

Feasibility Study:
Living wall system for multi-storey
buildings in the Adelaide climate

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The Government of South Australia

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Aspen Developments

Aspen Developments through its clear focus at City Central on "building green" is delighted to be part of the SA Government's search for innovative ways to further reduce the carbon footprint of commercial office buildings.

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01

Executive Summary



Living wall systems for multi-storey buildings in the Adelaide climate

The feasibility of establishing viable living wall systems suitable for application on multi-storey buildings in the Adelaide CBD in South Australia has been investigated via a collaborative research project. The research was undertaken on behalf of Aspen Developments by the project team of Graeme Hopkins and Christine Goodwin of Fifth Creek Studio, and Milos Milutinovic and Michael Andrew of Woods Bagot.

Fifth Creek Studio specialises in living architecture, in particular green roofs and living walls and their role within a broader sustainable green infrastructure. Directors Graeme Hopkins and Christine Goodwin have many years of professional experience and have won national and state awards in architecture, landscape architecture, urban design and heritage. They have presented papers and presentations on living architecture at national and international conferences.

Graeme Hopkins is a Registered Architect, Registered Landscape Architect, Fellow of the Australian Institute of Landscape Architects and Adjunct Associate Professor at the University of Adelaide. He was awarded a Churchill Fellowship in 2005 to research green roofs and living walls in North America, Japan and South East Asia.

Christine Goodwin has a background in teaching, public art and arts administration, and holds a Masters Degree in Architecture (Research). A book titled Living Architecture: green roofs and living walls for climate change (focusing on Australia and New Zealand), by Hopkins and Goodwin, is being published by CSIRO and due for release by early 2011.

Woods Bagot is a global design studio specialising in design and planning.

Woods Bagot has Sustainability (Green) Teams established in all studios. There are a number of Accredited Professionals in all Woods Bagot studios including GBCA Green Star, LEED and BREEAM systems.

Research is the principal foundation that underpins the Woods Bagot methodology. Our global research brand, Public, has been established to bring a formal focus to our applied and theoretical research. It captures new thinking and acts as a platform for clients, staff and collaborators to feed ideas and challenge conventional theory. Created by Woods Bagot staff in conjunction with world-leading thinkers, entrepreneurs and academics, research is disseminated through published papers, seminars, books, blogs, podcasts and projects.

Michael Andrew and Milos Milutinovic bring numerous years of experience in high-rise commercial architecture to the team. In addition their experience also includes delivery of leading sustainable projects such as Adelaide's City Central precinct development.

The context of this project is a growing awareness of the potential role of green infrastructure, such as living walls, in addressing climate change in the urban form and particularly how individual green buildings can contribute significantly to the reduction of Greenhouse Gases (GHG) and the Urban Heat Island (UHI) effect produced by the built environment.

The feasibility study has three main aims:

- Identify the living wall design criteria appropriate to the extreme conditions of Adelaide's climate
- Assess the potential for reduction in Greenhouse Gases, CO₂ and the Urban Heat Island effect
- Address and resolve the hurdles to achieving large scale coverage at height on multi-storey buildings

Design Criteria

Climate

The climate in Adelaide is extremely demanding, especially for plants, and when they are placed high on an exposed wall these conditions are even more extreme.

Given that the changing climate predictions are for hotter and more extreme conditions, this study recommends the system be designed to survive in temperatures up to 45°C with a relative humidity of just 4% on some days.

Plant Selection

In addition to temperature and humidity, wind is a significant factor, as positive and negative pressures are created around the building, causing shear forces over the living wall systems. These influences, together with the facade orientation, are extremely important design criteria. If the system fails during an extreme climatic event the plants could dry out and collapse beyond recovery.

Hardy, drought tolerant plants that are endemic to the Adelaide Plains will be utilised, as these have naturally adapted to growing in harsh environments and our climate.

Reducing Greenhouse Gas Emissions and the Urban Heat Island Effect

Living wall systems are part of the climate change and GHG mitigation processes that cities are adopting around the world. By shading the building facade with a living wall the building heats up less, therefore the building uses less energy for cooling and produces less GHG. Plants absorb the sun's radiation and through evapotranspiration produce water vapour which cools the air temperature. This reduces the UHI effect of individual buildings and the city as a whole.

Large Scale and Height on Multi-Storey Buildings

The feasibility study investigated living wall systems currently available, which fall into two main categories. The first is the green facade, a climber trellis system that allows ventilation and light through, with climbers planted in the ground or planter boxes. The second is the green wall that uses panels (of approximately 0.5m²) containing growing medium held in framework that is fixed to the wall. This system shades the wall and creates cool air movement behind the system. Both these systems are quite labour intensive in implementation and are suitable for walls 1-4 storeys high as maintenance is from the ground.

Given that the proposed living wall system is to cover facades up to 20 or so storeys a new system is required. Multi-storey building facades are designed and constructed on a large scale, so the living wall system needs to be of equal scale in design and in its components to take advantage of economy of scale in its implementation.

Concept for a New Living Wall System

Current multi-storey building design uses a double skin or environmental screen to protect the building interior from heat build up. This screening is held on a steel framework attached to the facade. If this outer layer was replaced by a living wall that combined the benefits of both green facade and green wall attached to a steel framework, this could replace the current screen. It would provide a living environment on the wall, converting CO₂ into O₂ and water vapour, and cooling the building.

The project team propose to develop panels up to 2 storeys high by 1500 mm wide or equivalent to the particular building module, to be installed as pre-fabricated units. This new proposed system is being called a hybrid living wall system.

Benefits to the Building

The proposed hybrid system is a steel framework attached to the building with the green living wall on the outside of the framework. Within this framework all maintenance activities can occur for the building façade, thereby doing without façade BMU maintenance systems. The advantages of this system are:

- Reduces the building's heating and cooling costs by shading (less energy and GHG)
- Reduces the maintenance capital and ongoing costs
- Spandrel panels are covered with the green wall section of the system and the glass curtain wall is no longer needed, therefore normal shopfront windows can be used between floor slabs
- Cost of irrigation is reduced by 2/3 of an existing green wall system
- Reduces the reflective heat and uses the evapotranspiration of the plants to cool the surrounding environment, therefore reducing the UHI effect and GHG
- Can be retrofitted to existing building stock provided there are fixing points to the primary structural frame of the building.

Benefits to the City

The hybrid living wall system will become a very visual element within the public realm, whether located in private or public air space. This will be an important urban design element as well as signalling the green credentials of the building and city. Living walls can become one of the important layers for the built form to address climate change in the city. Living walls are part of the city's water sensitive urban design (WSUD) system, as a living wall intercepts 20% of the rainfall before it reaches the ground. A living wall placed in the urban canyon can reduce the adjacent pavement temperature by 5oC, and with its visual amenity creates an inviting place for commercial activities to occur, increasing the liveability of the urban canyons within the city.

These living wall systems can be an integral part of the city's urban ecology by providing new habitats and forming stepping stone corridors throughout the city, thereby increasing biodiversity within the city environs.

Making it Happen

The feasibility study is being followed by the design and installation of a prototype hybrid living wall system for Tower 8 in the City Central precinct. The system will be monitored for 12 months so that data can be collected and analysed to quantify the benefits of this new living wall system, with specific application to Adelaide.

the 1990s, the number of people in the world who are under 15 years of age is expected to increase from 1.1 billion to 1.5 billion.

As a result of the rapid increase in the number of people in the world, the demand for food and other resources is increasing rapidly.

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Literature and Product Review

Introduction

This feasibility study is the first of three projects assisted by the South Australian State Government's Building Innovation Fund, providing assistance to Aspen Group to work collaboratively with Woods Bagot and Fifth Creek Studio: Living Architecture to investigate the feasibility of designing and installing an appropriate living wall system for Adelaide's demanding climate. Feasibility considerations include: climate change adaptation, reducing the greenhouse gas produced by buildings, determining an appropriate cost effective system for new buildings and retrofitting existing buildings.

The feasibility study is directed towards development of a living wall system for Tower 8 of the City Central Development. While Tower 8 is being completed a prototype system will be designed and installed on the nearby old telephone exchange building and monitored for its potential benefits to the building and to the wider city environment. Once Tower 8 is completed the living wall will be moved to Tower 8 in Bentham Street, with the same orientation maintained. In another project green roof prototypes will be trialled on top of a building in the same city precinct.

The multiple benefits of vegetation in urban areas have long been established within most cities around the world. This has been achieved by implementing street tree planting, urban parks and wetlands programs to assist with a range of issues from air pollution, air temperature control, to stormwater management, and biodiversity and habitat protection. A relatively recent component of city greening is the implementation of green roofs and living walls. Living walls, also known as green walls or vertical gardens can provide the benefits of vegetation, with added space saving advantages within densely built up urban spaces, where it might be difficult to establish more traditional plantings. The particular benefits of living walls are the focus of this feasibility study, as they are rapidly becoming a significant component of an integrated green infrastructure that addresses a broad range of climate and sustainability issues.

Adelaide's climate, especially when dealing with the predicted rise in temperature, more frequent lengthy heat wave conditions and extremely low humidity levels, creates difficult growing conditions. By using endemic species that are accustomed to these conditions a micro climate effect surrounding the building can be developed by raising the humidity through plant transpiration. In addition to the greenhouse gas reduction potential of this micro climate there are other environmental benefits. These include physical shading that lowers the skin temperature of the building and interior cooling that reduces air conditioning requirements and energy. By using the living walls system to reduce the levels of heat radiation from the building surface and heat energy being expelled from the building, the ambient temperature can be lowered. There is also a greater benefit to the wider city environment and reduction of greenhouse gas levels. This can play an important role in urban heat island (UHI) effect reduction.

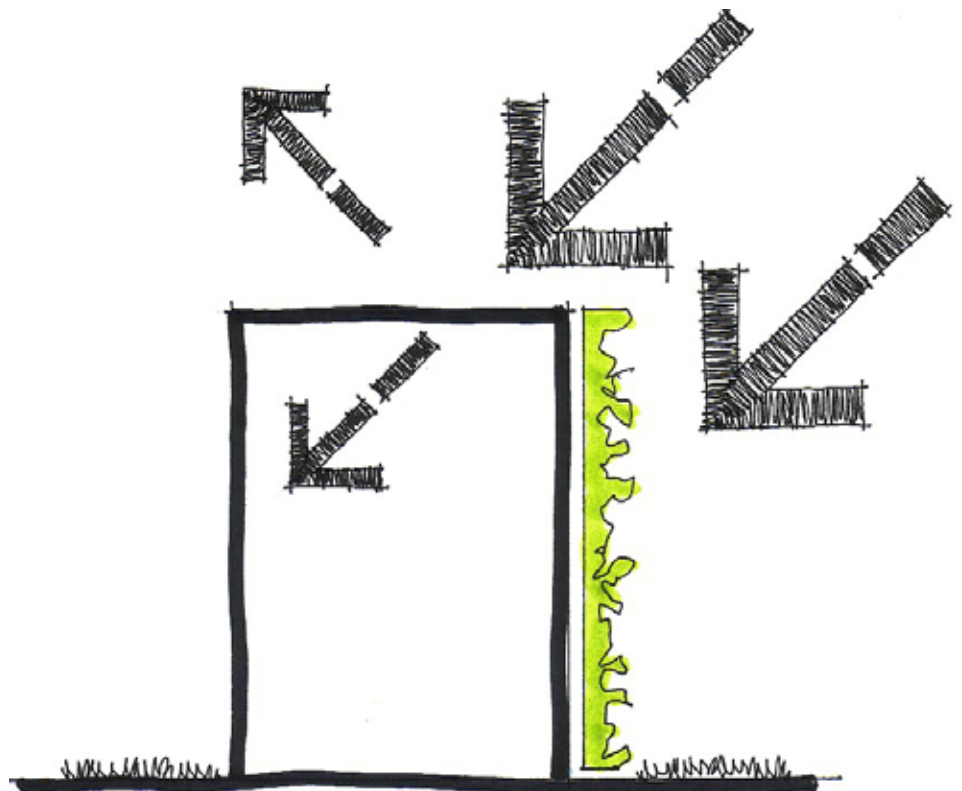
Living walls have the potential for carbon sequestration, which can be quantified and used as carbon credits. This same process also increases the carbon dioxide/oxygen exchange in the city environs, thereby reducing potential health risks and lowering the CO₂ dome over the city.

In addition to their energy and environmental benefits, living walls can also improve the well being of city inhabitants by restoring links between humans and nature, this is also translated into an urban design feature creating urban texture to the public and private realm.

While these systems can reduce the carbon footprint in an innovative way they still need to be cost effective and appropriate for new and retrofitted buildings, making them a universal component in the green building tool kit.

It is important to understand the site specific conditions in order to select the most appropriate living wall system. It has been a general belief that any commercial system is appropriate for any position or climate, however, recent experience has shown that this is not the case. For instance, the vegetated mat wall system that relies mainly on epiphytic plants and constant moisture can suffer in extreme heat and low humidity to the point of failure. This is especially relevant for a city such as Adelaide.

Each of the systems has advantages and disadvantages for various conditions and climate. Identifying these will enable the designer to reduce the risk factors and give greater opportunity for optimum growth and success.





Literature and Product Review

Introduction

Domestic and commercial scale systems

In the current market there are minimal distinctions between domestic and commercial products and systems. However, there are some very important differences relevant to this study.

The scale of commercial living walls for multi-storey buildings require a different approach to domestic scale systems. The materials need to be of particularly high quality and longevity to accommodate the rigours of the extreme conditions. For instance the extreme solar radiation in the harsh city environment would break down UV unstable materials very quickly. Structural stresses on the framework to support the system, as well as the wind loading, requires more intensive engineering than with smaller scale domestic applications. The higher the living wall the greater the wind loadings will be. In addition, the issue of services and maintenance requires integration into the building systems, rather than applied as an add-on component more applicable in a domestic scale.

Common terminology for living walls

The terminology to describe living walls needs to be defined. There are many terms used in the industry and in different countries, including vertical garden, green wall, bio-wall and green façade. This study is adopting the now generally accepted classification system where the term 'living wall' covers all variations, but can be subdivided into two major areas: 'green façade' and 'green wall'.

Most of the available documentation is based on overseas conditions with very little information that is specific to Australian conditions. This study will examine components and systems from manufacturers and installers, and assess relevant research within an Australian context, with particular application to the drier regions such as Adelaide.

Literature and Product Review

Classifications

Living walls can be external or internal to the building envelope, but for this study we will only consider external living wall systems. They can be classified into two categories: green facade and green wall.

Green facade

This is a type of living wall system in which climbing plants or cascading ground covers are supported on specially designed structures. The plants are either grown in the ground or in elevated containers where they are watered and fertilised.

Self-clinging plants have been used to create green walls for centuries, however their 'sucker' roots system that attaches to the wall can damage the wall surface. Technical innovations in recent times have resulted in the development of new trellises, modular panels and cable and wire-rope net systems.

Trellis

A series of wires or cables is attached to a structure, allowing the climbing plants to grow up the cables to create a plant screen/wall. These structures can be attached to the building envelope or can be free standing.



Cable system with climbers in Japan
(Photo sourced from Fifth Creek Studio)



Capital Centre, Canberra living wall after 25 years - designed and constructed by Graeme Hopkins
(Photo sourced from Fifth Creek Studio)

Literature and Product Review

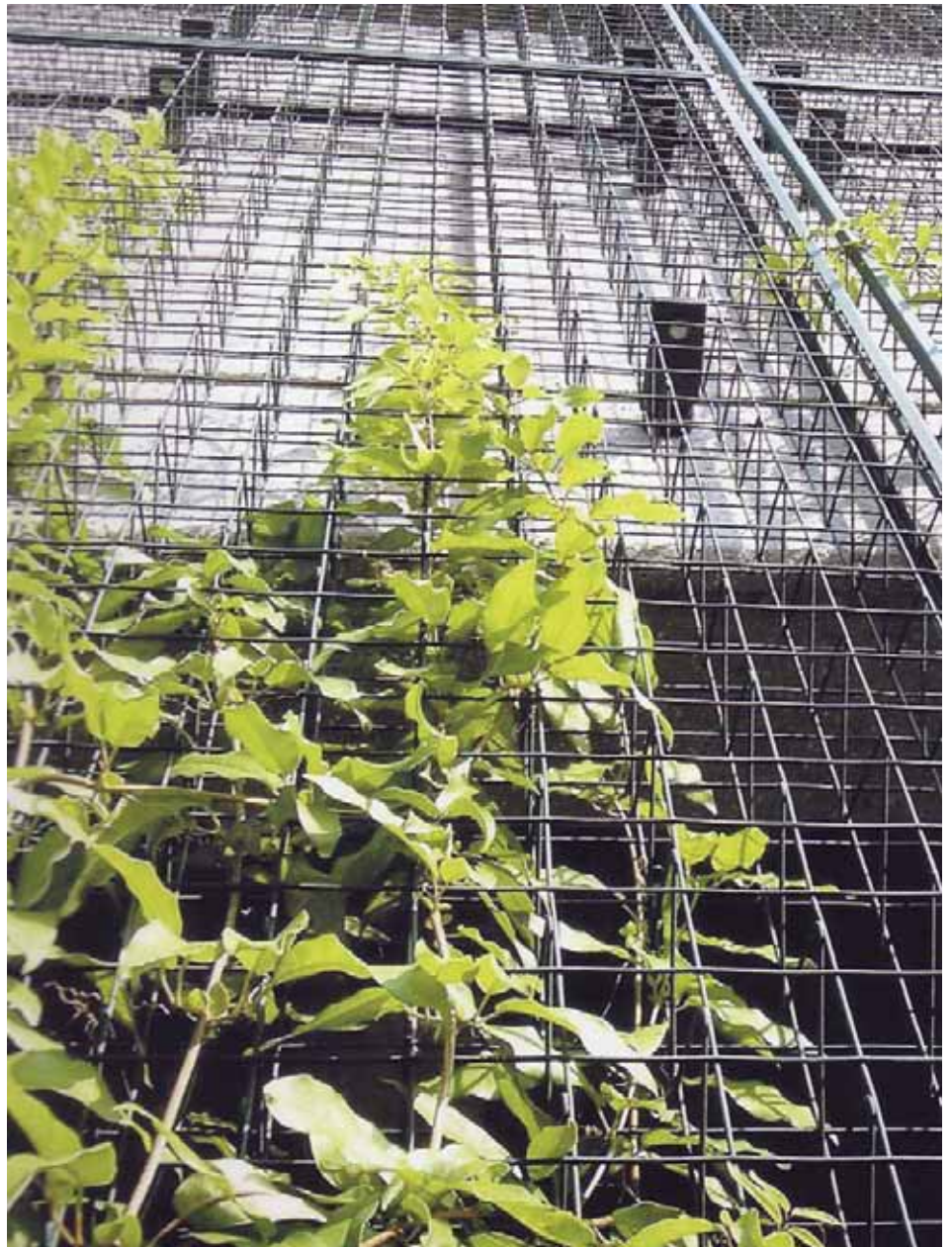
Classifications

Modular trellis panel system

The modular system is a rigid, light weight, three-dimensional panel made from welded steel that supports plants both on the face grid as well as the panel depth. This system is designed to keep the green facade off the wall surface so that the plant material cannot attach to the building. These panels can be stacked together or joined to span between structures.



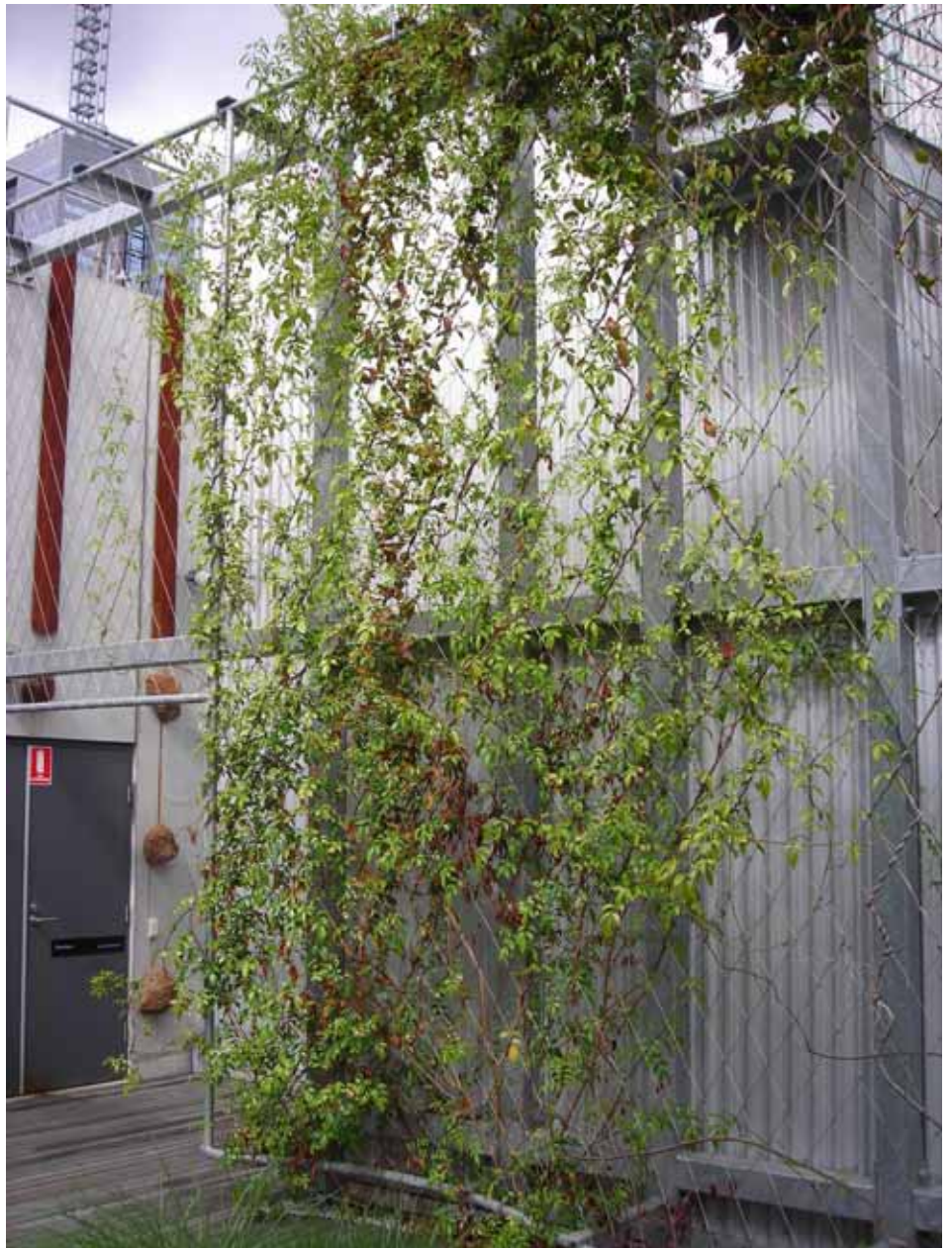
Climbers screening columns in Roppongi Hills, Japan
(Photo sourced from Fifth Creek Studio)



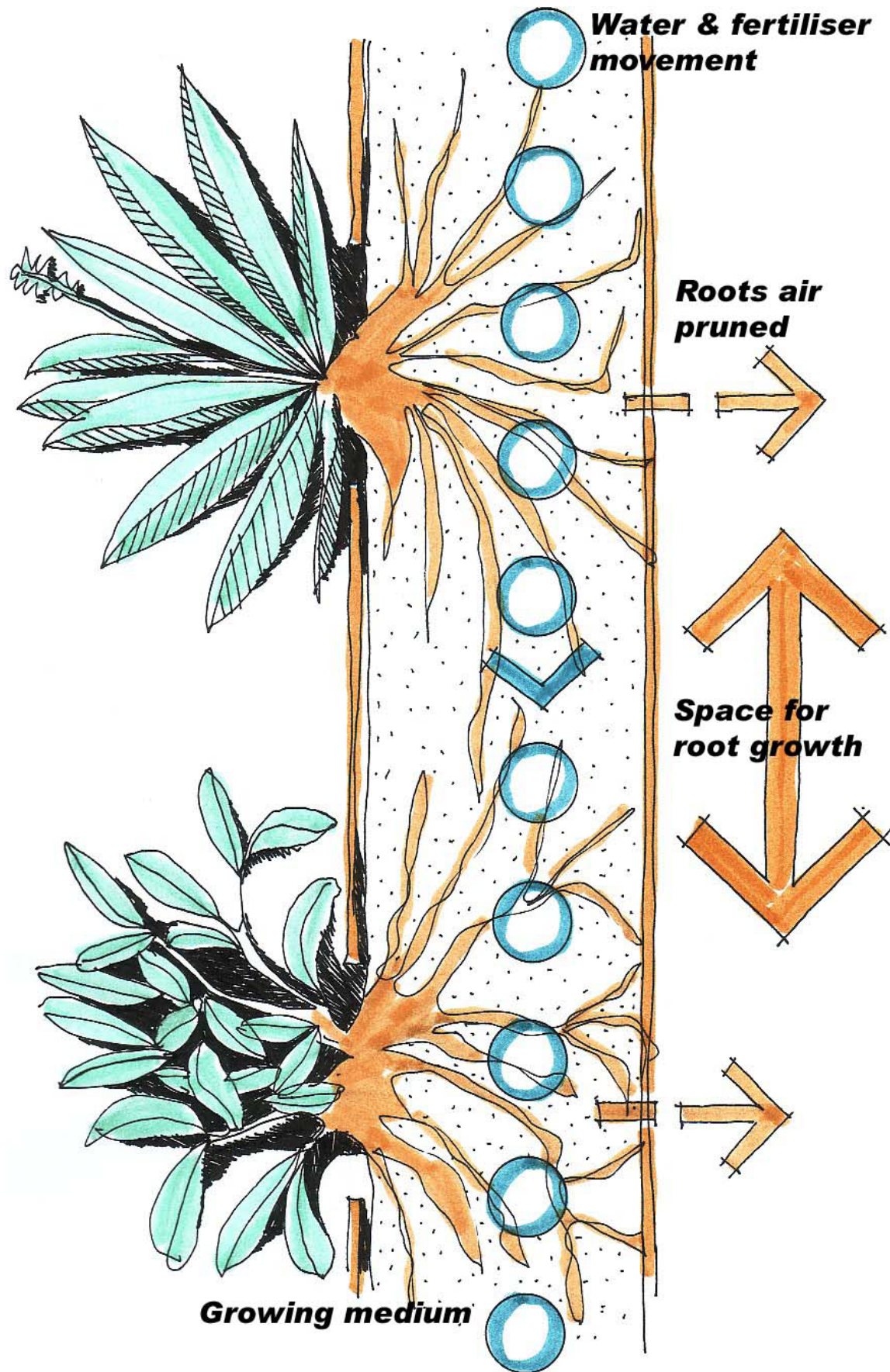
Green screen system publicity brochure

Cable and wire-rope net system

The cable and wire-rope net system uses either cables and/or wire net. Cables are usually designed for faster growing climbing plants, whereas wire nets are used for supporting slower growing plants that need support at closer intervals. Both systems use high tensile steel cables, anchors and supplementary equipment.



