will collect at the drains (determined primarily by roof pitch)
- the planned capacity of drains, including the drain dimensions and diameter of gutters and drainpipes

2.4 Existing structure and size

- Consider the quality of the roof or vertical surface. Is it currently waterproofed? Does the wall have a surface that needs protection from vegetation?
- Assess the area available – bearing in mind that costs increase with size. The useable area can be diminished if there are many windows on a wall or numerous vents and equipment on a roof.
- Roof slope – green roofs are ideal on slopes less than 15 degrees but can be constructed on steeper slopes with special materials.
- Water collection and storage opportunities – is there space to store water on-site? Tanks are usually located at ground level or in the basement of a building, and an irrigation tank may be co-located or shared with tanks for toilet flushing. Water storage can also be built into the design of some green wall systems.

2.5 Access

Evaluation of the site should review accessibility. Temporary access will be needed for machinery, and delivery and storage of materials during construction. For green roofs or multi-storey wall and facade greening, this might involve a crane to lift materials onto the site.

Consider how people will access the installation for maintenance, viewing or standing on. This might require stairs, lifts and viewing platforms for the general public or building tenants. It may also require balustrades, cables for attaching harnesses and ropes (fixed fall protection), ladders, elevated work platforms independent of the building, or swing stages mounted on the top of the building for maintenance personnel. Access for maintenance to walls and facades can also be considered from below, in which case space for a temporary elevated work platform is likely to be required. Further information about site safety is provided in **Chapter 4**.

Access for passers-by must also be considered, as there are regulations against vegetation that protrudes onto public space, and even in the private realm it is important to be aware of hazards that can be created for people using the space nearby.

2.6 Nearby vegetation

The local vegetation adjoining a site can influence design. If creation of habitat for biodiversity is a desired outcome for your green roof, wall or facade, consideration of the surrounding landscape could be useful. However, nearby vegetation can also be a source of weeds or contribute to a fire risk and should be included in site analysis.

2.7 Site assessment summary

The table below outlines information that is required in the analysis of a site for a potential green roof, wall or facade. Some of these elements will require specialist knowledge; for instance, the weight loading that can be applied to a roof or wall, will require consultation with an architect and structural engineer. Other issues can be answered either by direct observation on the site or through the use of downloadable resources, such as climate data for the local area from the Bureau of Meteorology's [Climate Data Online](#). The information collected will help determine the design and planning of the green roof, wall or facade.

Table 6. Site analysis requirements

<p>Information to collect during a site analysis</p> <p><u>Seasonal considerations and climate</u> Expected maximum and minimum temperatures Expected rainfall volume and distribution throughout the year How sun, shade, wind vary on the site throughout the year How the height of the building might influence some climatic factors Forecasts on how the local climate might change over time</p> <p><u>Local environment</u> Assessment of opportunities or risks that nearby vegetation will have on the site - fire threat, weed or pest invasion, biodiversity migration</p> <p><u>Weight loading</u> Load-bearing capacity Estimated transient loads, particularly wind forces</p> <p><u>Drainage</u> Storm water discharge points Assessment of whether drainage will be sufficient in the case of severe weather</p> <p><u>Irrigation</u> Water collection and storage opportunities, opportunities for delivery of irrigation water and for co-locating stored water with other grey water systems in the building</p> <p><u>Existing structure and size</u> Size of useable roof or wall area Available space for plants to be grown from ground level upwards Any slopes or angles to the roof or wall Quality of existing roof and wall materials</p> <p><u>Access</u> Access to site for cranes and other machinery, and for storage of materials during construction Access for maintenance and/ or visitors (consider safety such as a parapet on a roof and disability access requirements too) Access to utilities - water, electricity Ensure access for passers-by is not impeded</p>

Chapter 3. Design and Planning

The most important decisions about a green roof, wall or facade are made at the design stage. The benefits of the installation, how easy it will be to build and maintain and how it will operate day-to-day, all depend on the initial design. This chapter provides information to help develop a well-considered, achievable design that will work in the long term.

Along with understanding the site conditions (see [Chapter 2](#)), other important issues to consider at the design stage are:

- overall design outcomes sought from the project
- drainage and irrigation
- maintenance inputs
- sourcing the right information and expertise
- budget
- relevant building industry codes and planning assessment tools
- plant selection and establishment

Consideration of these issues is crucial to the successful design of a green roof, wall or facade, and should be well thought out before planning for construction.

3.1 Design objectives

The fundamental reason for undertaking a green roof, wall or facade project needs to be identified up front, as this will influence the design, construction and required level of maintenance for the system. When building a green roof, wall or facade on behalf of someone else it is crucial that the client's requirements are understood. For example, a green roof designed for the purpose of increasing aesthetic value might focus on species of ornamental significance more so than drought tolerance or low maintenance. However, the same design might not be suitable for a client who wants a low maintenance, water efficient installation.

It should be noted that green roofs, walls and facades will be part of a broader urban green landscape and their design should ideally ensure that they contribute to the goals for the surrounding landscape, along with street trees and other forms of 'green infrastructure'.

The following tables provide some examples of different considerations needed for different design goals. This is not an exhaustive list, and it has some very simple considerations: it is intended only to illustrate that different goals will require different inputs and system set-ups. Discussions with professional green roof, wall and facade installers, landscape architects and a review of relevant research will be needed to make final decisions about the most appropriate approach.

Green roofs

Design goals	Considerations
Reduced stormwater run-off	Increase depth and water-holding capacity of substrate, use plants with high water uptake
Recreation and amenity use	Increase weight loading, ensure ready roof access, planning and safety requirements
Lightweight, long-life and no irrigation	Choose stable, lightweight substrates and components, and high stress tolerant plants, e.g. succulents
Cooling and integration with photovoltaic panels	Select leafy plants, provide irrigation, plant around (but do not shade) solar panels
Maximise thermal insulation	Increase substrate depth, provide irrigation, select species for leafy plant cover in summer (passive heat gain in winter may be increased if the roof is bare in winter but this strategy increases maintenance and reduces aesthetic benefit)
Provide biodiversity outcomes	Include habitat plants (usually native/indigenous), habitat features (such as water and shelter), small changes in topography and variations in substrates. See Green roofs for biodiversity following
Produce food	Increase weight loading capacity of the roof, and depth and organic content

	of substrate, ensure good access to the site, provide irrigation
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Green walls

Design goals	Considerations
A multi-storey green wall	Ensure access for maintenance is possible, consider hydroponic system if weight loading is likely to be a problem, ensure species selection is appropriate for the specific light and wind exposures at different heights
Aesthetics and a design statement on a building	Include a variety of species with different flowering times, consider planting in patterns and consider textures, foliage colours and extending the planting area beyond the boundaries of the green wall surround
Low cost and easy to install on a residential building	Consider DIY installations, minimise the size of the system, self-contained units that recirculate water, systems that can be easily replanted
Provide biodiversity outcomes	Include a variety of species with habitat features such as fruits or nectar-producing flowers, or a niche design that provides protection from predators for particular species
Internal green wall	Ensure adequate light – possibly install artificial light
Long lasting wall	Consider quality of design and longevity of components

Green facades

Design goals	Considerations
Low cost and easy to install	Use a direct attaching species of plant, grown from the ground at the base of the wall
A multi-storey facade greening	Include containers at different heights, include cabling or lattice support structures for twining plants, ensure access for maintenance, provide irrigation, consider secondary protection of plants against stem damage, e.g. wind protection trellis
Screening of an unsightly view	Use evergreen species to ensure year-round screening, create a structure for the plants to grow on
Maximise thermal benefits	Use deciduous species if heat gain is desired in winter; ensure very leafy plants, covering the entire wall for providing best shade in summer, particularly on north and west facing walls; provide a structure at least 100 mm off the wall of a building for the plants to grow on, leaving an air gap between the building and green plants to maximise cooling effect.
Produce food	Increase depth and organic content of the substrate, ensure good access to the site, provide irrigation
Provide biodiversity outcomes	Include a variety of species, with habitat features such as nectar producing flowers, fruits, capacity to support nests, create protected or visually prominent areas

Green roofs for biodiversity

Green roofs that are designed to increase biodiversity should feature indigenous vegetation local to the area. Biodiversity roofs should also incorporate different vegetation layers and landscaping features to increase opportunities for wildlife to feed and shelter. These may include hollow logs or twig bundles, rocks, different substrate types, such as areas of sand or rubble, and spaces for shelter, such as roof tiles and nesting boxes.

The value of green roofs for biodiversity will depend on their characteristics and location. In general, larger green roofs on relatively low buildings closer to natural areas will be more valuable than small, high green roofs in dense urban areas remote from parks or native vegetation remnants.

In the Northern Hemisphere, biodiversity roofs often have only a shallow (< 150 mm) depth of substrate, and receive little to no irrigation or maintenance. In most parts of Australia, the longer growing season and typically hot, dry summers make it unlikely that herbaceous vegetation on shallow green roofs could be sustained in the long term.

Irrigation may need to be provided during hot dry periods to ensure greater vegetation success. The vegetation must not create a fire hazard or block drains, so non-vegetated areas around the roof perimeter, drains or other fixtures must be kept clear.

If a low to no-maintenance approach is taken for a biodiversity roof, there must be an understanding that some plant species may be short-lived. Species' persistence can be improved through plants that

readily seed and self-sow, or produce underground storage organs (bulbs or tuberous roots) that are dormant for part of the year.

Planting a diverse range of species on a green roof is more likely to attract a broad range of invertebrates, birds and other wildlife than a monoculture of a single species.

Urban Food Production

Just as walls and roofs of buildings provide a surface for greening in dense urban areas with very little ground-level space, they also represent a possible location for urban food production.

In some parts of the world large areas of rooftops in inner urban areas are being transformed into urban farms. More commonly, roofs are used to house hydroponic or container-based plots for food production, such as the Pop Up Patch at Federation Square, Melbourne.

Walls have only been experimented with on a small scale. Facades tend to lend themselves to the production of food from climbing plants such as beans or passionfruit.

Some of the challenges to be overcome with rooftop and vertical food production include:

- access for harvesting the produce
- load bearing capacity that will allow for the necessary numbers of people and equipment needed at harvest time
- ensuring the produce is not contaminated from pollutants in the air – research is being conducted on this. Note that research from Germany on urban horticulture production relates the contamination to traffic levels and indicates that a building is a barrier to pollution from traffic, indicating that walls and facades should be away from heavily trafficked roads but perhaps roofs will be buffered simply because they are away from the roadside
- sustainable water use – food-producing plants tend to need a lot more water than a number of other plants typically found on roofs, walls and facades. So it is imperative that rainwater can be collected, and possibly recirculated, to irrigate large urban agriculture plots
- nutrient management – every crop harvest takes nutrients out of the system, so to keep adequate nutrition up to food-producing plants, growing substrates will need to have either a higher organic matter rate than traditionally used in facades or roofs or more nutrients will need to be applied to the plants. This will necessitate close monitoring of run-off to ensure that the water leaving the site is not polluted

As the issue of adequate plant nutrition is so crucial to food production, it is uncommon to see examples where urban agriculture is practiced on roofs where the layers are loose-laid, rather than in containers. Where containers are used it is possible to remove all the growing substrate and replace completely. In fact, there are some urban agriculture rooftops where the food is grown on hydroponic systems on the roof to avoid the need for a growing substrate altogether.

Urban agriculture on roofs and walls can be part of community gardens, private residences, school farms, social enterprises or may have potential to be commercial farms. The scale of the project and intended level of production will determine how the challenges above are dealt with. Careful consideration needs to be given to plant selection as roofs and walls can be much hotter, darker or more windy than ground sites.

3.2 Planning for drainage and irrigation

Good drainage ensures that the green roof, wall or facade does not compromise the structural integrity of the building and that plants are not adversely affected by waterlogged substrate. A drainage system must effectively remove surface and sub-surface water from the roof or wall.

While green roofs, walls and facades are able to reduce the flow and assist in retaining stormwater run-off, it is still necessary to have drainage systems that can cope with extreme rainfall events or flooding caused by other factors on the site. See **Chapter 2** for more information on drainage systems. All roof drainage systems (green or otherwise) should be designed to handle the most intense 60-minute duration rainfall that has a one per cent probability of being exceeded in one year (in Melbourne, this is a 48.5 mm rainfall event, but

is subject to change). Green roofs will not directly increase drainage needs on a roof, however design must ensure that excess surface run-off can be discharged readily through the roof drainage system. The components that make up the substrate will affect the flow of water through a green roof profile.

Irrigation is critical to the success of most green roofs, walls and facades, and many green walls have a particularly high water demand. It is strongly recommended that non-potable water sources for irrigation are explored, particularly for systems/designs that are water intensive. The likely water demand of vegetation can be estimated by developing a water budget based on multiple characteristics of the green roof, wall or facade, including

- calculating total water needs based on the 'landscape coefficient' or 'crop factor' values (see Glossary)
- evaporation data
- effective rainfall
- the capacity of the substrate to store water

A number of horticultural publications provide more information on these issues, including *Growing Media for Ornamental Plants and Turf* (Handreck and Black), *Water Use Efficiency for Irrigated Turf and Landscape* (Connellan) and *Water Use Classification of Landscape Species – a method for estimating the water requirements of landscape plants, based on species, vegetation density, and microclimate* (University of California Cooperative Extension and the California Department of Water Resources).

Sustainable design of green roofs, walls and facades should incorporate key principles of water sensitive urban design (WSUD), particularly to manage stormwater in the landscape, rather than into the stormwater drainage system. For green roofs in particular, it is desirable to maximise water retention in the system for as long as possible, and to send reduced volumes of high quality (low nutrient) run-off off the roof. Re-use of irrigation water is useful in green roof, wall and facade installations, where large volumes of water flow through the system. Treatment to disinfect and treat run-off water is needed in these situations as continuous recycling of untreated water can spread soil-borne disease and/or lead to the build-up high levels of nutrients.

In many green wall installations, water reticulation and reuse is standard practice. More specific advice on drainage and irrigation for green roofs is available in **Chapter 5**.

3.3 Designing for maintenance

Design and planning of a green roof, wall or facade must incorporate an understanding of how the system will be maintained. Buildings owners and property managers need to understand what is involved in maintaining the roof, wall or facade and must be committed to managing it, otherwise the benefits outlined earlier in this document may not be achieved.

The systems, or assets, created must not exceed the skills, technologies and resources of those who will be given the responsibility for their maintenance. There are examples of green roofs in Melbourne that have been designed which require complex horticultural management, but the management has fallen to contract staff with no specialist expertise in green roofs, and the landscapes begin to deteriorate. This can result in user complaints and/or the need to replace an asset prematurely, which is inefficient and unsustainable both economically and environmentally. It may be that the green roof, wall or facade provider is best placed to undertake on-going maintenance on a contract basis.

The person or team with ultimate responsibility for management of the project/property must be clear about maintenance objectives and their capacity to undertake them with available resources. All design options proposed must be fully evaluated in terms of the maintenance they will entail.

Including ongoing maintenance costs is an important part of the design considerations, especially from the point of view of the client, or asset owner. To determine the ongoing maintenance requirements of a green roof, wall or facade consider engaging a consultant or contractor with relevant experience. Advice can be provided on the resources needed to maintain different design options and the likely expenditure needed to maintain the materials used. For large commercial projects, a maintenance impact statement can be provided by the landscape designer. Alternatively, specify maintenance objectives and standards early, so that the designer has these in mind to start with. **Chapter 8** provides information on common maintenance tasks and the development of a maintenance plan.

Consideration may be needed for renewal or removal of a green roof, wall or facade, especially where a temporary or short-term installation is proposed. The Melbourne Central shopping centre green wall was designed as a temporary installation, however with various interventions its life was extended for some years. Ultimately it was dismantled due to high maintenance costs for a wall in a position with very limited light. Although roofs, walls and facades can, of course, be designed from the outset to last for decades, in some cases they will be designed for a limited lifespan and therefore the opportunities for renewal or process for removal should be considered in the design stage.

3.4 Sourcing skills, expertise and information

Most projects require the involvement of a number of different trades and skills, and the more complex the project, the more elements there are to coordinate. It is crucial that a specialist, experienced, green roof, wall or facade designer is engaged during the design and consultation phase, rather than at the end of this process.

Although there are no Australian standards for the specific purpose of green roof, wall or facade installation, some Australian building code standards are relevant. International standards that are often referred to in Australia are the German FLL guideline, ASTM International (formerly the American Society for Testing and Materials) and Singapore's Centre for Urban Greenery and Ecology (CUGE). See **Standards** in the **References and source material** section of this guide for more information.

The website of **Green Roofs Australasia** features a business directory covering aspects of green roof, wall and facade design and construction. The **Landscaping Victoria** website provides a list of commercial and residential landscape contractors, landscape designers, and landscape service and product suppliers. There are a number of useful books on various aspects of green roofs, walls and facades, some of which are listed in the **References and source material** section of this guide.

You may need to consult with various professionals, some of them possibly on an ongoing basis, throughout both the design and construction phases of your project. For small-scale projects, a green roof, wall or facade provider will often supply several services, from engineering to irrigation to project management and design. In other cases, it will be imperative that the provider is collaborating with the rest of the design and project management teams. The following list describes specific areas of expertise involved:

Project Manager:

- Develops a project timeline
- Manages construction budget and payments
- Ensures contractors have appropriate registration, licensing, insurance and working at heights training
- Manages site inductions for all personnel.

Construction Manager/Principal Contractor:

- Plans and oversees construction activities
- Engages contractors, or sub-contractors

Architect or landscape architect:

- Designs the project, working with the client to select the most appropriate system for the site, including consideration of how it will be managed and maintained in the long term
- Coordinates planning and building permits, either directly or through a building surveyor
- Reviews progress and inspects construction
- Provides advice on the installation in the context of the whole site/landscape

Note: architects and landscape architects with experience and specialised knowledge of green roofs, walls and facades will be best able to provide conceptual designs and specialised design of support structures and plantings.

Structural engineer:

- Examines the existing building, or the proposed design for a new building
- Determines the structural elements required to achieve the desired weight loading.

Builder:

- Constructs the building, or installs any structural reinforcement needed in a retrofit green roof project
- Installs any built-in elements associated with the roof, wall or facade, often in conjunction with the green roof, wall or facade provider.

Building surveyor:

- Reviews and approves building plans
- Reviews construction for compliance with the regulations
- Arranges for Building Permits and Occupancy Permits with local councils.

Waterproofing supplier and contractor:

- Reports on the condition of the existing roof (retrofit), and recommends the most suitable waterproofing for the project
- Prepares the roof and installs waterproofing.

Leak detection specialist:

- Carries out leak testing at specified stages of construction, and as part of regular scheduled maintenance.

Horticulturalist:

- Provides advice on growing substrate
- Recommends and sources suitable plants
- Seeks specialist advice (for example, arboricultural advice for tree selection)
- Coordinates delivery and installation of plant materials.

Green roof provider:

- Provides design advice to architect/landscape architect (or may undertake all design work in a small project)
- Provides advice on all elements required for the green roof build
- Supplies and installs all green roof elements, usually including growing substrate and plant materials
- May provide advice on maintenance and long-term management requirements.

Green wall provider:

- Designs and installs the green wall

- Provides advice on the most appropriate treatment for the site, including plant selection, irrigation and ongoing management.

Green facade provider:

- Designs and installs the green facade
- Provides advice on the most appropriate treatment for the site, including plant selection, irrigation, cabling, trellising and container-growing systems, and ongoing management.

Irrigation consultant/hydraulic engineer:

- Advises on a suitable irrigation system during the design process based on the proposed substrate depth/volume and water-holding properties
- Advises on use of recycled/harvested water, pumps, and storage tank volumes and configurations
- Advises on approaches to sustainable and efficient water management in the context of the whole site (water sensitive urban design)
- Advises on integration of the irrigation system with the rest of the building's water system.

Landscape manager/maintenance manager:

- Oversees maintenance contractors
- Negotiates and manages contractual arrangements
- Allocates budget and resources to maintenance activities.

3.5 Cost considerations

Each roof, wall or facade will vary significantly in terms of cost, depending on the design site, the system installed and the construction materials used. Costs can be reduced in small projects as 'do it yourself' (DIY) installations, involving less personnel and smaller spaces. There may also be economies of scale for large projects which will bring costs down, especially if there are other efficiencies in terms of access for construction, and if the build already lends itself to a green roof, wall or facade.

The long term savings should be considered when analysing costs, for instance a green roof might provide energy savings over the life of a building, because of its effect of cooling the structure.

Generalisations of costs, based on 2013 prices, are provided here, and are indicative only as each project will present different opportunities and challenges. The case studies included in this guide (**Section 4**) provide an indication of costs of particular installations (at the time of their construction). Up-to-date pricing, and advice on the costs likely to apply to a particular project site, need to be sourced from expert practitioners, providers, architects and engineers.

Construction costs will vary according to some of the following issues:

- type of structure (and any need for structural reinforcement)
- design
- site location, size and access
- distances for transport
- storage of materials on or off-site
- access for mobile cranes, access to goods lifts
- roof height, dimensions and load-bearing capacity
- roof construction, complexity of roof design including roof penetrations
- timing of project, including contract growing of plants

Typical maintenance costs include irrigation water, fertiliser, replacement plants, weeding and pest and disease management. Periodic inspection and maintenance of the site, from the irrigation system to clearing drains to re-tensioning of cables or repair of loose wall fixings, will be needed. Maintenance costs may include access costs if, for instance, an elevated work platform is required (more information on maintenance can be found in **Chapter 8**).

A design contingency to cover additional costs during the development of the design of the green wall, facade or roof should be budgeted for, as should a construction contingency for unexpected problems arising during installation.

Green Roofs

It should be noted that it is significantly cheaper per square metre to install a green roof on a new building than to retrofit an existing building, as the structural load-bearing capacity can be more easily integrated into a new project compared to augmenting the structural capacity of an existing building.

Notwithstanding this, it is feasible to retrofit many buildings, either by providing additional structural supports or a new 'floating' roof to carry the green roof.

A small green roof (30-50 m²) with reasonable access would cost between \$150 and \$400 per square metre to install. This does not include:

- design fees
- planning and building permits
- permits for lifts and cranes
- demolition or relocation of existing infrastructure on the roof
- addition of specific hard infrastructure elements, such as furniture, shade structures, decking, paving, planter boxes or structures to support climbing or trailing plants.

It also assumes that the roof has sufficient structural capacity and does not require strengthening.

Example costs for strengthening the roof:

Existing roofs may require additional strengthening work in order to accommodate the weight of people, plants, substrate, and other items. The following rates for strengthening an existing roof can be used as a guide. Please note that these costs may vary according to the issues outlined above under 'Cost considerations'.

- Strengthen concrete roof slab under trafficable areas \$450-\$650/m²
- Strengthen a steel roof \$240/m²
- Additional column supports and foundations \$2,500 to \$7500 each

Example costs of individual components of green roofs:

The following rates for green roof components can be used as a guide; however, these costs may also vary according to the issues outlined above under 'Cost considerations'.

- Waterproofing \$100/m²
- Drainage and protection layers \$20-\$30/m²
- Growing substrate, plants, irrigation \$100-\$500/m²
- Edge restraints \$50/lin.m
- Paving, decking, flooring \$200-\$400/m²
- Balustrading \$150-\$300/lin.m
- 100,000L tank, pump and associated equipment \$25,000

Green Walls

DIY individual wall components for retail sale may be relatively cheap, at \$160/m² for the system and \$150/m² for the substrate, plants and irrigation system.

A professionally installed wall will cost between \$1,100 and \$2,800/m² and will often include maintenance visits for 12 months in the price.

Green Facades

Professionally installed green facades will cost from \$400/m² upwards. DIY facades can be established more cheaply.

Example costs of individual components of green facades:

The following rates for green facade components can be used as a guide. Please note that these costs may vary according to issues outlined above under 'Cost considerations'.

- Climbing structure, including installation \$150-\$350/m²
- Substrate, plants and irrigation in planter boxes \$100-\$150/m²
- 15,000L tank including installation \$10,000

Contingencies and other fees

In professional quotes the following contingencies are often allowed for, in addition to the construction/installation costs of the green roof, wall or facade:

- Design contingency of 10 per cent
An amount included in a construction budget to cover additional costs for possible design changes.
- Cost escalation of three (3) per cent
Anticipated changes in the cost or price of labour or materials over a period of time.
- Construction contingency of five (5) per cent
An amount included in a construction budget to cover unforeseen situations/costs arising during construction/installation.
- Consultant fees of 10 per cent

3.6 Planning, regulations and local laws

3.6.1 Planning

The construction of a green roof, wall or facade may require a planning permit from the local council. At present, there are no specific planning guidelines or requirements for green roofs, walls and facades in Victoria, however associated building works may require a planning permit. Such works may include, for example, replacement of an existing roof or building new structures such as handrails, or the supporting structures for green facades and walls.

A planning permit will most likely be required if the building is affected by a planning overlay such as a Heritage, Neighbourhood Character or Design and Development overlay.

