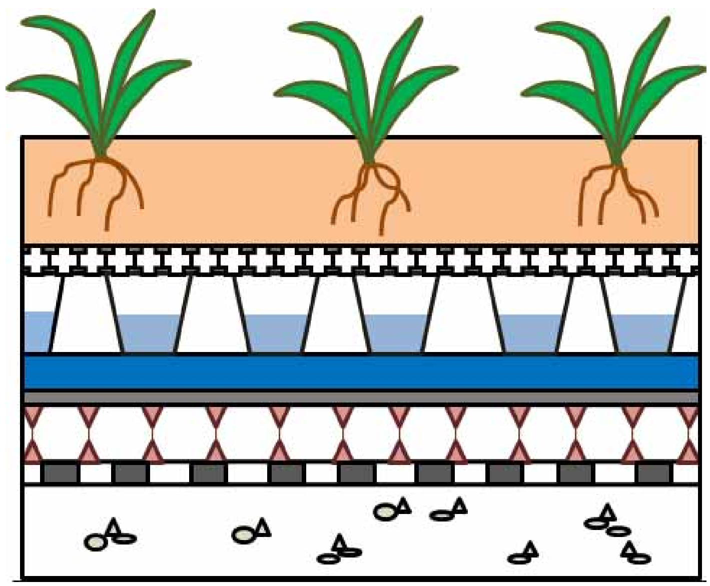
CIBSE Hong Kong Branch

Technical Guidelines for Green Roofs Systems in Hong Kong



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Preface

Nowadays many cities in the world are facing problems of urban heat island (UHI) effect and lack of greenery space. In Hong Kong, with the growing concerns about environmental issues and the need to promote sustainable urban environment, green roofs have attracted much attention in recent years. However, the market for green roofs in Hong Kong is still developing. There is a lack of good information and understanding on their technical design, effectiveness and actual benefits.

In fact, green roofs are not a new phenomenon. They have been standard construction practice in many countries for hundreds, if not thousands, of years. The ancient Babylonians incorporated elaborate vegetated roofs in the Hanging Garden's terraced structures (http://en.wikipedia.org/wiki/Hanging_gardens_of_Babylon), which were built around 500 B.C. and were considered one of the Seven Wonders of the Ancient World. Many European countries and cities provide incentives or requirements for green roof installation.

The environmental, social and visual contributions that green roofs can make towards creating sustainable living environment in high-density cities are accepted worldwide. It is believed that green roofs and other greening methods will become an important feature in the urban landscape and can perform a vital role in helping cities adapt to the effects of climate change. But they can only provide these environmental benefits if designed and installed in way which ensures minimum performance criteria are met. It should be noted that although green roof technology is relatively straightforward, it is possible for people who are unfamiliar with the technology to make mistakes or miss opportunities to maximise the benefits.

This document highlights the important considerations for green roof planning, design, installation and maintenance, and provides guidance as to how they can be accommodated in the final green roof scheme. It is hoped that the document can help promote awareness of green roofs, facilitate the effective planning, design and implementation of sustainable green roof projects in Hong Kong, and stimulate an increase in the uptake of green roofs on new developments and existing buildings.

The technical guidelines provide key information on green roof design, specification, installation and maintenance. However, there will be special cases where additional considerations will need to be made. The guidelines do not cover certain technical areas of green roof technology such as drainage flow rates, growing medium performance criteria or waterproofing. If the readers require technical information of this type, they may refer to the FLL (Forschungsgesellschaft Landschaftsentwicklung Landschaftbau) Guidelines from Germany (www.fll.de) and the relevant standards as described in Appendix IV.

Green roofs offer an important way forward in urban greening, bringing natural wildlife back into the urban realm and providing much needed ecosystem services to the built environment. It is believed that our cities and towns need to embrace green roofs to ensure that we adapt and mitigate our impact on the environment to achieve a liveable quality and sustainable built environment.

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List of Abbreviations

AFCD	Agriculture, Fisheries and Conservation Department, HKSARG
AP	Authorized Person
ArchSD	Architectural Services Department, HKSARG
ASTM	American Society for Testing and Materials
BCIT	British Columbia Institute of Technology (Canada)
BD	Buildings Department, HKSARG
BEAM	Building Environmental Assessment Method
BSE	Building Services Engineer
CEDD	Civil Engineering and Development Department, HKSARG
CIBSE	Chartered Institution of Building Services Engineers
CUGE	Centre for Urban Greenery and Ecology, Singapore
DEVB	Development Bureau, HKSARG
DSD	Drainage Services Department, HKSARG
EB	Education Bureau, HKSARG
ECF	Environment and Conservation Fund
EMSD	Electrical and Mechanical Services Department, HKSARG
ENB	Environment Bureau, HKSARG
ETWB	Environment, Transport and Works Bureau, HKSARG
FBB	Fachvereinigung Bauwerksbegrünung e.V. (German Green Roof Association)
FLL	Forschungsgesellschaft Landschaftsentwicklung Land-schaftsbau e.V. (Research Society for Landscape Development and Landscape Design)
GFA	Gross floor area
GRO	Green Roof Organisation (UK)
HKPSG	Hong Kong Planning Standards and Guidelines
HKSAR	Hong Kong Special Administrative Region
HKSARG	Hong Kong Special Administrative Region Government
HKU	The University of Hong Kong
HVAC	Heating, Ventilating and Air Conditioning
IGRA	International Green Roofs Association
JPN	Joint Practice Notes
LandsD	Lands Department, HKSARG
LEED	Leadership in Energy and Environmental Design
LUSH	Landscaping for Urban Spaces and High-rises programme (Singapore)
NParks	National Parks Board (Singapore)
NRCA	National Roofing Contractors Association (USA)
PlanD	Planning Department, HKSARG
PNAP	Practice Notes for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers
PV	Photovoltaic
RSE	Registered Structural Engineer
SC	Site coverage
SEGES	Social and Environmental Green Evaluation System (Japan)
SPRI	Single Ply Roofting Industry (USA)
UHI	Urban heat island
URA	Urban Redevelopment Authority (Singapore)
USGBC	U.S. Green Building Council

1. Introduction

Green roof systems are living vegetation installed on the roofs and can provide many environmental and social benefits for achieving low carbon high performance building (Hui, 2010). They could contribute positively to make cities more liveable by providing green spaces, mitigating urban heat island (UHI) effect, reducing air quality problem, enhancing stormwater management and biodiversity (Cantor, 2008; Doshi, *et al.*, 2005; Dunnett and Kingsbury, 2008; Hassell and Coombes, 2007; Hui, 2006).

Many cities in the world are now facing problems of UHI effect and lack of greenery space. As Hong Kong has extremely high population densities in the urban areas, it is believed that the urban environment is threatened by an intense UHI effect and that urban greening is very important for resolving the issues (BD, 2009; Hui, 2009). Green roofs can help to mitigate the adverse effects of UHI and bring the nature back to the urban area (Hui and Chan, 2008; Kumar and Kaushik, 2005; Liu, 2003; NRCA, 2007). They not only can help lower urban temperatures, but also can improve aesthetics and urban psychology, as well as reduce pollutant concentrations and noise (Wong and Chen, 2009; Wong, Tan and Chen, 2007). Figure 1.1 shows two examples of green roof systems in urban cities in the world (Japan and Canada).

ACROS Fukuoka Prefectural International Hall, Fukuoka, Japan (Source: www.greenroofs.com)

Library Square Building in downtown Vancouver, BC, Canada (Source: http://urbangreens.tumblr.com)

Figure 1.1 Green roof systems in Japan and Canada

1.1 Purpose

The purpose of the technical guidelines is to provide practical information on green roof systems for education and effective application. The guidelines establish recommendations and requirements on green roof planning, design, construction, maintenance and project management which apply in general terms to Hong Kong. This document is intended for use by professionals and other interested persons who are considering taking advantage of the economic, social and environmental benefits green roofs offer.

After reading this document you should be able to understand the following:

- The basic types and structure of green roofs
- The multitude of potential green roof benefits
- The important knowledge and best practice for green roof projects
- The key technical issues to address during planning, design, construction, maintenance and project management of green roof systems

The guidelines are divided into three parts as shown below and will provide a systematic guidance to the readers on planning, design, construction, maintenance and management of green roof systems. Useful references from overseas have been studied (Dvorak, 2011; FLL, 2008; Loesken, 2009). Local data and information are also used, wherever appropriate.

- Part 1
    - Chapter 1. Introduction
    - Chapter 2. Scope
    - Chapter 3. Definitions
- Part 2
    - Chapter 4. Planning Requirements
    - Chapter 5. Design Considerations
    - Chapter 6. Construction Methods
    - Chapter 7. Maintenance Issues
    - Chapter 8. Project Management
- Part 3
    - References
    - Appendices

By clarifying the myths surrounding green roof installations and developing reliable guidance, it is hoped to promote industry confidence and prevent low-quality products and construction from entering and dominating the market. Other resources and further information about green roof systems can be found in the References section and in Appendix I – Useful Websites and Resources.

1.2 Benefits of Green Roofs

Green roofs can address many of the challenges facing urban cities. It is well proven in the world that green roofs are an investment which provides a significant number of social, environmental and economic benefits (Banting, *et al.*, 2005; Doshi, *et al.*, 2005). They have a potential to:

- Reduce energy demand on space conditioning
- Reduce storm water runoff
- Expand the lifetime of roofing membranes

- Reduce the urban heat island effect in cities
- Improve air quality and biodiversity
- Add aesthetic appeal
- Increase property values

1.2.1 Urban Management

The vegetation and the growing medium in the green roof keep the roofing membrane cool in the summer by shading, insulating and evaporative cooling (Liu, 2002 & 2003). Therefore, green roof can significantly moderate the daily temperature fluctuations experienced by the roof membrane. Also, green roof can protect the roofing membrane against ultra-violet (UV) radiation and puncture or physical damage from recreation or maintenance. The vegetation can alleviate air and water quality problems by filtering pollutants through the leaves or the roots. In addition, greening in urban areas has been shown to increase mental well-being, biodiversity and residential property values (Bass and Baskaran, 2003).

Apart from enhancing the city landscape and environment, mitigating the UHI effect and improving air quality, green roof can improve the microclimate and increase the life span of waterproof and insulation facilities on the roof. Consequently, roof greening with a sufficient large scale is conducive to energy conservation and life cycle cost saving for the urban city.

Moreover, green roofs have an important role to play in the society’s commitment to a more sustainable future. They provide a visual display and expression of the city’s intent to develop environmentally sustainable, climate-adapted urban management. The marketing benefits could encourage both private and public sectors to consider green roof projects.

1.2.2 Public and Private Benefits

Green roofs provide a wide range of benefits from amenity to ecological, technical advantages to financial aspects (Hui, 2006). Table 1.1 gives a summary of the public and private benefits of green roof systems. It is believed that cities could benefit from green roofs both in visual, aesthetic and local human climatic amelioration. However, it is not easy to quantify all of them for economic comparison.

Table 1.1 Public and private benefits of green roof systems

Public benefits:	Private benefits:
- Aesthetic value - Mitigate urban heat island - Stormwater retention - Create natural habitat - Functional open space - Agricultural space - Filter dust and pollutants - Filter rainwater - Carbon sequestration	- Increase roof life span - Reduce cooling loads - Contribute to green building rating credit points - Better use of space - Reduce noise levels - Reduce risk of glare for surrounding buildings - Possible food production - Increase property value - Improve efficiency of solar photovoltaic panels

The social benefits of promoting green roofs in Hong Kong should not be overlooked. For example, public housing can provide senior citizens and families with safe, accessible green space on top of the buildings, as well as improving their quality of life. Schools can integrate curricula and provide added green space for students' experimental learning (outdoor rooftop classrooms). Hospitals and other health care facilities can provide opportunities on green roofs for horticultural therapy, a proven method of speeding recovery rates and reduction of drug use. Commercial buildings can create green space and roof gardens for relaxing and promoting horticulture or community farming. Industrial buildings can incorporate specialized green roofs for cooling, to provide amenity space for employees, or simply to improve the aesthetic surroundings for buildings that overlook the roof.

If the site conditions permit, green roofs can also be designed to generate urban agricultural opportunities for the production of high quality organic foods, and medicinal and ornamental plants (Hui, 2011). This has the advantages of reducing associated transportation and refrigeration costs, reducing the time and distance from field to table, ensuring ripeness at harvest, and providing new employment opportunities for city dwellers (see also Section 5.7).

1.3 Major Barriers

Greening activities in urban cities often face a difficult situation because of disordered urbanisation and the escalation in land prices. With increasing population and limited land, the government policy may directly or indirectly result in development proposals tending to adopt a high density or high-rise strategy. Thus, space constraints have reduced the applicability of green surfaces in various areas surrounding the building envelope.

Like any innovation, lingering doubts about green roofs still persist, worries ranging from costs, leakage to mosquito prevent the widespread adoption of green roofs. Financial incentives, public awareness and building codes can help hasten the adoption of green roofs and other measures. It is important to help property owners and developers to look beyond the immediate financial burden to realise the long-term benefits and the pressing need to change the urban environment.

1.3.1 Constraints and Barriers

Urbis Limited (2007) has indicated the following key constraints affecting green roof development. Shepard (2010) also identified similar challenges in USA.

- Lack of knowledge and awareness
- Lack of incentive/statutory mandate
- Economic constraints
- Lack of available roof area
- Technical issues and risks associated with uncertainty

In Canada, Oberlander, Whitelaw and Matsuzaki (2002) had studied the major barriers to green roofs and concluded the following critical aspects: economic, safety issues, maintenance issues, education and permits.

From the economic point of view, there is a disconnection between who bears the cost of a green roof and who benefits. A developer may erect a building intending to sell it as soon as constructed. To keep costs low and maximise profits, amenities like green roofs will not be included unless required or encouraged. Table 1.2 shows the green roof benefits for developers, owners and community. In order to overcome the barriers, it is necessary to let more people understand the significance of greening and to design suitable green roof policy for the society.

Table 1.2 Green roof benefits for developers, owners and community

	Benefit	Developer	Owner	Community
1.	Aesthetics and property values	√√	√√	√
2.	Mitigate urban heat island			√
3.	Stormwater retention	√	√	√√
4.	Create natural habitat			√
5.	Provide functional open space	√√	√√	√√
6.	Provide agricultural space	√	√	√
7.	Filter dust and pollutants		√	√
8.	Filter rainwater			√
9.	Carbon sequestration			√√
10.	Increase roof life span	√√	√√	
11.	Reduce cooling loads		√√	
12.	Green building rating credit points	√√	√	
13.	Reduce noise levels		√	√
14.	Reduce risk of glare		√	√
15.	Possible food production		√	√√
16.	Increase property value	√√	√√	
17.	Improve efficiency of solar PV panels	√√	√√	

1.3.2 Hong Kong Situation

Hong Kong has a subtropical hot and humid climate and often faces typhoon and stormwater problems during the rainy season (Hui and Chu, 2009). The strong wind and heavy rainstorm could cause flooding and serious damages to the society. The most important climatic factors affecting rooftop greening include:

- *Typhoons*. The strong wind might blow away the vegetation and soil. Modules and plants must be well secured and protected.
- *Heavy rainfalls*. They are quite common in rainy seasons. The green roofs should be able to hold and drain the rain water without creating pools of stagnant standing water.
- *High temperature*. High temperature might affect some plant species. The heat stress can affect plant growth and development by influencing photosynthesis, respiration, water relations and membrane stability.
- *Strong sunlight*. Strong solar and UV radiation might cause photo-oxidative problems to the green roof materials and components (such as plastics and wood), limiting their useful life.

Although there have been many applications of green roof technology in the world, not all green roofs have remained green or performed equally (Dvorak, 2011). Several types of failings are found on green roofs including poor drainage and inadequate growth media design, exceedance of structural designs, and plant failures and difficulties with maintenance. Therefore, in order to avoid the pitfalls, it is important to have guidelines and performance standards for green roof systems set up in Hong Kong.

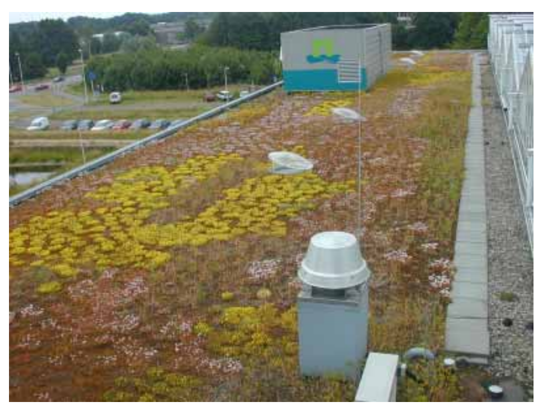
2. Scope

Green roof systems are also referred to as greenroofs, living roofs, roof gardens, eco-roofs, landscaped roofs, and vegetated roof covers. The green roof systems addressed in the guidelines are typified by a top layer of living plant material and soil (growth media or engineered soil) supported on the roofing assembly below. Green roofs are constructed using components that:

- Have the strength to bear the added weight
- Seal the roof against penetration by water, water vapour, and roots
- Retain enough moisture for the plants to survive periods of low precipitation, yet are capable of draining excess moisture when required
- Provide soil-like substrate material to support the plants
- Maintain a sustainable plant cover, appropriate for the climatic region
- Offer a number of hydrologic, atmospheric, thermal and social benefits for the building, people and the environment
- Protect the underlying components against UV and thermal degradation

Depending on the types of green roof systems to be used, the components used in green roofs may generally be the same as those in rooftop gardens, differing only in depth and project-specific design application. Figure 2.1 shows examples of modern green roof projects in Malaysia (a convention centre) and the Netherlands (a university building). Figure 2.2 shows another two examples in Singapore for municipal buildings.

Putrajava International Convention Centre, Malaysia
(Image source: Dr. Sam C. M. Hui)



IBN-DLO Wageningen, the Netherlands
(Image source: Dr. Sam C. M. Hui)

Figure 2.1 Examples of modern green roofs in Malaysia and the Netherlands


Bukit Panjang Sports Hall, Singapore (Image source: www.skyrisegreenery.com)


Marina Barrage, Singapore (14,000 m^2) (Image source: www.skyrisegreenery.com)

Figure 2.2 Examples of modern green roofs in Singapore

2.1 Green Roof Types

Modern roof greening has two main approaches: intensive and extensive (Dunnett and Kingsbury, 2008; Weiler and Scholz-Barth, 2006; Zinco, 2000). Extensive green roof systems are typically characterised by shallower system profiles of 60-200 mm depth, with a weight of 60-150 kg/m², with lower capital cost, no added irrigation and lower maintenance. Intensive green roof systems are those characterised by system profiles ranging from 150 to 1000 mm in depth, with a weight of 180-500 kg/m² and able to support a wider range of plants, though demanding more maintenance.

Semi-intensive green roofs fall in between extensive and intensive green roof systems. Table 2.1 shows the major types of green roofs and their characteristics.

Table 2.1 Major types of green roofs and their characteristics (Hui, 2006)

Characteristics	Extensive	Semi-intensive	Intensive
Depth of substrate	150 mm or less	Above and below 150 mm	More than 150 mm
Accessibility	Often inaccessible	May be partially accessible	Usually accessible
Fully saturated weight	Low (70-170 kg/m^2)	Varies (170-290 kg/m^2)	High (290-970 kg/m^2)
Plant diversity	Low	Greater	Greatest
Plant communities	Moss-sedum-herbs and grasses	Grass-herbs and shrubs	Lawn or perennials, shrubs and trees
Use	Ecological protection layer	Designed green roof	Park like garden
Cost	Low	Varies	Highest
Maintenance	Minimal	Varies	Highest

Depending on such site specific factors as location, structural capacity of the building, budget, client needs, and material and plant availability, each individual green roof will be different, likely a combination of intensive, semi-intensive and extensive systems. Appendix II provides further information about different types of green roof systems which are defined and applied in other countries.

2.1.1 Built-in and Modular Green Roofs

According to the basic construction method, green roof systems can be divided into two categories: built-in green roofs and modular green roofs. Table 2.2 shows the comparison of these systems. Figure 2.2 shows examples of built-in and modular green roof systems in Singapore which are installed on carpark roofs of the housing estate. Some green roofs are rolled out like sod, some are pre-planted in boxes, and some are installed layer by layer (Loh, 2009). Interlocking modular systems are also developed in recent years to suit particular site conditions (Hui and Chan, 2008; Velazquez, 2003).

Table 2.2 Comparison of built-in and modular green roofs

Built-in green roofs	Modular green roofs
▪ Installed as a series of layers ▪ Usually require a longer installation period ▪ More complex and permanent ▪ Time is needed for on-site installation & growing ▪ Excess weight (180 to 450 kg/m^2) ▪ Complexity of maintenance ▪ Separate installation of green roof components ▪ Increase design opportunities, biodiversity and experience ▪ Use various subcontractors for design and installation	▪ Prefabricated off-site and pre-grown in nursery ▪ Usually require a shorter installation period ▪ With modular design and sub-divided into standard interchangeable parts ▪ Ready made flexible (vegetative mats into a woven fabric) or firm (metal or recycled plastic) trays or modules ▪ The essential components of the system already combined ▪ Type of plants may be limited

Built-in green roof system

Modular green roof system

(Source: Dr. Sam C. M. Hui)

Figure 2.3 Examples of built-in and modular green roof systems in Singapore (on carpark roof of housing estate)

In general, the benefits of modular green roof systems include:

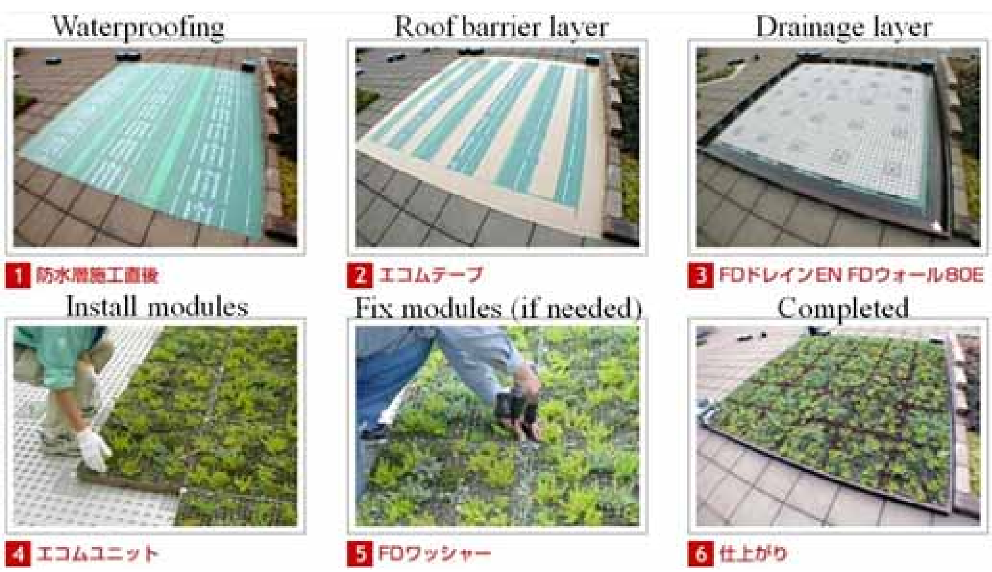
- Design simplicity & immediate roofscapes (instant greening)
- Easy and time saving installation
- Off-site planting
- Different growing medium types and depths
- Adaptive to all forms of irrigation
- Adjustment and rearrangement after installation are easier

Modular systems are commonly used in the form of trays of vegetation in a growing medium that are grown offsite and simply placed on the existing roof to achieve complete coverage. With a modular system, the drainage, soil substrate or media, and the plants are self-contained within the module, with varying dimensions. In effect, these three main components of a green roof are replaced by a fully planted module. When interlocked, they offer continuous roof drainage and coverage.

2.1.2 Examples of Modular Green Roof Systems

Modular green roof systems can be available in different depths of growing medium typically ranging from 75 mm to 300 mm. One particular form of modular green roof systems is the precultivated vegetation blankets that resembles green roof tiles and can be available in different dimensions. Figure 2.3 shows three examples of modular green roof systems including vegetated mat, tray and sack systems. Figure 2.4 shows the construction sequence of a modular green roof system from Japan. It can be applied to existing buildings and can also be changed or removed easily.

Figure 2.4 Examples of modular green roof systems (Hui and Chan, 2008)



(Source: www.tajima-roof.jp)

Figure 2.5 Installation sequence of a modular green roof system from Japan

2.2 Applications in Hong Kong

In Hong Kong, intensive green roofs are commonly found in the form of podium gardens which provide valuable functional open space for human use. Figure 2.6 shows an example of podium roof garden in Hong Kong. Some new commercial and residential buildings have sky gardens or greenery on the upper floors or at the top of the building. Many public open spaces are also built either wholly or partially on structure. Figure 2.7 shows some examples of green roof systems in Hong Kong.

However, the application of extensive green roofs and other urban greening technologies is still limited in Hong Kong due to various reasons. For instance, there is no government regulation on compulsory use of green roofs for private developers to build them on new projects and technical difficulties to install green roofs in existing buildings. But, these issues have been improved through the introduction of green building incentives (see Section 4.5) and the promotion of green government buildings (DEVB and ENB, 2009). Moreover, it is believed that extensive green roofs are better-suited to retrofitting projects which have their own technical constraints, and are not yet well-established in Hong Kong. Therefore, more information on extensive green roofs is provided in the guidelines.

