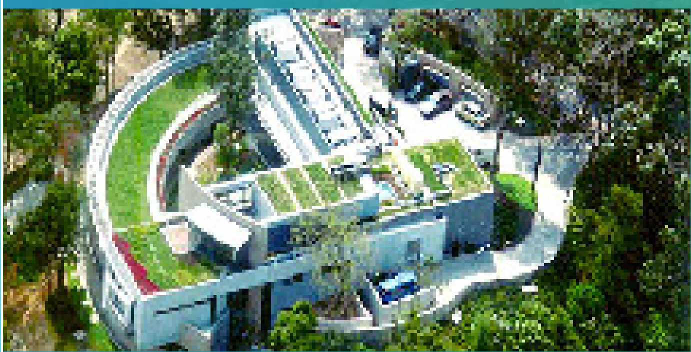
Architectural Services Department

Study on GREEN ROOF Application in Hong Kong

Final Report



Urbis Limited
in association with
Leigh & Orange Ltd

ARCHITECTURAL SERVICES DEPARTMENT

STUDY ON GREEN ROOF APPLICATION IN HONG KONG

FINAL REPORT

URBIS LIMITED

16 February 2007

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List of Abbreviations

AAC	Autoclaved Aerated Concrete
ACABAS	Advisory Committee on the Appearance of Bridges and Associated Structures
AFCD	Agriculture, Fisheries and Conservation Department
ArchSD	Architectural Services Department
ASLA	American Society of Landscape Architects
ASTM	American Society for Testing Materials (ASTM)
BD	Building Department
BEC	Business Environment Council
DE	Diatomaceous Earth
CAD$	Canadian Dollars

CEC	Cation Exchange Capacity
CEPAS	Comprehensive Environmental Performance Assessment Scheme
CIBSE	Chartered Institution of Building Services Engineers
CIRIA	Construction Industry Research and Information Association
CSO	Combined Sewer Overflow
CUHK	Chinese University of Hong Kong
ECC	Environmental Campaign Committee
EIA	Environmental Impact Assessment
EIAO	Environmental Impact Assessment Ordinance
EPD	Environmental Protection Department
EPDM	Ethylene propylene diene monomer rubber
FLL	Forschungsgesellschaft Landschaftentwicklung Landschaftsbau (German), translated as *Landscape Research, Development & Construction Society*
GFA	Gross Floor Area
G-S	Gammon-Skanska
GIS	Geographical Information Systems
HDPE	High Density Polyethylene
HIPS	High Impact Polystyrene
HK-BEAM	Hong Kong Building Environmental Assessment Method
HK$	Hong Kong Dollars
HKPSG	Hong Kong Planning Standards and Guidelines
HKU	University of Hong Kong
HPI	Hydrophobic Pore-blocking Ingredients
HyD	Highways Department
HVAC	Heating, Ventilation & Air Conditioning system
IFC2	International Finance Centre 2, Hong Kong
JPN	Joint Practice Note
LECA	Light Expanded Clay Aggregate
LegCo	Legislative Council
MVAC	Mechanical, Ventilation & Air Conditioning system
PGBC	Professional Green Building Council Hong Kong
PMMA	Polymethyl-Methacrylate
PlanD	Planning Department
PNAP	Practice Note for Authorised Persons and Registered Structural Engineers
PP	Polypropylene
PV	Photo-voltaic solar panels
PVC	Polyvinyl Chloride
SC	Site Coverage
SBR	Styrene-Butadiene-Rubber
SBS	Styrene-Butadiene-Styrene
SEBS	Styrene-Ethylene-Butadiene-Styrene
SCG	Steering Committee on Greening
SFr	Swiss Francs
TPO	Thermoplastic Olefins
TPO	Town Planning Ordinance
UHI	Urban Heat Island
US$	United States Dollars

PART 1

Green Roofs Overview

1 INTRODUCTION

1.1 DESCRIPTION OF THE STUDY

1.1.1 In May 2006, Urbis Limited was commissioned by Architectural Services Department to conduct a Study on Green Roof Application in Hong Kong.

Objective

1.1.2 The environmental, social and visual contributions that green roofs can make towards creating sustainable living in high-density cities are accepted worldwide. The objective of the Study is to conduct a quick review of the latest concepts and technology on green roofs and recommend guidelines adapted to suit local applications in Hong Kong to promote public understanding and awareness.

1.1.3 Upon satisfactory completion of the Study, the Government shall have a report and presentation package providing an overview of the general approaches, representative examples of green roof application, a better understanding of the benefits (environmental, aesthetic and economic) and constraints of green roofs, and good practice design guidelines including installation and maintenance aspects for public appreciation and understanding.

Background

1.1.4 The Steering Committee on Greening (SCG) chaired by Permanent Secretary for the Environment, Transport and Works (Works) at its meeting on 17 February 2006 supported the notion that roof gardens can be a means to improve urban greenery and subsequently endorsed the recommendation to carry out a research study with a goal to provide the general public with information on visual impact and environmental improvements. To this end, the Architectural Services Department (ArchSD) has commissioned this study focussing on the technical aspects of rooftop landscaping.

1.2 PURPOSE OF THE REPORT

1.2.1 The purpose of the Final Report is twofold.

1.2.2 The first purpose is to present the findings of the desktop literature search into green roof application, including:

- a brief review of the latest international and regional concepts and approaches, including policies / incentives and established standards (see Section 3 and Section 4.1);
- a search on available studies and records for percentage green roof distribution in major Southeast Asia cities and Hong Kong (see the Bibliography and Section 4.1);
- a list of the benefits and constraints for the community and private sectors (see Section 2 and Section 4.6) ;
- a list of the components of a green roof system (see Section 5); and
- a description of the climatic conditions and other environmental factors affecting application (see Section 4.4).

1.2.3 The second purpose is to present the way forward for green roofs in Hong Kong, including:

- Recommending design guidelines applicable to Hong Kong (see Sections 5, 6, and 7);
- Determining the range of capital and maintenance costs involved that might be expected in Hong Kong, and determining the commercial availability of materials described in the findings (see Section 8);
- Recommending the way forward for the successful promotion and implementation of green roofs in Hong Kong, covering technical, promotional and policy improvements. (see Section 10);

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2 GREEN ROOFS – DEFINITIONS, BENEFITS AND CONSTRAINTS

2.1 DEFINITIONS OF GREEN ROOFS

2.1.1 A 'Green Roof' development involves the creation of vegetated space integrated structurally on top of a man made structure. 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. Free-standing planters placed on top of a roof do not constitute the recognised international landscape industry definition of a green roof, which is characterised by the integration of the vegetation containment structure with the building roof structure. 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.

2.1.2 There are two basic types of green roof systems, identified in the international landscape industry as 'extensive' and 'intensive', as described below. The advantages and disadvantages of both major types of green roofs are summarised below in *Table 2.1*.

Extensive Green Roofs (Eco-roofs)

2.1.3 Extensive green roofs are characterized by their low weight, low capital cost and minimal maintenance. The growing medium, typically made up of a mineral-based mix of sand, gravel, crushed brick, leica, peat, organic matter and some soil, varies in depth between 50mm and 150mm. Due to the shallowness of the soil and the desert-like micro-climate on many roofs, plants must be low and hardy, typically alpine, dry-land or indigenous. Plants are watered and fertilized only until they are established and after the first year, maintenance consists of two or three visits a year for weeding of invasive tree and shrub species, mowing, safety, and membrane inspections. As a general rule, minimal technical expertise or practical experience is required for installation and maintenance.

Intensive Green Roofs (Podium Gardens & Sky Gardens)

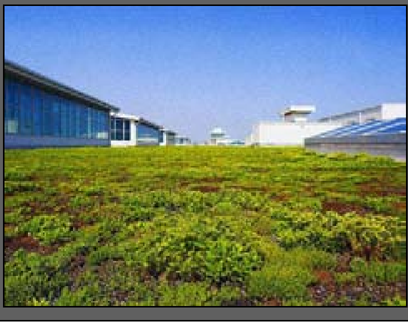
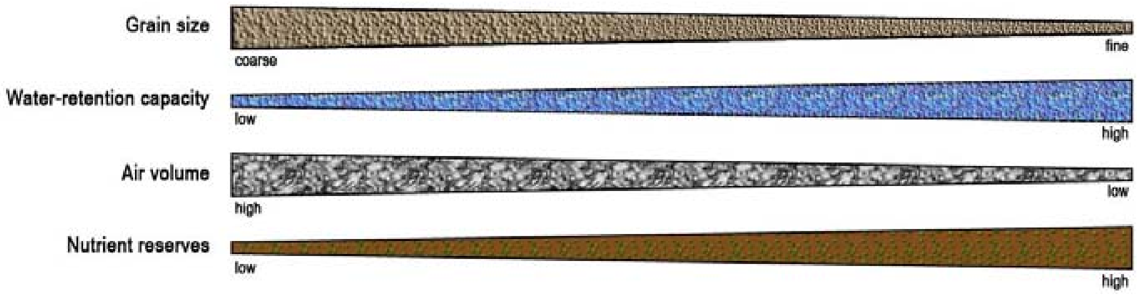
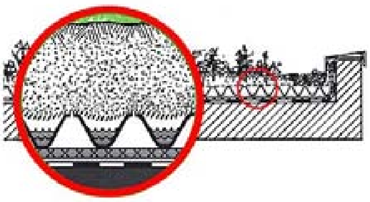
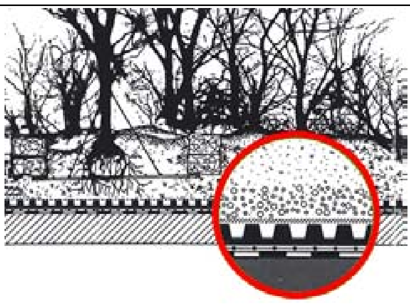
2.1.4 Intensive green roofs are characterised by greater weight, higher capital costs, more plantings and higher maintenance requirements. Plants are grown and maintained in ways similar to ground level gardens, with soil depths that vary according to plant requirements, ranging from a minimum of 200mm depth for lawns to up to 2000mm depth for tree planting, with corresponding structural loading implications. Due to increased soil depth, the plant selection can be more diverse including trees and shrubs, which allows a more complex ecosystem to develop. Requirements for maintenance and watering are more demanding and ongoing than with an extensive green roof.

2.1.5 Intensive green roofs are characterised by their use as a 'garden' in much the same way as people would use a garden at ground level. Intensive green roofs are widely occurring in Hong Kong in the form of podium level gardens.

General Application of Green Roofs

2.1.6 For existing roofs to be upgraded to "green roofs", the proposed soil depth, 50-150mm, can be adopted if structural limits allow. For new structures or developments, a minimum of 300mm soil depth should generally be adopted to create a better physical condition for planting and to plant species with all-year-round greening effect.

Table 2.1 - Comparison of Extensive and Intensive Green Roof Systems

	Extensive Green Roof	Intensive Green Roof
		
Soil characteristics  		
Typical details		
Brief description	• thin soil (50mm-150mm thick) • little or no irrigation • low maintenance ($0.8 to $2.25 /m²/year) • extensive application over large area for optimal environmental benefits	• deep soil (200mm-2000mm thick) • irrigation • normal maintenance ($6.5 to $44 /m²/year) • intensive capital and maintenance input for optimal benefits
Advantages	• lightweight (80 to 150 kg/m²) • low maintenance • suitable for retrofit projects • relatively inexpensive ($400 to 1000/m²) • suitable for large areas • suitable for roofs with 0-30° slope • can leave vegetation to develop spontaneously	• diverse utilization of roof (i.e. for recreation, growing food, as open space) with direct benefit to owner • greater diversity of plants and habitats • good insulation properties • can simulate a wildlife garden on the ground • can be made very attractive • often visually accessible
Disadvantages	• more limited choice of plants • usually no access for recreation or other uses • may be visually unattractive to some, especially in dry season	• relatively higher cost ($1000 to 5000/m²) • not usually suitable for green roof retrofit projects • greater weight loading (300 to 1000 kg/m²) • need for irrigation and drainage systems hence, greater need for energy, water materials etc.

(Adapted from Peck Callaghan & Kuhn (1999), p14)

(Images: source and copyright © (above) EarthPledge (2005) and (below) Zinco Ltd.)

2.1.7 It should be noted that the advantages and disadvantages described in ***Table 2.1*** provide generic information only. An individual green roof system may be a combination of intensive and extensive, depending on factors such as:

- location;
- structural capacity of the building;
- budget; and
- client and/or tenant needs.

Accessible and Inaccessible Roofs

2.1.8 Green roof systems can be further classified as being either 'accessible' or 'inaccessible'. An accessible green roof is an outdoor open space intended for use by people as a garden or terrace. These types of green roofs often involve surface planting, planter boxes, pathways, seating, water features, play areas and shade structures. Since these roofs are accessible by tenants, employees and/or the general public, certain safety requirements must be adhered to. These include emergency egress, guardrails and lighting.

2.1.9 An inaccessible green roof is only accessible for periodic maintenance. The green space can be viewed but not used, and as such, has no requirement for any special access or safety features any more than a normal roof. Inaccessible green roofs can be flat, curved or sloped up to 30°. Sloped and curved roofs need additional horizontal strapping to prevent slippage of the growing medium and plant layers when they become wet.

2.1.10 Accessible and inaccessible roofs are normally associated with intensive and extensive green roofs, respectively.

2.2 BENEFITS OF GREEN ROOFS (AESTHETIC, ENVIRONMENTAL, AND ECONOMIC)

2.2.1 There are many potential benefits of green roofs. These may be considered to fall into three main categories, namely, *Amenity and Aesthetic Benefits*; *Environmental Benefits* and *Economic Benefits*, although there is a great deal of crossover between categories.

2.2.2 *Amenity & Aesthetic Benefits* include: leisure and open space, visual aesthetic value; health and therapeutic value; and food production. *Environmental Benefits* include: ecological and wildlife value, water management; air quality, sound absorption; and reducing the urban heat island effect. *Economic Benefits* include increased roof life, building insulation and energy efficiency; and green building assessment and public relations.

2.2.3 These benefits operate at a range of scales. Some will only operate if relatively large numbers of green roofs are implemented in any particular area and their benefits will only be apparent at the larger neighbourhood or city scale. Others will operate directly on an individual building.

Private and Community Sector Benefits

2.2.4 Each of the above benefits may also be classified as either private and/or community sector benefits that can then be used to promote the idea to different audiences.

2.2.5 Private sector benefits are those which offer some direct benefit to the developer or owner of a building, and include items such as savings in energy costs, extension of the life of the roof, recreational use and aesthetic improvements.

2.2.6 Community sector benefits are those that offer benefit to the wider community e.g. public recreational use, storm-water management, urban climate mitigation, promotion of diversity & habitat.

2.2.7 Many of the benefits described below accrue to both the community and private sectors. Mention is made in the descriptions below regarding which benefits may be considered to accrue to the private sector and which accrue to the general community.

Amenity & Aesthetic Benefits of green roofs

<u>Leisure and Open Space</u>

2.2.8 In a dense urban environment with limited areas of ground level open space flat roofs present enormous potential in providing urban dwellers with the amenity and recreational space essential for healthy living. The sights, fragrances and sounds of a garden add immeasurably to the richness of experience and quality of life. Communal gardens also offer opportunities for social interaction between neighbours that might not otherwise be available, in both residential and commercial developments.

2.2.9 In Hong Kong, podium decks are used ubiquitously to provide some of the active and passive open space that is so essential for the well-being of the population. These roof open spaces may be private, for the sole use of occupants of the development, or public spaces for the use of the general populace.

2.2.10 Such accessible roof open spaces are classified as intensive green roofs. Publicly accessible roofs provide obvious community benefits. Privately accessed roofs offer private sector benefits by increasing property values, whilst also offering community benefits by contributing to the general community well-being and by reducing strain on public recreational resources.

2.2.11 The provision of public and private open space in Hong Kong is regulated in accordance with the Hong Kong Planning Standards and Guidelines (HKPSG), town plans gazetted under the Town Planning Ordinance (TPO) and private lot Lease Conditions. Frequently, both Government and the private sector achieve the required open space provision through the creation of intensive green roofs at podium level.

2.2.12 In Hong Kong it has been noted that some intensive green roofs on public buildings are not well frequented by park users. Common factors which should be considered at planning design and operation are:

- convenient access affecting park users, maintenance and management;
- avoiding concealed locations which may lead to the misuse of facilities and further deter the public from using them; and
- minimising the noise of vent shafts occasionally placed close to gardens.

<u>Visual Aesthetic Value</u>

2.2.13 An obvious and significant benefit of a green roof (subject to good maintenance) is the potentially attractive view offered to overlooking buildings. This is of great importance in a dense urban environment such as Hong Kong, where views of roofs are often associated with grey concrete slabs and the various paraphernalia of pipes, electrical and mechanical equipment and maintenance apparatus that usually clutters roof spaces.

2.2.14 Visual aesthetic benefits are offered by both intensive and extensive green roofs. However, for the same plan area, intensive green roofs offer potentially greater visual benefit than extensive green roofs, because the former may include large trees and shrubs which offer a three-dimensional greening effect, whereas the latter comprise only a thin two-dimensional ‘skin’ of green which may not be visible unless viewed from above.

2.2.15 Although many developments in Hong Kong have views of attractive podium landscapes (intensive green roofs), the potential visual benefits that extensive green roofs offer, have not yet been exploited in Hong Kong. This is most likely because such benefits would not accrue to the developer who is paying for the creation of the green roof, but rather to his neighbours who overlook his roof. There is therefore little financial incentive to the developer to develop extensive green roofs for visual benefits, unless the roof is visible by his own occupants.

2.2.16 Visual aesthetic benefits may either be private, community, or both, depending on whether the roof is viewed only by the building occupants and / or by the wider public. If adopted extensively in the city, green roofs have the potential to aid visual green space continuity throughout the urban area.

Health and Therapeutic Value

2.2.17 Visual contact with vegetation has proven direct health benefits. Psychological studies have demonstrated that the restorative effect of natural scenery holds the viewer's attention, diverts their awareness away from themselves and worrisome thoughts and elicits a meditation-like state[1]. People living in high density developments are known to be less susceptible to illness if they have a balcony or terrace garden[2]. This is partly due to additional oxygen, air filtration and humidity control supplied by plants. The variety of sounds, smells, colours and movement provided by plants, although not quantifiable, can add significantly to human health and wellness. This in turn can lead to some potential savings in community expenditure on healthcare.

Food Production

2.2.18 Roof spaces offer opportunity for growing certain types of food in high density urban environments where garden space is restricted. While food-producing plants may be substituted for ornamental plants in conventional roof garden situations, extensive areas of thinner roof coverings are also viable for production of herbs and vegetables.

2.2.19 Food production on roofs would:

- give occupants opportunity for full control of the growing regime in terms of growing medium, fertilisers and integrated pest management;
- give occupants access to fresh food that has not travelled long distances;
- provide educational value through learning how to grow produce;
- provide the therapeutic value of growing things; and
- provide economic value through savings in food costs and potential increased property values and rentals.

2.2.20 Roof spaces used for food production would usually be classified as intensive green roofs due to maintenance requirements.

2.2.21 The benefits of food production may be appreciated by both the private sector (increased property values, savings in food costs) and the community (social and therapeutic).

2.2.22 Overseas examples of food production on roofs occur in Russia, Thailand, Colombia, Haiti and Canada[3]. The Fairmont Hotel in Vancouver, Canada provides all the herbs used in the hotel, at an estimated yearly cost saving of CAD$25,000-30,000 (HK$175,000-210,000). It also provides amenity space and gives rise to higher room rates for those located adjacent to it.

2.2.23 One important cautionary negative note should be sounded in relation to food production on green roofs, and that is the positive ability of plants to absorb pollutants in the atmosphere (see section on Air Quality

(1) [1] Ulrich (1992), pp96 & 94

(2) [2] Johnson (1996) p33

(3) [3] Dunnett & Kingsbury (2004), p24

below). Whilst plants' ability to absorb pollutants such as heavy metals may help to improve air quality, it is a disadvantage if green roofs are to be used for food production in an urban area with poor air quality. Given the current relatively poor state of Hong Kong's air quality, it is therefore considered prudent not to promote food production on green roofs in Hong Kong until such time as the ambient air quality improves.

Environmental Benefits

<u>*Ecological and Wildlife Value*</u>

2.2.24 The enhancement of biodiversity through the use of green roofs is closely linked to the type of vegetation being used. If appropriate species are used, green roofs may provide an opportunity to provide natural habitat for resident and migratory birds and insects. This is achieved through the provision of one or more of birds' basic needs – food, water, shelter, and a place to breed.

2.2.25 Although individual vegetated roofs may not serve all of these functions, they may still act as 'stepping stones', creating links between larger habitats offered by nearby natural green areas, hillsides or parks.

2.2.26 Wildlife and ecological benefits are likely to be greater when the variety of soil depth, vegetation type and character is greater, and thus intensive green roofs would tend to offer greater benefits than extensive green roofs. The latter may still offer significant benefits since thin, relatively infertile soils tend to support large numbers of plant species. The vigorous aggressive plants that dominate and out-compete more delicate species in more fertile soils cannot get a hold, therefore enabling a much greater diversity of plant species to co-exist.

2.2.27 Numerous studies have been done on the biodiversity and wildlife value of green roofs. One of the most detailed studies has been carried out in Basle, Switzerland[4], in which the insect life and bird life on seventeen green roofs was monitored. Key findings included the fact that there was little difference in the number of spiders and beetles found on the roof and on the ground; that birds visited the roofs primarily for food; and that roofs in urban areas were visited more frequently by birds than those in urban fringe areas, implying the relative importance of green roofs in urban areas as a food source for birds.

2.2.28 The key message coming from the research is that diversity in planning and construction of a green roof leads to diversity in plants and animals. Having a variety of heights and slopes, open stony un-vegetated areas, a variety of vegetation types, and freely and poorly drained areas maximises their ecological value.