Other planning considerations include:

- siting controls, such as overlooking (particularly if it is a roof that is intended to be used as a space for people to congregate)
- overshadowing
- setback requirements.

Where mandatory height controls apply, rooftop structures may be prohibited. Green roofs can be used to meet private open space requirements in private dwellings. More information

about planning schemes and the overlays in any given municipality is available from the [Planning Schemes Online](#) website. It is also important to speak to the local council.

3.6.2 Local laws

Compliance with laws of the local council is required during the building and maintenance of green roofs, walls or facades. Laws will often address issues related to:

- Management and disposal of waste products, such as pruning material generated by maintenance contractors
- Management of vegetation considered to be a weed or fire risk
- Management of overhanging vegetation on public land or that which has a negative impact on lighting or traffic signs
- Drainage over public land
- Use of elevated working platforms or cranes on public land during construction or maintenance
- Access at street level for people with a disability – consider encroachment of plants or structures into footpath space
- Access by emergency services – do not impede the safe egress of occupants in an emergency

3.6.3 Building

Building permits are issued in line with the Victorian Building Regulations. Although there are no specific requirements relating to green roofs, walls and facades in the building regulations, a building surveyor will need to ensure the following aspects are satisfied before a building permit can be issued:

- Compliance with siting controls in the building regulations (for example, distance of set back from the street, avoiding vegetation protruding onto public space)
- Appropriate load-bearing capacity of the structure to accommodate proposed dead and live loads, determined in a structural engineer's report
- Management of waterproofing and drainage measures to ensure the building provides a healthy environment for its occupants
- Compliance with fire safety regulations, including fire-fighting equipment and fire resistance of materials used
- Safety of access and emergency egress for building users, including stairways, balustrades, number of exits, distance to exits, and the provision of ramps for disabled access
- Compliance with energy efficiency performance standards for new buildings, including evidence of the contribution of the proposed green roof, wall or facade to these performance standards

3.7 Building rating schemes and planning assessment tools

Property developers should consider the importance to them of building sustainability ratings schemes as they commission a design for a green roof, wall or facade. For instance:

- Public buildings can obtain Green Star points for green roofs, and other buildings have an indirect way of achieving points under the category of 'land use and ecology', if the installation is designed with native plant species and a focus on ecological value
- Under the National Australian Built Environment Rating Scheme, green roofs, walls and facades may be able to contribute to ratings in categories of thermal comfort and acoustic comfort
- In the green building certification program, 'The Living Building Challenge', green roofs, walls and facades may be able to contribute to building thermal performance, energy efficiency, and water re-use objectives

- NatHERS (Nationwide House Energy Rating Scheme) looks at the energy efficiency of new residential developments, and green roofs, walls or facades can be designed to improve efficiency

Melbourne Water's online **STORM** calculator assesses the effectiveness of 'water sensitive urban design' (WSUD) treatment measures on a site. This tool is often encouraged by planning departments of local councils, because Clause 56.07 of the Victorian Planning Provisions requires treatment of stormwater in all new housing developments. Green roofs, walls and facades have the potential to improve STORM ratings because they retain and/or slow entry of run-off into the stormwater system, and green roofs reduce the area of impervious roof surface. Local councils in built-up urban environments are likely to respond more favourably to building proposals that show an understanding of their water flows onto and out of a site and have measures to manage these responsibly.

Other rating systems sometimes applied at local council level include the STEPS (Sustainable Tools for Environmental Performance Strategy) tool and the Sustainable Design Scorecard (SDS) aimed at residential and non-residential developments, respectively. These tools can be used in the assessment of developments at the planning permit stage as they provide an indication of the environmental performance of a given planning application.

Although these Australian tools and rating schemes do not yet explicitly include green roofs, walls and facades in their range of treatment options or as a stand-alone category for points, knowledge gained from local green roofs, walls and facades will influence their future development. Research will be important to ensure the thermal, biodiversity and stormwater retention benefits of green roofs are quantified and modelled. There are examples of international rating schemes that explicitly rate green roofs, such as Leadership in Energy and Environmental Design (LEED®) – the green building rating system developed by the United States Green Building Council.

3.8 Selecting plants

Vegetation choices depend on the purpose and type of the green roof, wall or facade. A successful green roof, wall or facade planting will be based on robust, reliable species that are known, or likely, to tolerate the area's temperatures, winds and rainfall. Look for species that perform well in challenging locations: these may be good candidates.

Ensure that species are not prone to pest infestation or disease. Avoid species that are an irritant or poisonous, or that are prone to nutrient deficiency or toxicity. Species that are weedy or that have weed potential should be avoided.

Plant selection for green roofs and facades is highly related to growing substrate. It is important to consider how deep the substrate will be – which, in turn, is determined by the weight loading capacity of the roof or facade, and the project budget. The depth of substrate influences the size of plants that can be grown and, to some extent, how much water will be available for the plants. Certain types of substrate will hold more or less water. See **Appendix A** for further information on substrate properties that influence plant growth.

Substrate is not such a constraining factor for green walls, as these tend to be engineered to suit the plant species chosen. Epiphytes and lithophytes, plants that do not require soil, are often used on green walls and can grow to mature sizes. Even species that normally do grow in soil can be grown with no substrate through a hydroponic system.

Plant selection must consider maintenance requirements of different plants and their desired appearance; for instance, manicured versus natural. Maintenance needs will be determined by the preferred look and performance of the end result and a willingness to meet the costs involved.

Species that are prone to grazing by possums or damage by birds may not be suitable. Select the most robust species possible, in keeping with aesthetic and other design aims of the project.

3.8.1 Sourcing plants

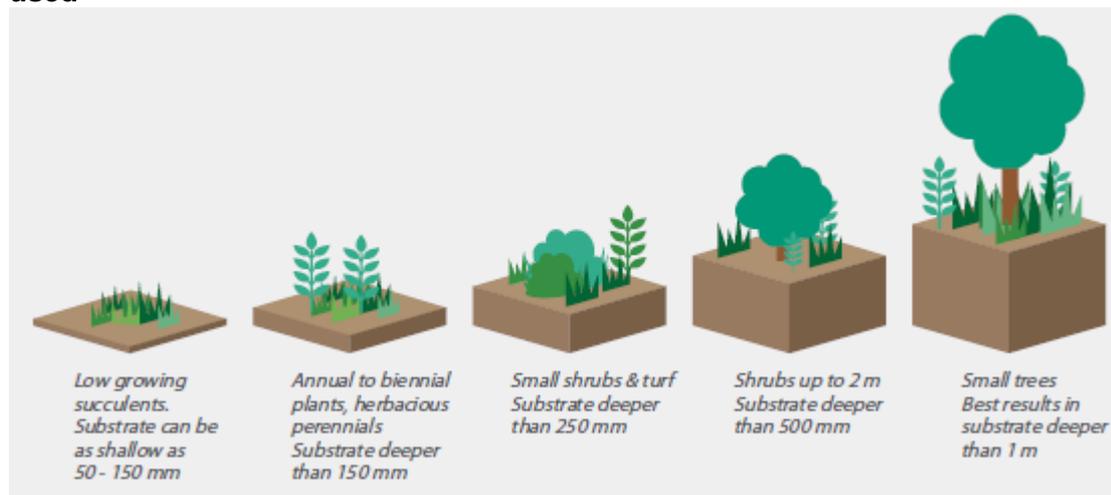
Plants can be sourced from retail nurseries, grown at home, or ordered on contract from wholesale nurseries for large projects. Be aware that many retail nurseries do not have experience with green roofs, walls and facades, but requesting plants with particular characteristics, as outlined on the following pages, should assist. For large green roof, wall and facade projects it is important that plant orders are placed early – wholesale nurseries prefer three to six months' notice when hundreds of plants are required. It is important to insist that weed free 'sterile' growing media is used in propagation.

3.8.2 Green roof plant selection

Green roofs are hostile sites. The combination of elevated temperatures, wind exposure and high light provide challenging conditions for plant growth. Plant selection requires careful consideration of site, microclimate, substrate and maintenance factors, linked to the desired aesthetic, functional and management outcomes for the project.

A useful way to categorise plant suitability for green roofs is required substrate depth, shown in Figure 15. See also **sections on substrate** in the following chapters.

Figure 15. The substrate depth on a green roof influences the plant types that can be used



Plant selection for stormwater management

If a roof is designed to soak up water and remove contaminants in the water during storm events, species that use water effectively and that accumulate nutrients should be explored. Herbaceous or shrubby species, which use more water than succulent species, will be more effective plant choices. While it may seem counter-intuitive to choose plants that have a higher water requirement over those requiring less, water may move more effectively from its landing on the substrate and back into the atmosphere with herbaceous plants as the interface. In addition, higher levels of water loss provide greater water movement and increase localised cooling of the surrounding environment.

Plant selection for aesthetics

If aesthetics are important, then select plant species that will provide interest throughout the year, and consider both foliage and flowers. The period after flowering provides interest from dried flower or seed-heads, for example, *Leonotis leonurus*, *Agastache rugosa*, ornamental *Allium* species, and native species *Olearia axillaris*. Planting in layers, with drought tolerant

(seasonally dormant) species is another approach. *Bulbine bulbosa*, *Senecio spathulatus*, and other short-lived species can be added in with perennial species.

Plant selection for drought tolerance

Plants that come from ecosystems with shallow soils, such as rock outcrops, have been shown to both survive extended dry periods and make use of the high water available after rainfall and dry out the growing substrate. Successful species have also been shown to re-sprout after droughts, offering an 'insurance policy' if conditions are particularly harsh. These species include *Dianella revoluta*, *Stypandra glauca* and *Arthropodium milleflorum*.

Experience in Melbourne has shown that the succulent species *Sedum xrubrotinctum* and *Sedum pachyphyllum* were able to survive extreme dry conditions on the unirrigated shallow substrate green roof at The University of Melbourne's Burnley campus through the summer of 2008-09. Other species that failed under the extreme conditions of 2008-09 but survived the milder 2009-10 and 2010-11 summers without irrigation were *Sedum reflexum*, *Sedum mexicanum*, *Sedum spurium* 'Schorbuser Blut'.

3.8.3 Types of green roof plants

Low-growing succulents

Succulents, particularly colourful sedums, dominate shallow substrate green roofs across temperate Europe and North America. Their low growing and/or spreading habits, great drought tolerance, seasonal flowers and contrasting foliage colours, textures and forms make them ideal candidates for green roofs. Many will benefit from some irrigation, particularly during drier months of the year. In projects with no, or minimal, irrigation, thicker-leaved succulents are the most suitable. Succulents should be planted at high density (up to 16 per square metre) to provide adequate coverage of the growing substrate and aid shading across the surface.

Herbaceous perennials

This category includes a range of non-woody plants, many with persistent roots or underground stems (such as rhizomes and stolons, etc.) that enable the plant to regrow and persist for many years. The most useful herbaceous perennials for Melbourne green roofs are those originating from dryland habitats. Flowering perennials are used mainly for display and seasonal interest, and many indigenous flowering plants used will also have significant habitat values. Ornamental grasses and grass-like plants, especially those forming upright tussocks, provide useful contrasts in texture and form and can be managed through pruning to maintain their shape and habit. Some may have high water needs over summer and large biomass forms could present a fire hazard in some locations.

Geophytes (bulbs, corms, and tubers) are another group of herbaceous perennials that can be extremely useful, particularly for seasonal interest and display. Many of the spring and autumn flowering geophytes are also summer dormant, making them particularly useful drought 'avoiders' over the warmer months of the year. Larger succulents with upright growth habits are also useful for green roofs, although their mass over time can be considerable. While many herbaceous perennials can be grown in substrate depths as little as 150 mm, irrigation will be needed for long-term success at these depths. Some caution is needed in the use of plants with vigorous rhizomes or stolons (such as some Bamboo species); they can become excessively dominant and damage green roof profile layers.

Annual and biennial plants

A range of annual and biennial plants can be used successfully on green roofs and tend to fall into two distinct groups. Quick growing annuals and ephemerals, particularly those originating from dry and arid climates, can be spectacular additions to display plantings, but will need irrigation to be sustained for longer periods. Vegetables are the other main group of annual plants used on green roofs. These require irrigation and a substrate depth of at least

200 mm. Careful plant selection and maintenance is needed to ensure annuals do not become weeds on a green roof.

Turf

Some green roofs are constructed specifically to support sports turf. Careful species selection is needed to ensure outcomes can be met: the surface and play requirements are much more demanding than for amenity turf.

Sports turf requires a designed soil or growing medium to ensure effective drainage and a substrate depth of at least 250 mm. It also requires regular irrigation, fertilising and mowing to maintain sward performance and health. Many facility managers seek expert advice on the use of sports turf on green roofs to ensure design outcomes and maintenance can be properly resourced and managed. On smaller scale green roofs, species with excessive vigour, such as Couch Grass (*Cynodon dactylon*) and Kikuyu (*Pennisetum clandestinum*), should be avoided: their rhizomes can be invasive and may damage waterproofing membranes.

Small shrubs

Shrubs to one metre in height are best used in substrate depths of 250 mm or more. Small shrubs provide cover, display and habitat values, and often form the bulk of plantings used on green roofs with deep substrates. Increasing the substrate depth and irrigation will also increase the range of plants that can be used successfully. Excessively vigorous species should be avoided unless there will be sufficient maintenance to manage their growth, some low hedging plants could be in this category.

Shrubs

Shrubs up to two metres high can be used where substrate depths are at least 600 mm. They provide screening, space definition, ground coverage and seasonal flowers. Like any plant group, shrubs require careful selection and consideration of their maintenance needs. Plants with dense, upright habits should only be used where there is minimal wind exposure and/or significant protection can be afforded to support the canopy and prevent wind forces. Hedges and screening shrubs will require regular maintenance, including pruning and removal of biomass off the roof.

Trees

While many small trees (to five metres) can be successfully grown on substrate depths of 600 mm, depths of 1,000 mm or greater will ensure the best outcomes are achieved. Trees are dominant elements in any landscape, and on a green roof trees will generally be stunted in height and spread, when compared to those planted at ground level. The greater the roof exposure and overall site 'hostility', the more important tree selection becomes. Trees with sparse canopies, flexible stems and high tolerance to heat are best in areas of high wind exposure, although some form of anchorage will always be needed to manage them successfully.

Table 7. Suitable plants for green roofs in Victoria

Bold text indicated native species.

Provided as a guide only, and should not be considered as an exhaustive list or suitable for all sites.

Plant group	Type	Examples
Low growing succulents	Small and/or thin leaves	<i>Crassula multica</i> <i>Sedum mexicanum</i> , <i>S. reflexum</i> , <i>S. sexangulare</i>
	Thick leaves and/or stems	<i>Carpobrotus rossii</i>, <i>C. modestus</i> <i>Disphyma clavellatum</i> <i>Carpobrotus edulis</i> <i>Cotyledon orbiculata</i> <i>Crassula tetragona</i>

		<i>Kleinia mandraliscae</i> , <i>K. repens</i> <i>Lampranthus deltoides</i> <i>Mesembryanthemum echinatum</i> , <i>M. lehmanii</i> , <i>M. floribundum</i> <i>Sedum nussbaumerianum</i> <i>Sedum pachyphyllum</i> <i>Sedum xrubrotinctum</i> , <i>xGraptosedum</i> 'Bert Swanwick', <i>xSedeveria</i> 'Pat's Pink'
Annual and biennial plants	Plants for floral display	<i>Calandrinia eremaea</i>, <i>C. polyandra</i> <i>Calendula officinalis</i> <i>Tagetes patula</i> , <i>T. erecta</i> <i>Zinnia elegans</i>
	Culinary herbs and vegetables	<i>Ocimum basilicum</i> <i>Petroselinum crispum</i> <i>Salvia officinalis</i> , <i>S. 'Greek Skies'</i> <i>Thymus vulgaris</i> <i>Origanum vulgare</i> <i>Allium schoenoprasum</i> With suitable substrate and irrigation, most vegetables that can be grown in containers should succeed on a green roof
Turf	Amenity turf	<i>Zoysia macrantha</i> <i>Stenotaphrum secundatum</i> <i>Zoysia species</i> <i>Festuca arundinacea</i> <i>Festuca rubra</i> 'Commutata' <i>Poa pratensis</i> <i>Lolium perenne</i>
	Sports turf	<i>Cynodon dactylon</i> <i>Pennisetum clandestinum</i> <i>Digitaria didactyla</i> <i>Lolium perenne</i>
Herbaceous perennials	Upright flowering perennials	<i>Brachyscome ciliaris</i>, <i>B. multifida</i> <i>Calocephalus citreus</i> <i>Calotis cuneifolia</i> <i>Chrysocephalum apiculatum</i>, <i>C. semipapposum</i> <i>Leptorhynchos tenuifolius</i> <i>Podolepis jaceoides</i> <i>Rhodanthe anthemoides</i> <i>Veronica gracilis</i>, <i>V. perfoliata</i> <i>Vittadinia cuneata</i> <i>Wahlenbergia communis</i> <i>Xerochrysum bracteatum</i> <i>Achillea</i> cultivars <i>Agastache</i> species and cultivars <i>Euphorbia rigida</i> , <i>E. myrsinites</i> <i>Nepeta</i> cultivars <i>Pelargonium sidoides</i> <i>Hylotelephium</i> 'Matrona', <i>H. 'Autumn Joy'</i> <i>Hylotelephium cauticola</i> 'Ruby Glow' <i>S. nemorosa</i> cultivars
	Low, spreading ground covers	<i>Dichondra repens</i> <i>Einadia nutans</i> <i>Eutaxia microphylla</i>

		<p><i>Grevillea lanigera</i> <i>Kennedia prostrata</i> <i>Myoporum parvifolium</i> <i>Senecio spathulatus</i> <i>Viola hederacea</i></p> <p><i>Aptenia cordifolia</i> <i>Cerastium tomentosum</i> <i>Convolvulus sabatius</i> <i>Glechoma hederacea</i> <i>Tradescantia pallida</i> 'Purpurea' <i>Thymus pseudolanuginosus</i>, <i>T. serpyllum</i></p>
	Geophytes (bulbs, corms, tubers, etc)	<p><i>Arthropodium milleflorum</i> <i>Bulbine bulbosa</i>, <i>B. crassa</i>, <i>B. vagans</i> <i>Pelargonium rodneyanum</i></p> <p><i>Allium</i> species and cultivars <i>Tulbaghia violacea</i></p>
	Larger succulents (upright and rosette forms)	<p><i>Aeonium arboreum</i> <i>Aeonium haworthii</i> <i>Aloe mitriformis</i> <i>Aloe</i> 'Gemini' <i>Aloe brevifolia</i> <i>Crassula falcata</i>, <i>C. ovata</i> 'Blue Bird', <i>C. tetragona</i> <i>Echeveria ximbricata</i> <i>Echeveria</i> cultivars <i>Hesperaloe parviflora</i> <i>Yucca desmetiana</i></p>
	Grasses	<p><i>Austrodanthonia caespitosa</i>, <i>A. setacea</i> <i>Austrostipa scabra</i> <i>Chloris truncata</i> <i>Deyeuxia quadriseta</i> <i>Dichelachne crinita</i> <i>Orthrosanthus multiflorus</i></p> <p><i>Helictotrichon sempervirens</i> <i>Miscanthus</i> cultivars</p>
	Flowering plants with 'grass-like' foliage	<p><i>Anigozanthos</i> cultivars <i>Conostylis</i> species & cultivars <i>D. caerulea</i>, <i>Dianella revoluta</i>, <i>D. tasmanica</i> species and cultivars <i>Ficinia nodosa</i> <i>Lomandra micrantha</i>, <i>L. multiflora</i> and cultivars <i>Poa hiemata</i> <i>Stypandra glauca</i> <i>Themeda triandra</i></p> <p><i>Armeria maritima</i> <i>Sisirhynchum</i> cultivars <i>Iris unguicularis</i> <i>Liriope</i> species and cultivars <i>Ophiopogon japonicus</i></p>
Small shrubs (to 1 m)		<p><i>Acacia amblygona</i> <i>Correa glabra</i>, <i>C. reflexa</i>, <i>C. decumbens</i> and cultivars <i>Olearia axillaris</i> <i>Plectranthus argentatus</i></p> <p><i>Buxus sempervirens</i> and <i>B. microphylla</i> species and cultivars <i>Cotoneaster dammeri</i> <i>Erysimum xcherei</i></p>

		<i>Gaura lindheimeri</i> species and cultivars <i>Helichrysum italicum</i> <i>Lavandula</i> species and cultivars <i>Nandina domestica</i> 'Nana' <i>Plectranthus ciliatus</i> , <i>P. parviflorus</i> <i>Salvia chamaedryoides</i> , <i>S. microphylla</i> species and cultivars <i>Santolina magonica</i> , <i>S. chamaecyparissus</i> , <i>S. neapolitana</i> cultivars <i>Teucrium marum</i>
Shrubs (to 2 m)		<i>Callistemon</i> 'Little John' or 'Captain Cook' <i>Correa alba</i> <i>Eremophila debilis</i> <i>Grevillea obtusifolia</i>, <i>G. rosmarinifolia</i> <i>Lasiopetalum behrii</i> <i>Melaleuca incana</i> <i>Westringia</i> species and cultivars <i>Cistus</i> species and hybrids <i>Escallonia</i> cultivars <i>Juniperus horizontalis</i> , <i>J. sabina</i> <i>Leonotis leonurus</i> <i>Nandina domestica</i> <i>Pittosporum tobira</i> <i>Raphiolepis umbellata</i> , <i>R. indica</i> species and cultivars <i>Rosmarinus</i> species and cultivars <i>Viburnum tinus</i>
Small trees (to 5 m)	Trees	<i>Acacia cognata</i> cultivars, <i>A. pendula</i>, <i>A. stenophylla</i> <i>Brachychiton rupestris</i> <i>Eucalyptus caesia</i> 'Silver Princess', <i>E. dolichorhyncha</i>, <i>E. macrocarpa</i>, <i>E. pauciflora</i> <i>Ficus microcarpa</i> var. <i>hillii</i> <i>Tristaniopsis laurina</i> <i>Arbutus</i> species and hybrids <i>Cercis siliquastrum</i> <i>Citrus limon</i> <i>Cussonia paniculata</i> <i>Jacaranda mimosifolia</i> <i>Lagerstroemia indica xfauerii</i> cultivars <i>Malus ioensis</i> 'Plena' <i>Metrosideros excelsa</i> <i>Pyrus salicifolia</i> <i>Quercus ilex</i> , <i>Q. suber</i> , <i>Q. coccifera</i> <i>Geijera parviflora</i> <i>Ulmus parvifolia</i> <i>Olea europaea</i> 'Tolley's Upright' or 'Swan Hill' <i>Laurus nobilis</i>
	Tree-like forms	<i>Dracaena draco</i> <i>Yucca gigantea</i>

3.8.4 Green wall plant selection

Depending on the scale of the wall, plantings can range from ground covers to larger herbaceous species, shrubs and even small trees.

Plant selection should firstly consider the desired outcomes of the green wall. Certain plants will be better for aesthetic and landscape design values, drought tolerance, water purifying, air filtering or habitat provision. It is important to realise that plant growth form, sun and shade exposure as well as wind exposure, is notably different on vertical surfaces compared to a roof or at ground level. Obtaining specialised advice and visiting existing green walls will improve understanding of which species will be best suited.

The selection of species will also depend on the climatic conditions on-site. Consider the level of natural or artificial light available. (Be aware that plant selection will require an understanding of 'photosynthetically active radiation', the type of light that a plant responds to, rather than simply a measure of how the human eye perceives brightness). Select very shade tolerant species to suit the lowest light conditions. In highly exposed locations, select robust species that can tolerate sun and wind. Look for species that have shallow, fibrous root systems to promote strong anchorage in the limited volume of growing medium available. Recognise that the tops, corners and sides of the wall will have greater wind exposure. Investigate species that thrive in exposed conditions, such as coastal cliffs or inland rocky outcrops.

Larger plants may grow to shade others, so this must also be considered in the placement of species. External green walls are often exposed to strong and frequent wind. Vigorous growth increases maintenance requirements and slow growing plants are often preferred. However, vigorous species can be used to create protected niches for the inclusion of sensitive species in high exposure areas. This can help provide light or shade for other species, wind protection or humidity conservation. Consideration of where each species will be placed in relation to others (the array of plants) helps develop a working artificial ecology on the wall. Understanding how the ecology will morph as the plants mature is important, as niches will evolve beneath, next to and above certain species.

Plant selection must be matched to the particular green wall system and technology that is being installed. Not all species will grow well in each system. Some systems might cater well for terrestrial plant species (and need an appropriate growing substrate); others have an irrigation/fertigation or growing media system that favours epiphytic/lithophytic species (plants that do not require soil for growing and can exist on branches or rock surfaces).