(Source: Dr. Sam C. M. Hui)

Figure 2.6 Podium green roof in Hong Kong

Ocean Park Hong Kong

EMSD Headquarters

Parklane, Tsimshatsui

A school in San Po Kwong

(Source: Dr. Sam C. M. Hui)

Figure 2.7 Examples of green roof systems in Hong Kong

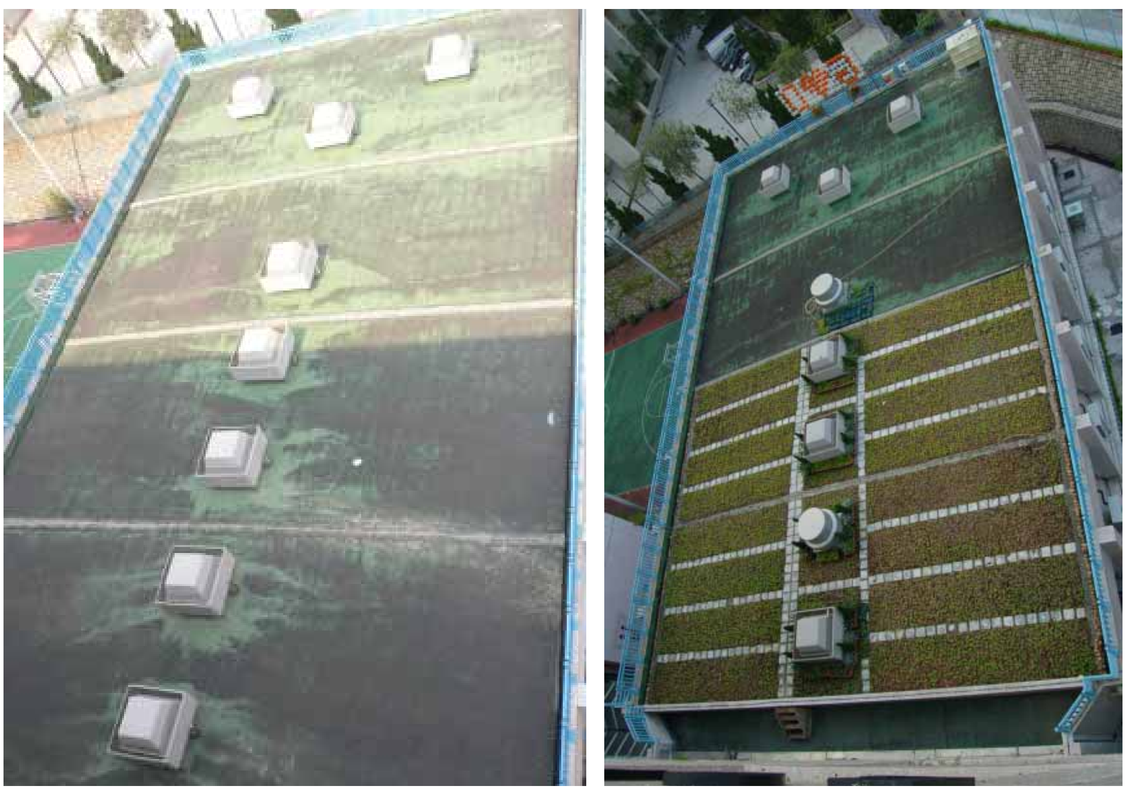
When green roof systems are applied to new buildings, there are some advantages over existing buildings (Urbis Limited, 2007). Firstly, costs can be saved in the design stage since the systems can be part of the existing contract. Secondly, roof slabs can be designed to take heavier soil depth loads. Thirdly, irrigation and water supply can be built into the roof from the beginning. Fourthly, utilities can be arranged to maximise green roof area. Fifthly, barrier-free access (e.g. lifts) can be incorporated into the design if public access is considered. Finally, extended side walls to protect green roofs from excessive wind may be incorporated at the design stage.

2.3 Green Roofs for Existing Buildings

However, for widescale installation of green roofs to take place in a way that has a significant impact on the reduction of the UHI effect or rainfall run-off at a sub-catchment (district) level, the majority of green roofs will need to be retrofitted (Liu, 2011). It should be noted that green roofs on existing buildings through retrofit projects is an important consideration for urban cities like Hong Kong because existing buildings constitute a major portion of the building stock. Also, in order to maximize the greenery of the built-up areas (CEDD, 2010), the roof greening is one of the effective measures. When applied to these buildings, the green roof design will be limited to the loading capacity of the existing roof unless a higher initial cost is paid to upgrade the structure. Thus, a suitable green roof system (usually light-weight) and proper design arrangement are important for existing buildings.

Owners of commercial and institutional buildings normally repair or refurbish roofs during the lifetime of the building (typically every 15-20 years) and do not require planning permission to do this. In most situations on commercial or institutional buildings retrofitting of green roofs is technically feasible. When this occurs, this presents an opportunity for the community to encourage the building owner to green the roof. This may be achieved to some extent simply through education alone (when the building owner becomes aware of energy savings and other benefits, he or she may decide to invest in a green roof). However the additional cost associated with purchasing and installing green roofs may deter some owners. In the short to medium term, it may be necessary to establish a subsidy or grant scheme in order to encourage green roof installation. In the longer term, as energy prices increase, reductions in building running costs and extension of roof life may be incentive enough.

When considering a retrofit project, the age and condition of the existing building and roof will affect the feasibility of a green roof. Roof-top utilities and plant space can constrain the possible area of green roofs. The current structural loading and building requirements may limit growth medium depth and type of vegetation. Also, the installation of additional rooftop water points and new drainage points may be needed. In addition, if access to the roof may be difficult (e.g. only by using cat ladder), then additional safety devices may need to be installed. In some situation, barrier-free access may be impossible to retrofit. Figure 2.8 shows an example of retrofit project with green roof on a school building in Hong Kong.



Before retrofit After retrofit with a green roof system

(Source: Dr. Sam C. M. Hui)

Figure 2.8 Retrofit project with green roof on a school building in Hong Kong

3. Definitions

A green or living or vegetative roof can be considered as a system where vegetation is incorporated into a roof, usually supported by a growing medium, filter sheet, drainage/reservoir layer, root barrier and waterproof membrane (FLL, 2008). Green roofs can block solar radiation, and reduce daily temperature variations and thermal ranges between summer and winter. NRCA (2009) defines green roof system as “a roof area of plantings/landscape installed above a waterproofed substrate at any building level that is separated from the ground beneath it by a man-made structure”.

A green roof development involves the creation of vegetated space integrated structurally on top of a man made structure (Urbis Limited, 2007). The word ‘roof’ in this context refers to any continuous surface designed for the protection of inhabitants from the elements, whether open or closed on the sides. The vegetated space may be below, at, or above grade, located on a podium deck, a ‘sky garden’ on an intermediate floor level, or at the very top level of the building, but in all cases the plants are not planted in the ground.

Freestanding containers and planters placed on top of a roof are not generally considered to be true green roofs, although this is an area of debate. However, there are circumstances, particularly in retrofitting, where use of planting in pots or planters may provide a practical solution and an acceptable greening effect.

3.1 Structure of Green Roofs

A green roof requires appropriate levels of each of the following in order to flourish: sunlight, moisture, drainage, aeration to the plants root systems and nutrients. Figure 3.1 shows the typical structure of extensive green roof (Hui, 2009). It is composed of a waterproof membrane, followed by a root barrier, a layer of insulation, a drainage layer, the growing medium or soil substrate, and the plant material. A shallow layer of gravel or pebbles are placed from 0.5 m to 1 m within the outside perimeter of the roof, providing additional drainage, fire control, and access to the roof for maintenance. Other components and accessories of green roofs may include insulation, membrane protection layer, leak detection system, ponds and pools, irrigation system, walkways, curbs and borders, railings and lighting. The thermal insulation layer is optional and will be needed according to the climatic conditions and local thermal efficiency regulations. Table 3.1 describes the functions of the major components of the green roof system.

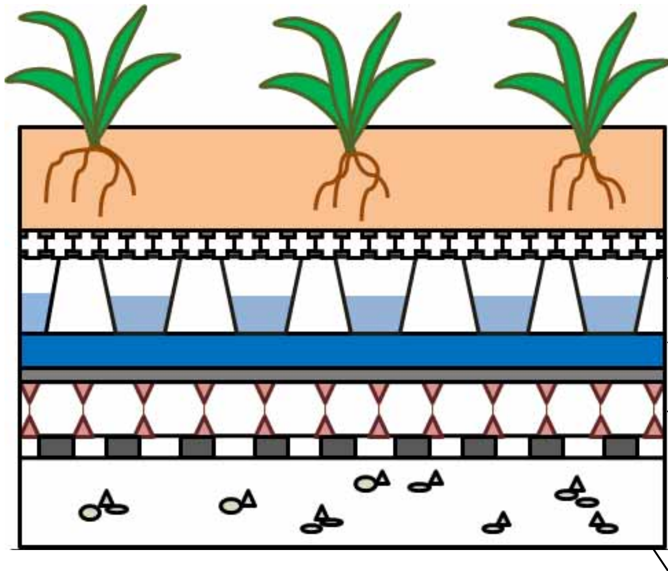


Figure 3.1 Typical structure of extensive green roof (Hui, 2009)

Table 3.1 Major green roof components and their performance characteristics

Layer	Functions	Performance Characteristics
Vegetation	Various types of vegetation could be chosen for intensive or extensive systems. Shrubs, coppices and tress can be found in intensive systems; while grasses that require low maintenance and capable of self-propagation are usually used in extensive systems.	▪ Appearance ▪ Species diversity ▪ Indigenous species ▪ Plant characteristics ▪ Perennials or annuals ▪ Water consumption pattern ▪ Environmental tolerance
Substrate/ Growing medium	An engineered soil replacement that contains a specified ratio of organic and inorganic material; specifically designed to provide green roof plants with the air, water and nutrient levels that they need to survive, whilst facilitating the release of excess water.	▪ Weight (kg/m²) ▪ Resistance to wind and water erosion ▪ Free from weeds, diseases and pests ▪ Appropriate water retention ▪ Appropriate supply of nutrients
Filter sheet	A geotextile that avoid fine soil or other substances get into the drainage layer to ensure the efficiency of drainage layer and maintain permeability.	▪ Weight (kg/m²) ▪ Tensile strength (kN/m²) ▪ Flow rate under hydraulic head of 10 cm (l/s/m²) ▪ Effective pore size (m²) ▪ Penetration force (N)
Drainage/ storage layer	Made of hard plastic, polystyrene, foam, coarse gravel or crushed recycled brick; act as a water reservoir to retain water to certain level and can drain out excess water.	▪ Water storage capacity (l/m²) ▪ Filling volume (l/m²) ▪ Flow rate (l/s/m²) ▪ Weight [dry] (kg/m²) ▪ Compressive strength (kN/m²)
Moisture mat	A geotextile blanket, available in varying thicknesses (typically between 2-12 mm); provide an additional measure to retain water; protect the waterproof membrane during the installation.	▪ Water storage capacity (l/m²) ▪ Thickness (mm) ▪ Weight [dry] (kg/m²) ▪ Tensile strength (kN/m²)
Root resistant membrane	The membrane can be a chemical agent of a physical root barrier. It is essential in the system to prevent the root of plant from penetrating into the roof structure, which will lead to water leakage problem and even damage to the building structure.	▪ Density (kg/m³) ▪ Tensile strength (N/mm²) ▪ Elongation to break (%)

3.2 Green Roof Guidelines and Standards

Germany and Japan are technically more advanced and have done a lot of pioneering work in supporting roof greening with various innovations. Figure 3.2 shows examples of extensive green roof systems from Germany and Japan.

(Source: Dr. Sam C. M. Hui)

Figure 3.2 Extensive green roof systems from Germany (left) and Japan (right)

3.2.1 Germany

The FLL, established in 1975 as a not-for-profit organization, is the Research Society for Landscape Development and Landscape Design (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.) (www.fll.de). It is a key player in the development of the green roof movement in Germany (Lawlor, *et al.*, 2006). When the green roof market boom first took off in Germany, many unqualified green roof companies surfaced, leaving behind a legacy of poorly constructed green roofs. The FLL guidelines (FLL, 2008; FLL, 2002) have been highly successful in setting quality standards for green roof systems throughout Germany. Home and building owners are guaranteed a sound product when purchasing green roof systems and products designed according to the FLL guidelines.

The FLL guidelines contain the types of green roofs, the various vegetation types, requirements for the building technique, green roof procedures as well as upkeep and maintenance for green roofs. They are available in German and English but the content applies to the middle European climate region and the common German green roof system build-up. The FLL guidelines and related standards for planning and designing green roof systems are widely adopted and referred in many other countries. First published in 1982, they have formed the basis of similar standards in many countries that have adopted green roofing standards. The FLL has also developed specific tests to determine the root resistance of waterproofing materials and root-barriers, to evaluate water-holding capacity of media, and to estimate maximum weight of green roof media.

3.2.2 Japan

In Japan, the Organization for Landscape and Urban Green Technology Development (known as "Urban Green Tech"), set up in November 1990 (www.greentech.or.jp), is responsible for promoting urban greenery and green spaces. It has developed and published a few important guidelines on roof-top and wall greening (written in Japanese) (Organization for Landscape and Urban Green Technology Development, 1996, 1999 & 2000):

- Neo Green Space Design, Volumes 1 to 4 (1996)
- Guide to Roof and Wall Green Technologies (1999)
- Green Roof Q&A (2000)
- Green Wall Q&A (2006)

With the support of the Ministry of Land, Infrastructure and Transport and the Ministry of the Environment in Japan, Urban Green Tech organised annual competition on specialized greening technology for rooftops, wall facings and new green spaces since 2002. It also coordinates research and development work, conferences and incentive schemes on urban greening. These financial incentives are important, as they offset the higher costs of green roof technology. However, as green roofs are more widely implemented, technology costs fell.

Similar to Germany, because Japan has a mature green roof market, some green roof suppliers and companies prepare and provide planning guides and information for the practitioners. The local provincial governments also developed their requirements and standards, together with incentive schemes. This helps to ensure quality of work for the green roof systems and promoting the market development.

3.2.3 Other Countries

The guidelines and standards of Germany and Japan are useful references for Hong Kong because they show the advanced information and practical considerations for green roof systems. In recent years, some other countries and cities have also developed guidelines, manuals and codes for green roof systems to suit their own needs. A summary of them is given in Appendix III.

Besides green roof guidelines and codes, some countries have also developed technical testing standards in order to specify the quality and requirements of green roof systems and components. Appendix IV gives a list of the technical standards for green roofs. Whether green roof guidelines exist or not, the complementary country regulations and guidelines must also be considered. These guidelines can include: building technique (e.g. load bearing capacity, wind uplift protection, fire protection, temperature, noise protection, etc.) and the roofing technique (waterproofing material and installation, upstands, slope, drainage, etc.). Consideration must also be given to any existing regulations and guidelines for garden and landscape architecture (e.g. soil and plants, lawn, seed mixture, upkeep and maintenance works, etc.).

4. Planning Requirements

Each individual green roof project will vary from the next. When creating and planning a green roof, the first consideration is to establish its objectives and functions. For example, is the green roof to be used for environmental and green building benefits? Or is it also accessible by, and to provide recreational amenities to, the people? The crucial factors are the load-bearing capacity of the roof construction and the choice of appropriate green roof build-up.

Identifying the scope of work is essential when considering a green roof installation. Project goals need to be established with a plan for implementation, financial constraints, time-line and intent of the project. Determining factors for design team selection include new or retrofit construction, budget, size of the project, construction time, system type and category, and programmed use. Appendix V shows checklists for green roof planning which can help people to consider the key issues.

4.1 Functions and Effects

The primary functions a specific green roof is required to perform will have a profound effect on its overall design. For example, a green roof designed for agricultural uses may look very different from one whose main purpose is to brighten a hospital courtyard or for educational tools in schools. Each individual green roof project would differ according to its use, whether it was created for ecological, recreational, economic, or aesthetic purposes.

Along with the question of aesthetics are inherent differences in the required depth of growing medium, the ongoing maintenance programme, and overall cost. This is not to say that a green roof designed to retain storm water cannot or should not also be aesthetically pleasing. Indeed, it can be both, but limiting factors in the budget or the building structure, among others, may concentrate the focus on one or another of these functions.

Location of the green roof plays an important role in the design process. The height of the roof, its orientation, its exposure to wind, sun and shading by surrounding buildings will have an impact. Views to and from the roof may also determine where certain elements are located for maximum effect. If the green roof can be designed as a roof garden for public access, then other social functions can be considered, including urban farming, education, leisure activities and horticultural therapy. The stakeholders’ involvement and support are crucial for developing these functions.

4.2 Structural Loading

Additional loading is one of the main factors in determining both the viability and the cost of a green roof installation. If a green roof is part of the initial design of the new building, the additional loading can be accommodated easily and for a relatively minor cost. However, if a green roof is installed on an existing building, the design will be limited to the carrying capacity of the existing roof, unless the owner is prepared to upgrade the structure, which can be a significant investment. Hence, the critical factor in deciding what type of greening to use and how to cultivate the site are the design loads of the system.

4.2.1 Typical Loading

Loads can be classified into two types: dead and live (or imposed) loads. Dead loads in a green roof, also known as constant loads consist of super structural components such as membranes, non-absorptive plastic sheet component, metallic layers, fabrics, geo-composite drain layers, growth media, granular drainage media, and plant materials. Live (or imposed) loads in a green roof system excluding that of construction activities, is defined as the weight of transient water that can be held temporarily in granular drainage materials layer and composite drainage layer, i.e. the transient water held due to a continuous rainfall or irrigation until the drainage layer reaches saturation point. Architectural elements such as walkways, pavements, walls, water pools, play areas, pergolas (shaded walkways), large scale bushes and trees, in addition to live loads of construction activities and wind loads are calculated separately. The typical structural loading for extensive green roofs is about 80 to 150 kg/m^2 and for intensive green roofs is about 300 to 1000 kg/m^2 (remark: 1 kPa ≈ 100 kg/m^2). Tables 4.1 and 4.2 give the typical weights of green roof substrate materials and common building materials.

Table 4.1 Weight of substrate materials

Substrate materials	**Weight of a 1-cm layer (kg/m^2)**
Gravel	16-19
Pebbles	19
Pumice	6.5
Brick (solid with mortar)	18
Sand	18-22
Sand and gravel mixed	18
Topsoil	17-20
Water	10
Lava	8
Perlite	5
Vermiculite	1
Light expanded clay granules (LECA)	3-4

(Source: Dunnett and Kingsbury (2008))

Table 4.2 Weight of common building materials

Materials	Weight (kg/m^3)
Stone (granite, sandstone, limestone)	2300-3000
Concrete (precast)	2100
Concrete (reinforced)	2400
Concrete (lightweight)	1300-1600
Hardwood timber	730
Softwood timber	570
Cast iron	7300
Steel	8000

(Source: Dunnett and Kingsbury (2008))

4.2.2 Structural Analysis and Design

Structural load bearing capacity will determine the access, function and type of green roof, growing medium type and depth, plant selection, replacement and repair strategies. The structural analysis should consider the waterproofing membrane, plant weight at maturity, fully saturated growing medium and drainage layers and weight of all components including dead and live weights for all phases of the green roof. Spot loadings generated by large-scale bushes, trees and structural components will need to be calculated separately. The weight of every layer in a green roof system is determined at the point of maximum water capacity including materials and stored water. Typical wet soil weighs approximately 1,600 kg/m^3 which is quite significant. Some green roof suppliers have developed various types of lightweight growing media in order to reduce the overall weight of the green roof system.

As different types of green roofs require differing loading capacity, it is possible to mix types of roofs on one installation to accommodate the structural load. For instance, heavier materials such as trees can be placed on higher weight bearing areas, such as columns or roof perimeters. This is especially important in retrofit projects where it may be necessary to be creative in the location and use of heavier structures. A thorough analysis of the roof structure may reveal areas where point loading can be increased, perhaps over a column or along a bearing wall, thus allowing for a combination extensive and intensive (or semi-extensive) system, with specific areas for deeper growing medium and larger plants. Building owners, tenants, and building managers should be made aware of the roof's loading restrictions, through a plan or as a part of a maintenance manual, to avoid future improper relocation or additional plantings in areas which cannot accommodate the weight.

4.2.3 Practical Considerations

In Hong Kong, the *Code of Practice for Dead and Imposed Loads* (BD, 2011c) should be applied to evaluate the likely structural loading. The weight of roofings such as waterproofing membrane, protective screeding, and tiles shall be calculated from the weight of the component materials and their geometry such as the thickness and area. Where a roof is to be provided with greenery, the weight of soil, waterproofing and drainage system, and plants for greenery shall be taken as dead loads. The uniformly distributed load and the concentrated load shall be considered separately.

Green roofs can be installed on commercial or residential buildings as well as on underground structures. For existing buildings, structural integrity of the building must be verified prior to consideration of retrofitting the building with a green roof. For both existing and new construction, it is essential that a multi-disciplinary team of structural engineers, building services engineers, architects and landscape architects be involved early in the process to ensure that the building's structural characteristics and site conditions are appropriate for green roof installation.

Understanding structural load (dead and live loads) during implementation is especially important. The determination of structural loading capacity is a combination of dead loads (all permanently placed parts of the roof above and below, including hardscape, plants, growing medium, features, etc.) and live loads (inconsistent weight such as people, rainwater, temporary components and equipment). During construction the temporary placement of heavy components such as trees, pallets of stepping stones, growing media, concrete cast-in-place planters, walls and furniture needs to be carefully planned and calculated. Carefully staging delivery and installation of growing media is recommended to keep labour costs down and ensure the schedule stays on track.

4.3 Accessibility and Site Conditions

The accessibility of the roof is a critical component of any green roof installation, not only for installation and ongoing maintenance, but also for bringing up materials, soil and plants. The success of a green roof depends on the ease and safety of access during and after installation, whether for frequent visitors or occasional maintenance.

4.3.1 Green Roof Accessibility

All green roofs require some degree of accessibility. Some green roofs might only be accessible for maintenance and other green roof gardens are designed specifically for daily use and high traffic volumes of visitors and users. Types of access may be a lift, stairs, a stairwell with doorways or a hatch. During the design phase of the project, access for installation and maintenance must be included and meet job site safety standards and building regulation requirements.

If the green roof is designed for public use, then access and exiting of the roof should comply with relevant safety and security requirements through adequate vertical transportation systems and staircases. Roofs which are fully accessible to public will require more safety concerns, such as guard rails, lighting, fire safety, and disabled access. The construction requirements for buildings might have to be adapted to the specific needs of disabled persons, elderly and handicaps too.

With a new building, the design of internal stairs or an extra lift stop in the planning stages is easy and relatively inexpensive; to retrofit an existing building can become costly. Where a lift does not go to the roof, material will have to be transported by hand up stairs and utility ladders, or hauled up with a crane, both of which can result in additional labour and equipment costs. An interior ladder or staircase may be safer than one attached on the outside of the building, and access through a "man door" is preferable to a small roof hatch. If the green roof is designed for use by tenants or the general public, then questions of access and of exiting are taken to another level altogether, from mere convenience to strict standards of safety and security as regulated by the local building regulations, such as ArchSD (2010).

4.3.2 Site Conditions and Roof Space

For successful establishment and long lasting vegetation it is crucial to consider the local site conditions. Table 4.3 shows the major considerations of site conditions for green roofs (FLL, 2008). The general climate of the area and the specific microclimate on the roof must be considered.

Table 4.3 Major considerations of site conditions [adapted from (FLL, 2008)]

Climate and weather	▪ Regional climate ▪ Local microclimate ▪ Pattern and amount of rainfall ▪ Average exposure to sunshine ▪ Shadowing effect of the surrounding buildings ▪ Any incidence of periods of drought ▪ Direction of prevailing wind ▪ Airborne contamination ▪ Whether it is located extremely close to sea or high on the mountain
Structure	▪ Design loads for the roof structure ▪ Exposure of roof surfaces ▪ Gradient of slope of the roof surfaces ▪ Existence of any major plants and exposed pipe-works on the roof ▪ Areas exposed to the sun and shaded areas ▪ Deflection of precipitation by the structure ▪ Wind flow conditions and wind uplifting effect
Plant	▪ Current drainage arrangements on the roof ▪ Water requirements ▪ Power supply requirements (for lighting & equipment)

The vegetation layer and plant communities can be modified according to site conditions; whereas, the roof height and roof slope and the predominant climate are fixed. Additional considerations include: sunlight and wind exposure, air pollution, variation of temperature, local moisture conditions, access to water and electricity supply. Even on one roof various microclimatic conditions can occur. For existing buildings, if the roof is in need of replacement or major repair, particular care must be taken to water leakage and proofing.

If the roof space is also being used for other utilities (pipes, plant rooms, etc.), then sufficient space for area of mechanical plants, access pathways, safety railings is important in the roof planning and design. Where plant rooms are required for the building services systems, two approaches can be taken. The area of plant room can be reduced to a series of storage areas on the roof, surrounded by the green roof technologies and green planting including vegetated green walls. The second approach is to incorporate all the plant room activities into an additional floor at the top of the building and then cover the entire plant room with a green roof.

In Hong Kong, many existing or planned roof spaces in the urban area that offer potential for development as green roofs are shaded from the sun by surrounding tall buildings for much of the day. This influences plant selection and growth. Appendix VI shows a sun path diagram for Hong Kong which can be used to evaluate the solar access and daylight availability.

Hong Kong has a high building density and the high-rise buildings usually have very limited roof area (Hui and Chan, 2008). It is usually more effective to apply green roofs to the top of medium- or low-rise buildings/structures or the intermediate podium roofs. By doing this, the occupants from surrounding tall buildings can enjoy the green roof and appreciate the application.

4.4 Water Proofing

High quality waterproofing is a critical issue for success of green roof. Suitable arrangement and design of waterproof membrane can reduce the cost of repairing and achieve the goal to extend life of the roof.