2.2.29 Ecological and wildlife benefits are usually a side-benefit resulting when a green roof is created for other purposes, such as recreation provision. However, some green roofs have been created with ecology as a prime factor. For example the award-winning green roof on an office building at the corporate campus for The Gap at Cherry Hill, California[5], uses native grasses of relict coastal communities, linking the building with the surrounding landscape and extending the distribution of the natural plant community into an urban setting.

2.2.30 However, one potential drawback of adopting a 'laissez-faire' ecological style planting, in which plants are not grown in a 'gardenesque' manner but rather left to 'do their own thing', is that this ecological style of planting is best appreciated, from a visual standpoint, at large scales, and that at the relatively small scales of green roofs, ecological planting is likely to appear untidy, 'scruffy' and un-maintained (especially in the dry season when vegetation is likely to turn brown), and therefore likely to draw criticism from those people (and they are many) who seek the 'neat and tidy' approach to landscape. This is particularly true in Hong Kong where there is little experience of ecological planting in the urban context.

2.2.31 Ecological and wildlife benefits should be considered as wider community benefits since they do not accrue at the building unit level (unless under another category such as visual).

(4) [4] Dunnett & Kingsbury (2004), p38

(5) [5] Dunnett & Kingsbury (2004), p37

Water Management

2.2.32 In urban areas, man-made hard surfaces (roads, paving, roofs, etc.) are impermeable and drainage schemes for these surfaces are devised to remove rainwater from them as fast and efficiently as possible. As a result, around 75% of rain falling on an urban area is lost directly to run-off, compared with 5% in a forest where the other 95% either infiltrates into the ground or is intercepted by vegetation[6].

2.2.33 This impermeable nature of urban paved areas and ensuing high run-off has created a number of problems such as:

- Flooding. With increasing urbanisation, increasing strain is placed on natural drainage systems surrounding the urban area which cannot cope with the sudden surge of drainage water during rainstorms, resulting in floods which cause significant disruption and financial damage to private and public property. This has been a feature of the New Territories in Hong Kong during the new town development of the past thirty years. This in turn leads to the need to canalise natural river systems, with associated negative visual and ecological impacts.
- The contamination of storm-water. As storm-water runs off impermeable surfaces, it picks up particulates, oil, grease, heavy metals, rubber and garbage from roads, driveways, car parks, pavements and roofs before it reaches storm drains. In a number of cities, including Toronto, storm-water is the prime cause of water pollution in local rivers[7].
- Combined sewage overflows. In older urban areas, sewage and storm-water systems are sometimes combined, and surges in storm-water can lead to overspill of untreated sewage into public streets.
- Increase in water temperatures. Run off from paved areas is at higher temperatures than in the surrounding natural drainage systems and large surges of run-off can negatively impact aquatic plants and encourage algal blooms.
- Drop in local water tables. This occurs because of the large proportion of natural precipitation being discharged into the artificial drainage system, rather than infiltrating into the ground. This in turn makes it harder for local vegetation to survive without artificial irrigation.
- Heavy investment in artificial drainage systems. The large surges in storm drainage created by impermeable surfaces result in the need to invest large sums of public money in storm-water infrastructure that is capable of coping with these surges.

2.2.34 Roofs account for up to 50% of the impermeable surfaces in many urban areas (Hong Kong's average figures are expected to be lower) and as such have an important role to play in determining urban water management and in mitigating potential adverse impacts on natural drainage systems.

2.2.35 Green roofs can influence roof water run-off in a number of ways. Water that falls on the roof can be absorbed into pore spaces in the substrate or taken up by absorbent materials in the substrate. It can also be taken up by the plants and either stored in plant tissue or transpired back into the atmosphere. Some water may lodge on plant surfaces and subsequently evaporate away. Water may also be stored and retained by the drainage system on the roof.

2.2.36 The two main resulting effects are firstly a reduction in total run-off (by absorbing water and returning it to the air, the roof reduces the amount of water available for run-off); and secondly spreading the residual run-off over a longer period (by storing it for a period before it runs-off, the roof acts as a buffer between the weather and drainage systems). (These effects are reduced during long periods of heavy rainfall

(6) [6] Dunnett & Kingsbury (2004), p43

(7) [7] Peck, Callaghan & Kuhn (1999), p27

when the green roof system reaches water saturation point.)

2.2.37 There are three significant benefits resulting from these two effects, namely:

- a reduction of pressure on urban drainage systems and downstream natural drainage systems (a community benefit);
- significantly reducing downstream flood risk (a community benefit); and
- reducing cost of drainage schemes because smaller pipes are possible (a private sector and community benefit).

2.2.38 Other water management related benefits of green roofs include:

- the absorption by vegetation of the pollutants in rainwater (a community benefit);
- the possible use of recycled water for irrigation (a private sector and community benefit);
- the possible integration of rainwater with a grey water system, exploiting the natural filtration system offered by plants and / or gravel (a private sector and community benefit); and
- a reduction in the contamination of storm-water since there is less direct run-off from paved surfaces (a community benefit).

2.2.39 Water management is a very significant benefit of green roofs, and currently the most important area of research in roof greening, with a number of state funded research institutes and commercial bodies actively involved[8].

Air Quality

2.2.40 Air pollution manifests itself in several forms including particulates (primarily from vehicle engines); heavy metals (in vehicle and factory emissions); and ozone. (Particulate levels in Hong Kong are about 40% higher than Los Angeles, the most polluted city in the USA.). Although not directly fatal in itself, air pollution causes fatalities when respiratory problems already exist. The numbers of premature fatalities attributable to air pollution can be large – an estimated 3 500 people per year in Hong Kong, which is 50% worse than the UK (per capita). The pollution-attributable heath care costs can also be high. In Hong Kong this is estimated to be between HK$1 billion to HK$1.5 billion per year (which excludes the subjective value put on lives lost which may push the total up to HK$19 billion per year).[9]

2.2.41 Vegetation in urban areas can filter out fine air particles as the air passes over the plants, the particles settling on plant surfaces, and subsequently being washed into the soil by rain. Foliage can also absorb gaseous pollutants lodging the material in their tissue.

2.2.42 However, there is little research to establish the extent to which this mitigating effect of plants occurs, although studies have shown that green roofs can trap up to 95% of cadmium, copper and lead and 16% of zinc[10]. Other studies have shown that 1 square metre of grass can remove 0.2 kg of airborne particles per year.[11]

2.2.43 Air quality benefits within a specific geographical area will only occur to a significant degree if large areas of roofs within that locale are 'greened'. Furthermore, intensive green roofs, with trees and large shrubs presenting large three-dimensional surface leaf area will have a much greater effect than extensive green roofs which have a relatively flat, 'two-dimensional' vegetation profile.

2.2.44 Air quality benefits, such as they are, should be considered as wider community benefits since they do

(8) [8] Dunnett & Kingsbury (2004), p46

(9) [9] Hedley, et al (2006), p1-2, Air Pollution: Costs and Paths to a Solution.

(10) [10] Dunnett & Kingsbury (2004) p50

(11) [11] Green Roofs for Healthy Cities Coalition, 2002.

not accrue at the individual building unit level.

Sound Absorption

2.2.45 The hard surfaces of urban areas reflect sound rather than absorb it, and roofs are no different. Green roofs, however, can absorb sound, with the substrate tending to block higher sound frequencies, and the vegetation tending to block lower frequencies.

2.2.46 Research in Germany has revealed that a 10cm thick green roof at Frankfurt airport reduced sound transmission into buildings by a minimum of 5 decibels. However, there is generally currently little scientific evidence to provide guidance on exactly how much sound reduction is provided by green roofs of different depths, although there is clearly some increased effect with increased depth.

2.2.47 Although building occupants may benefit from sound reduction due to green roofs, there may also be some general reduction in ambient environmental sound experienced by building neighbours who benefit due to the roof vegetation dissipating and dispersing the ambient sound waves that would otherwise be reflected off a hard roof surface. However, this is also hard to quantify.

2.2.48 Reduction in ambient noise levels may be considered both as a private sector benefit and a community benefit.

Reducing Urban Heat Island Effect

2.2.49 The 'Urban Heat Island Effect' is the well documented phenomenon that urban areas are generally hotter than the surrounding countryside due to a variety of factors including the large number of built structures with heat absorbing properties; the reduction in evaporating surfaces; the lack of vegetation cover and increased surface run-off; an increase in air pollutants; the heat production from buildings; and less cooling wind because of shelter from buildings.

2.2.50 For example, the centre of Berlin on a clear windless night can reach 9°C (16°F) higher than the outskirts[12]. In Chicago, air temperatures range from 1°C to 2.7°C (3°F to 5°F) higher than the outlying countryside. Another example is Tokyo which now experiences a mean temperature increase of 2.9°C (5.2°F).

2.2.51 Hong Kong is no exception to the Urban Heat Island effect phenomenon. Research conducted by the Hong Kong Observatory indicates that Hong Kong has been warming up during the past 118 years, in line with the global warming trend. In the last ten years or so, the rural areas of Hong Kong have been warming up at a rate of about 0.2°C per decade. At the Observatory Headquarters in the heart of urban Hong Kong, the corresponding rise was about 0.6°C per decade. The difference of 0.4°C per decade between temperatures in urban and rural areas can be attributed to the effects of urbanization. (Refer Figure 2.1.)

2.2.52 Vegetation can have a cooling effect by dissipating some of the city heat through the process of evapo-transpiration.

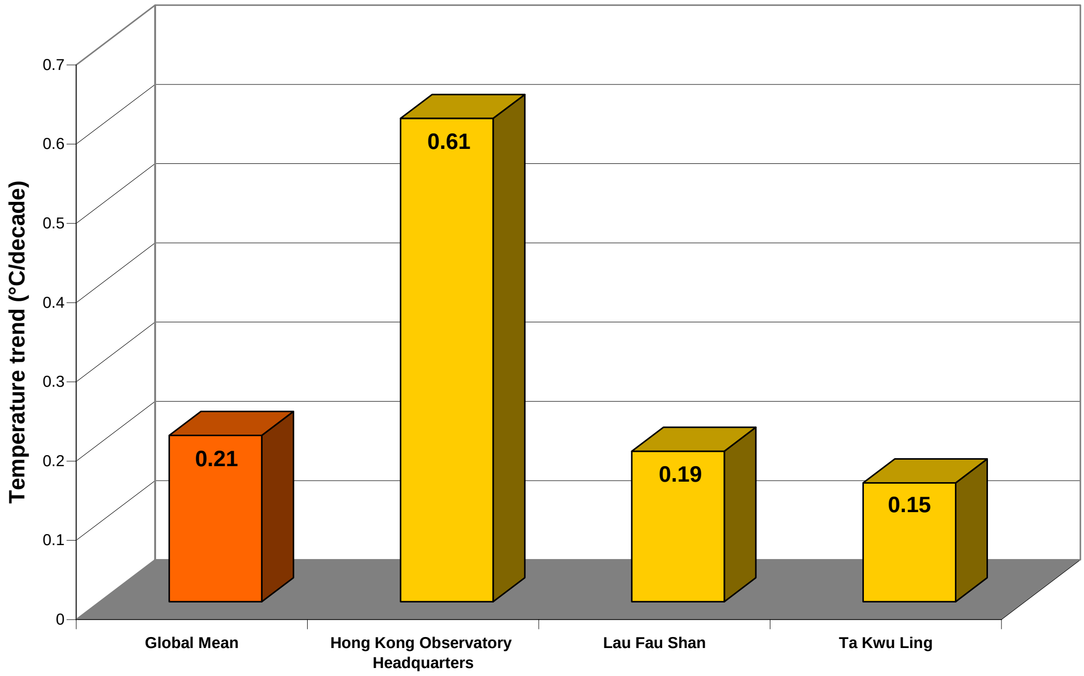
2.2.53 However, the effect of green spaces on urban climates has received little scientific attention. What research has been done suggests that the larger the green area, the greater the degree of temperature moderation within it. The cooling effect can also spread to adjacent areas (the so-called urban park cool island effect) but this effect can be negated if the green area is surrounded by walls or if it lies in an area of low-lying land from which the cool air will not spread.

2.2.54 The reduction of the heat island effect is the green roof benefit most difficult to quantify. Any such benefit should be considered as a wider community benefit since it does not accrue at the building unit level.

(12) [12] Dunnett & Kingsbury (2004) p51

2.2.55 Early research by the Toronto Green Roof Infrastructure Research and Demonstration Project (a project that evaluates the environmental performance research of green roofs), released key findings in 2002. Using 6% green roof coverage over 10 years (representing only 1% of Toronto's total land area), it found, could result in an average overall reduction of 1°C (1.8°F) in the urban heat island effect, with a reduction of as much as 2°C (3.6°F) in some areas. However, development of new green roofs at an estimated cost of CAD$ 45.5 million (HK$318 million) per year for ten years would be required to achieve this level (6%) of green roof coverage.

Figure 2.1 Warming trends, globally and in Hong Kong stations



(Source: Adapted from results from Hong Kong Observatory)

Economic Benefits

2.2.56 Green roofs require greater structural loading, to varying degrees, and therefore require greater capital cost. However, there are economic benefits which compensate for this as noted below.

Increased Roof Life

2.2.57 Studies have demonstrated[13] that green roofs, when properly constructed, can extend the life of a roof. Degradation by ultraviolet light and the constant expansion and contraction caused by daily extremes of temperature are the prime cause of the disintegration, cracking, delamination and splitting of roofing materials. Green roofs insulate the materials from ultraviolet light and reduce the thermal extremes, thus prolonging roof life.

2.2.58 German researchers have found out that reductions of diurnal temperature variations of up to 94% could be achieved with green roofs, although that was heavily dependent on the type of vegetation used. This high figure was achieved with a sward containing a wide variety of grasses and forbs similar to a European meadow. Less bio-diverse grass swards achieved lower reductions, down to 12% in some cases. Ground cover perennials were also trialled and again the bio-diverse mixes were most effective, with a reduction in temperature variation of 90%. The better performance of bio-diverse mixes probably

(13) [13] Dunnett & Kingsbury (2004), pp29-32

relates to the plants varied height structure and form, resulting in greater cushioning of air leading to stronger microclimatic effects.

2.2.59 The second 'Building Failure / Damage Report' issued by the German government in 1988 identifies roof greening as a solution to flat roof membrane failure. For example, a London department store installed a roof membrane under planting in 1938 and 50 years later, the membrane was still in excellent condition[14].

2.2.60 Since lengthening of roof life will reduce an individual building's life cycle costs, this might at first be considered an economic benefit to the private sector. However, if the building developer intends to sell the property once built, the long term savings would not accrue to him and therefore would not be an incentive to invest the additional capital cost to install a green roof. Similarly, many homebuyers in Hong Kong relocate after a few years, and the roof life of the property would probably have little or no impact on the perceived property market value. Therefore this benefit may be better viewed as a community benefit since longer building life-cycles offer economic savings at the community level.

2.2.61 It is important to note that the increased roof life benefit is dependent on proper green roof maintenance. Horticultural attention is needed to ensure unwanted plant species (self-seeded trees in particular) do not invade and cause damage. Regular maintenance such as checking the drains regularly is also needed to preserve the healthy functioning of the green roof and to gain the benefits of an increased roof life.

Building Insulation and Energy Efficiency

2.2.62 One of the most important benefits that green roofs offer the private sector is the tangible economic benefit resulting from reduced maintenance costs due to increased building insulation and energy efficiency.

2.2.63 Green roofs can contribute to building insulation and energy efficiency in several ways:

- by trapping an air layer within the plant mass, the building surface is cooled in summer and warmed in winter;
- by covering the building with vegetation, summer heat is prevented from reaching the building skin, and in winter, the internal heat is prevented from escaping; and
- by acting as a buffer against wind moving along the building surface, which would otherwise reduce the building's energy efficiency.

2.2.64 A study in Singapore measured temperatures in an intensive green roof in the city over a range of materials and vegetation[15]. Temperatures were measured on the roof and indoors. The results showed that over a typical 48 hour period, roof surface temperatures reached a peak of 57°C on exposed paved surfaces, with a maximum diurnal fluctuation of 30°C, whereas the temperature measured under Raphis (a common palm species) was only 27°C and the maximum diurnal fluctuation was only 3°C.

2.2.65 The net heat gain or heat loss was also calculated from a room beneath the different surfaces. Under the unvegetated surfaces the room beneath the roof experienced a net heat gain over the period of a day: even during the night heat was still entering the building because of the absorbed heat energy of the roof. However, under the vegetated surfaces there was a net heat loss from the room. Interestingly, the rate of heat loss from the room at night was the same under the vegetated surfaces as from the bare soil. This indicates that in this situation there was little additional insulating benefit from the presence of vegetation and that the main effect of plants is to reduce solar heat gain through shading during the day.

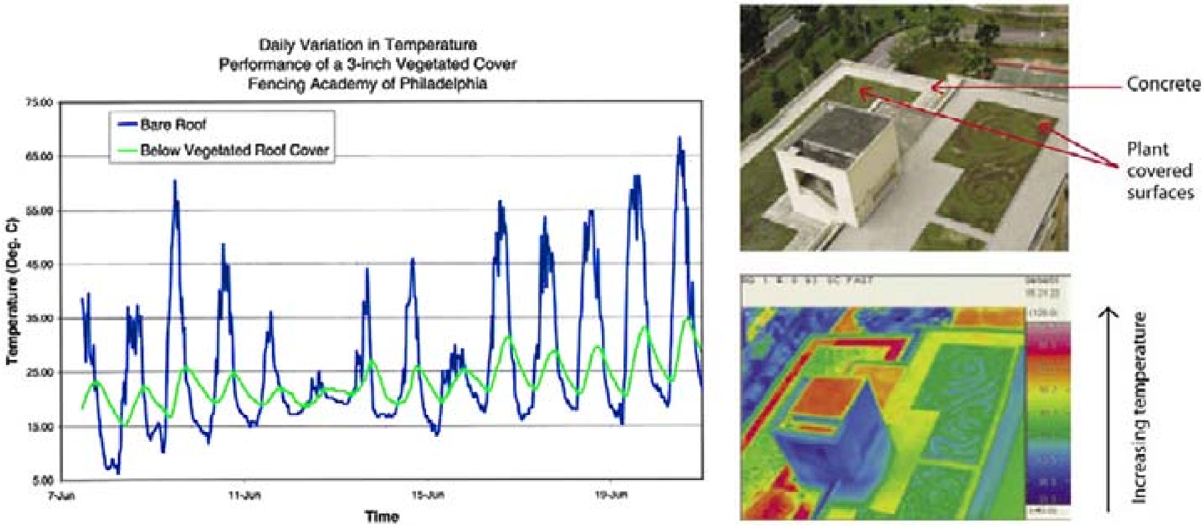
2.2.66 The shading effect of vegetation works even with low-growing plants such as sedums. Because green roofs reduce temperatures in buildings partly through shading and partly through evapo-transpiration, the

(14) [14] Peck, Callaghan & Kuhn (1999) p30

(15) [15] Dunnett & Kingsbury (2004) p34

plants have to be actively growing rather than in a state of heat-induced dormancy for the roof to be fully effective. For this reason effective cooling by green roofs necessitates some irrigation to keep the plants alive and green.

Figure 2.2 Typical Roof Temperature Differences and Infra-red Imaging



(Source (Left) Adapted from www.roofmeadow.com, Source (Right) Yok, T. P., & Sia, A., Selection of Plants for Green Roofs in Singapore, p9 (Copyright © 2005 by National Parks Board, Singapore)

2.2.67 The insulating benefits of green roofs can provide immediate tangible savings in regular building maintenance costs. This is of direct economic benefit to the building owner and can also benefit the building developer (who builds then sells) due to the increased property value. There is also an economic benefit to the community since less energy is required to satisfy the building's needs, contributing to a net reduction in the community's overall power consumption.

2.2.68 Heat transfer through the roof and building walls into the rooms below is unique for every building making it difficult to determine a general benefit for all green roofs. Factors that influence heat transfer include: the external air temperature and humidity, the amount of direct radiation from the sun (overcast or not), the building materials, the ratio of hard to greened surfaces, the roofing material and colour (see **Figure 2.3**), the depth of the soil, the type of vegetation used, the vegetation coverage and the colour of any exposed soil, and the water content of the soil. Despite these difficulties, it is important to determine the ultimate effects on internal room temperatures to determine what kind of energy savings can be expected. Early research in Shanghai by ZHAO Ding-guo and XUE Wei-cheng shows that a **room temperature reduction of 2°C** can be expected, at least on the top floor of any building. This research states that other studies have found room temperature differences of 4-5°C.[16] Research by Dr. Nyuk Hien WONG, at the National University of Singapore indicates that **net annual energy savings are around 15%** (results applicable to a five-storey commercial building in Singapore – the closest available model and climate equivalent to Hong Kong)[17].