Water requirements can be minimised by selecting species that are low water users. Recognise that more water may be available toward the base of a green wall system, so species should be selected and positioned on the wall with moisture gradients in mind. If the system recycles water, species selection may have to cater for elevated salt levels and amended pH levels.

Table 8. Suitable plants for green walls in Victoria

Shrubs	<i>Correa</i> cultivars <i>Escallonia</i> cultivars <i>Ficus</i> species <i>Metrosideros excelsa</i> 'Nana'
Evergreen herbaceous perennials	<i>Spathiphyllum</i> cultivars <i>Philodendron</i> 'Winterbourn' and 'Xanadu' <i>Monstera</i> species <i>Liriope</i> species and cultivars <i>Scheffera</i> species <i>Viola</i> species <i>Erigeron karvinskianus</i> <i>Chlorophytum comosum</i> <i>Peperomia</i> species <i>Plectranthus</i> species <i>Rhipsalis</i> species <i>Bromeliad</i> species Orchid species
Herbaceous ground covers	<i>Epipremnum</i> species <i>Plectranthus ciliatus</i>
Ferns	<i>Asplenium</i> species <i>Blechnum</i> species <i>Davallia pyxidata</i> <i>Humata tyermanii</i> <i>Nephrolepis</i> species

Grass-like foliage forms	<i>Acorus gramineus</i> cultivars <i>Bulbine</i> species <i>Ficinia nodosa</i> <i>Dianella</i> species <i>Dietes</i> species <i>Lomandra</i> species and cultivars <i>Ophiopogon japonicus</i>
Lilies & irises	<i>Arthropodium cirrhatum</i> 'Te Puna' and 'Parnel' <i>Arthropodium</i> species <i>Neomarica gracilis</i> <i>Patersonia occidentalis</i>

3.8.5 Green facade plant selection

Plant selection for green facades is strongly influenced by the mode or method of climbing plant attachment. Most climbing plants attach themselves to a surface or structure in one of two ways (see Figure 16):

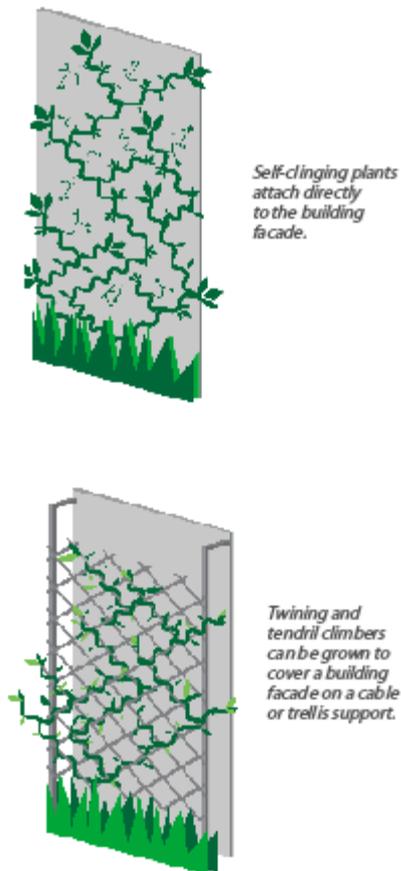
- self-clinging – attachment through adhesive suckers, disks or adventitious roots. These climbers then form a self-supporting vegetation layer on a solid wall or surface.
- twining and tendrils – attachment by twining stems or by hooking and clasping tendrils (modified leaf/stem organs). These climbers require a specialised support system and can produce both upward and cascading (or trailing) stems.

Another group of climbing plants have a scrambling habit and are known as scandent shrubs. These have no direct means of attachment and need to be tied and managed onto the structure that supports them. They may be vigorous and woody in their growth habit, which can make them difficult to be sustained on a structure without significant pruning and maintenance (such as *Bougainvillea glabra*).

Self-clinging climbers create green facades that can provide effective and long-term cover but may not be suited for buildings where the surface fabric is in poor repair. Many self-clinging climbers will mark a wall surface through their attachment, however this is rarely seen because of the foliage cover. Excessively vigorous species such as Common Ivy (*Hedera helix*) should be avoided and regular pruning will always be necessary to maintain suitable plant growth, form and size.

Twining climbers require a support system, such as cable or trellis, to support their growth habit. These supports may be attached to the building, or mounted independently. Plant selection needs to consider the available space for plant growth as the distance between the wall and the support structure will impact on plant performance and climate control.

Figure 16. Climbing plants used on green facades have different modes of attachment



Climatic factors

Species tolerant of low light are required for deeply shaded urban ‘canyons’ while high light tolerance is needed in exposed and elevated settings. Generally, full sun is considered to be four hours of sun per day and most species will require at least some direct sunlight to grow.

Facades can be established in areas of full shade, but the range of species that will grow in these conditions is limited. Facades at high elevation, in coastal areas or urban street canyons can be exposed to strong and frequent wind. Some plant species, twining climbers in particular, are more tolerant of wind and more mature plants tend to be more resilient in these environments. Self-clinging facades may be pulled away from the wall in very windy conditions. Small-leaved species with strongly attached foliage may be more suitable on sites prone to strong blasts of wind: large foliage may be stripped or shredded in these conditions.

Long-term maintenance

The plant’s lifecycle and growth rate will affect the time it takes for the facade to establish and the amount of ongoing maintenance required. Consider the mature size of the species as well as the level of foliage coverage required. Many climbing species exhibit early rapid growth but slower mature growth rates. Some green facade plants, such as Creeping Fig (*Ficus pumila*), require rejuvenation pruning to ensure juvenile foliage is maintained. With this species, adult foliage grows horizontally, does not attach directly to the building and creates a deeper, denser canopy of woody stems. While this may provide effective shading and create an insulating layer of air between the foliage and the building, it is inherently unstable because this canopy is not directly attached to the building. Woody climbers need careful selection as maintenance needs often increase over time, as stems grow larger and thicker and the plant increases in size: for example, *Wisteria sinensis* and *Vitis vinifera*.

Climbing plant species ideal for screening will have multiple features including:

- retention of lower foliage
- high shoot density
- pendulous leading shoots
- tolerance of and recovery from severe pruning (rejuvenation)
- longevity
- reliable growth rate

These features contribute to the production of consistent and uniform vegetative cover.

In their natural habitat, many climbing plants grow upwards towards the light, by twining or scrambling, and over time, they lose foliage cover at their base. Such species may be unsuitable as screening plants in the long term, if they do not respond to hard (rejuvenation) pruning to encourage new basal shoots, such as *Pandorea jasminoides* (Bower Vine).

The following table indicates some common climbing plants used in Victoria, how they attach, their ability to cover an area of facade – how well they screen (high to low cover) and how fast they grow (this indicates how much maintenance they require) – and their light tolerance. Average in the table indicates that they are not known to be particularly needy of high light nor particularly tolerant of low light. Note that the mature size will be affected by the soil volume available.

Table 9. Suitable plants for green facades in Victoria

Species	Type	Screening and Growth Rate	Light Tolerance
<i>Akebia quinata</i>	Twining	Medium cover and growth rate	Average
<i>Aphanopetalum resinosum</i>	Twining	Medium cover and growth rate	Average
<i>Cissus antarctica</i>	Tendrill	High cover and growth rate	Tolerates low light
<i>Clematis aristata</i>	Twining	Medium cover and growth rate	Tolerates low light
<i>Clematis armandii</i>	Twining	Low cover and growth rate	Average
<i>Clematis montana*</i>	Twining	Low cover and growth rate	Average
<i>Distichlis buccinatoria</i>	Tendrill	High cover and medium growth rate	Requires high light
<i>Ficus pumila</i>	Self-clinger	High cover and medium growth rate	Requires high light
<i>Hibbertia scandens</i>	Twining	Medium cover and growth rate	Requires high light
<i>Muehlenbeckia complexa</i>	Twining	High cover and growth rate	Average
<i>Kennedia rubicunda</i>	Twining	Medium cover and high growth rate	Requires high light
<i>Pandorea pandorana</i>	Twining	High cover and growth rate	Average
<i>Pandorea jasminoides</i>	Twining	Medium cover and growth rate	Average
<i>Parthenocissus quinquefolia*</i>	Self-clinger	High cover and medium growth rate	Average
<i>Parthenocissus tricuspidata*</i>	Self-clinger	High cover and growth rate	Requires high light
<i>Podranea ricasoliana</i>	Scandent shrub	High cover and growth rate	Requires high light
<i>Vitis vinifera*</i>	Tendrill	Medium cover and high growth rate	Requires high light
<i>Trachelospermum jasminoides</i>	Twining	High cover and medium growth rate	Average
<i>Wisteria sinensis</i>	Twining	Low cover and high growth rate	Requires high light

* *deciduous*

3.9 Designing for plant establishment

Good plant establishment is critical for the long-term health and performance of plantings in green roofs, walls and facades. In the design stage this includes consideration of multiple factors, including:

- Use of high quality planting stock. Stock that is too advanced or has overgrown its containers has high water needs and can be slow to establish on a site. Planting stock should be of an appropriate size to achieve the aims of the project, in terms of growth rate and coverage. It should also be completely free of weeds, pests and disease.
- Plant production in a high quality growing medium. In some cases using a medium with similar physical properties to the final growing substrate will assist in promoting plant growth.
- Working in with seasonal conditions. In most situations planting is best completed between autumn and early spring. This will assist plant establishment and growth, well before the warmer and drier conditions of summer.
- Establishment irrigation. Allowance should be made for suitable irrigation, usually for a minimum of six months, to avoid moisture stress and to promote plant growth across the site.
- Weed control. During establishment, weeds will compete vigorously with designed plantings on a green roof, wall or facade. Weeds must be controlled until the plantings achieve the desired growth rates and/or coverage.

Further information about establishing vegetation can be found in **chapters 5, 6 and 7.**

Chapter 4. Building and Installation – General Advice

This chapter provides general advice about building green roofs, walls and facades, including occupational health and safety, insurance considerations and what to expect at project completion on a large-scale job which has a project manager and several consultants.

4.1 Occupational Health and Safety (OH&S)

As for all construction work, the construction (and maintenance) of green roofs, walls and facades is subject to the Victorian *Occupational Health and Safety Act 2004*. This Act governs all Victorian OH&S laws and codes of practice and sets out the key principles, duties and rights in relation to OH&S.

The hierarchy of regulation in Victoria is shown in the diagram below.

Figure 17. Occupational Health and Safety legislative framework in Victoria



Guidance materials available from WorkSafe Victoria inform duty holders on how to comply with Victorian OH&S legislation. Consultants can also provide advice on ensuring OH&S requirements are met.

Note that National Workplace Health and Safety codes and guidance materials have no legal status in Victoria.

High-risk construction work

Some construction projects involve high-risk construction work and additional regulations govern management and procedures in such cases. High-risk construction work is of particular relevance to the design, construction and installation of green roofs, walls and facades as it is likely to involve work:

- where there is a risk of a person falling more than two metres
- on or near electrical installations or services, for example, the possibility of drilling into a wall containing live electrical wiring
- at a workplace where there is any movement of powered mobile plant, for example, working in an area of a construction site with moving skid steer loaders, telehandlers, backhoes, mobile cranes or trucks

Materials handling and storage

As on any building site, the materials used to construct a green roof, wall or facade should be delivered in a timely way to meet construction schedules. Consideration must be given to where materials will be unloaded and stored and how they will be moved to and from site. Secure storage and safe handling of materials on-site may be needed. For safety reasons, a roof must not be used for materials storage when a green roof is being constructed, as it is a building site and must be managed for weight, access, security of materials and safe movement of personnel.

Working at heights

The design and installation of all green roofs – and many green walls and facades – involves work at heights. The associated risks and responsibilities must be managed through a combination of training and safety features on the site including the use of barricades, railings, or other fall arrest systems, such as ropes and harnesses.

Consult the WorkSafe Victoria Compliance Code 'Preventing Falls in General Construction' with regard to specific OH&S issues associated with working at heights and management solutions. Wherever possible, the risks and hazards of working at heights should be removed or reduced and the design team must consider these as part of project planning.

Safety in design legislation

A Safety in Design risk assessment or workshop should be undertaken with the design and construction team/s to identify risks and determine the actions necessary to remove or reduce the likelihood of occurrence and severity of these risks.

4.2 Insurance and system warranties

The scale, complexity and overall cost of a green roof, wall or facade will determine whether insurance and warranties are relevant. Almost all professionally-installed projects will include them; smaller, DIY projects may not.

Until the local industry is further developed, it may be beneficial to consider insurance companies with a global reach that gives them relevant understanding and experience. Commercial insurer FM Global provides useful specifications for green roof design, installation and maintenance that can be used as a risk management tool during design and planning.

The warranty for a green roof, wall or facade will be straightforward if an established installation company, or a contractor licensed by that company, installs a proprietary system. Under these circumstances, the parent company should provide a warranty against failure of any or all of the components. Custom-built green roofs, walls or facades, with mix-and-match components, or multiple providers, may not be as straightforward to warrant or insure.

Waterproofing is more likely to be warranted separately if it is installed by a third party. However, the company supplying and/or installing the waterproofing may not take responsibility for breaches of the membrane that occur after it is certified as watertight, if they have no ongoing involvement with the project. Ensure there is clarity around the warranty conditions.

The client usually has the option to negotiate a defects liability period with the contractor. The contractor will be responsible for repair of defects that appear within an agreed period of time after project completion and may have responsibility for defective work beyond the product warranty period. Warranties may be waived if a DIY approach is undertaken with the product.

4.3 Project completion

Contractors and sub-contractors must provide necessary certifications at the completion of their work. At handover, the project manager will provide documentation of all necessary inspections and relevant certifications to the building owner. These should include:

- warranty on waterproofing
- drawing showing 'as built' planting (the actual planting may have varied from the design drawings)
- certificate of completion from a registered building inspector
- certificate of electrical safety from a licensed electrician (if relevant)

- certificate of occupancy (if relevant) from a building inspector/local council – this will relate mainly to safety and access requirements, including step heights and access points

Operational manuals must be handed over to the owners and/or contractors who will be engaged in operation or maintenance of the site. This must include the setting of an agreed time for any initial or ongoing training in the operation of systems installed on the site. Provision of funds for such training should be included as a contingency item in the budget during the design phase.

Maintenance or operational manuals may include:

- a planting maintenance plan
- an irrigation operations manual
- schedules for cyclical maintenance

Maintenance is discussed in more detail in **Chapter 8**.

Chapter 5. Building and Installation – Green Roofs

Once the planning and design stages of a green roof are complete, well-planned construction can deliver the project objectives. This chapter provides specific information about how to construct a green roof.

Green roofs are built up as a series of layers, with each performing a specific function. The most typical build-up is shown below and includes:

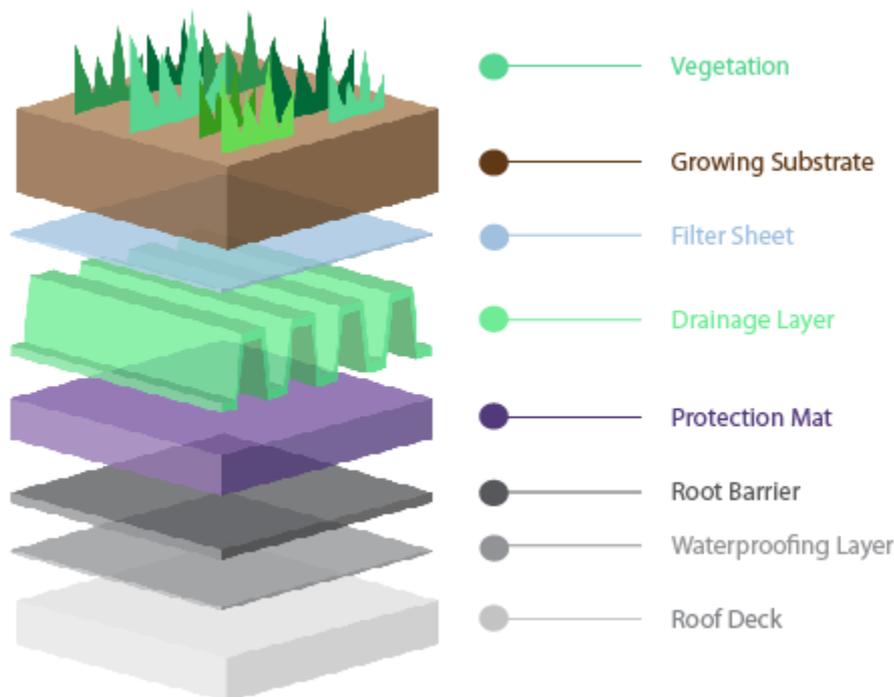
- the roof structure (roof deck)
- waterproofing layer
- protection layers (including the option of a protection mat and/or root barrier layer)
- drainage layer
- filter sheet
- growing substrate
- vegetation

The role of each of these components is outlined in the following pages. This chapter also covers other elements that may be incorporated into a green roof system, or are relevant to construction of a green roof, such as:

- leak detection systems
- thermal insulation
- irrigation
- greening in windy environments or on a pitched roof
- hard landscaping elements

Specialists in green roof design and installation can provide advice on the most suitable system and the most appropriate construction approach.

Figure 18. Layers of a green roof



A green roof contains plants that are grown in a layer of substrate varying in depth from a few centimetres to well over a metre. The growing substrate is usually composed of a high proportion of mineral particles with a long lifespan, with a small proportion of organic matter. A filter sheet retains the substrate and prevents washout into the underlying drainage layer. A protection mat and a root barrier

may be installed to prevent damage to the underlying waterproofing membrane that covers the roof deck.

5.1 Roof deck

Green roofs can be installed on roofs made of concrete, timber, sheet metal (usually clip-lock, or corrugated galvanised steel) and a range of other materials. However, it may be difficult to obtain insurance for green roofs installed on roof decks made from materials other than structural concrete or metal. Green roofs are most commonly installed on concrete roof decks because of structural integrity, ease of design, durability and amenity when complete. See Chapter 5.12 **Slopes and wind protection** for specific considerations relating to pitched roofs.

Greening a tiled roof requires special treatment. A green roof cannot be installed directly on a tiled roof. If the building has adequate load capacity, or if structural reinforcement and a support system can be incorporated into the design, a green roof may be constructed as a self-contained waterproof module that sits above the existing roof. Drainage from the green roof must connect directly into the lower level roof drainage system. It may be more economical to replace the roof to make it suitable for a green roof.

The components installed on the roof deck will be either loose-laid over the roof surface or installed as modules that connect together to form a continuous effect. Individual containers that are separately placed on a roof deck are considered a roof garden rather than a green roof, and because they do not cover a significant proportion of the roof they do not provide most of the benefits associated with green roofs.

It may be necessary to remove or relocate existing infrastructure on roof decks, or the green roof can be built around the equipment.

5.2 Waterproofing

A watertight roof is critical to successful green roof construction. While some roofs are intrinsically waterproof when built, most will require some form of treatment to prevent water entry into the building. Waterproofing treatment must provide a strong but flexible layer that allows expansion under physical or thermal movements of the building structure, without compromising watertightness. Vegetation generally should not be installed over areas such as expansion joints, where regular inspection of the waterproofing will be necessary.

Advice should be sought from a specialist waterproofing manufacturer to find the most suitable type of waterproofing treatment for the roof structure and the proposed green roof design. The manufacturing and installation of waterproofing membranes should comply with Australian Standards (see **Chapter 6.2** for more information).

In Australia, waterproofing is likely to be installed by a third party waterproofing contractor. The involvement of an independent contractor means that a clear agreement between all parties must be established for responsibility of the waterproofing membrane once it has been installed and certified as watertight. An independent leak detection specialist should test the waterproofing after its installation, and again after the green roof build-up is installed, prior to handover (see also **Chapter 4.3**).

The following tables contrast the two major types of waterproofing – liquid applied treatments and preformed sheets.

- Liquid applied treatments can be composed of bitumen emulsions, modified bitumen, polymer cement systems, polyurethane, polyurethane modified acrylic, acrylic or two-part polyurethane hybrid elastomers that require mixing prior to application.
- Preformed sheets are asphalt-based or comprised of thermosetting polymers or thermoplastic polymers.

Prefformed waterproofing may suit green roofs with gentle slopes and large uninterrupted areas. A green roof with many fixings onto the roof deck or penetrations, such as for lighting, power or ventilation, may be more suited to liquid applied waterproofing that is sprayed on or rolled on to form a cohesive single layer.

Waterproofing membranes must be protected from physical and chemical damage. This includes cuts and tears, the action of invasive roots and rhizomes, and exposure to the elements. All membranes will become brittle over time, and this is accelerated by exposure to cold, heat and UV rays from sunlight. A green roof will shield the membrane from damage and can significantly lengthen its life. Some prefformed membranes have a surface coating that provides additional protection.

Ensure that the waterproofing material is certified root resistant, suitable for the substrate, and installed by experienced, trained and certified professionals.

Root resistance may be built into waterproofing membranes either by the addition of root-inhibiting chemical treatments, or because the composition of the membrane provides an impenetrable barrier to root growth. Root resistant waterproofing is quicker to install than separate waterproofing and root barrier layers, but can be more costly. Examples include certain types of ethylene propylene diene monomer thermosetting, thermoplastic PVC and thermoplastic polyolefin membranes; however, the root-resistance of a product must be confirmed with the manufacturer, with certification provided.

Table 10. Common waterproofing treatments

Liquid applied waterproofing treatments		
Suitability	Advantages	Disadvantages
Complex designs with many upstands ¹ , corners or curves Roofs where access for sheet installation is difficult	<ul style="list-style-type: none"> • Seamless • Often trafficable • Flexible and capable of elongation • Easy to apply • Tolerant of some degree of surface imperfection • Easily repaired by re-application over breaches • Bonded to the roof 	<ul style="list-style-type: none"> • Pin-holes may develop on poorly prepared roof surfaces² • Solvent-based treatments become brittle over time and with exposure to sunlight and high temperatures • Root resistance • Not easy to ensure uniformity of thickness • Not recommended for use in permanently wet conditions, as they absorb moisture and soften over time

Prefformed waterproofing sheets			
Membrane composition	Application methods	Advantages	Disadvantages
Asphalt-based	Loose-laid	<ul style="list-style-type: none"> • Loose-laid membranes quick to install compared to bonded • Fully bonded more resistant to wind uplift than partly bonded • Fully bonded recommended by some green roof installers and lower risk of uplift makes insurance easier to obtain • Easier to locate leaks with precision with fully bonded membranes • More resistant to wind uplift than loose-laid 	<ul style="list-style-type: none"> • Loose-laid not recommended if high risk of wind uplift • Soft structure means membranes are usually not trafficable, UV resistant or root-resistant • Prone to failure and root penetration along seams due to softness of composition • Installation requires a high degree of skill to ensure high quality detailing of seams and around upstands¹ • Become brittle over time through exposure to sunlight, heat and cold
	Fully bonded 'torch-down'		
	Partly bonded		
Thermoplastic	Fully bonded	<ul style="list-style-type: none"> • UV stable and weatherproof 	<ul style="list-style-type: none"> • With classes of membrane other

		<ul style="list-style-type: none"> • Seams can be welded with heat or solvent³; or heat only⁴ • Bonding of membrane to the roof with heat, solvent, water-based adhesive, or tape reduces risk of wind uplift • PVC membranes are breathable, and well suited for bonding to the roof deck with glue or tape adhesives • PVC, thermoplastic polyolefin, ethylene vinyl acetate and ethylene butyl acrylate membranes are likely to be classified as root resistant: check manufacturer's specifications • Mechanical fastening to the roof deck may be suitable for some applications 	<p>than PVC, condensation of moisture may soften glue or adhesive tapes used to attach membrane to the roof deck, increasing risk of wind uplift</p>
Thermosetting	Fully bonded	<ul style="list-style-type: none"> • Ethylene propylene diene monomer (EPDM) and Butanoyl® membranes are likely to be classified as root resistant: check manufacturer's specifications • UV stable and weatherproof: long lifespan • Bonding with glue or adhesive tape reduces risk of wind uplift 	<ul style="list-style-type: none"> • Condensation of moisture may soften glue or adhesive tapes used to bond waterproofing to the roof deck • Carbon content of EPDM/Butynol® membranes makes them intrinsically electrically conductive and therefore unsuitable for electronic leak detection

¹ Upstands are structural penetrations from the roof such as vent pipes that will need to have the waterproofing layer brought up ('dressed up') around them to terminate above the level of the substrate.

² Note that the waterproofing consultant must certify that the roof is fit to receive the membrane prior to installation.

³ Thermoplastic polymers composed of chlorinated polyethylene, polyvinyl chloride (PVC), thermoplastic polyolefin, ethylene vinyl acetate and ethylene butyl acrylate.

⁴ Thermoplastic polymers composed of ketone ethylene ester.