One of the most important components of the green roof system is the waterproofing/roof membrane. Green roofs should not be installed until waterproofing inspected and tested. For an existing building, the membrane should be carefully inspected to determine if it needs to be repaired or replaced before the installation. Many suppliers of green roof systems will not provide a warranty on the green roof system if new membranes are not applied. The normal 10-15 year reroofing cycle provides a window of opportunity to investigate the potential of applying a longer lasting green roof.

To protect the membrane, it is important to minimise the number of penetrations and transitions and all the expansion joints must be accessible. Low points should be levelled to avoid water ponding. If the membrane, existing or new, contains bitumen or any other organic material, it is crucial to maintain a continuous separation between the membrane and the plant layer, since the membrane will be susceptible to root penetration and micro-organic activity. Some of the new membranes developed specifically for green roof applications, although still bituminous, now contain a root-deterring chemical or metal foil between the membrane layers and at the joint/seam lines to prevent root damage. The chemical makeup of the membrane must also be compatible with the system components with which it will be in direct contact.

Although the green roof will retain much of the rain that falls onto it, maintaining proper drainage on the roof is still very important. Parapets, edges, flashing, and roof penetrations made by skylights, mechanical systems, vents, and chimneys must be well protected with a gravel skirt and sometimes a weeping drain pipe. If the drainage layer is too thin or if the routes to the roof drains become blocked, then leakage of the membrane may occur, due to continuous contact with water or wet medium. The growing medium itself may sour, causing the plants to drown or rot.

As mentioned in Section 3.1, the root resistant membrane or barrier can protect the waterproofing membrane and/or insulation layer during installation of the green roof. Many different materials can be used for this purpose including synthetic thermoplastic, recycled foam/rubber mats, polyethylene net composite and non-rotting fiber. The material should add little weight to green roof system. However, it may not be required if the roof is rigid and strong enough.

4.5 Green Building Credits

Green building assessment methods, such as LEED (USGBC, 2009) and BEAM-Plus (BEAM Society, 2010a & b), are becoming more and more popular and important in Hong Kong and other countries. For example, in USA, the use of green roof systems has been encouraged by the need to obtain credit points for LEED. In fact, green roofs can contribute to the credit rating of developments assessed under such schemes. In addition, a green roof can be a highly visible way in which a building development can draw attention to its environmental or sustainability 'credentials', which may contribute to increased property value. In the commercial sector, for example, it is anticipated that buildings which compare unfavourably to their market peers in sustainability terms will be at risk of accelerated value erosion and earlier physical obsolescence.

4.5.1 LEED and BEAM Plus

Building designers can pursue sustainable design and earn points towards project certification. Green roofs could potentially assist in gaining credits under several environmental criteria in the green building assessment. Tables 4.5 and 4.6 gives examples of credit points related to green roof systems in LEED 2009 version and BEAM Plus, respectively. The main criteria impacts and secondary credit impacts are shown. It can be seen that the greening technology has significant implications to the results of the assessment schemes. It is hoped that this can help to promote greenery to developers and building professionals.

Table 4.5 LEED 2009 credit points of green roof systems

LEED criteria impacts:	Points
Sustainable Sites (SS)	
Credit 5.1 Site development – protect or restore habitat	1
Credit 5.2 Site development – maximize open space	1
Credit 6.1: Stormwater design – quantity control	1
Credit 6.2: Stormwater dseign – quality control	1
Credit 7.2: Heat island effect – roof	1
Water Efficiency (WE)	
Credit 1: Water efficient landscaping	2-4
Energy and Atmosphere (EA)	
Credit 1: Optimize energy performance	1
Materials and Resources (MR)	
Credit 4: Recycled content (roof components)	1
Credit 5: Local/Regional materials	1
Secondary credit impacts:	Points
Water Efficiency (WE)	
Credit 2: Innovative waste water technologies	2
Credit 3: Water use reduction	2-4
Innovation in Design (IN)	
Credit 1: Innovation in design	1-5

Source: extracted from USGBC (2009)

Table 4.6 BEAM Plus credit points of green roof systems

BEAM Plus criteria impacts:	Points
Sites Aspects (SA) Perequiste: Minimum landscape area SA 5: Ecological impact SA 7: Landscaping and planters SA 8: Microclimate around buildings (roof)	 Required 1 1-3 1
Materials Aspects (MA) MA 7: Recycled materials (roof components) Credit 5: Local/Regional materials	 1 1-2
Energy Use (EU) EU 1: Reduction of CO_2 emission EU 2: Peak electricity demand reduction	 1-15 1-3
Water Use (WU) WU 1: Water efficient irrigation WU 6: Effluent discharge to foul sewers	 1 1
Secondary credit impacts:	Points
Water Use (WU) WU 4: Water recycling (rainwater)	 1-2
Innovations and Additions (IA) IA 1: Innovative techniques	 1-5

Source: extracted from BEAM Society (2010b)

4.5.2 Green Building Incentives in Hong Kong

In Hong Kong, the Government has developed incentives and guidelines to promote green and sustainable buildings by granting exemptions of gross floor area (GFA) and site coverage (SC) to building developers and by encouraging sustainable design features as well as green building assessment (using BEAM Plus) in building projects. The relevant documents, known as Practice Notes for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers (PNAP), are shown below.

- Joint Practice Notes No.1 & 2, Green and Innovative Buildings (BD, LandsD and PlanD, 2011a & 2011b)
- Practice Note APP-151, Building Design to Foster a Quality and Sustainable Built Environment (BD, 2011b)
- Practice Note APP-152, Sustainable Building Design Guidelines (BD, 2011d)
- Practice Note APP-122, Provision of Sky Garden in Refuge Floor (BD, 2010)
- Practice Note APP-42, Amenity Features (BD, 2011a)

Building features such as communal podium gardens and sky gardens that can improve the built environment are accepted for the incentives. Site coverage of greenery and BEAM Plus certification are pre-requisites for granting the GFA concessions. For government buildings, they are required to consider use of green initiatives or comply with BEAM Plus standards where applicable or feasible (DEVB and ENB, 2009). Under these policies, the use of green roof systems is encouraged. Therefore, it is important to consider them in order to obtain supports for implementing green roofs in Hong Kong.

5. Design Considerations

Green roofs can be designed to be a beautiful landscape and functional green space. They can also be designed to generate urban agriculture and promote sustainable technologies. For a successful green roof, the design and selection of growing media, irrigation systems, and plantings must be carried out as a system.

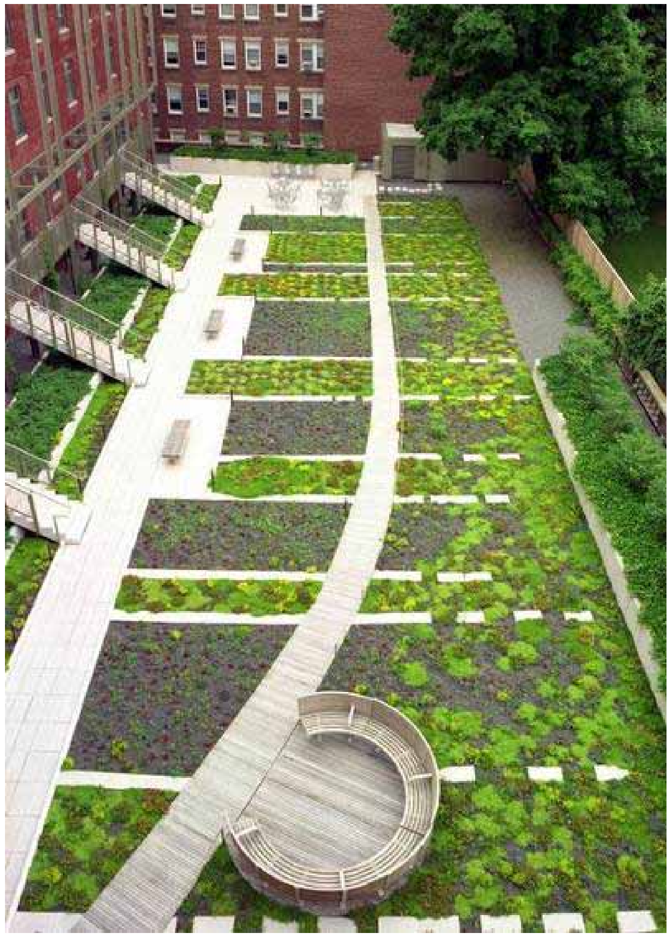
5.1 Landscape Design

To achieve quality landscaped areas for green roofs, it is important to study the components of landscape design which include the practical, aesthetic, horticultural, and environmental issues of the softscape and hardscape. Softscape refers to the elements of a landscape that comprise live, horticultural elements, such as flowers, plants, shrubs, trees, flower beds, etc. The purpose of softscape is to enable character to the landscaping, create an aura, ambience, and reflect the sensibilities of the inhabitants. In contrast, hardscape represents inanimate objects of a landscape such as pavers, stones, rocks, etc. When designing a green roof, combining the colour and beauty of plants with architectural pavers can yield aesthetically pleasing results.

In non-modular green roof systems, the planting medium is supported by the drain layer and contained at the perimeter by a metal or plastic barrier, or the roof parapet. In modular systems, containment refers to actual plant containers. For proper edge treatment, the vegetation should be separated from the parapet or edge by a hard paving of a width of at least 500 mm. Figures 5.1 and 5.2 show examples of landscape design for green roof systems. Table 5.1 describes the major considerations of landscape design for green roof systems.

(Source: Hong Kong Housing Authority) (Source: Drainage Services Department)

Figure 5.1 Landscape design for green roof systems in Hong Kong



(Source: Harvard University)

Figure 5.2 Landscape design for a roof garden in Harvard University

Table 5.1 Major considerations of landscape design for green roof systems

Issue	Design consideration
Water use	▪ Aim to be sustainable in water use ▪ If possible, harvest stormwater and reuse for irrigation ▪ Where appropriate use grey water technology
Landscape materials	▪ Soil profile to include free draining sand-like product, clay minerals ▪ Incorporate sustainable landscape materials wherever possible (this reduces the ecological footprint). Consider a specially formulated growing medium which includes a recycled component locally available such as crushed brick ▪ Use light coloured wind resistant landscape mulches to help reduce soil temperatures and reduce evaporation from soils. Examples include light coloured 10 mm gravel
Site ecology	▪ If practical and if original soils have not been adversely affected aim to restore some of the existing ecology to the site – this will improve site biodiversity ▪ If possible link site to existing open spaces and reserves to create habitat corridors
Choosing plants	▪ On green roofs, plants will be subjected to more extreme conditions than those in a garden bed at ground level. They will be subjected to higher temperatures, windier conditions, leading to rapid water loss and frosts during the cooler months. Therefore plants need to be chosen well
Maintenance	▪ Ensure a landscape management plan is in place to protect investment in the green roof/wall technology. Maintenance and replanting are vital in maintaining healthy green roofs
Monitoring	▪ Include a proportion of the budget for weather station monitoring equipment

For intensive (or sometimes semi-intensive and extensive) green roof applications, there are a number of hardscape paving materials that can be used to provide a walkway or sitting area. Precast concrete architectural pavers are commonly used and are installed in an open joint assembly (supported at the four corners on spacer tabs or pedestrals). This method of installation allows for water to drain below the wearing surface rather than pond on it, this eliminating the likelihood of dangerous pedestrian conditions, as well as possible heaving resulting from trapped moisture. In addition, the open joint assembly provides easy access to the assembly components and structure below, facilitating maintenance and future deck alternations.

5.2 Water Supply and Drainage

The number of water mains pipes and junction points required for watering, along with the sizes used, will depend upon local conditions and on the structure involved. During the planning and design stage, water mains demand will need to be established by considering the local conditions and the form of cultivation to be used for the vegetation. Sometimes, it is possible to collect the water outflow from the green roof for another use or to even irrigate itself.

5.2.1 Water Supply and Retention

Extensive green roofs with drought resistant plant species have to be irrigated only during planting and installation maintenance over the first year. After its establishment, the annual rainfall is sufficient to sustain the vegetation. In contrast, the requirements are more involved for intensive green roofs with lawn, shrubs, bushes or trees. An adequate number of precisely dimensioned hoses with automatic irrigation units make plant maintenance during drought periods more manageable. The water supply for roof gardens with no slope can be increased through additional dam-up irrigation. In order to lower the consumption of fresh water, roof gardens can also be irrigated with reclaimed rainwater or waste water.

Green roofs retain a high percentage of rainwater; excess water must be drained from the roof by surface roof drains, gutters, or other drainage systems. Figure 5.3 shows the principles of the drainage/storage layer in an extensive green roof. The water retaining capacity of the green roof system has to be adjusted to the average local precipitation. Proper roof drainage design should incorporate a minimum of two outlets, or an outlet and an overflow. Outlets should be kept clear of vegetation by installing a vegetation-free zone around the outlet and a cover that exclude light from entering the drain area. Inspection chambers may be required to ensure that outlets are kept free of blockages.

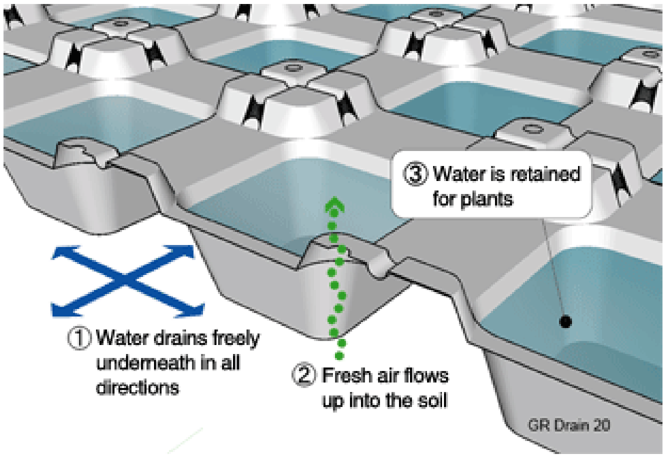
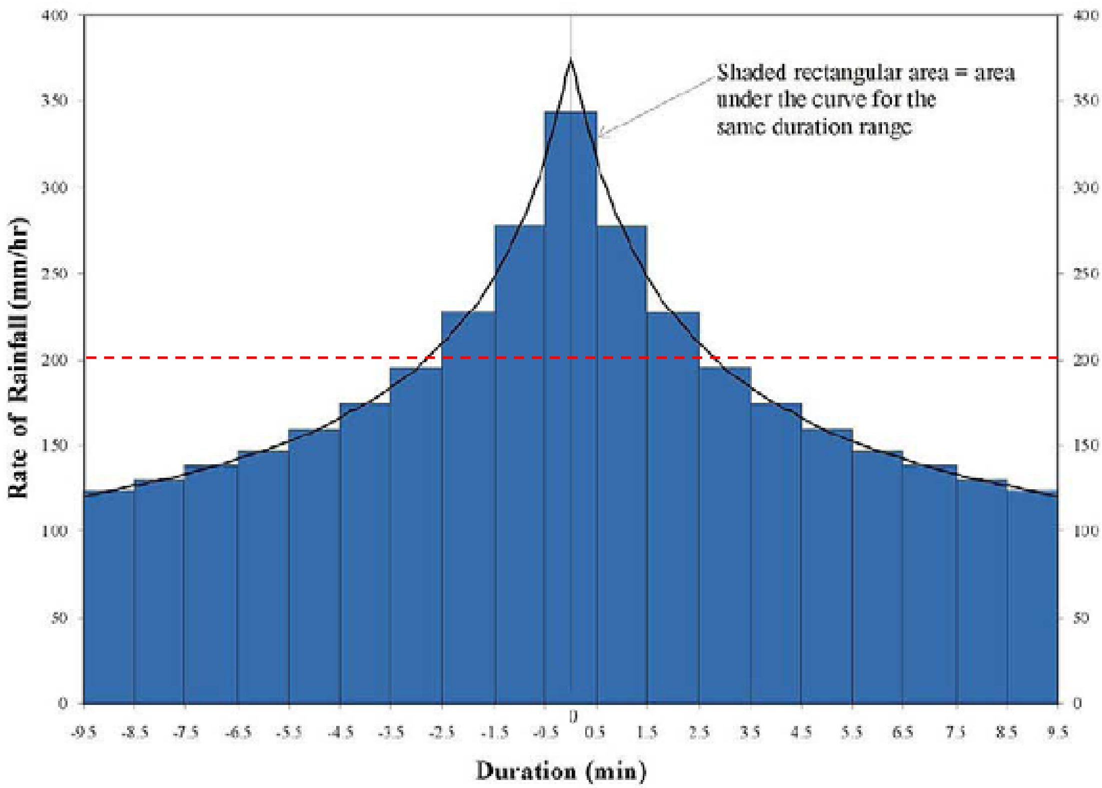


Figure 5.3 Principles of the drainage/storage layer in an extensive green roof

5.2.2 Drainage Systems

Two drainage systems should be considered: (a) part of the green roof system (drainage layer) and (b) part of the building (system of drains and pipes). Usually the information regarding design rainfall intensity and duration at that location will be used to design the roof drainage systems. Figure 5.4 shows the design rainfall profile statistics for Hong Kong. For a 20-year return period, the design rainfall intensity is taken as 200 mm/hr.



(Source: Hong Kong Observatory, www.hko.gov.hk)
Figure 5.4 Design rainfall profile statistics for Hong Kong

Excess water should be drained by roof outlets and box/eaves gutters which must be kept clear of vegetation to avoid blockage. Gravel can act as a separation barrier for plants. Vegetation-free zones should be installed at all perimeters and penetrations. These areas generally consist of a recommended 500 mm wide path of graved or architectural pavers. The purpose of a vegetation-free zone is to protect the roof flashings from the plants roots, as well as provide wind lift protection and ease of access to the flashings (if needed). Inspection chambers over all roof drains are recommended to preclude plant growth in the drain. For very large green roof areas, vegetation free zones are also recommended to divide the roof into smaller zones in case of a leak or system failure.

To withstand constant moisture and corrosive nature of some fertilizers, corrosive resistant materials might be used. If only a portion of the roof is installed with green roof systems, then both the drainage within the vegetation area and outside the vegetation area must be planned and designed properly. In addition to horizontal roof surfaces, the designer should ensure the drainage design accounts for vertical sheet flow from large façades due to wind-driven rains.

5.3 Wind Design

Green roofs are often exposed to high wind levels. Wind can generate positive and negative pressure forces, as well as friction, which act on structure. A green roof must be able to withstand wind loading, especially in cases of strong wind. When designing and installing the green roof, safety measures against wind uplift must be considered. This is especially important when the green roof provides the load for a loose laid waterproofing and root barrier. It should be noted that layers of green roofs are vulnerable to wind shear. The actual influence from the wind depends on the local wind zone, height of the building, roof type, slope, and area (whether corner, middle or edge) and the substructure. Figure 5.5 illustrates the wind effect and wind uplift for green roofs.

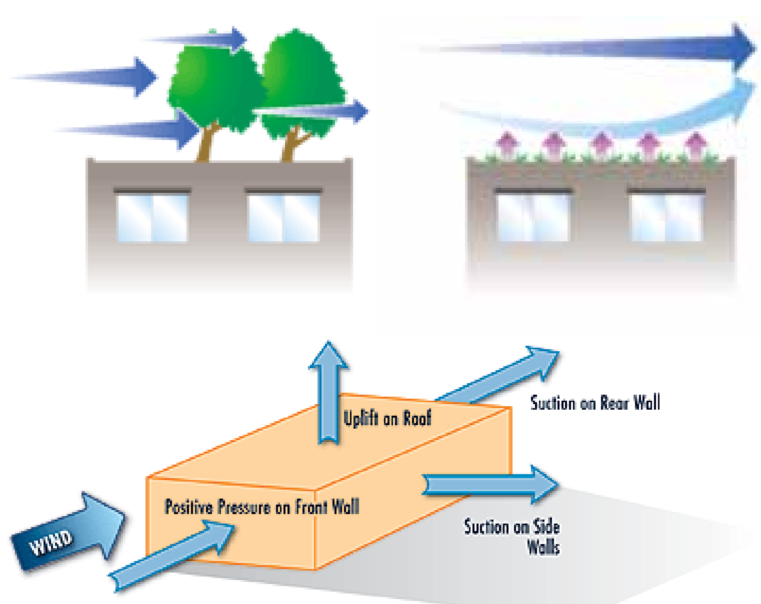


Figure 5.5 Wind effect and wind uplift for green roofs

5.3.1 Wind Uplift and Ballast

Wind loads can damage anything built on top of the roof, either during construction or after work has been completed. The following areas on the roof are the most affected by the wind pressure uplift and require appropriate protection:

- Corners: stress levels are very high
- Edges: stress levels are high
- The central area: stress levels are low

In fact, the wind pressure can vary across a roof, depending on location. At the centre of the roof, a thin layer of soil may be adequate. At perimeters and corners, high winds may necessitate the use of large stone ballast or multiple rows or precast pavers to prevent uplift. A strip of gravel, stones, or pavers around the edge can prevent the wind damage and such strips also act as vegetation barriers. In general, taller structures have a greater risk of wind uplift. Ballasting requirements vary by building height, parapet height, and wind design speed. SPRI (2010a) provides a method of designing wind uplift resistance of vegetative roofing systems.

In green roof systems, ballast is the weight provided by growing medium or stones or pavers to provide uplift resistance for roofing systems that are not adhered or mechanically attached to the roof deck. The ballast also provides drainage options when the roofing membrane is mechanically attached or fully adhered. When growing medium is installed and protected by vegetation that nominally covers the visible surface of the growing medium or the growing medium is protected by a system to prevent wind erosion, the weight of the inorganic portion of the growing medium can be considered ballast weight. When modular trays that are filled with growing medium are covered by vegetation that nominally covers the visible surface of the growing medium or the growing medium is protected by a system to prevent wind erosion the weight of the inorganic portion of the growing medium can be considered ballast weight. Ballast can also consist of large stones, paver systems, or lightweight interlocking paver systems.

5.3.2 Calculation of Wind Uplift Design Pressures

Low-rise buildings present fewer challenges in regard to positive or negative wind forces. A lower parapet design in low rise building may avoid potential air turbulence and help minimise uplift forces. High-rise buildings are exposed to increased wind pressure resulting in higher positive and negative uplift forces. Increasing the parapet height can be an effective tool in moderating uplift forces.

Some green roof systems have been tested for wind uplift resistance. The wind uplift design pressures and wind rating pressures of the systems are determined. A minimum safety factor (say 1.7) should be applied for wind uplift calculations based on appropriate wind uplift design pressures for the local design wind loads. The calculation is based on a dry condition (no water present in the growth media, retention mat, drainage panel, etc.) and without the presence of any vegetation load.

Growing medium may be used as a secondary ballast material; that is, it may be used to ballast the loose-laid roofing components above the waterproofing membrane (i.e., drainage panel, retention mat, root barrier, and insulation board), but not the membrane itself. When growing medium is used to ballast the loose-laid above-membrane components, the wind uplift calculations should use wind uplift design pressures, a dry condition (no water present in growth media, retention mat, drainage panel, etc.), no vegetation, and a minimum safety factor of 0.85.

5.3.3 Practical Considerations

Nevertheless, the growing medium on a green roof system can be prone to scour from wind and water action and therefore may not be a reliable source of uniform ballast for waterproofing components when provided in shallow depths. Growing medium typically contains aggregate materials, including crushed porous rock (e.g., pumice, expanded shale) or crushed clay brick, that can create a potential source of wind-borne debris similar to roof gravel. Although vegetation will provide a certain amount of wind shelter and the plant roots will help anchor the surrounding growing medium, it can take several growing seasons for the vegetation to become sufficiently established to protect the growing medium from wind action.

Pre-cultivated vegetated mats (rather than direct planting of plugs or cuttings) are sometimes used for green roofs (see Section 2.1). Where vegetated mats are installed, they should be anchored until the mat's root growth has achieved sufficient attachment into the growing medium to adequately resist wind action (at least one full growing season). If pre-cultivated vegetated mats are to be used as ballast for the roofing membrane or other waterproofing elements, it is important to ensure that vegetated mats are properly anchored or ballasted against wind forces based on a safety factor of 1.0.

Hong Kong often faces typhoon and stormwater problems during the rainy season (Hui and Chu, 2009). The strong wind and heavy rainstorm could cause flooding and serious damages to the society. The typhoon might blow away the vegetation and soil, therefore, for green roof systems that do not have proven wind uplift resistance, they must be well secured and protected. Also, the green roof should be able to hold and drain the rain water without creating pools of stagnant standing water.

5.4 Plant Selection

Careful plant selection is essential to the success of the green roof system. Designs vary widely to incorporate different plant species and aesthetic functions, but the vegetative layer needs to be carefully considered for the conditions and the projected goals. Plant selection objectives are dependent upon the design goals of the roof, whether the goals are related to function, performance, education or aesthetics. The plant selection depends on the growing medium as well as local conditions, available maintenance and the desired appearance.

5.4.1 Typical Plants

By necessity green roof plants must be tougher and less nutrient-reliant than plants found in most parks. Other limitations are climate, structural design and maintenance budgets, and the roofscape designer's imagination. In general, the most successful plants for green roofs are heat, cold, sun, wind, drought, salt insect and disease tolerant. Low maintenance, durable and drought resistant plants are used for extensive green roofs, whereas, a nearly limitless plant selection for intensive green roofs.