Rooftop of CH2 Council House, Melbourne
(Photo sourced from Fifth Creek Studio)



Literature and Product Review

Classifications

Green wall

These systems can be constructed from pre-vegetated panels, vertical modules or planted blankets (vegetated mat wall) that are fixed to structural framework or to a wall.

These systems are typically made from steel framework, plastic, expanded polystyrene and synthetic fabric to support a variety of diversity and density of plant species. Green walls tend to require more maintenance such as fertiliser and water than green facade systems that are planted into the ground.

Literature and Product Review

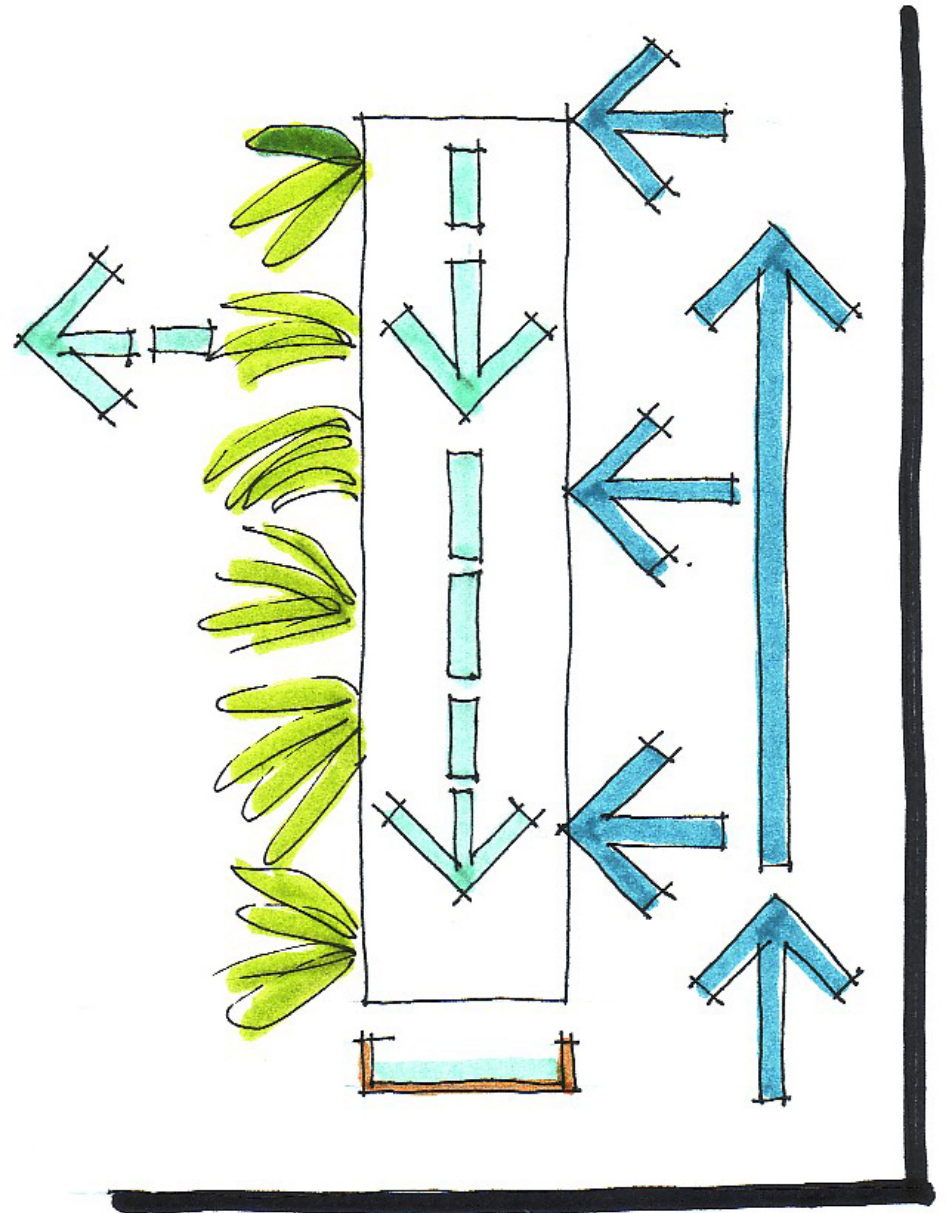
Classifications

Modular green wall

Modular systems consist of panels that hold growing media to support the plant material. Usually these panels are pre-grown, providing an instant effect after installation. These systems require irrigation at different levels along the wall using gravity to move the water through the growing media; similarly the nutrient and fertilising is carried out through this method.



Living wall trials at Fytogreen
(Photo sourced from Fifth Creek Studio)

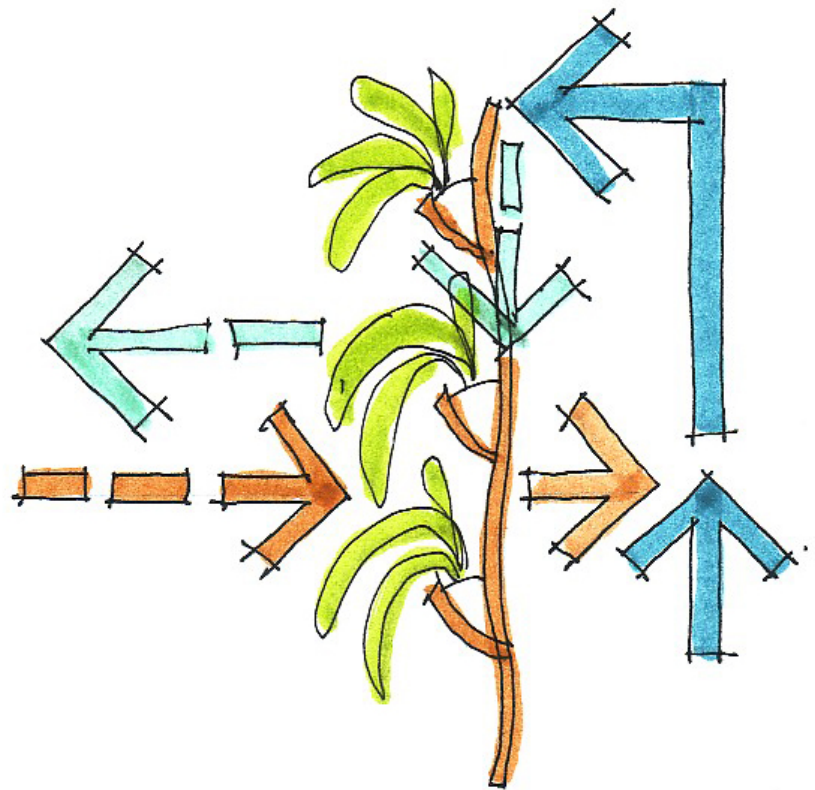


Vegetated mat wall

This system, pioneered by Patrick Blanc, is composed of two layers of synthetic fabric with pockets filled with the plants and growing media. The fabric walls are supported on a framework and backed by a waterproof membrane against the building wall. Nutrients and water are delivered through an irrigation system at the top of the wall.



Trio Apartments, Sydney - designed by Patrick Blanc
(Photo sourced from Fifth Creek Studio)



Literature and Product Review Classifications

Interior green wall

Interior living walls can be constructed from any of the above systems. There is a particular system designed for interior purposes, called the Biofiltration system, that is integrated into the building infrastructure and designed to biofilter indoor air and provide thermal regulation.



JAS Robertson building, Toronto
(Photo sourced from Fifth Creek Studio)

The JAS Robertson Building

BIOWALL

The BIOWALL located in the lobby of the JAS Robertson Building, is a new technology that uses a living biological system to clean indoor air. This natural system helps to improve the environment and our well-being.

THE PROBLEM:

- Environment Canada and the US Environmental Protection Agency have indicated that pollutants can have indoor concentrations over twice that seen in outdoor air.
- Canadians spend more than 80% of their time indoors, hence indoor air quality has a significant affect on overall health.
- Indoor air can have over 200 different airborne gaseous pollutants such as benzene and formaldehyde, which have serious health effects.

THE SOLUTION:

- The BIOWALL is a new technology that integrates a living biological system into the building air handling system to remove airborne pollutants and deliver cleaner air to the building occupants.
- The BIOWALL utilizes the ability of biological systems to degrade pollutants.
- The BIOWALL contributes to a healthier indoor space by reducing the threat of airborne pollutants, by reducing stress levels and creating a more aesthetically pleasing environment.

THE JAS ROBERTSON BUILDING BIOWALL:

- The BIOWALL measures 8 m wide by 3.6 m high for a total surface area of approximately 28 sq.m (260 sq.ft.)
- The system filters the air in the lobby. The cleaned air then diffuses through the rest of the building.
- Light levels for the wall are supplemented with two halogen grow lights.

BENEFITS OF THE BIOWALL:

- Traditionally, air quality systems in buildings replace used, "dirty" indoor air with new outside air. In the summer, this new air must be cooled and in the winter it must be heated before being distributed. This conditioning of the new air represents a substantial portion of the energy costs of the building. The BIOWALL can lower energy use of the building by reducing the need to bring new air into the space.

HOW IT WORKS:

- The wall consists of synthetic media, covering a perforated structure called a "plenum" that supports and regulates airflow through the BIOWALL.
- A diverse selection of tropical ferns, foliage and flowering plants are planted hydroponically (without soil) into the synthetic media.
- A circulating nutrient solution feeds the plants.
- The BIOWALL contains an inner air handling system that draws "dirty" lobby air over the root zone of the plants. At the same time, plant leaves utilise carbon dioxide (CO₂) in the air for photosynthesis and release oxygen (O₂) back into the building.
- The root zone of the plants becomes home for beneficial microorganisms. The microorganisms use airborne pollutants as food, and break them down into water and carbon dioxide.

Diagram: An artist's representation of a BIOWALL (left). Air quality within the space is maintained by drawing polluted air through the wall and plant covered surface. The cleaned air is then returned to the room. Plants facilitate the breakdown of pollutants (right).

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Biowall and information panel explaining the biofiltration system
(Photo sourced from Fifth Creek Studio)

Spontaneous living walls

These are living walls that occur in the urban area where seeds germinate wherever they can and start growing, usually in hostile environments. These plants are often garden escapees or weeds that create a new urban habitat or environment to support greater biodiversity in the cities.



Spontaneous growth along the train line near the Sydney Olympic site redevelopment
(Photos sourced from Fifth Creek Studio)



Literature and Product Review

Benefits

There are a number of benefits that living walls bring to the individual building and to the wider community within the city. These include:

- Reducing the urban heat island (UHI) effect
- Reducing energy consumption and greenhouse gases
- Increasing the thermal performance of buildings (lowering energy costs)
- Reducing runoff and improving water quality (WSUD)
- Improving air quality
- Reduction of noise pollution
- Increased urban biodiversity and urban food production
- Improved human health and wellbeing (connection to nature)

All benefits do not necessarily occur on each individual living wall as they depend on the particular site and type of system. When designing a living wall system, consideration should be given to as many of the above benefits as possible.

Public and private benefits

Some of the benefits of living walls relate directly to the public environment and can be classified as public benefits. The benefits that affect the building itself and its occupants are described as private benefits.

Public benefits

- Reduces urban heat island (UHI) effect: promotes natural cooling processes, reduces ambient temperature in urban areas, breaks vertical air flow which then cools the air as it slows down, shading surfaces/people.
- Improved exterior air quality: captures airborne pollutants and atmospheric deposition on leaf surface, filters noxious gases and particulate matter.
- Aesthetic improvements: creates visual interest, hides/obscures unsightly features and provides interesting freestanding structural elements.

Private benefits

- Improved energy efficiency: traps a layer of air within the plant mass, limits movement of heat through thick vegetation mass, reduces ambient temperature via shading and plant processes of evapotranspiration, creates a buffer against the wind during the winter months, interior walls reduce energy associated with heating and cooling outdoor air for indoor use.
- Building structure protection: protects exterior finishes from UV radiation, the elements and temperature fluctuations that wear down materials, benefits the seal or air-tightness of the building.
- Improved indoor air quality: captures airborne pollutants such as dust and pollen, filters noxious gases and VOCs from carpets, furniture and fittings.
- Noise reduction: the growing media in living wall systems contributes to a reduction of sound levels that transmit through or reflect from the living wall.
- Marketing: improved aesthetics that help to market the project and provide valuable amenity space. Current research is showing that green buildings (including living walls) are gaining a premium price and also leasing earlier and at a higher rent.



MFO Park, Zurich (Photos sourced from Lambertini & Leenhardt)



Ex-Ducati Building, Rimini, Italy (Photos sourced from Lambertini & Leenhardt)



Centre Commercial Quatre Temps, Paris (Photos sourced from Lambertini & Leenhardt)



Quai Branly Museum, Paris (Photo sourced from Lambertini & Leenhardt)

Literature and Product Review

World Context

Europe

Europe has had a long tradition with green roofs, and has lead the way in research and development similarly with particular areas of living walls, notably the green façade and the vegetated mat wall system. Especially on a commercial scale.

These green façade projects have been seen to push the envelope within this discipline for both constructability and for building environment benefits, as well as aesthetics and wellbeing benefits. With examples such as: a cable and wire-rope net system, as used on the MFO Park Zurich, where the metal structure that encompasses MFO Park has elevated platforms and walkways to take over the vertical dimension.

A second example using a trellis system is the Ex-Ducati Building at Rimini Italy, where the growth of the climbing plants is supported by the metal trellis that will eventually close the surface of the façade. Only the glass surface on the ground floor will be free of plant growth.

A well known living wall designer Patrick Blanc pioneered the vegetated mat wall system and has exported this concept from Paris to all parts of the world. This system is the most recognised of all living wall systems as a result of the publicity and adventurous projects, especially in scale. Although there are a number of successful projects around the world, especially indoors, this system relies on constant hydroponic technology where water and nutrient loads are delivered by gravity through a membrane. In very hot weather with dry humidity, plant material can dry out and collapse if not constantly monitored. In locations of extremely dry humidity such as Adelaide this system will have difficulty to keep up with the evaporation rates of the plants.



Vancouver Aquarium (Photo sourced from Living Architecture Monitor)



Vancouver Aquarium (Photo sourced from Living Architecture Monitor)



North American green facade (Photo sourced from Living Architecture Monitor)

Literature and Product Review

World Context

North America

Canada and the USA have seen rapid growth in the green roofs industry, but have not taken on the living wall technology at the same pace. Researchers in Canada developed a Biofiltration wall system, often referred to as an 'active' living wall that filters indoor air and provides thermal regulation. This system has been used in the interior of buildings and consists of two layers of a synthetic fabric, with plants sandwiched between. This system is fed by a hydroponic system and the nutrient rich water is delivered at the top and gravity fed through the membrane. The root microbes remove airborne volatile organic compounds (VOCs) while the foliage absorbs carbon monoxide and dioxide. The plants' natural processes produce cool fresh air that is drawn through the system by fans and distributed throughout the building. Although this system is for the interior of buildings the principles for a living wall on a commercial building are very relevant to this study.

The general trend in North America has been to use a green façade system or vegetated mat wall system or variations of this system. It was not until 2007 with the Vancouver Aquarium project that a thick media based modular system (G-Sky) was first used. This was an award winning wall by Sharp and Diamond Landscape Architects. This wall impressed the designers and client with the root growth in the thicker media. Due to the climate in North America the requirement of moisture retention in the media is not such a consideration, but even there if this media acts more like growing media the root development is far better and enhances the plant growth.

Green façade systems on the other hand are well developed in North America, and are commonly used on large commercial scale buildings. This system has been developed to assist with the thermal control of buildings and the encouragement of biodiversity habitat within commercial developments.



Singapore Botanic Gardens living wall shortly after installation in 2006 (Photo sourced from Fifth Creek Studio)



Newton Suites, Singapore (Photos sourced from Architecture Australia)



Literature and Product Review

World Context

Singapore

The Singapore Government through its National Parks Board has been one of the powerhouses in research and development of living walls. They took the approach of working towards a clear understanding of which systems and plants best suit Singapore's climate before embarking on a role-out of this technology.

The National Parks Board has set up a series of trials at their new Botanic Garden visitor reception precinct. Featuring a number of commercial living wall systems that are available now or will be in the near future, so that the performance of each system can be observed by the community. The trials include a number of experimental living walls as an integral part of the built form. Although their relatively wet climate has helped this process, the principle of integrating the living wall as part of the building should be noted within this study.

This type of performance based research is something that could be developed in South Australia through our Botanic Gardens, providing an exemplar for the community with the necessary research for our testing climate.

Also in Singapore, a green façade system has been developed for appropriate use on high rise buildings on the Newton Suites project. The green façade application contributes to the building comfort and visual delight, as well as bringing the indoor/outdoor potential of the tropics to life in a sustainable high rise building. This principle should be noted and included into this study as a valuable component of high rise situations.



Temporary building site hoardings in Tokyo (Photo sourced from Fifth Creek Studio)



Green screens used on public rooftops (Photo sourced from Fifth Creek Studio)



Living wall on a nightclub in Japan, and detail of the mat system (Photo sourced from Fifth Creek Studio)



Literature and Product Review

World Context

Japan

Japan can be identified as one of the most progressive and developmental countries for living wall systems. Both green façade and green wall systems are advanced in design, plant material, application and fabrication materials, using only the very best materials such as stainless steel and wire-rope systems for safety and longevity. The Japanese designers and clients saw this technology as a long life solution for the life of the building. There were innovative systems being developed creating hybrid systems between green façade and green wall systems. This hybrid way of thinking is important to this study in that not just one system may be the solution, but a combination could be the answer.

Many of the large building contractors were developing modular living wall systems as many of the new developments required green roofs and walls as part of their approval process. This is the major commercial driver for this research and development in Japan. These green walls tend to be based on a modular design that could be incorporated into the building or bolted to the finished structure or even to building hoardings as temporary installations.

Green façade systems are often used to screen or shade an area of building that fronts onto the public realm, especially in high rise open spaces. This could be achieved by quick coverage of a trellis or cable system and is also notable for being light weight.

Japan also provides a number of impressive vegetative mat wall systems adapted to high rise buildings. These systems appear to be an integral part of the building design unlike an add-on or after thought.



Adelaide Zoo living wall installation in early 2010 (Photo sourced from Fifth Creek Studio)



Trio Apartments, Sydney - designed by Patrick Blanc (Photo sourced from Fifth Creek Studio)

Literature and Product Review

World Context

Australia

Australia's position relative to the rest of the world is fairly advanced in the living wall discipline. The first commercial systems appeared on the market in 2006. There has been considerable research and development since then with many new proprietary systems and installations occurring, both interior and exterior. There were a few experimental green walls earlier, but only on an individual case such as various projects by Mark Paul from the Greenwall Company.

Although some green façade installations date back to around 1985 with projects in the ACT by Graeme Hopkins, and vegetative mat wall systems developed by landscape architecture firm Room 4.1.3 (Richard Weller and Vladimir Sitta), the bulk of Australian living walls is very recent. Some of the current Australian living wall technology is leading the world.

Most of the living wall projects installed today are domestic in scale and in interior locations. Very few commercial scale projects have been installed so far. A recent commercial project has been the Adelaide Zoo project featuring a large outdoor living wall as the major attraction that is integrated into the built form of the new zoo entry. The scale of this project introduces many of the issues encountered on high rise buildings.

Another project that has relevance to this study is the new work of the 'world's tallest living wall' by Patrick Blanc on a residential development in Sydney's inner west. This is a 33 storey north facing vegetated mat wall system using 4,528 native Australian plants from 69 species that are fed by a grey water dripper irrigation system. The decidedly commercial scale of this project establishes a challenging measure for comparison of other projects, including this study.



Literature and Product Review

Proprietary Systems in Australia

The following information is taken directly from promotional material that is publicly available. These products are not endorsed, however they are included to give some sense of what is currently commercially available in Australia.

Selection of living wall systems and website links

Fytowall by Fytogreen

<http://www.fytogreen.com.au/Fytowall/>
This is a modular system that has been used successfully in Adelaide and has been on the market for a number of years. It is used for domestic and commercial scale applications, but needs modification for high-rise use, as the front of the panels would need retaining and securing to the supporting framework.

Junglefy Green Wall

<http://www.junglefy.com/web/green-walls.html>
This is a modular system that is very new to the market and is directed to domestic scale application. Not suitable for high-rise application in its current form.

Greenwall Company (Ex-Parrot)

<http://www.greenwall.com.au/Exparrot.aspx>
This is a modular system that has been on the national market for a number of years, but has only been used in one major indoor application in Adelaide. The system is made from metal mesh bent into shape, thus has potential for high-rise application because of its structural capacity.

Elmich Green Wall

<http://www.elmich.com.au/VGM/about.php>
This is a modular system that has been used in Adelaide and has been in the marketplace for some time. The system is made up from plastic boxes with metal framework. For high-rise application there could be some questions about the plastic structural integrity.

Ronstan

http://www.ronstanarchitectural.com/arch_au/story.asp?story=2096
This is a cable and net wire-rope system that could be used in Adelaide.

Atlantis Gro-Wall

<http://www.gro-wall.com.au/>
Newly available modular system that is directed to the domestic scale market.

Greenwall Australia

<http://www.greenwallaustralia.com.au/>
Specialising in modular and vegetated mat indoor systems.

Patrick Blanc

<http://www.verticalgardenpatrickblanc.com/>
The vegetated mat wall (or mur vegetal) system has been used in Sydney and Melbourne with varying success. It is suitable for high-rise application, but this system is questionable in Adelaide's climate.

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03

Site Research

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Site Research

Climate Influences

Global warming trends indicate that temperatures in Adelaide are gradually rising, and according to the Intergovernmental Panel on Climate Change (IPCC), the increase here is at a rate higher than the national trend.

The IPCC states that Adelaide's summer temperatures are predicted to rise by 0.4 to 0.9°C by 2030, or even higher if CO₂ emissions are not stabilised.

As well as higher temperatures, Adelaide's average number of days per year over 35°C is projected to increase to 21-26, and the average number of days per year over 40°C is projected to increase to 3-5. These climate change projections provide a compelling argument for living wall initiatives.

A brief look at some of the climate data currently available for Adelaide will help to set the scene for the future, given these climate change predictions. Living walls, with their many benefits, can be employed to help mitigate the effects of climate change, however, in designing successful living walls the extremes of our climate must be taken into consideration.

Plants in Adelaide's climate need to adapt to extremes in a number of factors: heat, evaporation and very low relative humidity. These factors are important to the success of living walls, especially green walls where the growing medium is exposed to the surrounding atmospheric conditions. Extremely high temperatures, combined with hot, dry winds, create high evaporation rates and very low relative humidity. Thus the growing medium is under stress with the potential of drying out. If the root systems, and in particular the root hairs, dry out then the plant system collapses. Therefore the critical climatic factors that need to be understood and considered are: temperature, relative humidity, evaporation and wind.

Temperature, relative humidity and evaporation

The Australian Government's Bureau of Meteorology (BoM) has figures for two sites for the Adelaide CBD; one being the current observation site in Kent Town, some 2km east of the city centre, and the second being the West Terrace site, 3.2km west of the city centre, with figures up to 1977.

When designing living walls it is important to understand the local climate and the specific characteristics the climate presents. Looking only at the monthly average temperature and relative humidity over a number of years will not give a true picture of the extreme conditions, whereas examining the figures on an individual monthly or even daily basis will provide information that is more useful to designers.

This is illustrated by the following Bureau of Meteorology figures. The first set of observations represents the mean temperature and relative humidity figures for January for the years 1977 to 2009, while the second set shows the mean for January 2009.

Site Research

Climate Influences

Kent Town observations 1977-2009

January mean maximum temperature	29.1°C
January mean temperature (highest) at 9am	21.6°C
January mean relative humidity (lowest) at 9am	53%
January mean temperature at 3pm	27.8°C
January mean relative humidity (lowest) at 3pm	37%

Kent Town observations 2009

January mean maximum temperature	32°C
January mean temperature at 9am	23.7°C
January mean relative humidity at 9am	37%
January mean temperature at 3pm	30.8°C
January mean relative humidity at 3pm	23%

As can be seen, the figures for January 2009 show higher temperatures and lower relative humidity than the mean figures taken over a period of approximately 30 years. These differences would affect the design basis for a living wall. Given that the expected weather conditions are predicted to become more extreme, with heat waves occurring more often, the design should consider these extreme conditions otherwise the systems will fail.

By examining the daily figures within the month of January 2009 the extreme conditions can easily be seen. For instance, instead of a monthly mean maximum temperature of 32°C, the maximum daily temperature of 45.7°C needs to be considered. Similarly the lowest relative humidity reading was only 4% at 3pm on one particular day, so this demonstrates an extreme condition compared with the monthly mean of 23%.

In practical terms this means that if a living wall system is designed to withstand the average summer temperature and humidity levels, when extreme conditions inevitably occur the living wall may not survive.

Design Criteria

– Design for local climate extremes, not just for average climatic conditions

Further comparisons can be made between the month of January in the years 2009 and 2010, including evaporation rates and wind speed figures from BoM observations.

Kent Town observations

January 2009

Highest maximum temperature	45.7°C
Lowest relative humidity at 9am	10%
Lowest relative humidity at 3pm	4%
Highest evaporation (North wind speed 30km/h)	32.2mm

Kent Town observations

January 2010

Highest maximum temperature	42.8°C
Lowest relative humidity at 9am	7%
Lowest relative humidity at 3pm	13%
Highest evaporation (North wind speed 57km/h)	36mm

Not only are the highest maximum temperatures consistently well over 40°C, but the relative humidity range of between only 4% and 13%, means that to avoid dehydration most living things, including plants, animals and humans, need a regular supply of water to compensate for the lack of moisture vapour in the air. An evaporation rate of 36mm at the height of summer is put into context when compared with the mean evaporation rate of just 3.3mm for the winter month of August 2009. The significance for living walls of wind gusts on moisture levels and other factors is further examined below.

Design Criteria

- Maximum temperature 45°C
- Relative humidity at 9am 7%
- Relative humidity at 3pm 4%
- Evaporation rate 36mm with North wind speed 60km/hr

If the living wall system cannot withstand these extreme climatic conditions it will fail.

Site Research

Climate Influences

Wind effect

Wind flow around high rise buildings needs to be understood, firstly for the building in isolation, and secondly within a city or street formation.

Wind flow on a single high rise building has been well documented, and a general understanding is that wind velocity increases with height and that above 10 floors the velocity increases at a higher rate than below 10 floors.

When wind is perpendicular to the high rise building the wind is diverted over the roof, around the ends of the building and some is diverted down the facade to ground level and some up the facade to roof level.