2.2.69 The arguments for whether a cheaper, highly reflective "white roof" might give the same energy savings as a green roof has been studied by the Centre for Climate Systems Research of Columbia University, New York, and the Penn State Centre for Green Roof Research of Penn State University[18]. Results favour green roofs for two reasons:

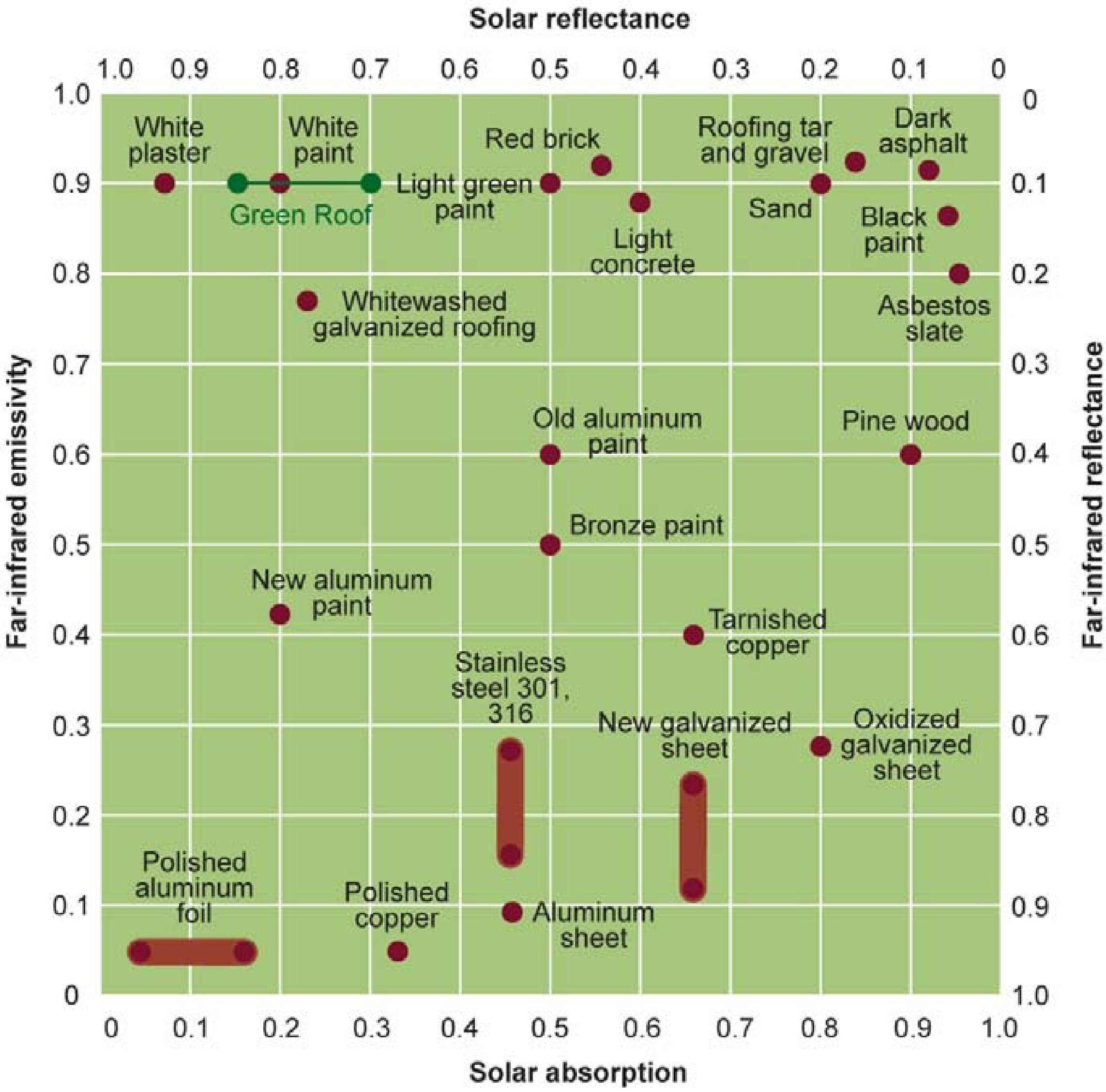
(16) [16] ZHAO Ding-guo & XUE Wei-cheng (2005)

(17) [17] Wong (2002) http://www.nus.edu.sg/occ/pressrel/0209/020905.htm and (2002) http://www.bdg.nus.edu.sg/research/Rooftop.pdf

(18) [18] Gaffin, S. et al (2005) Energy Balance Modelling Applied to a Comparison of White and Green Roof Cooling Efficiency

- The equivalent energy-reflecting white surface (commonly referred to as its *albedo*) needs to be so pure and radiantly white that keeping it so may require maintenance exceeding that of an extensive green roof and be more hazardous for labourers too (see Figure 2.3 below)
- With respect to the heat flow downwards into the room below, green roofs have shown significantly lower temperatures than their surface temperatures simply because the rooms are further insulated by the green layer above it. If this is factored into the equation then it becomes obvious that pure white surfaces pale in comparison to green roofs when it comes to total energy efficiency.

Figure 2.3 Albedo Values of Roofing Materials



(Adapted from Florida Solar Energy Center)

2.2.70 As green roofs and solar panels may often compete for the same rooftop space, there is also some debate as to which technology best solves the city's energy problems. Theoretical knowledge of photo-voltaic (PV) semi-conductors suggests that these two technologies actually work best in tandem.[19] It is well-known that PVs work more efficiently when the ambient temperatures are lowered to below 25°C -

(19) [19] Kohler, M., et al (Rio 02 – World Climate & Energy Event, Jan 2002) Photovoltaic-Panels on Greened Roofs - Positive Interaction Between Two Elements of Sustainable Architecture http://www.rio02.de/proceedings/pdf/151_Koehler.pdf

which in many cases can only be done cost-effectively through greenery. Similarly, PVs provide some shade which expands the available plant palette and ameliorates the growing and soil conditions. Research into this symbiotic relationship is early and ongoing. Apart from combined weight constraints, there is little preventing solar panels being installed on frames above a green roof. In fact, combing the routine inspections for both technologies may also provide a saving than if only one of the technologies were used.

Green Building Assessment and Public Relations

2.2.71 It is estimated that half of the energy derived from fossil fuels is consumed by buildings. The challenge for architects is to develop buildings that incorporate sustainable technologies and so reduce their pollution and running costs. Three quarters of everyday energy use in buildings is accounted for, in more or less equal proportions, by artificial lighting, heating and cooling.[20] Responding to this need are Green building assessment schemes which exist in several countries, including Hong Kong. Their purpose is to encourage environmentally sound building practice, and there is also considerable public relations value in projecting an environmentally conscious image for a building development or organisation.

2.2.72 Green roofs can contribute to the credit rating of developments assessed under such schemes, and a green roof can be a highly visible way in which a development can draw attention to its environmental 'credentials', which may contribute to increased property value.

2.2.73 In Hong Kong there is currently one private sector initiated green building assessment scheme in operation, the Hong Kong Building Environmental Assessment Method (HK-BEAM), and one other scheme currently being planned by the Government, the Comprehensive Environmental Performance Assessment Scheme (CEPAS). Brief descriptions of these schemes are provided below.

Hong Kong Building Environmental Assessment Method (HK-BEAM)

2.2.74 HK-BEAM is a private sector voluntary initiative first implemented in 1996. HK-BEAM is currently managed by the HK-BEAM Society, which was created in 2002, and is:

- an industry-led initiative to assess, improve, certify and label the environmental performance for the life-cycle of buildings;
- a comprehensive standard and supporting process covering all building types, including mixed-use complexes, both new and existing;
- a means by which to benchmark and improve performance; and
- a voluntary scheme developed in partnership with, and adopted by the industry.

2.2.75 The aims of HK-BEAM are to:

- stimulate demand for more sustainable buildings in Hong Kong, giving recognition for improved performance and minimising false claims;
- provide a common set of performance standards that can be pursued by developers, designers, architects, engineers, contractors and operators;
- reduce the environmental impacts of buildings throughout the planning, design, construction, management and demolition life cycle;
- increase awareness in the building community, and ensure that environmental considerations are integrated right from the start rather than retrospectively; and
- be a driver for and a means by which to assure healthier, higher quality, more durable, efficient, and environmentally sustainable working and living environments.

(20) [20] (Sir) Richard Rogers (1997)

2.2.76 The HK-BEAM Society is a non-profit organisation that owns and operates, on a self-financing basis, the HK-BEAM. The Society oversees the on-going development and implementation of HK-BEAM standards for building assessment, performance improvement, certification and labelling. This is undertaken as an industry-led, voluntary initiative to benefit the community.

2.2.77 Formalised in 2002, the HK-BEAM Society consists of individual and corporate members from all disciplines in the private sector (owners, developers, facility managers, designers, researchers, contractors, product and material suppliers, etc) with an interest in enhancing building environmental performance.

2.2.78 Buildings are independently assessed and receive a HK-BEAM certificate and rating of Bronze, Silver, Gold or Platinum, according to performance.

2.2.79 HK-BEAM defines over 100 best practice environmental criteria on the key aspects of Hong Kong's buildings and provides a forum for the design / management team to work for the same environmental goals:

- hygiene, health, comfort, and amenity;
- land use, site impacts and transport;
- use of materials, recycling, and waste management;
- water quality, conservation and recycling; and
- energy use, efficient systems and equipment, and energy management.

2.2.80 Adopted by almost 100 premises (covering some 60 million ft^2), HK-BEAM Society claims that HK-BEAM is one of the most widely used assessment and labelling schemes for buildings in the world.

2.2.81 Green roofs could potentially assist in gaining credits under several environmental criteria in the assessment, including Ozone Depleting Substances; Water Pollution and Drainage; Microclimate around Buildings; Landscaping; Planters on Buildings; Water Conservation; Recycling Facilities; and Environmental Management Plan.

Comprehensive Environmental Performance Assessment Scheme (CEPAS).

2.2.82 CEPAS is a green building assessment scheme under planning by the HKSAR Government Building Department (BD). BD's intention is to create a user-friendly assessment scheme for buildings in Hong Kong that is suitable for all types of new and existing developments. It is intended that CEPAS:

- be an assessment tool applicable for assessing entire building developments as well as individual components or features of a building, and be able to assess all these at different stages in the building life-cycle;
- form the basis of a green labelling system which can be adopted for both an incentive and non-incentive basis; and
- be a tool to encourage up-grading of the environmental performance of buildings in Hong Kong.

2.2.83 BD intends that CEPAS includes assessments on:

- holistic life-cycle including the planning, design, construction, maintenance and demolition stages;
- use of natural renewable resources and recycled / green building material;
- energy efficiency, in particular non-renewable types;
- construction and demolition waste minimisation; and
- indoor environmental quality.

2.2.84 In 2002, BD commissioned a consultancy study to develop the scheme. The study was completed in mid 2005, and it has been presented to various stakeholders, including LegCo and the Provisional Construction Industry Co-ordination Board. The study recommendations have not yet been implemented.

Benefits unique to Green Roofs

2.2.85 Some benefits that are similar to those described above may be achieved by using other (non-vegetative) types of roofing material. However, many of the benefits described are unique to green roofs and cannot be provided by other roofing materials. These include: *Amenity & Aesthetic Benefits* (i.e. leisure and open space, visual aesthetic value, health and therapeutic value; and food production) and *Environmental Benefits* (i.e. ecological and wildlife value; and air quality). Green roofs, in some locations, also provide comfortable open spaces where elevated panoramic views of the city or surrounding landscapes can be enjoyed.

Benefits of Intensive versus Extensive Green Roofs

2.2.86 The benefits of green roofs, both intensive and extensive, are roughly the same. Intensive green roofs generally provide these benefits to a better degree and also provide additional functional open space which is greatly needed in Hong Kong. **Table 2.2** compares intensive and extensive green roofs and highlights the main reasons for choosing one type of green roof over another.

Table 2.2 – Comparison between Intensive and Extensive Green Roof systems

Intensive Green Roof	Extensive Green Roof
• Provides functional open space and can provide a local micro-climate (with shade) that is user-friendly. • Increased amenity value can increase property values. • Greater plant range (including trees) that work reliably in Hong Kong. • Is more visible and visually appealing. • Provides better environmental benefits (adding to ecology and wild-life, water-management, air-quality improvements and the reducing of Urban Heat Island effect). • Provides better building insulation benefits (sound absorption, heat transfer and air-conditioning savings)	• Low capital costs • Low maintenance costs • Light weight • Suitable for retrofit projects

2.3 CONSTRAINTS OF GREEN ROOFS

2.3.1 As intensive green roofs are widely occurring in Hong Kong it is apparent that any constraints presented by the construction of intensive green roofs have already been overcome. The technical issues associated with intensive green roofs are well understood by the local construction industry.

2.3.2 On the other hand, with no incentive and minimal knowledge about the emerging technologies, there are very few examples of extensive green roofs in Hong Kong.

2.3.3 The constraints or barriers against the development of green roofs (which apply in Hong Kong to differing degrees for intensive and extensive green roofs), may be considered to fall into four categories, each of which is briefly described below, namely:

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

Lack of knowledge and awareness

2.3.4 Although there is widespread knowledge and awareness in Hong Kong of intensive green roof construction technology, there is very little awareness of extensive green roof technology.

2.3.5 The lack of extensive green roof pilot projects; the uncertainty within the market over costs and benefits; the lack of local research on suitable plant species for low maintenance and/or inaccessible roof applications; and the unfamiliarity among users and clients all act together as a barrier against the development of extensive green roofs in Hong Kong.

2.3.6 In the Hong Kong context, the key groups of stakeholders who require additional knowledge on extensive green roofs are:

- Policy Makers. Politicians and staff at all levels in government need knowledge of the costs and benefits of green roofs.
- Professionals. The construction and building management industry needs to familiarise itself with existing extensive green roof construction technology and adapt it to Hong Kong requirements. More local research is required on suitable plant materials and substrates for extensive green roofs.
- General Public. Public knowledge of the benefits of green roofs will create political demand for government incentives as well as market demand for properties incorporating such green roofs.

Lack of Incentive

2.3.7 The development of the green roof industry in Europe is largely a result of legislation passed in Germany in 1989 requiring new developments to install green roof systems. Without this statutory requirement, the initial inertia caused by lack of knowledge and perceived technical problems would have been harder to overcome.

2.3.8 Furthermore, several of the benefits described earlier in this chapter are long-term private sector benefits or community benefits which would not accrue to a property developer who builds and sells immediately. Since most property development in Hong Kong is of this type, it may be necessary to offer developers more direct incentives to build extensive green roofs in Hong Kong.

Economic Constraints

2.3.9 There is a lack of understanding about direct tangible and long-term economic benefits of extensive green roofs, and this uncertainty may mean that costs are thought to be higher than they actually are and consequently the market fails to drive implementation.

2.3.10 Structural loading requirements require additional capital expenditure, the extent of which depends on the nature of the green roof. Structural costs for extensive green roofs would represent a significantly smaller percentage of overall construction costs than costs for intensive roof gardens which are already widespread in Hong Kong.

2.3.11 Additional maintenance costs may be required, though this will vary greatly depending on the design. Long-term maintenance costs of extensive green roofs should be a relatively small proportion of total building maintenance costs, especially since damage to the building envelope will be reduced, but these exact costs are not known. Long-term maintenance also requires initiative on the part of the owner / manager.

2.3.12 Additional design costs may be required due to the need for specialist advice.

2.3.13 Additional infrastructure costs may be required, e.g. additional stairs for access and safety railings for accessible roofs.

Technical constraints and risks associated with uncertainty

Plan Area

2.3.14 Although, from a technical standpoint, there is no minimum area for a green roof, the smaller the roof is, the harder it would be to create effective greening alongside other elements that have to be located on the roof. This is a significant consideration in Hong Kong where building footprints are frequently quite small.

2.3.15 Very small intensive green roofs may still provide useful benefits by virtue of their ability to create usable space for leisure and amenity, and also generate comparatively large volumes of greenery from trees growing out of a small floor plan.

2.3.16 On the other hand, the benefits of a small extensive green roof would be less than those of a small intensive green roof, since the former's 'two-dimensional' nature has less visual greening impact than the latter's 'three-dimensional' qualities; it cannot be used as leisure or amenity space; and the environmental benefits of extensive green roofs described in **Section 2.2.24** above are most effective when extensive areas of roof are greened.

Altitude

2.3.17 Although there is no technical limit on the altitude of a green roof (since plant species may be chosen for any given situation), significant changes in environmental and microclimatic factors occur as the altitude increases, leading to significant constraints in design requirements and opportunities. Green roofs located at higher levels above ground require plants suited to cool, windy, exposed locations, and will present far more limited opportunities for human use.

Structural Loading

2.3.18 Although there is no technical reason why a sufficiently strong structure cannot be created for a green roof, there may be financial constraints on the provision of a suitably strong structure. This is more likely to be the case for intensive green roofs which require greater structural loading than extensive green roofs.

Water Leakage

2.3.19 From a technical standpoint, there is no reason why leaks should occur any more than in a normal roof system, (in fact they should be less likely to occur due to protection from weather, as noted in the section on benefits) but if leaks do occur, they are potentially more difficult to trace.

Maintenance

2.3.20 If roofing components need replacement, a more complicated process is likely, since plant material and growing medium would likely need to be removed and replaced.

2.3.21 Accessible roofs need on-going care. The more complex the planting scheme, the more care is required, (e.g. pruning, etc.). However, this is already well understood and implemented on intensive green roofs throughout Hong Kong.

Safety

2.3.22 Accessible roofs must have full perimeter safety protection. Adequate safety protection must be provided for maintenance staff.

Plant Selection

2.3.23 Plant selection for use on intensive green roofs is well understood in the local landscape industry, and there is a huge variety of ground covers, shrubs and trees that are commonly used on podium landscape gardens in Hong Kong.

2.3.24 However, the limited experience of extensive green roofs in Hong Kong means that there is uncertainty on the correct plant species for use on this type of green roof in the local context.

2.3.25 The ornamental 'neat and tidy' approach to landscape that is prevalent in Hong Kong suggests that the dry seasonal browning of ecological style planting on extensive green roofs may not be well received by certain sectors of the general public. (For example, grass on natural hillsides in Hong Kong turns brown during the dry season – which appears quite natural and not out of place - but grass planted as part of slope greening measures along highways in urban areas seems to be expected to stay green all year round and is frequently criticised for not achieving 'greening' objectives when it turns brown as part of its natural cycle.) A desire for 'neat and tidy' and 'always green' landscape implies higher levels of maintenance with associated costs.

2.3.26 Although requiring less maintenance than intensive green roofs, extensive green roofs still need to be maintained to ensure that unwanted plant species (e.g. large shrubs or trees) do not invade the roof and cause damage.

3 SHOWCASE EXAMPLES

3.1.1 Provide below are seven showcase examples of buildings with successful green roofs, two from outside Asia, two from Asia and three from Hong Kong and Guangdong.

- Unterensingen, Germany, (Intensive and Extensive Green Roof)
- Chicago City Hall, USA, (Retrofitted Extensive Green Roof)
- ACROS Building , Fukuoka, Japan (Intensive Green Roof)
- Roppongi Hills, Tokyo, Japan (Intensive and Extensive Green Roof)
- Tai Lung Laboratory, Hong Kong. (Intensive Green Roof)
- Guangzhou Green Roofs, Gaungdong, China. (Extensive Green Roof)
- IFC2, Hong Kong (Intensive Green Roof)

3.2 UNTERENSINGEN, GERMANY

3.2.1 This building provides examples of both intensive and extensive green roof systems.

Figure 3.1 Lauer Building, Unterensingen, Germany

The building with its green roof level, eight years after completion, showing both intensive and extensive green roof systems. (Source and copyright © 2002 by Zinco Ltd.)

3.2.2 When planning the new administration and research building in Unterensingen for the computer company Lauer Systems´, it was decided to vary the architecture from the surrounding industrial buildings which had monotonous flat roofs. An ambitious landscape design with a lot of green was requested. As the footprint of the building was going to take up most of the development area, it was planned to provide intensive landscaping on the three lower roof levels. Only the upper roof was provided with an extensive landscape. The three intensive roof areas are landscaped to reflect the internal functions at each level, providing outdoor areas for the Casino and conference rooms, to hold company picnics and other events.

3.2.3 Green roof characteristics are as follows:

- Area: 1200 m²
- Soil Depths: 200mm to 700mm
- Construction year: 1993
- Client: Knut Lauer
- Architects: Kolb & Prassel, Hochdorf
- Design: Dieter Grau & Albrecht Hild

3.2.4 The landscaping consists of lawn, shrubs, bushes and trees in a design that made use of numerous proprietary layers and substrates ranging from 200mm to 700mm, including special filter sheets, drainage layers, insulation protection mats with root resistant waterproofing.

Figure 3.2 Intensive Green Roof, Lauer Building, Unterensingen, Germany

An avenue of trees surrounds a timber decked catwalk. The roof garden on the second floor is used by the employees during breaks. A circular pergola with its seating acts as a central meeting area. (Source and copyright © 2002 by Zinco Ltd.)

3.3 CHICAGO CITY HALL, USA

3.3.1 This building provides an example of a retrofitted extensive green roof system. As a part of its effort to become the "greenest city in America", Chicago now claims more green roofs than any other US city. The elaborate green roof on the century-old City Hall was among the first, and is now an important research and demonstration site for studies on the benefits of green roofs, comparisons of green roof technology, and the survivability of both native and non-native plant species.

3.3.2 Over 150 varieties of trees, vines, grasses, and shrubs are the subjects of ongoing experiments. Plants are organized into bands of different colours, which change as the season progresses. These bands are not merely aesthetic, but allow the same plant materials to be tried in various soil depths, slopes, and drainage patterns. Although the roof is not accessible to the public, it is visible from more than thirty tall buildings in the city centre. Limited tours are given to industry professionals.

3.3.3 The black tar roof of the adjacent Cook County Administration Building serves as a control for comparative studies. Tests have shown that the average temperature on the City Hall green roof is 8°C (78°F) cooler than on the Administration Buildings' tar roof. Chicago's City Hall green roof continues to provide the essential data that can ultimately support government incentives and investment in green roofs as a way to mitigate the urban heat island effect.