(a) Extensive Green Roofs

Plants for extensive green roofs have to survive intense solar radiation, wind exposure, drought, low nutrient supply, extreme temperatures and limited root area. Suitable plant varieties are those growing in severe locations with little moisture and nutrient supply, such as, dry mountain environments, coasts, semi-deserts or dry meadows. The main varieties are Sedum, Sempervivum and Saxifraga; all of which belong to the succulent species (see Figure 5.6 for some examples). The plants are able to store high amounts of water in the leaves, are stress resistant and recover easily from periods of drought. Other varieties such as Dianthus species, Asteraceae and ornamental grasses are also suitable for these conditions, but they will require more maintenance and irrigation. It is very important that plants which are native to the local conditions are taken into consideration, in order to support biodiversity.

Sedum sinica

Sedum sarmentosum

Sedum lineare

(Source: Dr. Sam C. M. Hui)

Figure 5.6 Examples of sedums used in extensive green roofs

(b) Intensive Green Roofs

Having an appropriate green roof system build-up and sufficient growing medium (with higher root penetration volume, nutrients and water supply) growth of sophisticated plant varieties on the roof is possible. The selected plants need to be resistant to intense solar radiation and strong winds. Vegetation with various plant varieties such as perennials, herbs, grasses and trees allow for a natural character on the roof. However, having a broader plant community increases the amount of maintenance required.

Factors for consideration when making plant selections include growth rates, nutrient requirements, sensitivity to pollution, wind resistance, solar exposure, drought tolerance. Location, wind, rainfall, air pollution, building height, shade, and soil depth are all factors in determining what plants can be grown and where. The ability of plants to survive on a green roof is directly proportional to the amount of maintenance time and budget allocated to the project, particularly in the first two years when they are getting established.

5.4.2 Hong Kong Situation

Climatic conditions on a rooftop are often extreme. Unless one is willing to provide shading devices, irrigation, and fertilization, the choice of planting material should be limited to hardier or indigenous varieties of grasses and sedums. Root size and depth should also be considered in determining whether the plant will stabilize in 10 cm or in 60 cm of growing medium. It is vital to know where the plants were previously grown and if the growing conditions were comparable to the ones on the roof to ensure their ability to adapt and flourish.

In Hong Kong, Urbis Limited (2007) had developed a plant selection matrix for green roofs (intensive and extensive). The list was derived from existing local knowledge and other overseas sources with humid climatic conditions similar to Hong Kong (such as Singapore). Usually trial planting and testing are needed in order to verify the suitability of the plant species. Other useful references for plant selection are identified and shown below.

- A Selection of Plants for Green Roofs in Singapore (Tan and Sia, 2008)
- Green Roof Plants: A Resource and Planting Guide (Snodgrass and Snodgrass, 2006)
- Neo Green Space Design, Japan (Organization for Landscape and Urban Green Technology Development, 1996)
- Planting Green Roofs and Living Walls (Dunnett and Kingsbury, 2008)

The Architectural Services Department (ArchSD) of the HKSAR Government has tried and tested some plants for green roofs. For instance, the ArchSD had considered various vegetation and planting species including three groundcover species: Arachis duranensis (蔓花生), Liriope spicata (山麥冬) and Rhoeo discolor (蚌花). For extra-light-weight green roof systems, two interesting species have been used: Sedum lineare (佛甲草) and Sedum mexicanum (金葉佛甲草).

For low-maintenance application to new and existing buildings, sedums which are commonly known as stonecrops are often the core species for the green roof systems. They are a versatile and attractive ground cover plant belonging to the Crassulacaea family. Sedums are evergreen, self-generating, drought resistant and capable of withstanding extremes of climate. Requiring very little attention and no mowing or cutting back, they give excellent foliage colour and texture and are attractive to all kinds of insects and birds. Sedums are generally pest and disease free but like most plants, can suffer from aphids, mealy bugs, thrips or vine weevil which can be controlled by biological means. Sedum plants are very economical when it comes to fertilizer. A slow-release, low-nitrogen granular fertiliser applied once a year (preferably in spring) is all that is needed.

5.5 Roof Slope

In urban areas pitched green roofs are a special attraction and planted sloped or pitched roofs look great due to their high visibility. Green roof systems for pitched roofs differ significantly from system build-ups for flat roofs. Plant selection and planting methods are to be adjusted to the relevant slope and exposure. Appropriate measures are needed to cope with the shear forces and soil retention. While the basic components of a sloped green roof are similar to that of a flat system, the building project team must pay particular attention to water management, erosion control, and maintenance.

5.5.1 Reinforcing Measures

In general, intensive green roofs are applied on slopes of up to 5 degrees, while extensive green roofs on slopes of up to 30 degrees. The maximum slope for extensive green roofs which is commonly used is 45 degrees. As the steepness of the slope increases, the structure requires more protection against shear and slide forces whereas controlled drainage and soil depth should be considered.

Usually, green roofs should not be applied to roofs with slopes greater than 45 degrees due to the extreme difficulty in managing soil moisture on a roof of such steepness. In such slopes the water will tend to run out of the system resulting in dry areas at the top, and moist areas at the bottom. For slopes of angles less than or equal to 20 degrees (36% gradient), antishear protection is not required, while slopes at angles greater than 20 degrees (36% gradient), anti-shear protection is needed. In cases where angles are greater than 30 degrees (58% gradient), separate static calculations are required to ensure that the action taken to prevent shearing doesn't create tension at the contact point with the waterproof membrane and the root barrier. In summary, the reinforcing measures with increasing slopes are given below:

- 10-15 degrees: Root resistant waterproofing/reinforced eaves
- 15-20 degrees: Use of anti-erosion net
- 20-30 degrees: Use of additional shear barriers
- > 30 degrees: Use of pre-cultivated elements or vegetation mats

5.5.2 Design Considerations

To protect plants from erosion or sliding, the support coarse of the plants should be cultivated in a way which ensures that the structural soundness is not affected by water. It can be achieved through using fine to medium sized chipped gravel or through minimizing the amount of material which could get washed out.

On a roof slope greater than 20 degrees, the green roof installer needs to ensure that the sod or plant layer does not slip or slump through its own weight, especially when it becomes wet. This can be prevented through the use of horizontal strapping, wood, plastic, or metal, placed either under the membrane, or loose-laid on top. Support grid systems for green roofs have been designed by some green roof suppliers specifically for this application.

Whether a roof is green or not, a slope of 1%-2% should be applied on it to allow water to move smoothly towards the drain holes (openings). This slope is usually maintained using a lightweight concrete (screed) layer between 50-70 mm thicknesses. Appendix VII provides more detailed information about design considerations for pitched green roofs.

5.6 Sustainable Technologies

Green roof systems can incorporate other sustainable technologies so as to improve the environmental performance and energy balances of the building. For example, the integration of green roofs and renewable energy systems such as solar photovoltaic (PV) and wind energy can lead to a better use of roof space and higher efficiency of the solar systems. The power generated from the solar PV or wind energy systems can be used to provide power supply on the roof (e.g. for lights for access, emergency exit signs and water pumps). Also, rainwater harvesting and recycling can be applied because green roofs retain a high amount of rainwater and drastically reduce the amount reaching the urban sewage system. The excess rainwater is of good quality and can be used in flushing toilet systems or for irrigation purposes. It is also possible to attain clear run-off water if special substrates are being used for achieving the filtration.

5.6.1 A Pilot Study

A pilot study on green roof and sustainable technologies had been developed in a primary school in Hong Kong since 2008. Figure 5.7 describes the concept of the integration and Figure 5.8 shows an overview of the roof area (which is on top of an assembly hall) for the pilot study. The following sustainable technologies were applied in the study:

- Irrigation water from rainwater harvesting
- Electricity from micro-wind turbines (for water pumps) and photovoltaics (for weather station)
- Fertilizer from composting (installed at ground floor)

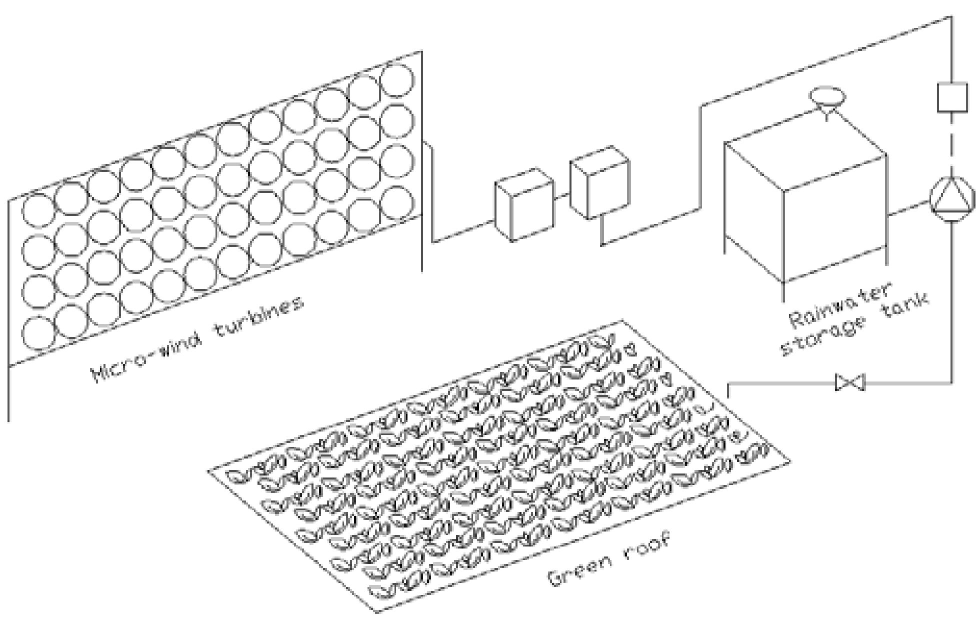


Figure 5.7 Integration of wind energy, rainwater recycling and green roof system

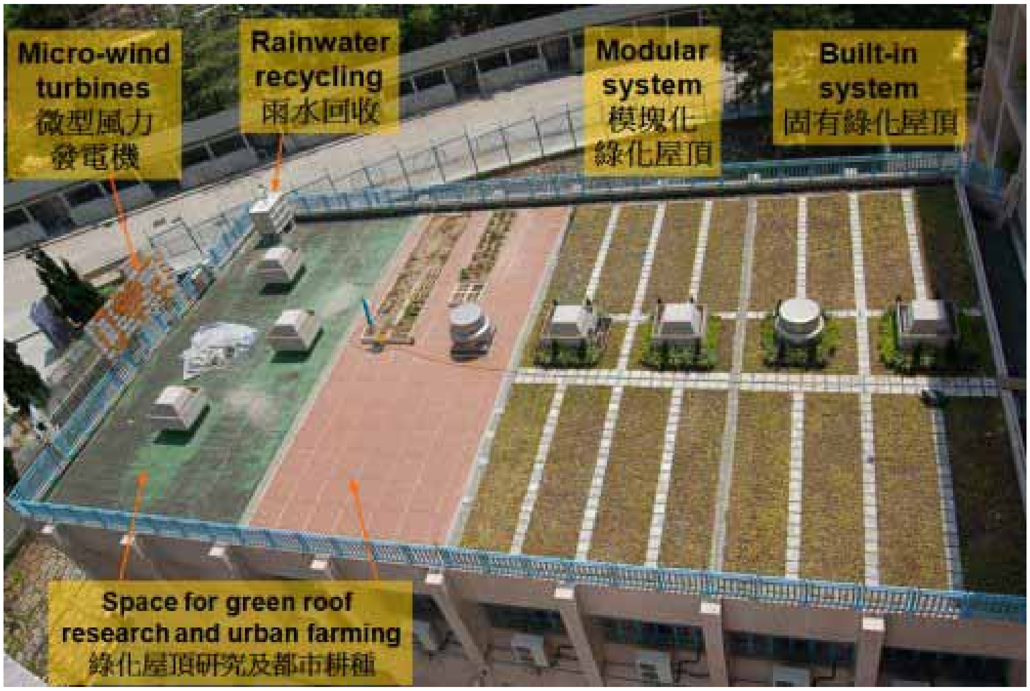


Figure 5.8 Integrated green roof systems at the assembly hall of a primary school

5.6.2 Integration of Green Roof and Solar Photovoltaic Systems

A new and quite successful trend is to integrate solar PV panels on green roofs (Hui and Chan, 2011b). Studies have shown that there is a symbiotic beneficial relationship between green roofs and solar panels through creating an interesting micro-climate. The green roof will lower the temperature of the roof and ultimately ensure a greater solar panel efficiency. In turn, the solar panels shade the roof from excessive sun exposure and high evaporation, thus providing temporary relief from the sun, reducing drought stress of plants and allowing for a wider range of planting choices from full sun to half shade. Figure 5.9 shows an example of green roof and solar PV integration. The main advantages of this combination are: easy installation of solar unit; reliable stability of solar units from load of the green roof build up and higher efficiency of the PV module due to the cooling effect of the green roof.

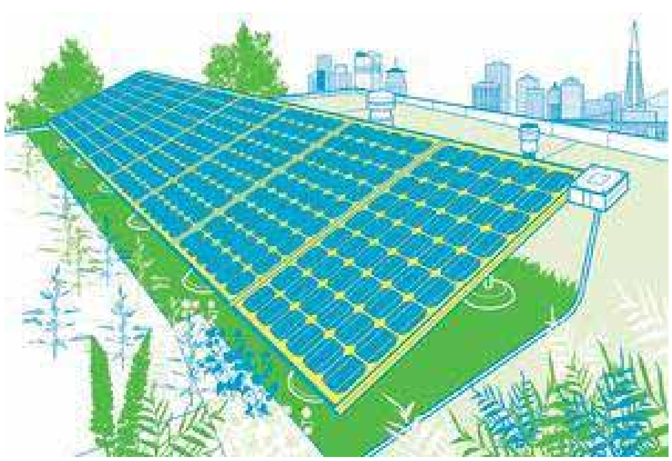


Figure 5.9 An example of green roof and solar PV integration (Peck and van der Linde, 2010)

On roofs with solar panels, usually only extensive vegetation can be installed. The solar units have to be installed above the vegetation level so that the panels are not shaded. Special frames of aluminium are made in order to put the panels above the vegetation level. In traditional solar PV systems, the solar units were mounted on concrete bases or slabs and partially filled with gravel; however, they are now mounted on framework which is fixed to plastic boards. The profiled plastic boards are covered with substrate and allow rain water to drain through; thus, allowing plants to grow underneath the solar panels. With the solar panels mounted on the plastic boards the load distribution is spread over a large area and prevents the roof construction from being damaged by point loads. However, if such detail is too complicated for a green roof project, then people may also put solar PV and green roof side by side. Figure 5.10 shows one example of such design in a library building in Taiwan.

(Photos taken by Dr Sam C. M. Hui)

Figure 5.10 Green roof and solar PV systems at the Beitou Taipei Library, Taiwan

5.6.3 Sustainable Materials

If the green roof components are made from recycled or waste materials (such as crushed clay brick or tiles, brick rubble) and obtained from local or regional sources, then this could contribute to reduction of environmental impacts on the material side. To be more sustainable, materials should be environmentally friendly with respect to the amount of energy consumed to produce the material. Locally sourced materials are preferred to imported expensive ones. Endemic and indigenous plant species are recommended with plant schemes emulating the communities found in the local environment.

5.7 Farming and Food Production

Green roofs can also be applied for various uses if the structural engineering and the accident prevention measures allow for it. The roofs can be used for crop growing, recreational gardens, roof cafés or leisure and sporting facilities. Accessible roof gardens can be designed as roof top allotment gardens for local food production or beehives located for the production of honey. The produce can be used by the farmers or supplied to kitchens/restaurants and market. By setting up edible rooftop gardens or farming on suitable buildings, it is possible to promote more useful and meaningful functions for the green roofs (ARGP, 2008; Hui, 2011).

5.7.1 Agricultural Green Roofs

In recent years, concerns about the environment have combined with increased interest in health and community building issues, giving rise to support for food systems as an integral part of sustainable development. Figure 5.11 shows how green roofs could contribute to the sustainability of an urban environment, by promoting and integrating green building, urban greenery and urban agriculture.

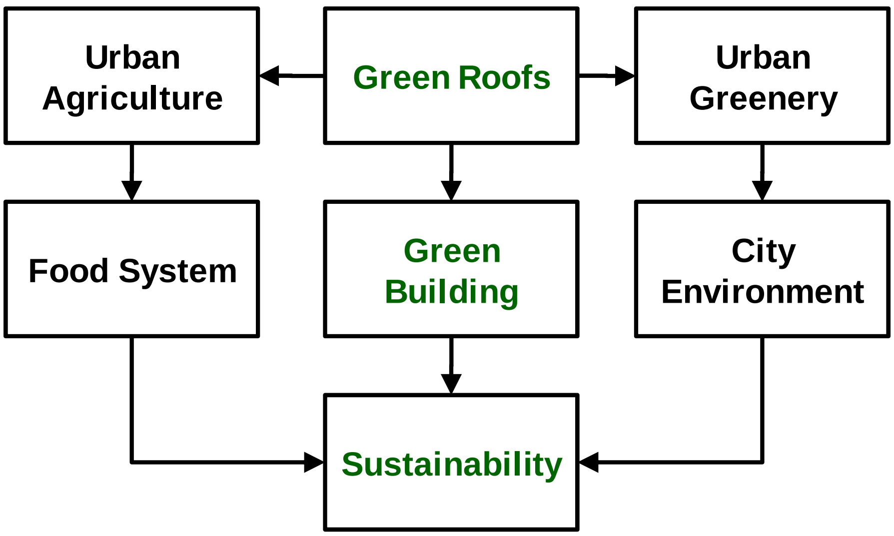


Figure 5.11 Contribution of green roofs to sustainability of an urban environment

As compared with non-agricultural green roofs, rooftop farming has other benefits, different design requirements and implementation considerations. In summary, agricultural green roofs are designed for the following purposes to enhance sustainability in the urban city:

- Food production (e.g. community gardens and growing of healthy food)
- Active recreation
- Re-using wastes (compost, stormwater)
- Educational opportunities
- Local job creation (direct and indirect)

Figure 5.12 shows some pictures of a pilot study on sustainable rooftop farming in a primary school in Hong Kong (see also Figures 5.7 and 5.8). Organic farming, onsite composting for producing fertilizer, rainwater harvesting and renewable energy (micro-wind turbines and solar photovoltaic system) are applied in this study. The farming is carried out by the students and their parents with the support from the school teachers. The vegetables and produce are shared by the students.

Farming on the roof

Vegetables and herbal plants

Water melon

Green beans

(Source: Dr Sam C. M. Hui)

Figure 5.12 Pilot study on urban farming for green roofs

5.7.2 Design Strategy

Although green rooftop farming has a lot of benefits, there are a few constraints and limitations on farming in urban areas.

- Lack of available land and suitable space
- Land use control and building regulations
- Microclimate conditions
- The urban way of living makes people disconnect with their own communities

Green roofs might not replace large scale farms, but can assist in developing a model for small scale food production. Community gardens located on rooftops can be places for education and local distribution, as well as a showcase for commercial endeavors such as restaurants utilizing the roof for kitchen gardens. Figure 5.13 shows examples of rooftop urban farming in other countries. For example, a proposal to develop rooftop farming in the public housing estates in Singapore was put forward to address the issue of food security and reduce the carbon footprint associated with food imports (Lim and Kishnani, 2010). If such a scheme is implemented extensively in Singapore, then it could result in a 700% increase in domestic vegetable production, and so satisfying domestic demand by 35.5%.

An organic rooftop herb and vegetable garden on a high-rise building in Lak Si District in Bangkok (Source: www.time.com)

Rooftop container garden in Taipei, Taiwan (Source: http://photo.xuite.net/yiutsay)

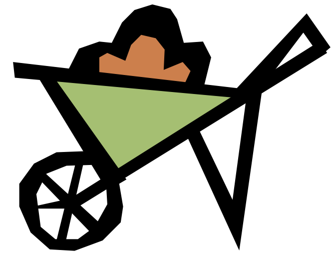
Eagle Street Rooftop Farm in New York City (Source: http://blog.anandaharvest.org)

Green rooftop with bee keeping in London, UK (Source: www.time.com)

Figure 5.13 Examples of rooftop urban farming

Green roofs for food production require little alteration from the standardised system, but a few issues need to be considered such as:

- The depth of the growing medium needs to be sufficient for anchoring and sustaining food plants.
- Waterproofing membrane needs to be sufficiently protected from frequent use of gardening tools.
- Fertilization may be required to sustain nutrient availability in heavily used growing medium.
- Safety and quality of produce must be considered.



6. Construction Methods

Contractors should be fully trained in the installation of green roofs and must have a specialist understanding of the green roof system as well as general construction knowledge. In general, green roof contractors should have knowledge and training in the following areas:

- Site preparation prior to installation
- Preparation and logistics
- Essential system components
- Growing medium
- Planting programme
- Installation of support system to the plants
- Installation of plants
- Post installation maintenance

6.1 Green Roof Installation

The installers should have experience with green roof systems. In fact, it may be preferable to have one company handle the whole project, from re-roofing to planting, thus avoiding scheduling conflicts and damage claims between the various trades. It will also bring single point responsibility post-construction.

Some plants can be installed while dormant. But during the rainy season, there may be some erosion of the growing medium through wind and rainwater runoff. Covering the roof with burlap or some other material could reduce this problem. Compartmentalization of the green roof into sections may allow for easier access to the membrane and the roof drains, for inspection and maintenance, without having to pull up the whole installation.

Due to the diversity of products available from the various green roof suppliers, it is recommended that specific installation advice is sought from the specified system provider to ensure compliance with supplier’s recommendations.

Methods for getting the materials up to the roof should be discussed to determine cost and potential equipment rentals. Timing is also important. The choice of lifting substrate up to the roof level and subsequent dispersion of it across the roof has significant budgetary and scheduling implications. Each project should be assessed for its specific conditions (i.e. roof area, slope, structure, access, plant equipment availability, etc.) to determine the most time- and cost-efficient installation method.

6.2 Safety Issues

Working on roofs bears a higher risk for accidents due to the exposed location. This has to be taken into consideration during the planning, design and installation phases. The need to have fall arrest systems is universal for green roof systems, however the type of system required varies depending on the type of green roof and the resultant requirement for maintenance. Securing measures are necessary at a height of more than 3 m. Fall protection measures include: railings, scaffolding or nets as well as ropes and chains. Various systems provide fall protection by using the weight of the green roof system build-up and also avoiding the penetration of the waterproofing. Figure 6.1 shows the safety measures to avoid falling from height.

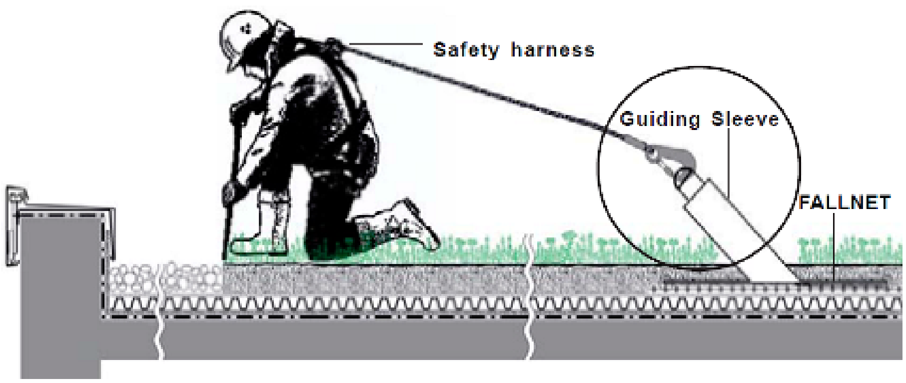


Figure 6.1 Safety measures to avoid falling from height (Source: Zinco)

Strict safety standards and requirements for protection against falls have to be taken into account during planning, execution and utilization of the roof (CUGE, 2010c). For example, railings for public access, anchors for maintenance access, and barrier-free direct access path to emergency exit should be provided. Roof access staircases must be non-slippery and equipped with handrails. Potential dangerous items such as TV cable and electric wire should be removed or relocated on the roof, if needed.

6.3 Fire Precautions

Green roofs, like any vegetation-covered surface, need to be designed to provide the necessary resistance to the external spread of fire, even when subjected to prolonged periods of drought (SPRI, 2010b). There is evidence suggesting that green roofs can help slow the spread of fire to and from the building through the roof, particularly where the growing medium is saturated. However, plants themselves, if dry, can present a fire hazard. The integration of "fire breaks" at regular intervals across the roof, at the roof perimeter, and around all roof penetrations is recommended. Certain plants should be avoided from use on rooftops for fire safety reasons; plants that are highly flammable, or that develop large root systems and thus high biomass, or that are excessively thirsty.

Traditional 'biomass roofs' made of reeds may have a high fire risk. In general, fire risk of extensive green roofs is not high because the heat load of burning the sedum vegetation is low (burn-resistant) and flammable materials are not used for green roof components. In fact, in some buildings, extensive green roofs can be used to reduce the risk of fire. Intensive green roofs provide preventative fire protection in the case of sparks and radiating heat. The criteria that extensive green roofs must meet in order to be considered fire resistant, are already met by most green roof systems that are offered by suppliers. Openings within the green roof (e.g. skylights) need to be installed with a vegetation free zone (approx. 500 mm). On larger roof areas a vegetation free zone or fire stops (e.g. gravel strip or concrete slabs) are to be installed at least every 40 m and around parapet.

6.4 Vegetation Planting Method

There are four different ways of planting the green roof vegetation: (a) seed sowing, (b) cuttings (Sedum varieties), (c) root ball plants and (d) pre-cultivated vegetation mats. The German FLL guideline (FLL, 2008) specifies the amount of seeds, cuttings, plants or mats needed for green roofs. The recommended planting period is in early spring (April-June) and late summer (September). For planting during the dry season, it is important to provide enough water to compensate for periods of low precipitation. In winter, precautions should be taken to prevent damage of the plants due to cold weather. Pre-cultivated plants should be stress resistant; if not, higher maintenance is required in terms of irrigation and fertilization.