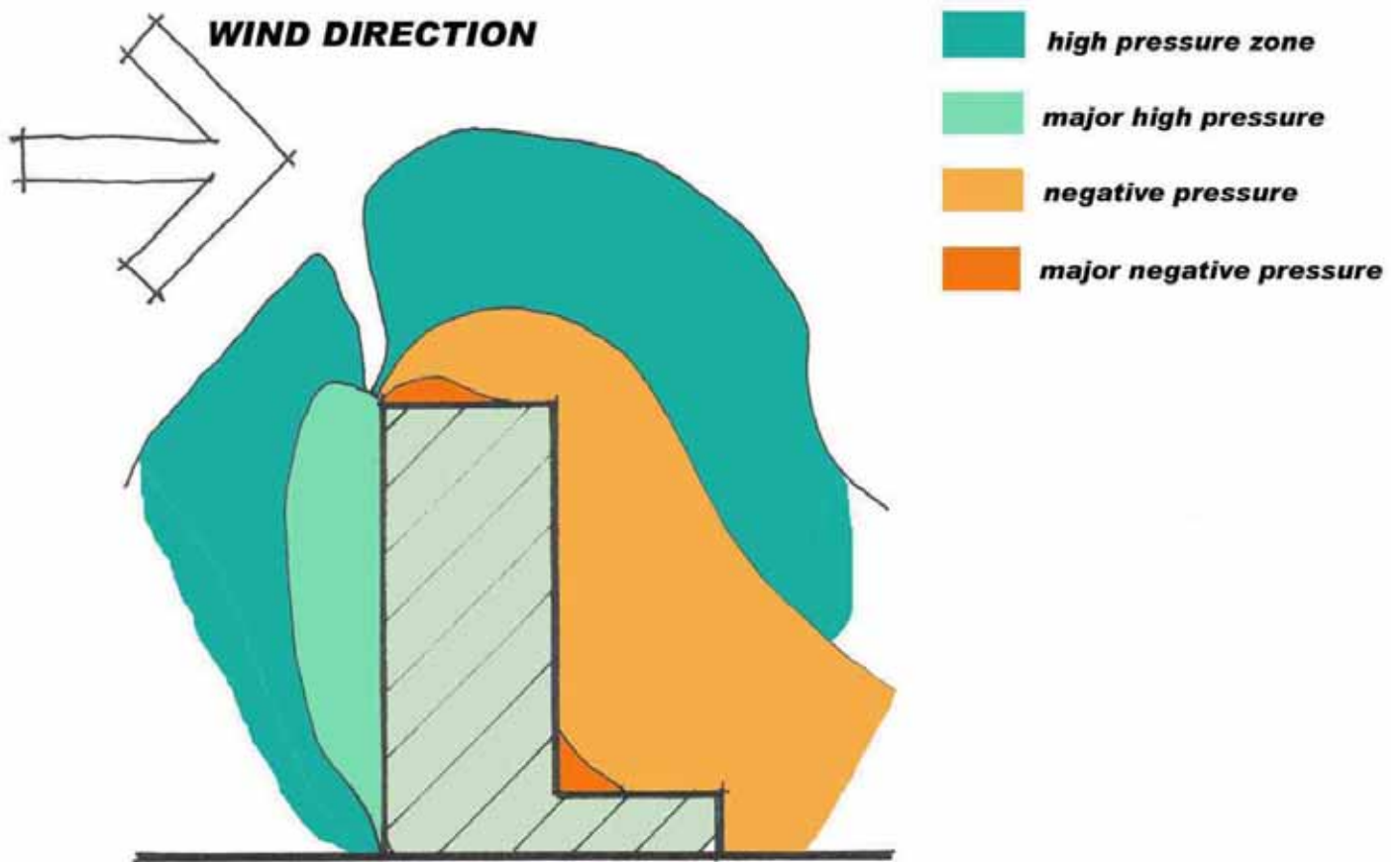


Diagram from Ken Yeang

When this wind is diverted around the building the velocities change as the air is compressed around the building corners. Wind shadows are also created on the leeward side of buildings.

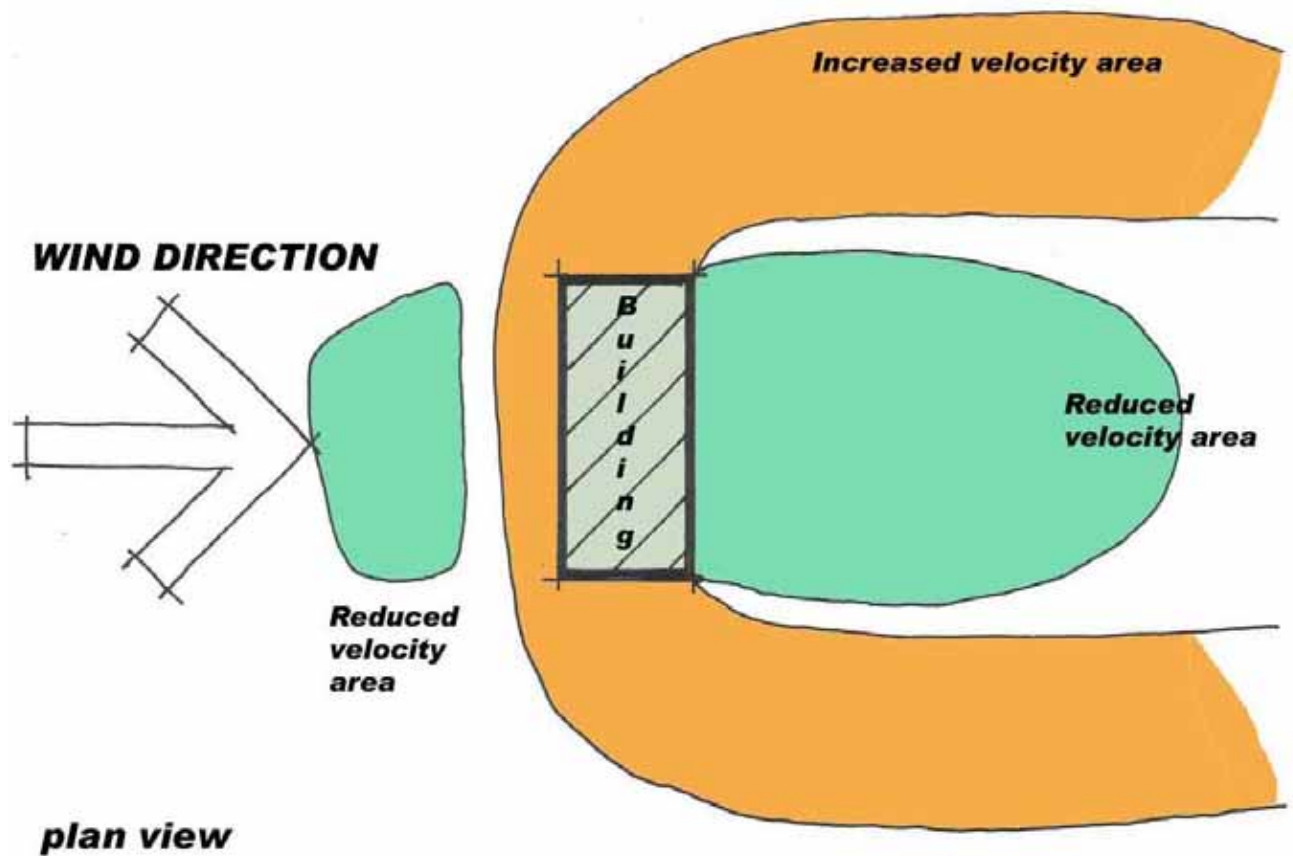


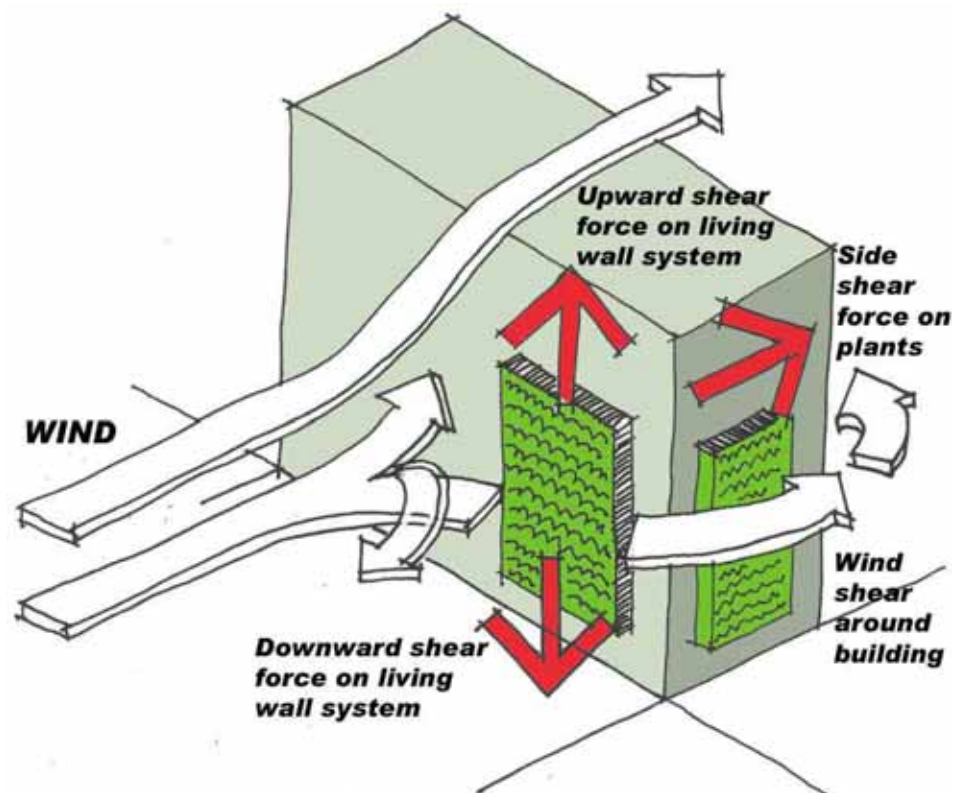
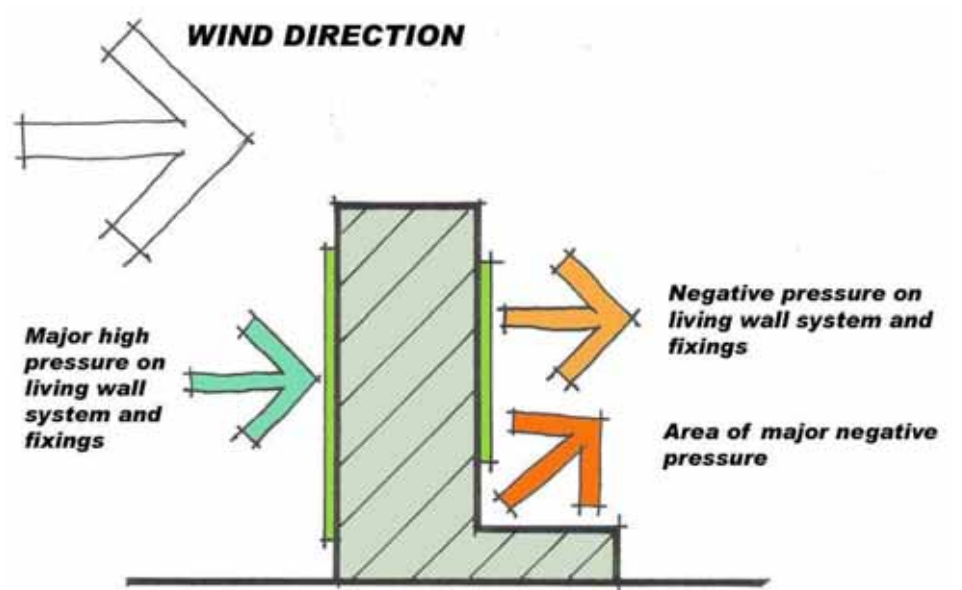
Diagram from Ken Yeang

Site Research

Climate Influences

The windward façades of tall buildings have localised wind currents and increased velocity, causing downdrafts to ground level and updrafts to the top of the building.

These wind currents are of particular interest to living wall systems as increased wind velocity has an impact on the growing conditions of the plants, the structural capacity of the plants and the structural capacity of the system and how it is fixed to the facade.



When buildings are in clusters or in a street environment there are additional influences on the wind patterns and velocities. Localised wind patterns and turbulence, eddies and swirls occur as well as increased velocities, as the wind is often forced through smaller openings.

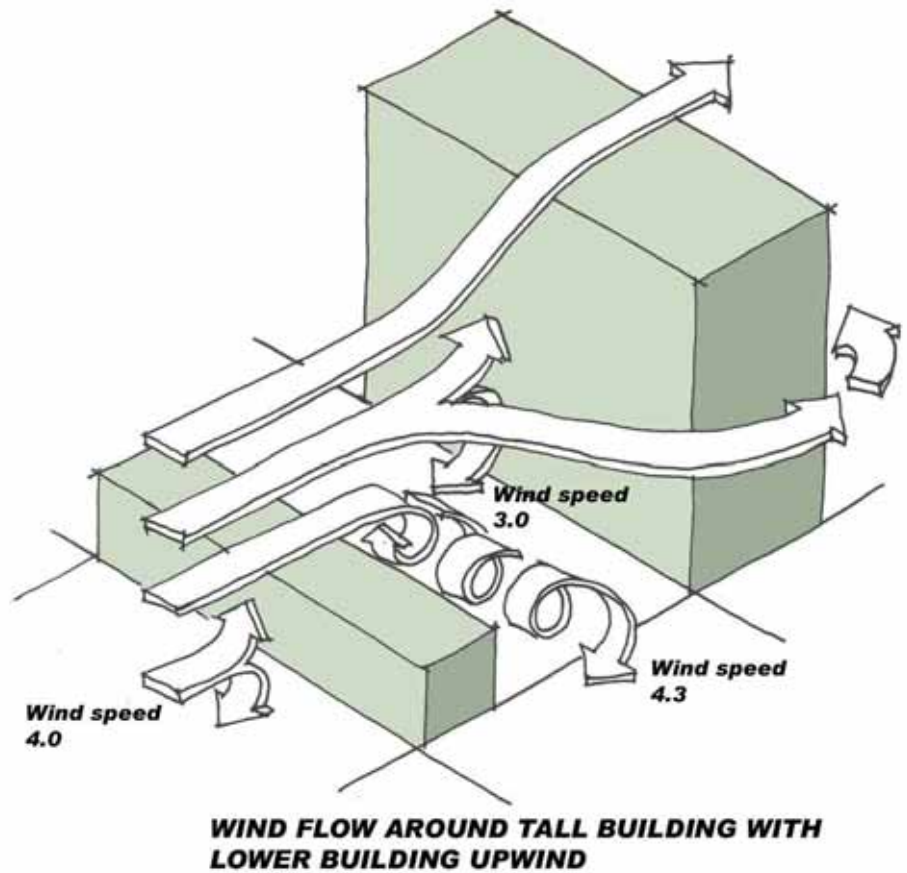
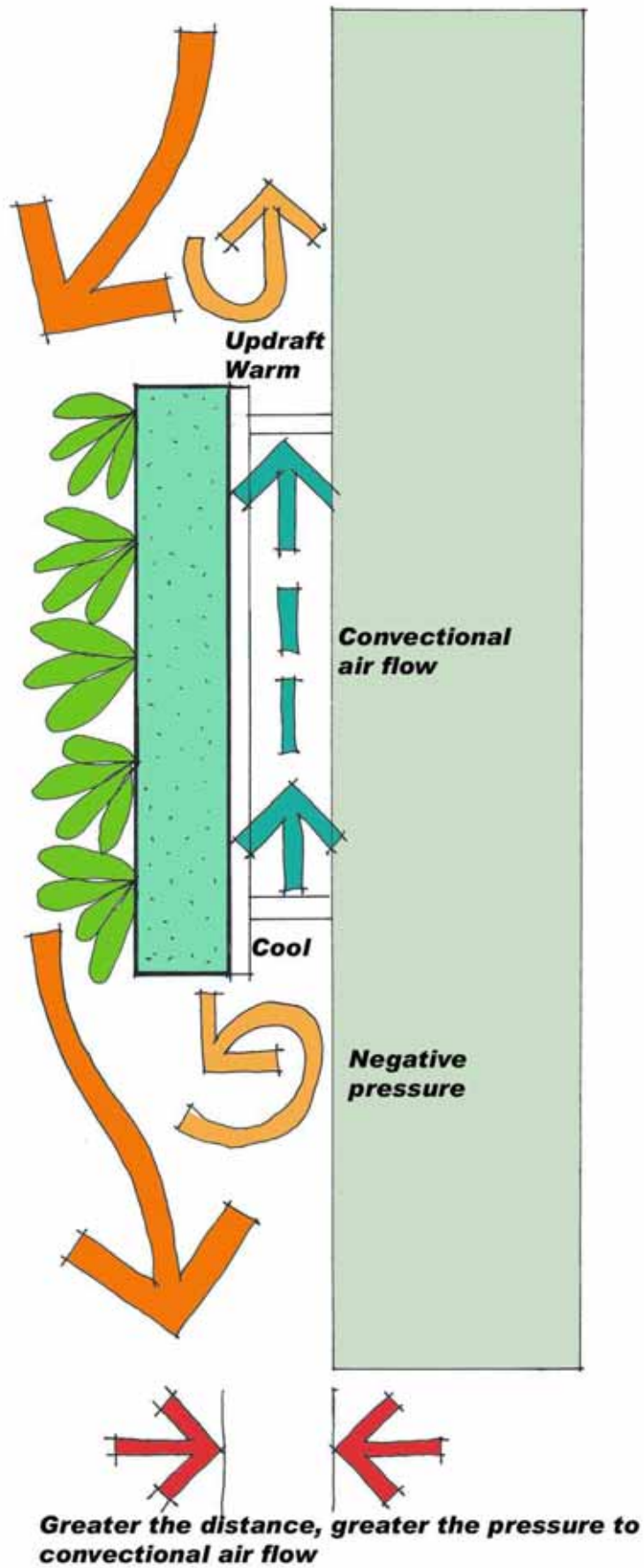


Diagram adapted from Pierre Teasdale



Site Research

Climate Influences

It has been noted that in Melbourne at 'sixty-five metres above the ground the winds often gust at velocities well over 100 kilometres per hour'(O'Loan). This would not be dissimilar to conditions in Adelaide. Thus if the living walls were at a lower level then the wind velocities will be less and therefore less demanding on the systems.

The individual plants need to be fixed into the system so that they are not blown away by the wind on the windward side and similarly fixed into the system to prevent being sucked out on the leeward side of the buildings.

As shown above, greater wind speed is associated with increased evaporation, which is an important factor to be considered in living wall design if the plants are to be provided with sufficient water for strong growth. Different plants have different water requirements, so selecting the most appropriate plants for the particular location is critical, and is discussed in more detail below.

Wind loadings on the structural frame of the living wall system will become a prominent factor in the design of the framing, especially when the living wall is located higher on the high rise facade.

Specifically, the wind loading on the fixing device onto the facade is extremely critical given the potential air pressure differential in the gap between the facade and rear of the framing system.

The next critical factor is the fixing between the plants and planting medium container and the framing system. Most of the proprietary systems have a large proportion of plastics and it is difficult to predict their structural behaviour under extreme wind loadings. Many of these new and recycled materials have a low distortion level without structural failure, and combined with potential long term UV degradation; these materials may not be suitable. Preferably the framing and container systems should be of metal so that the structural capacity can be easily calculated and their weathering longevity assured.

Design Criteria

- Wind velocity increases with building height
- Wind velocity and turbulence is affected by the space between buildings
- Structural fixings and framing for wind loading



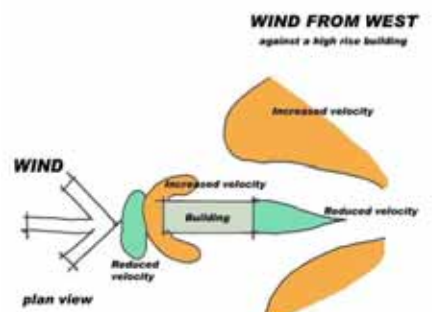
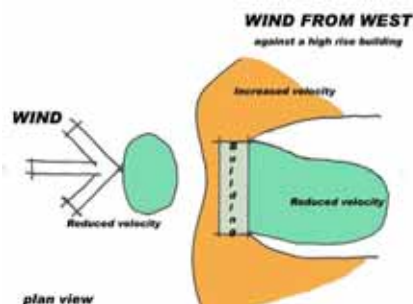
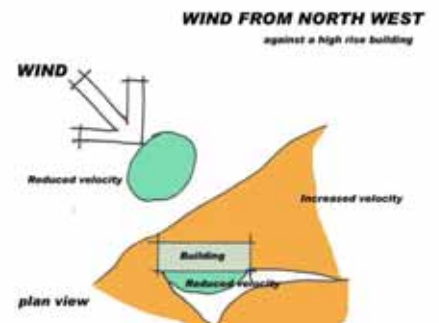
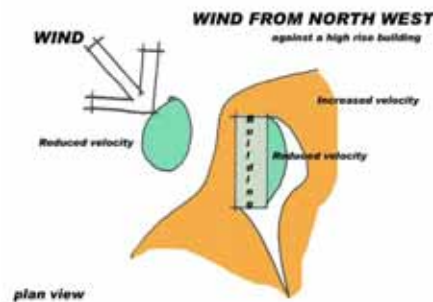
Site Research

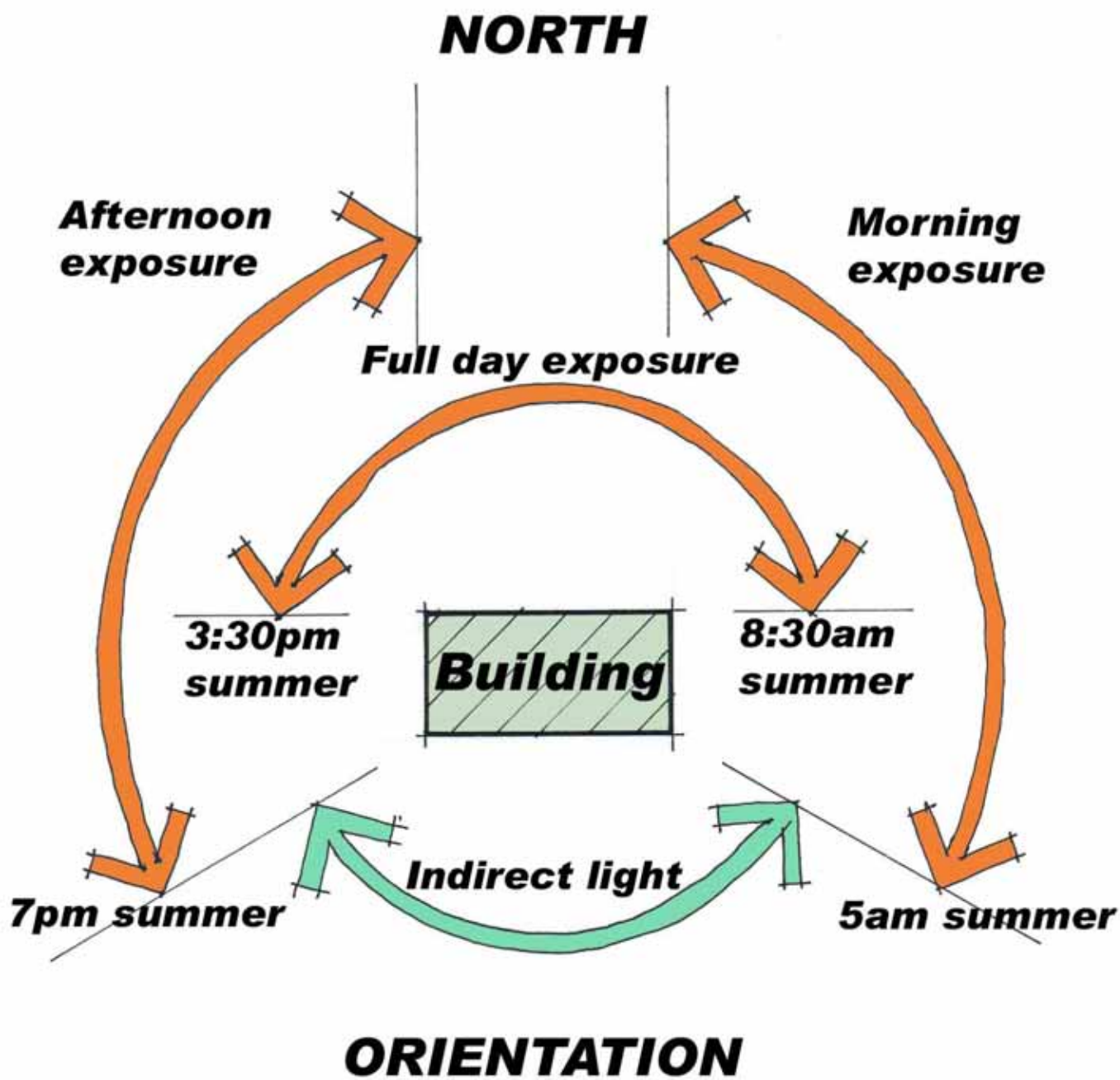
Climate Influences

Orientation

The orientation of the living wall is critical for its success due to many factors. A crucial one is the position on the building wall. If possible at street level it may be shaded by other objects, or if high on the facade it may receive the full exposure of the sun.

The orientation will affect the performance of the living wall system and careful consideration should be given before designing the systems and their location on the building. For instance, thermal protection from early morning sun can be provided on the eastern side of the building, or alternatively afternoon protection from the hot west sun might be required. If the system is for food production then a northern aspect would be preferable.





Site Research

Climate Influences

In the orientation diagram it can be seen that, for instance, on the northern side of a building there could be full day sun exposure extending from 8:30am to 3:30pm in summer. Whereas on the western side of the building this sun exposure would extend through to 7pm. Plants need to be selected according to their light and heat requirements and to their capacity to withstand the particular conditions. On the south side of the building only indirect light is available, so plants selected for this orientation would need to have low light and cooler temperature requirements, which would also reduce the level of irrigation necessary.

Similarly the dominant wind pattern should be a consideration, especially the hot, dry summer wind or strong rain laden wind in the winter or autumn. The dominant winds in Adelaide are north to northwest in summer and southwest in winter.

The location on the facade will also affect the orientation, as the higher the system the greater the exposure and less the shadowing from neighbouring properties. The orientation and height location will be important factors for the evaporation rate, affecting the water requirements/irrigation and plant selection.

Design Criteria

- Wind velocity varies depending on the facade orientation
- Aspect e.g. north facing wall
- Sun exposure
- Wind exposure
- Height on the facade

Site Research

Plant Selection

As shown, wind is one of the major plant growth factors for living walls as the wind or air movement increasing over the plant leaves decreases the ability of the plant to absorb moisture from the air. With increased velocities this becomes a major drying issue for the leaves as well as the root systems. It does not matter how much water is available to the root system, because if the evaporation rate is extremely high the loss of water via the plant leaves cannot be matched by the water uptake of the root system.