Figure 3.3 Retrofitted Extensive Green Roof on Public Buildings, Chicago City Hall

Views showing the City Hall building before and after the addition of extensive rooftop gardens.
(Source and copyright © Earth Pledge, 2005)

Shrubs and climbers are also tested in these locations.
(Source and copyright © Earth Pledge, 2005)

Annuals, bi-annuals and grasses are also being tested on this site.
(Source and copyright © Earth Pledge, 2005)

3.3.4 Green roof characteristics are as follows:

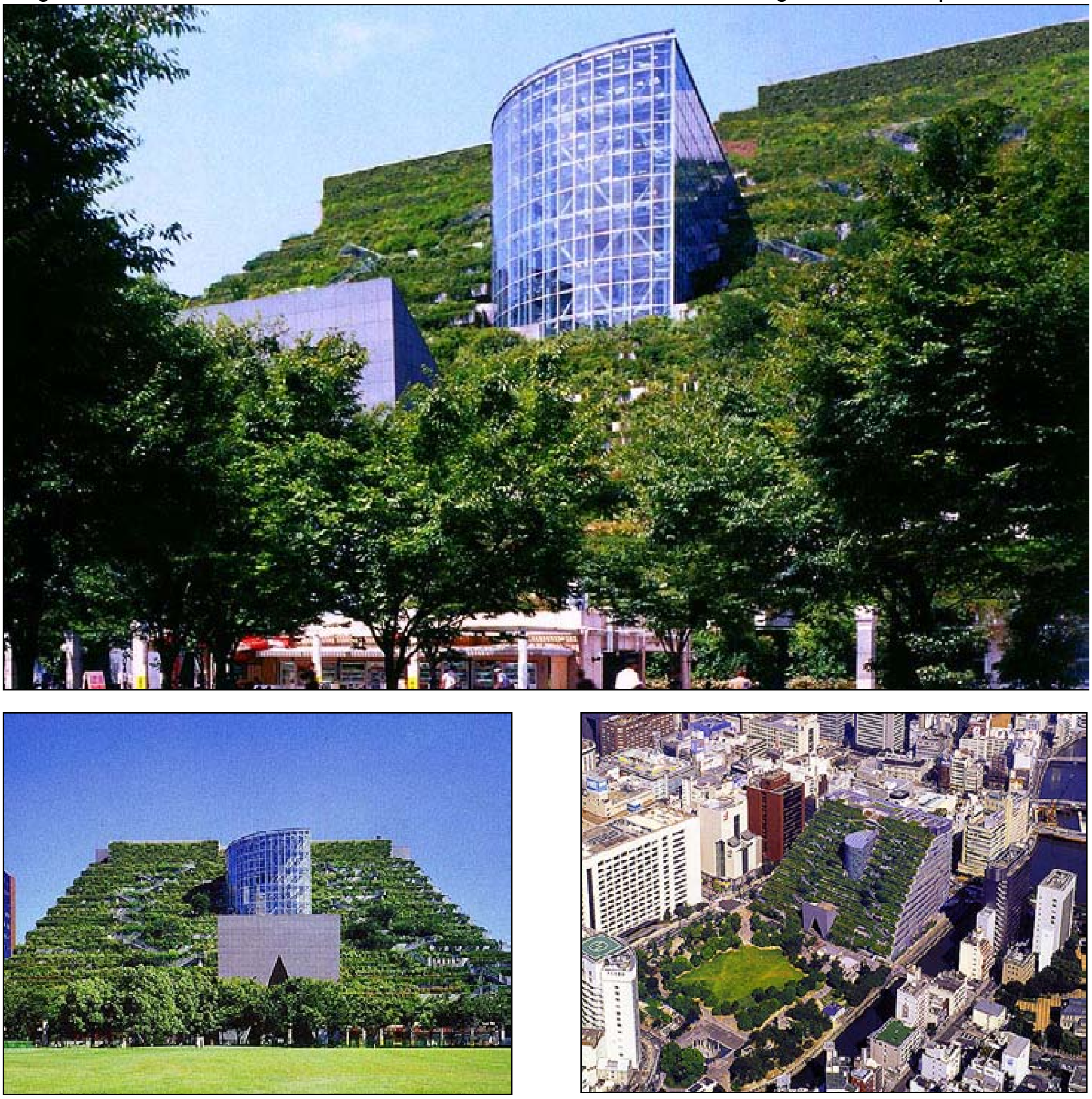
- Area: 2000 m² (22 000 ft²)
- Roof Coverage %: 56%
- Soil Depths: 100mm, 150mm, 450mm
- Costs: US$ 490/m² (HK$3800/m²)
- Construction year: 2001
- Client: City of Chicago
- Architect: William McDonough & Partners
- Landscape Architect: Conservation Design Forum

3.3.5 Interest in the City Hall roof and in the city's support of green roofing has been so great that a multi-departmental team developed a brochure entitled "A guide to Roof-top gardening" to respond to public demand for information.

3.4 ACROS BUILDING , FUKUOKA, JAPAN

3.4.1 This building provides an example of an intensive green roof system. The Asian Crossroads Over the Sea (ACROS) building in crowded Fukuoka offsets the impact of its development on the adjacent Tenjin Central Park with a series of elaborate stepped green roofs. The project is an articulate fusion of public and private space, which more than doubles the size of the park whilst creating over one million square feet of multipurpose space, including a museum, a theatre, shops and offices.

Figure 3.4 Intensive Green Roofs on the ACROS Office Block Building, Fukuoko, Japan



This building was designed for maximum greening and integrates with the Park below. The effect is reminiscent of the hanging gardens of Babylon. (Source and copyright © Earth Pledge, 2005)

3.4.2 The city-owned land was the last large undeveloped plot in central Fukuoka and is next to the only park in the area. The city chose to develop the site in a joint venture with private enterprise. The goal was to create new public land equal to that lost to the development. The north face of the building is traditional, with a formal entrance onto one of the most prestigious blocks in the city. On the south side, 15 vegetated terraces climb the full height of the building. Each floor has landscaped gardens for meditation, relaxation and escape from the congestion of the city below. The top terrace is a grand belvedere, with views of the bay of Fukuoka and the surrounding mountains. A series of reflecting pools are connected by water jets, creating a climbing waterfall that masks the ambient noise of the city.

3.4.3 The design reconciled the developer's desire for profitable site use with the public need for open space. The nearby park and the ACROS building are visually and physically integrated, demonstrating how a major building complex can co-exist with public green space.

Figure 3.5 Close-up view of Intensive Green Roofs on the ACROS Office Block Building

Roof-top utilities are bounded by walls covered in greenery. (Source and copyright © Earth Pledge, 2005)

3.4.4 In 2001, elaborate building heat measurements were taken which have helped to prove conclusively that building efficiency, the surrounding areas, and the urban heat island effect can indeed be positively influenced by architecture and urban forms that embrace greenery[21].

3.4.5 Green roof characteristics are as follows:

- Area: 9300 m² (100 000 ft²)
- Roof Coverage %: 80%
- Soil Depths: 300mm to 600mm
- Construction year: 1995
- Client: Dai-Ichi Mutual Life Mitsui Real Estate
- Architect: Emilio Ambasz
- Landscape Architect: Niho Sekkei Takenaka Corporation

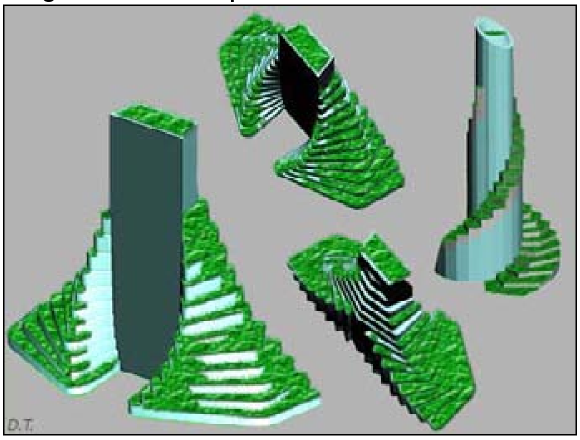
(21) [21] http://www.takenaka.co.jp/takenaka_e/news_e/pr0108/m0108_05.htm

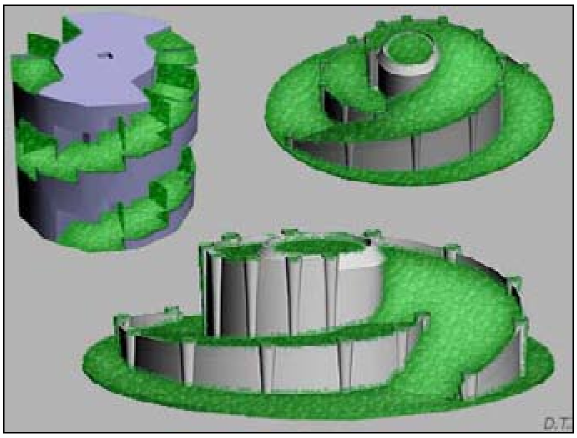
Green Roof Architecture

3.4.6 The ACROS building in Fukuoka, Japan illustrates the first steps in a new architectural approach where buildings are shaped specifically to accommodate green roofs. If the complete benefits of green roofs are to be realised for a city then a new kind of architecture, as implemented at ACROS, needs to be invented that would maximise the amount of greenery a building can facilitate. It would need to be an architectural style that does not see greenery as the amenity decorations for the incidental space left over on the site or the incidental horizontal space created by its roof. Instead, an architectural style is needed that integrates and welcomes the landscape in a truly 'symbiotic' relationship, where the building benefits as much from the integration as the open space does. Looking closely at the ACROS building, the following design principles can be observed:

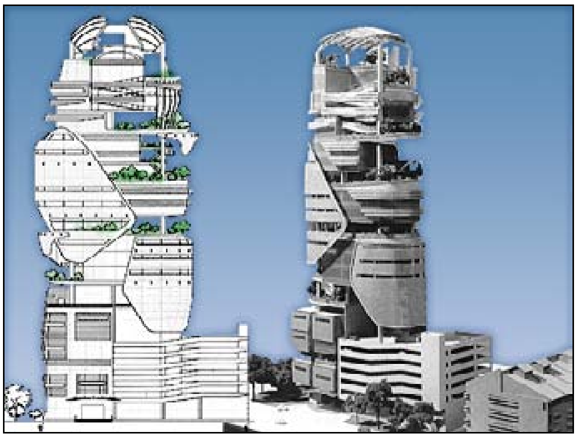
- ♦ The architecture responds to the landscape below, respecting the scale of the park users below, rather than boxing them in.
- ♦ The outer surface area of the building is maximised to accommodate greenery.
- ♦ Adequate natural lighting can still enter the building.
- ♦ Greenery on the building is designed to be visually accessible from ground level.
- ♦ The stepped layout allows for large planting to be installed without the danger of anything being blown off and falling far to the ground.
- ♦ The stepped layout provides sound insulation to the sides of the building, not just the top.
- ♦ The stepped layout allows for easy access for building occupants and maintenance staff.
- ♦ Even the rooftop utility buildings have extensive green roofs installed. These are also screened with a green wall (low enough for maintenance considerations).

Figure 3.6 Conceptual Architecture for Green Roofs





(Source and copyright © Urbis Ltd, 2006)



(LEFT) Menara Mesiniaga, Kuala Lumpur, Malaysia, 1992 (RIGHT) Hitechniaga HQ Tower, Malaysia (1995, not built)
(Source: Adapted from 'Rethinking the Skyscraper – The Complete Architecture of Ken Yeang'.)

3.5 ROPPONGI HILLS, TOKYO, JAPAN

3.5.1 This building provides examples of both intensive and extensive green roof systems. Roppongi Hills is an experimental urban development in the heart of Tokyo. The complex was envisaged as a way to revitalize a depressed downtown enclave, not only through economic development, but also by adding much needed green space in a city that suffers from intense urban heat island effect. The Tokyo Metropolitan Government worked with the developer Mori Building Company to design Roppongi Hills as an entertainment district and a lush garden neighbourhood in the heart of the city.

Figure 3.7 Intensive and Extensive Green Roofs on the Roppongi Hills Main Building

This green roof includes intensive and extensive green roofs, arranged so that the public space is not obstructed by utilities. (Source and copyright © Earth Pledge, 2005)

3.5.2 The area's skyscrapers maximise the available space for housing, offices, and entertainment in the dense city centre. Site planners were creative in their use of greenery, knitting together the complex with a network of pathways, gardens, and green roofs. In a city with only 14% green space, Roppongi Hills has twenty-six percent of its land area planted with vegetation.

3.5.3 The Keyakizaka complex rooftop boasts a rice paddy and vegetable plot, while the Sakurazaka roof exhibits public art and street furniture in a garden setting. There is a 4000m² (43,000 ft²) traditional Japanese garden, and most of the residential area is designed in a blended Japanese-British style. Almost all the buildings, including the Asahi Television tower and the Virgin Cinema complex, have green roofs. The variety of landscaping on the Rappongi Hills buildings showcases the potential for inventive green and vertical urban development.

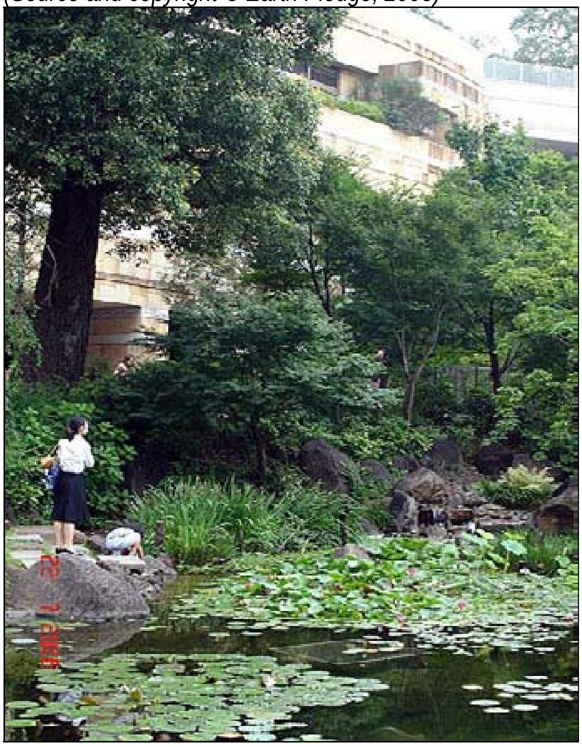
3.5.4 Green roof characteristics are as follows:

- Area: 13000 m² (143 000 ft²)
- Roof Coverage %: 26%
- Soil Depths: 30mm to 1200mm (1.17 - 46.8 in)
- Construction year: 2003

- Client: Roppongi 6 Chrome Redevelopment Association
- Architect: Conran & Partners, JPI, KPF, and Mori Building Company
- Landscape Architect: Yohji Saski & Dan Pearson

Figure 3.8 Intensive Green Roofs at Roppongi Hills, Tokyo

This green roof includes traditional rice fields.
(Source and copyright © Earth Pledge, 2005)



Buildings, footbridges and podium gardens are connected.
(Source and copyright © Earth Pledge, 2005)

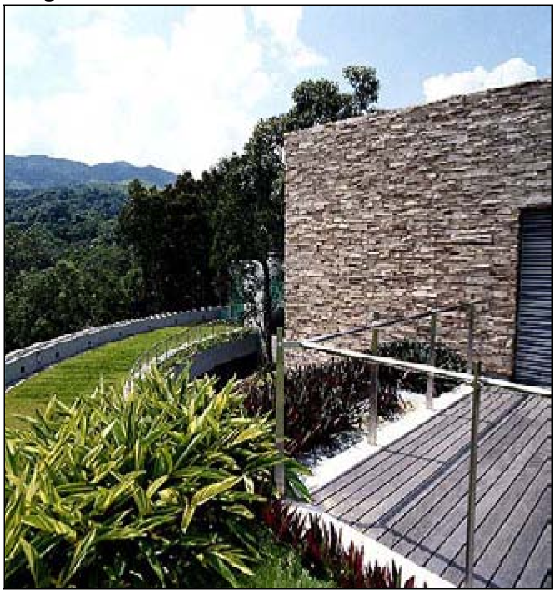
3.6 TAI LUNG LABORATORY, HONG KONG

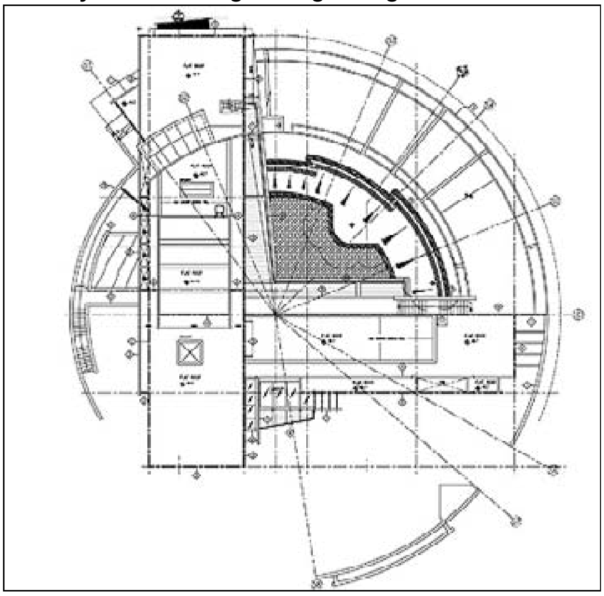
3.6.1 This building provides an example of an intensive green roof system. *Sustainability* was critical to the design of this building and included:

- Arranging the building forms to harmonise with the site profile. They were also arranged to optimise solar exposure as well as prevailing winds.
- Keeping the building footprint as small as possible to minimize disturbances to the existing slope.
- Arranging all building blocks to avoid felling existing mature trees.
- Providing Roof-gardens and landscaped terraces which compensate for the trees felled.

3.6.2 The two-storey complex included; 8 laboratories for conducting a wide range of veterinary experiments, 2x level-three bio-safety laboratories (with supporting facilities to handle animal carcasses and to perform post-mortem operations) and office accommodation and ancillary facilities for staff and technicians.

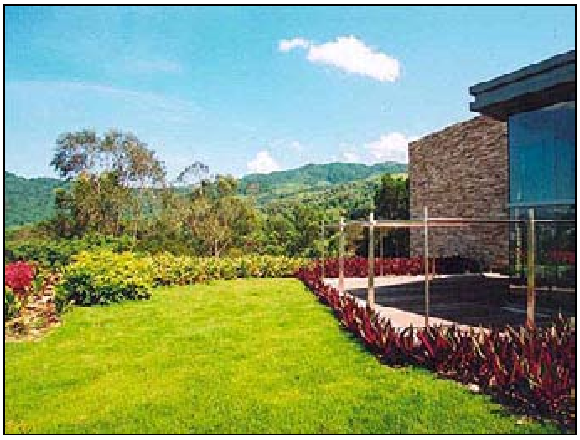
Figure 3.9 Intensive Green Roofs at Tai Lung Laboratory, Yuen Long, Hong Kong





Organic forms, natural materials and rooftop gardens were synthesized into a building that respects nature, minimises impacts and compensates for losses. (Source and copyright © ArchSD, 2002)

(Source and copyright © ArchSD, 2002)



(Source and copyright © ArchSD, 2002

3.6.3 Green roof characteristics are as follows:

- Areas: 400m² (of 780m² possible roof area, site area 2800m²)
- GFA: 1,107m²
- Roof Coverage %: 51%
- Soil Depths: 360mm
- Construction dates: 2002
- Clients: AFCD (project manager: ArchSD)
- Architect & Architectural Services Department
- Landscape Architect: Architectural Services Department

3.7 GUANGZHOU GREEN ROOFS, GUANGDONG, CHINA

3.7.1 These buildings provide examples of retro-fitted extensive green roofs in the Guangdong region and demonstrate a particular Sedum cultivar suited for conditions similar to those found in Hong Kong. These examples appear to be showcase examples for the Chinese Government.

3.7.2 Emulating the extensive green roofs seen is Europe and Germany is dependent on finding plant material which functions in much the same way (i.e. such as Sedums). Various local conditions (climate, typhoon winds, vigour of local invaders, etc., as described in Section 4.4) make this a difficult exercise. However, a cultivar of *Sedum lineare* has been developed in Guangzhou which shows promising results in conditions very similar to Hong Kong.

Figure 3.10 Specialized Sedum Cultivar

(Source by Urbis Ltd., and copyright © ArchSD, 2006)

3.7.3 This cultivar was derived from a plant species in Hunan province and has been developed over the last 10 years in Guangdong to suit local conditions and for a better aesthetic appearance. The original plant species was leggy and sparse. The cultivar has been commercially available for the last 4 years. Like Sedums in other parts of the world the cultivar appears robust and capable of withstanding harsh conditions.

3.7.4 The main advantages of this cultivar are that:

- It establishes itself easily and fast, and is transported easily without soil. Early cost estimates were quoted at HK$ 250/m², (including delivery, waterproofing, water retention layer, special soil substrate, LECA drainage layer, and 3 months establishment maintenance)
- It grows on very thin soil substrates: 50-60mm
- It tolerates temperature extremes
- It prefers direct sunlight
- Minimal maintenance required
- It can apparently withstand long periods without watering and can also tolerate long periods being water-logged.
- It can apparently tolerate varying soil conditions, but naturally prefers alkaline soils.
- It appears very vigorous and out-competes other invaders

3.7.5 The main disadvantages are:

- It is a single colour (grass green) and does not flower in the Hong Kong climate where it does not get enough winter cold or long nights to trigger its reproductive/flowering mode.
- It does not tolerate being trodden on, taking more than a week to recover
- It is very vigorous and may out-compete other roof-top species
- It occasionally reverts to its old form requiring minimal maintenance to pluck those forms out.

3.7.6 This cultivar has apparently also been successfully installed in numerous cities in China, and is illustrated below in three different sites in Guangzhou.

- SITE A: Feng Huang Shan Hostel and adjacent residential buildings, initiated by Guangdong Province Agricultural Department Enterprise Unit.
- SITE B: Guang Wei Lu residential buildings, initiated by Yue Xiu Municipal People's Government.
- SITE C: Dong Wang Market and adjacent residential buildings, initiated by Bai Yun Municipal People's Government.