5.3 Protection layers

5.3.1 Root barrier

Root barriers are often used in green roofs to provide some protection to the waterproofing from invasive stolons, rhizomes and from woody roots from trees and shrubs. The most common root barriers used are thin polyethylene sheets, laid over the waterproofing membrane. These may not be required if the waterproof membrane is certified as root-resistant. Thicker, welded root barriers will be needed for green roofs involving trees, bamboo or other vigorous, spreading grasses.

It is important to check the compatibility of the product with bitumen and polystyrene, especially where there is direct contact with a bitumen-based waterproofing or polystyrene insulation. The root barrier must also be resistant to the humic acids produced when plants decompose.

Separation sheets are sometimes installed between the waterproofing and root barrier to provide additional protection and separate materials that are not compatible. These are typically HDPE sheets laid directly on the waterproofing.

5.3.2 Protection mat

Protection mats or boards are used to protect the waterproof membrane from damage following installation. The most common materials used are water-permeable, hard wearing and dense synthetic fibres, polyester and polypropylene.

Protection matting is installed directly on the waterproofing layer (for root-resistant membranes) or atop the installed root barrier layer, providing further (uncertified) protection against root penetration and doubling as a separation sheet. The protection matting may provide some noise-absorbing capability. It can add to water retention on the roof, although the amount varies (from 3 l/m² to 12 l/ m²) and is only really useful on slopes below 15 degrees. A range of different products are available, reflecting the required functions, and apart from the material itself vary according to thickness (3 mm to 20 mm), fibre density and mass (320 g/m² to 1500 g/m²).

Protection mat sheeting should be installed with overlaps of 100 mm and some products have rubber backing that requires gluing in situ. The product should extend 150 mm above the finished surface of all upstands (such as vent pipes, chimneys and other roof penetrations) to ensure complete roof protection.

5.4 Drainage layer

Good drainage is critical for green roofs and ensures that large amounts of water are not retained on the roof, compromising both the structural integrity of the building and plant health through waterlogging and oxygen-depleted substrates. Sub-surface run-off must drain efficiently from the substrate, into the drainage layer, off the roof surface, and into drains to the stormwater or rainwater collection. The growing substrate must be kept separate from the drainage layer with a filter sheet.

Older green roofs often used a permeable layer of rock aggregate (such as scoria or gravel) for drainage. The clay and silt content of materials used in a rock aggregate drainage layer should be ≤ 10 per cent by mass. The rock aggregate should also have a suitable pH and be low in soluble salts to ensure plant growth is not adversely affected. This form of drainage is heavy and does not allow for air pruning of roots, which is now achieved with plastic drainage cells. However, in some situations, rock aggregate drainage does a better job controlling peak flow.

On modern, lightweight, green roofs, plastic drainage sheets or boards are the preferred drainage materials. Plastic drainage layers may be rigid, open mesh structures that allow unrestricted drainage of water, or they may have a cup-style, 'egg carton' design that enables water to be stored at the base of the profile (see image below). The advantage of the latter is that water can be stored and used later by the plant. The volume of water that can be stored varies with each product and the size and packing density of the cells.

Drainage is installed as a continuous layer over the entire surface of the green roof. Cup-style drainage sheets should be overlapped to eliminate the possibility of gaps being created between sheets. Other plastic drainage types should have adjacent sheets butted together. Very rigid drainage layers should be installed in trafficable areas of the green roof to avoid compression of the layer.



Egg-cup shaped drainage layer retains some water. Image: KHD Landscaping Engineering Solutions

5.5 Filter sheet

A filter sheet acts to retain the growing substrate, by preventing wash-through of the substrate particles into the underlying layers, and to prevent clogging of holes in the drainage layer. Filter fabric is sometimes referred to as geotextile fabric.

Considerations in the selection and use of filter sheets include:

- the expected flow rate of water as it drains through the system
- substrate type – if components of the substrate have sharp edges, the filter sheet should be strong
- vegetation type – the filter sheet must allow penetration of roots, and certain roots will be more or less aggressive (for example, herbs versus trees roots)

The filter sheet can be either a woven or non-woven material. A non-woven material is preferable as it is more resistant to root penetration and can sometimes be used as a root barrier system. The filter sheet is not weatherproof and should not be exposed to sunlight for any length of time, and it should therefore be laid immediately prior to the installation of growing substrate. At boundaries or edges of planting beds, the filter sheet should be installed with upturns to at least the same height as the top of the growing substrate (see image below).



A layer of filter sheet will prevent substrate dropping into the drainage layer. Enough filter sheet is set down over the roof so that at the vertical edges of the planting beds the sheet will be the same height as the substrate.

5.6 Growing substrate

The growing substrate supplies water and nutrients to plant roots, ensures gas exchange at the roots and provides anchorage to support plants.

Growing substrates for green roofs are typically composed of a mix of inorganic (mineral) and organic components. They can include scoria, ash, pumice, sand, coir, pine bark, porous, chemically inert foams and even recycled materials such as crushed bricks, and roof tiles. Organic matter is usually kept to a low proportion (typically 20 per cent or less) because it has a relatively short lifespan, degrading and slumping over time, and may become water repellent and difficult to re-wet if it dries out. The physical and chemical properties of the substrate mix, together with its depth and total volume, influences what vegetation can be supported on the green roof.

A substrate should:

- have a known saturated weight loading, that forms part of the structural load capacity of the roof; this is referred to as the saturated bulk density
- drain freely, to reduce waterlogging and prevent inundation during heavy rain, but also retain adequate water to sustain plant growth outside of heavy rain events
- be stable over time, usually achieved by using a high proportion of mineral components and a lower proportion of organic components

Soil is generally not used on green roofs, as its properties will be less well known compared to an engineered substrate, and therefore its longevity and suitability is harder to judge. Also, silt particles from soil can clog filter sheets and cause drainage problems.

Installers of green roof systems will be able to arrange the supply of a suitable substrate mix. **Appendix A** provides more information on substrate characteristics.

Transport and installation of growing substrates requires consideration in the pre-construction planning process. Most can be installed by either lifting bulker bags by crane or 'blowing' from a truck-mounted hopper, although each project will have its own specific considerations. See **Substrate Installation** below for more on installation.

A range of mineral and sheet mulches can be used successfully on green roofs but need to be considered carefully. Organic mulches, particularly fine materials, are generally unsuitable for use on green roofs as they can be easily blown off the roof, degrade rapidly, block drains, or create a fire risk in hot dry conditions. The saturated bulk density of any proposed mulch layer must be included in the weight loading calculations for the green roof build-up.

SUBSTRATE INSTALLATION

On large green roof projects, growing substrates can be installed by crane or by 'blower'. Substrate may be delivered in multiple bulker bags, typically of one cubic metre capacity, although a larger crane lifting bags of greater volume may be possible if site access permits. Care must be exercised in point loading of substrate on to the roof and movement across the roof ([see Chapter 4.1](#)).

'Blowing' a substrate involves the use of a compressor pump and hose to blow the substrate up to the roof. Sometimes substrates that are 'blown' onto a roof will have altered properties (due to finer particles aggregating during the process) and may need re-mixing on the roof to ensure success.

Growing substrate should be delivered before the day it is to be installed and stored as closely as possible to the crane, with clear access for the forklift or other machinery that will transport it to the crane lifting point. Growing substrates should be installed with minimal handling and be 'moist' to reduce the release of fine particles into the air. Appropriate personal protective equipment should be worn: gloves, dust filter masks, safety glasses and hardhat.

5.7 Vegetation

A range of planting stock can be used for green roofs, including seed, cuttings, seedlings, tubestock and larger containerised plants. See **Chapter 3** for information on species selection.

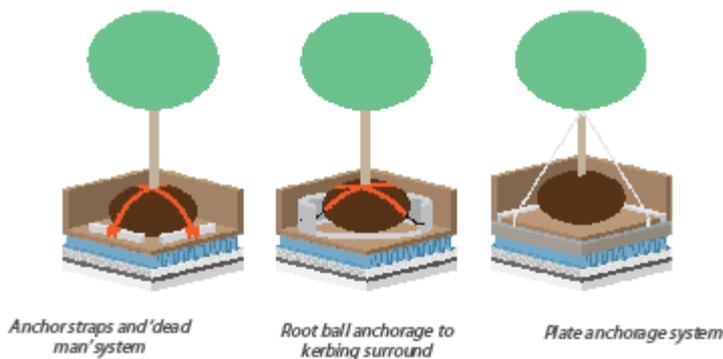
Planting is best completed in autumn and winter to assist plant establishment before summer. Irrigation should be provided while the plants establish. Depending on the time of year and rainfall, establishment irrigation could be required for up to six months.

It is helpful to acquire container-grown nursery plants that have been grown in the substrate they are to be planted into; otherwise, reduce the amount of potting mix held around the roots when transplanting into the green roof.

Controlled release fertiliser (CRF) can be added to the growing substrate or applied after planting is completed (top dressing). Careful consideration of rates and application methods is needed to ensure proper distribution and to limit any rapid discharge of nutrients (more information on plant nutrition is provided in [Chapter 8](#)).

Trees planted on green roofs will require a deep substrate as well as anchorage to prevent wind-throw. Various anchorage systems are available as illustrated in Figure 19. Tree bracings must be checked regularly to ensure they are functioning as specified, and not causing damage to the tree. Trees will require construction of a tree 'pit' in the substrate to house the tree roots: this needs to be deep and wide enough for lateral root growth to ensure tree stability. Consult an arborist for specialist advice.

Figure 19. Tree anchoring systems



Contract grown plants

Plants can be sourced from retail nurseries or grown at home for small projects. Generally, plants for larger projects will be grown to a contract with a wholesale nursery. Contract growing lead times may range from several months to more than a year, depending on the type of vegetation that is required. The growing contract will specify a date for completion and delivery of plants. It should outline the terms and conditions of a further holding period, for instance, if the planting date is postponed because of delays in construction. Ensure plants purchased are weed and pest free – look for nurseries with good hygiene. If in doubt, remove the top centimetre of growing medium to reduce the weed seed bank.

5.8 Thermal insulation

In some cases, a green roof may include thermal insulation, typically a layer of extruded polystyrene. While this can be positioned below the roof deck, installation above the waterproofing (known as an inverted green roof) is preferred, as it further protects the membrane from condensation and physical damage. Advice should be sought from a building energy consultant to establish the value of additional insulation, considering the insulating properties of the green roof assembly, substrate and vegetation. Research has been conducted into green roof insulation values in Adelaide and can be found at the [Building Innovation Fund website of the South Australian Government](#).

5.9 Leak detection

Leak detection is carried out when the waterproofing installation is complete. There are three methods typically used for testing the effectiveness of the waterproofing layer on green roofs:

1. Electrical field vector mapping (EFVM[®]) is suitable for electrically conductive and electrically grounded roof decks such as steel and reinforced concrete roofs. EFVM[®] can be used on wooden roofs or precast concrete slab roofs if a conductive layer of

metal foil or mesh is applied to the roof deck before the waterproofing layer is installed. The decision to use EFVM[®] must therefore be made at the design stage.

2. Destructive testing is used for preformed waterproofing membranes. The membrane is perforated at the lowest parts of the roof deck to check for the presence of any water beneath the membrane. The penetrations made through the waterproofing must then be repaired to restore the membrane's integrity. Destructive testing may be the only method that can be used on older existing green roofs. For new projects, EFVM[®] should be considered during design, as it is simpler, safer and non-destructive of the waterproofing system.
3. Flood testing is suitable only for flat roofs with slopes of up to 2 per cent. Flood testing involves temporarily blocking the roof drains and flooding the roof membrane with a known depth of water for a set period of time. The weight loading of the roof must be checked against the weight of water that will sit on the roof during the test. This ensures that the structural integrity of the building is not compromised.

It is advisable to perform an additional leak test prior to installation of the growing substrate if significant time has elapsed since the waterproofing was completed, or if there has been construction activity or other traffic on the roof. The repair of leaks presents a greater challenge once the growing substrate and vegetation are installed. However, EFVM leak detection should be performed at this time (project completion). It may also be carried out prior to the expiration of membrane warranties.

5.10 Irrigation

An irrigation system is highly advisable on green roofs: to extend plant species selection options, to improve plant growth rates and increase long-term vegetation success – thereby ensuring aesthetic and environmental (such as building cooling, stormwater reduction) outcomes can be achieved. Planning for irrigation on a green roof should consider the site layout and conditions (access, exposure), type of plants, climate and water supply issues (pressure, quality, etc.). Substrate properties and depth are also important as they influence water infiltration, holding capacity and drainage. In most cases, irrigation design will be heavily influenced by the nature of the water supply resource (for example, harvested vs. potable water) and a water budget should be used to guide not just irrigation but also plant selection (see **Chapter 3**). In larger green roof projects, irrigation is best undertaken by a specialist consultant to guide system design, component selection, installation and maintenance. Table 11 provides an outline of different options for irrigation of green roofs.

Automatic systems

If an automatic irrigation system is to be installed on a green roof, consider a system that incorporates a rain sensor that shuts off the system in the event of rainfall above a certain threshold. This removes the risk that the roof loading may be compromised if the irrigation system is running during a heavy downpour. Even automatic systems require regular physical checks and operation tests.

Low irrigation

It is important to understand that, while some succulent species can survive on rainfall alone, plants that experience moisture stress will decline over time. This leads to a loss of vigour, leaf shedding, canopy reductions and ultimately plant death. Plant failure means more water run-off from the roof, less transpirational cooling and more opportunities for weed invasion. As such, irrigation is advisable. However, if designing for very low water use, select plant species that are better able to tolerate the extreme moisture stress on a green roof during a typical summer. Selection tools to guide the identification of low water use plant species can be found at the [Smart Garden Watering website](#). Another option is to provide supplementary irrigation on a contingent basis during the hotter periods of the year.

Depending on the level of attention that can be provided, inclusion of indicator species with moderate requirements for water may be helpful to show when supplementary irrigation is necessary. This avoids compromising the performance of all the plants.

Irrigation frequency

During the establishment phase after planting, irrigation may be frequent, for example, two to three times per week. For food crops, irrigation will also be necessary during high activity phases of the growth cycle, such as when the plant moves into flowering and fruit set. The frequency of irrigation should be matched to the drainage and water-holding capacity of the mix: frequent irrigation of a very free-draining substrate is likely to waste water.

The irrigation delivery method will partly determine the timing of irrigation. Watering in high daytime temperatures will transfer more heat into the building, as water heats up as it passes through the hot growing substrate and transfers some of this heat into the building when it drains onto the roof surface. For surface and sub-surface irrigation, there is little to no wetting of the foliage, which lowers the risk of fungal disease. If spray irrigation is used, it should be applied very early in the morning to enable foliage to dry off throughout the day and thus reduce the likelihood of disease.

Moisture sensors

Be aware that moisture sensors used to estimate moisture content in standard landscaping soils do not provide reliable information about the moisture content of free-draining, porous growing substrates used on green roofs.

Table 11. Irrigation methods for green roofs

Delivery method	Advantages	Disadvantages
Microspray	Low cost, visible, easy to install, reliable	Uneven distribution (plant interception), high water loss (wind, evaporation), foliage wetting (increased disease potential)
Surface drippers/perforated pipes	Low cost, visible, even delivery of water	Moderate water loss
Sub-surface drippers/perforated pipes	Low cost, moderate efficiency (water delivery to root zone)	Non visible (difficult for maintenance), higher potential for damage by people digging
Sub-surface capillary	High efficiency	High cost, maintenance and repair is difficult because not visible, 'capillary rise' of substrate needed or water will not reach plants
Wicking associated with irrigation in drainage layer	High efficiency, ease of installation	Linked to proprietary systems, 'capillary rise' of substrate needed, this may be unsuitable for plant establishment if the water is applied too deep for the plant roots to reach
Hose	Good for domestic application for easily accessed areas, not so good for other areas. Allows monitoring to occur at the same time	Cost (requires someone to be present on-site), low water efficiency, foliage wetting, uneven distribution

5.11 Wind considerations

Even on flat roofs, wind uplift may present serious challenges for retention of substrate and plants. Wind damage can be dangerous to people and property and costly to repair. Retention systems may be required to ensure that materials cannot be blown off the roof.

Wind uplift pressure is lowest on the centre of the roof and highest at the edges, around the perimeter and at corners. The higher the building, the greater is the risk. On pitched roofs, the roof peak is also subject to uplift. Minimising untethered components greatly reduces the risk of damage to the green roof by uplift.

Where possible, waterproofing should be fully adhered to the roof, or mechanically fixed. For waterproofing layers that are not bonded to the roof, the green roof assembly must provide adequate ballast to prevent uplift. Edge treatments are the most critical: the un-vegetated zone around the perimeter of a green roof (see **Chapter 5.13**) may require heavy concrete paving slabs rather than loose gravel ballast. The materials used must conform to the design wind load calculated for the specific green roof location.

On some green roofs, perimeter balustrades or parapet walls will provide some protection against wind flow. Other treatments, such as jute erosion control netting (see **Chapter 5.12**) or coated wire retaining systems, may be useful.

Plant selection may also be used to mitigate the impact of winds. If the tolerance of different species to wind exposure is understood, plantings can be planned so that the lowest-growing, most robust species are planted in the most exposed areas. Taller, less wind tolerant species are installed behind them. The resulting gentle gradation of vegetation heights interrupts, and slows, wind flow over the planting.

5.12 Slopes and wind protection

Landscapes on pitched roofs are subject to wind forces and gravity affecting the stability and retention of the growing substrate and plants. In many cases slippage can lead to poor plant performance and ultimately green roof failure. For roof pitches of up to 15 degrees, no additional protection is needed, unless there are strong wind issues on the site.

Waterproofing must be root-resistant, and covered with a protection mat. A drainage layer is not always required as the roof can drain effectively through gravity. The stability of steeply pitched green roofs is increased by maintaining vegetation cover: provision of irrigation is essential.

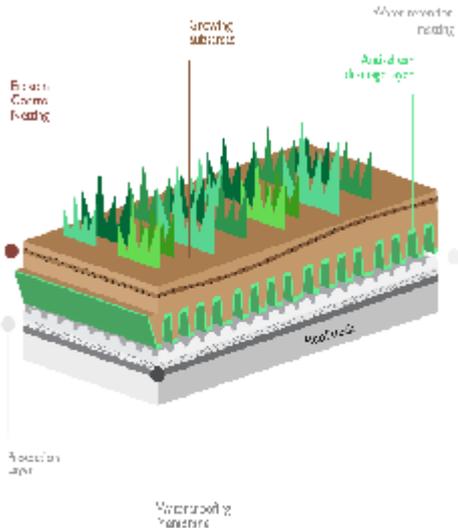
For green roofs constructed on pitches greater than 15 degrees, basic protection can be provided through anti-erosion jute netting installed just below the substrate surface to provide some anchorage to plants (see image). This netting breaks down over time, and is used simply to help keep the substrate in place whilst the plants establish.



Anti-erosion jute netting installed on a sloped green roof. Ideally a layer of substrate should be covering the netting. The netting will degrade over time. Image PAD Creations

Greater protection can be provided on steeper sites by using a drainage layer with large cells, or cups. The growing substrate fills the cells of the drainage layer, reducing slippage and providing spaces for plant roots to grow, ensuring further stabilisation (see Figure 20). A filter sheet must be placed beneath the drainage layer to reduce wash-through of fine particles from the substrate.

Figure 20. Layers of a sloped roof



A green roof on a slope can include a drainage layer with large cells to retain substrate as well as a layer of erosion control matting laid close to the top of the substrate to help retain substrate and plants during the establishment period.

For green roofs with slopes between 20 degrees and 45 degrees, ‘honeycomb’ webbing, comprising multiple, enlarged drainage cells, can be installed above the drainage and filter sheet layers (see image below). This holds the substrate in place, increases stability and reduces slippage. Other specialised structural elements can be incorporated to transfer shear forces into stable, reinforced abutments that form part of the roof structure, or wind barriers can be installed.



Honeycomb webbing used to stabilise substrate on a pitched green roof. Image: NHD Landscape Engineering Solutions

5.13 Hard landscape elements

Some of the functional elements that are used in green roofs include:

- non-vegetated zones
- retaining edges
- flashings
- drains and gutters
- planting containers
- topographical construction
- a range of other elements, not discussed in detail here, such as:
 - harness attachment points
 - controller boxes/solenoid boxes (to house irrigation components)

- decorative and functional landscape elements such as decking, paving, seating, shade protection, ponds and lighting

The colour of materials should be considered as this will affect their heat gain. Consider location of shade structures as additional elements.

Non-vegetated zones

Non-vegetated zones are used to group roof penetrations, vent pipes and other upstands and assist in lateral drainage. They are generally constructed with large diameter aggregate rock or ballast (16-32 mm size), rather than the growing substrate, and provide additional lateral drainage into the roof drains. They are usually between 300-500 mm wide and are separated from the roof perimeter ballast by metal edging installed around the planting area. Similar vegetation-free zones may be created through use of paving slabs or ballast to provide access pathways across the green roof, or as firebreaks on very large roofs.

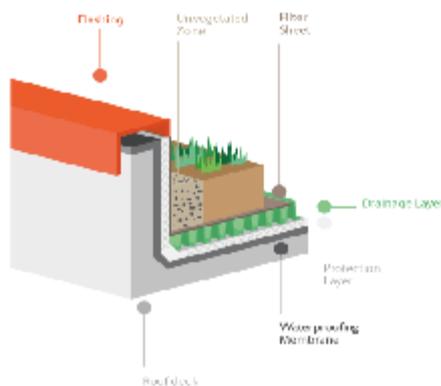
Retaining edges

Edging can be used to define and retain planted and non-vegetated zones across a green roof. It can include concrete, stainless steel, recycled plastic or aluminium products; L-shaped edges are installed above the filter sheet and often have perforations to allow drainage through the profile.

Flashings

Roofs with a parapet that extends above the roof deck require installation of a cover (flashing) to protect the building fabric. This should be included in the waterproofing installation to ensure that membrane terminations, and any areas of membrane extending over the vertical and horizontal surfaces of the parapet, are not exposed.

Figure 21. Functional elements on a green roof can include flashing (capping) and non-vegetated zones



Drains and gutters

All drains must be accessible for maintenance, protected from blockage by leaf litter and substrate wash, and housed with inspection chambers, drain covers, filters or strainers. Inspections after construction, following storms and every three months are recommended.

Selection of drainage hardware depends on the required function and appearance; examples are provided in the section on drainage in **Chapter 2**. For drains located flush with the roof surface, a grille should be installed to prevent drain clogging.

Planting containers

Planters must be made from weather resistant materials, and the components must be physically and chemically compatible with each other. Common examples of materials used

to build planting containers are powder-coated metal, galvanised steel, ceramic, timber, UV stable plastic and glass reinforced concrete (lightweight concrete).

Topographical construction

Blocks of polystyrene foam can be used to build up areas to create mounds or hills without the additional weight of the substrate. Topographical variations on a green roof create different growing conditions and microclimates to increase habitat opportunities for beneficial insects, as well as visual, aesthetic interest.

Chapter 6. Building and Installation – Green Walls

Green wall systems vary greatly in their design and construction from DIY projects to modular green wall systems available to buy 'off the shelf', through to proprietary systems that are custom-fitted to a wall. Specialists in green wall design and installation can provide advice on the most suitable system and the best construction approach. Green walls can deliver more than aesthetic benefits, and this requires consideration in the design stage. This chapter provides advice on the structures and components required for green wall systems, waterproofing, irrigation and nutrition, vegetation and lighting. This information should be read prior to starting a green wall-building project.

6.1 Structures and components for green wall systems

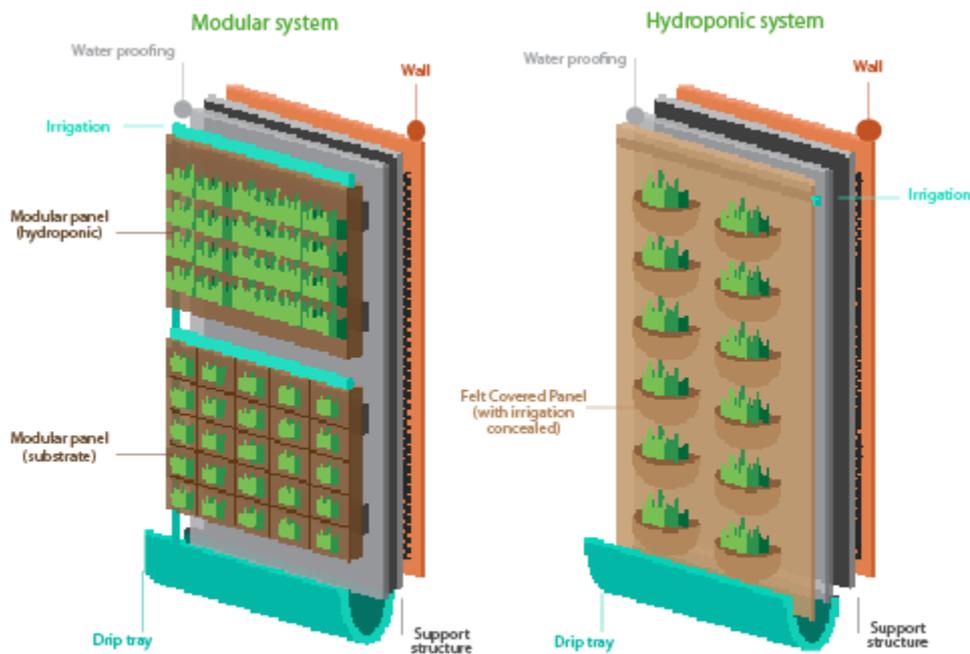
Hydroponic green wall systems can be either modular containers or large panels. The systems are installed via brackets that sit out from the load-bearing wall (or a stand-alone structure) to create an air gap between the wall (or other structure) and the backing sheet of the green wall system. In a hydroponic system, an inert growing medium is provided to which the plants physically anchor, such as a horticultural foam, a mineral fibre or a felt mat. These materials can act as a water retentive sponge, although the more they soak up the heavier the system becomes. The advantage of the hydroponic system is that there is no structural decay of the growing medium, no salt build up from fertilisers and nutrients are supplied in a precise and controlled manner. Over time, plant roots grow and ramify through the entire system to create a very robust network.