Apart from wind exposure, temperature becomes a critical factor as plants start to become stressed around 32°C and start to shut down around 40°C to maintain their survival. Drought tolerant plants often display a mechanism where the stomata in the leaves actually close during the hottest part of the day and open only in early morning and evening. This is to reduce the evapotranspiration and is a means of conserving water for survival. These plants show strong characteristics suitable for living walls, especially at height on buildings.

There are a number of plant species occurring in natural environments and also in the harsh built environment that can adapt to and exist in these conditions. For instance, plant species that grow on cliff tops or on the face of cliffs can be suitable species for living walls, as a cliff face acts in the same way as a building facade does in its interaction with wind. In the built environment plant species planted along the road edge or in median strips are subjected to wind buffering from passing vehicles, so many of these species would exhibit the characteristics needed for a high rise living wall. Plants in natural associations that are exposed to high wind velocities will exhibit the characteristics of co-dependence and a self-sustaining habitat, which is a good starting point for plant selection for high rise living walls.

The traditional way of creating a wall covered with vegetation that dates back centuries, is to grow self-supporting creepers. The species most commonly used in the temperate climates were ivy (*Hedera helix*), Boston ivy (*Parthenocissus tricuspidata*) and Virginia creeper (*P. quinquefolia*). This method has some limitations in that the climbers usually only grow about 10m, occasionally 20m, with exceptional examples sometimes reaching 30m in height.

Virginia creeper is a preferred species as it does not have a tendency to damage the wall substrate in its process of supporting itself, as opposed to ivy. Virginia creeper uses minute suction caps to secure the plant structure to the wall, typically brick or masonry walls. This type of screen planting is classified as a green facade system and utilises the natural characteristics of climbing plants to provide vegetation cover.



Virginia creeper on a building facade, Toronto
(Photo sourced from Fifth Creek Studio)

There has been very little research carried out on planting species suitable for living walls in Australia, and in particular in Adelaide, apart from Fifth Creek Studio who have carried out trials since 2006 using species from the Adelaide plains and commonly used hybrids of native species. In Victoria, University of Melbourne's Burnley Campus lecturer John Rayner has carried out research and provided consultation on the City of Melbourne's CH2 Building.

There has been some research by system manufacturers for their own information and usage, predominantly using species known from overseas experience. Species from sub tropical climates, like epiphytes, lithophytes, bromeliads and ferns, have been typically used in other states, but with Adelaide's unique climate these species are not suitable for outside living walls. However, they can be used for interior living walls where the climate can be controlled.



Living wall trial at Fifth Creek Studio, South Australia
(Photo sourced from Fifth Creek Studio)



Living wall trial at Fytogreen, Victoria
(Photo sourced from Fifth Creek Studio)

Site Research

Plant Selection

Species selection

Species selection should be based on design criteria for the particular type of living wall system and the climate. Criteria for the two main categories of living walls:

Green facade

Climber species that utilise the natural characteristics of climbing plants:

- Fast growing
- Foliage from ground to top
- Resistant to wind buffering
- Orientation to full sun exposure or shading
- Partial shadowing during the day from nearby buildings

Green wall

Plant species grown in a medium with limited root zone volume:

- Fibrous root system
- Strong stem to root connection
- Resistance to wind buffering
- Good growth habit
- Orientation to full sun exposure or shading

Careful consideration of the growth habits of species needs to be made, as some species tend to change habit as they mature, such as phototropism, where they grow outwards towards the full sun (light) until gravity takes over and the plant starts to bend downwards. This can create an overshadowing effect that shades the plants immediately below. If these lower plants have a requirement for full sun exposure then they would suffer or even die under these conditions.

Design Criteria

- Type of living wall system proposed
- Plant selection criteria

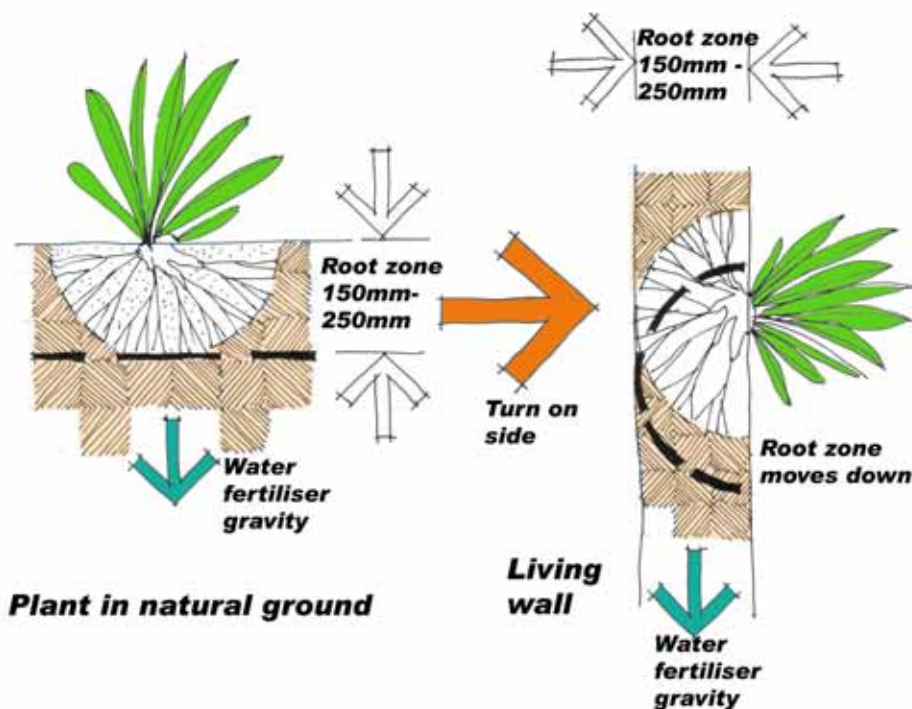
Site Research

Soil Growth Medium

A basic understanding of growing medium and its behaviour when placed on the side of the building, with certain above ground influences is needed. This is especially important for the root zone of the plants, as these characteristics become crucial to successful growth. In natural ground water and nutrients are found in the topsoil layer, usually at a depth of 150-250mm, so the plants' feeding roots are also found in this layer. In a living wall situation the topsoil layer is turned vertically, therefore a depth of 150-250mm below the plant in the wall is its feeding zone, as well as on the horizontal plane.

The soil surface temperature for bare soil can easily heat up to 50°C, therefore the resulting subsoil temperatures climb steeply. Temperatures above 35°C at the root zone area can cause the roots to begin to shut down, therefore no water is sent to the leaves for transpiration and the leaves start heating up as well. This can be a potential issue for living walls in Adelaide's summer, with hot dry air surrounding the growing medium. If the soils are wet, the soil heats up more slowly than dry soil does. Water takes more energy - latent heat - to heat up than soil elements. Therefore the growing medium should not be allowed to dry out completely but be kept moist to reduce the soil/growing medium temperature.

Once the root system has shut down from excessive heat, such as during a heat wave, the roots are unable to take up large quantities of water in the soil. The root system will not use all the available water, thus allowing the air spaces in the soil to be replaced with water. The soil becomes oxygen depleted and water logged, allowing potential fungus growth. Therefore the growing medium must be relatively free draining but be able to retain some moisture for the root system.



Design Criteria

- Growing medium minimum depth 150-250mm
- Growing medium to be kept moist
- Growing medium to be free draining

Site Research

Irrigation

Living walls consist of two types of growing systems: in-ground for green façades, and the green wall container type using hydroponic watering principles. Typically, living walls use about half the water that a standard in-ground garden consumes.

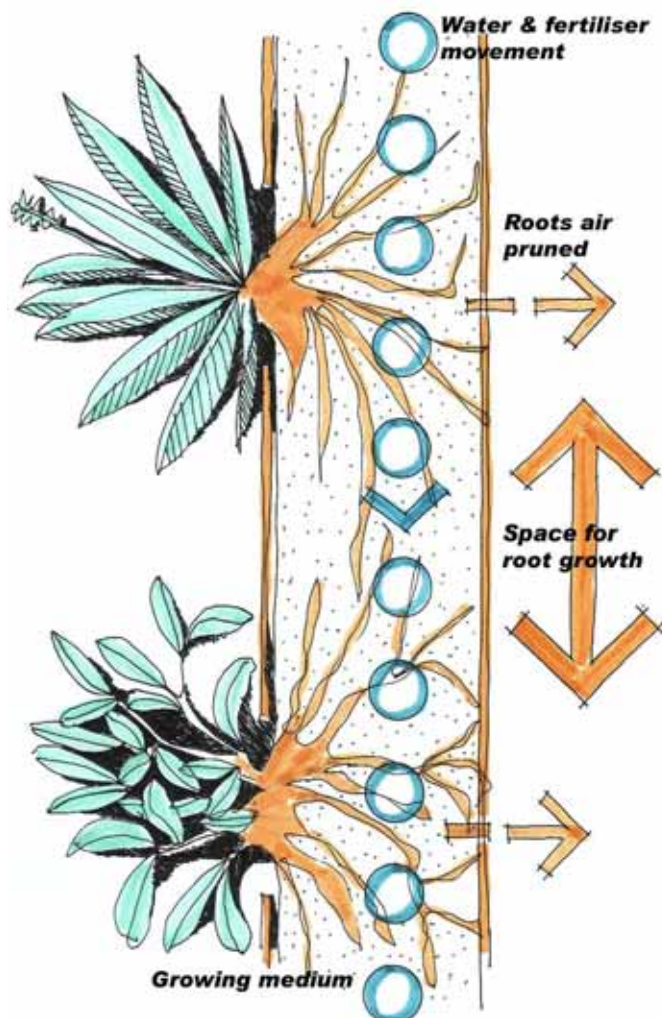
In-ground green facade system

This uses a low volume, low pressure drip system or sub soil drip system for the in-ground grown climbers. The system is similar to common garden bed irrigation systems.

Green wall container system

This is basically a hydroponic system that supplies the growing medium with water and nutrients via some means of mechanical irrigation. Each container or module is irrigated by a drip line at the top of the module and the water and nutrient is carried down through the module by gravity.

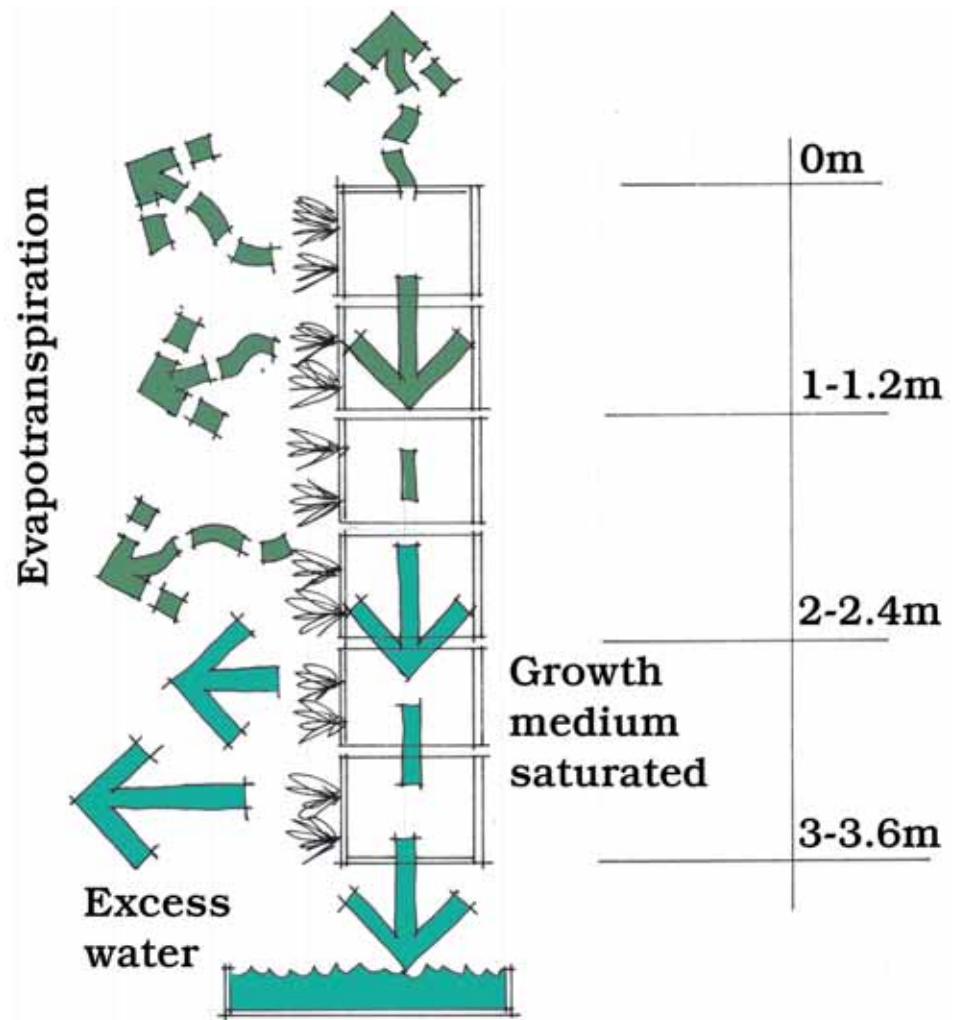
At the bottom of the module or container system a drip tray should be incorporated into the system to collect excess water and nutrient from the system. This excess water and nutrient can be recycled back into the feed system. If this recycled system is used it should be noted that there will be an increased level of nutrient and adjustment should be made within the system, so that plants are not over fertilised, which can be damaging.



In the modular container system there should be a drip tray located at about every four to five modules high, or about 3 metres apart, otherwise the water and nutrient level will build up in the bottom modules due to the gravitational pull of water through the system.

Typically a modular container system's water requirements for maximum summer use are 5 litres/m² per day, and in winter, 1 litre/m² per day.

Water sensors can be placed within the living wall system to monitor the moisture level and automatically turn on or off the irrigation system as required. The sensors should be placed in the root zone, not on the surface, as in Adelaide's unique climate the characteristics of the root zone is critical for the plant's survival.



Site Research

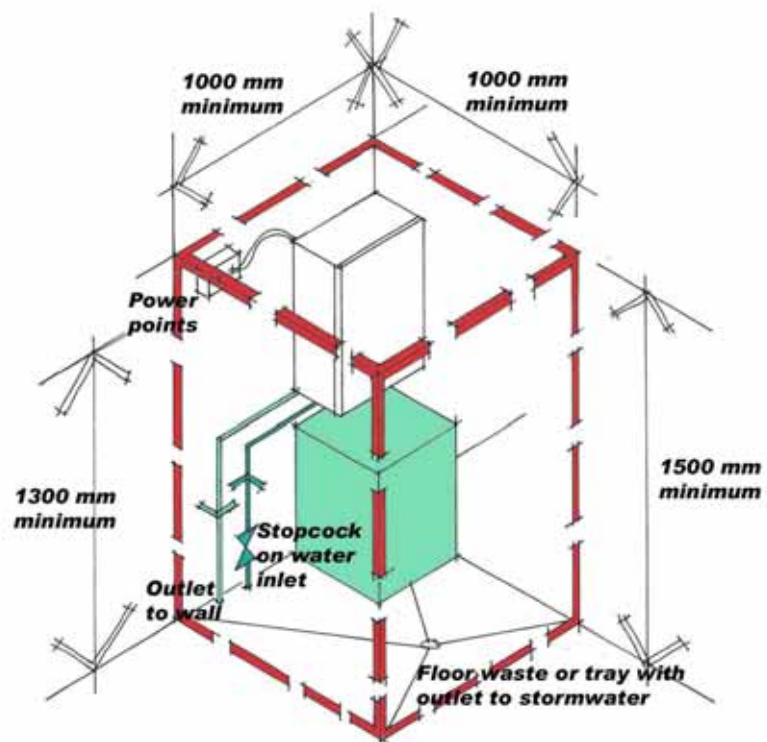
Irrigation

Equipment and services requirement

All living walls require space for irrigation and a controller cabinet remote from the wall. The physical requirement is about 1m x 1m x 1.5m high. Electrical requirements are a double GPO installed at a minimum of 1300mm from the floor or ground. A water supply is required with a lockable 20mm gate valve, with female thread. The irrigation out feed line can be a 20mm PVC pipe to the living wall.

The water supply can be mains pressure, preferably separate to the building supply, but on-site rainwater collection and storage is encouraged to be used in the system. The irrigation controller can be linked into the building services system, like CBUS, but recent experience has shown that a separate and independent system from the building services is desirable. This has been a problem for a number of existing living walls that dried out or had major water related problems.

A small weather station can be used for monitoring the micro climatic conditions around the living wall, and can be connected to the irrigation controller so that water is delivered precisely when needed. This is a similar process to the system used for water fountains, where wind velocity is monitored for optimum performance. In the case of a living wall the monitoring of temperature, evaporation and relative humidity can be useful when shading occurs across the living wall at various times of the day or in a wind tunnel effect zone. The efficiency of water supply to the living wall can be maximised, with cost benefits as well as improved growth of the plant material.



Space required for irrigation controller & fertilisation

Grey water recycling

There are some proprietary systems that use non-potable water (grey water) and clean this water to a recyclable non-potable standard to be reused within the building or outside in the landscape. These living wall systems can be developed into ecological systems, such as the outdoor example at Vacluse, New South Wales by the Greenwall Company, and the indoor system in the boardroom of the Canada Life building in Toronto.

These systems reuse the water for fish habitat, and the nutrient rich water is then pumped up to the top of the living wall as irrigation water. The nutrients fertilise the plants and the plant roots clean the water, with the refreshed water returned to the fish pond. This principle could be used on a grander scale as part of an ecological statement for the building or the neighbourhood.

Design Criteria

- Type of living wall
- Height of wall
- Water supply, storage and potential recycling
- Services and space requirement for equipment



Private Residence, Sydney
(Photo sourced from Greenwall Company website)



Canada Life boardroom, Toronto
(Photo sourced from Fifth Creek Studio)

Site Research

Costs Benefits

Overseas experience indicates that living walls provide significant cost benefits to buildings and to the wider environment, however, there are no precise figures yet in an Australian context. This feasibility study will be followed by a large scale constructed prototype and detailed monitoring so that data on energy, water and temperature benefits can be collected and analysed. Meanwhile we can summarise the projected benefits within three main areas: economic, ecological and social.

Economic benefits

Living walls can provide financial benefits directly to building owners and occupiers, and more broadly to the community and the city's infrastructure costs.

Thermal performance

The shading properties of a living wall can reduce the skin temperature of the facade and improve the building's thermal performance. This is achieved by reducing the internal building temperature in summer, thus reducing the cooling requirements of the building. Similarly in winter the skin temperature is increased by the blanketing effect of the living wall, thereby reducing the heating requirements. This modification of the building's thermal performance has a direct financial benefit.

It has been reported that a particular proprietary system in Melbourne has achieved an 11°C summer reduction, using a green wall container system. The prototype wall to be installed in Adelaide following this feasibility study will be used to monitor the skin temperature of the building and its effect on the interior of the building.

Cost Benefit

- Reduce building skin temperature by shading
- Modify internal temperature
- Reduce energy consumption

Urban heat island (UHI) effect

By lowering the temperature of the building's exterior surface the surrounding ambient temperature can be lowered, which contributes to a lowering of the UHI influenced temperature of the city, and ultimately reducing the city's energy consumption and lowering greenhouse gas emissions.

A living wall adjacent to the street can create a favourable environment for outdoor activities such as cafés and restaurants.

It has been shown that wall-climbing vines can reduce summer temperatures on a street by 5%, so if strategically positioned, living walls can offer an economic advantage to street focused businesses and the public realm.

By reducing street and city temperatures the public health risk from heat related illness is also dramatically reduced, thus creating an economic saving to the health system and emergency services. The number of extreme days over 38°C can be reduced by lowering city temperature.

Cost Benefit

- Reduce surrounding temperature
- Reduce extreme temperature days
- Reduce greenhouse gas emissions

Water sensitive urban design

Living walls can become part of the city's stormwater management through reducing the amount of runoff, via their ability to absorb and recycle water. As the rainwater percolates down the living wall some is absorbed by the plants and later transpired back into the atmosphere. This lessens the amount reaching the city's stormwater system. It has been estimated that 20% of rainfall is retained in living wall systems. By collecting rainwater living walls reduce reliance on mains water supply, conserving the mains supply for potable water requirements.

Living walls can be designed as vertical wetlands where the building's grey water from each floor is passed through a horizontal reed bed, cleaning the water to a non-potable recycled standard to be used in the next floor down.

Cost Benefit

- Reduce stormwater up to 20%
- Recycle grey water
- Recycle collected rainwater

Site Research

Costs Benefits

Space saving benefit

Living walls offer an opportunity to develop the building facade as a landscape element that otherwise would remain vacant. They can replace the ground level landscape requirement, which frees up valuable ground space for other activities, whether in the public or private realm. The economic benefits of creating extra space are particularly relevant within the restricted spatial environment of the city, but the principle applies to any situation where living walls are installed.

Cost Benefit

- Saving ground space

Property values

Incorporating living walls into a development or building adds value by making a 'green' statement, and adds to the physical attractiveness of the building. Green elements add value to the property through increasing the sale price and making sales quicker, and they attract higher rentals with quicker letting turnaround. While there are no precise figures for the increased value brought by living walls in particular, there is evidence of the economic benefits that landscape or greenery brings to a property. In discussing the economic benefits of green roofs, Steven Peck, founder of Green Roofs for Healthy Cities, refers to studies in America and Britain in the late 1990's showing that 'good tree cover increases property value by 6-15%' (Peck et al., 1999).

Although living walls do not offer the same level of recreational accessibility that some green roofs do they do provide a high level of visibility within the public realm. An article by Tomalty and Komorowski in the North American Living Architecture Monitor (2010) offers the following assessment of the monetary value associated with green roofs, from which we can extrapolate that financial benefit also applies to living walls.

“...properties with accessible green roofs are subject to a 20 percent property value premium, while those with rooftop food gardens gain seven percent in property value. Neighbours of both types of green roofs also stand to benefit significantly from their presence.

Those who have views onto a green roof could gain up to 4.5 percent of property value, while those adjacent to rooftop food gardens could gain from two percent to seven percent. It should be noted that the sum of the [sic] all the property value gains accruing to neighbouring properties could be considerably larger than the value of the benefit accruing to the host property.

... For example, a recreational roof garden was built on a four-storey commercial building at 401 Richmond Street West in Toronto. The garden is accessible to the residents of the host building and visible from a 14-storey residential building across the street. Using the formulae given above, the total property value increase due to this roof garden can be estimated at \$2.3 million.”

Further, the economic benefit extends beyond increased sale and rental values. The Property Council of Australia actively facilitates sustainable building design and construction, and through its website ‘your building’ provides a platform for information sharing. An article by Wasiluk and others (2007) clearly articulates the flow-on value of sustainable commercial building practices, which could be readily applied to living walls, as one sustainable component of a building

“Building owners and occupiers may benefit from an improved corporate profile and community relations: ‘The owner of a green building or the company it houses can find that its image is seen much more positively. This helps to attract and retain tenants, employees, clients and suppliers and thus, arguably, to make it more attractive to owners, occupiers and shareholders’ (RICS, 2005, p.20).

Others, such as developers, builders, designers and managers, may benefit from additional publicity and marketability due to their association with a sustainable commercial building. Service providers can establish a profile of projects to demonstrate their firm's commitment to sustainability and to creating buildings that meet and exceed client needs and expectations for sustainability.”

Site Research

Costs Benefits

Ecological benefits

The ecological cost benefits are especially important to climate change issues and the adaptation of cities to climate change. The cost benefits are relevant to the city as a whole as well as the individual buildings by reducing temperature and the emission of greenhouse gases. The open space, biodiversity and corridors are especially important to allow movement through the city as habitats change in response to the changing climate.

Open Space

It is important to understand that open space is not only on the horizontal plane, but can also be on the vertical plane. Utilising the building façade as a green open space, especially in high density areas like Adelaide's CBD, creates additional open space that may not be usable for walking on, but is great for visual pleasure and wellbeing. As ground open space would require considerable expense to acquire in the middle of the CBD, this living wall concept could provide additional open space under both private and public ownership.

Cost Benefit

- Additional open space without taking up valuable ground space

Biodiversity

As another form of open space, living wall systems will provide extra habitat within the city area in addition to existing ground space. Various plant species and habitats can be targeted to encourage selected species or to discourage other species, especially within the bird community. Using dense clumping plant species in the living wall will attract small bird species as the foliage will provide a protected habitat.

Cost Benefit

- Additional habitat to city area without taking up valuable ground space

Corridors

Living walls can form habitat and open space corridors connecting the ground with the rooftops as well as across the city, potentially connecting to the Parklands. If these living walls could be strategically placed on building facades, this could form stepping stone corridors for animal, birds and insects to pass through and breed in the city. This would enrich both the biodiversity and the health of human inhabitants in the city centre. This positive biophysical effect of people's connection to nature has been well documented.

Cost Benefit

- Inter-connectivity of habitat and human wellbeing

Oxygen/CO₂ exchange

Living walls can play an increasingly important role in reducing the amount of CO₂ in the atmosphere through the process of photosynthesis where plants absorb CO₂ and release O₂ into the atmosphere. With increased levels of CO₂ from climate change plant growth will increase and therefore absorb more CO₂ and release more O₂. By this mechanism plants (living walls) can stabilise the atmosphere's composition (oxygen, nitrogen plus small amounts of CO₂, water vapour, argon and other trace elements).

Research by Kuhn in 1996 says that through the process of photosynthesis: *155m² of plant surface area can produce enough oxygen for one person for 24 hours.*

In city streets where space and services occur that do not allow for street tree planting then living walls could become the replacement for these street trees and their environmental benefits like removing airborne pollutants and providing the CO₂/O₂ exchange.

Cost Benefits

- Living walls can replace street trees and their environmental benefits
- 155m² of plant surface area produces enough O₂ for one person for 24 hours

Social Benefits

Living walls provide therapeutic and public health benefits that can be equated with considerable cost benefits to the community and individual building owners. The biophysical benefit of visual and physical contact with nature can reduce stress, improve patient recovery rates and provide higher resistance to illness. This then reduces the use of the public health system and therefore reduces the health budget.

Similarly the health and wellbeing of office workers in high rise buildings is affected. Introducing living walls to office buildings will reconnect workers to the biophysical benefits of vegetation and increase worker productivity and reduce the number of sick days, as has been documented for Melbourne City Council's building CH2.

Living walls can modify the local micro-climate by reducing the temperature and providing a pleasant environment or public space that encourages new economic opportunities such as cafes and outdoor eating.

Cost Benefit

- Reduce stress on the public health system in high density areas
- Increase office worker productivity
- Encourage new economic opportunities by creating pleasant public spaces

Site Research

Maintenance

Maintenance of a living wall should be no more onerous than with landscape plantings in the ground: pruning, feeding, weeding and watering. If maintenance of the living wall is considered at the design stage any issues can be resolved in the design. The space for equipment and supply of power and water need not be an issue if they are accommodated at the design stage.