Figure 3.11 Site A – Feng Huang Shan Hostel and Adjacent Residential Buildings

Sedums planted are 4 years old and show no signs of dying back or of being taken over by invaders (Source by Urbis Ltd., and copyright © ArchSD, 2006)

Figure 3.12 Site B – Guang Wei Lu Residential Buildings

Examples in these locations are surviving in the heart of the city (Source by Urbis Ltd., and copyright © ArchSD, 2006)

Figure 3.13 Site C – Dong Wang Market and Adjacent Residential Buildings

This example shows Sedums planted with bands of Rhoeo discolour for aesthetic effect. The Sedum is vigorous and is out-competing the Rhoeo. More effective techniques will need to be developed if combinations of species are proposed in the design. Due to its low tolerance for being trodden on, access paths need to be incorporated into the design of this type of green roof.(Source by Urbis Ltd., and copyright © ArchSD, 2006)

3.7.7 Green roof characteristics for the 3 sites are as follows:

- Areas: 6000m^2, 3500m^2, and 23000m^2
- Roof Coverage %: 95%, 95% and 95%
- Soil Depths: 30-40mm, 30-40mm, and 60mm to 80mm
- Construction dates: May 2002, September 2005, and February 2006
- Clients: Guangdong Province Agricultural Department Enterprise Unit, Yue Xiu Municipal People's Government, and the Bai Yun Municipal People's Government.

Figure 3.14 Example of *Sedum Lineare* in Shenzhen

(Source and copyright © Yu Yu Environmental Protection Science and Technology Co. Ltd, 2006)

3.8 IFC2, HONG KONG

3.8.1 This building provides a local example of an intensive green roof system.

3.8.2 The IFC2 development contributes a number of open spaces which enhance the public realm of the Central Business District. These comprise large urban public open spaces, two of which are Designated Public Open Spaces and are accessible 24-hours a day.

3.8.3 The Second Public Open Space comprises a Podium Garden at Level 4, and the Harbour-side Terrace at Level 3. Both the garden and the terrace serve community needs for more passive recreation spaces in the Central Business District, and are fully integrated with adjoining retail and entertainment uses in the retail podium.

3.8.4 As usable urban public open space is highly prized in the Central Business District, the usability of the public open space is maximised by minimising low planting and planters which visually and physically break up the space and inhibit free pedestrian circulation. 'Greening' is provided in the form of a series of raised lawns, which can be used as informal recreation areas, and groves of semi-mature trees which will, in time, create a virtually continuous shade canopy.

3.8.5 Selected trees comprise blocks of dark-foliage semi-mature *Ficus altissima* at the podium edge, and larger blocks of light green foliage semi-mature, semi-deciduous *Ficus rumphii* which provide light shade to seating areas. *Cerbera manghas* are planted along the Harbourside Terrace, and *Plumeria rubra* on the roof of the retail bridges.

Figure 3.15 Roof Garden at IFC2 Showing Trees, Seating and Water features

(Source and copyright © Urbis Ltd., 2006)

(Source and copyright © Urbis Ltd., 2006)

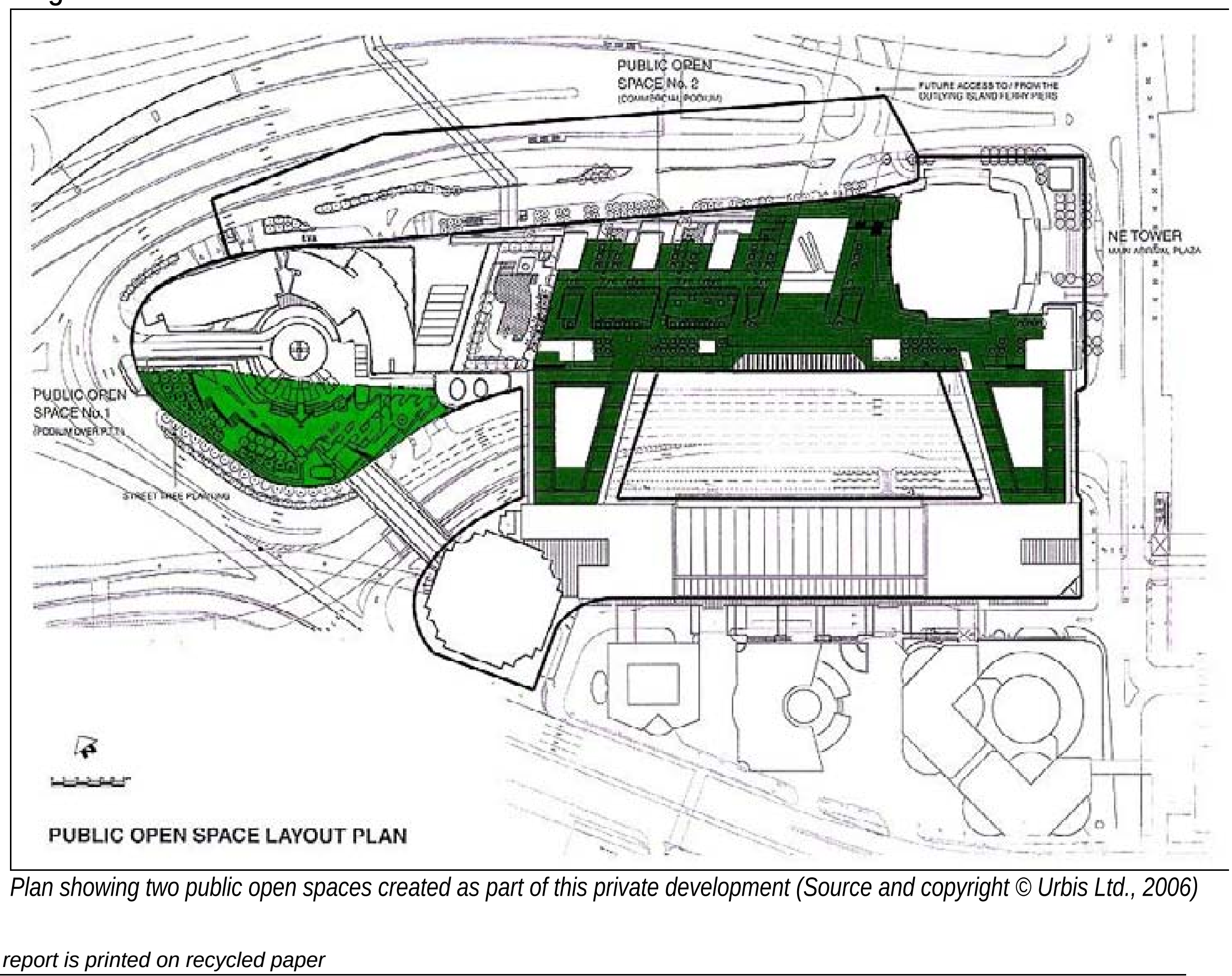
Figure 3.16 Roof Garden at IFC2 Showing Lawned Areas and Cafeterias

(Source and copyright © Urbis Ltd., 2006)

3.8.6 Green roof characteristics are as follows:

- Area: 13000 m²
- Soil Depths: 600mm to 1200mm
- Construction year: 2003
- Client: Central Waterfront Property Development Ltd.
- Architect: Rocco Design Ltd
- Landscape Architect: Urbis Limited

Figure 3.17 Plan of Roof Gardens at IFC2



Plan showing two public open spaces created as part of this private development (Source and copyright © Urbis Ltd., 2006)

4 FINDINGS OF DESKTOP RESEARCH

4.1 REVIEW OF INTERNATIONAL APPROACHES, STANDARDS, AND COVERAGE OF GREEN ROOFS

Overseas Policy Approaches

4.1.1 Worldwide, green roof policies are not prescribed at a national level. However, it is often the case that municipal regulations are borne from directives initiated at top level. This appears to be the case in Germany, Canada, the USA, and Japan.

4.1.2 Germany has led the development of green roofs, particularly extensive green roofs. There are four general categories municipal policies and incentives in operation in Germany[22], many of which have been in place for over a decade:

- *Direct Financial Incentives.* These financial incentives customarily take the form of subsidies available to property owners and developers who build green roofs. As an incentive, this approach can be tailor-made for any jurisdiction. It does not force property owners to create green roofs; they act voluntarily through clear economic gains and are still encouraged to retro-green existing buildings. It is an incentive that operates on a clear per square metre basis and is proportional to the environmental benefits.
- *Indirect Financial Incentives.* This approach uses *Split Wastewater Fees* and targets the storm water runoff problem created by impervious buildings. Sewers collect wastewater from both sanitary disposal and also storm-water disposal. This system provides monetary discounts to the storm-water part based on the storm-water infrastructure savings that green roofs contribute. It requires municipalities to split the municipal rates.
- *Ecological Compensation Measures.* This is a policy that stems from the German "Intervention Rule" which is based on the Federal Building Code, the Federal Nature Conservation Act, and the Environmental Impacts Assessment Act. The Intervention rule is a decision-making process applied at the land-use and development level. It follows a set of questions and prioritised options aimed at complete restoration of natural balances that are disrupted. *Avoidance*, *Minimization, Compensation* and *Replacement* are the terms used and are not unlike Hong Kong's EIAO. In Germany green roofs may be used in the *Compensatory* option but are very specific to what the roof is compensating for and has proven difficult to monitor over the long term.
- *Integration into Development Regulations*. Integrating development regulations is another tool available to increase the coverage of green roofs. Local authorities may include green roofs in their development regulations based either on *Ecological Compensation Measures* or based on the German Federal Building Code. In some instances compulsory measures can be more effective than voluntary incentives though typical protests against perceived additional costs may be encountered. Its main benefit is that it requires no direct monetary input from government, though monitoring may still incur an expense. Density bonus regulations (green roofs as compensation for higher density) can also be integrated into development plans according to the Land-Use Regulation. From the German experience, introducing regulations into new development areas has proven especially effective while applying it to existing areas as retro-fit projects has been difficult.

4.1.3 Apart from regulations and incentives, there are numerous other tools available to municipal authorities to encourage green roofs. These include:

(22) [22] Ngan, (2004)

- Competitions and Media Coverage,
- Leading by Example - Greening Public Buildings, and
- Performance Rating Systems.

4.1.4 Toronto has been pro-active in encouraging green roofs by installing green roofs on its municipal department buildings, helping the green roofs industry, and embarking on a free green roofs advice educational campaign.

City Policy Case Studies

Policy Case Study No. 1 - Portland, Oregon

4.1.5 In Portland, the motivation for developing green roofs has been concern about water pollution from combined sewer overflow (CSO), particularly in light of major pollution of the Willamette River[23]. Portland promotes green roof development through a number of policies, but requires green roofs only on public buildings. Portland has implemented the following strategies:

- All new City-owned buildings are required to be built with a green roof that covers at least 70% of the roof. The remaining roof area must be covered with Energy Star rated roofing material. When practical, all roof replacements must also include a green roof. The City has internal green building consultants to assist City buildings in meeting green building policy objectives. Most public green roof projects have been financed by storm-water fees (see below).
- The City Zoning Code offers developers floor area bonuses when they implement stipulated options, like a green roof. The bigger the proportion of green roof coverage, the larger the bonus offered. The owner must sign an agreement ensuring proper roof maintenance (although proper long-term maintenance continues to be a concern).
- Portland levies a storm-water management charge for commercial, industrial, and institutional rate-payers that is based on the amount of impervious area on site (US$6.45 per 1000 square feet of hard surface per month). There is an initiative under consideration to reduce charges by 35% for owners who install green roofs with coverage of at least 70%. Residences are charged for storm-water management at a flat rate.
- In the Central City District, developments must comply with architectural design guidelines, and are subject to a general design review process prior to approval. A green roof in a design is considered an asset and will assist the proposal being approved.
- Portland provides education and outreach on green roof development, by providing technical assistance to building owners and guided tours of green roofs. It also monitors green roofs.
- Portland has funded green roof demonstration exhibits and test sites.
- Green roofs are formally recognized as a Best Management Practice in the City's storm-water manual.
- A citizens' group called "Eco-roofs Everywhere" promotes green roof development for lower income areas. It creates affordable demonstration projects, secures grants for small-scale developments, and negotiates lower prices with vendors.

4.1.6 These efforts have been effective in promoting green roofs - Portland is considered one of the North American leaders in green roofs. There were approximately 2 acres (0.81 ha) of green roofs in Portland in 2005, with about another 2 acres (0.81 ha) committed to be built. The City of Portland has promoted

(23) [23] City of Toronto Discussion paper (2005)

green roofs so effectively that the private sector and some private citizens are starting to build or install them on their own initiative. However, green roofs have not yet taken off in the industrial sector.

Table 4.1 Extract from Portland's Zoning Code

33.510.210 Floor Area and Height Bonus Options

C.4 Rooftop gardens **[Intensive Green Roofs]** *option. ……. For each square foot of rooftop garden area, a bonus of one square foot of additional floor area is earned. To qualify for this bonus option, rooftop gardens must meet all of the following requirements.*

a. The rooftop garden must cover at least 50 percent of the roof area of the building and at least 30 percent of the garden area must contain plants.
b. The property owner must execute a covenant with the City ensuring continuation and maintenance of the rooftop garden by the property owner. The covenant must comply with the requirements of 33.700.060.

C.10. Eco-roof **[Extensive Green Roof]** *bonus option. Eco-roofs are encouraged in the Central City because they reduce stormwater run-off, counter the increased heat of urban areas, and provide habitat for birds. An eco-roof is a rooftop stormwater facility that has been certified by the Bureau of Environmental Services (BES). Proposals that include eco-roofs receive bonus floor area. A proposal may not earn bonus floor area for both the eco-roof option and the rooftop gardens option; only one of these options may be used.*

a. Bonus. Proposals that include eco-roofs receive bonus floor area as follows:
(1) Where the total area of eco-roof is at least 10 percent but less than 30 percent of the building's footprint, each square foot of eco-roof earns one square foot of additional floor area.
(2) Where the total area of eco-roof is at least 30 percent but less than 60 percent of the building's footprint, each square foot of eco-roof earns two square feet of additional floor area.
(3) Where the total area of eco-roof is at least 60 percent of the building's footprint, each square foot of eco-roof earns three square feet of additional floor area.
b. Before an application for a land use review will be approved, the applicant must submit a letter from BES certifying that BES approves the eco-roof. The letter must also specify the area of the eco-roof.
c. The property owner must execute a covenant with the City ensuring installation, preservation, maintenance, and replacement, if necessary, of the eco-roof. The covenant must comply with the requirements of 33.700.060.

Policy Case Study No. 2 - Chicago, Illinois

4.1.7 In Chicago, the motivation for developing green roofs is concern about the urban heat island (UHI) effect, air quality and its effects on public health, and aesthetics[24]. The Mayor has been a strong advocate of green roof development. Chicago has a variety of policies and programs that encourage green roof development, specifically:

- The 2001 Regulation called the Energy Conservation Code requires that all new and retrofitted roofs should meet minimum standards for solar reflection (0.25 reflectance). Chicago's Bureau of the Environment deemed that green roofs are an acceptable way to lower roof reflectivity, mitigate UHI and improve air quality.
- A "Building Green/Green Roof" policy applies to construction projects that receive public assistance or certain projects that are subject to review by the Department of Planning and

(24) [24] City of Toronto Discussion paper (2005)

Development. Through this policy, the City of Chicago grants a density bonus option to developers whose buildings have a minimum vegetative coverage on the roof of 50% or 2000 sq. feet (whichever is greater), usually in the form of a green roof.

- Chicago has various City-sponsored green roofs, including demonstration sites, test plots, and others. The City has partnered with green roof providers to build and compare test plots that use different kinds of plants and material. It has issued a report on some of its findings.
- Chicago has engaged the Chicago Urban Land Institute, a non-profit organization of real estate professionals, in seminars and surveys. This helped to determine which kinds of incentives would encourage green roof development.
- Chicago offers a storm-water retention credit for green roofs, but does not levy a storm-water impact fee.
- The City has a website that supports green roof installation, and provides information and technical assistance.
- In 2005, Chicago offered a limited number of US$5,000 (HK$40,000) grants for building small-scale residential or commercial green roofs.
- There was no requirement in 2005 for green roofs in the private sector.

4.1.8 As of June 2004, Chicago had more than 80 green roofs over municipal and private buildings in various stages of installation. The total area of these roofs is over 1 million square feet (9.3 ha).

Policy Case Study No. 3 - Basle, Switzerland

4.1.9 In Basle, the motivation for developing green roofs is an interest in energy savings, and promoting protection of biodiversity[25]. Basle has promoted green roof development through a number of policies, specifically:

- In the mid-1990's, after a public poll found general support for an electricity tax to promote energy saving measures, and after consultation with stakeholders, Basle invested 1 million SFr. (HK$6.4M) from electricity fees into a two-year incentive programme, providing a subsidy of 20 SFr./m² (HK$128/m²) of green roof. Another programme like this is planned for 2005/06
- Since 2002, building regulations stipulate that all new and renovated flat roofs must be greened to provide valuable habitat (primarily for invertebrates), using specified materials.
- Basle provided a grant for research on the biodiversity protection benefits of green roofs. The results of this study shaped the design specifications for green roofs in Basle.
- Basle promoted the programme by holding a contest for the best looking green roof.

4.1.10 In 1996/7, there were 135 applicants for the green roof subsidy, and 85,000m² of roof-scapes were greened, resulting in 4 GW/year of energy savings. As a result of the regulations for new and renovated flat roofs, 15% of flat roofs in Basle have been greened. Basle is now exploring ways of enforcing proper green roof quality.

4.1.11 Basle's incentive programme concentrated efforts into a two year period, thereby raising the profile of green roofs in the City. The incentive programme was well received, media interest was high, and Basle received nationwide prominence as a result.

4.1.12 Basle's green roof regulations did not meet with any significant resistance, because all stakeholders were involved in the process from the beginning, and because of the success of the incentive programme.

(25) [25] City of Toronto Discussion paper (2005)

Policy Case Study No. 4, Munster, Germany

4.1.13 In Munster, the motivation for developing green roofs has primarily been concern about storm water management, and also interest in increasing green space[26]. Munster has promoted green roof development through a couple of policies/programs:

- Munster charges a storm-water fee, according to the amount of storm-water that runs off a property and into the sewer system (i.e. if there is no run-off, there is no fee). The fee is reduced by 80% or more when a green roof is installed. To implement this program, the Public Works department sends property owners a bill stating the amount of pervious and impervious surface area on the property, with the corresponding storm-water fee. The fees are used for maintenance of the sewer system.
- Munster has also had an evolving incentive programme for a variety of environmental measures that can include green roofs. Subsidies were provided for green roof development, but this programme ended in 2002, due to financial constraints.

4.1.14 Munster's incentive programme was effective, resulting in a total of approximately 12,000m² of green roof coverage by the end of the programme.

4.1.15 The storm-water fee has also been very successful, and it has been accepted well by the community, however specific information about additional green roof development resulting from the fee is not yet available. This programme does have a considerable administrative component, as pervious and impervious areas for each property must be determined, verified, and in the case of adjustment, reassessed. Costs for administration can be offset by the fee.

Policy Case Study No. 5, Stuttgart, Germany

4.1.16 In Stuttgart, the motivation for developing green roofs has primarily been concern about air quality, since the city is situated in a basin-like valley where pollution tends to settle[27]. Urban growth that has removed vegetation from surrounding slopes has exacerbated the problem. There is also interest in mitigating urban heat island effect. Stuttgart promotes green roof development in three ways:

- Stuttgart is greening the roofs of its public buildings. It has an annual budget allocation for green roof development, and most green roofs are installed when the roof is due to be replaced.
- Stuttgart has provided a financial incentive for green roofs since 1986. The programme has the equivalent of HK$567,000 available each year, and pays for 50% of costs, or a maximum of the equivalent of HK$196/m² of roof. The City provides a free consultation and a comprehensive brochure to property owners explaining how to install green roofs.
- Stuttgart has regulation requiring all flat and slightly sloped roofs (up to 12 degrees) of new development to be extensively greened to certain standards. Trade-offs or compromises with developers are common in the roof greening process.

4.1.17 All three approaches have been successful. 105,000m² of public roofs have been greened, and 55,000m² of roofs have been greened through the incentive programme. No data is available on the amount of roofs greened through regulation.

Policy Case Study No. 6, Toronto, Canada

4.1.18 After numerous investigations of other cities around the world, Toronto has recently embarked on its own policies towards green roofs[28]. These are generally motivated by all green roof benefits; the potential to

(26) [26] City of Toronto Discussion paper (2005)

(27) [27] City of Toronto Discussion paper (2005)

(28) [28] Toronto Policy and Finance Committee Agenda Meeting No.1, Jan 2006

mitigate impacts on storm-water quality and quantity, improves buildings energy efficiency, reduces the urban heat island effect, improves air quality, beautifies the city, provides natural green spaces in built-up areas, holds grounds for gardening, food production and horticultural therapy, and increases passive recreational space in densely-populated neighbourhoods. Toronto supports green roofs through various initiatives:

- Toronto has stipulated that green roofs (with coverage of 50% - 75% of the building footprint) be constructed on all new and existing City-owned buildings.
- Toronto has begun adapting its zoning by-laws and regulations relating to site plan control applications to achieve green roofs.
- Toronto has begun with direct financial incentives programme for the retro-greening of existing buildings. Pilot incentive programs in this regard have begun.
- Toronto has stipulated that a ‘green roofs resource person’ is identified in each of the municipal divisions (Buildings, City Planning, Water, Facilities and Real Estate, Shelter, Support and Housing Administration, and Technical Services).
- Toronto has actively embarked on a green roofs education and publicity campaign. These include technical booklets on construction and maintenance, holding workshops for developers and building owners, staff training, listing green roof suppliers and contractors, and establishing a green roof ‘one stop shopping’ page on the city’s official website.
- Toronto has also added an element of competition to its green roofs drive by adding Green Roofs as a Category for the Green Toronto Awards and has invited the Green Roofs for Healthy Cities to hold its 2008 international conference in Toronto to highlight its showcase examples.