Substrate-based systems use substrate-holding containers made of plastic or metal. The substrate is packed directly into the empty container or placed in a water permeable, synthetic fibre bag. The containers are connected together and anchored to the wall or to an independent, structurally secure metal rack or framework. Alternatively, plastic or metal growing containers can be hung on a metal grid fixed to the wall. Individual growing containers can be removed for maintenance or replanting. Most substrate-based systems are designed for automatic irrigation, just like the hydroponic green wall systems.

The growing medium in these systems provides a structure to support the plant and facilitates water, air and nutrient access, decreasing the need for constant management associated with hydroponic systems. However, over time the reserve of nutrients will be exhausted and there can be a build up of salts in the growing medium. Traditional potting mix is not a suitable substrate for green walls. A specialist green wall provider will advise on the most appropriate growing medium for a particular green wall design. See also **Appendix A** for information about substrate characteristics.

Figure 22. Types of green wall configurations

Note: Green wall systems vary enormously, these are two general types – modular, which can be hydroponic or substrate-based, and felt covered hydroponic panels. Note that the support structure and waterproofing are optional and depend on the site.



Drip trays are used to capture excess irrigation water from the growing medium as well as water droplets that drip off foliage. The size of the drip tray should be sufficient to hold an entire irrigation cycle's water volume (before draining away prior to subsequent cycles starting). Drip trays may not be necessary if the run-off is intended to irrigate vegetation below the green wall. If drip trays are not used, ensure run-off does not create slip hazards, damage the building fabric or provide excess moisture or nutrients to ground-based plantings below.

Water captured in the drip tray or reservoir at the base of the planting system can be pumped back to the top of the wall for re-use rather than being wasted, provided that it is treated to prevent build-up of nutrients. Drip trays should have a drainage pipe of sufficient diameter to empty the drip tray or manage water capture sufficiently to mitigate overflow of the tray. Fascia treatments may be added to conceal the edges and functional elements of the green wall system, such as the irrigation system and drip tray.

6.2 Waterproofing

Waterproofing is project-dependent; in some cases there will be a sufficient air gap between the back of the planting system and the wall, making waterproofing treatment unnecessary. The air gap prevents movement of water between the wall and the planting system, and air-prunes plant roots to reduce the risk that they will directly contact the wall and provide a path for movement of moisture. Provision for an air gap between the planting system and the building wall will also prevent growth of mould. Where waterproofing is necessary, it will prevent damage to the wall from moisture and dissolved salts from fertilisers. In some cases the supporting wall might be considered waterproof as is; for example, a preformed concrete wall may be thick enough to be rated as fully waterproof, or a wall constructed from marine-grade plywood will have some degree of waterproofing from the glues used within the ply. Consideration must be given to waterproofing penetrations to the wall as well as junctions between surrounding fascia (if used) and junctions between wall waterproofing and drip trays (see box). Roller-applied liquid waterproofing treatments can be used on internal and

external green walls. When considering waterproofing for any green wall, seek advice from a waterproofing consultant to ensure the most suitable treatment is chosen.

The manufacturing and installation of waterproofing membranes should comply with the Australian Standard for membranes used to waterproof exterior areas of buildings (AS 4654.2-2012 Waterproofing membranes for external above ground use – Design and installation). Waterproofing membranes used for internal walls should be manufactured and tested to AS/NZS 4858:2004 Wet area membranes. Waterproofing treatment should follow the procedures used in other internal areas of residential buildings, such as bathrooms, kitchens and laundries. These are specified in AS 3740-2010 Waterproofing of domestic wet areas.

	<p>WATERPROOFING WALLS – LESSONS LEARNED</p> <p>This indoor green wall is located within an office conference room in Melbourne. Within a week of installing the waterproofing and drip tray treatments, water leakage was observed. The area connecting the waterproofed wall to the drip tray had not been completely sealed and allowed water to collect and drain between the two.</p> <p>The modular nature of the green wall assembly enabled this fault to be easily repaired – the area was sealed, and this mitigated any further damage.</p> <p>This example reinforces the importance of testing and checking the work undertaken and completed by every contractor against project specifications.</p>
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An improperly sealed joint created a leak behind this green wall

6.3 Irrigation and plant nutrition

Green walls cannot be sustained without irrigation. Interruptions to the water supply are a common cause of plant failure on green walls. Systems designed with inbuilt irrigation should mitigate plant losses due to inconsistent moisture management, although errors can still occur.

Automated, remotely controllable irrigation systems are used for walls in high profile locations, or in situations where access is challenging. Note that the quality, design and costs will vary between different systems. The most sophisticated systems enable the maintenance supervisor to keep track of the automated performance of the system, including the volume of irrigation delivered, its frequency, substrate moisture content, as well as pH and nutrient levels in the water supply. The settings can be overridden if needed; for instance, the frequency or duration of irrigation cycles may be increased on hot days.

In hydroponic systems, plant nutrition is delivered by a fertiliser injection system that releases controlled doses of fertiliser into the irrigation system (fertigation). Management of fertigation systems and rates of delivery requires specialist knowledge, as it is more complex than fertilising soil or growing media. Hydroponic systems require continual monitoring of pH, water hardness and total dissolved solids (TDS), and adjustment of these parameters where necessary.

For hydroponic green wall systems, the fertigation system may apply 0.5-20 litres of irrigation solution per square metre per day. Internal green wall requirements are at the lower end of this range, and external green walls at the higher end. Irrigation cycles typically last a few minutes and will be required several times a day. Keeping irrigation volumes low minimises waste and reduces run-off. Irrigation run-off may be captured in a tank at the base of the wall and recycled back through the green wall system.

Green walls that use a high quality, water-retentive growing medium, and are not in an exposed or particularly hot location, may thrive on a weekly watering regime. In most simple, substrate-based systems, including DIY systems, controlled release fertiliser is mixed in with the growing medium, rather than using a fertigation system.

Irrigation must be available as soon as the plants are installed in the wall system. The irrigation system requires a water meter to monitor irrigation volume, and a pressure gauge to monitor the even application of water. The need for ongoing regular irrigation and the expectation that water will be used sustainably means that stored (harvested or recycled) water should be used whenever possible, so a pump is usually necessary too.

6.4 Vegetation

The size of plant materials used in green walls will depend on the required look and finish of the wall at project completion. Planting densities can be as high as 25 to 30 plants per square metre. Decorative patterns can be designed by repeat planting across an area; however, these patterns can be difficult to implement if shadows and light across the different parts of the wall have not been considered. Systems incorporating smaller plants at the outset will take longer to fill out than those using well-established container plants. The dimensions of the planting module will determine the size of the planting stock. Different green wall systems will be better for different types of plant growth habits, from those that grow upright to those with a clumping growth habit, scrambling, cascading or creeping. See **Chapter 3** for information on plant selection.

6.5 Special considerations for walls

Lighting is often required for green walls positioned in low light exposure areas. Many green walls are installed within non-lit areas. Lighting green walls is highly specialised, requiring the services of a lighting designer or engineer. Plants require very specific lighting quantities and qualities to photosynthesise, grow, flower and develop appropriately. Tropical and subtropical green wall installations can generally survive in lower light conditions than Mediterranean, temperate plantings. Extensive knowledge of horticulture and design of green wall systems is needed to choose the right species for the light levels available on-site.

Another consideration for green wall installations is air movement around the foliage. This is important to help prevent fungal growth, and additional ventilation may be needed to ensure sufficient air movement for indoor walls. Outdoor walls usually create their own microclimate that creates enough air movement, but in very sheltered positions attention should be given to this issue.

Chapter 7. Building and Installation – Green Facades

Green facades can range from complex systems for multi-storey buildings, with plants growing in containers at different heights, to simpler systems where the plants grow from the ground, allowing inexpensive installation of greenery on low-rise buildings. This chapter provides information about building and installing green facades. The information should be considered prior to starting a building project.

7.1 Wall protection and different facade treatments

Waterproofing treatment of the wall is not required for green facades. It is important to select plant species with a growth habit that will not damage the fabric of the wall. Some species with adventitious roots or scrambling stems can damage the building fabric over time, such as Common Ivy (*Hedera helix*). However, self-clinging climbers are exceptionally well suited to many vertical building surfaces, particularly old stone structures or those with minimal exposed mortar, and have lasted a long time without negative impacts on the building fabric.

Plants can damage buildings by physical and chemical means, over timescales of centuries. Damage can be superficial, causing only aesthetic changes to the facade, or more structural damage may result, usually over much longer time periods. If in doubt, choose a green facade where the plants are grown on a support system that is installed separately from the building.

Support systems for facades involving plants that have tendrils or twining stems (see Chapter 3) may be made of plastic, timber, metal, or stainless steel cables or cable mesh. Design of the support system must consider the intended lifespan of the facade, the growth habit of the plant species, and how spacing and offset from the wall can help to provide the desired end result. Possible designs are shown in Figure 23.

For containerised systems, plant species choice and the spacing and volume of containers are critical for establishing effective facade coverage. Specialists in green facade design and installation can provide advice on the most suitable system and the best construction approach.

Wooden trellises are prone to damage by weather and plant growth and many plastics become brittle over time with ongoing exposure to UV light, heat and cold.

Metal systems have the longest lifespan and require less maintenance. Stainless steel cables and trellis are low maintenance and have a long lifespan and probably offer the greatest flexibility to suit a variety of plant species and wind loads. Steel nets and mesh provide additional options, with closer 'weaves' than horizontal and vertical cabling.

Support systems are suitable for very structured arrangements where greening has to be maintained away from windows or because of the other building constraints, such as the geometry of the building facade. A facade support may provide aesthetic appeal when the plants have not yet grown to full size and in winter where deciduous climbing species are used. Support systems can be separate from a building and used to create a green facade for privacy or shade.

Figure 23. Support structures for green facades grown with twining climbers



Single cables provide subtle screening and prevent people climbing



Stand-alone trellis systems that provide intrinsic visual interest



Containerised mesh system for multi level structures



Wall-mounted cable grids can cover plain unsightly walls

7.2 Soils and growing substrates

Plants used for facade greening may be grown in soil in the ground, or in containers filled with a well-designed growing medium. The principles outlined in growing substrates for green roofs, outlined in **Chapter 5** and **Appendix A** are also relevant to green facades.

The use of planter boxes, mounted at varying heights above the ground, can allow greater coverage of the facade, where the building is so tall that ground level plants will not reach the top. The advantage of in-ground planting, where soil is of a reasonable quality, is that the plants will have more access to water (the soil will not dry out as quickly as in a container) and will have more space for their root systems to grow.

Container growing media must be designed to support ongoing growth of plant shoots from a limited, contained root volume, and at elevation. Although many climbing plant species have superficial root systems and may thrive in a small volume of substrate, there is a notable link between root volume and sustainable foliage volumes. Climbers required to cover greater areas will require greater substrate volumes. However, weight loading restrictions may limit the depth that can be supported for container systems at elevation.

In-ground plantings will generally outperform container plantings in the long term. Ensure the planting bed soil or growing media has a suitable balance of porosity and water-holding capacity, and an adequate supply of nutrients to ensure optimal growing conditions. In a garden setting with good quality soil and adequate irrigation, there should be little to impede strong plant growth. In city landscapes, with large areas of impervious paved surfaces and soils that may be highly compacted, soil structure may be poor. In such cases, consider installing a 'structural soil' that can be compacted to enable footpaths or other hard surfaces to be installed, while still providing adequate porosity to support root growth. In some buildings the foundations sit out from the wall, underneath the ground – these footings should be set deep if a garden bed is planned adjacent to the wall.

Seek the advice of a horticultural consultant to ensure the volume of soil or growing medium will support the desired height and spread for the green facade.

7.3 Vegetation

For rapid coverage of a green facade, plant specimens should be healthy and vigorous, with numerous basal shoots. They should be of the largest possible size to suit the installation.

To support the vegetation at installation, the growing substrate used to support container-grown facade plantings should incorporate controlled-release fertiliser at planting (see more information about plant nutrition in **Chapter 8**). New plantings should receive irrigation to promote their strong establishment, which depends on season planted and plant size. Establishment is when new roots have grown and the plant is acclimatised and actively growing.

Pruning and training of new plants is essential to promote the development of an effective facade. Plants may need to be trained to the facade support, or temporarily attached to the wall after planting, to encourage upward growth. Once the plant is established, the main runners should be trimmed to encourage lateral shoots that will create a more radial growth pattern. If this is not done, the climbers will typically branch out only once they have reached a significant height, and it may take years for the lower portions of the facade to receive any coverage. The use of diagonally oriented cables on facade systems facilitates horizontal, as well as vertical, growth of the plant (preferred over the plant shooting straight up) and thereby increases the density of foliage cover. For long-term installations, pruning to rejuvenate might be required. As climbers age their growth can decrease and cutting back to hard wood can revitalise a plant and allow for longer lifespans. This means that after five to seven years, especially with woody climbers, it may be necessary to prune back a large portion of foliage.

7.4 Drainage and irrigation

Garden beds, or at-ground planter boxes used for climbing plants for facade greening, should have drainage appropriate for the plant species selected for use. Container systems placed at elevation on the face of a building should have a free-draining growing substrate to avoid potential waterlogging in the event of prolonged periods of wet weather. The potential for ponding of water above the top of the growing substrate should be minimised by providing overflow drainage holes in the sides of the container, just higher than the level to which the container is filled. In most cases, run-off through the base of the growing containers will simply run down onto the ground beneath, but drip trays can be installed to collect water.

The vigour of many climbing plant species means that irrigation will be required to maintain high-density foliage cover and long-term performance of the green facade. In-ground plantings in domestic settings will need irrigation at least during the hotter months, if not year-round. Harvested, recycled water should be used for irrigation wherever possible. Irrigation frequency will depend on the plant species selected, the type of growing medium used, and how exposed the facade is to sun and drying winds.

At-ground plantings can be irrigated by automatic systems or manually with a hose. Surface or sub-surface dripper systems are suitable automatic systems. Irrigation supplied to elevated planters requires appropriate water supply pressure from tank, recycled and mains water supplies. See **Chapter 5.10** for information about irrigation systems and methods of delivery and **Chapter 3** for more information on drainage and irrigation in general.

Facades in containers – lessons learned

A roof garden incorporating green facades was built at Council House 2, central Melbourne, in 2006. Its design included the incorporation of 950 mm deep plastic planters, connected to a cable and stainless steel trellis (X-TEND®) mesh for growth of the facade. The intention was to increase greenery across the building through use of the roof and facades.

Unfortunately, the facade plantings have not grown well due to multiple problems with the planters, growing substrate and irrigation. The black colour of the planters leads to considerable heat gain in the root zone over summer, causing difficulties for plant growth. The planters also tend to split, the side wall plastic seemingly unable to tolerate the high bulk density of the growing substrate. Additional metal frames were used to support the replacement containers. The substrate itself has also had issues, with plants failing or growing poorly and a considerable drop in the total volume since

installation. A further complication has been the irrigation system. Each planter is irrigated via combination of a valve, water reservoir and foam 'wicking', all enclosed in the base of the container. The valves function at a much lower pressure than the mains supply, meaning most failed when they were first operated. This in turn affected any possible 'capillary irrigation' upwards to the root zone in each container, leading to extensive plant death shortly after installation. Replanting has occurred but all containers now need to be hand-watered. The City of Melbourne is currently investigating cost effective options for resolving these problems.

The City of Melbourne recommends thorough research or peer review to assist and support decision-making around the design and use of new technologies.

Chapter 8. Maintenance

This chapter provides information to help with the development of maintenance plans. A detailed maintenance plan will outline performance standards, tasks to be undertaken and the resources required to achieve them. Once created, maintenance plans should be reviewed at least annually to ensure all maintenance needs are being met.

8.1 Maintenance planning

A maintenance plan should include a clear description of:

- maintenance objectives – created based on the design intent, or the landscaping or environmental objectives that were the basis for the roof, wall or facade development
- performance targets, such as the time frame for complete coverage of an area by plants and foliage
- responsibilities of various personnel involved in operating the building, outlining the type, scope, duration of task and occurrence
- training requirements (such as Working at Heights certification) and safety equipment
- resources available

Maintenance planning should also incorporate risk management, with the aim of reducing or eliminating the likelihood of failure that could result in property damage or personal injury.

For large projects, maintenance planning is often based on ‘asset management planning’ where the whole life of the asset is considered, including design, construction, establishment, operation, maintenance, renewal and demolition/replacement.

For some green roofs, walls or facades, particularly those located on commercial premises, maintenance will be undertaken by someone other than the building owner. A maintenance agreement with the installation company or with a recommended third party may be the most economical way to ensure the best long-term performance of a green roof, wall or facade. If a maintenance contract is used, it is important to be clear about the duration of the maintenance agreement, the scope of maintenance responsibility, and the need for handover at changeover to either new contractors or back to the building owner.

A supervisor may be designated to oversee the overall and ongoing management of maintenance activities, and can provide direction to maintenance staff and assess that work has been carried out satisfactorily. The supervisor’s role will involve:

- scheduling of maintenance: flexibility may be needed, as, for instance, additional visits may be necessary to repair damage following extreme weather events
- signing maintenance contractors in and out at the start and end of a visit, offering a toolbox talk at the commencement of a visit, and providing keys and providing any specialist equipment that is required
- occupational health and safety: ensuring contractors have appropriate certification; scheduling mandatory annual checks (and repair or replacement if necessary of safety anchor points); ensuring conditions are safe for maintenance staff to perform their work; providing safety signage or other barriers to restrict access during maintenance; and ensuring that staff understand the process for reporting actual or potential hazards
- informing other contractors who work on the building about the roof, wall or facade, so that they do not inadvertently damage the asset (for example, water service contractors turning off water for a prolonged period)

Access for maintenance

Roofs that are not generally accessible to the building owner or tenants may need to be accessed by ladder, using ropes and harnesses or other ‘fall arrest’ systems to work safely. For small wall and facade installations, within a few metres of the ground, a mobile work platform at ground level is

probably the most efficient solution for access. However, ropes and roof-mounted attachments may be required for larger areas or higher buildings. Green walls and facades extending more than 10 metres above ground level will usually be maintained from a roof-mounted work platform. A hybrid living wall system developed in Adelaide addressed maintenance access with an inbuilt platform at each floor level that allowed safe access for maintenance of the vegetation and for other services such as window cleaning.

8.2 Maintenance tasks

Maintenance falls into a number of categories:

1. **Establishment maintenance** occurs during the first one to two years after installation and is undertaken to fully realise the design intent and outcomes. For vegetation, this includes tasks such as pruning, weed control, and irrigation to ensure healthy and vigorous plant growth.
2. **Routine or recurrent maintenance** includes regular works that are undertaken to ensure the roof, wall or facade is maintained to a minimum or required standard of appearance, functionality and safety. For vegetation, this can include tasks such as weeding, pruning, removal of leaf litter and, in some cases, mowing.
3. **Cyclic maintenance** is scheduled interventions at less frequent intervals that maintain infrastructure. It includes maintenance of the underlying building structure and of specific components of the green roof, wall or facade system. This may include infrequent pruning or other formative management of woody vegetation, such as coppicing, or annual treatment of decking or other hard landscape elements to maintain their safety and functionality.
4. **Reactive and preventative maintenance** is undertaken when some component of the system fails suddenly, or shows signs of imminent failure. Failure may be due to a long-term problem that has gone undetected (such as blocked drains by tree roots), or sudden damage resulting from an extreme weather event (such as stormwater incursion).
5. **Renovation maintenance** includes works that change the design intent. This may arise after a change of ownership of a building which instigates a desire for change, through to remediation of a design failure (see **The Venny** case study).

Some typical maintenance activities for green roofs, walls and facades are outlined in the table below. These are intended as a general guide only: each site will have its own specific requirements and some listed will be more relevant and/or specific to a wall, roof or a facade.

Table 12. Common maintenance tasks

Maintenance objective	Tasks
Maintain planting design	Plant replacement, infill plantings
Maintain plant growth	Remove waste plant material (leaf litter, prunings, weeds), inspect for signs of pests or disease and treat as needed, make seasonal adjustments to irrigation volume and frequency as needed, ensure adequate nutrition levels for plants; inspect after severe weather events (e.g. wind or heat) to look for signs of stress
Minimise weeds	Mulching, weed control
Manage lawns	Regular mowing, annual renovation
Maintain trees	Regular pruning, annual tree inspection, brace and support as needed
Maintain climbing plants	Annual or biannual pruning to maintain density and cover and to remove growth from fixtures (windows, drains). Rejuvenate to renovate habit and growth
Rejuvenate climbing plants	Vigorous pruning to renew stems and encourage new basal growth (every 5-7 years)
Monitor plant performance	Maintain records of plant health, vigour and coverage, pest and disease impact
Maintain substrate	Top-up of growing substrate may be required due to wind, rain or animal activity (check the depth of the growing substrate before any additions are made to ensure weight loadings are not exceeded)
Maintain irrigation (and fertigation) systems	Manually test and inspect the irrigation system regularly and monitor any automated systems (check volume of irrigation delivered, its frequency,

	substrate moisture content, and, for hydroponic green walls, nutrient levels in the water supply)
Monitor plant nutrition	Maintain a log of fertiliser additions and records of pH and electrical conductivity values before and after addition of fertiliser
Maintain drainage	Ensure roof drains are clear and functioning, remove dirt, litter and other deposits from drain inspection chambers, check plumbing hardware, check condition of filter sheet and deeper layers if necessary
Maintain non-vegetated zones	Remove vegetation from perimeter zones and around other equipment and fixtures
Maintain wind protection features	Check the condition and fit of protection systems
Maintain safety systems	Check safety anchor points for fall arrest systems, check access points, e.g. ladders and stairways, check electrical safety of power points, lighting and irrigation control system
Maintain waterproofing	Inspect flashings over waterproofing membrane terminations, inspect wall fabric for any damage from water, fertiliser or plants, conduct leak detection of waterproofing on a green roof – if possible
Maintain other hardscapes	Clean or oil decking or furniture, inspect green wall or facade support systems for any loose attachments or fittings

Fire

Maintenance plans must ensure that the vegetation present on a green roof, wall or facade does not create fire hazards. Dead or dry vegetation must be removed as part of regular maintenance. Fire resistance can be increased by installing breaks in the vegetation or using plants with low biomass (such as native grass tussocks with a low amount of leaf matter). Green facades with deciduous or evergreen climbers are unlikely to create a fire risk as long as dry leaf litter falls away cleanly and is removed during routine maintenance. Vegetation on green walls that receives regular irrigation and maintenance does not pose a fire hazard.

8.3 Plant nutrition

An important element of maintenance is ensuring that plants receive adequate nutrition. This section provides information on nutrition for roofs and facades. Walls are not addressed here because green wall installers will provide specific instructions for meeting the nutrition requirements of the particular plants in the particular wall. Fertilisers for green walls are delivered in liquid form, via the irrigation system (see [Chapter 6.3](#)).

In consultation with the designer and client, establish the lowest appropriate application rate for controlled release fertilisers (CRF). The aim is to provide sufficient nutrition for strong plant performance while minimising nutrient loss into irrigation/stormwater run-off. As such, fertiliser rates are usually significantly lower than those recommended for garden or container plants. Where the plantings are limited to succulents there may not be any ongoing addition of fertiliser.

CRF is the most suitable choice for plant nutrition in green roof settings or green facades in containers. The fertiliser comes in the form of water permeable resin granules or beads and is applied on the substrate surface but should be raked or mixed through, ensuring an even distribution. Each rain or irrigation event dissolves a small amount of the inorganic nutrients stored in the bead. If the roof or container is being irrigated from below (a sub-irrigation system) then it is important to mix the fertiliser well into the substrate.

The elevated temperatures on a roof or facade can lead to excessive fertiliser loss and damage plant growth. For Australian natives on green roofs, low phosphorus CRF can be used at half to quarter of the rate recommended for garden or container plants.