There are three major maintenance issues to be considered:

- Sufficient watering during establishment
- Airborne seed germination
- Access to the wall for equipment

A maintenance plan and budget needs to be part of the design process and not an afterthought once the project is completed. Maintenance is especially critical during the establishment period to ensure the success of the living wall. This includes adjusting the irrigation system to accommodate any changes or special issues.

Regular maintenance inspections should be programmed for the water and fertiliser systems, and a fail safe device installed with electronic communications to the maintenance personnel or contractors so that any system failures can be addressed quickly. Unwanted spontaneous weeds should be removed immediately before they take hold.



Adelaide Zoo living wall installation using a forklift system (Photo sourced from Fifth Creek Studio)



Cable anchor point on green roof at Adelaide Zoo (Photo sourced from Fifth Creek Studio)

Access to the living wall may need to be provided by a lifting device so that maintenance personnel can be lifted up the wall to undertake any required weeding or pruning annually. Access equipment can take the form of work platforms, elevating work platforms, forklift trucks, scaffolds, forklift working platforms, industrial rope access systems or ladders. A stable area of paving is required at the base of the wall, and vehicle access to deliver and remove such equipment.

If an abseiling system like the sort used for window cleaning for high rise buildings is used, it will require a framework built into the living wall frame, either at the top of the system or above the wall attached to the building structure. Two Australian Standards need to be taken into account: AS 1891 Industrial fall-arrest systems and devices and AS 4488 Industrial rope access systems. These standards cover a range of factors including selection, use and maintenance, safety belts and harnesses, loads and deflection, suspension trauma, pendulum effects, testing criteria, and service intervals and checks. AS 4488 Industrial rope access systems includes a requirement of two trolleys per person – one for the working line and one for the safety line.

All maintenance systems proposed and installed must comply with relevant Australian Standards as summarised by SafeWork SA in the document Working at Heights:

- AS/NZS 1576 Scaffolding
- AS 1657 Fixed platforms, walkways, stairways and ladders – Design, construction and installation
- AS 1801 Industrial safety helmets
- AS/NZS 1891 Industrial fall-arrest systems and devices
- AS 1892 Portable ladders
- AS/NZS 2210 Occupational protective footwear
- AS 2359 Powered industrial trucks
- AS 2550 Cranes – Safe use
- AS/NZS 4576 Guidelines for scaffolding
- AS 4488 Industrial rope access systems

Information on personal fall protection provided in SafeWork SA's Working at Heights is of particular relevance to living walls. Systems of work and equipment that secure a person to a building or structure are defined as personal fall protection, and should be used to minimise the risk of:

- A person falling from a height (travel restraint devices)
- Injury to a person after they have fallen from height (fall-arrest systems).

04

Benefits to Adelaide Buildings

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Benefits to Adelaide Buildings

Building Environment Control

Thermal control - shading/insulation

All living walls will provide a certain level of shading onto the building façade, but some types will have more intense shading than others. Green facades for instance generally are more transparent and therefore give less shading and insulation than green walls that are usually solid and allow no light through them. Shading the building façade will affect the heating and cooling loads on the air-conditioners and thus affect the running costs of the building.

Green façade

Depending on the plant species selection, planting centres, type of supporting system, and height for the plant to cover, varying densities can be developed from very light 10% cover to very dense 80% cover. An important factor is whether the plant species is deciduous, creating varying densities throughout the year from very little coverage during winter to allow winter sun into the building, to denser cover in summer to prevent the extremely hot sun penetrating into the building.

Green wall

By their very nature, being an envelope or framework containing growing medium, then one would expect no light to penetrate into the building through the green wall. Similarly, the insulation properties of these green walls are quite considerable, with anecdotal readings of temperature drops of 2-11°C.

Thermal control - evaporative cooling

Living walls with their planting and vegetation cover produce a process of evapotranspiration, consuming CO₂ and producing water vapour. As described in the section on UHI, the process of evapotranspiration actually cools the surrounding air therefore reducing the heat load onto the building façade. As discussed, the air containing water vapour cools to the open sky quickly thus reducing the local air temperature.

Natural lighting

There can be a conflict or competing uses between the need for a living wall and the need for natural light. Similar to the shading effect, a green wall will block out the natural light into the building, whereas a green façade will allow light to pass through it, depending on the density of planting.

There are other techniques for having a green wall and natural light at the same time. For instance the CH2 building in Melbourne required both natural light and a living wall, so they set the living wall at right angles to the building to shade the building at an angle while allowing natural light to stream into the building.

Pollutants and dust control

One of the benefits of living walls is their ability to trap dust and remove pollutants from the air and from rainfall. Placing living walls in urban canyons such as busy city streets can be beneficial to the city environment, as by using the vegetation close to the point source of the pollution the plants can absorb or hold the airborne pollutants. At the same time the extra CO₂ being produced can be used by the vegetation on these walls. Research carried out alongside motorways in Germany measured the percentage of particulate coverage on the leaf surface of plants such as ivy. It was found that particulates and dust covered 40% of the leaf surface.

Noise dampening

All living walls have an effect on noise transmission to varying degrees. Green walls reduce noise transmission considerably because they are made of solid materials, growing medium and planting, whereas green facades are permeable and filter noise through the system, reducing the sound levels to a lesser degree. Green walls can be used strategically in their placement to intercept the noise and absorb or reflect the noise away from the area to be protected.

Connection to nature

It is important for cities like Adelaide to not lose the connection with nature in the urban environment. It has been well documented that urban environments that lose their connection to nature develop public health related problems. This is extremely important in commercial buildings that look out onto other commercial building facades and where people work in them for long hours. Monitoring of Melbourne's CH2 building, with its green façade and natural ventilation, showed an increased productivity of 10.9% in the first year, together with a reduction of sick days. This is attributed in part to the green façade that people can see from their desks and at break out areas.

A high rise commercial building can house 2,000 people and these people need access to natural surroundings, just as they need break out spaces for coffee and from the constant artificial interior environment. The population of these buildings can be compared to a small suburb of 2,000 people where open space is required for the wellbeing of the residents, so this principle should equally apply to high rise buildings. Living walls can be seen as the landscape component or the natural element in the building.



Birds nest on a living wall at Fifth Creek Studio
(Photo sourced from Fifth Creek Studio)

Benefits to Adelaide Buildings

Biodiversity Habitat and Corridors

Living walls can play a significant role in the integration of natural systems, plant communities, animals, birds and insects interacting with each other to survive and operate as an ecosystem. Just as boundary hedges and fence-line shrubbery in suburban situations provide a haven for small birds in particular, in a city environment living walls can provide much needed shelter and a source of food for small creatures. When living walls are combined with green roofs they make connections between the landscape on the roof and the landscape on the ground, enhancing opportunities for habitat diversity and accessibility even further.

It has been shown in European and North American studies that even green roofs not specifically designed as 'living biodiversity' roofs have been colonized by spontaneous development from airborne seeds and animals. This opportunistic colonisation of ecosystems will behave like any other ecosystem once established, requiring the same key factors to survive. Living walls can play a vital role in adding to a mosaic of stepping stone habitat and migration corridors across the city. By utilising a bioregional biodiversity design approach a series of vegetation stepping stones could eventually link the city centre with the surrounding parklands and landscaped squares via a network of green open spaces.

In terms of urban ecology, both resident and migratory biota utilise and are often dependent on such interlinked networks. Species such as birds, nocturnal microbats (especially valuable for eating mosquitoes), butterflies and other insects are able to move between islands of vegetation to source food and shelter. In fact a close mosaic of stepping stone habitat patches may be as effective as a continuous strip in allowing many species to permeate the whole area.

In Adelaide, the term 'bushtop' has been coined to refer to a rooftop landscape that brings a little of the bush or outback into the city. Bushtops are not only sites for native flora, but are habitats for native fauna, so living walls can provide the transport link between the ground and the roof for species such as small lizards.

Benefits to Adelaide Buildings

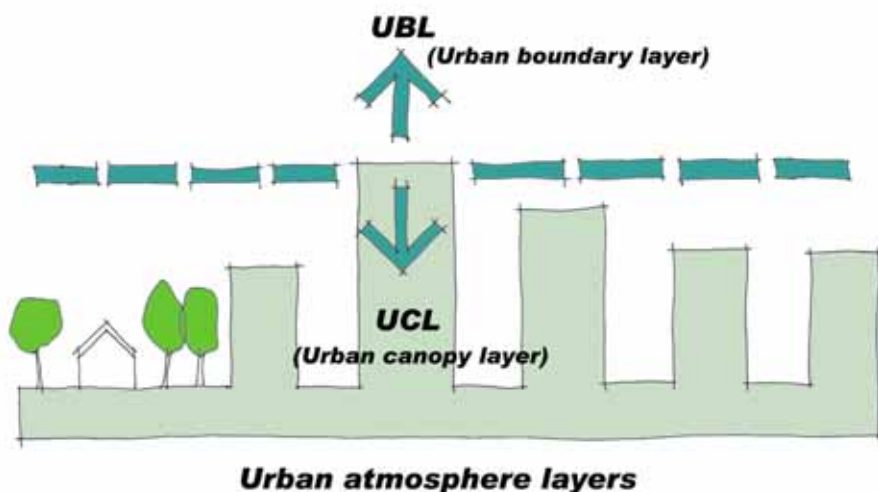
Urban Heat Island (UHI) Effect

The urban heat island (UHI) effect refers to the warming of the urban temperature compared to the surrounding non-urban areas. The UHI is caused by the storage of solar energy in the urban fabric during the day and release of this energy into the atmosphere at night. The process of urbanisation alters the balance between the energy from the sun used for raising the air temperature (heating process) and that used for evaporation (cooling process), because the cooling effect of vegetated surfaces is replaced with impervious engineered surfaces.

The UHI is an anthropogenic modification of the climate, caused by changes to the land surface and atmosphere. By replacing green spaces with impervious surfaces like buildings and roads the thermal, radiative, moisture and aerodynamic properties of the land surface and atmosphere are altered. Urban construction materials have different thermal (heat capacity and thermal conductivity) and radiative (reflectivity and emissivity) properties compared to the surrounding rural areas, which allows more sun's energy being absorbed and stored in urban surfaces, compared to rural surfaces.

An additional cause is the height of buildings and how they are arranged, which affects the rate of escape at night of the sun's energy that is absorbed during the day by the building materials. The result is that urban areas cool at a much slower rate than rural areas at night, thus maintaining comparatively higher air temperatures. Also urban areas tend to be drier than rural areas because of lack of green space compared to impervious surfaces and drainage systems that are designed to remove water quickly from the urban environment. This combination of causes alters the energy balance of the urban environment, allowing more sun's energy absorbed by the land surface going into heating the atmosphere and thus raising the air temperature, rather than into evapotranspiration, which is a cooling process.

There are different types of UHI, as defined by surface or air temperature. To distinguish the different types the following descriptions apply. There are two main layers in the urban atmosphere: the Urban Boundary Layer (UBL) that is above the average height of the buildings, and the Urban Canopy Layer (UCL) that is below the rooftops in the space between buildings, as shown in the diagram below.

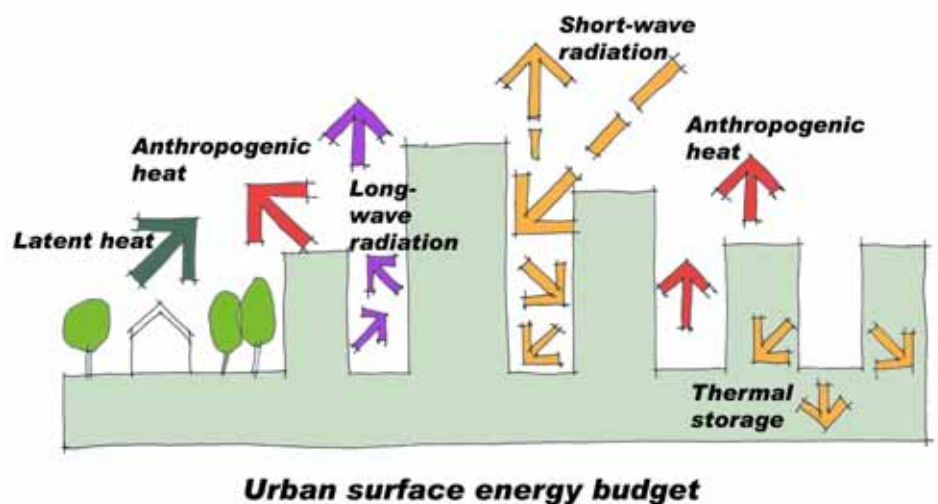


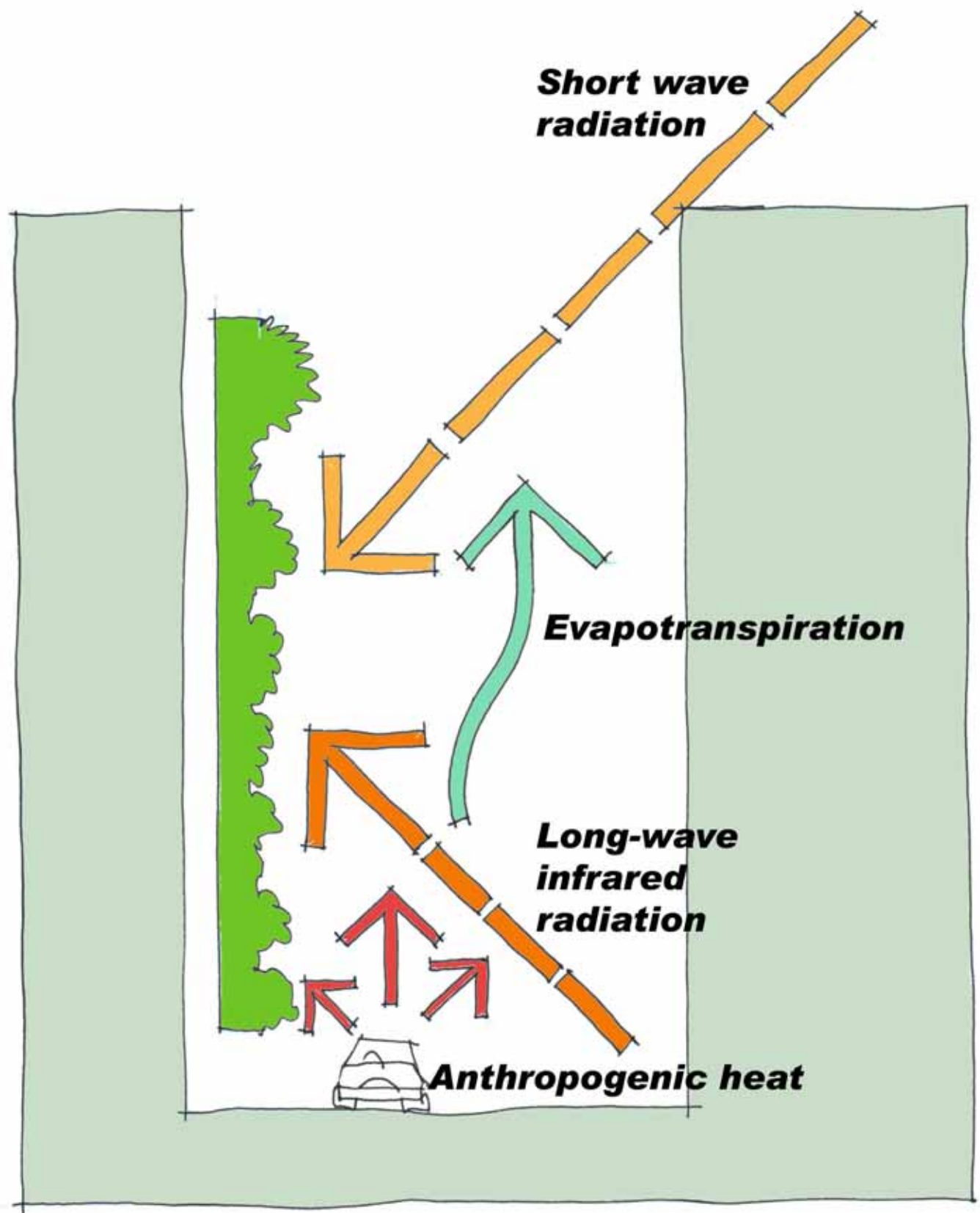
The UHI effect on the city's overall energy and temperature uses the UBL layer data, whereas when looking at the UHI effect created by an individual building we use the UCL layer data. Living walls on buildings are located within this UCL layer.

The energy balance can be quantified by incoming and outgoing energy flow or flux, to create a surface energy budget, as shown in the diagram below. This budget is different for urban and rural areas, due to the impervious or vegetated surface differences described above. Such differences can affect the generation and transfer of heat for surface and air temperatures of various urban and rural areas.

There are 6 elements that make up this surface energy budget:

- Short-wave radiation: is ultraviolet, visible light and near-infrared radiation from the sun that reaches the earth. This energy is the key driver of UHI.
- Thermal storage: is partly due to lower solar reflectance of urban surfaces (albedo), also influenced by the thermal properties of construction materials, and urban geometry. Urban geometry can cause short-wave radiation especially within the urban canyon to be reflected onto nearby surfaces such as building facades where it is absorbed rather than escaping into the atmosphere.
- Long-wave or infra-red radiation: can be intercepted on its way to the atmosphere through the urban geometry such as urban canyons. The incoming short-wave radiation that is absorbed by buildings can be re-radiated as long-wave energy or heat. If the urban geometry or urban canyon is such that the long-wave energy cannot easily be released to the cooler open sky the heat builds up and contributes to the UHI.
- Latent heat: is the energy consumed in the process of evapotranspiration. This is evaporating water from the earth's surface to the air and we commonly feel it as humidity. Urban areas tend to have less evapotranspiration because of impervious dry surfaces that heat up to high surface temperatures, contributing to higher air temperatures.
- Sensible heat: this is the warming of the air from the hot surface and the formation of convection circulation upwards.
- Anthropogenic heat: refers to heat generated by human made sources like cars, air-conditioners, industrial facilities etc.





Urban canyon with living wall

Benefits to Adelaide Buildings

Urban Heat Island (UHI) Effect

Effect of living walls on UHI

Living walls can become an integral part of the urban geometry, making a significant impact within the urban canyon. By shading the building facade a living wall intercepts short-wave radiation and reduces thermal storage and re-radiation of long-wave or infrared radiation to the open sky. As the building interior is shaded from thermal storage the energy requirement of the building is reduced and the anthropogenic heat is also reduced. Similarly with greater evapotranspiration occurring around the living wall, the air temperature will be reduced through the latent heat process. Consequently the level of humidity within the urban canyon (street) will be raised.

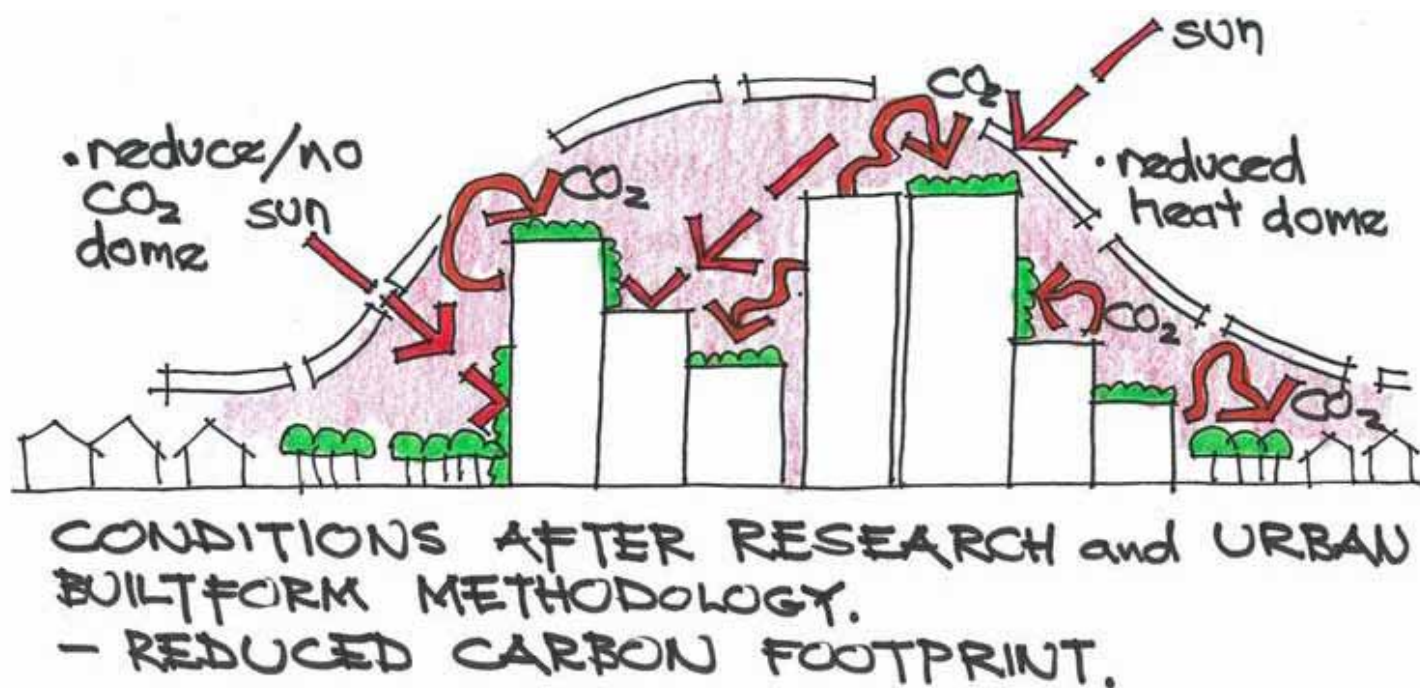
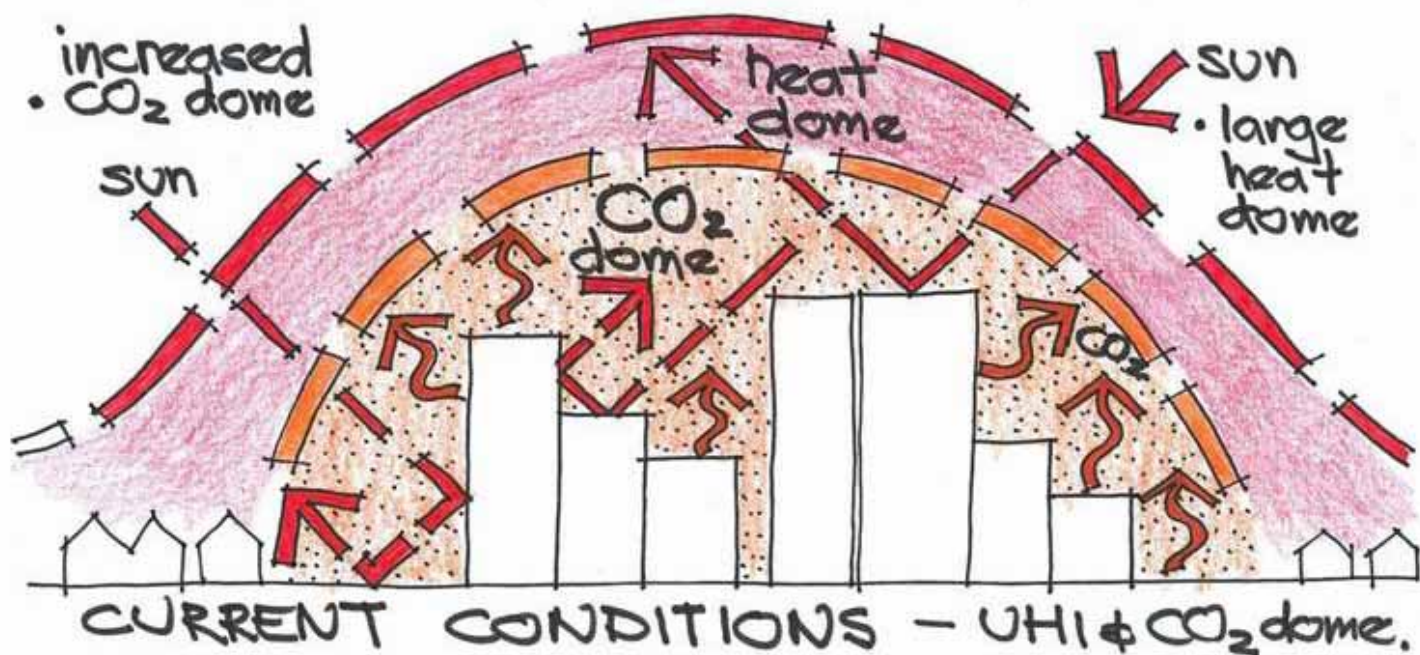
The raised level of anthropogenic heat from traffic volumes in the street also produces CO₂ which may be beneficial to the living wall by encouraging greater rates of growth for the vegetation within the living wall, thus increasing the evapotranspiration and latent heat cooling effect.

The cooling effect in the urban canyon can be influenced by air temperature and water vapour. As stated by Clay, Maghrabi and Wild (2006), 'Bodies on the surface of the Earth radiate (thermal) energy into space through our atmosphere ...by a broad range of wavelengths ... sometimes referred to as long-wave infra-red'. One of the observations they make is that air with higher water vapour content will cool quicker to the clear sky, thus reducing the temperature. 'This observation may then be related to the enhancement of the effect of any clear sky temperature changes since the cold, local, air will have a particularly strong long-wave infra-red emissivity with its additional water vapour content'.

Therefore if a living wall placed in an urban canyon is in the process of evapotranspiration the water vapour will escape quickly to the clear sky in long-wave infra-red wavelengths, reducing the surrounding air temperature.

Urban cool island (UCI) effect

In cities like Adelaide and other cities with similar Mediterranean climate an urban cool island (UCI) effect can develop within the urban geometry of the urban canyon. If the canyon geometry provides summer shading this will create a cooling effect. Similarly in winter, if the urban canyon geometry is such that the long-wave radiation or infra-red radiation is allowed to escape directly to the open sky then a cooling effect occurs (UCI). Work being developed by Williamson and Soebarto at the University of Adelaide examines this effect and supports it with a computer modelling tool to calculate the reduction in energy consumption in the surrounding buildings.



Benefits to Adelaide Buildings

CO₂ and Carbon Footprint

In densely developed centres like Adelaide's CBD where space for trees, shrubs and lawns is restricted, living walls offer an alternative for tackling environmental issues like CO₂ consumption and the production of O₂ through processes like photosynthesis. The European city of Stuttgart has been providing financial support for green roofs since 1986 and also supports the implementation of living walls to provide similar benefits. It is claimed that a 'green wall just under 40 square metres in size is as much benefit to the environment as a tree with a crown measuring five metres in diameter'.

Overseas research has found that a carbon dioxide dome is created over a city, with higher levels of CO₂ than the surrounding suburbs and this CO₂ dome will influence the micro climate of that city. Research being carried out by the Department of Planning and Local Government and Flinders University on the Adelaide CBD and the influence on the UHI effect of the parklands and localized vegetation on buildings will also potentially identify the presence of a CO₂ dome over Adelaide. The results of this research will enable us to incorporate vegetation with the built form to address the increased CO₂. This is illustrated in the diagrams adjacent.