4.1.19 Toronto’s enthusiastic approach is very new (January 2006). The effectiveness of its approach should be reviewed after it has been in place for some time.

4.1.20 Prior to the above-mentioned policies, Toronto hired a team from Ryerson University to undertake a study of the municipal level benefits and costs of implementing green roof technology in Toronto.[29] The team conducted an extensive literature review to identify and quantify the benefits related to green roofs. It also collected information on the types of buildings in Toronto and their geographic distribution. The information collected was modelled and applied to an inventory of existing flat roofs within the City for aggregating the benefits on a citywide basis. The team also developed a method to compute the monetary value of the benefits. A survey of the existing green roof technologies and standards was carried out to improve upon the development of minimum requirements for green roofs.

4.1.21 The study quantified some of the many benefits associated with green roofs, based on currently available research data, but recognized that the benefits that were not quantified (such as aesthetic improvement of the urban landscape, increases in property values, use of green roofs for food production, and increased bio-diversity) still have value. The study quantified the benefits from storm water flow reduction - including impacts on combined sewer overflow (CSO), improvements in air quality, reductions in direct energy use, and reductions in urban heat island effect. The benefits on a citywide basis were calculated based on the assumption that 100% of available green roof area would be used. The available green roof area included flat roofs on buildings with more than 350m² of roof area, assuming that at least 75% of the roof area would be greened. The total available green roof area citywide was determined to be 5,000 hectares (50 million m²). The benefits were determined as initial cost savings related to capital costs, plus a level of annual cost savings. These are shown in the table below.

(29) [29] Ryerson University, Environmental Benefits and Costs of Green Roof Technology for the City of Toronto, Oct 2005

Table 4.2 – Cost Benefits analysis in Toronto (in CAD$)

Benefits	Initial Cost Savings	Annual Recurrent Cost Savings
Storm water		
▪ Alternate best management practice cost avoidance	$79,000,000	
▪ Pollutant control cost avoidance	$14,000,000	
▪ Erosion control cost avoidance	$25,000,000	
Combined Sewer Overflow (CSO)		
▪ Storage cost avoidance	$46,600,000	
▪ Reduced beach closures		$750,000
Air Quality		
▪ Impacts of reduction in CO, NO_2, O_3, PM_{10}, SO_2		$2,500,000
Building Energy		
▪ Savings in annual energy use		$21,000,000
▪ Cost avoidance due to peak demand reduction	$68,700,000	
▪ Savings from CO2 reduction		$563,000
Urban Heat Island		
▪ Savings in annual energy use		$12,000,000
▪ Cost avoidance due to peak demand reduction	$79,800,000	
▪ Savings from CO_2 reduction		$322,000
TOTAL	$313,100,000	$37,135,000

(Source: Environmental Benefits and Costs of Green Roof Technology for the City of Toronto, Oct 2005)

4.1.22 The report also presents its assumptions used in calculating City benefits as the minimum design criteria for a green roof to achieve the stated benefits. The key considerations were that the roof system be "extensive", that it cover a significant portion of the roof, have a maximum storm-water run-off co-efficient of 40%, and have a growing medium depth of at least 150 mm, where structural loads permit. Green roofs with shallower growing media could be used on roofs where structural loading does not permit the 150 mm. depth, although it would be recognized that the benefits would be reduced.

4.1.23 Green roofs are an emerging technology and some questions need further exploration. These include uncertainty related to some of the calculated benefits, the impact of less than 100% green roof coverage, the impact of building-specific constraints, quantification of other social benefits and consideration of the effectiveness of alternative technologies to green roofs. Moreover, the calculation of City program costs would allow a complete cost benefit analysis of green roofs to the City. These questions are important and will need to be considered further as the City develops its policy on green roofs. Nevertheless, there is enough evidence of the benefits calculated in the report to show that there is a case for developing public programs and promoting green roofs in Toronto.

Policy Case Study No. 7, Tokyo, Japan

4.1.24 After more than five decades of nearly unmitigated growth, only 14% of Tokyo's land area remains green. In fact, Tokyo has the lowest green-space-to-impermeable-surface ratio of any major metropolis. The resulting heat island effect has caused Tokyo's temperatures to increase at a rate five times faster than global warming. Tokyo was once a temperate seaport but has become ever more tropical with the number of hours above 30°C tripling. Energy consumption for cooling has increased by 15% from 1990 to

1998, winters are shorter and the annual cherry blossom festival has been rescheduled due to an earlier Spring. Palm trees and wild parakeets have appeared and small outbursts of Dengue fever have also occurred.

4.1.25 In 2001 an Environment Ministry study found that the high ratio of impermeable heat absorbing surfaces directly contributed to the city's warming. In the face of intolerable temperatures, environmental and health concerns, and a land-use policy that was impossible to change at this stage, the city turned to green roofs as a solution. The urban heat island effect is therefore the city's prime reason for establishing green roofs.

- Tokyo began with an informal incentive program that provided a free consulting service. This was followed by a subsidy program which resulted in 7000m² of rooftop greening.
- Tokyo then accelerated the process by mandating that all new-construction buildings were to have green roofs. Private buildings larger than 1000m² and public buildings larger than 250m² must green 20% of the rooftop or pay an annual penalty of US$2000. In the first year (2000 to 2001) this law had a dramatic effect - it doubled the net area of green roofs in the city from 52,400m² to 104,400m². New reports[30] indicate that green roof coverage is now 5 times what it was in 2000.
- Tokyo has also set target goals, with the *Green Tokyo Plan* aiming at 1,200 ha (12,000,000m²) as its ultimate goal.
- To promote the legislation, the city has constructed a green roof demonstration on the Tokyo Council Building and other facilities.

4.1.26 Although the laws are forceful towards new buildings, they have been widely accepted by industry, an aspect largely attributed to Japan's cultural sense of social and civic responsibility. Before the legislation, numerous surveyed companies were willing to convert to green roofs at their own expense. After the legislation, full compliance has been found with no penalties issued.

4.1.27 Encouraged by improvements, the Japanese government has followed Tokyo's lead. In 2003 the Ministry of Land, Infrastructure and Transport announced revisions to the national nature conservation regulations, mandating that all new constructions (multiple dwelling houses and offices buildings) green at least 20% of their rooftops. This law went into effect in 2005.

Overseas Green Roof Standards and Regulations

4.1.28 As a means of successfully establishing Green Roof technologies in Hong Kong, the American Society for Testing Materials (ASTM) has developed numerous testing regulations that may be suitable. Some of the standards relevant to Green Roofs include:

- WK575 Practice for Assessment of Green Roofs
- WK4235 Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roofs
- WK4236 Standard Practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems
- WK4237 Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roofs
- WK4238 Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roofs
- WK4239 Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Green Roofs
- WK5566 Standard Guide for General Principles of Sustainability Relative to Buildings

(30) [30] Oriental Daily, 25 September 2006

- WK7319 Standard Guide for Use of Expanded Shale, Clay or Slate (ESCS) as a Mineral Component in Growing Media for Green Roof Systems.

4.1.29 A more established green roof standards publication is the *Guideline for the Planning, Execution and Upkeep of Green Roof Sites*, provided by the FLL (*Landscape Research, Development & Construction Society)* in Germany. This guideline was initiated by the German *Ministry of Planning, Building Construction and Urban Areas* who gave the FLL the responsibility of researching cost effective methods for extensive and simple intensive green roofs. The guidelines were first published in 1990 and were revised in 1995 and 2002 to incorporate latest technologies. It is now widely accepted as a technical standard and is regularly referred to by the German DIN Standard. It covers the following topics:

- Waterproofing;
- Structural Loading;
- Protection against root penetration;
- Protection against mechanical damage;
- Protection against corrosion;
- Joints and borders;
- Protection against emissions (such as on vent buildings);
- Wind loads;
- Fire Protection;
- Protection against slipping and shearing;
- Trafficable paved surfaces;
- Landscape furniture (trellises, pergolas, lighting, ponds, etc);
- Working layers: soil substrate, filter layer, drainage layer, protection layer, root barrier, separation layers, anti-bonding layers;
- Construction techniques;
- Water retention (maximum water capacity, water permeability, discharge co-efficient, etc.);
- Water storage and additional watering;
- Drainage Layer (materials and types, physical requirements, granule size, structural stability, behaviour under compression, water permeability, pH, carbonate content, salt content and construction);
- Filter Layer (materials and types, physical requirements, weight, cut-through strength, filtration effectiveness, susceptibility to root penetration, weathering, resistance to soil-borne solutions and micro-organisms, tensile strength, flexibility, frictional co-efficient, and construction);
- Soil substrate (materials and types, physical requirements, granule size, organic content, structural stability, behaviour under compression, water permeability, water storage capacity, air content, pH, carbonate content, salt content, nutrient content, weed content, foreign substances, and construction);
- Application of Vegetation;
- Erosion Protection;
- Final care and readiness for handover;
- Subsequent upkeep and maintenance
- Warranties and periods of limitation;
- Testing and monitoring methods; and
- Reference Values for design loads.

4.1.30 There are currently no existing British Standards for Green Roofs but the Construction Industry Research and Information Association (CIRIA) is due to produce a *Building Green* report in late 2006[31]. (CIRIA is a not-for-profit organisation whose mission is to improve the performance of all concerned with construction and the environment. This UK organisation works with industry to develop and improve practice, leading to better performance by creating, sharing, and supporting the application of information and knowledge across four research themes.)

Percentage distribution of green roofs in Hong Kong and Southeast Asian cities

4.1.31 It appears that no information exists on the percentage distribution of green roofs in Hong Kong.

4.1.32 In Shanghai green roof coverage has increased from 120 000m² to 450 000m² from 2003 to the end of 2005. Early research in Shanghai shows that a room temperature difference of 2°C can be expected in the top floor of any building. This research states that other studies have found room temperature differences of 4-5°C.[32] Currently about 100 green roof projects are being built in Shanghai[33].

4.1.33 To improve its image during the Olympics, Beijing is sponsoring ¥100/m² for green roofs on buildings close to olympic venues. Beijing is aiming to achieve 300,000m² coverage per year. Other reports[34] say that Beijing is hoping to cover 40,000,000m² for the 2008 Olympic Games. It is estimated that 60% of low-rises and 40% of high-rises could be covered.

4.1.34 Chengdu has so far been the most successful green roof city in China with 2 000 000m² already covered.

Conclusion

4.1.35 It should be noted that the above-mentioned standards, incentives and regulations for private and public application of green roofs vary greatly. They depend on a city's context, social values and individual case settings. The International policy approaches quoted above have arisen from their own background of social or environmental needs such as storm water management in Germany. In Hong Kong, thorough investigation into community cost and benefits are required before evaluating the need for, and direction of, policy and regulations.

4.2 REVIEW OF APPROACHES TO GREEN ROOFS IN HONG KONG

Policies in Hong Kong

4.2.1 Existing HKSAR government policies and standards influence the creation of intensive green roofs in the public and private sector in both direct and indirect ways.

Government Policy on Green Roofs for Public Buildings

4.2.2 The Government's greening policy is to uplift the quality of the living environment through active planting, proper maintenance and preservation of trees and other vegetation. The target is to bring about noticeable improvements in urban greenery, to enhance existing greened areas, and to maximize greening opportunities during the planning and development of public works projects. In this regard, the Government's latest Policy Address[35] reads that "The Government will adopt the concept of greening of rooftops whenever practicable in the design of new buildings. We are studying the wider application of the concept with a view to encouraging more projects to adopt this approach."

(31) [31] CIRIA http://www.ciria.org/buildinggreener/guidance_introduction.htm

(32) [32] ZHAO Ding-guo & XUE Wei-cheng (2005)

(33) [33] Oriental Daily, 26 September 2006

(34) [34] Positive News (Hong Kong Edition), Winter 2006 and http://www.msnbc.msn.com/id/7911618

(35) [35] Paragraph 55 of the Hong Kong Policy Address 2006-2007 http://www.policyaddress.gov.hk/06-07/eng/p52.html

4.2.3 ArchSD has taken an active role in support of the greening policy and is targeted to provide roof-top greening as far as possible to all new government building projects subject to the consent of the client departments undertaking the after-care requirements.

4.2.4 Currently, ArchSD is undertaking this study on “Green roof application in Hong Kong”. The objective of the Study is to conduct a quick review of the latest concepts and technology on green roofs and to recommend guidelines adapted to suit local applications in Hong Kong to promote public understanding and awareness.

Government Incentives to the Private Sector

Joint Practice Note No.1: Green and Innovative Buildings (JPN1)

Joint Practice Note No.2: Second Package of Incentives to Promote Green & Innovative Buildings (JPN2)

4.2.5 JPN1 (Feb 2001, revised Oct 2004) and JPN 2 (Feb2002, revised Feb 2006) are designed by Government to protect and improve the built and natural environment by promoting the construction of green and innovative buildings. ‘Green’ in this context refers to wider environmentally friendly considerations, rather than vegetation.

4.2.6 The objective of the JPNs is to encourage the design and construction of buildings that encompass the following features:

- adopting a holistic life cycle approach to planning, design, construction and maintenance;
- maximising the use of renewable resources and recycled / green building material;
- maximising the consumption of energy, in particular those non-renewable types; and
- reducing construction and demolition waste.

4.2.7 The JPNs set out the initial incentives that Government is providing to encourage the incorporation of these features, and give guidance on how to apply for them under the Buildings Ordinance, the Lease Conditions and the Town Planning Ordinance, as appropriate. Government’s intention is that the list of features is continuously reviewed and expanded to keep pace with ongoing development of green buildings.

4.2.8 The mechanism by which JPN1 and JPN2 promote certain ‘green features’ is by setting the criteria and conditions under which these features may, upon application, be exempted from Gross Floor Area (GFA) and Site Coverage (SC) calculations under the Building Ordinance, Lease Conditions and TPO, with resultant economic benefit for the developer. ‘Communal Sky Gardens’ and ‘Communal Podium Gardens’ are listed among the green features to be exempted. JPN1 refers to residential developments and JPN2 refers to commercial developments.

4.2.9 However, the adoption of the incentive to include sky gardens has been relatively limited. The statistics illustrating achievements since the issue of Joint Practice Notes on promotion of green buildings indicate that between March 2001 and May 2005, only 19 out of 208 approved buildings plans provided sky/podium gardens, while 191 and 130 came with balconies and utility platforms respectively. It is surmised that the latter two were perceived by property buyers as usable areas, being private not communal, and thus more popular.

Practice Note for Authorised Persons and Registered Structural Engineers No. 116 – Amenity Features (PNAP116)

4.2.10 The purpose of PNAP116 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; encourage efficient and effective building management; obviate the desire or temptation for unauthorised building works; and improve the environmental compatibility with the neighbourhood.

4.2.11 The provision of podium roof gardens and play areas is encouraged in PNAP116. Where these facilities are under and within the perimeter of a domestic tower, they will be considered for exemption from GFA calculations.

Indirect Encouragement of Green Roofs in the Public and Private Sectors

4.2.12 The provision of public and private open space in Hong Kong is regulated in accordance with HKPSG, town plans gazetted under the TPO and private lot Lease Conditions. The HKPSG are non-statutory guidelines, while the requirements of Lease Conditions and town plans are statutory.

4.2.13 Since there is very limited space available for the creation of such open space at grade, it is sometimes the case that both Government and the private sector achieve the required open space provision through the creation of intensive green roofs at podium level.

4.2.14 However, although many intensive green roofs have been provided at podium deck level, relatively few have been provided at other levels of Hong Kong buildings.

Current Green Roof Construction Practice in Hong Kong

4.2.15 Intensive green roofs (roof gardens) are a well established phenomenon in Hong Kong, usually as landscape podiums in residential complexes. Many public open spaces are also built either wholly or partially on structure (e.g. Harcourt Garden). The abundance of roof gardens in Hong Kong is a direct response to the interaction of several factors, which include:

- Hong Kong's dense urban environment and lack of space for passive and active recreation at ground level;
- a market-driven desire for attractive landscaping of residential and, to a lesser extent, commercial developments; and, perhaps most importantly,
- requirements in Town Planning Conditions and Lease Conditions for private sector property developers to provide minimum standards of passive and active open space provision and landscaped amenity within private property developments, which available space within the development often dictates must be located on structure to a greater or lesser extent.

4.2.16 Extensive green roofs on the other hand, are notably absent in Hong Kong presumably because:

- there is no direct government requirement or industry incentive in Hong Kong for private developers to build extensive green roofs; and
- the constraints of building extensive green roofs are perceived by property developers to outweigh the benefits.

4.2.17 Apart from environmental and amenity benefits, Intensive Green Roofs provide what Hong Kong needs most - valuable functional open space for human use. It is therefore not surprising that Hong Kong already has as high a percentage of intensive green roof coverage as any other city. Extensive Green Roofs, on the other hand, are limited in that they are used overseas mostly to improve the environment and for building efficiency. Their popularity has yet to catch on in Hong Kong.

4.3 LOCAL ISSUES, CONCERNS, AND RESEARCH

Research on Intensive Green Roofs in Hong Kong

4.3.1 There does not appear to be any detailed organised research done locally into intensive green roofs – neither into their construction technology, nor into attempting to quantify the benefits derived from them.

Research on Extensive Green Roofs in Hong Kong

Gammon-Skanska / University of Hong Kong / Chinese University of Hong Kong

4.3.2 A small research project was initiated in 2004 by Gammon-Skanska (G-S) and is being conducted and monitored by Dr. Sam C.M. Hui, a Building Science Researcher at The University of Hong Kong (HKU), the environmental engineers at G-S, and latterly also Professor Chiu Siu-wai of the Chinese University of Hong Kong (CUHK).

4.3.3 The project was initiated by G-S through a desire to moderate the temperatures inside their many site offices located throughout Hong Kong, thereby creating more comfortable offices for their staff and providing energy savings. After discussing potential technologies (solar panels, specialised ceramics, green roofs etc.), G-S and Dr. Hui determined that green roofs would likely be the most successful.

4.3.4 The experimental green roof was installed on the sloping roof (approximately 25° degrees) of a G-S site office in Tsing Yi (see ***Figure 4.1***) and was designed to be lifted and re-used elsewhere. The growing trays are 200mm deep and include a formula of Light Expanded Clay Aggregate and Pumice. Traditional *Sedum* species were planted at first but these did not do well and were quickly invaded by unsightly weeds. Consequently, a slow-growing lawn grass species was then planted which has proven far more successful. With sufficient irrigation (lightly, twice per day with a tap operated drip irrigation system), growth has been thick and lush and has effectively blocked out invader weeds. Currently, one side of the roof is being maintained in a neat and tidy condition with irrigation, the other side is being allowed to develop naturally with no irrigation.

Figure 4.1 Extensive Green Roof Research Project by Gammon-Skanska

Early photos of original Sedum planting before subsequent invasion by grasses and weeds.
(Source and copyright © Gammon-Skanska, 2004)

Recent photos showing one side covered in lawn and the other left to its own resources.
(Source and copyright © Gammon-Skanska, 2006)

4.3.5 No research papers have been published yet by HKU, but the interim findings have demonstrated that the energy savings have been worthwhile. Sound insulation tests have also shown a marked improvement. According to Dr Hui, this experiment, although showing beneficial results pertaining to unique site office conditions can not readily be extrapolated into usable data for common building conditions. The reasons for this include:

- ♦ The site office has a built-in skylight which is not a good thermal insulator and distorts the mitigating effects of the green roof.
- ♦ The irregular behaviour of people within the site office greatly affects the readings. This includes how many people are active within the office, what machinery is operating, and how often doors are opened and closed.
- ♦ The metallic roof of the site office has characteristics very different to conventional roofs.

4.3.6 CUHK started monitoring the ecological value of the roof in summer 2005. CUHK have noted the colonisation of the 'natural' side of the roof with 20 plant species, and it seems to be developing its own ecosystem, attracting a lot of insects which CUHK are monitoring.

4.3.7 CUHK intend to produce a paper summarising their observations. CUHK believe that several of the invasive species offer potential for wider use in extensive roof gardens. CUHK also believe that they may be able to formulate a substrate suitable for use on extensive green roofs in Hong Kong.

4.3.8 As a result of the research project, G-S is internally promoting the use of green roofs on their site offices. However, the decision whether or not to install a green roof on any specific site office is made by project managers on a project specific basis. This is because of the varying types of site offices (sometimes steel containers are used) and the varying lengths of time that they would be in commission. From a purely commercial standpoint, site offices in commission for short contract periods would not recoup enough savings in energy costs to compensate for the initial fixed installation costs. The G-S site office has recently been short-listed for a Green Building Award (2006) by the Professional Green Building Council Hong Kong (PGBC) in the Research and Planning Section award category.

<u>CLP / University of Hong Kong</u>

4.3.9 CLP has also begun its own research into the benefits of green roofs which may prove effective, especially for the cooling of its power substations (the first being installed at Sham Shui Po substation). CLP has collaborated with Prof. Jim of the University of Hong Kong who has initiated his own experiments at Hong Kong University. This green roof, shown below in **Figure 4.2**, uses different substrate depths and species as part of its ongoing experiments. The research data gathered from this recently installed green roof will only be available in months to come.

4.3.10 The site was divided into 3 study areas, each approximately 6m x 6m (total approx 108m^2). The first area uses a lawn grass, *Zoysia japonica.* The second area uses a common low ground cover, *Arachis pintoi* The third area uses a common shrub, *Duranta repens.* The growing substrate consists of a lightweight moisture reservoir 40mm thick with standard topsoil above (of varying levels for the grass, groundcover and shrubs). Irrigation is achieved by a simple sprinkler system - 3 heads connected to a new rooftop water-point with a simple automatic timer attached. Irrigation is done every day, weeding about once per month and fertilizing four times per year. Systems for integrating dissolved fertilizer into the irrigation system are currently being explored.