Liquid fertilisers are not suitable for routine use on green roofs, as nutrients are more likely to leach out of the mix and leave via stormwater run-off.

Facade greening planted in the ground in a good quality, sandy loam topsoil should not require additional fertiliser. The addition of composted organic matter once or twice a year to garden beds where facade greening is planted will supply nutrients and improve water

retention. CRF suitable for the species planted may be incorporated into the garden beds, if desired, according to the rates recommended by the manufacturer.

Visual inspection plays an important part in determining whether plants are experiencing nutrient deficiencies (see *Growing Media for Ornamental Plants and Turf* for further information).

Monitoring of fertiliser levels

It is useful to undertake soil testing of pH and electrical conductivity to establish the conditions under which plants were started. Ongoing, strong plant growth and coverage is the best sign that growing conditions are suitable. As long as there are no problems with the performance of the plants, the manufacturer's recommendations for rate and frequency of fertiliser application may be followed. If plants do not perform well, or there are any signs of nutrient deficiency, a sample of growing substrate should be collected for testing of pH and electrical conductivity (EC) or total dissolved solids (TDS), following the same test procedure as was used at planting. Additional fertiliser should be added if EC or TDS results suggest nutrient levels are simply running low. If possible this should be incorporated through the growing substrate to ensure its even distribution, though this may be difficult to achieve for green facade containers installed at elevation.

Chapter 9. Conclusion

This guide has been developed in collaboration with government, industry and universities. It provides advice specific to conditions in Victoria, Australia. It is hoped that this guide will help to increase the number of high quality, multifunctional green roofs, walls and facades to make our cities more liveable and sustainable.

Section 4. Victorian Case Studies

The Venny Green Roof

Location:	JJ Holland Park, 85 Kensington Road, Kensington, Victoria
Completion date:	September 2010 (remediation works July 2013)
Area:	108 m ² lower roof; 103 m ² upper roof on a new building

Description

The Venny green roof comprises a lower flat roof, with planting designed around three sections – A, B, and C (Figure 1) – and an upper, sloping green (roof D), a later addition to the original brief. The green roof can be viewed from the ground, access is only available for maintenance. The upper roof contains an array of photovoltaic cells (44m²), two solar hot water panels and a roof ventilator, leaving approximately 46m² for planting.

Introduction

The Venny is a community facility for children from the Melbourne suburb of Kensington and surrounding neighbourhoods. Design of The Venny was commissioned by the City of Melbourne, incorporating the use of recycled shipping containers. As protection was needed to insulate the spaces below the metal containers, a green roof was suggested as the most appropriate solution. It was also anticipated that the roof would expand the local knowledge of green roof design, installation and maintenance at a residential scale.

The project was a joint venture between the City of Melbourne, The University of Melbourne and Melbourne Water. The roof has also been a research site for The University of Melbourne, with funding provided through the Australian Research Council.

Detailed design of the lower areas was undertaken by The University of Melbourne and the upper green roof was designed by Junglify Pty Ltd.

Design and components

A ZinCo system was used for the waterproofing and drainage components. A low cost membrane material, Volclay Swellite®, was used. The lower green roof comprises a ZinCo system, including a 25 mm drainage cell, and two different mineral-based substrates developed by The University of Melbourne. The upper roof used an alternative system incorporating a basal protection layer with irrigation (capillary irrigation matting) and, originally, a 100 per cent coir media at 100 mm depth. Galaku erosion control netting was used to hold the plants in place on the upper roof.

Plants for the green roofs were researched and selected by The University of Melbourne, based around aesthetic properties, drought tolerance and low resource inputs (water, fertiliser and maintenance). Most were succulents, particularly sedums, aloes and related species. They were planted at high densities to provide rapid cover and discourage weed infestation.

The upper roof has been designed to hold a green roof with a saturated load of 160kg/m² (including all plants, substrate, irrigation system and waterproofing). In addition to the 160kg/m² there has been an additional live load allowance of 40kg/m².

Plant species used on the upper roof 2010
<i>Lampranthus deltooides</i>
<i>Sedum mexicanum</i>
<i>Sedum pachyphyllum</i>
<i>Sedum reflexum</i>
<i>Sedum xrubrotinctum</i>

Maintenance

Management and maintenance was considered in the initial design, and a safe maintenance access point was important. A lockable alcove was designed with a purpose-built ladder and signage to comply with occupational health and safety standards. Paths of chipped recycled brick were incorporated into the initial design of the lower roof to minimise the impact of maintenance and research activities on plants and green roof infrastructure. These factors, combined with the specific species selection of drought tolerant plants and a close planting design, were considered to culminate in a green roof that could be safely managed, with low impact, and low maintenance requirements.

The first two years of maintenance and management was undertaken by The University of Melbourne, as part of its research studies, and Junglefy Pty Ltd. A comprehensive management plan was devised by The University of Melbourne and handed over to the City of Melbourne. This was the first green roof that the City of Melbourne's landscape maintenance team had experienced and some problems did occur when the irrigation system failed over summer. The maintenance visits also became infrequent which meant that the health of some of the species was compromised. After approximately six months' maintenance by the City of Melbourne the roof was evaluated and it was determined that while the lower green roof was satisfactory, the upper roof had not performed well. The coir growing media failed to support plants adequately – the only surviving species had drifted to the base of the roof slope. While disappointing, the substrate was used as a trial and the substrate and plant replacement was not an unexpected expense for the project.

Remediation of the upper green roof took place in July 2013. The University of Melbourne was contracted to develop a lightweight, mineral substrate and complete a planting design. Junglefy were re-engaged to take the lead in the remediation works – including the removal and replacement of the growing medium and the installation of new plants.

New ZinCo products, specifically designed for sloped roofs, were used, a 'back to base' alarm system for monitoring irrigation was installed, and Junglefy has continued ongoing maintenance of this space.

Cost

Lower Green Roof

Total: \$69,070.

Specific costs of project components:

- Shipping container steel frame Recycled
- Drain pipe system \$5,000
- Bentonite liner \$16,000
- Concrete screen \$18,000
- ZinCo system (supply) \$7,150
- ZinCo system (install) \$1,360
- KISSS 'Below Flow Flat' irrigation
and associated controls \$6,330
- Substrate growing medium and
crushed brick paths \$5,900

- Coir mulch matting \$1,270
- Plants (supply) \$4,520
- Plants (install) \$3,540

Upper Green Roof

Total cost: \$11,000, including the waterproofing layer, growing substrate, irrigation, plants and planting, labour and materials.

Note: it would be unrealistic to expect to replicate such a build for the same price today. Junglefy's involvement in construction was undertaken at cost due to its interest in developing this industry.

Remediation works in 2013 cost approximately \$43,000.

Results and reflections

According to The Venny manager, the roof adds environmental, educational and economic benefits to the building. As a small-scale building the design could be applied in a residential context.

Lessons learned included that:

- the bentonite liner and concrete screed on the **lower roof**, expensive items which did not live up to expectation, would be avoided in future
- the use of 100 per cent coir as a substrate on the **upper roof** would be avoided (this was addressed in the remediation)
- the slope called for a water retention layer (this was added in the remediation in 2013).

The Venny has proven to be a pioneering project that has provided a valuable learning experience for the emerging green roof industry. Those involved in similar projects should invest in good materials for waterproofing and drainage, as well as consulting those with expertise in design and application to ensure plants are appropriate for the type of roof.

A consistent message in the reflections of The Venny green roof partners was that patience is required when undertaking something that is untested: it is a collaborative learning process through all stages from design through to management.

The Triptych Green Wall

Location:	8-10 Kavanagh Street, Southbank, Victoria
Completion date:	2009
Area:	206 m ² on a new building

Description

Triptych Apartments include a large hydroponic green wall on the building's exterior south-east facade, extending up from the second level, above the footpath. It is visible to all vehicular and pedestrian passers-by, and is viewed by neighbouring office and apartment buildings.

Introduction

Visible from the street, the green wall feature was considered by the developer to provide a 'wow-factor', setting the building apart from other inner-city residences and blending in with the leafy streetscape.

The purpose of the green wall was to:

- obscure the view of the exterior of the multi-level parking area
- use foliage to soften the built environment
- provide habitat and increase diversity through the use of native and exotic plant species
- utilise collected rainwater.

The property was owned by the Stable Group, and the project was completed by Nettletontribe architects and green wall specialists, Fytogreen.

Design and components

The wall includes 362 planting panels measuring 100 cm x 500 cm x 15 cm along with 44 planting panels measuring 75 cm x 50 cm x 15 cm. It is designed for a weight loading of 80kg/m² dead load.

A spray-on waterproofing material was used. A root barrier layer was not required because the air barrier between the wall and the modular system allows for air pruning. (Roots become exposed to the air, which dehydrates them and stops them growing further.) Polyurethane foam, a Fytogreen patented product, with felt wrapping was used as the growing medium. The foam modules are held in a steel cage, mounted on a wall using steel brackets.

Plants are irrigated using a controlled release dripper system that runs to each separate module, using collected rainwater supplemented with mains water as required. Fertiliser is also delivered via the irrigation drip system. The stainless steel fascia surrounding each panel guides any excess moisture to a steel drip tray at the base of the vertical garden.

Irrigation equipment includes a controller for timed irrigation cycles; a fertigation system for controlled fertiliser dosing through the irrigation system; water meter; pressure gauge; controlled volume drip irrigation line; and water storage tanks, filters and pumps.

Native and exotic plant species, chosen for aesthetic appeal, durability and biodiversity, are featured. The planting plan considered the differing levels of sun and shade across the wall surface, and the impact of plants shading one another as they grew. At 15 plants per panel, a total of 5,958 plants was required. For the planting stock, 140 mm container specimens were grown in an offsite greenhouse for eight to 12 weeks before installation. The benefit of using fully-grown plants is the immediate visual impact when installed.

The swathes (planted sections of different species) were specifically designed to control lateral wind movement over the host wall surface, either mitigating wind damage or creating niches for species in the leeward sides.

In addition to aesthetic appeal, plant species were chosen to be hardy, low maintenance and shade tolerant. Many of the species feature coloured foliage or flowers throughout the year, contributing to the beauty of the design.

Careful consideration was given to the combination of species used, and their placement in relation to each other. All species were selected to offer cumulative control of pests and disease spread, wind, light and moisture, and to manage competition between species. The long-term growth patterns and likely reaction to the environment were also considered. High foliage coverage was sought for visual appeal and also to out-compete weeds.

Species
Dianella 'Little Jess'
Dianella 'Emerald Arch'
Dianella 'Breeze'
Lomandra 'Tanika'
Lomandra 'Wingarra'
Viola hederacea Native Violet
Rumohra adiantiformis Leatherleaf Fern
Nephrolepis oblitterata Sword Fern
Asplenium bulbiferum Mother Spleenwort
Correa 'Dusky Bells'
Ficinia nodosa Knobby Club Rush
Orthrosanthus multiflorus Morning Iris
Campanula poscharskyana Serbian Bellflower
Liriope muscari 'Evergreen Giant'
Plectranthus ciliates Spurflower
Aristea ecklonii Blue Star
Pachysandra terminalis Green Carpet
Sarcococca confuse Sweet Box
Liriope spicata Lilyturf
Arthropodium 'Parnell'
Arthropodium 'Te Puna'
Davalia tyermanii Bear's Paw Fern
Schefflera aboricola Dwarf Umbrella Tree
Strobilanthes anisophyllus Goldfussia
Erigeron karvinskianus Seaside Daisy
Acorus gramineus Green Acorus
Rosmarinus officinalis horizontalis Prostrate Rosemary
Chlorophytum variegatum Spider Plant
Cerastium tomentosum Snow-in-summer
Escallonia 'Newport Dwarf'
Euphorbia 'Chameleon'
Euphorbia 'Blackbird'
Viola oderata Sweet Violet

Maintenance

By choosing species that respond well to each other, the green wall requires less maintenance than a more rigid design. The owners favoured this approach because it offered a long-term, adaptable and sustainable solution.

Fytogreen is contracted to undertake the maintenance. Maintenance is moderately fluid, pending seasonal changes and the client's aesthetic expectations. The Triptych owners embraced natural aesthetic forms and ongoing species self-adjusting, leading to a less restrictive maintenance process. Knuckle Boom lift access, requiring a small team of horticulturists, is generally conducted every three months.

Monthly checks, conducted by one person, assess water supply, quality and general garden condition.

Cost

Total: \$350,000.

This budget included a 12-month contract with Fytogreen covering maintenance of the green wall and defects liability. After this time, the maintenance contracts were negotiated between the parties and open for tender.

Results and reflections

Fytogreen reports that this is a statement green wall that has proven to be functional in terms of water usage, visual impact and has assisted with the selling of apartments. Using harvested rainwater from the building the plants are thriving and habitat is being created.

Fytogreen notes the visual amenity provided to all surrounding parties, including passers-by.

In retrospect Fytogreen states it would have changed only one thing, and that was to have set up the wall to also be a research space for vertical garden species.

Fytogreen concludes that this is a large-scale green wall that puts Melbourne on the map. As it is free to view to all passers-by it provides inspiration to all to question technology, property value and the impacts of vegetation on built surfaces.

RMIT University Building 21 Green Facade

Location:	RMIT University, 124 Latrobe Street, Melbourne, Victoria
Completion Date:	2011
Area:	122 m ² on an existing building

Description

The green facade was constructed on the north and west-facing external walls of Building 21, a 60-year-old brick building. Planter boxes at the base of the facade support plants that climb up a trellis stretching the height of the wall. The wall can be viewed by the general public and is mostly seen by RMIT students and staff.

Introduction

The RMIT University city campus in Melbourne is a publicly accessible space made up of historical and modern buildings, interspersed with functional open areas. With the completion of University Lawn Precinct and the refurbishment of all of the surrounding buildings, Building 21 needed a facelift as the last piece in the precinct. A green facade was constructed on the rear of the building.

The Building 21 green facade was a joint project between RMIT University, Peter Elliot Architecture and Urban Design, engineers BHS Consultants, landscape architects Rush Wright Associates and TJS Services. The specific facade structure was provided by Ronstan Tensile Architecture.

Design and components

The facade includes the following elements:

- a Ronstan X-TEND® mesh trellis system in a diamond-shaped pattern. The trellis system is secured in place by steel framing at the top, bottom and sides of the wall. There is a 40 cm gap between the trellis system and the brick facade of the building so no root barrier or waterproofing layers were needed
- planter boxes, which are mounted to the existing brick facade using a galvanised steel frame which encases the entire planter box. Zinc sheet vertical cladding covers the front of the boxes and extends down to hide the drainage system below.

The sides and base of each planter box are lined with Atlantis® 30 mm Flo-Cell™ drainage cell and slotted Agridrain Pipe, and then covered with 2 mm geotextile Bidim® A14G membrane. The bases are lined with a 40 mm sheet of Hyrdocell hydro foam.

A drip irrigation system is used, with a slotted drainage pipe running along inside the base of the planter boxes to provide drainage.

Hydrocell 40 extensive media, a lightweight soil mix, was chosen to reduce stress on the existing brick wall. The substrate was topped with a 45 mm thick stone mulch layer to provide protection from the elements.

Forty-nine individual 140 mm plants, *Kennedia rubicunda* (Dusky Coral Pea), were installed in the planter boxes. Temporary bamboo supports were used to help the plants grow up and onto the trellis. Plastic clips were used at intervals of 40 cm to secure the climber to the trellis. Provided by Ronstan, the clips are designed to allow for the plants' growth.

Maintenance

The design of the green facade included maintenance requirements. The site can be accessed with an elevated work platform. The planter boxes are raised above pedestrian level, but are low enough to be accessed using a ladder.

The green facade requires a moderate level of maintenance, contracted to the university's general landscaping contractor. Regular maintenance tasks include:

- monthly inspection of irrigation system function
- twice yearly (spring and autumn) pruning and retraining climbers around windows
- twice yearly (spring and autumn) fertilisation, plus additional if required
- monthly comprehensive visual inspection
- weekly general inspections (including removal of rubbish)

Cost

Total: \$230,000 (excluding ongoing maintenance).

Specific costs of project components:

- | | |
|--------------------------------|-----------------------------------------------------------|
| • Planter boxes | \$80,000 |
| • Plants and substrate | \$25,000 |
| • Plumbing and irrigation | \$25,000 |
| • Trellis system | \$90,000 |
| • Hire of access equipment | \$10,000 |
| • Ongoing maintenance contract | N/A – part of general RMIT landscape maintenance contract |

Results and reflections

The architect believes that the building now sits comfortably as a backdrop to the University Lawn Precinct, with the creeper-covered walls meshing into the urban landscape. He notes the appearance of the building has been successfully transformed through the softening effect of the creeper-covered wall. Initial plant growth has exceeded expectations but will need to be monitored to be maintained into the future.

The ongoing level of required maintenance can be carried out as part of general RMIT landscaping. RMIT reports that no plants have been removed or replaced to date, due to adequate facade coverage.

Freshwater Place Green Roof

Location:	1 Queensbridge Square, Southbank, Victoria
Completion date:	2004
Area:	1,650 m ² on a new building

Description

The green roof is an elevated landscape located on top of the nine-storey car park. It is made up of a series of garden mounds, a grass lawn, storage sheds and planter boxes for growing vegetables. A windbreak wall was added to protect the site from the strong southerly wind.

Introduction

Freshwater Place is a residential complex containing 534 apartments, located on the Southbank side of Melbourne's Yarra River. The aim of the project was to provide residents with a functional outdoor space that would enhance their inner-city lifestyle and add value to the property. The green roof is part of the communal facilities, which include barbeque areas, pool, gym and function spaces. Residents and their guests have full access to the level 10 roof and it can be seen from most of the apartments as they extend many floors higher than the car park. Maintaining the green roof's aesthetic appeal is the priority for all maintenance activities.

The green roof was a collaborative project between Bates Smart Architects, Australand and Laurence Blyton Landscape Architects. The green roof components were installed by Fytogreen and are maintained by Facility Management Victoria.

Design and components

The roof was installed using the following layers:

- waterproofing spray-on layer, installed by JA Dodds
- waterproofing protection layer, low-density polyethylene (LDPE) foam
- Flo-Cell™ drainage layer
- Bidim® geotextile layer
- Fytogreen Hydrofoam hard foam RG30
- growing substrate

Vegetable planter boxes, provided by the Little Veggie Patch Co, are made from recycled apple crates. Measuring 1.2 m along each side, and about 80 cm tall, the boxes are anticipated to last more than 10 years. The vegetable crates are located on the west side of the site and receive less sunlight than the other sections of the roof.

There are 30 established trees growing in the green roof garden beds, surrounded by a range of shorter shrubs. The substrate in these beds is 70 cm deep to accommodate the trees' root systems. Comparatively, the substrate under the large lawn area is only 35 cm deep. The substrate mix used throughout the site was prescribed by Fytogreen, and is made up of sand, organic material and water retention flakes. A river stone mulch layer sits on top of the substrate to reduce evaporation, reduce weed growth and stabilise the soil in the wind.

There is a mix of permanent green elements, seasonal interest from foliage and colourful flowers. There is also one lemon tree on the roof, after a request by a resident that it be planted. It is yet to fruit, but is growing well.

Replacement species have been selected from existing plants that have grown well.

The specific plant species used on the Freshwater Place green roof are listed in the table below. All species are low maintenance, can be grown in most climates and soils, are

tolerant of drought and wind, and prefer to be grown in full sun to part shade. They can be grown in urban areas where pollution levels may be high.

Plant species used
<i>Pyrus ussuriensis</i> Manchurian Pear cultivar
<i>Dianella</i> 'Little Jess'
<i>Juniperus sabina</i> Savin Juniper
<i>Liriope</i> cultivars Lily Turf
<i>Viola hederacea</i> Native Violet
<i>Viola labradorica</i> Labrador Violet
<i>Ixia</i> cultivars Corn Lily
<i>Escallonia</i> cultivars
<i>Ipheion uniflorum</i> <i>Spring Star</i>
<i>Freesia</i> cultivars
<i>Iris</i> cultivars
<i>Rahiolepis umbellata</i> <i>Yeddo Hawthorn</i>
<i>Pennisetum clandestinum</i> <i>Kikuyu</i>
<i>Trachelospermum jasminoides</i> Star Jasmine

The green roof drains into a 160,000-litre storage tank that sits beneath the paved area. Rainwater is also collected into this tank from other building surfaces. The collected water is used for irrigating the garden and can sustain the plants for up to three weeks in the height of summer, and as a result, potable water is rarely used.

A drip irrigation system was installed beneath the substrate in the garden beds as part of the initial construction, but this system is no longer used. Although it was functioning correctly, the system did not allow for the different water requirements of trees and other plants. In 2010, the maintenance team installed separate drip irrigation systems for the trees and shrubs, which run along the surface of the soil. The grass lawn is watered using automated sprinklers.

The plants are monitored daily to ensure that the irrigation is sufficient and to identify problems before the plants showed signs of distress.

In the initial design, five round plant rooms on the roof were topped with vegetation to provide residents in the apartments above with a consistent green outlook onto the green roof. Sloped at a slight angle to allow for drainage, these roofs were planted with succulents in a shallow substrate made of fine stone aggregate. Parts of these roofs became waterlogged and caused some plants to fail, resulting in patchy green coverage when viewed from above. Although the drainage could have been repaired and the roofs replanted, maintenance staff chose to not replace the plants, leaving the area with just the stones. This decision was made to ensure that the residents had a pleasing outlook onto the roof at all times.

Maintenance

Although the green roof at Freshwater Place has been designed to minimise maintenance, there are ongoing challenges. A different level of maintenance is required for the intensive garden beds and the extensive lawn area. For an annual fee of \$25,000, the maintenance is

carried out under contract and includes replacement of plants. Maintenance activities include:

- Irrigation: Three times per week in summer; varies for the shrubs and trees
- Pruning: Annually for trees; shrubs as required
- Plant evaluation: Weekly
- Lawn mowing : Weekly in spring; fortnightly at other times
- Scarifying the grass: Every three years
- Fertilising: Monthly for turf; plants every six months; annually for trees
- Plant renewal: As required in winter
- Cleaning and monitoring of hard landscape elements: Weekly
- Inspection of irrigation system function: Daily in summer; monthly at other times

A key challenge for maintaining the green roof has been ensuring that plants get enough water to maintain optimum growth and to look healthy and visually appealing. This requires regular monitoring, so it is important that the maintenance contractor understands the environment and how it can change very quickly.

Originally, Tall Fescue grass was used as lawn cover, but the maintenance team found it difficult to keep it looking good through water restrictions and the hot summer months. At times security staff hand-watered in summer to keep the grass green. Following a review of plant maintenance in 2007, the tall fescue was replaced with Kikuyu grass, a species with lower water requirements, and it has been very successful.

Exposure to the elements has also been a challenge, particularly for the maintenance of the large Manchurian Pear trees. The strong wind has caused them to grow at an angle, particularly in the older tree stock, due in part to the use of fully-grown trees at installation, As a consequence, the root systems did not establish in the soil as well as they could had younger plants been used. Their lack of stability in the wind required the use of support cables. Recently, some of these trees were replaced with younger plants and these have quickly grown to be equal in size to the existing trees, and are far more stable.

Maintenance processes are regularly reviewed to ensure they are consistent with the desired outcomes.

Results and reflections

Overall, the Freshwater Place management team is extremely happy with the aesthetic and social benefits of the green roof. The useability of the space gives the building a unique edge and adds value to the property.

The green roof is a well used space, particularly in the warmer months of the year. The barbeques are in constant use throughout the summer and the lawn is a popular place for picnics. The vegetable gardens are maintained by residents, who enjoy the social aspect of growing produce together.

Reflecting on the lessons learned over the last nine years, the management team has advice for anyone considering a green roof project:

1. Green roofs have their own challenges due to the unusual nature of the site, so it is best to keep the design simple.
2. Green roofs are not 'set and forget'. It takes some time to get the plants, irrigation and maintenance right, so be prepared to make adjustments as you go along.
3. Monitoring the green roof components and plants is essential for establishing a successful green roof. The monitoring should be regular and not reactive.

Minifie Park Green Roof

Location:	290 Belmore Road, Balwyn, Victoria
Completion date:	December 2012
Area:	440 m ² on a new building

Description

The roof is on a one-storey building in a park. There is no public access but the roof slope of 2 to 3 degrees means it can be viewed from ground level. The green roof includes a range of indigenous plant species to promote the use of local flora and provide habitat opportunities for fauna.

Introduction

Minifie Park Early Learning Centre is a council-owned, community-operated childcare centre located in North Balwyn, an eastern suburb of Melbourne. It was built to replace an older building.

Council decided to include a green roof as an integral part of the new facility. The purpose of the green roof was to provide thermal insulation and help the building blend in to the surrounding parkland.