For extensive green roofs, Table 6.1 shows four different planting options (Dunnett and Kingsbury, 2008).

Table 6.1 Planting options for extensive green roofs (Dunnett and Kingsbury, 2008)

Planting options	Description
Mono-culture Planting	This type of planting is simple and usually uses one plant species enmasse. It is the easiest to prescribe and install. It is argued that mono-culture plantings are visually uninteresting but in some circumstances a uniform appearance may be appropriate. From an ecological viewpoint they may be susceptible to total die-back if drought or disease severely affects the species in question.
Pattern Planting	This type of planting is used primarily for its visual effect but uses more than one species. As an open canvas, a wide range of designs are possible. The usual design elements may be used for good effect: a play with materials and colours; a play with proportion and balance; a play with texture, pattern and line; and the use of rhythm and repetition. This approach may require higher maintenance levels than other planting approaches.
Mixed Planting	The approach uses a mix of species to create a random but colourful carpet. It is a relatively safe approach as the successful growth of various species will eventually find their own equilibrium. This approach does not necessarily use indigenous species and in most parts of the world uses a mix of sedums.
Plant Communities Planting	This approach is based on natural habitats. Plants are chosen and combined in proportions approximating nature and their occurrence in the wild. Community-based planting tends to be self-sustaining, requiring low maintenance inputs for their upkeep. By their nature, they would be informal with a naturalistic appearance. This approach may often use wild grasses and may be considered untidy by some. Some examples from overseas have seen the careful and diverse selection of plants that flower almost year-round. This approach strives to use indigenous plants to fulfill a green roof's maximum ecological potential.

The vegetation layer can be installed using the following methods:

(a) Sedum Mat

A carpet of sedum species is field-grown to maturity, enabling it to be rolled directly on to the prepared substrate. The installed sedum mats should be thoroughly watered in and kept moist thereafter for 4-5 weeks, until the sedum mats become established. Mat edges are typically butt-jointed, although the specific supplier should be consulted to establish any shrinkage risk.

(b) Plug Planting

Rooted young plants (plugs), typically sedum species, are individually grown (in trays) and planted, with the opportunity to provide a greater diversity of planted species. Subject to the plant species selected, plants should be installed at a typical coverage rate of 15-20 plants per m^2. For optimum establishment, a minimum of six varieties of species are recommended per m^2.

Prior to installation of the planting, the substrate, drainage layer and any moisture mat should be saturated. The plants should be pre-watered before removing them from their trays. An approved slow release fertilizer can be applied on to the substrate (at an approximate rate of 50 grams per m^2). Then, the plants can be inserted and gently watered. It should be ensured that the substrate is kept moist for an initial period of 4-5 weeks to allow the plants to sufficiently establish themselves.

(c) Hydroplanting and Seeding

A mixture of sedum cuttings and seeds are spread on the prepared substrate, with mulch applied to allow cuttings to root and seeds to germinate. A minimum of six sedum species should be represented in the mix of cuttings and seeds, applied at a rate of approximately 150 grams per m^2 onto the surface of the substrate. The plant mix is typically spread by hand and covered with a liquid-applied mulch and an appropriate organic nutrient source.

6.5 Plants and Growing Medium

Care of the plants on the green roof will require the most attention during the critical establishment phase, which lasts approximately 18-24 months (unless the green roof is pre-grown and close to being established upon installation, as in the case of some modular systems). New green roofs will succeed with proper plant selection and care. A horticultural professional can assist with individuals caring for the green roof to organise schedules and routines for the following essential garden tasks:

- Hand weeding: necessary throughout life of the roof.
- Watering: necessary especially during establishment phase and might be necessary throughout the life of the roof and/or especially during droughts.
- Thinning: necessary after the establishment phase to promote plant health.
- Pruning: necessary after the establishment phase to promote plant health.
- Fertilizing: may be used during establishment phase to promote plant health (organic products are recommended). Fertilization should be done thoughtfully, keeping in mind that green roofs are confined planting areas. Excess fertilizer will be carried in stormwater run-off and likely end up in waterways.
- Replacing planting and in-fill in areas where plants have died off might be necessary for adequate surface coverage.

Not to be confused with soil, the growing medium is distinguished by its mineral content, which is often synthetically produced, providing the basis for an ultra lightweight growing medium. Applying wrong type of growing medium can result in inadequate drainage (leading to collapse), excessive weeds (seeds in the substrate), loss of species diversity, and loss of organic content through mineralization. The thermal mass of the growing medium plays a significant role in dampening the impact of ambient temperature fluctuations. This property can dramatically affect heat transfer through roof systems in hot climates.

Figure 6.2 shows some examples of growing medium for green roofs. In general, intensive green roofs need more organic matter to retain water and provide nutrients; extensive green roofs need bigger mineral aggregates proportion to retain water. The composition of growing medium is determined by weight loads, climatic conditions, drainage needs and plant requirements. Growing medium should be applied damp to avoid loss by wind, cover until plants established.

(Source: www.g-sky.com)

Figure 6.2 Examples of growing medium for green roofs

Water retention is another important parameter which can vary with the type and amount of vegetation, medium composition, and climate. Since absorption and flow rates are site and system specific, estimations of water retention characteristics must be calculated for individual cases. Growing medium depth and composition must also be appropriate for the selected vegetation.

Watering and weeding is especially important during the first two years of the green roof. The roof requires careful weeding before weed seeds are produced. Sterile growing medium may also contain weed seeds. A certain amount of weed growth is inevitable, as seeds arrive on the roof via wind, birds and shoes. For overall health of the green roof, weeds should be identified and removed early and often.

6.6 Inspection and Testing

Vertical components rising from the main structure such as walls, vents, HVAC systems and electrical boxes should not generate pressure on any part of the roof membrane, which could potentially over time compromise the membrane and cause water ponding or leaks. Regular inspections should take place around these vertical components to keep them clear of debris. These inspections may be scheduled at the same time as drain inspections.

Remedial works to the waterproofing require extensive investigations simply to locate the point of fault. Combined with the fact that the removal (and subsequent replacement) of the green roof build-up is so labour intensive, significant costs can arise from problems with the waterproofing layer. The inspection and testing of the water integrity of the roof covering prior to the green roof installation is therefore imperative, especially for existing buildings (Liu, 2011).

A ‘walk through’ is usually conducted with the roofing consultant and the general contractor prior to installing the membrane. It is imperative that the deck surface is prepared properly before installing the membrane. After membrane installation and prior to installation of all additional green roof system layers, a membrane leak detection test should be conducted to ensure the waterproofing membrane doesn’t have any leaks. The membrane test can help pinpoint design and construction errors and helps maximize owners protection under the terms of the roof contract and roof warranties. This test ensures that the roof has no leaks and is free of hidden defects in both waterproofing and flashing systems. Automatic leak detection systems are also available that can notify the owner of leaks after the green roof has been installed. Table 6.2 shows a list of the testing methods for leak detection.

Table 6.2 Testing methods for leak detection

Method	Description
Flood testing	It is a procedure in which a controlled amount of water, usually 10 cm, is temporarily retained (i.e., drains are closed, or sloped areas are dammed) for a period of 24 to 48 hours over a horizontal surface to determine the effectiveness of the waterproofing system.
Flowing test	Flowing water continuously over the surface of the waterproofing membrane for a minimum of 24 hours without closing the drains or erecting dams.
Electric field vector mapping (EFVM)	A conductor wire is looped around the area to be tested, on top of the membrane and connected to an impulse generator, prior to the installation of other components. During testing, an electric current is delivered at short, regular intervals. The current flows across the membrane, to breaches in the membrane, where it can access the grounded structural deck. Using a receiver connected to two probes, the testing agent can identify the current’s flow and accurately locate the breach.
Capacitance (Impedance) testing	It utilizes an electric field to determine the relative moisture content on and below the membrane, but may not pinpoint the exact leak. For accuracy during testing, the membrane must be dry and the assembly uniform in thickness and material.
Infrared (IR) thermal Imaging	It is an interpretive testing method based on the principle that wet and dry building components have differing rates of heat gain and retention. It can cover large areas quickly and cost effectively, above and below the surface of the membrane but may not pinpoint the exact leak. This testing method is not useful after a green roof has been installed, since the green roof reduces heat reflection.
Moisture sensors	Install moisture sensors at suitable locations of the roof to detect possible leaks.

Types of tests usually used for leak detection are flood test and flowing test. Other strategies for detecting leaks include electric field vector mapping, capacitance (impedance) testing, infrared thermal imaging, and moisture sensors.

Prior to the installation of the above-membrane components (drainage panel, growth media, vegetation, etc.), the contractor will conduct a standing water leak test (also known as a flood test). The test will involve flooding the entire green roof area with not less than 50 mm of standing water for a period of at least 24 hours with drains and scuppers blocked. Before draining the standing water, the owner's representative, supplier's representative, and contractor will inspect the roof for leaks from below, and from the roof surface; this will include walking all membrane seams. Once the standing water has been drained, the roof will be inspected and all membrane seams walked again. If areas are found that are suspected of leaking, the contractor will perform test cuts according to the supplier's directions. If test cuts are determined to be wet, the contractor will patch the test cut per the supplier's specifications and the flood test will be repeated.

In addition to leak detection, inspection for adequate slope to drain is also important. A maintenance plan should be established prior to the completion of all new green roofs. Both plant maintenance and inspection of membrane flashing points and various roof structural elements are regularly required.

7. Maintenance Issues

All roofs, green or conventional, require regular maintenance. Maintenance is an aspect that will determine the success of green roof systems (Urbis Limited, 2007). The maintenance requirements of green roofs are determined by many factors – height, micro-climate, soil types, soil depth, irrigation, species used and access. In high-density cities like Hong Kong, access is often a crucial factor influencing maintenance costs. Green roof design should consider this aspect.

Maintenance, conducted by qualified personnel will ensure the initial establishment and continued health of the green roof system. It is recommended that the installing contractor remains responsible for the maintenance of the green roof during this establishment stage (between 12-15 months) and prior to the assignation of maintenance duties to the building owner's representative. Maintenance contractors with specialist training in green roof care should be used, where possible.

7.1 Three Stages of Maintenance

To ensure the long term aesthetic and functionality of the green roof it is important to provide maintenance measures in a systematic way. There are three stages of maintenance concerning the vegetation:

(a) Installation Maintenance

Several aspects of maintenance and service are involved throughout the first year for the successful accrual of the plants after installation. It is important to provide sufficient water supply during the dry season. Replanting is necessary if there are dying or missing plants after installation and weeds and other unwanted plants need to be removed.

(b) Development Maintenance

It is essential to support the vegetation until total coverage of the roof is achieved. The development maintenance is equal to the installation maintenance but with lower intensity.

(c) Up-keep or On-going Maintenance

After the development of the plants on the green roof is ensured, it is crucial to maintain and inspect the roof once or twice a year. Weeds and other unwanted plants on the entire roof, at the perimeters and at the upstands need to be removed. The irrigation system and inspection chambers need to be monitored to ensure that water outlets are all free from blockages. For grass and herb vegetation the organic material has to be removed once a year and grass need to be pruned regularly.

Intensive green roofs require higher maintenance and service throughout the year.

7.2 Maintenance Requirements

Green roof plants require regular attention and care including irrigation, weeding, fertilizing, pruning and replanting. Some maintenance procedures should be scheduled after events (such as floods and storms) while others can be scheduled according to seasonal events. Like any garden, roof gardens do normally require frequent maintenance. However, extensive green roofs do not require any more maintenance than a conventional roof. They should be inspected annually in order to remove any unwanted plants and to unblock drains. Other types of green roofs will require more frequent maintenance, particularly if food is being produced. Appendix VIII gives a checklist for green roof maintenance.

7.2.1 Plant and Waterproofing Membrane

Both plant maintenance and maintenance of the waterproofing membrane are required. Depending on whether the green roof is extensive or intensive, required plant maintenance will range from 2 to 3 yearly inspections to check for weeds or damage, to weekly visits for irrigation, pruning, and replanting. To ensure continuity in the warranty and the upkeep, it is recommended that the fees for 3 to 5 years of this service be included in the original bid price, and that maintenance contracts be awarded to the company that installed the green roof, or to an affiliate. Intensive systems typically require more maintenance than extensive systems due to the greater diversity of plants.

Maintenance and visual inspections of the waterproofing membrane can be complicated by the fact that the green roof system completely covers the membrane. Although the green roof protects the membrane from puncture damage and solar radiation, doubling its lifespan, leaks can still occur at joints, penetrations, and flashings, due more to sloppy installation than to material failure. Regular maintenance inspections should be scheduled as for a standard roof installation, especially just before the warranty period expires.

7.2.2 Leak Detection and Membrane Replacement

Some companies are recommending the incorporation of an electronic leak detection system between or underneath the waterproofing membrane to pinpoint the exact location of water leaks (see also Section 6.5). Access strategies include keeping the sensitive areas free of plants and growing medium (e.g. gravel skirts), and dividing the green roof into distinct compartments for ease of removal.

Eventually, after 30-50 years, the membrane will have to be replaced. Depending on the roof size, building height, type of planting, and depth of growing medium, the system will either be removed and reinstalled over the new membrane, or replaced entirely. If the green roof can be removed and stored on the roof while the membrane is being replaced in sections, then the additional cost is "labour only" in comparison to the original cost. If the green roof has to be moved off the roof and brought back up, then costs will increase accordingly, and thereby the arguments for starting fresh, with new growing medium and plants, become more convincing.

7.3 Design for Maintenance

At the design phase, it is important that the green roof system is specified accounting for any budgetary constraints. The costs of roof maintenance should therefore form part of the life cycle cost analysis for the building, allowing the most appropriate green roof specification to be realised. After the initial installation of a green roof, on-going maintenance is a critical element for success; the first two years are the most important as the plants are establishing themselves and filling in any gaps for complete coverage, and fertilization should be minimal until the third year.

7.3.1 Major Considerations

At a minimum, the following points should be considered during design development to ensure ease of maintenance for green roofs during and after installation:

- Access for equipment and inspections following construction.
- Access for water is very important in most green roofs. Irrigation system, growing media and plant selection are critical factors determining long-term maintenance requirements and survival of the green roof vegetation under hot, dry conditions; otherwise, vegetation may have to be repeatedly replanted and/or the irrigation system replaced. Access to multi-functional irrigation timers is recommended.
- Where an under-drain system is used, a clean-out should be provided for both inspection and maintenance. There is potential over the long term for the roof under-drain system to become clogged with growing medium and organic matter that migrates down beneath the plant root zone. The ability to access the under-drain system, flashings, drains, etc. for clean-out is essential.

Plants are susceptible to insufficient drainage in the soil. If too much water is present and unable to drain, the plants will drown or rot. Regular inspections of drains should take place approximately three times per year, with additional inspections advised after major weather events. All drains must remain free of vegetation and foreign objects. Inspection of drainage flow paths is crucial because of the severe consequences of drainage back-ups. In order to allow for regular inspections and maintenance, every drain on a green roof must remain permanently accessible. Roof outlets, drains, interior gutters, and emergency overflows should be kept free from obstruction by either providing a drainage barrier (e.g., a gravel barrier between the green roof and the emergency overflows) or they should be equipped with an inspection shaft.

With proper design and regular maintenance, green roofs should last over 40 years. If there is space and loading capacity, then the green roof can be moved onto other areas of the roof and afterwards returned to the original site, whilst waterproofing is replaced. Some extensive system can be removed intact and relocated too.

7.3.2 Maintenance Procedures

The waterproofing roof membrane is the most vital aspect of green roof longevity and success. There are areas where regular inspections are advised at least three times per year. These include all joints, borders or other features penetrating the roof, such as all abutting vertical walls, roof vent pipes, outlets, air conditioning units and perimeter areas. In addition, joints must offer open access for inspection, maintenance and upkeep. Any areas or joints (such as vents, ducts, drains and expansion joints, etc.) where the roof is penetrated should be regularly inspected and kept free of roots, leaves, rocks and debris. A vegetation free zone of 300-500 mm around the perimeter of the roof and around all drainage locations is recommended. The vegetation free zone typically has rocks, stone or gravel.

Although the green roof system is built for low maintenance, extensive green roofs still need to be maintained to ensure healthy growth of plants, proper functioning of drainage layer, and so forth (DSD, 2009). It is also necessary to upkeep a certain level of maintenance to ensure that unwanted plant species and weeding do not invade the green roof system by causing damage and dominating the original plantings. Undesirable plant species are best avoided by establishing a complete coverage of the desired plant species. Any wind-blown seeds or cuttings should be removed before they have the opportunity to take root. Drainage outlets (including inspection chambers) and shingle/gravel perimeters should be cleared of vegetation, twice yearly. It is also important to investigate how to keep birds from inhabiting. Table 7.1 show the green roof maintenance procedures suggested for Hong Kong.

Table 7.1 Maintenance procedures for green roofs (Urbis Limited, 2007)

Maintenance Procedure	Intensive: Podium / Sky Gardens	Extensive: Extensive Green Roofs on Existing Roofs	Notes
Waterproofing Inspection	x1 per year	x1 per year	Inspection for water penetration through the concrete
Drainage Inspection	x1 per month	Every 2 months	Inspection of drainage outlets
Litter	X1 per week	None - As necessary	Includes removal of litter and emptying of bins. Depends largely on the type of green roof, visitor numbers & occasional litter that may fall on the roof.
Plant Health Inspections	x6 per year	2 /yr	Includes checking for insect and fungus infestations. Particularly relevant during establishment period
Replacement planting	As necessary	As necessary	
Irrigation	780 l/m²/yr	Low to none	Based on 15 litres per week (reduced from 25 litres due to HK's high rainfall during summer) for amenity planting.
Pruning	x2 per year	N/A	
Lawn Mowing & Rough Grass cutting	x9 per year x0 to x3 per year	N/A x0 to x3 per year	Depends largely on design and turf grass species used. Fallow grasses require less cutting than turf grasses.
Fertilizing	x1 to x2 per year	Every 4-5 years	May be increased for horticultural practices which remove biomass from the system, such as lawn mowing
Disease & Pest Control	X4 per year	X4 per year	Includes regular inspections.
Weeding	X9 per year	None to x3 per year	Weeding for extensive green roofs should be virtually none if installed correctly. Self-seeded trees may be a problem in urban fringe areas.

7.4 Warranties and Liability

Prior to implementation of a green roof project, it is essential to understand project specific needs for insurance and liabilities. Often these are tied directly to design, implementation, access and general use after completion of a project. Different green roof systems come with different warranties and it is recommended to draft a plan of tactics during the design phase of a project in case of a future leak. This plan might include a strategy for surveying and potentially replacing the entire membrane or part of the membrane. It might be helpful to plan a phased implementation, so only part of the roof would have to be exposed in order to survey and potentially replace part of the membrane in the event of leakage.

Not every warranty package is the same. A planted roof is a complete system and the waterproofing warranty should include all components of the waterproofing and planted roof. However, few suppliers will give you a warranty on something they do not sell and because green roofs are layered systems, that can sometimes be a challenge. Typically a well-coordinated roofing consultant/roofing contractor and landscape architect/landscape contractor can help. A mediocre green roof system can be selected simply because the team/owner feels more secure with a full warranty from a single source supplier. Single source suppliers count on this tendency. It is vital that the warranties offered by the suppliers are closely compared 'apples to apples'. Some might seem very inclusive at first glance but are actually very restrictive after further review.

Building insurance should not increase with the addition of a green roof, unless it is made accessible for tenant or public use. All manufacturers of green roof products will provide a warranty for their products as long as they are installed as per the manufacturer's specifications. This sense of security can be a selling feature for some clients, especially institutions, even though the price is typically higher than combining individual "off-the-shelf" products which perform the same function but were not specifically designed for use in green roof applications. If cost is a concern, then the only warranty or guarantee available for this "combining of products" will likely be related to the installation itself, and not the performance of the products.

If the entire system (waterproofing assembly as well as vegetated roof cover, including vegetation and growth media) is provided by a single source, then it is important to ensure the supplier's warranty includes the initial vegetation viability. In addition to the standard waterproofing warranty, the warranty should state that the proposed vegetated roof cover is completely compatible with the waterproofing assembly. Also, the warranty for the vegetated roof cover should indicate that the proposed waterproofing system is compatible with the vegetated system (including plant climate zone, roof slope, and irrigation and maintenance requirements). If the waterproofing and vegetated roof cover are not provided by a single source, then the waterproofing assembly should be warranted separately as to be independent from any warranty for the vegetated roof cover.

7.5 Irrigation

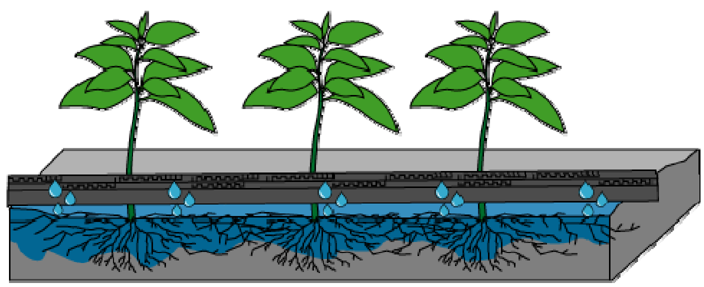
Irrigation is typically required for the initial establishment of the green roof. However, once plant cover is achieved, irrigation can be reduced (for intensive and semi-intensive roofs) or avoided (for most extensive roofs, subject to plant selection). The more intensive the roof, the more likely it will be that an artificial irrigation system is required. Rainfall is the typical source of water, however complementary irrigation options include hoses, sprinklers, overhead irrigation and automated systems that pump from some reservoir storage.

Irrigations systems and plant water requirements are highly dependent on site location, water supply and pressure, maintenance access, size of planter, type of vegetation and the expected lifespan of plants and the irrigation system (Urbis Limited, 2007). Selection of the principal ways of irrigation depends on the cost, advantages and disadvantages of each system. There are three principal ways of irrigating green roofs:

- Manual hose irrigation: a 20m hose pipe connected to water points located at 40 metre spacing.
- Fully automatic irrigation systems: a programmed system that irrigates at set times, running continuously with minimal supervision.
- Semi-automatic irrigation systems: a programmed system with various manual override options that are activated per day or as needs require.

The irrigation should be designed for easy access and water efficiency. If possible, stormwater runoff shall be collected and used for irrigation purposes. Water resources for green roof irrigation might include (a) roof drainage water (rainwater), (b) recycled building grey water, (c) air-conditioning condense water, and (d) backup water supply in case the water level inside the tank drops below the one day irrigation requirement level. The common types of irrigation method are: overhead spray, drip, hose bib or hose, and capillary. Figure 7.1 shows examples of irrigation methods for green roofs.


Water sprinkler for irrigation


Drip irrigation system


Water control (Source: www.gardena.com)


Endline drip head (Source: www.gardena.com)

Figure 7.1 Irrigation methods for green roofs

The decision to use drip or spray irrigation is based on growing medium characteristics and plant needs. Drip irrigation might prove insufficient if the growing medium restricts lateral movement of water. Custom detailing of irrigation systems may be necessary to avoid damage to the waterproofing membrane because of the shallow depths of growing medium. For example, typical concrete thrust blocks for irrigation mainlines may have to be detailed differently.

Drip irrigation is sometimes more effective when installed below the vegetation layer to avoid heating of the drip line and to get a more effective watering of the roots. Spray irrigation should be considered for shallow depth applications as drip irrigation may not spread laterally when applied over a rapidly draining medium.

Research studies suggest that non-succulents dry out faster (need more frequent irrigation), whereas succulent plants require less frequent irrigation. However, succulents tend to die rather than go dormant during prolonged dry periods. Installation of irrigation monitoring equipment such as timers, flow meters, sensors, runoff monitors and precipitation monitoring equipment can vastly improve irrigation procedures and conserve water.

7.6 Fertilization

Fertilization is the process by which additional nutrients can be supplied to the plants, enhancing germination, flowering and resistance to weather extremes. The regularity and type of fertilization requirement will therefore depend on the type of green roof and its plant specification. Fertilization will most likely be necessary during the initial establishment of the vegetation over the first and second growing seasons; after that time, occasional fertilization, perhaps once or twice annually, might be necessary.

Normally, a green roof planted correctly will reach maturity in two growing season, or less. It is necessary to consult the roofing contractor in order to determine which chemical fertilizers and pesticides, if any, are acceptable and will not damage the waterproofing assembly or void the warranty.

8. Project Management

Project management is critical to delivering successful green roof installations. The client should employ a consultant to prepare a proposal with regard to the choice of green roof, technical requirements, building requirements, maintenance requirements, cost estimation and time schedule. It is recommended that qualified professionals should be engaged to design the green roof system. Appendix IX gives a checklist for considerations before starting a green roof project.

Scheduling works to comply with the project programme (and the waterproofing installation in particular) and close collaboration with the green roof supplier will be essential to ensuring that materials arrive on site in a timely fashion, whilst minimizing the storage time of plant materials on site. The method of installation for the substrate and planting layer should be appropriate to the roof layout and objectives. Before commencing installation works, the integrity of the waterproof covering must be tested and approved. All drainage works, flashings etc. should be finished prior to the application of the green roof covering.