4.3.11 Each area has place for controlled weather and temperature monitoring equipment which measures among other things the roof-temperature above, within and below the green roof. The findings from this research will probably become the most accurate and relevant readings for Hong Kong to date. Research so far shows a dramatic difference in roof temperatures during August, as shown below in **Table 4.3.**

Figure 4.2 Green Roof Research at University of Hong Kong

Before (June 2006) & After (August 2006) photos of experimental green roof at University of Hong Kong.
(Source and copyright © Cheung Shing Yuk Tong Co., Ltd., 2006)

Table 4.3 Green Roof Temperature Measurements at the University of Hong Kong

Date	Max. Air Temp	Tiled Roof Surface Temp.	Roof Temp Below Duranta repens.	Roof Difference
2006-08-01	31.91°C	52.72°C	26.52°C	26.20°C
2006-08-09	32.70°C	46.83°C	28.68°C	18.15°C

(Source: Oriental Daily 25 September 2006)

Green Roofs on Bus Shelters

4.3.12 In January 2003 a bus shelter green roof feasibility exercise was conducted by First Bus Ltd. The green shelter was installed in Causeway Bay and used common amenity species in a shallow growth medium (165mm thick) of CDG, crushed clay brick and topsoil. The green roof was unfortunately removed at the end of the experiment. No maintenance was required in the brief months after installation which occurred during the rainy season. It was predicted that future bus shelters would require watering during the dry season using mobile tanks (bowsers) or hand operated pumps. Interest in tram shelter greening has followed on from this experiment and is under discussion between numerous parties.

Figure 4.3 Green Roofs on Bus Shelters

Before and After (June 2003) photos of bus shelter green roofs experiment in Causeway bay.
(Source and copyright © John YAU (Chun Wang), 2003)

Green Roofs at Kadoorie Farm & Botanic Gardens

4.3.13 Construction of a green roof on a Kadoorie Farm wing began in April 2002 and was completed in July 2002. Its growing medium (approx. 150mm thick) uses a mixture of CDG, crushed clay brick and topsoil.

4.3.14 The example at Kadoorie Farm uses *Zoysia japonica* grass and is reported to be reasonably successful with some maintenance. A drip irrigation system was installed on the roof and is used regularly. Grass requires cutting and weeding by hand to stay neat and tidy (once per month in summer and every second month during winter). Drains are checked every month.

4.3.15 The Farm will continue its investigations and studies into green roofs and has expressed willingness to co-operate in research to determine suitable species for Hong Kong.

Figure 4.4 Green Roof at Kadoorie Farm

Before (April 2002) and After (July 2002) photos of a green roof at Kadoorie Farm.
(Source and copyright © John YAU (Chun Wang), 2002)

Green Roofs at EMSD Headquarters Building

4.3.16 In 2006, EMSD have undertaken some research into the thermal performance of green roofs on the retro-fitted green roof at the EMSD Headquarters building in Kowloon Bay. The results were recently published by the Energy Efficiency Office of EMSD [36] and indicated that:

- The surface temperature of a vegetated area can be about 10°C to 15°C lower than that of a concrete roof on a sunny day (results taken during Autumn/Winter, 5 November 2006 and 3 December 2006).
- The thick roof structure of the EMSD Headquarters building (550mm thick, including the 150mm concrete slab) insulates the rooms below from solar energy, and its heat storage capacity makes it an effective thermal buffer (results applicable for Autumn/Winter).

Other Greening Studies Related to Local Application of Green Roofs

Sustainable Design

4.3.17 Buildings Department has recently begun a related study, *Consultancy Study on Sustainable Design in Hong Kong (Agreement no. BA/01/2006)*. The consultancy study is one of the follow-up initiatives after *The Report on the Engagement Process for a First Sustainable Development Strategy (2005)* and *A First Sustainable Development Strategy for Hong Kong (2005)*.

4.3.18 The study objective is to review how new building design can promote more sustainable urban living

(36) [36] Report on Thermal Performance of Roof Green Features at EMSD Headquarters Building, Energy Efficiency Office, EMSD December 2006

space in Hong Kong. According to the inception report of the consultancy study, the study would focus on site/neighbourhood amenities at an area outside the building envelope and within the site boundary. Lack of urban greenery is one of the generic problems to be addressed.

4.3.19 The Study's most current task is the review of local legislation & practices and research on overseas requirements & practices. At this stage, the effectiveness, deficiencies and constraints of related local and overseas requirements and practices are being studied.

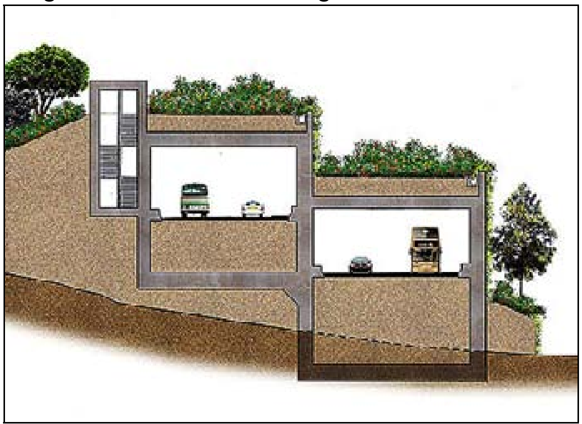
Greening of Highways Structures

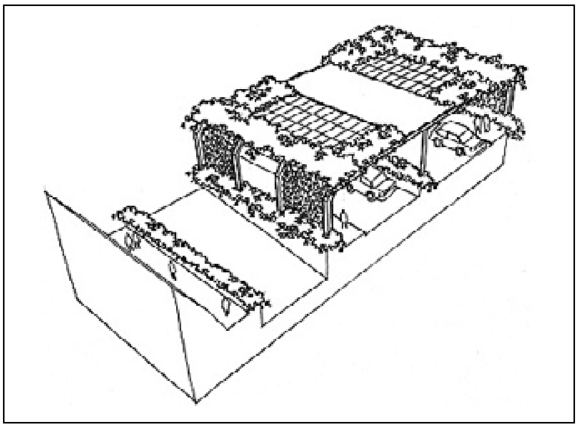
4.3.20 Highways Department is currently engaged in a related study, *Agreement No BSTR 1/2006, Investigation Study for Greening of Highway Structures*, which looks at different methods for greening and retrofitting highways structures, including vertical greening, parapet greening & green roofs. The study is expected to be completed by end 2006.

Greening of Noise Barriers

4.3.21 Highways Department has recently completed another related study, *Agreement No HMW 1/2005 (EP), Investigation Study for Greening and aesthetic Design of Noise Barriers*, which covers aspects of aesthetic design of noise barriers as well as greening. It covers green roofs briefly as part of the possible treatments for noise enclosures and partial noise enclosures. One of its case studies highlights an elaborate mountain-side cut-and-cover noise enclosure by CEDD on Route 8, Sha Tin Heights.

Figure 4.5 Roof Greening of Noise Enclosures





(Source and copyright © Urbis Ltd., 2006)

News Media Topics: Green Roofs versus At-grade Landscaping

4.3.22 Green roofs have been the subject of some recent public discussion in the press[37]. Three main viewpoints have been expressed by the public, namely:

- that greenery at ground level which is lost to development should be re-provisioned to some extent by green roofs on the developments;
- that green roofs nevertheless should not be considered a satisfactory substitute for the provision of the open space stipulated under Hong Kong's town planning guidelines; and
- that green roofs should not be used as an means or excuse for increasing densification of urban development

(37) [37] SinTao Daily, Apple Daily, Oriental Daily and others (see the Bibliography)

Intensive Green Roofs

4.3.23 Intensive green roofs can in some cases serve the same or similar purposes as gardens and open space at ground level and their increased development in Hong Kong is to be encouraged.

4.3.24 However, intensive green roofs should not be considered as substitutes for ground level open space. There are several reasons for this, as follows:

- Certain types of open space require very large continuous landscape areas which would be very difficult and expensive to provide as a green roof.
- Although not impossible, it is very difficult and expensive to achieve significant naturalistic earth mounding on green roofs, which therefore cannot achieve the same natural landscape character as can be created at grade.
- Trees which grow to large sizes (20m and upwards) require very large soil volumes to grow to their full potential height. Although it is normal practice in Hong Kong to provide adequate soil volumes for 'average' tree growth, it would be prohibitively expensive to provide sufficient soil for all tree species to reach their full height potential. Therefore, in this respect, green roofs have limitations - trees planted on green roofs can never fully substitute for ground level tree planting, and similarly open spaces created on roofs cannot achieve the same landscape character as certain types of open spaces created on grade.
- Green roofs, if elevated, may be less easily accessible to the general public, less easy to integrate with adjacent land uses, and therefore less used and less seen. (On the other hand, depending on local circumstances, green roofs may present opportunities for creating high level linkages between adjacent developments that may not be possible at ground level due to severance by roads.)

4.3.25 Intensive green roofs present great opportunities to create landscape spaces where there is simply not enough space to create ground level landscape. However intensive green roofs should be considered as being complementary to ground level open space, not as a substitute for it.

Extensive Green Roofs

4.3.26 Extensive green roofs serve different purposes from at-grade landscape and intensive green roofs, and cannot act as a substitute for either at-grade landscape or intensive green roofs.

4.3.27 Extensive green roofs provide a potential opportunity for new greening in Hong Kong that can complement and significantly add to the greening provided by at-grade landscape and intensive green roofs.

News Media Topics: Maintenance and Hygiene of Green Roofs

4.3.28 Articles referring to potential hygiene negatives associated with extensive green roofs have also been mentioned in the press[38]. In this regard, it should be noted that research (by CUHK at the Gammon-Skanska site office) only shows how *pioneer species* might rapidly colonise a derelict roof. Levels of bacteria or insect populations are measured in a state of transition and do not necessarily reflect what might be expected when a natural balance of *climax-community species* is achieved, or when a well-managed horticultural green roof is established and maintained. However, the point that green roofs, if not planted incorrectly or left completely unattended may produce unfavourable conditions, is a concern worth noting.

(38) [38] Ming Po, 13 October 2006 (Hong Kong newspaper). This article refers to the experimental research done by CUHK on the Gamman-Skanska site office where one side of the roofs has been left to grow wild for ecological study. The article reports on the estimated 30%-40% energy savings of this particular green roof but highlights other potential hygiene negatives. CUHK have distanced themselves from the conclusions and implications drawn by Ming Po.

4.4 CLIMATIC & ENVIRONMENTAL FACTORS INFLUENCING GREEN ROOF DESIGN & CONSTRUCTION IN HONG KONG

4.4.1 The local climate and environment have an important role to play in the design of green roofs in Hong Kong.

Wind

4.4.2 Typhoons can cause serious damage to plants, particularly trees. Trees on green roofs need to be well secured, particularly during establishment, to ensure that they do not blow over and cause damage. Trees also cause additional wind loading on structures and green roof systems.

4.4.3 Trees will grow only as much as the soil volume allows, and consequently trees of the same species tend to grow to smaller sizes on green roofs, where normally smaller soil volumes are available than at grade. Nevertheless, tree pruning regimes need to be adopted for trees on green roofs to ensure that they do not grow so large as to pose a safety hazard during high winds.

4.4.4 The dense high-rise nature of Hong Kong's urban areas can create shelter at the podium deck level, although this can also create problems if breezes cannot carry away localised air pollution from vehicles. Conversely, high rise buildings can also create localised wind gusting problems due to strong down-draughts sweeping down building facades onto podium decks.

Rainfall

4.4.5 Hong Kong's climate is characterised by high rainfall between April and September (wet season) and low rainfall between October and March (dry season). Consequently this means roof designs must be capable of shedding excess water in the wet season and retaining water in the dry season.

4.4.6 Much of Hong Kong's natural hillside vegetation turns brown or yellow brown during the dry season, and ecological style planting on extensive green roofs in Hong Kong might naturally do the same. However, as noted in **Section 2.3.25**, this may not be well received by certain sectors of the general public.

4.4.7 Green roof systems must also be able to hold water without creating pools of stagnant standing water which would encourage mosquito breeding and create a health problem.

Temperature

4.4.8 It is important to realise that the extensive green roof techniques gaining popularity throughout the world, particularly in the cooler climates of Europe and North America, cannot be immediately transposed to the warmer climates of Hong Kong without adjustment.

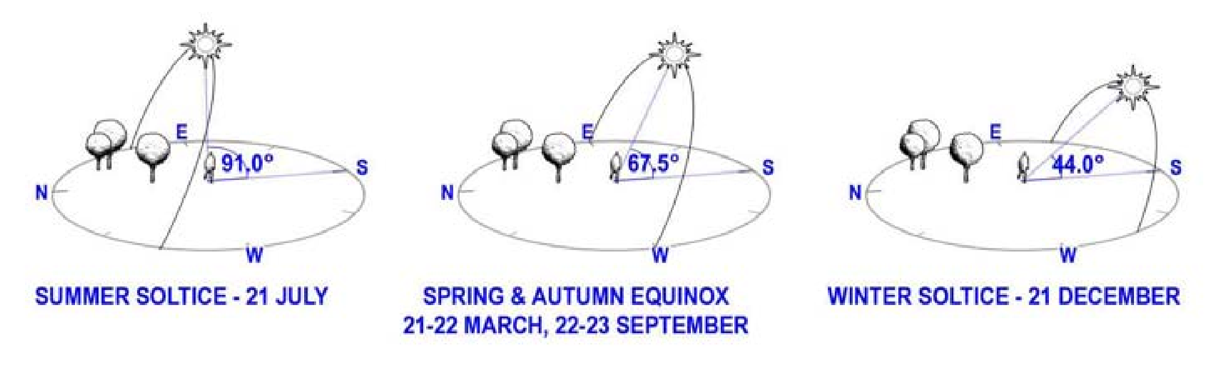
4.4.9 The reasons for this are several-fold:

- Extensive green roofs have been developed in Germany using low-maintenance alpine-meadow vegetation, mostly Sedums. These species are temperate climate plants not well-suited to Hong Kong's sub-tropical conditions, particularly the higher temperatures.
- Hong Kong's high rainfall and high temperatures during its summer months enables vegetation to develop prolific growth rates. This results in higher maintenance requirements when compared with cooler temperate climates.
- The fast growth rate of local vegetation also means that it would generally out-compete Sedum-like species, making invaders on extensive green roofs a particular problem.

Shade

4.4.10 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. **Figure 4.6** below illustrates sun paths as a means for predicting shaded areas throughout the seasons.

Figure 4.6 Sun Paths for Hong Kong, Latitude 22°N



Altitude and Exposure

4.4.11 Temperature drops and wind exposure increases with height above ground level, and green roofs built on upper floors of the types of high-rise developments common in Hong Kong would be subject to more extreme weather conditions than those at lower levels, resulting in harsher growing conditions and less suitability for human use.

Suitable Plant Species and Substrate for Extensive Green Roofs

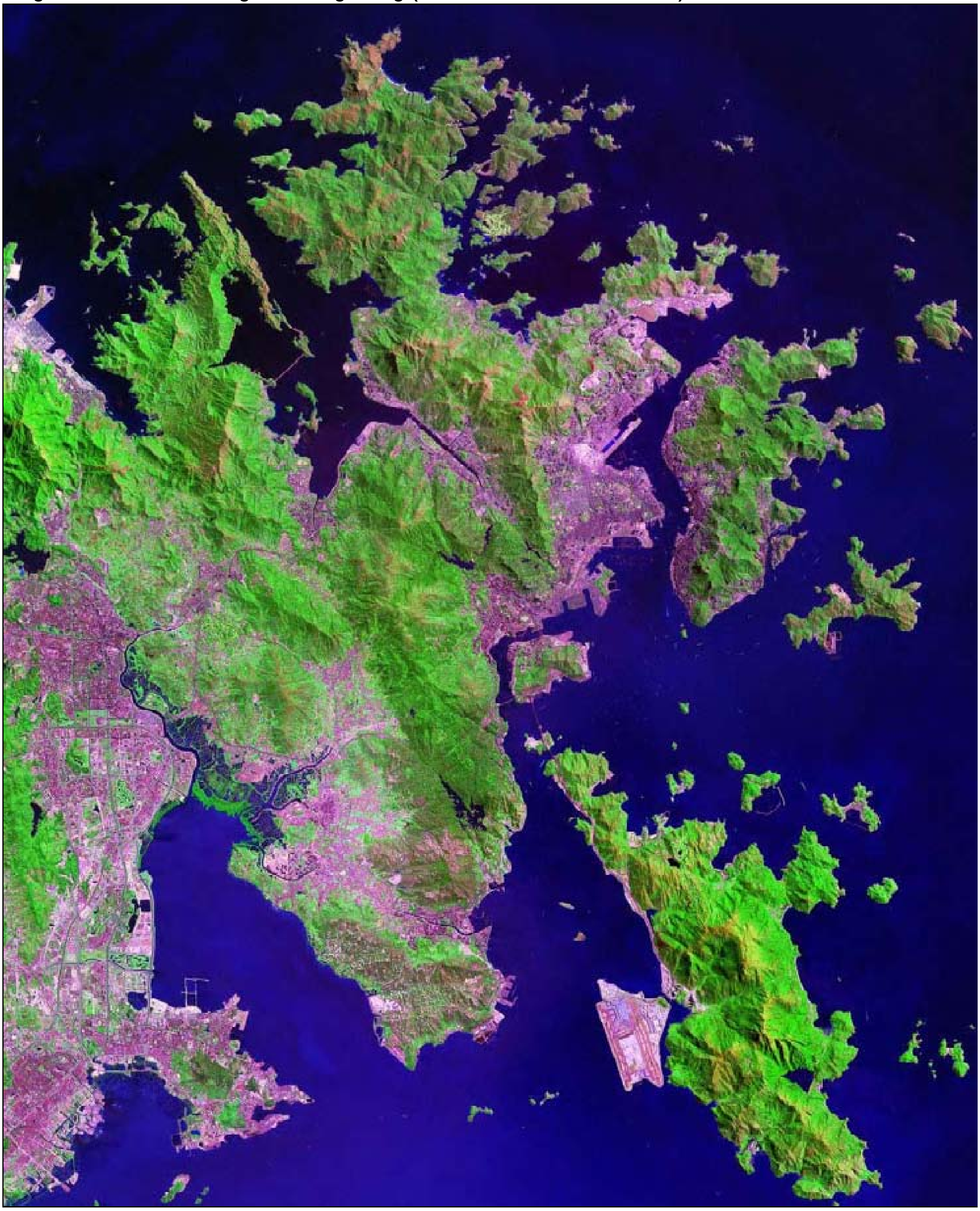
4.4.12 Identifying appropriate plant species that suit the local climatic and environmental conditions prevailing in Hong Kong, yet which possess the growth characteristics suited to extensive green roofs as exemplified elsewhere in the world, is critical to the success of extensive green roofs in Hong Kong.

4.4.13 Similarly, identifying a suitable substrate that encourages growth of desirable species but discourages undesirable species is also a key factor (*cf*. the infertile substrates used in European extensive green roofs encourage alpine sedums and discourage many weeds).

4.5 GREEN ROOF POTENTIAL IN HONG KONG

4.5.1 It is evident from the infra-red satellite image in **Figure 4.7** where the built up areas in Hong Kong are located. The hottest surfaces of the city show up as dark red-purple areas. Not surprisingly, it is the heavily trafficked city centre and industrial areas which show the strongest heat readings.

Figure 4.7 Landsat Image of Hong Kong (Shortwave Infra-red bands)



(Source and copyright © 2006, www.Geology.com, prepared by Angela King using data from NASA)

4.5.2 Photos illustrating the broad range of building types in Hong Kong are presented in Figures 4.8 to 4.14.

Figure 4.8 Green Roof Opportunities in the City (High Density)

Views from IFC, Central, looking East Towards Wanchai, Hong Kong Island
(Source and copyright © 2006 Urbis Ltd.)

Figure 4.9 Green Roof Opportunities in the City (Medium Density)

Views from IFC, Central, looking North towards Tsim Sha Tsui
(Source and copyright © 2006 Urbis Ltd.)

Figure 4.10 Green Roof Opportunities in Residential Areas

Village houses also offer opportunities for green roofing.

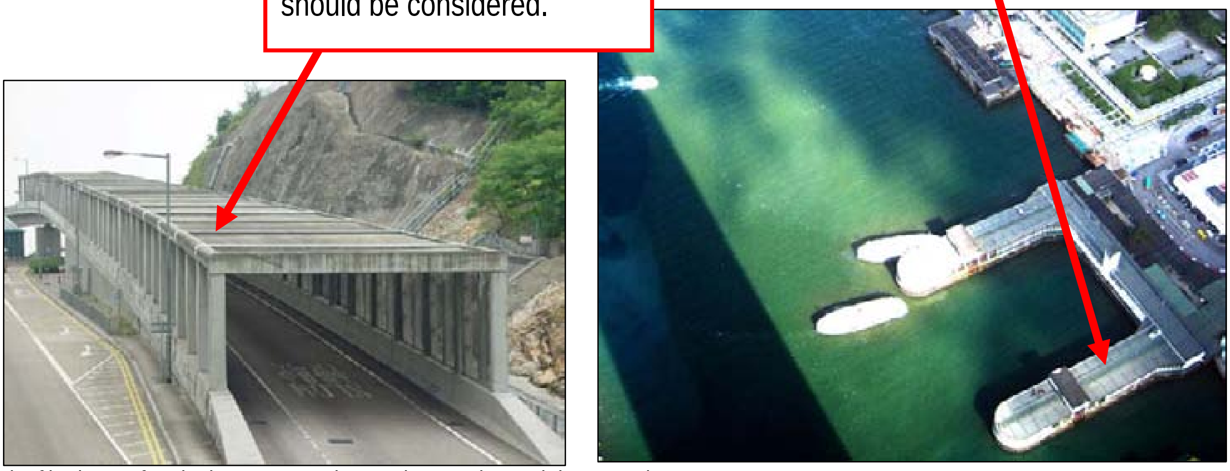
Large residential complexes offer space opportunities for green roofs. Regular heights allow for an environment without shadows which affects species choice.