The project received funding from Melbourne Water and the Victorian Adaptation and Sustainability Partnership to support the incorporation of water sensitive urban design features into the building.

The building was designed by the architectural firm FMSA and built by Behmer and Wright. The green roof was designed and constructed by Junglefy.

Design and components

The roof has a weight loading of 170 kg/m². A gutter guard has been installed in the box drains, and leaf traps in downpipes to prevent them from blockage by pine needles from an overhanging tree. There is 400 mm wide unplanted perimeter zone to keep the areas around drains clear of vegetation.

Kalzip® aluminium standing seam roof sheeting was used for the roof deck. It was installed over a steel-framed portal structure – a building frame with pitched rafters. The standing seam system was a key element in Junglefy's tender for the work, because its successful use on green roofs is well documented, and Kalzip was prepared to provide a 10-year warranty on the waterproofing. This is the first Australian green roof installed over this type of lightweight roofing system to Junglefy's knowledge. The Kalzip® roof system is intrinsically watertight so a waterproofing layer or protection layers were not installed.

The drainage layer was ZinCo FD40, with water-retention capacity. A ZinCo Filter Sheet SF was also installed.

The growing substrate was Junglefy's proprietary Victorian mineral mix. It was delivered in 5,000 kg capacity bags, lifted by crane and installed through a hose attachment, and applied 100 mm deep. The large single substrate bag could be moved around the roof and greatly reduced the installation time compared to using multiple smaller bags. The substrate was covered with a layer of jute netting to provide weed control and protection from slipping due to gravity and wind forces. Plants were installed through cuts made in the netting. A layer of substrate was installed over the top to reduce the potential for wind uplift.

The Early Learning Centre has an additional bare roof area of approximately 300 m². The green roof is irrigated with water collected over all roofs. Captured water is stored in an interconnected network of six tanks, with a total capacity of 24,000 litres, in the ground level plant room at the lowest point of the building. The modular tank system offers adaptability for current and future use: one or more tanks can be removed for repair or replacement without any need to interfere with the building structure and surrounds.

The irrigation system has ‘back to base’ control with sensor-driven monitoring from an inbuilt weather station enabling irrigation cycles to be missed during rain events exceeding a specified threshold. The system used is standard for parks and gardens irrigation throughout Boroondara. Water is pumped up to the roof from ground level and delivered to the plants through a KISSS Below Flow Flat capillary irrigation system. Initially, irrigation delivery was patchy across the roof causing uneven plant performance and the loss of a small number of plants, but adjustments to the system have resolved this issue.

The plant palette was a mix of low-growing Victorian perennial grass and herb species typically found in grassy/creek-line woodland (the likely original vegetation on this site). The herbs flower in spring and autumn, providing colour interest through a significant part of the year. Proposed additions include the planting of taller grasses to conceal the ventilation shafts.

Junglify’s custom-designed aluminium edge restraints separated vegetated and non-vegetated areas of the roof.

Planting stock was contract-grown by Australian Ecosystems, provided as tubestock, and inspected at the nursery prior to delivery. Planting took place in November, after a delay. As a result, hand-watering was necessary over summer, to ensure the plants were well established.

Species
<i>Austrodanthonia racemosa</i> Slender Wallaby Grass
<i>Austrodanthonia setacea</i> Bristly Wallaby Grass
<i>Poa morrisii</i> Velvet Tussock Grass
<i>Themeda australis</i> Kangaroo Grass
<i>Bulbine bulbosa</i> Bulbine Lily
<i>Chrysocephalum apiculatum</i> Common Everlasting
<i>Chrysocephalum semipapposum</i> Clustered Everlasting
<i>Dianella revoluta</i> Black-anther Flax Lily
<i>Einadia nutans</i> Nodding Saltbush
<i>Linum marginale</i> Native Flax

Maintenance

Junglify has maintained the roof since planting. The intention had been that roof management would move to the City of Boroondara. However, due to Junglify’s experienced management and competency to work at heights, they have been sub-contracted by the City’s Parks and Gardens team, and continue to maintain the green roof on a monthly basis. This arrangement has simplified management for the City of Boroondara.

The potential for acidification of the growing medium from the needles shed by a nearby overhanging pine tree is a source for concern.

Performance evaluation of the green roof plantings is being undertaken by the City of Boroondara.

Plant nutrition is provided as eight to nine-month low phosphorus controlled-release fertiliser applied at half the recommended rate.

Cost

Total: \$306,000.

This included:

- Design and preliminaries \$180,000
- Green roof installation and plants \$126,000

The total building cost was \$3.5M.

Results and reflections

Insulation properties were a major driver for the inclusion of a green roof in the building design. An anecdotal story from builder Behmer and Wright's site manager suggests that the green roof contributes to thermal comfort for users: after the green roof substrate was installed in winter, the builders elected to spend their lunchtimes in the facility as they found it was warmer than the site office. Monitoring of energy consumption for heating and cooling will reveal whether usage is lower than would be predicted for a building of this type without a green roof.

The City of Boroondara and the users of the Minifie Park Early Learning Centre feel very proud of the redevelopment and its green roof. The positive experience at Minifie Park has made Council enthusiastic to pursue future green roof projects. Council says that the local community has responded well to the green roof, seeing the views of vegetation as far superior to a bare metal roof. The design objective to create a connected visual experience between the building and the park has been met. The green roof demonstrates that a modern building development can be sympathetic to its surroundings.

Victorian Desalination Project Green Roof

Location:	Lower Powlett Road, Wonthaggi, Victoria
Completion date:	2012
Area:	26,000 m ² on a new building

Description

The Victorian Desalination Project green roof is the largest in the southern hemisphere. It covers a number of buildings of the process plant, ranging in pitch from 3.5 to 20 degrees. The undulating slopes of the roof are designed to limit visibility of the industrial buildings from the surrounding public areas and link to the nearby coastal landscape.

Introduction

The Victorian Desalination Plant provides for desalinated water to be delivered from the private sector to the State Government owned water authorities. The plant is capable of supplying up to 150 billion litres of water a year to Melbourne, Geelong and via other connections to South Gippsland towns.

The aesthetic focus of the project was to soften the visual impact of the process plant buildings. Several other objectives were also considered in design of the green roof, including, ecological restoration of the area, thermal performance of the building, minimising the noise impacts from the desalination process plant and protection of the roof from the harmful effects of solar radiation.

The Victorian Government's private sector partner, AquaSure, consists of Suez Environnement, Degremont, Thiess and Macquarie Capital Group. The Theiss Degremont Joint Venture was the design and construct contractor for AquaSure. The green roof design delivery was provided by ASPECT Studios, with technical design, installation and maintenance by Fytogreen.

Design and Components

With a saturated dead load of 143kg/m² plus live load, the roof is designed for maintenance access only.

The building is a steel frame structure with a timber ply roof deck. Waterproofing layer is Sika Sarnafil. A foam resin developed by Fytogreen was used as an underlay, trapping water and nutrients and helping the plants to grow. The drainage layer is a 20 mm Atlantis® Flo-Cell™ with a Bidim® A14 geofabric to filter sediment run-off.

The extensive green roof substrate mix was provided by Fytogreen and installed to a depth of 80 mm. The majority of the roof was constructed on a slope of less than 15 degrees and did not require any sheer protection. However, about 650 m² of the roof was installed on slopes greater than 15 degrees and Geoweb® Cellular Confinement System was used to stabilise the substrate and vegetation. The 150 mm deep Geoweb® cells were installed over four days, with anchoring tendons running through every second row of cells to secure the system in place.

Due to the strong winds to which the green roof is exposed, a system of stainless steel hold-down netting was required in the areas subjected to the highest wind speeds. These winds create a twin vortex effect where the combined lateral forces and vertical uplift would risk dislodging the substrate ballast layer. The primary function of the mesh was to mitigate the insurance risk during establishment when the mulch layer was exposed. As time goes on it is expected that the plants will ameliorate wind uplift.

A sub-soil irrigation system was designed for the green roof by Netafim™ and installed by Fytogreen. The automatic drip system includes a weather monitoring station to ensure irrigation frequency and volume is appropriate. Data is collected on the amount of rainfall and the level of evaporation. Water for irrigation is captured from a 3.7 ha collection area and stored in a 0.5 megalitre pond. In addition to the captured storm water, 600 litres of process sampling water per hour is available from the desalination process plant.

The Fytogreen design for the green roof was carefully considered to ensure consistency with the coastal character, and to meet the ecological objectives of the project. Species selection focused on plants that are locally indigenous to the area using seed that was collected within 40 km of the site.

Given the site's exposure to the elements in a windy and temperate coastal environment, testing was undertaken prior to construction to ensure that the species chosen would thrive in the conditions. Fytogreen established a test roof on a nearby site in 2009 to determine which species would respond well to the wind and variable temperatures, and to test planting patterns that would enhance the health of the plants.

Plants are fertilised using Osmocote® low phosphorus 12 to 14-month controlled release fertiliser. Application rates are adjusted as deemed necessary.

Plant species used
<i>Acaena novae-zelandiae</i> Bidgee-widgee
<i>Actites megalocarpa</i> Dune Thistle
<i>Apium prostrata</i> Sea Celery
<i>Ficinia nodosa</i> Knobby Club-rush
<i>Carpobrotus rossii</i> Pigface
<i>Correa alba</i> White Correa
<i>Correa reflexa</i> Native Fuchsia
<i>Dianella admixta</i> Spreading Flax-lily
<i>Dianella brevicaulis</i> Coast Flax-lily
<i>Dichondra repens</i> Kidney Weed
<i>Disphyma crassifolium ssp. clavellatum</i> Rounded Noon-flower
<i>Gonocarpus tetragynus</i> Common Raspwort
<i>Goodenia ovate</i> Hop Goodenia
<i>Lomandra longifolia</i> Basket Grass
<i>Olearia axillaris</i> Coastal Daisybush
<i>Rhagodia candolleana ssp. Candolleana</i> Seaberry Saltbush
<i>Senecio spathulatus</i> Dune Groundsel
<i>Stylidium graminifolium</i> Grass Triggerplant
<i>Tetragonia implexicoma</i> Bower Spinach

<i>Threlkeldia diffusa</i> Coastal Bonefruit
<i>Ozothamnus turbinatus</i> Coast Everlasting
<i>Chrysocephalum apiculatum</i> Common Everlasting

Maintenance

Fytogreen has a five-year contract to carry out any maintenance required for the green roof. Given the high profile of the project and the community expectations around aesthetics, the contract specifies standards for maintenance. This includes a requirement that vegetation cover must be at least 95 per cent, with no more than five per cent weeds. Fytogreen visits the site as required, to ensure these maintenance obligations are met. Visual inspections of plant health are important to ensure irrigation and nutrient levels are adequate.

Cost

Total: \$4M.

Results and reflections

The opportunity to develop an indigenous plant palette for such a large scale green roof has demonstrated the way the natural ecology evolves and responds to the site conditions and the development of microclimates as the vegetation matures.

Some of the initial planting stock struggled to survive the windy conditions on-site. However, Fytogreen anticipates that the existing vegetation will provide protection for new plants that grow from self-sown seed, allowing them to establish more strongly on the roof.

Fytogreen points out that the requirement for irrigation water should not be underestimated, and it is important to be mindful of the client's expectations in terms of the roof's appearance. The aesthetic value may become a higher priority than designing for minimum water use. Recovery of irrigation run-off enables 80 per cent of the water to be re-used and ensures that water sensitive design principles are maintained without compromising plant performance and appearance.

The vast size of the green roof planted with Australian natives leaves a positive impression with all visitors to the site.

The inclusion of the green roof on the Victorian Desalination Project was an inspired gesture that added to the acceptance of the project by the local community and the wider public. ASPECT Studios reflects that because this roof was constructed in the absence of a formed Australian green roof design standard it is a testament to the innovation and skill of the design and construction team. Initially viewed as a risk, the green roof has proven to be one of the most successful elements of this challenging project and represents the growth of the green roof industry in Victoria.

Burnley Biodiversity Green Roof

Location:	Burnley Campus, The University of Melbourne 500 Yarra Boulevard, Richmond, Victoria
Completion date:	February 2013
Size:	49 m ² on an existing building with heritage considerations

Description

The green roof is located above ground floor offices on a concrete roof deck with a 1 degree slope. The roof is accessible only to authorised staff or students with Working at Heights certification; however, it can be viewed from the first floor hallway window.

The Biodiversity Green Roof features:

- Victorian grassland plant species in a shallow scoria-based growing substrate
- a range of landscaping materials (sand, gravel, ash, rubble) and features (logs, rocks, hollow twigs, roof tiles, terracotta pots) to create habitat opportunities for birds, lizards, insects and other invertebrates
- a small ephemeral pond and shallow creek bed, that are supplied by rainfall run-off from the roof above.

Introduction

The University of Melbourne has a campus in Richmond, near the Yarra River, focusing on horticultural research and education. The main building was constructed between 1946 and 1949 and is protected by a Heritage Overlay, and the entire site is listed on the Victorian Heritage Register. The northern end of the roof of the main building has been developed into a Biodiversity Green Roof as part of the larger scale Green Roofs Project, which also includes a Demonstration Roof and a Research Roof on the same building. A design team from HASSELL worked with the University to provide design solutions to assemble the roofs. Junglefy constructed the roofs. A planning consultant was hired to navigate through the planning process and clarify which permits were required.

The Biodiversity Green Roof was developed as a part of the larger Burnley Green Roofs Project to encompass demonstration, education, extension and research. The Biodiversity Green Roof provides students and visitors to the University with an example of the design and features of a non-irrigated, shallow depth green roof designed for habitat.

Design and Components

The roof has a weight loading of 150 kg/m².

Replacement of waterproofing was avoided by patch repair of existing waterproofing: the estimated cost saving was \$2,000. Components include ZinCo SSM45 protection mat and high-density polyethylene (HDPE) root barrier, a ZinCo FD40 drainage layer and ZinCo Filter Sheet SF. A scoria-based growing substrate was delivered by crane in 1 m³ bulker bags, and installed to a depth of 100 mm.

A 400 mm wide unplanted perimeter zone keeps the area around the edge of the roof clear. Aluminium edge restraints separate vegetated and non-vegetated areas of the roof. Scoria aggregate was installed in the non-vegetated areas of the green roof.

The Biodiversity Roof receives run-off from two downpipes that drain the roof area above it. One is directed into the pond and ephemeral stream, the other enters a buried drain pipe that travels along the long axis of the roof. This allows lateral seepage of water into the substrate, and supports plant species with higher water needs, such as Kangaroo Grass (*Themeda triandra*). Drainage off the roof is achieved through two drains on the northern perimeter of the building.

There is no irrigation system on the Biodiversity Roof. It is watered infrequently by hand-held hose during hot weather or prolonged periods without rain.

The plant palette consists of Victorian perennial grasses, herbs, and one species each of an orchid and a fern. These species are typically found in grassland and woodland, and some are known sources of food and nectar for insects. Plants provide colour and interest through a significant part of the year. Tubestock (grown in the Burnley campus nursery, with a small number of plants purchased from Victorian indigenous nurseries) was planted in February 2013. The roof was hand-watered through autumn to promote establishment.

Herbaceous perennial herbs	
<i>Arthropodium milleflorum</i> Pale Vanilla Lily	<i>Ptilotus macrocephalus</i> Green Pussytails
<i>Asperula conferta</i> Common Woodruff	<i>Ptilotus macrocephalus</i> Green Pussytails
<i>Brachyscome basaltica</i> Swamp Daisy	<i>Rumex dumosus</i> Wiry Dock
<i>Brunonia australis</i> Blue Pincushion	<i>Rutidosis leptorrynchoides</i> Button Wrinklewort
<i>Bulbine bulbosa</i> Bulbine Lily	<i>Selliera radicans</i> Shiny Swamp-mat
<i>Calocephalus citreus</i> Lemon Beauty-heads	<i>Senecio quadridentatus</i> Cotton Fireweed
<i>Calotis anthemoides</i> Cut-leaf Burr-daisy	<i>Stylidium graminifolium</i> Grass Trigger-plant
<i>Chrysocephalum apiculatum</i> Common Everlasting	<i>Veronica gracilis</i> Slender Speedwell
<i>Cullen tenax</i> Emu Foot	<i>Vittadinia cuneata</i> Woolly Vittadinia
<i>Dianella revoluta</i> Black-anther Flax Lily	<i>Wahlenbergia communis</i> Tufted Bluebell
<i>Eryngium ovinum</i> Blue Devil	Grasses and grass-like forms
<i>Eryngium vesiculosum</i> Prickfoot	<i>Austrodanthonia carphoides</i> Short Wallaby-grass
<i>Helichrysum rutidolepis</i> Pale Everlasting	<i>Austrostipa scabra</i> Velvet Tussock Grass
<i>Hypericum gramineum</i> Small St. John's Wort	<i>Chloris truncata</i> Windmill Grass
<i>Leptorhynchus squamatus</i> Scaly Buttons	<i>Dichelachne crinita</i> Longhair Plumegrass
<i>Leucochrysum albicans</i> var. <i>tricolor</i> Hoary Sunray	<i>Lepidosperma concavum</i> Sword-sedge
<i>Linum marginale</i> Native Flax	<i>Lomandra filiformis</i> Wattle Mat-rush
<i>Lobelia pratioides</i> Poison Lobelia	<i>Themeda triandra</i> Kangaroo Grass
<i>Marsilea drummondii</i> Common Nardoo	Orchid species
<i>Microseris lanceolata</i> Yam Daisy	<i>Microtis unifolia</i> Common Onion-Orchid
<i>Pelargonium rodneyanum</i> Magenta Storksbill	Fern species
<i>Podolepis jaceoides</i> Showy Podolepis	<i>Cheilanthes austrotenuifolia</i> Green Rock Fern

Maintenance

Staff maintain the Biodiversity Green Roof: this takes about one hour per month. A photographic record of weed species is maintained to monitor those that germinate on the roof. Timely removal of these plants before they set seed prevents them from becoming more widespread. Plant nutrition is provided as eight to nine-month low phosphorus controlled-release fertiliser, applied at half the recommended rate.

Cost

Total: \$13,930

The following details outline the indicative cost of the Biodiversity Green Roof. As it was installed as part of the larger Burnley Green Roofs Project, with works carried out simultaneously (for example, substrates for all green roofs were lifted by crane on the same day), there were economies of scale for design and installation. However, for this case study, costs are provided for a stand-alone 'design and build', as the scale of this roof was small and simple in relation to the overall Burnley project.

Specific costs of project components:

• Preliminary costs: design, project management, etc.	\$3,000
• Repairs to existing waterproofing	\$1,500
• Protection Mat SSM 45	\$ 250
• Root barrier	\$ 100
• Aluminium retaining edge (33 linear m)	\$3,580
• FD40 drainage	\$1,100
• Filter Sheet SF	\$ 120
• Scoria-based growing substrate (10 cm depth)	\$ 680
• Scoria aggregate installed on non-vegetated perimeter	\$ 350
• Labour cost of installation including crane fees	\$1,020
• Temporary fencing (required on three open sides of the roof – 20 linear m)	\$ 630
• Plant production/purchase costs	\$ 600
• Materials collection and planting	\$1,000
TOTAL	\$13,930

Results and Reflections

Nine months after planting the vegetation is still quite sparse, although this is likely to fill in, particularly as the grasses self-sow over time. Plants were grazed by possums living in a pair of Italian Cypress trees (*Cupressus sempervirens* 'Swane's Gold') that were growing adjacent to the building. The trees were removed during 2013 because possum nesting and grazing caused irreparable damage to the trees' canopies. The rooftop plants recovered well over spring.

Australian ravens and magpies visit the roof to bathe in the pond, and also bring food to consume on the roof. Spiders have colonised the tree debris, and an ant colony has moved into the rocky substrate near the end of the stream. Burnley staff members have commented on their enjoyment of the colourful grassland species planted outside the first floor window.

Kangan Institute Green Roof

Location:	Docklands Campus, Kangan Institute, Harbour Esplanade, Docklands, Victoria
Completion date:	November 2012
Area:	250 m ² on a new building

Description

This water-efficient green roof is designed as a space to provide amenity for staff. The area is not open to the general public. Decking and seating is provided. The roof is built on a concrete roof deck with 1.5 degree slope, it is above the third storey.

Introduction

The Kangan Institute Automotive Centre of Excellence (ACE) is located in the Batman Hill Precinct of Melbourne's Docklands. The building holds a 5 Star Green Star rating. The building houses a 2,000 m² area of automotive workshops, and 1,200 m² of specialised training and office areas.

The green roof is located adjacent to the administrative offices, and over the learning suites, which will benefit from reduced heat loads.

The green roof was designed by ASPECT Studios, in collaboration with Gray Puksand Architects. Robert Bird Group provided structural and civil engineering services.

The green roof was installed on the concrete roof deck of the new concrete-framed building.

Design and Components

The roof weight loading is 200 kg/m². Roof drainage is achieved through a series of in-floor sumps, with overflow risers installed along the bottom of the roof slope.

The drainage layer is Atlantis® 20 mm Flo-Cell™ drainage cell, with flow across the roof to perimeter drain. The filter sheet is Bidim® geotextile, Grade A14. For waterproofing, Waterproofing Technologies' Enviro HP1200 was used. This is a two-component, spray-applied, flexible polyurethane membrane. A leak detection system was not installed.

As HP1200 waterproofing treatment is rated as root-resistant (through a testing procedure specified and assessed by CSIRO), a root barrier was not required. Separation sheets of low-density polyethylene (LDPE) were installed to protect the waterproof membrane during construction.

Stormwater run-off was captured to irrigate the green roof, as well as toilet flushing: one point was awarded under Green Star's WAT-3 criterion for the required measurable reduction (by 90 per cent) in potable water consumption on the site from these initiatives. Fytogreen Australia designed and installed the irrigation system. Irrigation is delivered through a Netafim™ sub-surface dripper system. This is water-efficient, programmable and automatic enabling the duration and frequency of irrigation cycles to be adjusted.

ASPECT Studios developed the planting design, which consists of low water use herbaceous and succulent perennials: all have performed strongly.

Plant species used

<i>Anigozanthus</i> 'Ruby Velvet' <i>Carpobrotus edulis</i> <i>Crassula capitella</i> 'Campfire' <i>Dianella caerulea</i> 'Cassa Blue' <i>Dianella caerulea</i> 'Little Jess' <i>Lomandra longifolia</i> 'Tanika' <i>Poa poiformis</i> 'Courtney' <i>Sedum palmeri</i>

Maintenance

Establishment maintenance was provided for eight weeks after planting. The green roof was then managed by the Kangan Institute maintenance team. Plant nutrition is provided as 12 to 14-month low phosphorus controlled-release fertiliser applied at half the recommended rate.

Cost

Total: \$56,000.

Results and reflections

The garden has suffered somewhat from a lack of maintenance. A maintenance strategy is now being developed. Bird control has been needed as seagulls have been nesting in the garden after being disrupted from nesting elsewhere on the building.

Growing Up Rooftop Garden

Location:	131 Queen Street, Melbourne, Victoria
Completion date:	July 2010
Area:	200 m ² on an existing building

Description

The roof space is surrounded by a 1.2 m high balustrade above the 8th floor of the building. The rooftop garden total area is 200 m², with planter boxes occupying 48 m², and a central 'hill' area of 43.5 m².

A trafficable zone expands and contracts around a central landscaped hill to create a number of gathering spaces of various scales and orientations. Bound by edges of seating and planting, inhabitants are surrounded by greenery.

About half of the 131 Queen Street roof area is occupied by plant and machinery: this is screened and separated from the accessible roof garden area by a picket fence.

An additional 38 m² green roof space (not publicly accessible) was installed above the lift motor room. This is part of an Australian Research Council Linkage Project Grant carried out by The University of Melbourne's Green Infrastructure Research Group, to investigate the performance of plants on green roofs in a variety of growing substrates.

Introduction

131 Queen Street is managed by Quayle's Owners Corporation Managers. The building was constructed in 1896 and the tenants include a range of private and public organisations. It was intended that the rooftop garden be used by building tenants for lunch and recreational breaks, meetings, workshops and classes, as well as special events.

The Growing Up roof was built after the Committee for Melbourne ran a design competition for a green roof. The Committee identified three potential CBD rooftops and ran the competition to demonstrate how a "vibrant, innovative and contemporary urban green space" could be created on a rooftop. Safety, maintainability, and durability were key considerations for assessment of entries in the design competition.

Bent Architecture won the design competition with its "Head for the Hill" submission, based on the roof at 131 Queen Street.

The builder was Better Projects Australia and engineers were Clive Steele Partners. The University of Melbourne provided guidance on substrate and planting design.

The project budget was \$200,000, with additional in-kind support provided by sponsors; for instance, VicUrban (the State Government's former development agency, now Places Victoria) provided a project manager to oversee construction and ensure that partners' objectives for the project were met.