8.1 The Role of Professionals

The building requirements should be verified by a building professional to consider the structural adequacy of the building or structure on which the green roof is constructed, any requirements for building alterations and the necessity of any statutory submission. In case a submission to the Buildings Department (BD) is required, an Authorized Person (AP) and/or Registered Structural Engineer (RSE) should be employed to prepare the plans and supervise the construction of building works. For a green roof project in a school, approval by the Education Bureau (EB) may be required as well. Additional administrative rules imposed by the EB with regard to appointment of an AP and tendering procedures and appointment of a Registered Contractor should be followed. For students' accessibility, EB requires the roof to have fence around the area with height at least 2.5 m, depending on factors such as the nature and extent of the green roof and the planning, design and intended use of the roof area.

Selection of professional consultants depends on the function of the green roof, the size of the project, the location of the project, and the green roof experience of the primary consultant and/or project instigator. A structural engineer may be required to determine the existing, or required, loading capacity of the roof. An architect may be required to co-ordinate the project as well as the design and detailing of the building and roof, including material specifications. A landscape architect may be required for the layout of the planting areas and the selection of the plants. A building services engineer (BSE) may be required to calculate the cooling and heating implications of the green roof, and to discuss integration with existing and proposed rooftop building services equipment, water/electricity supply and drainage needs. Depending on the primary function of the green roof, specialist consultants may also include a horticulturalist, a horticultural therapist, an ecologist or biologist, a roofing consultant, a planner, an artist, and marketing/advertising professionals.

8.2 Contractual Matters

Ideally, a green roof system should come from a single source; that is, a single supplier or contractor whose components are engineered to work together from the membrane up through the plants and with warranty as much as possible. Mixing and matching system components is a potentially risky proposition and is not a good idea because you are taking full responsibility for all the things that could go wrong. It is important to include in the specification a two-year maintenance contract for the green roof to make sure the roof is well cared for during that most-crucial time.

If the project is a shallower modular system with trays or a vegetative mat system, there might not be an actual design cost, as these modules and mats most often are pre-planted and pre-grown. If the project is a shallow (extensive) or deep (intensive) loose laid system, design fees can reach 10-15% (or more) depending on the complexity of the project. Planting plan, materials plan, grading plan and lighting plan corresponding to the architectural roof plan and site survey findings plus analysis from the structural engineering plan more than likely have to be generated. The consulting fee on green roofs systems depends on the size and complexity of the project.

Administrative review and project approval might constitute 0-10% of the overall project cost. Depending on the size, location and complexity of the project, certain regulatory reviews might be required that might have administrative fees associated with the project. Keeping a project on schedule is often extremely important to ensure a timely return in investment for the client. Project approval process, administrative meetings and regulatory reviews can result in costly project delays or waiting time if not coordinated carefully.

Installation could make up 0-10% of the overall project cost. If the project is a shallower modular system with trays or a vegetative mat system, there might be only a minimum installation cost. Deeper and more complex projects will more than likely have a higher installation cost. Other factors that affect cost are: access, size of project and approach for type of planting and implementation of components. Installation can sometimes be as expensive as (or more expensive than) the material cost of the project.

It is important that the installing waterproofing contractor is aware that a green roof will be installed over the roof covering, thereby allowing the detailing (e.g. upstands) to accommodate the increased build-up. For existing buildings, it is important to have written confirmation from a professional engineer certifying that the structure is capable of bearing the additional load of a green roof system.

For instance, the ArchSD has tried and applied two procurement methods for green roof projects in government buildings, using small quotation lump sum contract. The first method is a term consultancy by which the main contractor will appoint a specialist green roof contractor with proven job reference. The second method is small consultancy with the architectural consultant as lead consultant for builder works and landscape architect consultant as sub-consultant for green roof part.

8.3 Costs of Green Roof Systems

Cost and maintenance requirements are key considerations when evaluating green roof systems. The cost of a green roof system will vary based on size, complexity, location and any financial incentives. Green roofs are always cost effective when considered over the lifetime of the building because they increase income and decrease costs. Green roofs are initially more expensive than traditional roof systems; however, both short- and longer-term building owners reap rewards in several important ways, such as increased property values, improved building performance, and in the case of roof gardens, added usable space. Hence, when all of the benefits are considered the payback of green roofs usually makes economic sense. Therefore, planning and funding of green roofs requires an understanding of life-cycle costs (from cradle to grave) and the related environmental benefits.

8.2.1 Incentive Schemes

In the past, the cost related to the installation of a green roof has been high. As this industry develops, the initial cost of implementation will be reduced with standardised practices and programmes that allow consistent availability of products, suppliers and installers. In addition, incentives provided by the public and private sectors, technology advances and integrated building designs could decrease the project cost and make green roofs more cost effective and attractive to a wider range of clients. Table 8.1 shows three examples of incentive schemes for green roofs in Hong Kong. They are mainly designed for schools.

Table 8.1 Examples of incentive schemes for green roofs in Hong Kong

Environment and Conservation Fund (ECF) www.ecf.gov.hk ECF has been set up by the Hong Kong government since 1994 to provide funding support to local non-profit making organizations for projects and activities in relation to environmental and conservation matters. The Enviornmental Campaign Committee (ECC) has been authorized by the ECF Committee to vet and approve Environmental Education and Community Action Projects including Minor Works Projects that cost $2,000,000 or less, and this function is performed by the Environmental Education and Community Action Projects Vetting Sub-committee under ECC. Projects seeking more than $2,000,000 will be referred with its recommendation to the ECF Committee for consideration.
HSBC Green Roof for Schools Programme http://www.hsbc.com.hk/1/2/cr/community/projects/green_roof Initiated in 2007 by the Hongkong Bank Foundation in collaboration with The University of Hong Kong, the HK$5 million Programme has created outdoor classrooms on green roofs for teachers and students in 10 selected schools in Hong Kong.
Campus Green Roof Scheme (by Green Power and Citic Bank) http://www.citicbankintl.com/about-us/community-and-us/2010/en/index.jsp Green Power launched the bank-sponsored "Campus Green Roof Scheme" on 31 October 2010. Three rooftop gardens combining infrastructure and environmental education in Hong Kong were supported. The Scheme includes a total of three schools with diversified themes for the gardens, including a Herbs Garden, a Butterfly Garden and an Organic Farm.

8.2.2 Cost Evaluation

The cost required for a green roof is dependent on various factors. The type of green roof (e.g. extensive vs. intensive), green roof system build-up and different types of planting are the main factors. The logistic aspects and transportation of materials as well as the roof slope and the entire roof size are also very important. The larger the green roof, the cheaper the cost on a square metre basis. Other cost items include design and specifications, project administration and site review, maintenance and irrigation system. Table 8.2 shows the factors affecting the overall project cost of extensive and intensive green roof systems.

Table 8.2 Factors affecting the costs of green roof systems

Extensive green roofs	Intensive green roofs
• Access constraints to the site during construction. • Whether the project is a new construction or a retrofit project. • The slope of the roof. • Status of the existing roof (if a retrofit project). • The number and arrangement of rooftop utilities, affecting labour and wastage. • The materials used, and the type of plant material used. • Irrigation needs. • Growing medium depth. • Access or safety components that need to be added.	• Access constraints to the site during construction. • The ratio of hard- to soft-landscaping. • The amount of specialised thematic designs and materials including water features, canopies, etc. • Whether the green roof is part of a larger building contract or not. This affects the availability of building equipment already on site. For example, costs can be drastically affected if cranes are brought in just for landscaping. • Whether the contract needs to be built in access-limiting stages. When a site is being used by the public (often requiring pedestrian diversions), costs may be increased by these inconveniences. • The size and maturity of the trees being installed and the type of vegetation being prescribed (palms, bamboo, trees). • The depth of the topsoil. • Irrigation needs. • Lighting required. • Access or safety components that need to be added.

Urbis Limited (2007) has estimated the green roof costs in Hong Kong as follows (based on the information up to 2007). The cost estimate should be adjusted to current price level taking into account various factors that may affect the overall cost, such as market development of green roof projects in Hong Kong, site and project constraint, and use of recycled water for irrigation.

- Capital costs: (based on 2007 figures)
    - o Intensive green roofs: HK$1,000-5,000/m² (market average: HK$2000/m²)
    - o Extensive green roofs: HK$400-1,000/m² (market average: HK$500/m²)
- Recurrent costs: (based on 2007 figures)
    - o Intensive green roofs: HK$6.5-44/m²/year (average: HK$20/m²/year)
    - o Extensive green roofs: HK$0.8-2.25/m²/year

8.4 Regulatory Measures and Policies

Green roof systems are considered an extension of the roof system, and therefore must comply with requirements for structural loading and moisture protection. If the green roof is accessible for more than routine maintenance - in other words, if tenants or the public use the roof as an accessible outdoor green space - then the design must also comply with requirements for occupancy, exiting, lighting, guardrails, and barrier free access. To recognise the contribution of green roofs to green building and sustainable urban environment, some countries have adopted policies to require or encourage green roofs, and this has promoted the fast expansion of the green roof market.

8.4.1 Green Building Incentives

Development of a property, for a new building or in a retrofit situation, often requires a certain percentage of green space, depending on the site location and the occupancy of the building. Local planning and zoning may qualify a green roof as green space or landscaped open space. This could permit the developer to use more of the property at grade, or to qualify for density bonus. If the green roof is accessible to tenants, it may also qualify as an amenity space for that building, with no loss of gross floor area within the building envelope. In the future, green roofs may become a requirement for certain building types, or a source of yearly tax credits for retention of storm water runoff from the site. In the meantime, a proposed green roof may be used as a consideration on environmentally sensitive sites or with environmentally sensitive community groups.

Existing government policies and standards in Hong Kong influence the creation of green roofs in the public and private sector in both direct and indirect ways (see also Section 4.5). Joint Practice Notes 1 and 2 (JPN) (BD, LandsD and PlanD, 2011a & b) were designed by the government to set out the initial incentives that the government would be able to provide encouragement to the incorporation of 'green' features, and give guidance on how to apply for them under the Buildings Ordinance, the Lease Conditions and the Town Planning Ordinance, as appropriate. JPN 1 refers to residential developments and JPN2 refers to commercial developments. Furthermore, the purpose of JPN is to provide incentive to private developers to include amenity features that are not a statutory requirement but which enhance the quality of life for residents and users.

8.4.2 Green Roof Policies and Standards

Green roof policies are important for encouraging applications and promoting the fast expansion of the green roof market. Direct financial incentives, reduced stormwater taxes, density relief and regulatory measures, are some of the green roof policies which have been used in other cities (Shepard, 2010). In certain countries, such as Japan (Tokyo) and Denmark (Copenhagen), greenery installation to flat-roof areas is a legal requirement on new-build development. In Germany, an entire service industry has been formed around green roof installation, significantly reducing the first costs of a green roof. In the UK, there are no public policies now that relate directly to green roofs, however policies encompassing urban renewal, construction, open space, nature conservation and drainage all have relevance.

In Singapore, the Urban Redevelopment Authority (URA) and National Parks Board (NParks) had introduced since 2009 a series of initiatives to promote skyrise greenery, with the aim for an additional 50 hectares of skyrise greenery by 2030 (http://www.skyrisegreenery.com). Firstly, the URA's Landscaping for Urban Spaces and High-rises (LUSH) programme actively facilitates the provision of greenery within the private realm by encouraging developers to incorporate both ground greenery and skyrise greenery in the form of sky terraces and rooftop gardens. Secondly, NParks had introduced a pilot incentive scheme to encourage existing building owners to green up their rooftops. Cash incentives of up to half the cost of installation are provided to encourage building owners to install green roofs. To help developers implement green roofs smoothly, NParks will also provide technical advice on green roof technology.

In Hong Kong, there is an urgent need to enhance the policy framework for green roofs and urban greening in order to supports sustainable urban living space (BD, 2009). The policy measures might include financial incentives, development regulations, density bonus, land lease conditions, fast track approval and streamlining. It is also important to establish the knowledge and expertise to properly specify, construct and approve green roofs. Green roofs should be constructed to acceptable minimum standards. Currently German (FLL) standards are being used by most suppliers and installers and this is expected to continue. Once the green roof market has been successfully built up, it is necessary to develop performance rating to evaluate the effectiveness of green roofs in addressing various environmental attributes.

8.5 Green Roof Performance

The actual performance of green roof systems depends on a number of factors. Nowadays, some research studies have been done on thermal and energy performance (Bass and Baskaran, 2003; Hui, 2009; Niachou, *et al.*, 2001), hydrologic or stormwater management performance (Carter and Jackson, 2007; Hui and Chu, 2009; Köhler, *et al.*, 2001; Simmons, *et al.*, 2008), as well as air quality/ pollution control (Currie and Bass, 2008; Yang, Yu and Gong, 2008). The research information is helpful for understanding and evaluating the potential and limitation of green roof systems. Figure 8.1 shows an example of green roof research facility in Canada for testing green roof performance.

(Source: Dr. Sam C. M. Hui)

Figure 8.1 Green roof research facility at BCIT, Canada

8.5.1 Experience in Germany and Japan

To ensure that a green roof achieves its performance goals or performs its ecological function, it is necessary to examine the various performance aspects in a holistic manner. The experience in Germany would be a good reference (Lawlor, *et al.*, 2006). In Germany, the FLL developed a performance rating system for green roofs to aid with regulatory measures to ensure compliance. The points-based system assesses the components and functions of the green roof. To obtain the base value, it takes the depth of the green roof system that can be penetrated by the plant roots and assigns 10 points for each centimetre of penetration. For example, if the depth is 10 cm, the system's base value is 100 points. From here, the system sets performance criteria for four further categories as shown below. People can use this tool to ensure that a green roof meets the desired ecological functions.

- Water retention capacity of the growing medium
- Water retention capacity of the drainage layer
- Number of plant species for extensive green roofs
- Plant biomass or volume for intensive green roofs

In Japan, the Organization for Landscape and Urban Green Infrastructure had established since 2005 an evaluation system on green infrastructure called Social and Environmental Green Evaluation System (SEGES) (www.seges.jp). This method can be applied to all types of greening installations and considers the land use sustainability, green space management and greening functions for the assessment. It currently provides five levels of rating including Green Stage, Excellent Stage 1 to 3, and Superlative Stage.

8.5.2 Research in Hong Kong

It is believed that more research is needed to investigate the performance of green roofs and determine the best strategy for designing green roof systems in Hong Kong and other urban cities. At present, some research studies have been done on the study of thermal and energy performance of green roof systems (Hui, 2009), integration of green roof and solar photovoltaic systems (Hui and Chan, 2001b), green roof urban farming (Hui, 2011), stormwater mitigation (Hui and Chu, 2009) and modular green roof systems (Hui and Chan, 2008). Another research study on biodiversity has been started and it is briefly described below.

The expansion of urban spaces and built form has led to habitat loss and fragmentation for many animal species. Green roofs can provide suitable habitat and refuge space for many bird and invertebrate species in urban areas. Green rooftops can be designed to play two key roles: they can be a "stepping stone habitat," connecting natural isolated habitat pockets with each other, or an "island habitat" that is separate from habitats at grade for less mobile species. Because roofscapes make up 15 to 35 per cent of the urban footprint, they have great potential to mitigate lost biodiversity.

Hui and Chan (2011a) have researched the potential of using biodiversity as a criterion for assessing green roofs and studied the design strategies to maximise urban biodiversity of green roofs. A systematic method for assessing the biodiversity effects was developed. The method comprises of six major factors: (a) species diversity and richness, (b) substrate type and depth, (c) plant species selection, (d) connectivity to natural environment, (e) green roof ratio and (f) ecologically responsible development.

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Appendix I – Useful Websites and Resources

Hong Kong:

Architectural Services Department (ArchSD), HKSARG
www.archsd.gov.hk
Buildings Department (BD), HKSARG
www.bd.gov.hk
Development Bureau's Greening website
www.greening.gov.hk
Environment and Conservation Fund (ECF)
www.ecf.gov.hk
Greening Master Plan (GMP), Civil Engineering and Development Department
www.cedd.gov.hk/eng/greening/
HKU Green Roof Research
www.hku.hk/bse/greenroof/
Hong Kong Green Building Council (HKGBC)
www.hkgbc.org.hk
Hong Kong Institute of Architects (HKIA)
www.hkia.net
Hong Kong Institute of Landscape Architects (HKILA)
www.hkila.com
Hong Kong Institute of Planners (HKIP)
www.hkip.org.hk
Hong Kong Institute of Surveyors (HKIS)
www.hkis.org.hk
Hong Kong Institution of Engineers (HKIE)
www.hkie.org.hk
Hong Kong Planning Standards and Guidelines (HKPSG),
www.pland.gov.hk/pland_en/tech_doc/hkpsg/
Hong Kong Professional Green Building Council (PGBC)
www.hkpgbc.org
Institute of Horticulture (Hong Kong) (IHHK)
www.ihhk.org
Kadoorie Farm & Botanic Garden (KFBG)
www.kfbg.org.hk
Produce Green Foundation
www.producegreen.org.hk
Revitalising Industrial Buildings
www.devb.gov.hk/industrialbuildings/

International:

Green roof – Wikipedia
http://en.wikipedia.org/wiki/Green_roof
Green Roofs for Healthy Cities
www.greenroofs.org
International Green Roof Association (IGRA)
www.igra-world.com
International Promotion Centre for Vertical Planting (China)
www.greenrooftops.cn
World Green Infrastructure Network

www.worldgreenroof.org

Canada:

Centre for Architectural Ecology, British Columbia Institute of Technology (BCIT),
http://commons.bcit.ca/greenroof/

Germany:

FLL (Forschungsgesellschaft Landschaftsentwicklung Landschaftbau) (Landscape Research, Development and Construction Society)
www.fll.de

FBB (Fachvereinigung Bauwerksbegrünung e.V.) (German Green Roof Association),
www.fbb.de

Green Roof Centre of Excellence, Neubrandenburg, Germany,
www.gruendach-mv.de/en/index.htm

Japan:

Organization for Landscape and Urban Green Infrastructure (formerly, Organization for Landscape and Urban Green Technology Development (Urban Green Tech Japan) and Urban Green Space Development Foundation),
www.urbangreen.or.jp

Social and Environmental Green Evaluation System (SEGES)
www.seges.jp

Singapore:

Centre for Urban Greenery and Ecology
www.cuge.com.sg

National Parks Board
www.nparks.gov.sg

Skyrise Greenery
www.skyrisegreenery.com

UK:

Green Roof Centre (Sheffield, UK)
www.thegreenroofcentre.co.uk

Green Roof Guidelines
www.greenroofguidelines.co.uk

LivingRoofs
www.livingroofs.co.uk

USA:

Extensive Green Roofs (Whole Building Design Guide),
www.wbdg.org/resources/greenroofs.php

Greenroofs.com: The Resource Portal for Green Roofs
www.greenroofs.com

Green Roof Research program at Michigan State University
www.hrt.msu.edu/greenroof

Appendix II – Different Types of Green Roof Systems

[Adapted from Forbes (2006) and Loh (2009)]

A green roof is a roof with vegetation integrated into its design. The term 'green roof ' usually refers to an engineered system, thus many people would exclude lichen growing on roofs unintentionally. Since the advent of green roofs, a green roofs industry has developed and many other variations of green roofs now exist.

1. Extensive green roof systems are typically characterised by shallower system profiles of 60-200 mm depth, with a weight of 60-150 kg/m², with lower capital cost, no added irrigation and lower maintenance.

2. Intensive green roof systems are those characterised by system profiles ranging from 150 to 1000 mm in depth, with a weight of 180-500 kg/m² and able to support a wider range of plants, though demanding more maintenance.

3. Semi-intensive or semi-extensive or simple intensive green roof systems include features of both intensive and extensive green roofs. They are of slightly greater depth than extensive systems (100-200 mm), allowing for a greater diversity of plants to be grown and local habitats recreated. Based on the same principles as extensive roofs they are light weight and generally low maintenance.

There are also some variations or adaptations to the 3 principal green roof systems as described below.

a) Built-in or integrated green roofs: the green roof components are installed as a series of layers

b) Modular green roofs: they are partially assembled off-site and installed in units. Some modular systems feature plastic or metal trays that are filled with growing medium and placed on the rooftop. Plants can be grown in these trays before or after installation. Other systems feature plants pre-grown in mats that are laid onto the roof surface.

c) Sedum roofs: these are usually pregrown sedum mats based on 20 mm of substrate or systems of greater substrate depth (standard depth = 70 mm) in which sedums can be seeded or planted.

d) Meadow roofs: these roofs are based on 70-100 mm substrate depth. They involve the use of seeded or planted low, droughttolerant grasses, perennials and alpines. These can be native or ornamental species.

e) Brown or biodiversity roofs: are a low maintenance roof made of gravel or recycled material such as crushed brick or concrete with small amount of soil providing habitat for certain types of plant and insect life, and some moss covered roofs. Such roofs are designed to recreate natural and often local habitats rich in birds, plants and insects. This is often done by using the by-products of the development process such as rubble and subsoil which are left to colonise naturally overtime or seeded with wildflowers.

f) Wetland green roofs: are roofs that function as a wetland ecosystem usually in conjunction with grey water recycling of the building they cover.

g) Rooftop gardens: are where planting is not integrated into the roof system, and thus are technically not classified as green roofs. However, sometimes there is no clear distinction as some rooftop gardens have an amount of intensive or extensive planting together with container planting and permeable surfaces. Green roofs are not just confined to rooftops but include gardens built on building podia, ‘sky gardens’ (a Singaporean term) which can occur at mid-levels of building and also apartment balcony gardens.

h) Urban agriculture: includes examples of rooftops being used for aquaponic or hydroponic food production using either intensive green roof systems or equipment situated on rooftops. When cultivation uses containers, then the term ‘green roofs’ is used loosely.

Appendix III – Technical Guidelines and Codes for Green Roofing

Country	Green roof guidelines/codes (reference)
Australia	• Green Roof Resource Manual, Sydney (Environa Studio, 2010) • Green roofs – understanding their benefits for Australia, BDP Environment Design Guide (Loh, 2009)
Canada	• Design Guidelines for Green Roofs (Peck and Kuhn, 2004) • Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West, Toronto, Canada (Tolderlund, 2010) • Green Roofs: A Resource Manual for Municipal Policy Makers (Lawlor, et al., 2006) • Introductory Manual for Greening Roof (Oberlander, Whitelaw and Matsuzaki, 2002) • Toronto Green Roof Construction Standard: Supplementary Guidelines, (Toronto Building, 2010)
China	• DB11/T 281-2005, Code for Roof Greening, Bejing (BBQTS, 2005) • DB440100/T 111-2007, The Technical Code for Roof Greening, Guangzhou (GBQTS, 2007) • DB440300/T 37-2009, Code for the Design of Roof Greening, Shenzhen (SBQTS, 2009)
Germany	• Guidelines for the Planning, Construction and Maintenance of Green Roofing (FLL, 2008) • Guidelines for the Planning, Execution and Upkeep of Green-roof Sites (FLL, 2004)
Hong Kong	• Study on Green Roof Application in Hong Kong (Urbis Limited, 2007)
IGRA	• A Quick Guide to Green Roofs (IGRA, 2008) [IGRA = International Green Roof Association]
Japan	• Guide to Roof and Wall Green Technologies (Organization for Landscape and Urban Green Technology Development, 1999)
Singapore	• Handbook on Skyrise Greening in Sinagpore (Ong and Sia, 2002) • A Selection of Plants for Green Roofs in Singapore (Tan and Sia, 2008)
UAE	• Green Roof Manual, Dubai (Dubai Municipality, 2009)
UK	• ABG Guide to Green Roof 2010 (ABG Ltd., 2010) • Greater Manchester Green Roof Guidance (Drivers Jonas and EDAW AECOM, 2009) • The Green Roof Pocket Guide (Forbes, 2006) • The GRO Green Roof Code (GRO, 2011) • Green Roof Guidelines (Groundwork Sheffield, 2010) • Green Roofs, CIBSE (Hassell and Coombes, 2007) • Building Greener: Guidance on the Use of Green Roofs, Green Walls and Complementary Features on Buildings, Construction Industry Research Information Association (CIRIA), London (Newton, et al., 2007)
USA	• FM Global Property Loss Prevention Data Sheets 1-35: Green Roof Systems (FM, 2007) • The NRCA Vegetative Roof Systems Manual (NRCA, 2009)

Note: Please refer to the References section for details.

Appendix IV – Technical Standards for Green Roofs

American Society for Testing and Materials (ASTM), USA: (www.astm.org)

ASTM, 2011a. *ASTM Standard E 2396-11, Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Vegetative (Green) Roof Systems*, ASTM International, West Conshohocken, PA.

ASTM, 2011b. *ASTM Standard E 2397-11, Standard Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems*, ASTM International, West Conshohocken, PA.

ASTM, 2011c. *ASTM Standard E 2398-11, Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Vegetative (Green) Roof Systems*, ASTM International, West Conshohocken, PA.

ASTM, 2011d. *ASTM Standard E 2399-11, Standard Test Method for Maximum Media Density for Dead Load Analysis of Vegetative (Green) Roof Systems*, ASTM International, West Conshohocken, PA.

ASTM, 2006. *ASTM Standard E 2400-06, Standard Guide for Selection, Installation, and Maintenance of Plants for Vegetative (Green) Roof Systems*, ASTM International, West Conshohocken, PA.

Centre for Urban Greenery and Ecology (CUGE), Singapore: (www.cuge.com.sg)

CUGE, 2010a. *CS B01:2010, Guidelines for Tropical Turfgrass Installation and Management*, Centre for Urban Greenery and Ecology (CUGE), Singapore.

CUGE, 2010b. *CS E 01: 2010, Guidelines on Design Loads for Rooftop Greenery*, Centre for Urban Greenery and Ecology (CUGE), Singapore.

CUGE, 2010c. *CS E 02: 2010, Design for Safety for Rooftop Greenery*, Centre for Urban Greenery and Ecology (CUGE), Singapore.