Research in Melbourne by Coutts, Beringer and Tapper (2007) has shown that CO₂ in the atmosphere of urban areas is primarily from motor vehicle emissions. As a result they discovered that 'diurnal patterns of flux were largely influenced by traffic volumes, with two distinct peaks occurring at morning and evening traffic peak hours'.

Summer fluxes of CO₂ to the atmosphere were lower than winter fluxes due to the greater photosynthetic activity of vegetation, as well as reduced natural gas combustion in that season. Further, the photosynthetic activity of plants throughout the summer 'limited the source of CO₂ in the afternoon, yet was not enough to combat the strong local anthropogenic emissions' which were always dominant. These researchers concluded that the 'magnitude and patterns of suburban CO₂ fluxes in Melbourne were similar to those observed in Northern Hemisphere suburban areas'.

Given these findings we would expect similar results in Adelaide, but with a more exaggerated dome over the CBD as a result of the photosynthetic activity of the surrounding parklands. The results of the Melbourne research show that vegetation has an impact on the quantity of CO₂ so using living walls on city buildings in the streets of the source will substantially reduce the CO₂ in the atmosphere and reduce the dome effect. Addressing the CO₂ at its source point is an important option and using vegetation as a sink is critical for this reduction. Particularly where space is limited, living walls can address this issue.

Monitoring the living wall for the quantity of CO₂ being consumed will allow a quantitative estimate of the square metre amount of living wall required to reduce the CO₂ from anthropogenic emissions to an acceptable level. This will lower the carbon footprint of the building and surrounding environment.

Design Criteria

Living walls consume (x) CO₂ per m²

Living walls produce (x) O₂ per m²

Benefits to Adelaide Buildings

Water Supply and WSUD

All living walls require a safe, secure supply of water. Generally living walls require about half the water required for an in-ground garden bed during summer. To supply living walls with water in the city without using mains supply and the associated water restrictions requires the use of water sensitive urban design (WSUD) techniques to harvest stormwater. This can be either from the roof with no treatment, or via surface runoff that is treated, normally by bio-filtration and stored on site. If city buildings are to be greened by living walls then it is important that the water supply should come from the city stormwater and not be dependent on the city's mains supply.

Green façade system

If planted in the ground the vegetation would require similar water requirements to an in-ground garden bed of similar size. However, if the green façade system is planted in an elevated planting container then the water supply requirements will be similar to any containerised planting bed with drip or subsoil irrigation system.

Green wall system

This is basically a hydroponic system that supplies the growing medium with water and nutrients. This supply of water needs to be safe and secure so that no interruptions can occur.

Mains supply

Mains supply can be accessed from the building services system or have its own dedicated supply. From recent experience it is desirable to provide a dedicated supply for the living wall because this supply needs to be available every day to water the plants and not be turned off for other maintenance, damage or other activities elsewhere in the building complex. This dedicated supply line needs to be incorporated into the living wall system framework with its own lockable connection.

In times of water restrictions it is possible that mains supply to drip or subsoil irrigation may be restricted from time to time, therefore a backup supply should be designed into the system for these events. Other options such as utilising recycled water supplies should also be considered to determine the most effective supply for the particular project under consideration.

Rainfall roof harvesting

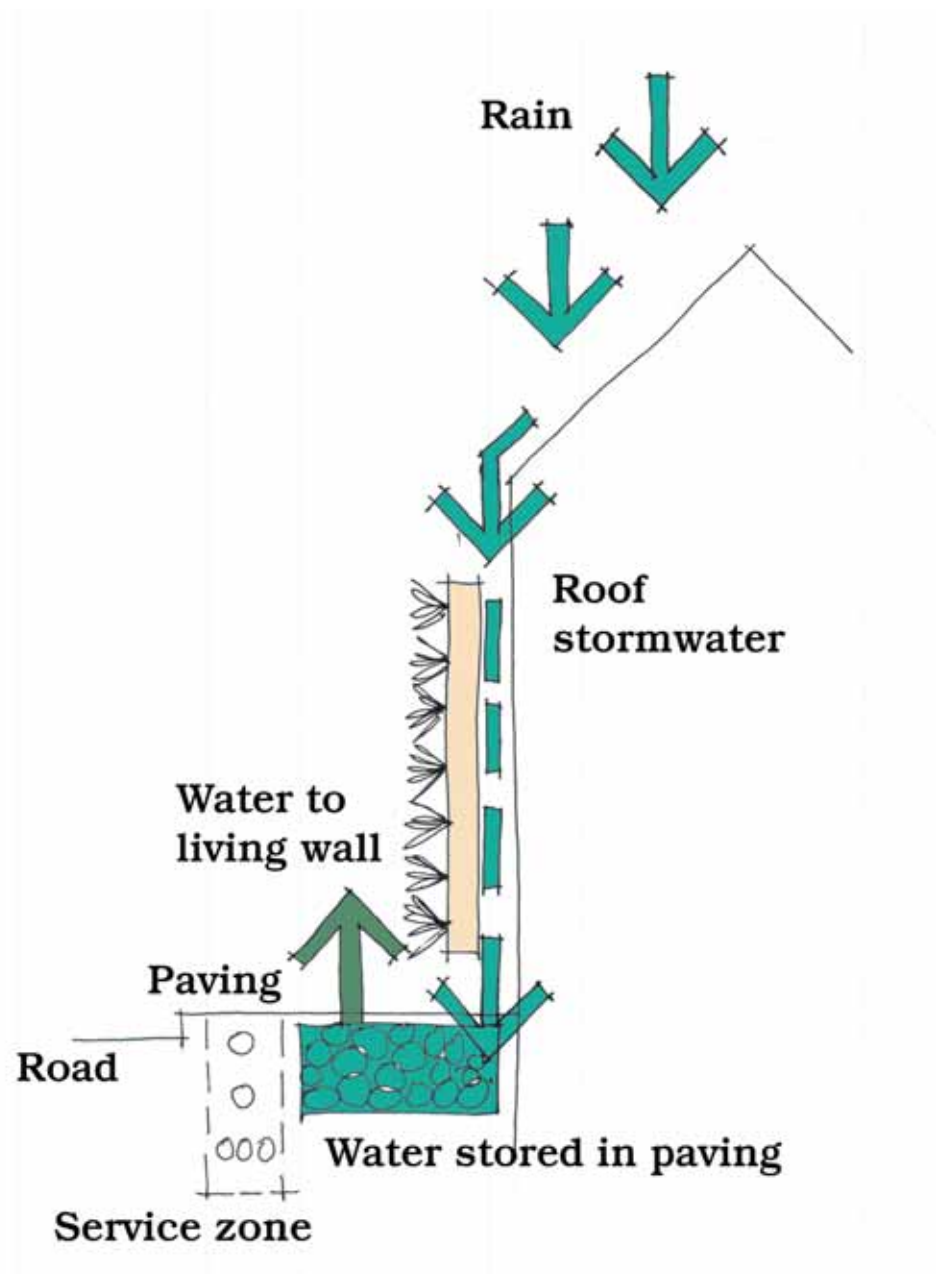
All roof stormwater should be harvested and stored for reuse, such as for living wall supply. The rain water storage tanks are usually located in the basement level or in the carpark levels of the building. If these storage tanks are not designed into the building at the start then they can take up considerable floor space. Most proprietary systems are circular and not space saving in their shape. However there are some new modular systems that come like a flat pack and clip together in rectangular sections to fit easily into building leftover spaces such as under staircases.

Stormwater harvesting storage

Paving stormwater can be harvested and stored, or cleaned through a bio-filtration strip or swale to make it suitable for reuse in the living wall system. It is possible to store this water in the public realm or private realm under the pavement or landscaped areas. It can be stored in the subgrade of the paving or even the road pavement without jeopardising the structural integrity, while still allowing surface usage. This is extremely useful for densely built up areas.

Storage within the living wall system

Storage of water where it is to be used is the most efficient use of energy, but there are several considerations. Water stored in the living wall framework creates issues for fixing to the façade as it adds considerable weight, and also a considerable quantity would need to be stored to maintain constant supply.



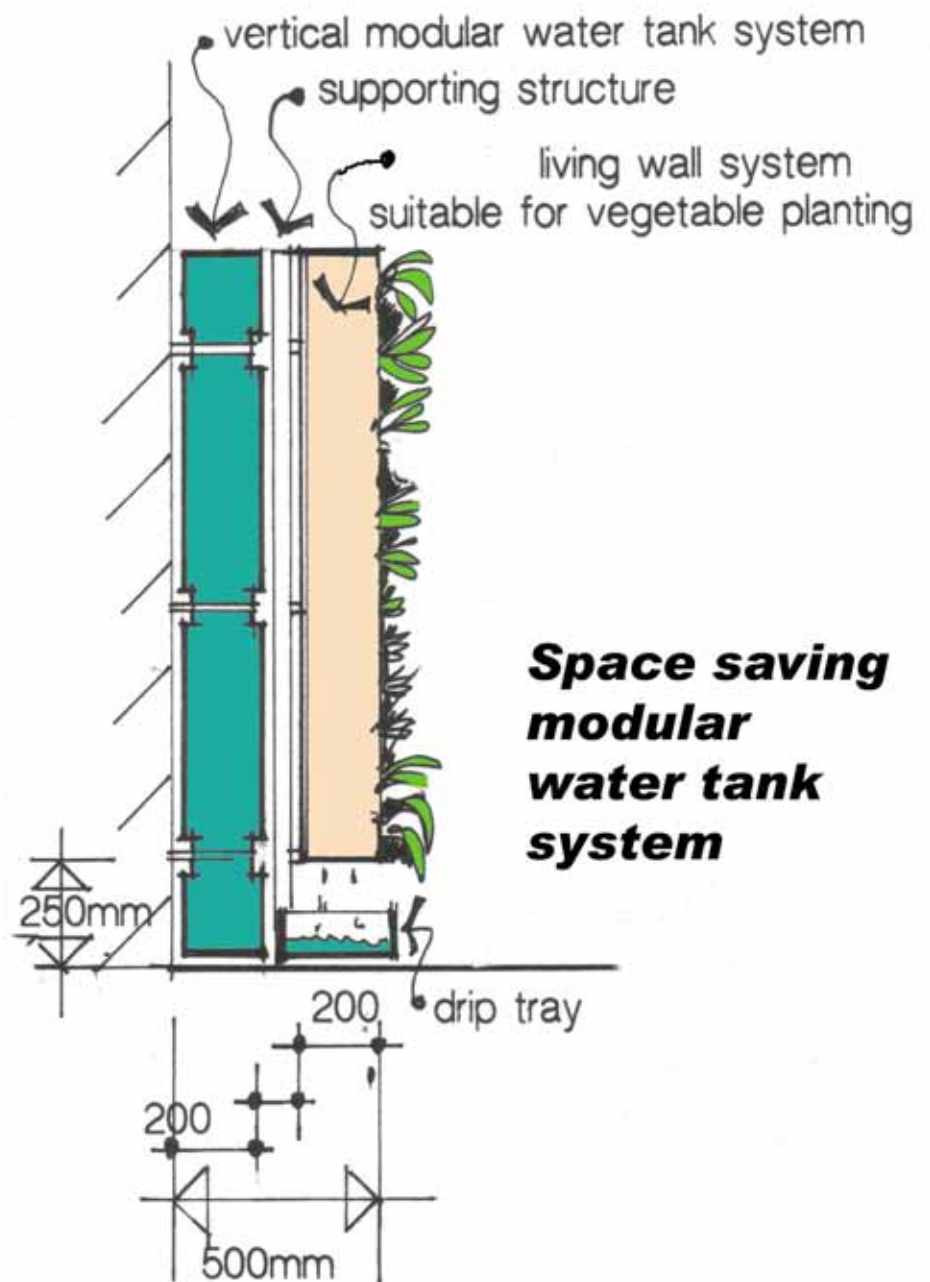
Benefits to Adelaide Buildings

Water Supply and WSUD

Recycling the waste water

Green wall systems and containerised green façade systems will require drip trays to collect the excess water draining through the system. This waste water should be recycled back into the irrigation system to be reused. Therefore a waste water pipe needs to be provided into the living wall framework.

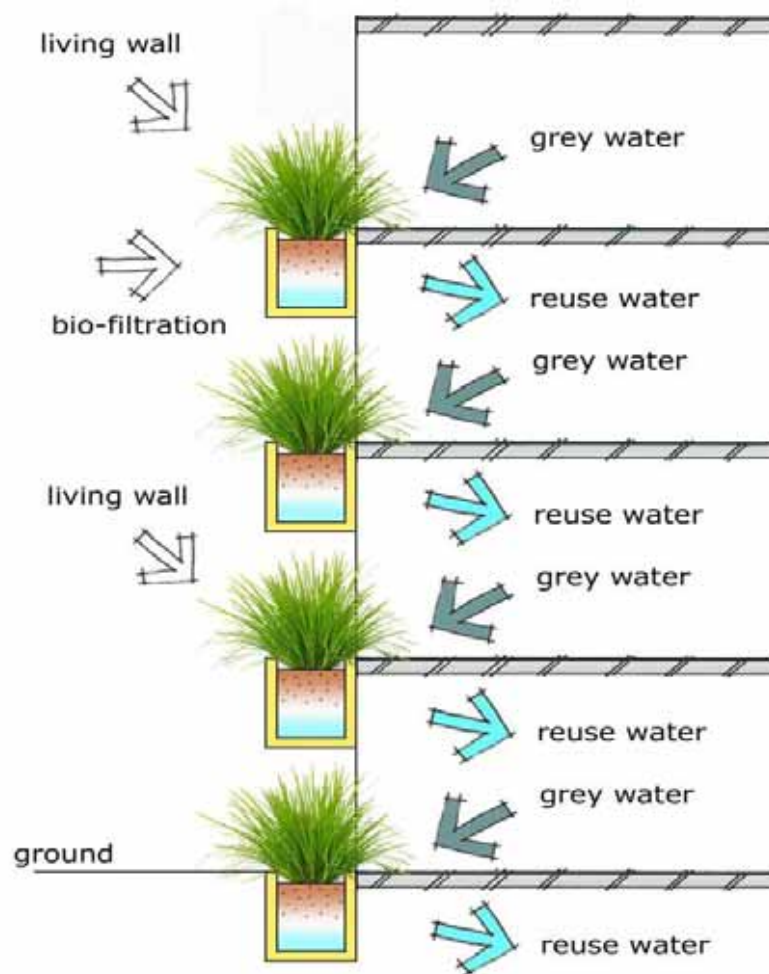
A cautionary note is that the waste water will contain some fertiliser and other elements in small quantities, which needs to be taken into account in the recycling system.



Recycling grey water from the building

Living wall systems can be developed to recycle grey water from the building and clean this grey water through a linear wetland or bio-filtration system incorporated into a green wall system to provide reusable water that is 'fit for purpose' at the other end.

This would create a cascade effect of grey water supply at one level, with water available for reuse on the next floor down.



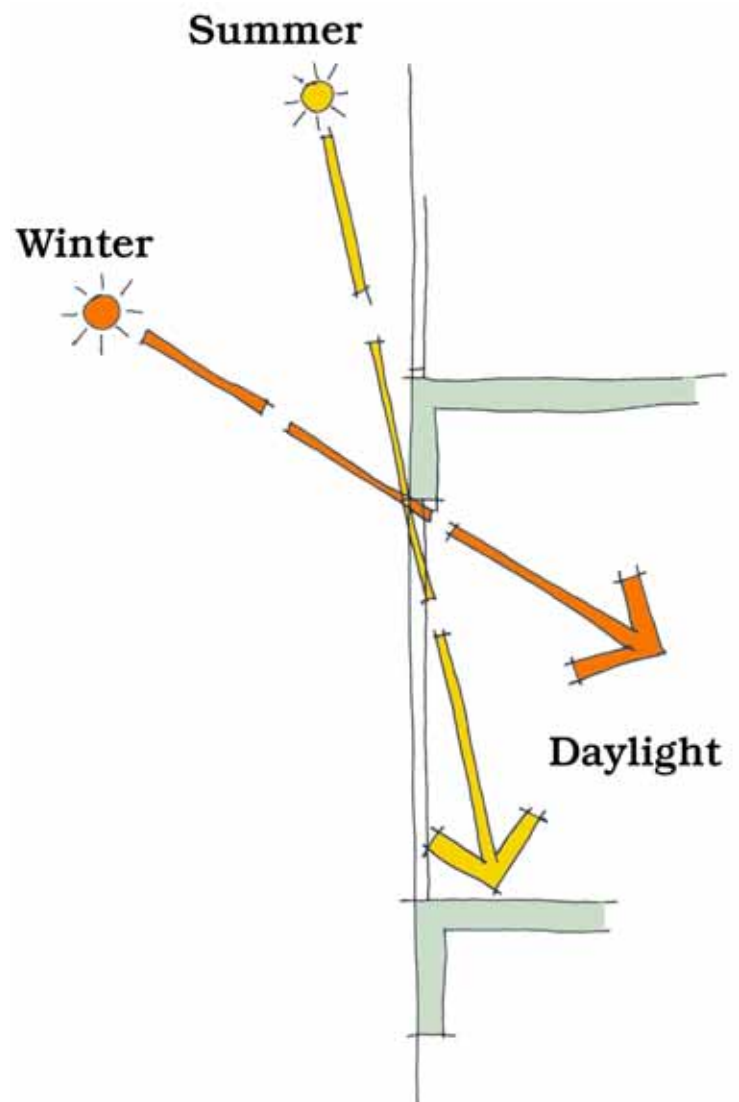
LIVING WALL FOR MULTI STORY BUILDING
- using cascade method for reuse of water

Benefits to Adelaide Buildings

Contribution to Shading and Ventilation

High rise buildings today require a high level of natural light to penetrate the interior space for human comfort and reduction of artificial light.

Placing a living wall in front of a window could create problems with light penetration, ventilation and vision out, but on a blank wall there are no issues concerning light. Heat, light and noise are easily transmitted into the building interior through the window, therefore if the window is shielded from these elements the building interior is also shielded, reducing the interior build up of heat. The placement of living walls requires a fine balance between protecting the interior from the elements and allowing daylight into the interior.



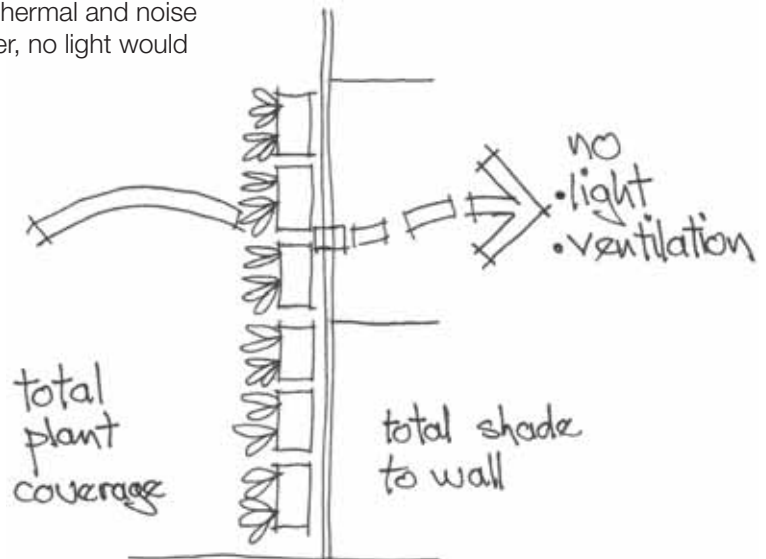
Green wall

If a green wall was placed on the building façade then there will be thermal shading benefits both to the façade and the interior of the building as previously stated. But if this was continued over the windows there would be great thermal and noise benefits, however, no light would penetrate.

Design options

Building use

- Plant rooms
- Carparks
- Service areas and lifts
- Factory used for blank walls



Green façade

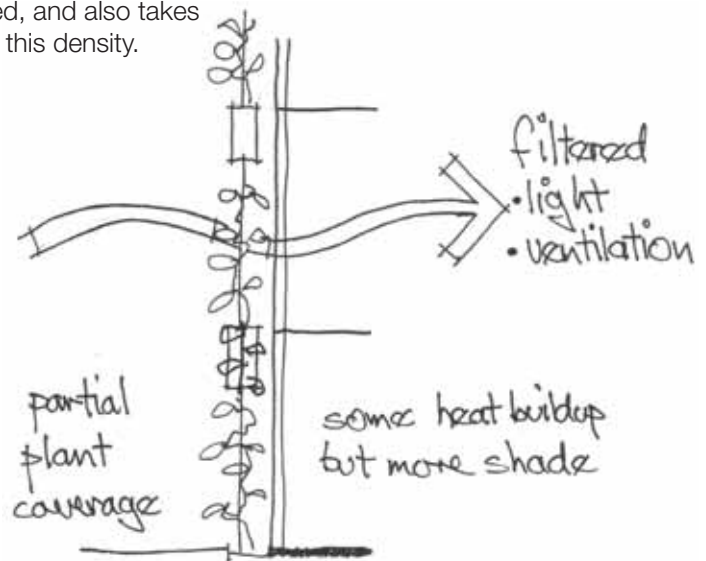
If a green façade was used the amount of light allowed to penetrate either onto the building façade or into the interior of the building can be controlled by the density of the green façade.

Design options

Building use

- Office
- Residential
- Car parking
- Commercial
- Used for glass facade buildings

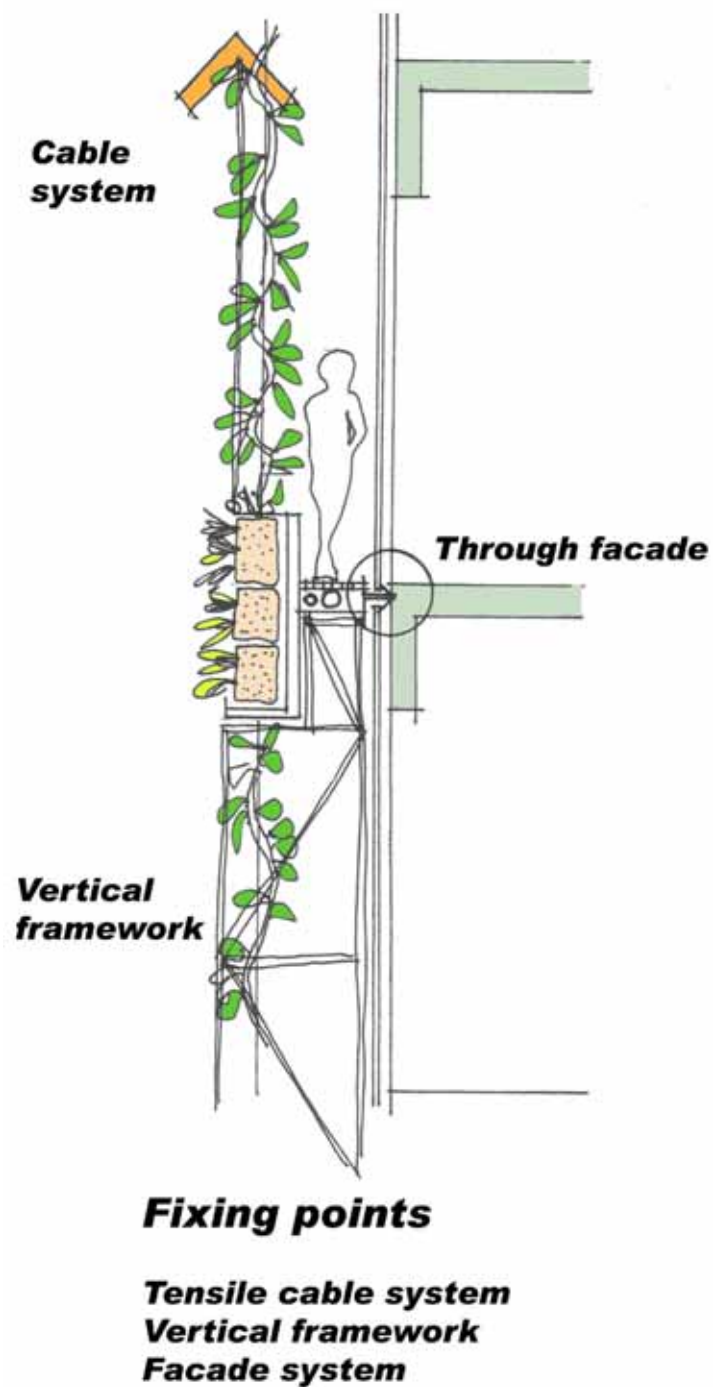
The issue here is that a green facade has a maximum of 4 floors growth height per planting bed, and also takes some time to achieve this density.



Benefits to Adelaide Buildings

Contribution to Shading and Ventilation

If the two façade systems were combined into a hybrid system then a compromise could be developed between light penetration and heat gain. If the green wall section was placed in front of the spandrel panel, this will provide shading and an awning effect for the sun cut-off angle to protect the building interior, while allowing light to be filtered by the green façade component of the living wall hybrid system.



Benefits to Adelaide Buildings

Contribution to Green Star Rating and NABERS

Initial consultation with the Green Building Council of Australia (GBCA) on the subject of living walls received the following information:

Green Star does address 'green walls' in a number of Credits in a variety of its rating tools more commonly in the Land Use and Ecology Category, specifically in the Eco-4 Change of Ecological Value Credit.

You may find that the use of 'green walls' may help contribute to credit points being awarded in the following Green Star tools Categories and Credits:

- Green Star – Office v3
- Green Star – Retail Centre v1
- Green Star – Education v1
- Green Star – Multi Unit Residential v1
- Green Star – Healthcare v1

In Category Eco-4 Change in Ecological Value:

- Green Star – Industrial PILOT
 - IEQ-19 Breakout Space
- Green Star – Multi Unit Residential v1
 - Eco-5 Outdoor Communal Facilities (GBCA email 10 March 2010)

The above list of potential credits seems rather limited, given that living walls provide building energy saving benefits, stormwater reduction, reduced UHI and so on. Once a prototype living wall is installed and monitored for temperature, shading, relative humidity and CO₂ then solid statements of benefit can be applied to each building proposal.

Similarly, once the prototype living wall is designed, installed and monitored its impact on building performance and environmental benefits can be assessed in relation to NABERS.

the 1990s, the number of people in the UK who are aged 65 and over has increased by 1.5 million (1990–2000) and is projected to increase by a further 1.5 million by 2020 (Office for National Statistics 2000). The number of people aged 65 and over in the UK is projected to increase from 10.5 million in 1990 to 12.5 million in 2000, and to 14.5 million in 2020. The number of people aged 65 and over in the UK is projected to increase from 10.5 million in 1990 to 12.5 million in 2000, and to 14.5 million in 2020.