Design and Components

The roof's weight loading is for a dead load of 300 kg/m² and a live load 150 kg/m². Total carrying capacity is 100 people. The weight loading precluded the original design from being realised, which was a hill with a large volume of soil and a mature tree growing on it. Instead a sculpture tree was constructed, centred over a column, and covered with wisteria to provide shade in summer and allow sun penetration onto the roof in winter. A hill was made from recycled, expanded polystyrene covered with a small volume of substrate and succulents.

Drainage outlets along perimeter walls lead to concealed downpipes. The roof deck is steel framed with precast concrete roof slabs and sand cement screed over to create fall from the roof to drainage outlets.

A new Polyseal Enviro 800 Pur Top-coat polyurethane waterproofing membrane was installed over the existing membrane. This carries a seven-year warranty. Elmich VersiCell® structural (weight-bearing) drainage modules were installed underneath pervious paving material. The open drainage layer allows free flow of water through to the waterproofed roof deck. No changes were made to the pre-existing drainage points. ZinCo Filter Sheet SF was used over the drainage modules.

The growing medium (saturated bulk density 750 kg/m³) was mixed by Debco to a recipe specified by The University of Melbourne's Green Infrastructure Research Group. Growing medium is used at depths of 200 mm in shallow planter boxes, and 400 mm in deep planter boxes. The same growing medium is used on the 'hill' at a depth of 200 mm over most of its face, although the depth increases to 400 mm depth at the top and on the western face of the hill, to allow for the expanding root system of the Chinese Wisteria. The build up of the hill is created from recycled expanded polystyrene blocks, overlaid with an Elmich VersiWeb® 200 mm deep cellular confinement system to contain the growing substrate. The hill is covered with geotextile, and plant root masses were installed into slits cut into the fabric.

The substrate and plant selection was made with consideration of the Growing Up team's desire to install a sustainable green roof that did not require irrigation. However, after project handover, the building owners installed a drip irrigation system for use particularly during harsh summer weather conditions. Captured rainwater is supplied to the productive garden and perimeter planters, but the hill zone is flourishing without irrigation.

Plants were supplied in a range of sizes, from tubestock, and 14 cm through to 30 cm containers from members of the Nursery and Garden Industry Victoria. The University of Melbourne's Green Infrastructure Research Group grew most of the succulent plant species that were installed as tubestock. A total of 1,664 plants were installed.

Plant type	Species
Grass-like	<i>Lomandra confertifolia</i> 'Little Pal'
	<i>Anigozanthos flavidus</i> Kangaroo Paw
	<i>Dianella tasmanica</i> Tasmanian Flax-lily
	<i>Themeda australis</i> Kangaroo Grass
Culinary herbs	<i>Origanum vulgare</i> Oregano
	<i>Rosmarinus officinalis</i> and <i>R. officinalis prostratus</i> Rosemary (upright and prostrate forms)
	<i>Salvia officinalis</i> Culinary Sage
	<i>Thymus vulgaris</i> Common Thyme
Climbers	<i>Passiflora edulis</i> Passionfruit
	<i>Wisteria sinensis</i> Chinese Wisteria
	<i>Aphanopetalum resinolum</i> Gum Vine
	<i>Pandorea jasminoides</i> 'Alba' <i>P. jasminoides</i> 'Lady Di' Bower Vine cultivars
	<i>Clematis glycinoides</i> Forest Clematis
Succulents	<i>Sedum pachyphyllum</i>
	<i>Sedum xrubrotinctum</i>
	<i>Sedum mexicanum</i> Mexican Stonecrop
	<i>Aloe</i> 'Always Red'
	<i>Aloe</i> 'Gemini'
	<i>Kleinia repens</i> Chalk Sticks
	<i>Lampranthus deltooides</i>

<i>Trees</i>	<i>Citrus limon</i> 'Meyer' Meyer Lemon
	<i>Olea europaea</i> (espaliered) European Olive
<i>Shrubs</i>	<i>Banksia spinulosa</i> 'Birthday Candles' Hairpin Banksia cultivar

Maintenance

The garden is maintained once a month by a horticulturalist, and the building management team carries out some maintenance in between these scheduled visits.

Plant nutrition is provided as eight to nine-month low phosphorus controlled-release fertiliser, applied at half the recommended rate, as required.

Cost

Total: \$219,000

Costs of project components:

• Timber and metal work fabrication and installation (including planter boxes, seats, pergola, roof lift, access ladder, fencing and sculpture)	\$135,850
• Building preparation works (including scaffold, handrail, crane)	\$ 14,500
• General construction items (including roof access anchors, signage, light, power and plumbing and upgrades for Building Code of Australia compliance)	\$ 35,608
• Roof garden construction items	
• Permeable paving	\$ 23,220
• Ronstan cables [†]	\$ 2,000
• Plants	\$ 5,000
• Rainwater tank and pump	\$ 2,500
• 300 m ² Elmich green roof system	in-kind*
• Growing media installation	in-kind‡
• Plants	in-kind ⁿ
Total	\$218,678

† Further structural rod & cable systems for green walls and landscaping and cable systems for balustrades and railings were provided at cost price by Ronstan Tensile Architecture, a sponsor of Growing Up

*The green roof system and labour for installation was provided as in-kind support by sponsor Green Roof Technologies, this had an estimated value of \$60,000.

‡ Provided as in-kind support by sponsor WeBlow

ⁿ Provided by sponsors Proteaflora, Aloe-Aloe Horticulture, Merrywood Plants and Majestic Plants, this had an estimated value of \$8,500

Results and reflections

The rooftop has been popular and is used throughout the year as a social space by the building occupants. The rooftop can be booked for functions and is open annually to the public as part of The Committee for Melbourne's 'Melbourne Open House'.

APPENDIX A. Green roof growing substrates

The design of a green roof growing substrate must include specification of the following physical properties, outlined in Table 13. Many of these measures are used in the development of growing media for containers and landscaping soils, making this information relevant to development and testing of growing media for use with some green wall and facade systems. Referenced standards used to develop this table are AS 3743 2003, Appendix B, and the Singapore Centre for Urban Greenery and Ecology Standards: these are listed in the **References** section. It is valuable to obtain independent testing and verification of the properties of substrate mixes on large scale commercial green roof projects.

Table 13: Properties that should be specified in growing substrates

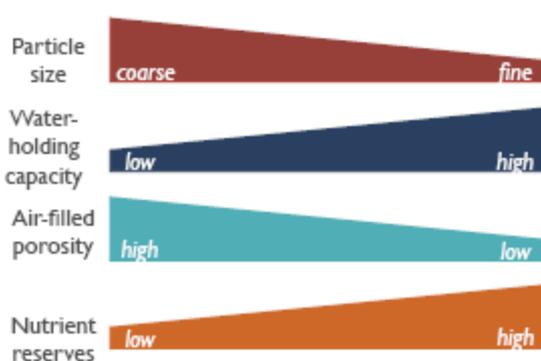
Property	Definition	What it means in relation to green roof substrates	Unit of measurement
Saturated bulk density	The mass of a known volume of a material under fully saturated conditions.	The maximum possible weight of the growing substrate (assuming no ponding water sitting above the top of the substrate) as it includes the weight of the material and of water that drained freely from it under test conditions. This parameter is set by the roof weight loading.	g/cm ³ or kg/m ³
Air filled porosity (AFP)	The percentage of air held by a known volume of fully saturated growing substrate, just after it has stopped draining. AFP is measured by watering and draining a known volume of substrate under a set of standard conditions described in AS 3743 2003, Appendix B.	AFP provides an indication of the likely aeration of the growing substrate and flags any potential for waterlogging, in conjunction with water-holding capacity (see below). AFP should be 10-20%	% (of known substrate volume)
Water-holding capacity (WHC)	The total amount of water a known volume of growing substrate can hold after it has been watered and drained under standard conditions described in AS 3743 2003, Appendix B.	WHC indicates how well the growing substrate retains water. WHC should be ≥35% or greater for an extensive green roof, and 45% for an intensive green roof (up to a maximum of 65%); WHC will vary inversely with AFP (above) and an acceptable balance of the two must be achieved.	% (of known substrate volume)
pH	The measure of the acidity or basicity (alkalinity) of a solution, expressed as the negative log concentration of free hydrogen ion (H ⁺) it contains.	Determination of pH of an aqueous extract of a growing substrate indicates whether any nutrient deficiencies are likely, as pH affects the availability of the nutrient supply to plants. Most plants show optimal growth in growing media with pH of 6 to 7. Optimum pH range may vary with substrate composition. pH 6 to 7.5 for mineral mixes; pH 5.5-6.5 for organic mixes; pH 5.5-8.0 should provide acceptable growth for most species.	No unit; range from 1 (acid) to 14 (alkaline, or basic). Solutions with pH below 4 are extremely acid, and solutions with pH above 10 are extremely alkaline
Electrical conductivity (EC)	Determination of the ability of salts dissolved in solution to conduct electricity.	An indication of the degree of salinity of a growing substrate: high salt content can impair plant growth. Growing substrates should have EC of less than 2 dS/m.	deciSiemens per metre (dS/m) or measure total dissolved salts in

Cation exchange capacity (CEC)	The ability of growing media to attract and hold positively charged ions (cations) thus making them available for plants to take up	Cations such as calcium, magnesium, potassium and ammonium (a source of nitrogen) are crucial for healthy plant growth. Decomposition of organic materials such as pine bark and coir increase the cation exchange capacity of growing substrates. Colloidal materials such as clay also provide CEC but these are usually present in very low proportions in green roof growing mixes. Analytical laboratories determine CEC by measuring the amounts of different exchangeable cations in growing media. Growing substrates should have CEC of 50 – 100 mEq/l.	ppm milliequivalents or ppm
Infiltration rate	A measure of how rapidly water soaks into a growing substrate, growing medium or soil.	For an extensive green roof growing substrate the infiltration rate should be 1.0 mm/min or 60 l/m ² /h. For an intensive green roof, infiltration rates should be 0.6 mm/min or 36 l/m ² /h.	mm/min or l/m ² /h

Australian Standards also specify testing requirements for growing substrates and media to ensure they are not toxic to plant growth.

Green roof growing substrates are designed to have a mix of large and medium-sized particles to create an open, porous structure inside which smaller particles can fit. The sizes and proportions of small particles and their packing inside the large pores make a major contribution to the amount of water the mix can retain. Water is held by capillarity between small, tightly packed particles in the growing substrate, and it is this water that is available to plants. A mix with a high proportion of fine particles will retain more water than a mix composed of few fine particles. Figure 24 compares the general characteristics of growing substrates used on deeper and shallower green roofs.

Figure 24. A comparison of growing substrates



A growing substrate designed for a shallow green roof (left hand side) will be more open and free draining than a substrate designed for a deeper green roof (right hand side). Because of the shallow depth of some roofs, the risk of waterlogging is great. Waterlogging decreases oxygen in the root zone, and limits plant growth. Diagram adapted from Zinco.

The report, [The Matter of Landscape: Sustainable Design Strategies for RMIT City Campus](#), provides further information on different elements growing mediums and their properties.

There are no Australian specifications for the composition and physical properties of green roof growing substrate, and often international specifications are used or adapted. Table 14 outlines the properties of green roof growing substrates as specified by Germany's FLL and Singapore's Centre for Urban Greenery and Ecology.

Table 14. Properties of green roof growing substrates

	Extensive	Intensive
Clay and silt content	≤15% by mass	<20% by mass
Proportion of particles > 4mm in diameter	≤ 50% by mass	≤ 40% by mass
Organic matter	≤ 65 g/l (FLL) 10-25% (CUGE)	≤ 90 g/l (FLL) 5-10% (CUGE)
Settling	No more than 10% of nominal depth	Average of ≤ 5 cm for substrates at least 50 cm deep
Water permeability	0.6 - 70 mm/min	0.3 - 30 mm/min
Water storage capacity	> 35% by volume	≥ 45% by volume (maximum of 65%)
Air-filled porosity	≥ 10%	≥ 10%
pH	6.0 – 8.5	6.0 – 8.5
Total soluble salts	1.5 - 3.5 g/l	1.5 - 2.5 g/l

Table 15 shows a range of components commonly used in green roof growing substrates and reasons for using them, along with indications of their saturated and dry weights. This represents a very small number of components that could be used in growing mixes. Comparative values for topsoil and sand are also provided for reference, but their high bulk density often limits or precludes their use.

Table 15. Comparison of materials used in green roof growing substrates and their saturated bulk density

Material	Component	Why used	Saturated bulk density (kg/m³)	Dry bulk density (kg/m³)
Recycled waste products	Ash	Waste product	1160 – 1310	640 – 900
	Organic materials (coir, pine bark, compost)	Waste product, water retention, CEC	930 – 1100	50 – 360
	Crushed ceramics (brick, roof tile)	Longevity, recycled	1090 – 1300	1640 – 1720
Quarried products	Scoria aggregate rock	Longevity	1290 – 1560	670 – 1000
	Scoria non-descript crushed rock (NDCR)	Longevity	1530 – 1730	1030 – 1270
Inert volcanic products	Perlite	Light weight	500 – 800	40
	Pumice (Hekla, Iceland)	Longevity; porous and light weight	540 – 753	260 – 490
Synthetic additives	Hydrocell	Inert, water-retention	660	27
Loamy topsoil			1700 – 2400	1000 – 1900
Sand			1800 – 2200	1440 – 1650
Water			1000	
Burnley extensive green roof medium			1370	850

Values compiled from Handreck and Black, University of Melbourne Green Roof Infrastructure Group research data, Weiler and Scholz Barth, Dunnett (Small Green Roofs) and JEI International.

Glossary

Basal shoots	Shoots arising from buds at the stem bases or roots of a plant. Continued production of basal shoots through rejuvenation pruning is important to promote coverage of the lower areas of a green facade, as some climbing plant species open up at the base over time.
Controlled release fertiliser	Fertiliser composed of inorganic cations and anions held within resin beads or prills. Nutrients are released over time as water solubilises the ions. Also known as slow release fertiliser. Abbreviated CRF.
Crop factor	A measure of water use by plants, taking into account their leaf area. The crop factor increases as plants increase in size and require more water to support their growth, and also varies with the season. Water use by leafy plants is higher when temperatures are warm and solar radiation is high.
Cultivar	Cultivated variety of a plant that has been selected for some special attribute. Cultivated varieties are indicated with a name included inside a pair of apostrophes e.g. <i>Achillea 'Walther Funcke'</i> .
Dead load	Permanent weight load imposed on a structure by the combination of fixed elements and by the weight of the structure itself. Measured in kilograms per square metre.
Electrical conductivity	A measure of the ability of salts dissolved in solution to conduct electricity. High salt content in the growing medium can impair plant growth. Abbreviated as EC.
Evapotranspiration	The combined loss of water from transpiration by plants and evaporation of water from the growing substrate and plant surface.
Fertigation	Delivery of water for irrigation containing dissolved low-level fertiliser, used in hydroponic growing systems.
Growing medium/substrate	Materials that act as a soil substitute, providing physical support to the root system of a plant, and delivering water, oxygen and nutrients needed for growth. Growing media includes potting mixes used for containers, through to specially-designed growing substrates composed of largely inorganic materials designed for use on green roofs.
Landscape coefficient	A factor that is used to calculate the rate of water loss by evapotranspiration, based on the <u>crop factor</u> , the density of planting, and microclimatic factors that affect water loss from the plants and growing medium (e.g. the degree of shade on a site).
Live load	Temporary weight load imposed on a structure by the addition of people and moveable items.
Personal protective equipment	Safety clothing, helmets, gloves, dust masks or independently ventilated masks, goggles and safety glasses. Abbreviated as PPE.
Petiole	The stalk of a leaf.
pH	The measure of acidity or alkalinity of a solution, pH ranges from 1 (acid) to 14 (alkaline). Optimal growth of most plant species is obtained with growing media that have pH values of 6 to 7.
Porosity	The ratio of the volume of void spaces in a substrate (or soil) to the total volume. Porous substrates allow water and air to move through.
Potable water	Water that is safe for humans to drink.
Rhizome	An underground stem, arising from the root mass of a plant, which gives rise to roots and shoots at nodes and the production of genetically identical plants.
Saturated bulk density	The mass of a known volume of a material under fully saturated conditions, expressed in g/cm ³ or kg/m ³ .

Stolons	Stems arising from buds the base of a plant, that grow horizontally at or just below the soil surface. Roots and shoots (leaves) will develop at nodes on a stolon, to produce a series of interconnected, genetically identical plants e.g. runners produced by strawberry plants.
Total dissolved solids	A measure of all inorganic and organic substances contained in a solution, measured in parts per million.
Transpiration	Water movement through a plant, from its uptake by the roots through water conducting tissues, to its exit through openings in leaves and stems.
Water-holding capacity	The total amount of water a known volume of growing substrate can hold after it has been watered and drained under standard conditions described in Australian Standard 3743 2003, Appendix B. Water-holding capacity is expressed as a percentage (of substrate volume). Abbreviated as WHC.
Water Sensitive Urban Design	The planning of water use on a site to build landscapes that work with the natural water cycle. It includes treatments that are designed to avoid, or at least minimise, the environmental impacts of urbanisation, such as rain gardens or biofiltration ponds that are important in cleaning urban run-off. Abbreviated as WSUD.

References and source material

This section provides a list of the books, Australian and international standards, and websites and companies that were used or provided as resources in writing Section 3: Technical Guide of *Growing Green Guide: A guide to green roofs, walls and facades in Melbourne and Victoria, Australia*. It is not an exhaustive list of resources relating to green roofs, walls and facades, and readers are encouraged to explore other sources of information.

The Green Roofs Australasia and Landscaping Victoria websites contain industry directories that list providers of green roofs, walls and facades, together with product suppliers and designers.

Text sources

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<http://sustainability.edu.au/material/teaching-materials/matter-landscape-sustainable-design-strategies-rmit-city-campus/>

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Snodgrass E, McIntyre L, *The Green Roof Manual: A Professional Guide to Design, Installation and Maintenance*, Timber Press 2010

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Tan A, Chiang K, *Vertical Greenery for the Tropics*, CUGE Singapore, 2011 reprint

Weiler SK, Scholz-Barth K, *Green Roof Systems*, John Wiley & Sons, 2011

Standards

Australian Standards

National Construction Code

- AS 1141.0 Methods for sampling and testing aggregates
- AS 1170.1 Dead and live load combinations
- AS1170.2 Wind loads
- AS3743 Potting Mixes
- AS 3740 Waterproofing of domestic wet areas
- AS4419 Soils for landscaping and garden use
- AS/NZS 4858:2004 Wet area membranes
- AS4654.2-2012 Waterproofing membranes for external above ground use – Design and installation

International Standards

Australia does not yet have its own standards for design, construction and maintenance. The Australian green roofs industry often bases decisions on international standards and literature, some of which are identified below.

FLL Guideline

The first guideline for the construction of green roofs appeared in Germany in 1982, under the title of “Principles of Green Roofing”. Since 1992 it has been known as “Guidelines for the Planning, Construction and Maintenance of Green Roofing – Green Roofing Guideline”. It is produced by the Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (abbreviated to FLL), or, in English, the Landscape Development and Landscaping Research Society e.V. The regulatory commission on Green Roofing oversees revisions of the FLL Guideline, in consultation with a large working group. The Guideline has been revised and updated seven times and provides the accrued benefits of three decades of extensive research and development. The FLL Guideline is available for purchase from the FLL website (www.fll.de). The most recent revision in English was published in 2008.

Centre for Urban Greenery and Ecology

In 2010, Singapore’s Centre for Urban Greenery and Ecology (CUGE) began to produce its own locally relevant set of standards. CS E: Skyrise Greenery is a set of nine guidelines covering all aspects of green roof design and construction.

1. CS E01:2010 Guidelines on design loads for rooftop greenery

2. CS E02:2010 Guidelines on design for safety for rooftop greenery
3. CS E03:2010 Guidelines on substrate layer for rooftop greenery
4. CS E04:2010 Guidelines on filter, drainage and root penetration barrier layers for rooftop greenery
5. CS E05:2012 Guidelines on waterproofing for rooftop greenery
6. CS E06:2012 Guidelines on irrigation for rooftop greenery
7. CS E07:2012 Guidelines on general maintenance for rooftop greenery
8. CS E08:2012 Guidelines on design and construction of pitched green roof
9. CS E09:2012 Guidelines for planting of trees, palms and tall shrubs on rooftop

ASTM International

ASTM International (formerly the American Society for Testing and Materials) oversees the development of standards used in many parts of the world, though predominantly in the USA and Canada. Several standards are available that relate to materials selection and testing of materials for green roofs, including ASTM E2400-06 Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems. Other guides currently in development by ASTM International include a selection guide for waterproofing membranes for green roofs, and a new guide for vegetative (green) roof systems. As with the German guidelines, these tie in closely with building regulations.

- ASTM C136-06 Standard test method for sieve analysis of fine and coarse aggregates
- ASTM E2396-11 Standard test method for saturated water permeability of granular drainage media [falling head method] for vegetative (green) roof systems
- ASTM E2397-11 Standard practice for determination of dead loads and live loads associated with vegetative (green) roof systems
- ASTM E2398-11 Standard test method for water capture and media retention of geocomposite drain layers for vegetative (green) roof systems
- ASTM E2399-11 Standard test method for maximum media density for dead load analysis of vegetative (green) roof systems
- ASTM E2400-06 Standard guide for selection, installation and maintenance of plants for green roof systems
- ASTM E2788-11 Standard specification for use of expanded shale, clay and slate (ESCS) as a mineral component in the growing media and the drainage layer for vegetative (green) roof systems

Web-based and company sources

<i>Alumasc</i>	www.alumasc.co.uk
<i>Ardex</i>	www.ardexaustralia.com
<i>ASPECT Studios</i>	www.aspect.net.au
<i>Atlantis</i>	www.atlantiscorp.com.au
<i>British Council for Offices: Green Roofs Research Advice Note</i>	www.greenroofs.com/pdfs/sg-green_roofs_advice_note_corpoflondon.pdf
<i>Carl Stahl GmbH</i>	www.carlstahl.com/divisions.html
<i>City of Chicago</i>	www.cityofchicago.org/city/en/progs/env.html
<i>City of London</i>	www.cityoflondon.gov.uk/services/environment-and-planning/planning/design/sustainable-design/Pages/green-roofs.aspx
<i>City of Sydney</i>	www.cityofsydney.nsw.gov.au/vision/sustainability/sustainable-city-living/greening-the-city/green-roofs-and-walls
<i>City of Toronto</i>	www.toronto.ca/greenroofs
<i>De Boer Waterproofing Solutions</i>	www.deboer.be/EXEN/site/index.aspx
<i>Elmich</i>	www.elmich.com.au/home.php

<i>Environment Design Guide</i>	www.environmentdesignguide.com.au/
<i>FM Global Data Sheets</i>	www.fmglobal.com/fmglobalregistration/
<i>Fytogreen</i>	www.fytogreen.com.au/
<i>Green Building Council of Australia</i>	www.gbca.org.au/green-star/
<i>Green Roofs Australasia</i>	https://greenroofsaustralasia.com.au/
<i>Green Roofs for Healthy Cities</i>	www.greenroofs.org/
<i>Green Roof Guide (UK)</i>	www.greenroofguide.co.uk/
<i>Greenscreen</i>	www.greenscreen.com/
<i>International Leak Detection</i>	http://leak-detection.com/
<i>International Green Roofs Association</i>	www.igra-world.com/
<i>Jakob Rope Systems</i>	www.jakob.ch/display/JAK/Produkte
<i>Junglefy</i>	http://junglefy.com.au/
<i>KISS America</i>	www.kisssusa.com/
<i>Landscaping Victoria</i>	www.liav.com.au
<i>LEED</i>	www.usgbc.org/leed
<i>Living Architecture Monitor</i>	www.livingarchitecturemonitor.com/
<i>Living Building Challenge</i>	http://living-future.org/lbc
<i>Melbourne Water</i>	www.melbournewater.com.au/
<i>National Australian Built Environment Rating Scheme</i>	www.nabers.gov.au/
<i>Nationwide House Energy Rating Scheme</i>	www.nathers.gov.au
<i>RCI, Incorporated</i>	www.rci-online.org/
<i>Ronstan Tensile Architecture</i>	www.ronstantensilearch.com/
<i>Sika Sarnafil</i>	http://aus.sika.com/en/solutions_products/02/02a011/02a011sa10.html
<i>Smart Gardening</i>	www.savewater.com.au/how-to-save-water/in-the-garden/plant-library
<i>Soprema Group</i>	www.soprema.com/
<i>Sustainable Tools for Environmental Performance Strategy (STEPS)</i>	www.sustainablesteps.com.au/
<i>Tensile Design & Construct</i>	www.tensile.com.au/
<i>Victorian State Government Planning Schemes Online</i>	http://planningschemes.dpcd.vic.gov.au/
<i>Water Use Classification of Landscape Species</i>	http://ucanr.org/sites/OC/files/132534.pdf
<i>Your Home Technical Manual</i>	www.yourhome.gov.au/technical/index.html