CUGE, 2010d. *CS E03:2010, Guidelines on Substrate Layer for Rooftop Greenery*, Centre for Urban Greenery and Ecology (CUGE), Singapore.

CUGE, 2010e. *CS E04:2010, Guidelines on Filter, Drainage and Root Penetration Barrier Layers For Rooftop Greenery*, Centre for Urban Greenery and Ecology (CUGE), Singapore.

CUGE, 2009a. *CS A01:2009, Specifications For Soil Mixture For General Landscaping Use*, Centre for Urban Greenery and Ecology (CUGE), Singapore.

CUGE, 2009b. *CS A02:2009, Specifications for Composts and Mulches*, Centre for Urban Greenery and Ecology (CUGE), Singapore.

Single Ply Roofting Industry (SPRI), USA: (www.spri.org)

SPRI, 2010a. *ANSI/SPRI RP-14, Wind Design Standard for Vegetative Roofing Systems*, Single Ply Roofting Industry (SPRI), Waltham, MA. (available at www.spri.org)

SPRI, 2010b. *ANSI/SPRI VF-1, External Fire Design Standard for Vegetative Roofs*, Single Ply Roofting Industry (SPRI), Waltham, MA. (available at www.spri.org)

Toronto Building, Canada: (www.toronto.ca)

Toronto Building, 2010. *Toronto Green Roof Construction Standard: Supplementary Guidelines*, Toronto Building, Toronto, Ontario. (www.toronto.ca/greenroofs)

Appendix V – Checklists for Green Roof Planning

[Adapted from International Green Roof Association (IGRA), www.igra-world.com]

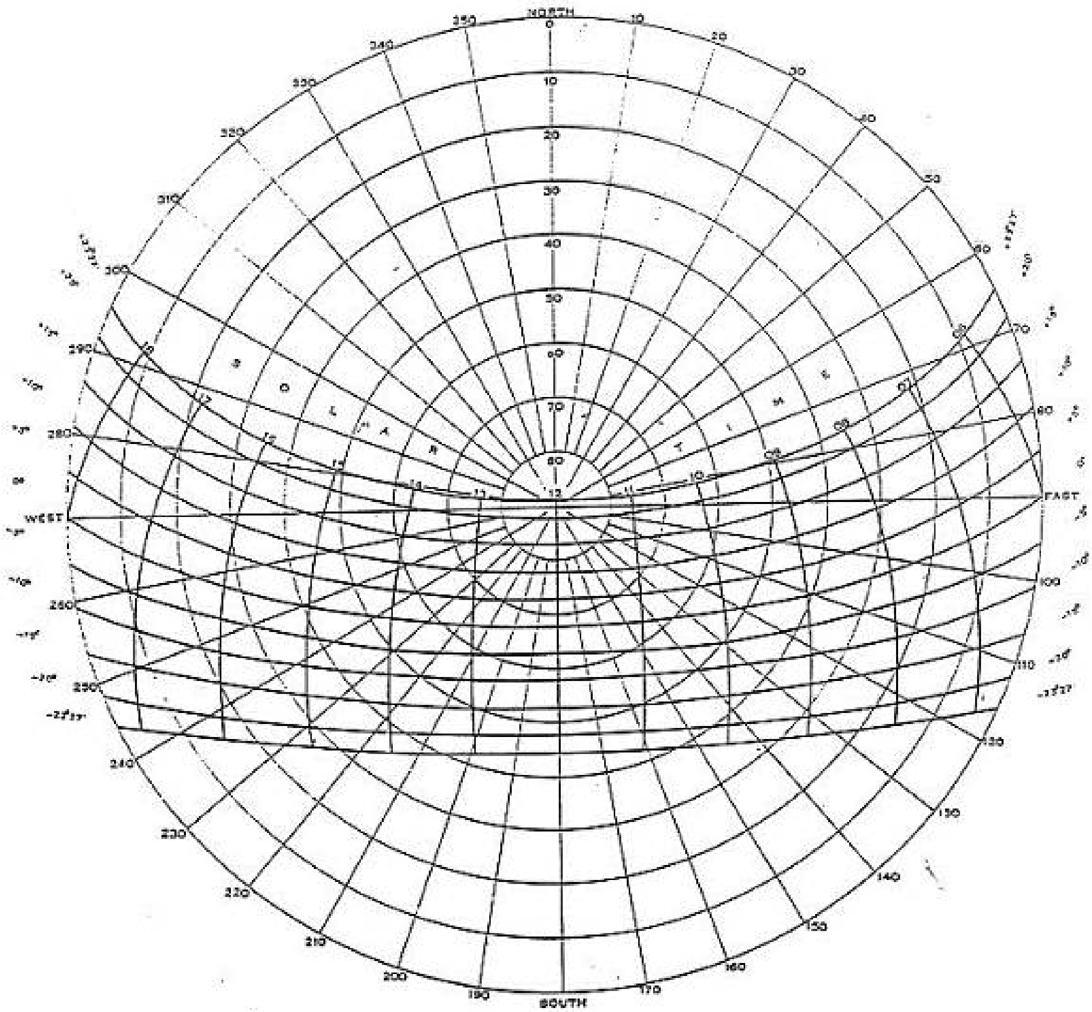
Construction Engineering	Vegetation Technology
Roof substructure Substructure (reinforced concrete, wooden substructure, metal sheeting, etc.) ***Waterproofing*** Refurbishment or new construction ***Roof parapets, roof penetrations and adjacent building parts*** Roof upstand and perimeter heights ***Roof slope*** Normal Green Roof system build-up, absorption of shear and erosion forces ***Roof construction*** Roof construction, thermal insulation, load bearing capacity ***Assumed load*** Area loads through Green Roof system build-up and usage of the roof ***Wind uplift*** Local wind effects, security measures ***Roof drainage*** Drainage devices, rainfall, roof outlets ***Irrigation*** Water connections, dam-up irrigation ***Fire prevention*** "Hard roofing", preventive protection ***Accident prevention*** Fall protection ***Roof access*** Installation, service and maintenance ***Additional functions*** Thermal insulation, usage of the roof, rainwater and solar energy ***Approval*** Building regulations	***Local conditions*** Climate, microclimate, rainfall, roof height, roof slope, roof exposure ***Desired green roof type*** Extensive Green Roof, Semi-Intensive Green Roof, Intensive Green Roof ***System build-up*** Functional layers: root barrier, protection layer, drainage layer, filter layer, growing medium, plant level ***Plant selection*** Seeds, plants and vegetation of Extensive Green Roofs and Intensive Green Roofs ***Different types of planting*** Seeding, cuttings, root ball plants, pre-cultivated vegetation mats ***Maintenance and support*** Installation maintenance, development maintenance, upkeep maintenance ***Water retention*** Water retention capacity, water run-off coefficient ***Costs/subsidies*** Costs, government subsidies or other funds

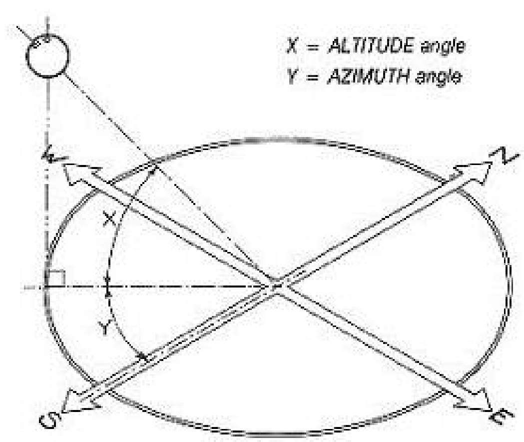
Green roof design checklist for HK: planning and feasibility (Urbis Limited, 2007)

Category	Checklist questions
1. General	What are the client's objectives for implementing a green roof? What are the city's main objectives for implementing green roofs? What kind of budget does the client have for both capital and recurrent costs? Who will see or appreciate the green roof? Is a green roof justified in the local context? Will the green roof be applied to special structures with special maintenance requirements or special access?
2. Type of roof	Is the roof new, existing, or in need of replacement or major repair? Can the existing waterproofing accommodate new layers and workmanship above without the need for new waterproofing? If so, who takes responsibility for the waterproofing?
3. Roof space	Is there sufficient space on the roof to incorporate a significant area of plants, access pathways, rooftop utilities, safety railings or devices, and access via ladders or staircases, etc? On new buildings, have the rooftop utilities been arranged to optimise the functional open space and to maximise the amount of greening?
4. Roof pitch	Is or will the roof be flat or sloped? Has slippage of the growing medium been considered? How is drainage affected by slope? Have the surface flows and water penetration rates been considered? Is the drainage layer below the growing substrate capable of removing excess water effectively?
5. Wind and climate	Will severe winds be a problem? Have the wind limits of the site been determined? Are the green roof layers vulnerable to wind shear? Does the waterproofing layer need to be bonded to the roof beneath? Has the wind erosion of the soil mix been considered? Has the staking or weighting down of trees been considered? If so, how does this interface with the waterproof layer if it needs to connect directly to the structure? Are additional lightning conductors needed to avoid striking people or trees?
6. Accessibility	Is or will the roof be accessible or inaccessible? How will the roof be accessed? If the roof is to be accessible, does it have space and loading capacity for additional railings, lights, paving, etc.? If accessible by the public will it be secure and safe? Have durable lightweight materials been used for the walkways?
7. Structural limits	What are the structural loading limits of the roof? Have the loading calculations been done by a Registered Structural Engineer or suitably qualified person? Has the dead load included all components (structure, paving, pipes, HVACs, etc)? Have the live load estimates included all components (rain, wind, people)? Has the dead weight of the green roof materials and plants been included? Do the soil substrate weights include moisture content at saturation point? Has plant weight at maturity been included, particularly for trees? Have maximum loading capacities for the roof been separated into different areas? Are polystyrene or other lightweight materials being used to increased depth without adding significant weight? Has the green roof manufacturer provided detailed information and attested to the fully saturated weight? Will any roofing components be removed from the roof which allows for additional weight?
8. General design	Have structural joints been incorporated into the green roof design from the beginning? Have maintenance paths been incorporated as part of the design?

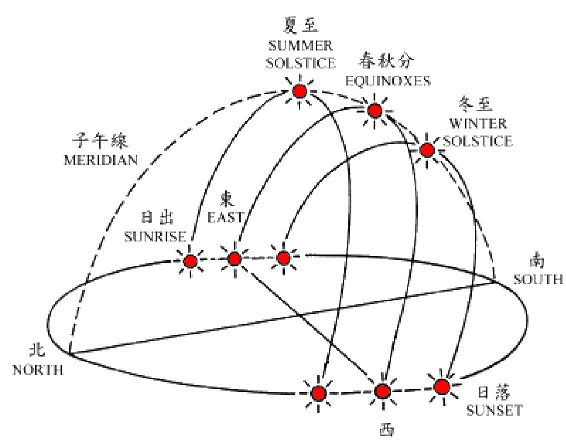
Appendix VI – Sun Path Diagram for Hong Kong and Shading Study

Hong Kong is located at latitude 22° 18' north and longitude 114°10' east (this refers to the weather station at Tsimshatsui, Kowloon).

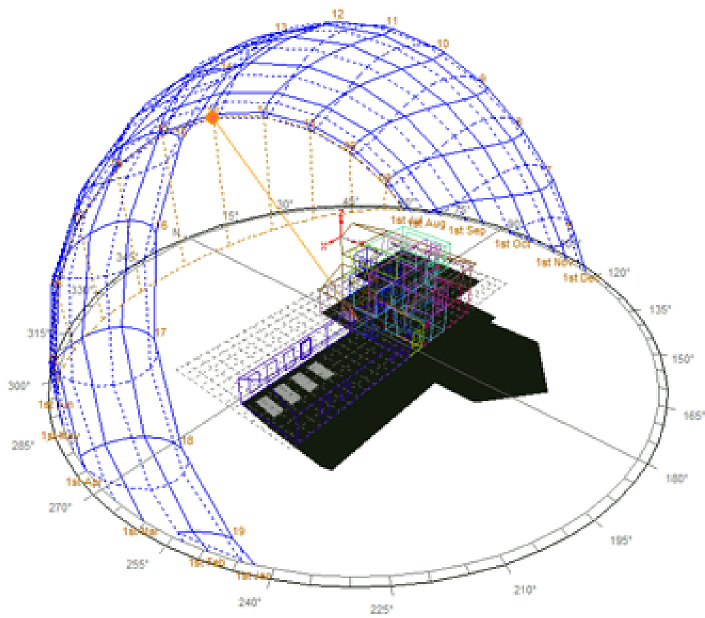


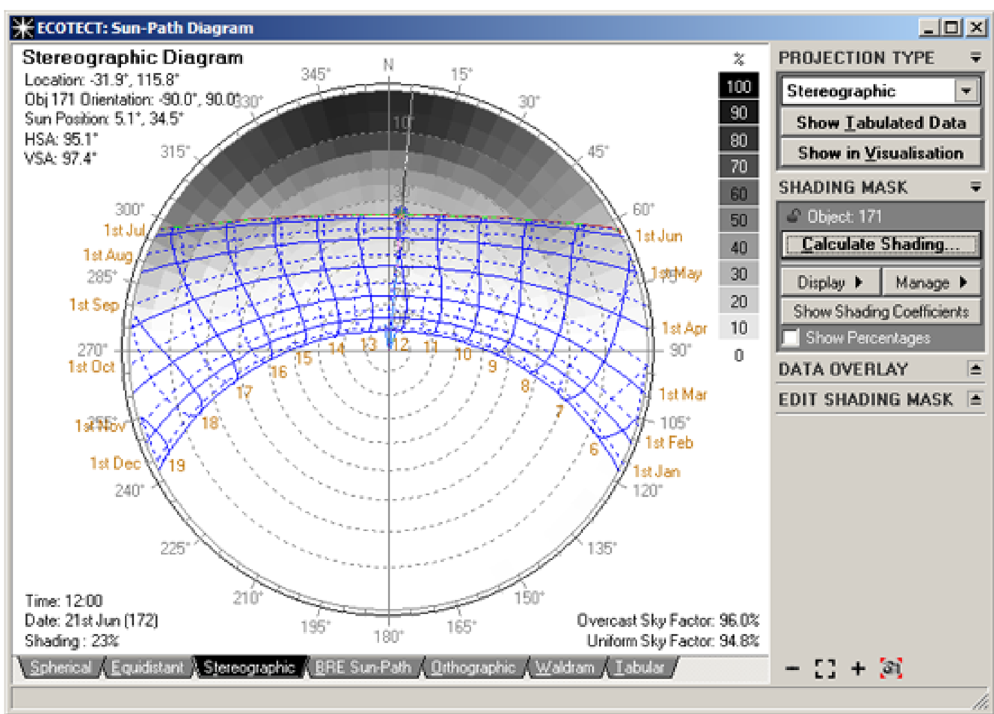


Solar Geometry



Example of sun path analysis and shading mask study (using Ecotect):





<u>Further information</u>:

The Sun and Building Design Process I, II,

www.arch.hku.hk/~kpcheung/teaching/lecture/65156-8.htm

Shading Design (Ecotect), http://wiki.naturalfrequency.com/wiki/Shading_Design

Appendix VII – Design Considerations for Pitched Green Roofs

(a) Technical requirements

Root resistant waterproofing is necessary for pitched green roofs; installing an additional root barrier, requires much effort and increases the risk of slippage. Stable abutments have to be installed on the eaves edges to transfer shear forces from the green roof system build-up and the additional rainwater or snow load into the roof construction. Additional shear barriers may be necessary to transfer the shear forces depending on the roof slope and the roof length.

With increasing slope the green roof system build-up is more complicated and the substrate has to be protected from erosion; plastic grid elements can be used for this purpose. Even though it is possible to build pitched green roofs with a slope of 45 degrees, it is not recommended to exceed 30 degrees due to significant limited accessibility for upkeep and maintenance.

(b) Plant selection

The success of the landscaping on pitched roofs depends on the plants. Appropriate selection of plants is important. Fast surface coverage is the highest priority. A dense planting of root ball plants or pre-cultivated vegetation mats are used in cases of steep slopes and allow for rapid coverage. It is also important to consider the exposure of the roof area, the slope and the location of the building when selecting plants. Perennials and grasses can be used for pitched green roofs; whereas, Sedum is the most suitable for pitched roofs, due to the species' high water retention capacity and erosion protection. The water run-off is much faster on pitched roofs compared to flat roof. It is advisable to plan for an additional irrigation system to provide water during dry periods. The irrigation can be provided either by drip irrigation or by sprinkler systems.

(c) Wind/Solar exposure

A sloped roof is subject to more adverse conditions than a flat roof that may have protection from parapet walls or other sheltering devices. It is essential to analyse sloped roofs for solar and wind exposure and the variability that may affect the roofing system. Since areas of intense sun or shade will change throughout the year, it is necessary to choose plant materials that can acclimate to the extremes in temperature and light in highly variable areas. Wind may cause the growing medium to erode while plant cover is being established and it may be beneficial to include an erosion protection layer.

(d) Make sure the roof will stay in place

The most critical component of any sloped green roof is the confinement system, which holds the growing medium in place during the roof’s early stages of development. A pitched vegetated roof can erode and slip under heavy rain, excessive irrigation, or poor plant growth if not properly secured. This is especially true the higher the pitch of the roof. Different strategies can be employed to distribute the weight. Some of the considerations that need to be addressed are inconsistent drainage, irrigation imbalance, and sheer force of gravity, potentially causing the roofing system to be unstable.

There are several approaches to designing a confinement system. Cellular confinement systems are installed on top of the drainage mat and feature flexible open cells into which the growth medium is poured. The result is a fully supported growing medium up to 200 mm in height are embedded in the growing medium in a similar fashion. The webbing, which is no thicker than 25 mm, is sandwiched between two layers of soil. As the roots grow, they become entwined within the thin webbing material, producing a stable cover. This material is good because the roots grab onto the material very quickly, usually within two weeks, and since it’s a continuous system, the growing medium stays in place.

For low-slope systems, an erosion mat may suffice. Common with roadside landscaping projects, erosion mat is usually manufactured using organic materials such as jute, wood, or straw and held together with synthetic mesh or strand. The mat is installed on top of the soil surface; openings are cut where the vegetation is planted. Erosion mats are designed to decay after one to three years, when the vegetation is fully mature.

Another method is to terrace the roof. Usually this approach installs edging bars at regular distance, say 4 m, so that if any soil slips, it will get caught by one of those bars.

(e) <u>Pay careful attention to peaks and valleys</u>

Irrigation can be difficult with sloped systems because the water tends to filter down the roof quickly. As a result, vegetation near the top of the roof can be neglected vital moisture, while plants near the bottom often get too much moisture as the water ponds and pools. To address this issue, the designer may plant water-loving vegetation at the bottom of the roof and varieties akin to arid soil at the top of the slope. The designer may also consider installing thicker growing medium near the top of slopes which is going to dry out first. Some suppliers advise the designer to install a moisture-retention mat underneath the soil so that the vegetation has more time to feed.

(f) <u>Specify a high-performance waterproofing membrane</u>

Don’t think that just because the roof slopes that the water is not going to pool. Don’t treat it any differently than a low-slope roof. Use a very good, continuous waterproofing membrane.

Appendix VIII – Checklist for Green Roof Maintenance

[Adapted from Tolderlund, L., 2010. *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West*, Green Roofs for Healthy Cities, Toronto, Canada.]

A green roof maintenance manual and/or maintenance agreement should be carefully composed for any green roof project and it should be taken into consideration all the components and details for each individual green roof project. A typical maintenance manual and/or maintenance agreement should, at a minimum, address and include the following:

<u>Fertilization/Spraying:</u>
How often will plant material (overall roof and/or specific planter) be fertilized?
What type of fertilizer should be used? – Should it be from a specific provider?
Are there any particular applications for specific plant needs and seasonal color?
Will insects be treated with horticultural oil or detergent-based insecticides or pesticides?
Will there be a need for aerobic bacterial treatment?

<u>Pruning:</u>
How often will plant material be pruned and dead headed?
Will clippings and dead leaves be composted? Where?

<u>Weed Control:</u>
The time to prepare for the oncoming of weeds is in the dormant season by applications of pre-emergence applications.
How often will planters be manually weeded?

<u>Clean Up:</u>
How often will drainage outlets, water features and filters be cleaned?
How often will entrances, planter edges, paths, etc be cleaned?

<u>Maintenance of Furniture, Paths, Decking, Planters and Railings, etc.</u>
What products are recommended for upkeep of planter edges, furniture, decking, etc?
What products are NOT recommended due to potential chemical effect on other components of the roof assembly?
What are specific recommendations for what tools to use (and not use) for the upkeep and maintenance?
Where are maintenance tools, ladder, hoses, security harnesses and other equipment stored?

<u>Watering:</u>
How will the roof plants be irrigated – hand watering and/or irrigation system?
How frequently will the roof plants be irrigated – during the summer?
Will there be hand watering during the winter? How frequently?
How often will the controller system and operating system be checked?
Are irrigation systems installed with a back-flow preventer valve that can be drained in case of a freeze?

Are there any specific requirements for upkeep and clean-up of water features?
What is the typical lifespan of plants used on the green roof?

Seasonal Recommendations:
Are there recommendations for or against seasonal soil amendments and/or adding mulching material?
How often will biomass be removed if needed?
How often will control burning be conducted if needed?

General Information:
Create and keep updated a contact list for all parties involved in the design, implementation and maintenance of the green roof.

Appendix IX – Considerations before Starting a Green Roof Project

[Adapted from Tolderlund, L., 2010. *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West*, Green Roofs for Healthy Cities, Toronto, Canada.]

1. Client expectations
2. Climate and geographical location/wind uplift during and after construction
3. Buildings intended current (and future) use and design life.
4. Structural analysis including building movement
5. Snow loads and water retention loads
6. Exterior and interior temperature, humidity and use conditions
7. Green roof system type including overburden
8. Green roof waterproofing membrane
9. Penetrations
10. Slope and drainage
11. Type and condition of growing medium
12. Type and amount of insulation, protection and drainage needed
13. Worker safety
14. Local code requirements
15. Need for ventilation during installation
16. Compatibility with adjacent building and/or system components
17. Construction sequence
18. Construction traffic
19. Accessibility and building configuration
20. Odor generated by certain system application methods
21. Considerations of green building certification assessment
22. Future maintenance of all green roof components (vegetation, drains, etc.)
23. Potential future building additions

Appendix X – Case Studies in Hong Kong

(a) Hong Kong Wetland Park Phase II: Visitor Centre

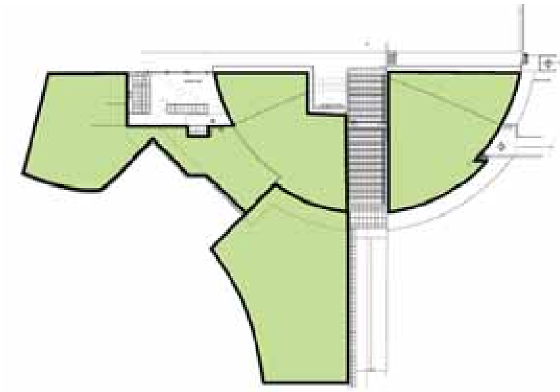
<u>Address</u>: Wetland Park Road, Tin Shui Wai, New Territories
<u>Building Type</u>: Eco-tourist visitor centre
<u>Completion</u>: 2005
<u>Total Floor Area</u>: 10,000 m² (concealed beneath the landscape, giving the impression of a green hill rising above the entry plaza)
<u>Green Roof Area</u>: about 10,000 m² (sloping lawns)
<u>Green Roof Type</u>: Intensive and semi-intensive

(Source: www.centamap.com)

Hong Kong Wetland Park Phase II: Visitor Centre:

(Image source: Architectural Services Department)