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05

Building Interactions

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Building Interactions

Design Options

Each living wall system has advantages and disadvantages depending on the location and specific requirements of the particular application. In summary:

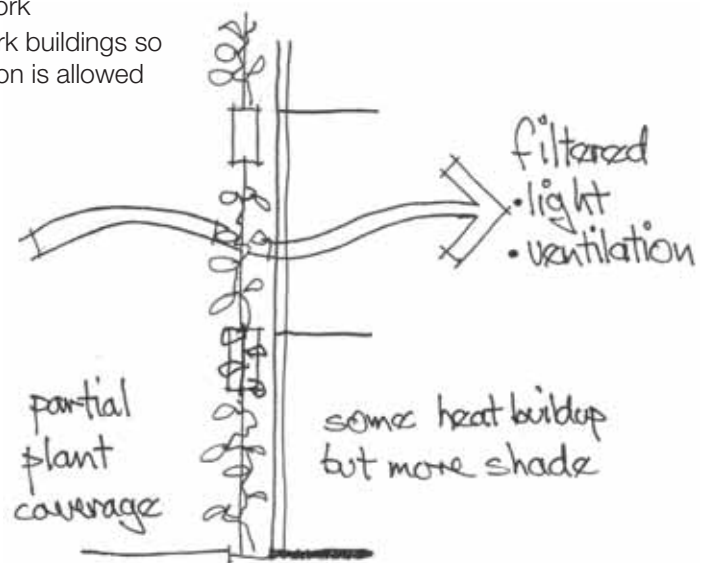
Green facade

- Allows light and ventilation to penetrate through to the building
- Using in-ground climbers there is a maximum of 4 floors in height before planter containers need to be introduced onto the facade, requiring a structural framework
- Very useful in carpark buildings so that natural ventilation is allowed through the facade

Design options

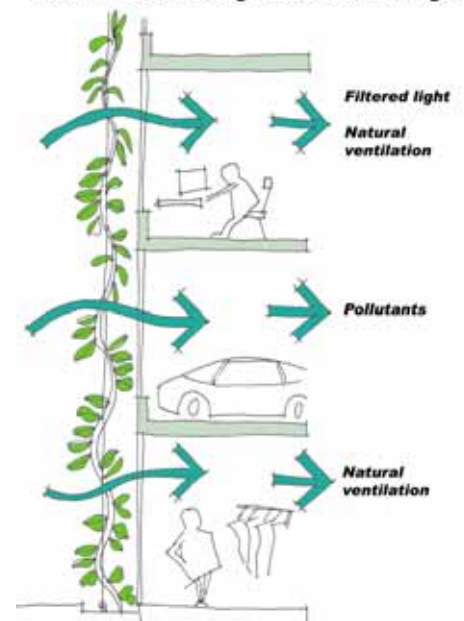
Building use

- Office
- Residential
- Car parking
- Commercial
- Used for glass facade buildings



Capital Centre, Canberra (Photo sourced from Fifth Creek Studio)

Green facade - design uses for buildings



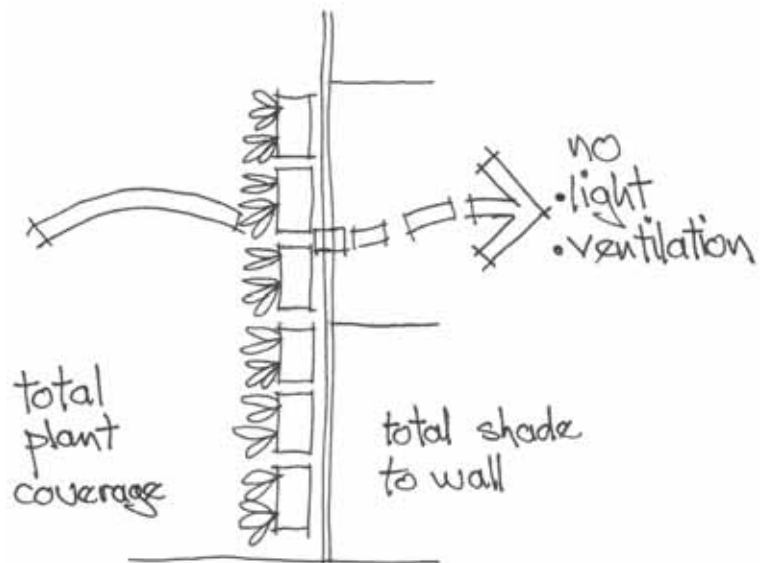
Green wall

- Provides total vegetation coverage and shade for the building
- Can be fixed directly to large expanses of blank concrete such as tilt-up panels or masonry walls. These modular growing panels are fixed to a framework attached to the solid wall
- Can be strategically placed to utilise microclimate conditions such as cool air for air intake or for cooling the wall temperature

Design options

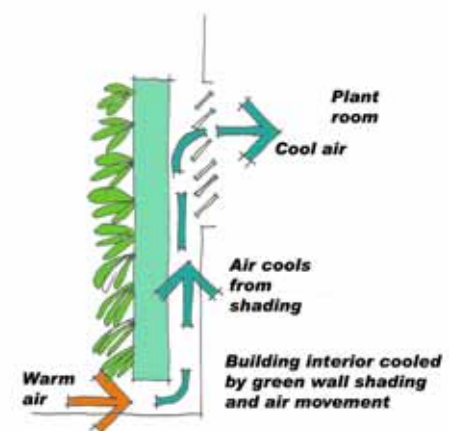
Building use

- Plant rooms
- Carparks
- Service areas and lifts
- Factory used for blank walls



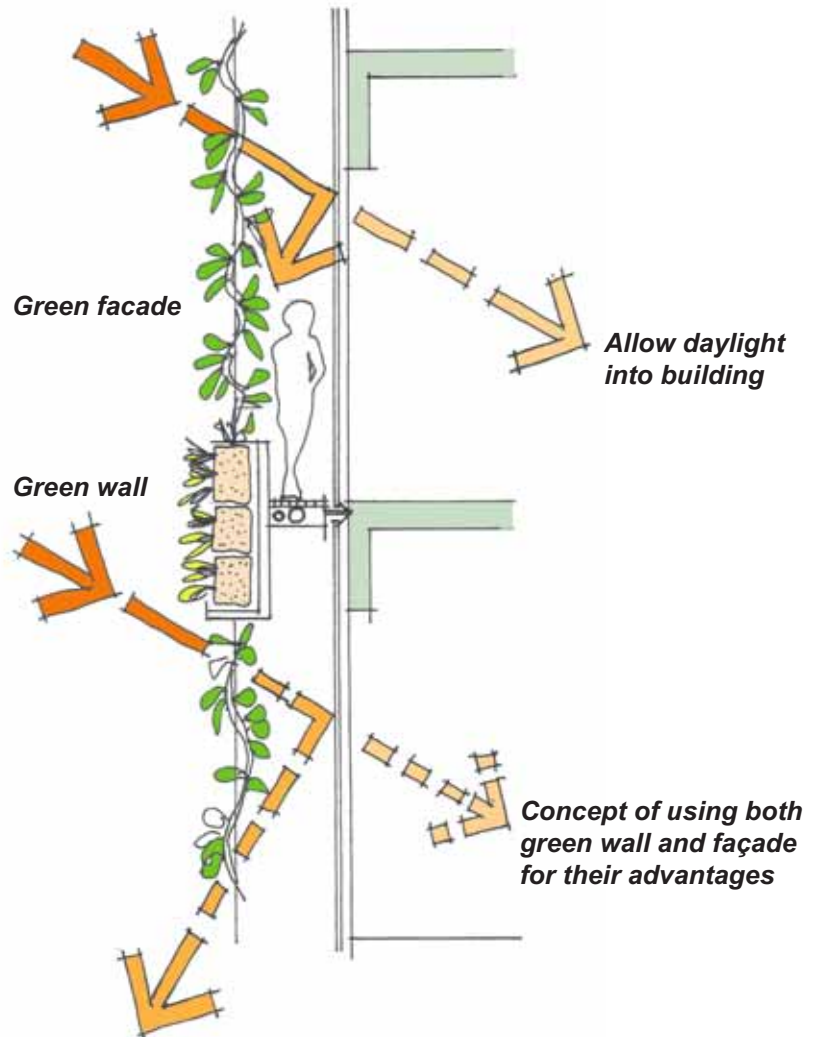
Adelaide Zoo, Adelaide SA (Photo sourced from Fifth Creek Studio)

Green wall - design uses for buildings



Building Interactions Design Options

Developing New Hybrid System



Glazing issues

Light penetration
Reflectivity - heat
- various wavelengths

Combining the screening effect already
used in multistorey green buildings



City Central Tower 2 (Photo sourced from Woods Bagot)

Building Interactions

Systems for Multi-storey Building Facades

This feasibility study is looking at multi-storey facades with heights of up to 68m (17 floors) or possibly even higher. The proposed location on Tower 8 is 5m above the ground and covers a number of storeys. Therefore the scale of living wall and its componentry will be different to that of a 1-2 storey high living wall at ground level.

The proprietary green walls currently use relatively small tablets or panels of about 0.5m² that need to be installed by two people and are time consuming in placement, so therefore costly over a large area. Maintenance of these systems requires access for equipment such as a 'cherry picker' or window cleaning system from above. This requires a system separate from the green wall installation, an added cost.

Similarly the green facades commonly used only extend 2-3 floors high above the ground as they utilise in-ground growing medium. In multi floor coverage higher up the building facade this becomes an issue to establish the height of climber species required or other means of planting higher up the building. Also, maintenance requires equipment access in front of the wall or some system from above quite separate from the green facade, adding to the operating costs.

Hybrid system

The issues above point to the development of a hybrid system so that large areas can be covered during the installation process. If larger 2-3 storey panels can be installed in one operation this process would become more economic. This system also needs to have a maintenance system integrated into the fabric of the living wall. The Tower 8 location has no ground access to the wall, so maintenance access must be either integrated or provided from above.

If the green wall and green facade systems are combined into a new hybrid system the advantages of each different system can be maximised. This hybrid system uses the green wall system as the growing container and would be placed in front of the spandrel panel only, providing shade to the spandrel panel and allowing light into the building. The services and access tracks can be placed behind the green wall panels on a framework without interrupting light penetration into the building.

The green facade section will connect the green wall growing containers and form a veil of green that allows the light to penetrate into the building, but at the same time reduce some of the heat build up and building energy usage.

Such a hybrid system should not start below the second or third floor level for several reasons. The ground floor frontage should be an active frontage relating to the public realm and footpath and therefore should not be closed off. Also, the first couple of floors would not benefit from the shading effect because of the city canyon street configuration where there is no direct sunlight to be filtered. Finally, a non continuous framework from the ground level up will remove potential vandalism options.

Recommendations

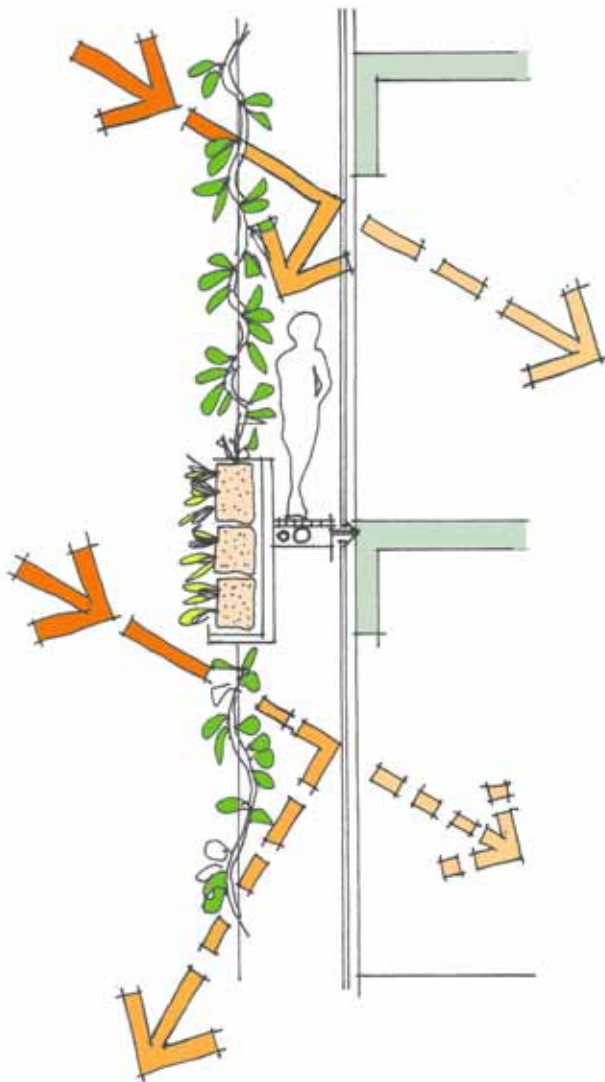
- Green walls - Lower floors up to 3 or 4 floors high against solid walls
- Green facades - Lower floors up to 3 or 4 floors high if using in-ground plants to cover large areas of facade
- Hybrid system - Higher floors to cover large areas of facade starting from 1 to 4 floors above ground level

Building Interactions

Integration with Building Facade

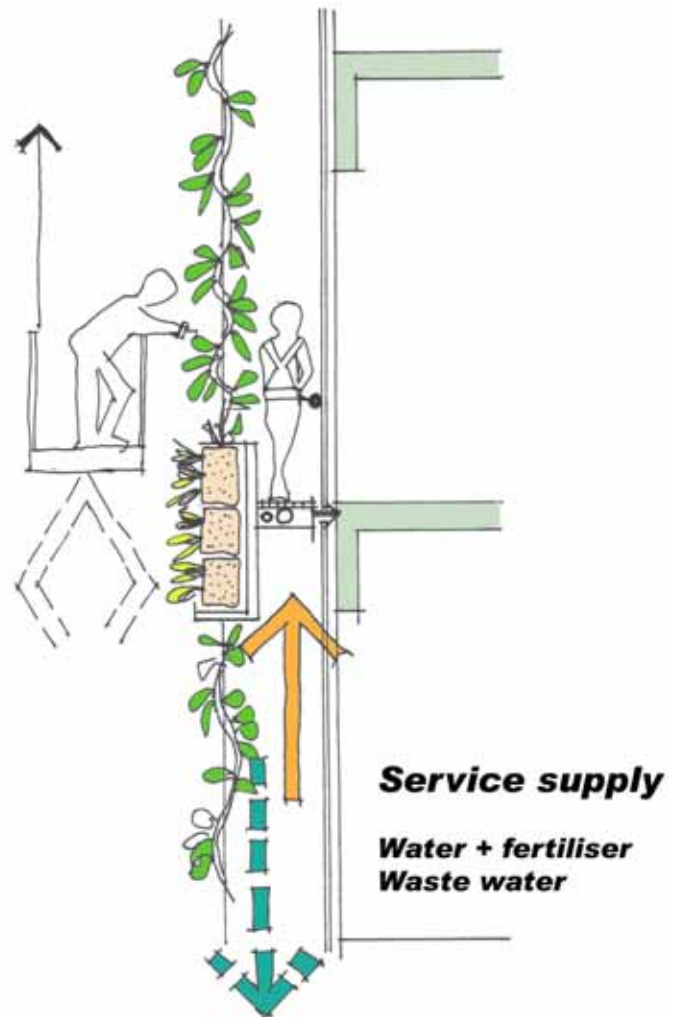
Using the hybrid system for a living wall gives the opportunity to integrate this system with the building facade and the building structural system, with advantages to both the living wall system and the building.

This integration reduces the stand alone structural system and the wind loading on the system and building, and has advantages for the glazing system and reflectivity of various wave lengths of sun light, supply of services such as water and waste, and maintenance access. These issues are illustrated in the diagrams.



Glazing issues

Light penetration
Reflectivity - heat
- various wavelengths



Maintenance issues

Methodology
Built in
External

The integration of the living wall structure with the building facade and structural elements of the building right from design stage through to the construction will have considerable savings in time and costs. If the hybrid system is used then there are some advantages in the facade construction methods, with considerable savings for the facade square meter rate. The glass curtain wall system for the facade can be replaced with the living wall framework and the windows can be standard shop front glazing systems that are considerably cheaper than curtain walls.

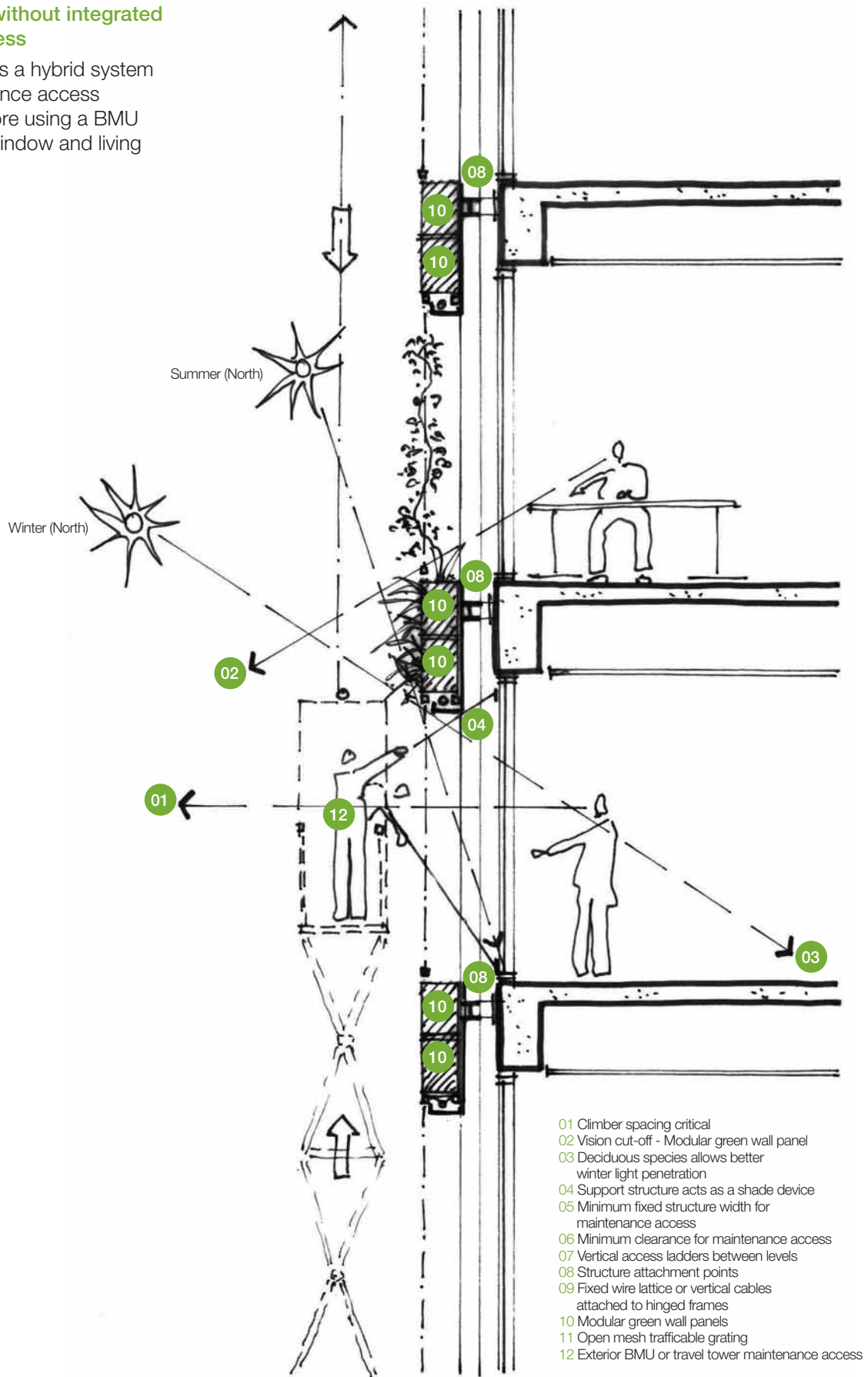
Similarly, the outside maintenance of the high rise building can determine the type of living wall hybrid system required. Designing the living wall framework with an access for maintenance works for the plants, services and windows means a BMU platform will not be needed, giving a saving of up to \$300,000 in some cases. These savings can go towards the cost of the living wall framework system.

Building Interactions

Integration with Building Facade

Hybrid System - without integrated maintenance access

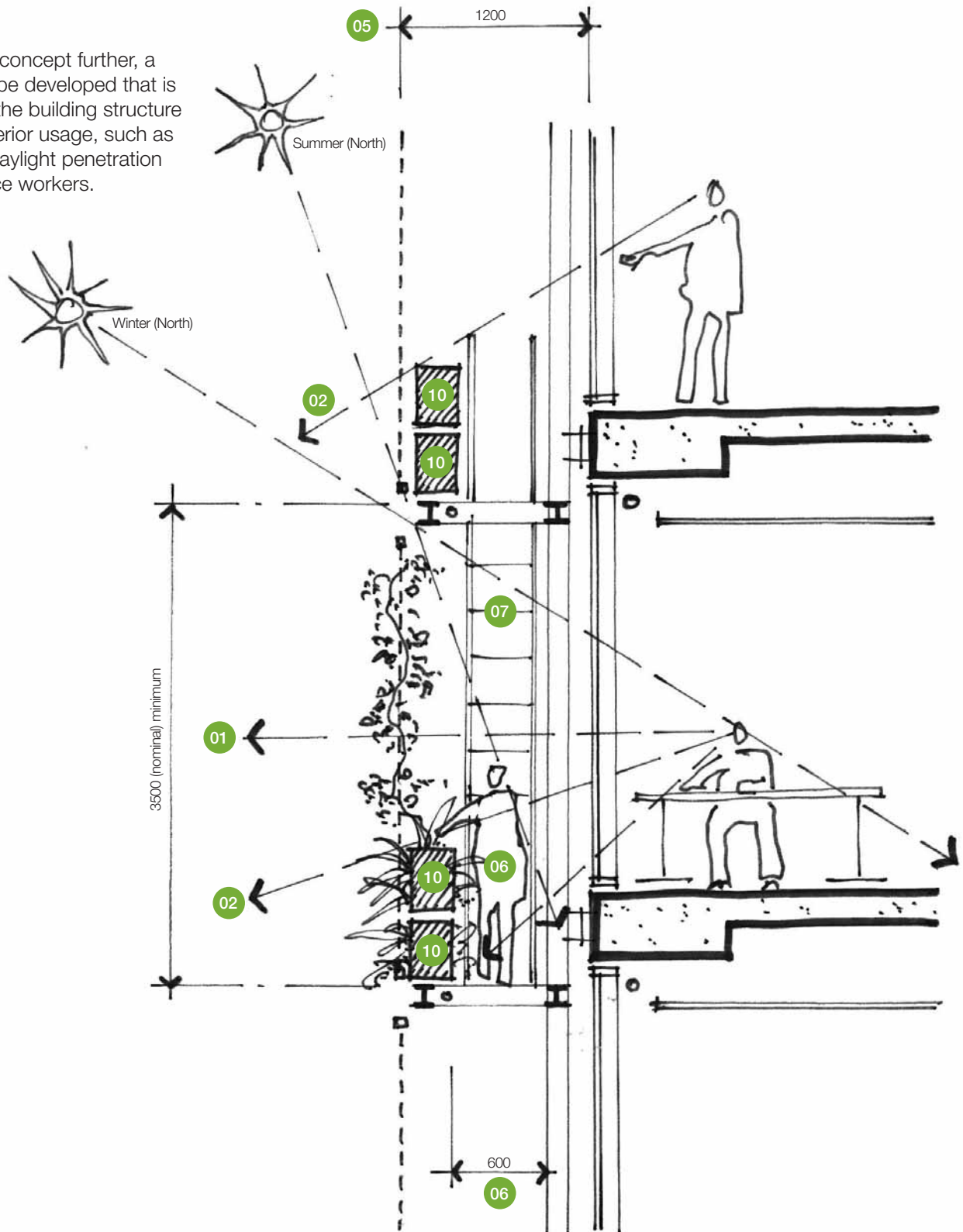
This diagram shows a hybrid system without a maintenance access system, but therefore using a BMU platform for both window and living wall maintenance.



Hybrid System - with integrated maintenance access

This diagram shows a system that is fixed at floor to floor, allowing some access from the building to the access run in the living wall framework.

Developing this concept further, a framework can be developed that is integrated with the building structure and with the interior usage, such as the amount of daylight penetration required for office workers.





Building Interactions

Integration with Building Facade

Summary of hybrid systems options

The hybrid Green Facade systems proposed can be categorised into two types:

- Hybrid system: without integrated maintenance access
- Hybrid system: with integrated maintenance access

Both systems offer the following advantages over conventional multi-storey curtain wall facades:

- Use of low cost “shop front” style floor to floor glazing systems considerably lowering the glazing system cost. More expensive curtain wall systems offer no architectural or constructional advantage.
- Integrated shading system lowering the performance requirements of facade glazing and spandrel construction.
- Creation of a building envelope micro climate lowering life cycle energy consumption.
- Creation of an urban wildlife sanctuary.
- Eliminates high solar light and heat reflection from glazed facades absorbing and filtering sunlight. Instead of energy being absorbed and re-radiated, the energy is converted into growth, photosynthesis and renewal at the same time absorbing and reducing CO₂ levels.
- Reduces the urban heat island effect contributing to lowering summer precinct temperatures
- Reduces reflected heat on adjacent buildings so reduces their cooling loads.

The following issues are points of difference between the two systems discussed:

Hybrid system: without integrated maintenance access

Advantages

- Minimizes up front capital cost
- Minimizes spatial requirement offset from glazed facade (600mm nominal)

Disadvantages

- Limited to low rise facades up to 5 stories
- Requires good access for maintenance from ground level platforms all round the building
- Glazing maintenance must be carried out through the climbing plant support system.

Hybrid system: with integrated maintenance access

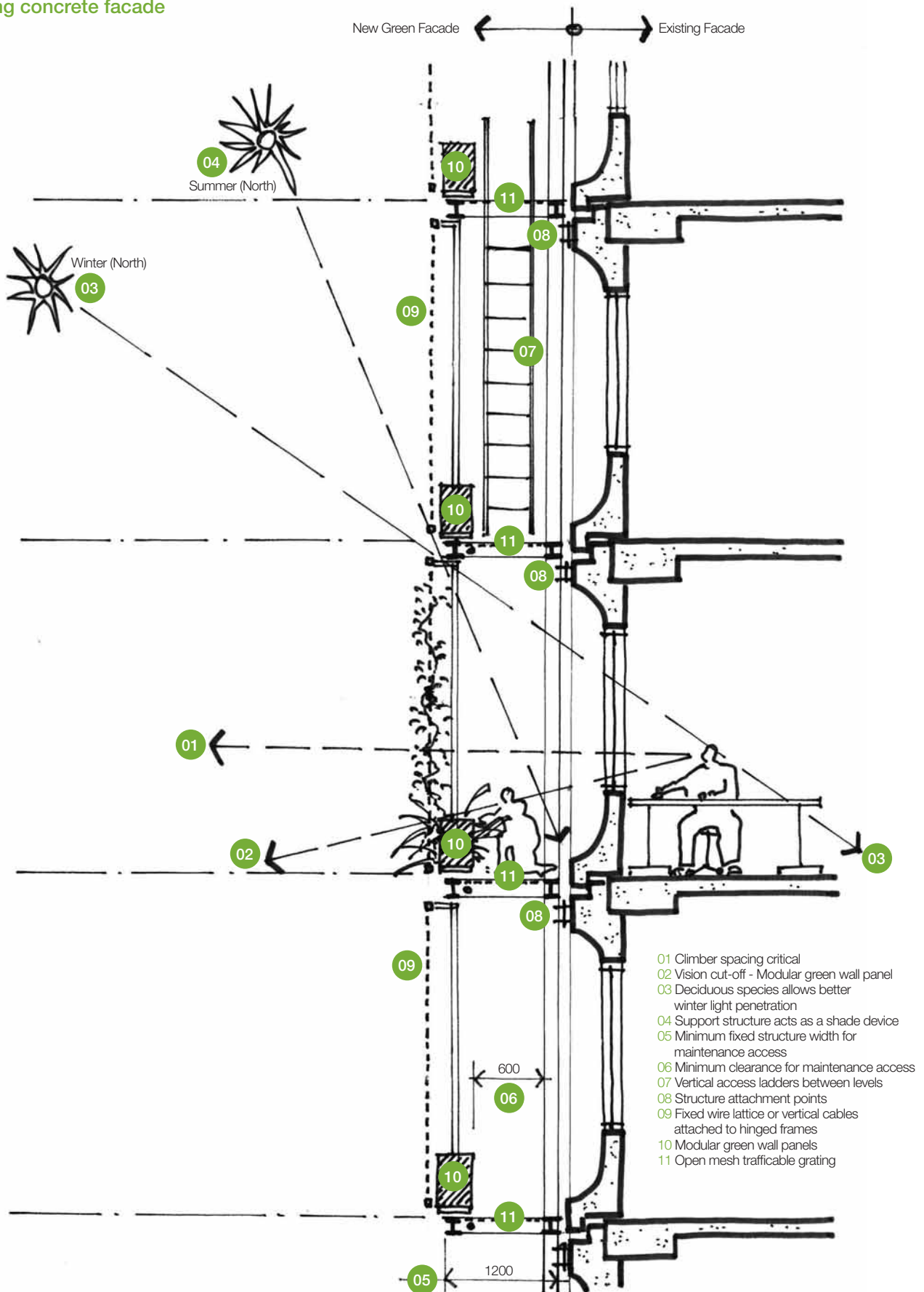
Advantages

- Integrated maintenance access frees the building of the need for a dedicated facade maintenance system
- Not limited to low rise facades

Disadvantages

- Higher up front capital cost
- Larger spatial requirement offset from glazed facade (1200mm nominal) which may become significant for encroachment / air rights issues with adjoining owners.

Existing concrete facade



Building Interactions

Retrofitting Options

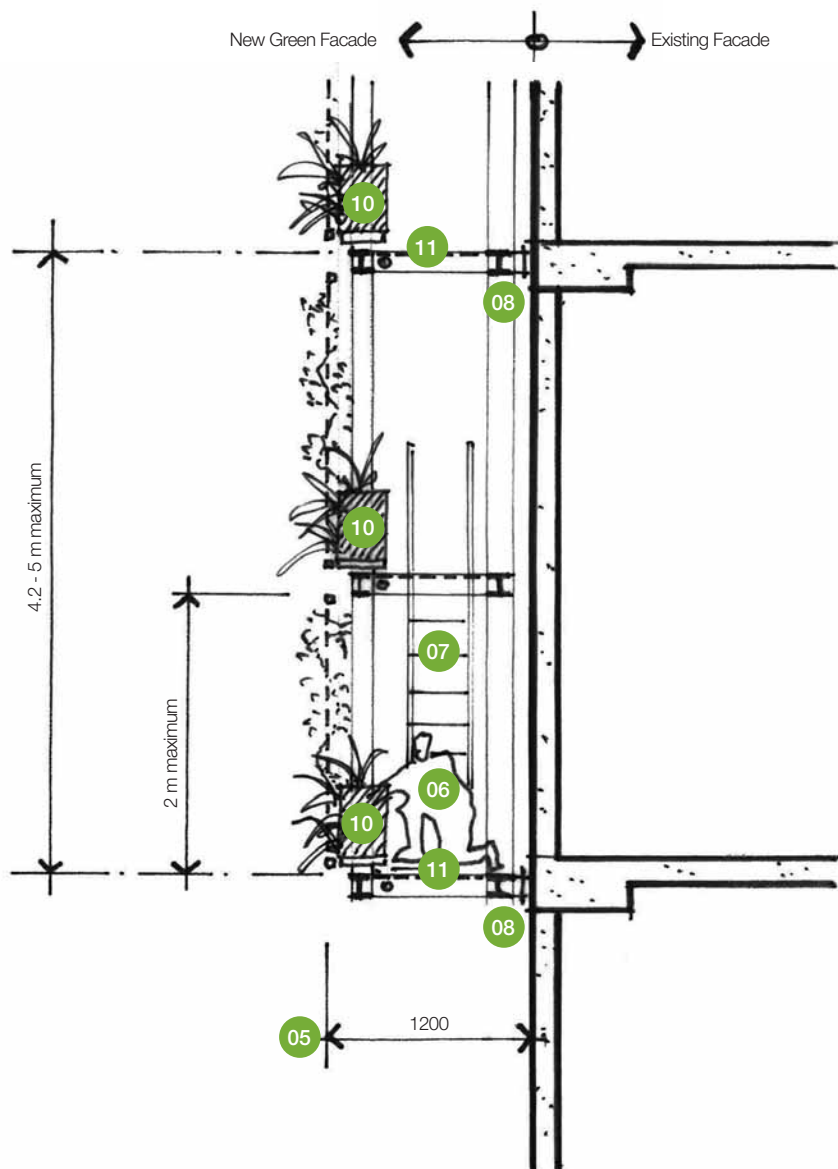
All three systems can be retrofitted to existing buildings provided that the wall structure has sufficient structural capacity to hold the selected system.

Green facades create less structural load onto the wall, particularly when the plants are planted directly into the ground, with no weight of planting medium to be carried by the wall. Even when planted into containers attached to the wall, these are spaced between floors with relatively lightweight cables carrying the climbing plants between containers.

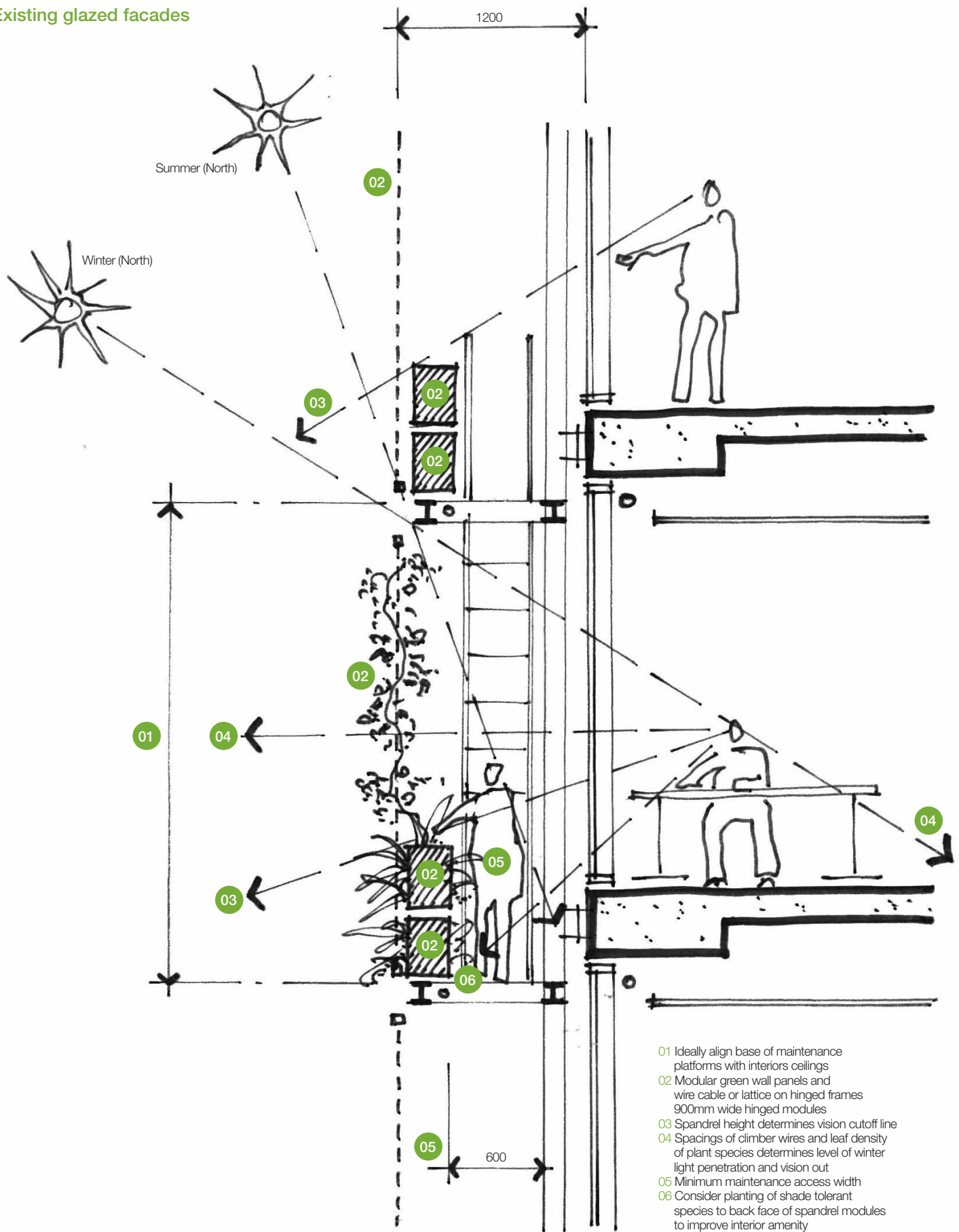
On the other hand green wall systems, consisting of solid panels of growing media held in a metal framework that is fixed directly to the building wall, have a greater weight which needs to be structurally accommodated.

Existing blank or solid walls lend themselves to the green wall system, which can be bolted directly onto the wall.

Existing blank walls



Existing glazed facades

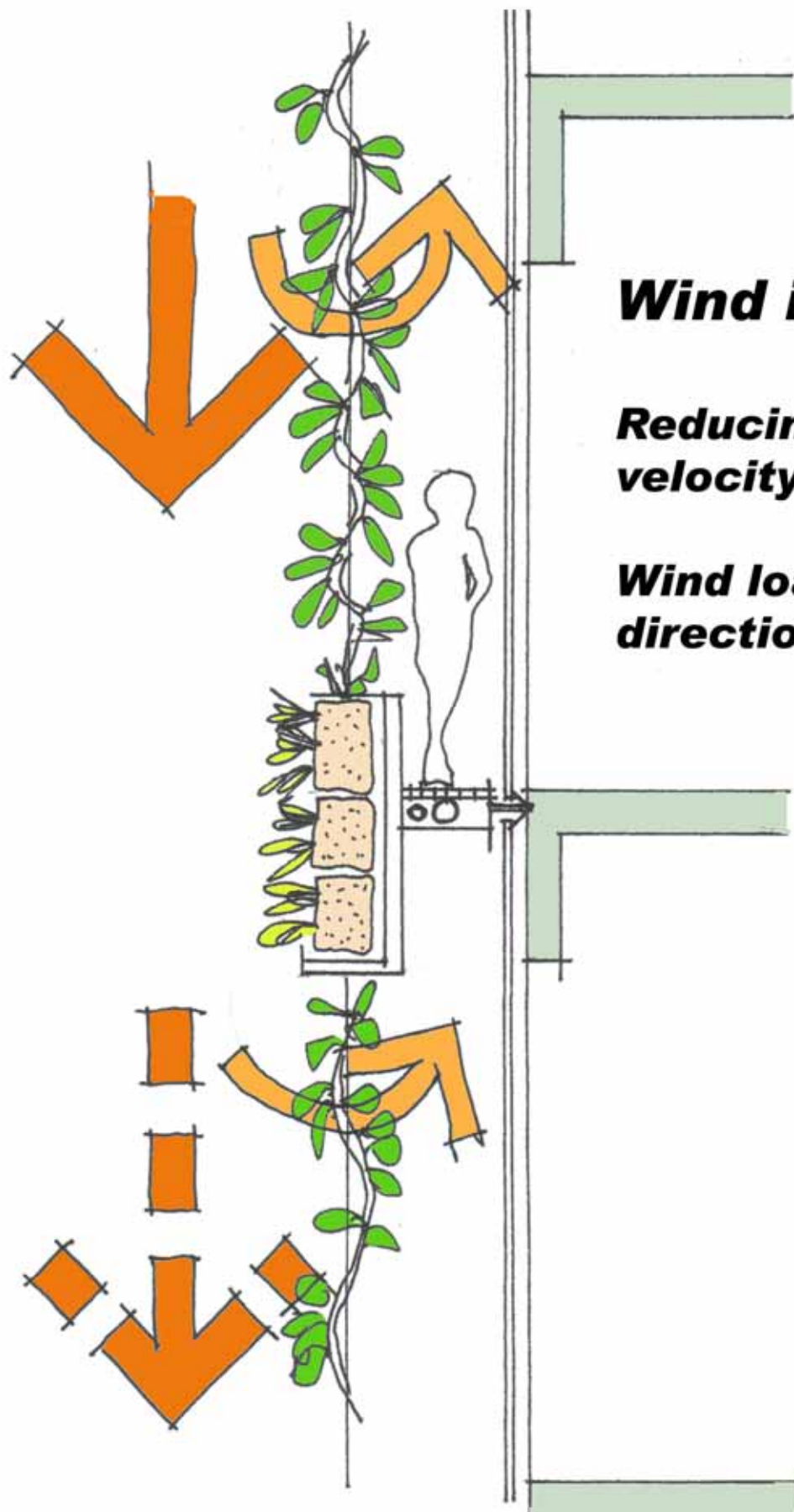


Building Interactions

Retrofitting Options

Existing glazed and precast panel facades are more problematic as the fixing points to the facade may not have the structural capacity for the additional loading and the points may be too far apart.

However, if the green facade system can be attached directly to the primary structure, retrofitting should be relatively straight forward. Existing facades with expressed spandrel zones lend themselves most suitably to green facade systems, water proofing of attachment points being the critical factor.



Wind issues

***Reducing
velocity***

***Wind load
direction***

Building Interactions

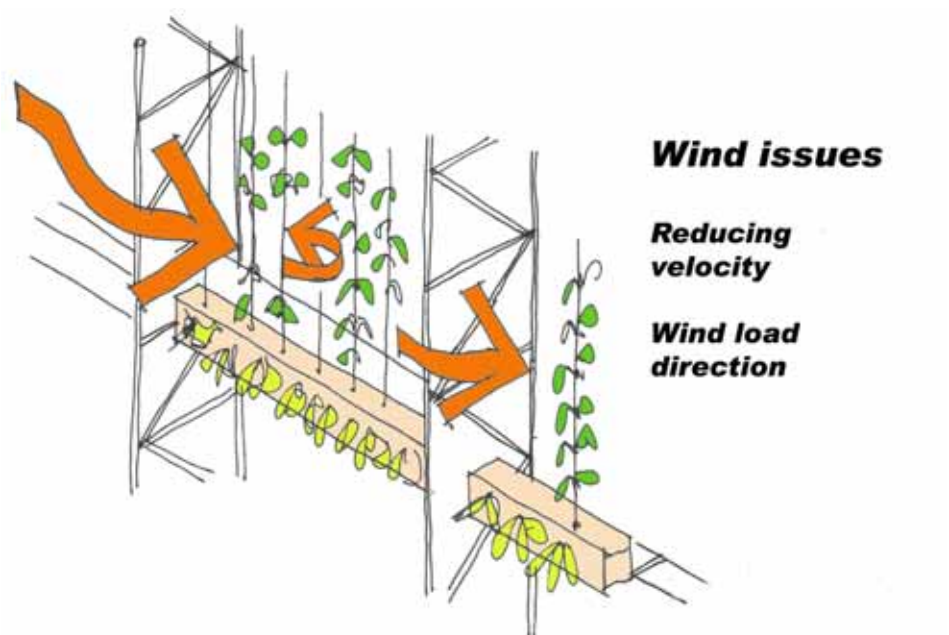
Retrofitting Options

Maintenance

Maintenance is a major consideration in the high rise living wall retrofit installation as there is no provision made for the existing window maintenance system. If a BMU is provided on the building roof then this can be used but if not, access via abseiling or ground base access up to 4-5 stories via travel tower are the only alternatives. Therefore a maintenance platform system built into the living wall hybrid system, accessible from the building interior, should be incorporated.

Loadings

The position of the living walls on the building is also important, as previously pointed out in relation to wind loading. The loadings may be vertical, down or up, and on the lee side the suction outward may be the dominant force. These factors are important in assessing the requirements for retrofitting.

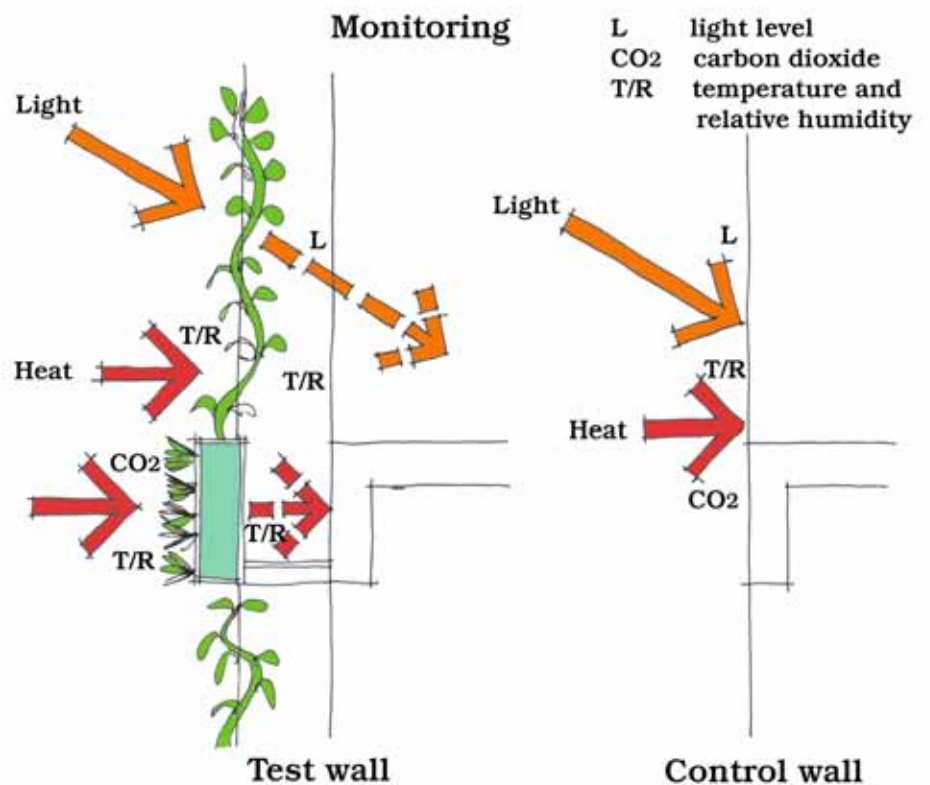


Building Interactions

Monitoring Methodology

Living walls in Adelaide, indeed in Australia, need working figures for the environmental benefits to the building and also to the surrounding environment. At the moment there is no published information on the performance of living wall systems, especially for high rise buildings, and their effect on the surrounding precinct and the effect on the atmospheric make up, such as water vapour and CO₂ composition.

The living wall prototype to be designed and installed in Adelaide following this feasibility study will be monitored with a series of systems to cover temperature, relative humidity, light intensity and CO₂, compared with a neighbouring control wall of the same construction and aspect.



The methodology will be to record readings on the trial living wall at various positions and monitor at selected times during the day and night for a full 12 month period to acquire the full range of seasonal variations. The loggers will be positioned on the living wall at the outside edge, on the inside edge, and also on the building facade surface. This will give the differences through the living wall as well as on the facade surface. Once these facade figures are available then a calculation through the facade can be made to show the difference in the building interior. This will be compared to the control wall for changes in CO₂, temperature and relative humidity, and the facade surface.

The potential changes in the CO₂ and relative humidity readings between the prototype and control wall will show the differences in surrounding atmosphere that affects the micro climate of the building. This will show the CO₂ changes brought about by the living wall and potentially can be used for calculations to offset the carbon production of the building.

The measurement of the light difference in the living wall will be of value to the architect for the amount of daylight entering the building through the windows. Monitoring the various densities of the wire/cables and different plant species will demonstrate the various daylight intensities within the building.



University of Adelaide Associate Professor Terry Williamson installing temperature loggers on Fifth Creek Studio's trial living walls in 2009 (Photo sourced from Fifth Creek Studio)

Building Interactions

Air Rights and Encroachments

In the situation where a building is built against the property boundary, a living wall attached to the building might overhang or encroach onto the adjacent property, even if it is well above ground level. Where this is over private property a negotiated agreement between the parties for use of air rights can occur, either by renting the air space or buying this space. In the city centre if an encroachment is over public land, including roads and community land, Adelaide City Council has an Encroachments Policy and provides a set of Operating Guidelines - Encroachments to assist with permit applications.

The Operating Guidelines - Encroachments states that, 'Considerations of encroachments over the public realm need to be balanced between short term and long term gains. In addition, encroachments need to be considered in relation to what benefits they offer to the public. Encroachments can add visual interest to the streetscape and individual buildings and improve pedestrian amenity by providing shade, shelter and informal surveillance'. Potential public benefits are considered within Council's principles to make the City of Adelaide culturally vibrant, socially just, environmentally sustainable, economically viable and outward looking. Where these living wall encroachments occur in the public realm no part of the living wall shall contain any form of commercial operation or building space. While this relates specifically to the City of Adelaide, those seeking to develop living wall projects in other metropolitan or regional council areas should consult directly with their local authorities.

Building Interactions Procedures

The following standard operating procedures relate to the assessment of encroachment permit applications.

Application

An application for an Encroachments Permit is received (if a development application is lodged prior to an Encroachment Permit application, the encroachment should be identified during the initial planning assessment and the application referred to Approvals);

Preliminary Assessment

The application is assessed to determine whether the encroachment proposal is in accordance with the Encroachments Policy and Operating Guidelines and whether a permit should be issued. 'In principle' approval or refusal of an Encroachment Permit is indicated to the applicant and Development Assessment;

Development Assessment

The development application is assessed against the Adelaide (City) Development Plan and a decision made in relation to whether all of the relevant consents can be granted (including Provisional Development Plan Consent, Encroachment Consent, Building Rules Consent and Development Approval);

Permit Issue

If an Encroachments Permit can still be supported, the Permit (including conditions and fees) is generated and then issued with the Development Approval;

Enforcement

Ensuring that all encroachments have the necessary permit, and that the encroachment is maintained in accordance with the permit conditions;

Maintenance

Administration of renewal of, changes in, or cancellation of permits and collection of annual fees.

(City of Adelaide)

Building Interactions

Cost Analysis

The two hybrid systems being considered offer the advantage that curtain wall façades can be replaced with glazed shop front construction between floor slabs. This greatly simplifies construction and reduces the cost of the glazed facade component.

Indicative costings are based on the two proposed hybrid options which are still at the feasibility stage, so are general in nature and not intended to provide any specific advice.

The two hybrid systems are:

- Hybrid System: without integrated maintenance access
- Hybrid System: with integrated maintenance access

A brief summary of the cost implication that would be common to both systems:

- Saving on the curtain wall facade (assumed ordinary shop front can be used)
- Saving on sun shading
- Saving on building maintenance unit (BMU) for high rise buildings.
- Reduces the amount of special glazing (low E, applied film, tinted glass etc.)
- Indirect savings from reduced AC plant and equipment costs

More detail on the above savings will be available after the performance of the prototype that follows this feasibility study has been assessed over its monitoring period.

Hybrid System: without integrated maintenance access

The single frame system and shop front glazing would be approximately the same cost as the curtain wall facade and the planting and container system would add an extra 40% approximately of the cost of a standard green wall system. A BMU would still be needed for high rise cleaning and maintenance access.

Hybrid System: with integrated maintenance access

The double frame system with walkways would be an additional 30-35% cost over the normal curtain wall facade, plus 40-45% of a standard green wall system extra for planting and container systems. If the planting for the spandrel was double sided then this would come to about 80% of the standard green wall system cost.

These figures are only a guide and are indicative of the preliminary concepts for this hybrid wall system.

Building Interactions

Future Directions

In the prototype project that will follow this feasibility study, the proposed hybrid living wall system will be designed and developed into a 2 or 3 floor high modular system with a bolt-on framework. Initially it will be installed on the old telephone exchange building, and eventually relocated to Tower 8 at an appropriate stage of the building's construction. This relocatable option opens up many possibilities for the future, but especially for retrofitting to existing buildings.

A modular hybrid living wall system with an internally accessible frame could potentially be disassembled and relocated to other buildings. If this was installed over the air rights of a privately owned space this could be rented out until the adjoining site was redeveloped. The hybrid living wall could then be relocated to another site, allowing the infrastructure to be recycled rather than lost.

The possibilities are exciting and point to a future mobile green infrastructure that enhances the sustainable, green credentials of Adelaide.

06

Summary

This study into the feasibility of living wall systems suitable for application on multi-storey buildings in Adelaide's challenging climate is collaboratively funded by The Government of South Australia and Aspen Group. Research has been undertaken by Fifth Creek Studio and Woods Bagot with contributions from Aurecon and Davis Langdon.

In summary the feasibility study includes:

- Living wall benefits – private and public
- Living wall classification system
- Living wall design factors
 - Climate
 - Planting
- Benefits to the building
 - Nature and water
 - Urban heat island effect and CO₂
- Living wall design options
 - Multi-storey retrofitting to existing stock
 - Multi-storey integrated with façade
 - Air rights and costs

This study shows that living walls offer multiple economic and environmental benefits to individual buildings, the wider environment and the public realm. They are becoming a significant component of an integrated green infrastructure and Adelaide will see many more exciting and innovative living wall projects in future.

To ensure the success of these living wall projects, Adelaide's particular climate and the local natural and built environment needs to be considered in the design, fabrication and ongoing maintenance programming. When planning large installations on high rise buildings, these considerations become even more critical, with issues such as wind, solar access, built form configuration and potential encroachments all impacting on these living systems.

This feasibility study provides an illustrated guide through a complex range of issues to propose several options for a living wall system suitable for multi-storey city buildings. In the end there will be no single design solution, but the design principles outlined in this study provide a clear starting point.

It is hoped that designers, developers, government representatives and members of the community embrace the concept of living walls, and support the ongoing growth of the industry and associated research and development.

$\frac{1}{2} \times 100 = 50\%$

07

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