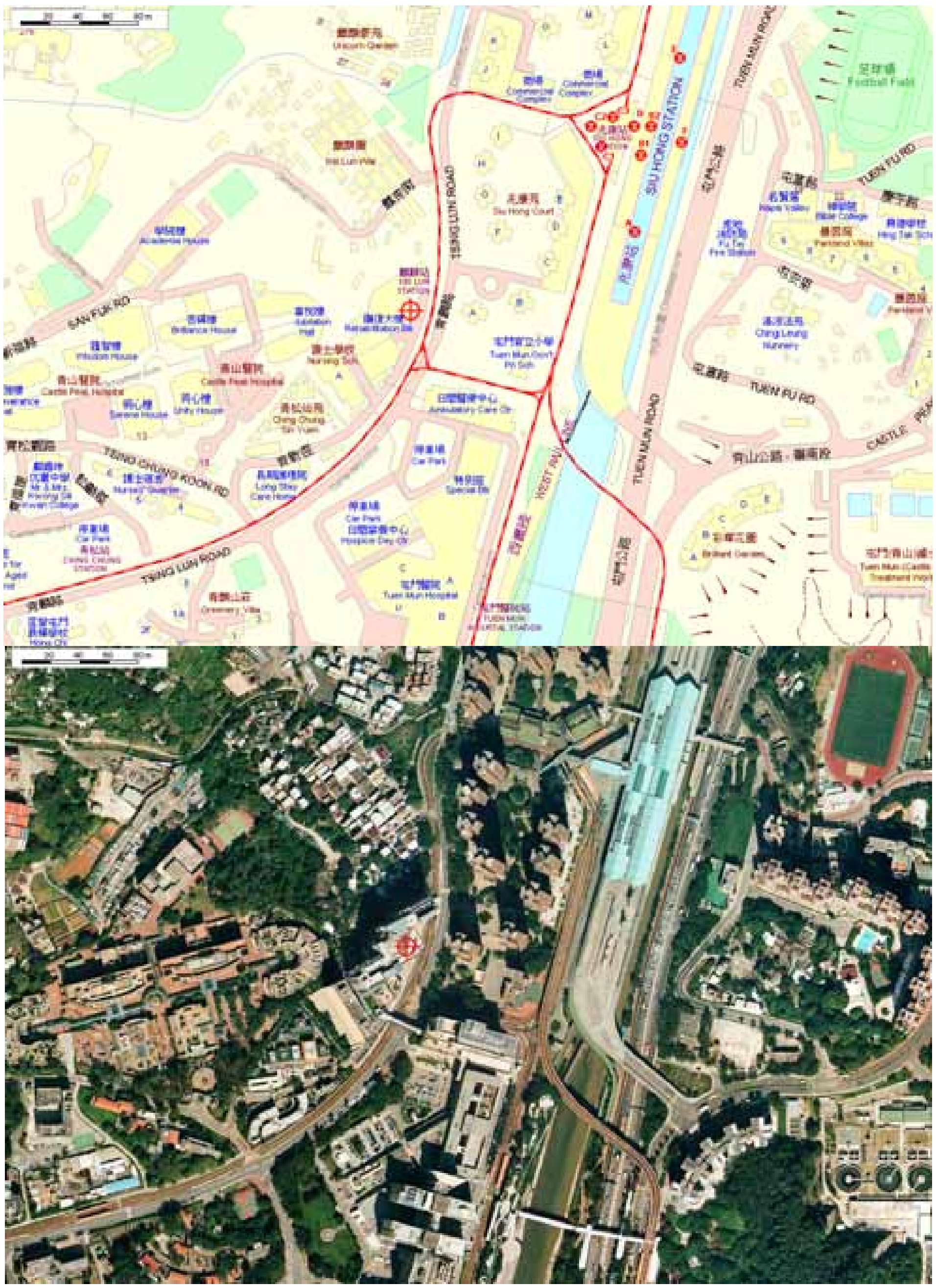
Hong Kong Wetland Park Phase II: Visitor Centre:



(Image source: Architectural Services Department and Dr. Sam C. M. Hui)

(b) Rehabilitation Block at Tuen Mun Hospital Phase II

<u>Address</u>:	23 Tsing Chung Koon Road, Tuen Mun, New Territories
<u>Building Type</u>:	Hospital
<u>Completion</u>:	June 2007 (New building block)
<u>Site Area</u>:	10,761 m²
<u>Green Roof Area</u>:	717 m² (distributed on 4 levels)
<u>Green Roof Category</u>:	Extensive, semi-intensive and planters
<u>Media Depth</u>:	varies 400 to 600 mm thick
<u>Type of Membrane</u>:	Mira drain system with 50 mm styrotherm insulation



(Source: www.centamap.com)

Rehabilitation Block at Tuen Mun Hospital Phase II:


2/F Podium


4/F Podium


5/F Podium


12/F Podium

(Image source: Architectural Services Department)

Typical plant materials (4/F Podium):

Tree:	Ficus benjamina 垂葉榕 Ficus benjamina 'variegata' 花葉垂榕 Terminalia mantalyi var. 花葉細葉欖仁
Shrub:	Brunfelsia calycina 鴛鴦茉莉 Duranta repens 'variegata' 花葉連翹 Spathiphyllum x 'cleverland' 白掌
Groundcover:	Asparagus densiflorus 'myers' 狐尾天冬 Arachis pintoi 'golden glory' 花生藤 Syngonium podophyllum 'variegatum' 白蝴蝶

Rehabilitation Block at Tuen Mun Hospital Phase II:

4/F Podium:

(Image source: Architectural Services Department)

(c) Belilios Public School

<u>Address</u>:	51 Tin Hau Temple Road, North Point, Hong Kong (www.belilios.net)
<u>Building Type</u>:	Secondary school
<u>Completion</u>:	July 2010 (Retrofit project)
<u>Green Roof Area</u>:	800 m²
<u>Green Roof Category</u>:	Extensive (because of limitation of roof loading)
<u>Site Constraint</u>:	No noisy work during school time that affect school operation. The final solution is to adopt a self protective waterproofing membrane directly applied on existing finishes to avoid noisy work caused by demolition and hack off activities.

(Source: www.centamap.com)

Belilios Public School:

(Image source: Belilios Public School)

Belilios Public School:

(Image source: Architectural Services Department)

Problem Encountered and Solution: Raised green roof and new floor finishes will raise finished floor level resulting in the height of parapet wall being less than 1.1 m. Thus additional railing had to be installed at peripheral parapet wall. Safety issues such as level difference at open rain water channel. Tailor-made channel gratings were installed. Provision of additional discharge water channel to cater for irrigation water to resolve hygiene problem. In addition to provision of greenery, consideration should also be given to the compliance of statutory regulations, safety issues, surface discharge and hygiene problem.

Appendix XI – Case Studies in Other Countries

(a) California Academy of Sciences - San Francisco, California, USA

Year:	2008
Building Type:	Educational
Greenroof Type:	Extensive, Test/Research
System:	Custom
Green Roof:	10,780 m^2
Waterproofing:	2,550 m^2
Slope:	65%
Access:	Inaccessible, open to public

Designers/Manufacturers:

- Greenroof Consultant: Rana Creek Living Architecture
- Ecological Consultant: Paul Kephart, Rana Creek
- Architect: Renzo Piano Building Workshop
- Architect: Chong Partners Architecture
- Engineering and Sustainability Consulting: Arup
- Landscape Architecture: SWA Group
- General Contractor: Webcor Builders
- Waterproofing: American Hydrotech
- Building Envelope/Waterproofing Design: Simpson Gumpertz & Heger
- Senior Curator of Botany: Frank Almeda, California Academy of Sciences
- Modular Greenroof System: BioTray

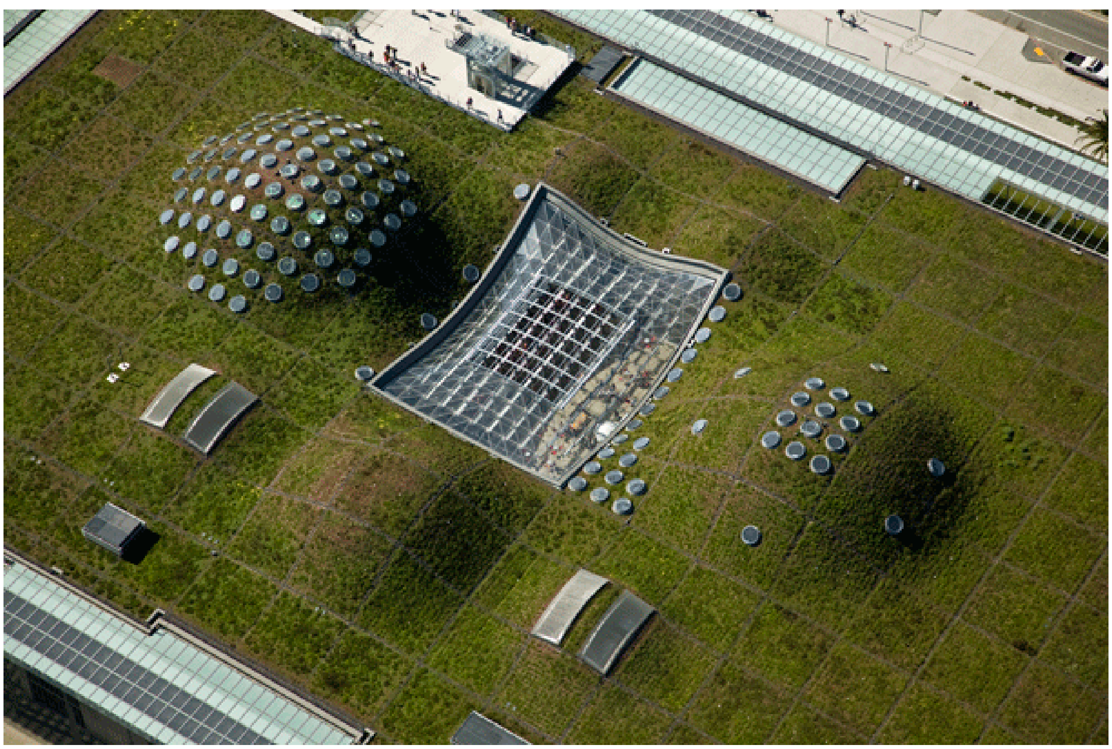
Awards:

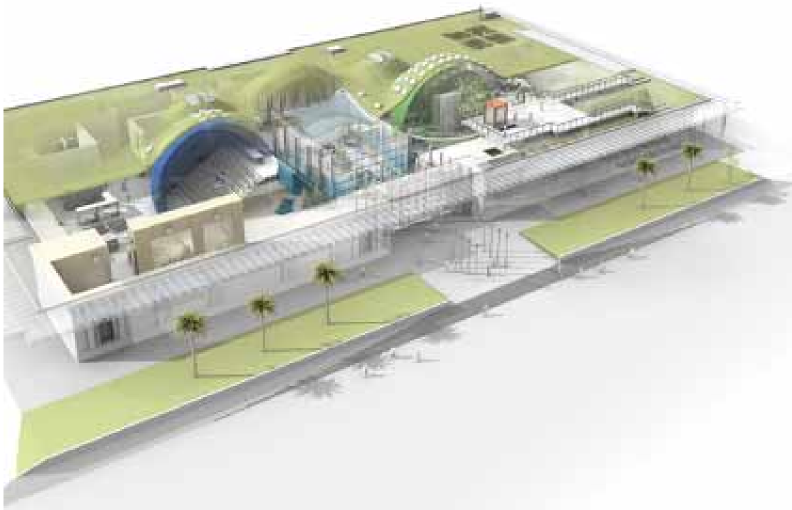
- 2008 Green Roofs for Healthy Cities Award of Excellence - Extensive Institutional Category
- 2009 ASLA Professional Award - General Design Category
- LEED Platinum-rated museum

Modular trays of plant material pre-grown and installed (BioTray, a biodegradable, reinforced, modular propagation tray made from rapidly renewable coconut coir fibers). Maintenance is controlled by replacement & rotation of individual trays.

(Source: WolfmanSF)


(Source: www.hydrotechusa.com)


(Source: www.asla.org)



(Source: www.bryanchristiedesign.com)

(Photos taken by Dr. Sam C. M. Hui)

Further information:

http://www.calacademy.org
http://www.calacademy.org/academy/building/the_living_roof/
http://www.greenroofs.com/projects/pview.php?id=509
http://en.wikipedia.org/wiki/California_Academy_of_Sciences
http://www.swagroup.com/project/california-academy-of-sciences.html
http://www.hydrotechusa.com/cas_index.html
http://www.asla.org/2009awards/111.html

(b) Vancouver Convention Centre West, Vancouver, BC, Canada

Year: 2008
Building Type: Municipal/Government
Greenroof Type: Intensive
System: Custom
Size: 24,290 m^2
Slope: 56%
Access: Inaccessible, private

Designers/Manufacturers:

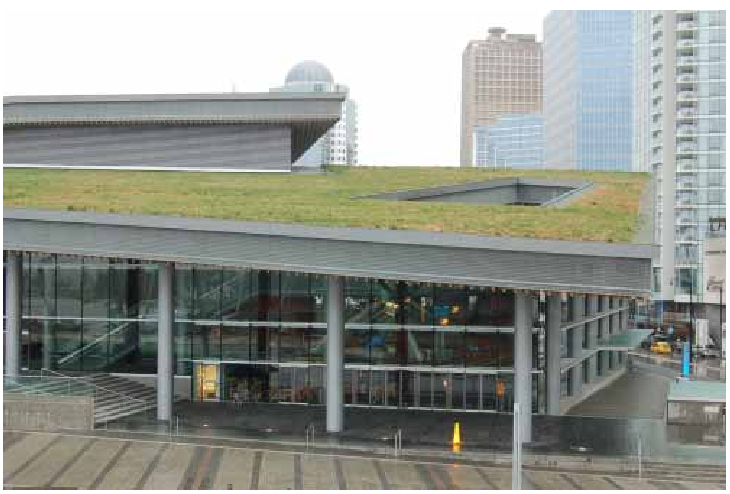
- Horticultural & Ecological Consultation: Paul Kephart, Rana Creek Habitat Restoration
- Architect: Musson Cattell Mackey Partnership; Downs/Archambault & Partners; LMN Architects
- Plant Propagation for Living Roof: Holland Landscapers
- Roofing Contractor: Flynn Canada Ltd
- Landscape Architect: PWL Partnership Landscape Architects Inc.
- Plant Supplier: NATS Nursery
- Steep Sloped Green Roof Components: American Hydrotech, Inc.

Awards:

- 2010 Green Roofs for Healthy Cities Award of Excellence - Extensive Institutional Category
- LEED Platinum-rated

(Source: http://lmnarchitects.com)

(Source: http://lmnarchitects.com)



(Photo taken by Dr. Sam C. M. Hui)

<u>Further information</u>:

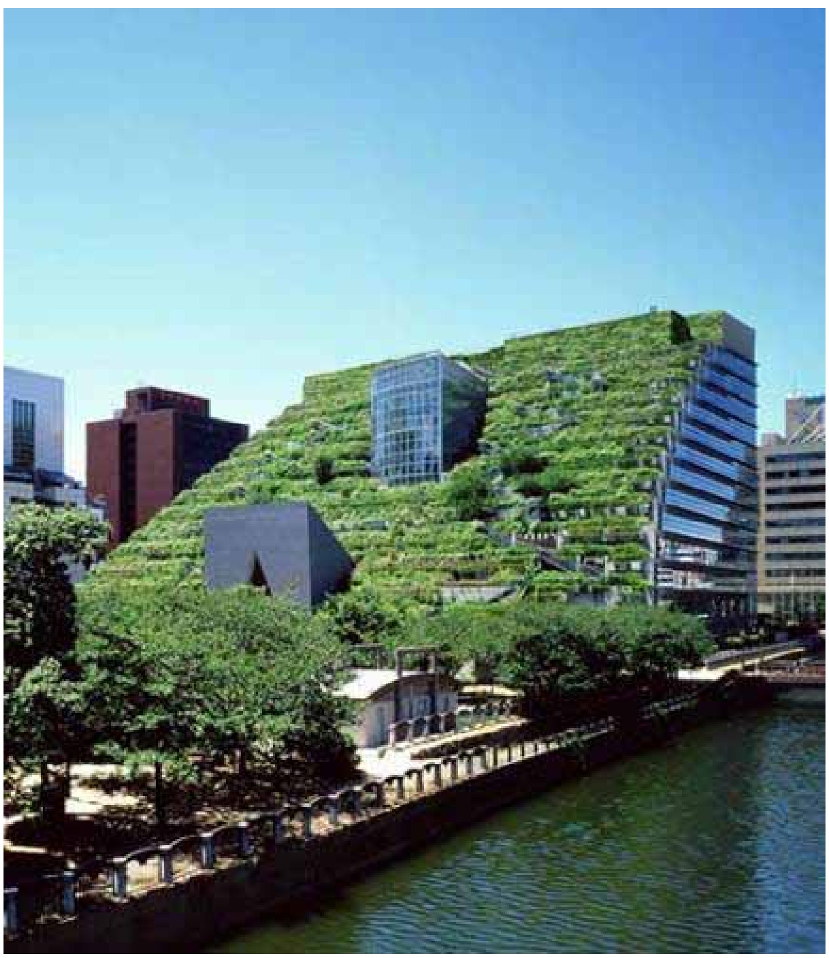
http://www.vancouverconventioncentre.com
http://www.greenroofs.com/projects/pview.php?id=545
http://lmnarchitects.com/work/vancouver_convention_centre_west
http://www.youtube.com/watch?v=OX0JHdVd27o

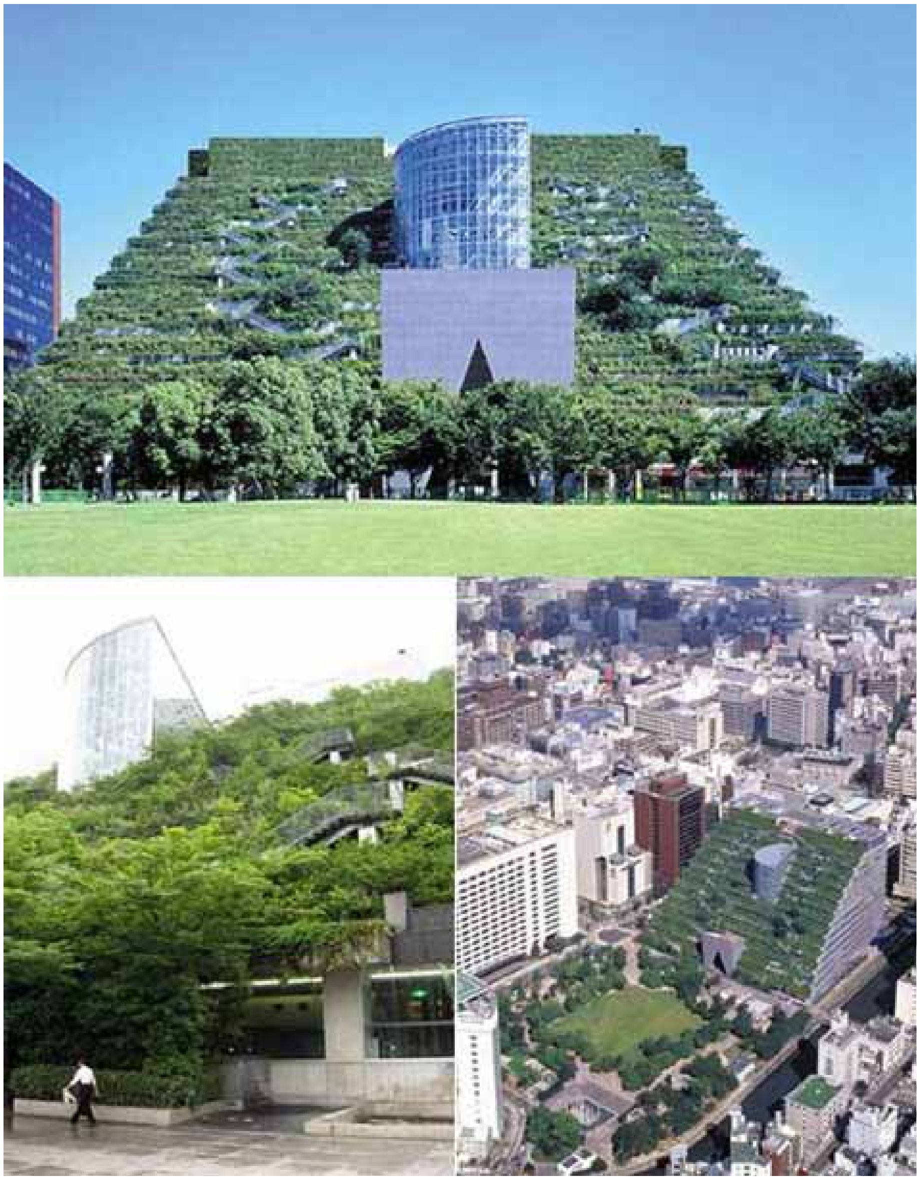
(c) ACROS Fukuoka Prefectural International Hall, Fukuoka, Japan

Year: 1994
Building Type: Commercial
Type: Intensive
System: Single Source Provider
Size: 97,528 m^2
Slope: 2%
Access: Accessible, Private

Designers/Manufacturers:

- Architect: Emilio Ambasz, Emilio Ambasz and Associates, Inc.
- Associate Architect: Nihon Sekkei
- Landscape Architect: Nihon Sekkei Takenaka Corporation
- Engineer: Nihon Sekkei Takenaka Corporation
- Engineering Consultant: Plantago Corporation
- System Manufacturer: Katamura Tekko Company
- Photographer: Hiromi Watanabe





(Source: http://weburbanist.com)

<u>Further information</u>:

http://www.greenroofs.com/projects/pview.php?id=476
http://www.ecofriend.com/entry/acros-fukuoka-the-serene-green-roof-of-japan/

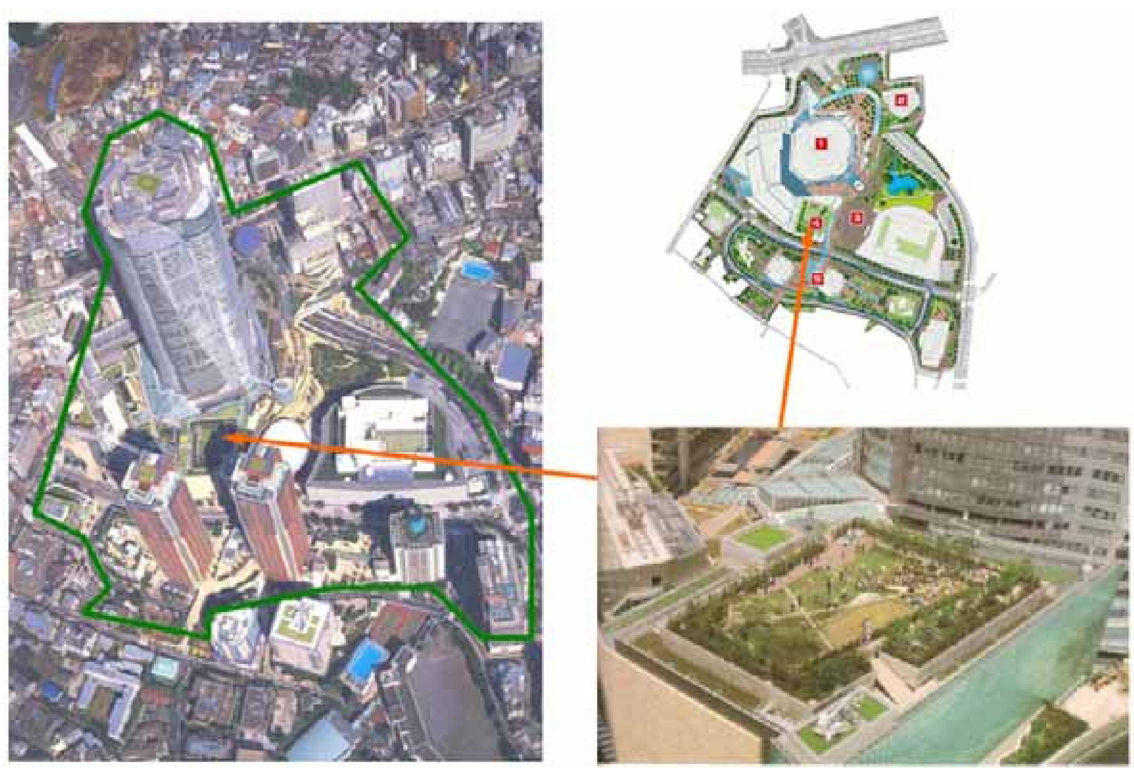
(d) Roppongi Hills Keyakizaka, Tokyo, Japan

Year: 2003
Building Type: Commercial
Greenroof Type: Extensive & Intensive, Test/Research
System: Custom
Size: 13,000 m^2
Slope: 1%
Access: Accessible, Open to Public

Designers/Manufacturers:

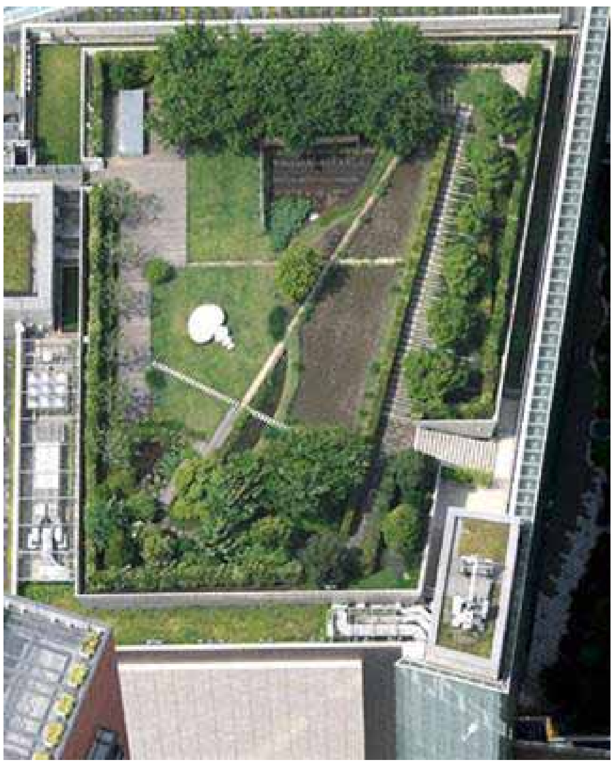
- Architect: Conran & Partners, JPI, KPF, and Mori Building Company,
- Landscape Architect: Yohji Saski & Dan Pearson

Keyakizaka complex rooftop boasts a rice paddy and vegetable plot
Sakurazaka roof exhibits public art and street furniture in a garden setting
A 4000 m² traditional Japanese garden
Almost all the buildings have green roofs
Showcase the potential for inventive green and vertical urban development
Rice paddy and vegetable plot
A 4000 m² traditional Japanese garden (Mohri Garden)
Green roofs 26% of its land area planted with vegetation; soil depths: 30-1200 mm
Roppongi Sakura-zaka (the Gardening Club)



(Source: www.roppongihills.com)

(Source: http://www.urbangreen.or.jp)



(Source: www.roppongihills.com)

<u>Further information</u>:

http://www.roppongihills.com
http://www.roppongihills.com/en/green/
http://www.roppongihills.com/green/rooftop_garden/
http://www.greenroofs.com/projects/pview.php?id=782