Views from above Sai Kung, New Territories and Tai Koo Shing,Hong Kong.
(Source Source and copyright © 2006 Urbis Ltd.)

Figure 4.11 Green Roof Opportunities on other Structures

Noise enclosures offer good opportunities for green roofs, though sufficient sky-lighting should be considered.

Low-rise ferry piers are another prime location for visible green roofs.



(Left) Views of typical concrete noise enclosure. (Copyright © HyD).
(Right) Views from IFC looking at the Star Ferry Pier and Queen's Pier (Source and copyright © 2006 Urbis Ltd.)

Figure 4.12 Green Roof Opportunities on other Structures

Elevated footbridges, noise barriers, noise enclosures, pumping stations, electrical substations, warehouses, petrol stations and even bus shelters are feasible locations for green roofs.

(Left) Views from residential towers looking at DSD pumping station. In other rural areas, where the visibility of roofs is not significant, roof greening may not always be as cost-effective as at-grade planting. (Source and copyright © Urbis Ltd., 2006)
(Right) View of bus shelter in Causeway Bay. (Source and copyright © John YAU (Chun Wang), 2002)

Figure 4.13 Green Roof Opportunities on other Structures

Elevated footbridges and covered walkways offer numerous opportunities for green roofs. There are many of these in Hong Kong. Their highly visible location makes these structures an ideal location for green roofing.

(Left) Views illustrating covered walkways in Admiralty, Hong Kong Island. (Source and copyright © Urbis Ltd., 2006)
(Right) Views showing network of covered walkways connecting ferry piers near to IFC2, Central, Hong Kong Island. (Source adapted from GoogleEarth)

Table 4.4 – Building Types in Hong Kong

Building Type	Description	Rooftop Space avail. (H/M/L)	Need for Urban Greenery (H/M/L)	Recommendations
Old City Centre (Sheung Wan, Central, Admiralty Wan Chai, Causeway Bay) (See Figure 4.8)	Multiple level sky-rises (mostly offices) ranging from 10 to 40 storeys. Rooftops are often exposed and windy. Scenic views of city are common on some buildings. Rooftops are larger with less utilities and obstacles cluttering the area. Building owners can often afford green roofs or roof garden.	Low	High	Intensive Green Roofs are needed and should be promoted for all new buildings. Extensive Green Roofs should be promoted for existing buildings.
New City Centre (Kowloon) (See Figure 4.9)	Multiple level sky-rises (mostly offices) ranging from 10 to 50 storeys (max 80). Sun and shade is unpredictable and often shady on lower rooftops. Rooftops are often exposed and windy. Scenic views of city are common on some buildings. Rooftops are often cluttered with utilities and obstacles. Building owners can often afford green roofs or roof garden.	Medium	High	Intensive Green Roofs are needed and should be promoted for all new buildings. Extensive Green Roofs should be promoted for existing buildings.
CDA high-rises (See Figure 4.10)	New high-rises (residential or office blocks) ranging from 20 to 40 storeys with garden podiums levels below (5 storeys, mostly retail shops). Buildings are usually of a similar height making rooftop access to the sun constant (though podium gardens may often be shaded. Rooftops are often exposed and windy. Podium gardens can sometimes be vulnerable to down-drafts created by the building faces. Building owners can often afford green roofs or roof gardens.	Medium	Medium	The practice of installing Intensive Green Roofs on Podium Levels should be continued. Extensive Green Roofs should be promoted for all existing buildings.
Older Residential towers (See Figure 4.8 & Figure 4.10)	Older High-rise residential towers ranging from 15 to 30 storeys. Building owners can sometimes afford green roofs or roof gardens.	Medium	Medium	Intensive Green Roofs are needed and should be promoted for all new buildings. Extensive Green Roofs should be promoted for existing buildings.
Industrial buildings	Older buildings ranging from 10 to 15 storeys. Building sizes are often wider than other buildings. Building owners can sometimes afford green roofs or roof gardens.	High	Medium	Intensive Green Roofs and public accessibility should be promoted for all new buildings. Given the large areas available, Extensive Green Roofs should be actively promoted for existing buildings and for all non-accessible buildings.
Village Houses (See Figure 4.10)	Buildings range from 1 to 4 storeys. Building owners can sometimes afford green roofs or roof gardens.	Medium-Low	Medium-Low	Given the surrounding greenery, lower need for greenery and probable budgetary constraints, Extensive Green Roofs should be actively promoted.
Other Low-rise structures (See Figure 4.11, Figure 4.12, and Figure 4.13)	Covered Pedestrian Walkways and Footbridges, Covered roads and noise enclosures, vent buildings, power substations, stadiums, service reservoirs and pump houses.	High-Medium	High	Given the lack of accessibility to rooftops as well as the large areas available, Extensive Green Roofs should be actively promoted.

4.6 GREEN ROOF BENEFITS TO HONG KONG

4.6.1 An analysis of the benefits that Hong Kong might experience is presented in **Table 4.5.** (Also see **Sections 2.2 to 2.6**)

Table 4.5 – Benefits Applicable to Hong Kong

KNOWN GREEN ROOF BENEFITS	WHO BENEFITS?	HOW DO THEY BENEFIT?	HOW SIGNIFICANT IS THE BENEFIT?
AMENITY & AESTHETIC BENEFITS OF GREEN ROOFS			
Leisure and Functional Open Space	Public / Building occupants / Property Owners	Additional passive recreational space is added to the city where the public or building occupants can escape from the busy streets below. Property Owners may benefit from increased property prices	**High**
Visual Aesthetic Value	Public / building occupants / HK government	The city is more appealing to look at. The government gains from a better image of the city	**High** – but only if a significant number of visible roofs are covered.
Health and Therapeutic Value	Public	Therapeutic benefits of calming the observer.	**Moderate to High** – but depends on location.
Food Production	Roof Garden Grower	Food cost reductions and therapeutic value of gardening.	Low – not expected to run at any appreciable scale in the city centre.
ENVIRONMENTAL BENEFITS			
Air Quality	Public	Healthier air to breathe. Scenic visibility might be improved with a reduction of city smog.	**Moderate** – but only if large areas are covered
Reducing Urban Heat Island Effect	Public	Air-conditioning costs might be reduced (reduction in pollution associated energy production)	**Moderate** – but only if large areas are covered
Ecological and Wildlife Value	Wildlife	Habitat creation	Moderate to Low – depends on location and species used
Water Management	HK government / Wildlife	Potential costs on storm-water infrastructure can be reduced. Contaminated storm-water entering the ocean is reduced.	Moderate to Low – most locations in Hong Kong are close to the sea making storm-water infrastructure a relatively small issue for the city compared to other cities. Presence of Green Roofs is unlikely to change drainage engineers calculations
Sound Absorption	Building Occupants	Slightly quieter environment. (only 5dB)	Low – benefits are likely to be only on the top floors below the green roof and from noise from above.
ECONOMIC BENEFITS			
Building Insulation and Energy Efficiency	Building Occupants	Air-conditioning costs might be reduced by around 15%	**High** – though benefits are likely to be appreciated by upper floors only
Green Building Assessment & Public Relations	Property Owners / Developers / HK government	They benefit from an improved image of being environmentally friendly and sustainable	**Moderate** – (noted from Gammon-Skanska site office publicity). This benefit is equally applicable to Government's image.
Increased Roof Life	Property Owners/ Building Occupants	Property owners may derive roof cost savings but only if they intend to own and maintain the building in the long-term. This is not the case for most developers. Roof life costs are therefore a low incentive to developers.	Low – most developers in Hong Kong build to sell and would therefore not see the benefits gained years later. **Moderate** –for Government owned buildings this issue becomes more relevant.

4.6.2 It is clear from the above that Green Roofs offer distinct benefits for Hong Kong. Clear community benefits that would be enjoyed by the public include: increased public open space; increase visual amenity; improved air quality and a reduced urban heat island effect.

4.6.3 However, the direct financial benefit for developers and property owners is less easy to determine since although overseas data suggests that green roofs provide tangible financial benefits for the private sector, there is no hard data from local research to substantiate this in the local Hong Kong context.

PART 2

DESIGN & TECHNICAL GUIDELINES

5 GREEN ROOF SYSTEMS

5.1 ROOF TYPE SCENARIOS IN HONG KONG

5.1.1 In Hong Kong there are three main green roof scenarios – Sky Gardens, Podium Gardens (New Buildings) and Existing/Low-maintenance Buildings.

- Sky Gardens are found on top of any high-rise buildings (usually 20 storeys and above). Sky Gardens are usually designed as part of the building and may be **intensive or extensive green roofs** depending on usage.
- Podium Gardens are usually 2 to 5 storeys up forming the base of a residential or office tower. These gardens are usually intended for full access by the building occupants or the public and are therefore always **intensive green roofs.**
- Existing and low-maintenance buildings include existing office and residential towers and other buildings such as public infrastructure buildings. Due to weight constraints and the need for low maintenance **extensive green roofs** would generally be prescribed.

Figure 5.1 Roof Type Scenarios in Hong Kong

(Left) Sky Gardens (Source and copyright © EarthPledge, 2005)
(Centre) Podium Gardens, (Source and copyright © ArchSD, 2005)
(Right) Existing Buildings (Source and copyright © Urbis Ltd., 2006)

Table 5.1 Considerations for New Buildings and Existing Buildings

NEW BUILDINGS	EXISTING BUILDINGS
• Costs can be saved in the design stage, as part of the existing contract. • Roof slabs can be designed to take heavier soil depth loads. • Irrigation and water supply can be built into the roof from the beginning • Waterproofing can be part of the concrete roof slab rather than using a membrane tanking system (see **Section** 5.2.2). • Utilities can be arranged to maximise the green roof area. • Favourable marketing opportunities may arise from the inclusion of green roofs. • extended side walls to protect green roofs from excessive wind may be incorporated at the design stage • barrier-free access (e.g. elevators) can be incorporated into the design if public access is considered.	• Building requirements may limit growth medium depth. • The age and condition of the existing building and roof affects the feasibility of a green roof. • Installation of rooftop water points may be needed. • Installation of new drainage points may be needed. • Waterproofing needs to be considered as an additional layer. • Roof-top utilities placed in ad-hoc arrangements can limit the area of green roofs. • Access may be difficult and additional safety devices may need to be installed (Barrier-free access may be impossible to retro-fit).

Sky Gardens

5.1.2 As Sky Gardens are found on high-rise buildings, they will have unique factors influencing their design.

- Extreme growing conditions are often present. Wind is of particular importance and in some instances may rule out large trees. Conditions are also very exposed, enduring direct sunlight and temperature extremes. This may stunt the growth of some plants. Trees may be protected from high winds using wind screens. Structural anchorage as well as regular pruning of trees is important to avoid typhoon damage.
- Safety is always a concern on high buildings. Railings for safe access are essential. The potential for lightning strikes also needs to be considered
- Rooftop utilities are often located in positions that compete for space. It is essential to group rooftop utilities to maximise the space available for greenery. Refuge floor requirements are another building requirement that could potentially compete for space. Preserving panoramic views of the surrounding city is also an important factor affected by rooftop utilities.
- Water pressure at roof top locations may also be a problem which may require complex tanks and/or pumps. Possible access by the public is another issue.
- Hauling of materials and plants is a potential and expensive complication. Large trees are particularly difficult to move.
- Waterproofing is critical on any roof and should be protected continuously from damage during construction, and after establishment. Special leak detection systems may be installed.
- Critical plant selection is needed that includes non-invasive root systems and suits site-specific microclimates.

Figure 5.2 Sky Gardens

(Left: source and copyright © EarthPledge, 2005) (Right: source and copyright © Greenlink Küsters Ltd.)

(Left & Right: source and copyright © ArchSD, 2005)

Podium Gardens and Conventional Roof Gardens

5.1.3 Podium Gardens are usually 2 to 5 storeys high and are generally built for functional open space. As such numerous unique design issues need to be considered.

- Safety is always a concern on roof gardens that are intended for high public usage. Railings for safe access are essential and may even include wind screens or clear panel noise barriers made of PMMA (Polymethyl-Methacrylate) for a quieter experience (see Figure 5.3 below). Designs need to address the potential for creating mosquito problems. Playground equipment may be considered and needs to be designed with safety in mind. Structural anchorage as well as regular pruning of trees is important to avoid typhoon damage.
- Podium floors are also often designed as refuge floors which may compete for space.
- Waterproofing is critical on any roof and should be protected continuously from damage during construction, and after establishment. Special leak detection systems may be installed.
- Critical plant selection is needed that includes non-invasive root systems and suits site-specific microclimates. Podia are often very shady or receive full sunlight for brief periods during the day.
- Planting design needs to accommodate distant viewers who may look down onto the roof garden as well as the users of the garden. Variety, colour and scale of the planting design is therefore an important consideration.

Figure 5.3 Podium Gardens

(Left & Right: source and copyright © ArchSD)

(Left & Right: source and copyright © ArchSD)

Existing and Low-Maintenance Buildings

5.1.4 Existing and low-maintenance buildings are designed and retro-fitted primarily for environmental & building efficiency performance. Design issues usually revolve around loading, existing roof status, maintenance access and safety, soil depth, and successful low-maintenance species.

- <u>State of the existing roof</u> is critical. The allowable weight and safety margins need to be critically assessed. The loading for extensive green roofs ranges from 80 to 150 kg/m² though loading may occasionally allow for Intensive Green Roof components at some locations. The state of the existing waterproofing is another major consideration.
- <u>Waterproofing</u> is critical on any roof and should be protected continuously from damage during construction, and after establishment. Special leak detection systems may be installed.
- <u>Safety</u> for maintenance access also needs to be considered. This may take the form of additional railings, a clear gap away from the edge or safety harnesses.
- <u>Critical plant selection</u> is needed that includes plants that 1) do well in lightweight and shallow soils, 2) are wind tolerant, 3) are drought tolerant, 4) are pollution tolerant, and 5) have non-invasive root systems.
- <u>Growing media</u> generally needs to be 1) super light-weight, 2) inert, 3) well-drained, 4) well-aerated, 5) fire resistant, and 6) nutrient retentive. Despite being lightweight the growing media should provide adequate anchorage for all plants and also be resilient to wind erosion.

Figure 5.4 Existing and Low-maintenance Buildings


(Left: source and copyright © ArchSD) (Right: source and copyright © Greenlink Küsters Ltd.)


(Left & right: source and copyright © Greenlink Küsters Ltd.)

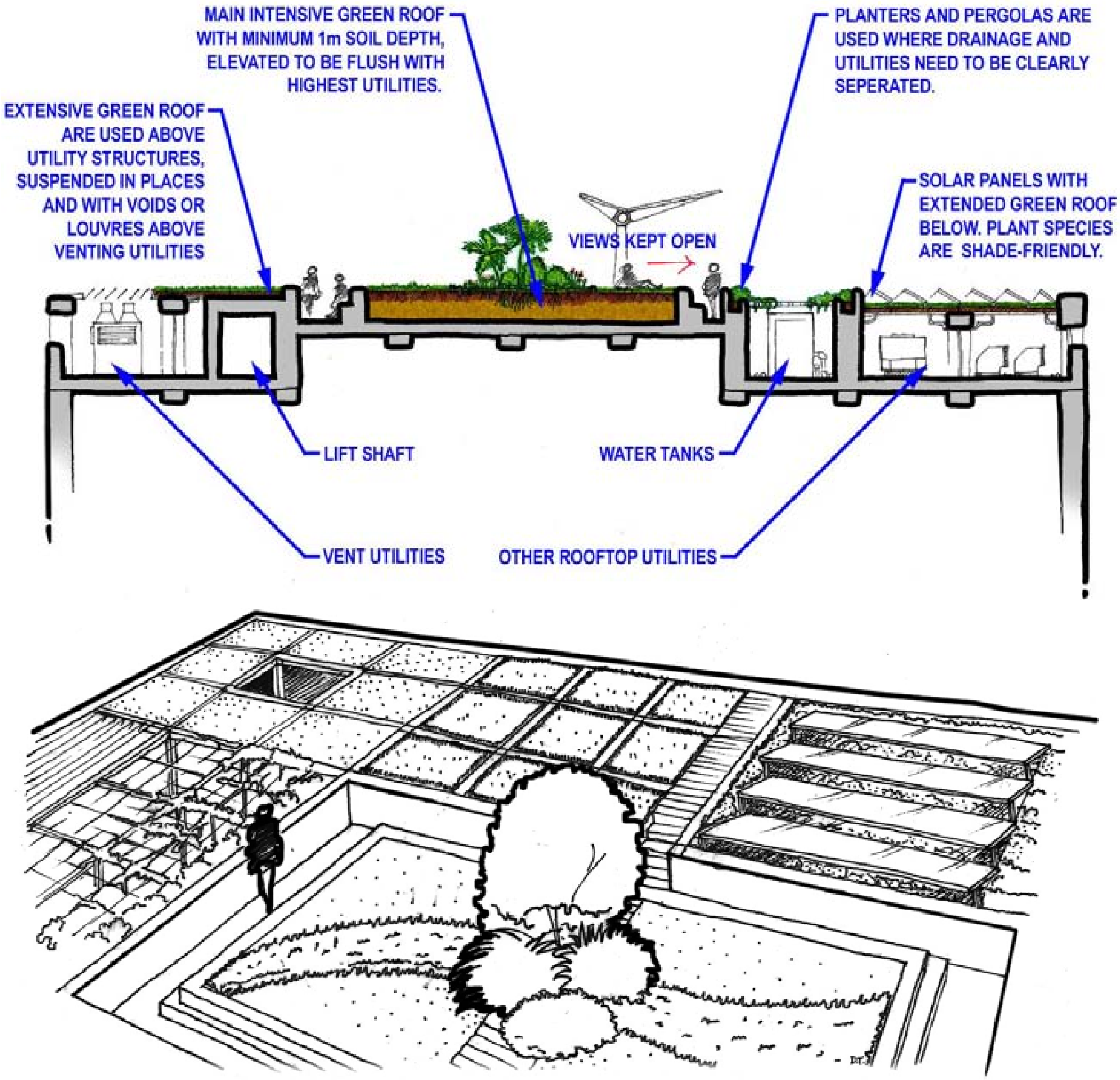
Utilities on New Buildings

5.1.5 Rooftop utilities can significantly influence the design, cost and eventual success of any green roof. Utilities on *extensive green roofs* can, if oddly placed, result in wastage of up to 30%. Rooftop utilities on *intensive green roofs* are even more important because they can significantly hinder the creation of user-friendly roof-top spaces.

5.1.6 The arrangement of rooftop utilities on all new buildings is therefore an aspect that should receive significant consideration during the early design phase of a building. This is particularly important in the Hong Kong context where tall finger-like buildings are largely cluttered with rooftop utilities.

5.1.7 The example in Figure 5.5 below shows how a variety of greening techniques (intensive and extensive), and a well thought-out use of level changes, can be adopted to achieve an uncluttered appearance. Users of the space are able to enjoy unobstructed panoramic views of the city – one of the few unique advantages that green roofs offer over at-grade greenery. Similar principles were followed at Roppongi Hills, Tokyo, as seen in Figure 3.7 and Figure 3.8.

Figure 5.5 Utilities on New Buildings



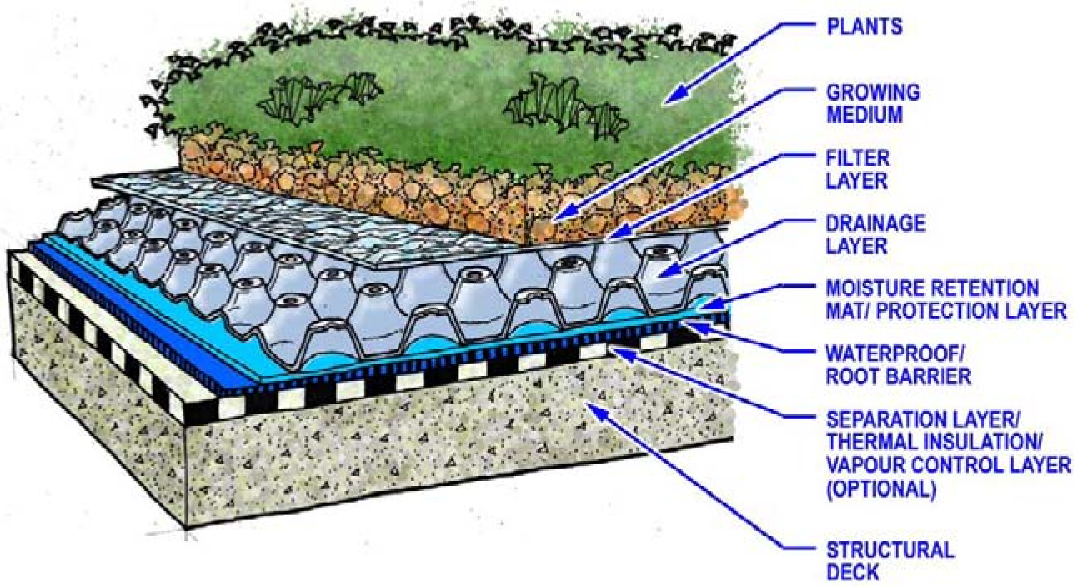
(Source and copyright © Urbis Ltd., 2006)

5.2 BASIC COMPONENTS

5.2.1 Green roofs are feasible on any properly designed roof deck, including steel, wood, concrete, plastic or composites, as long as the necessary structural considerations are met. The basic components of green roof systems are basically the same for intensive and extensive green roofs and are presented below in Figure 5.6 and Figure 5.7. Numerous specialised layers may vary from the illustration below and may cater for unique conditions such as steep slope scenarios. The basic functions of these systems include:

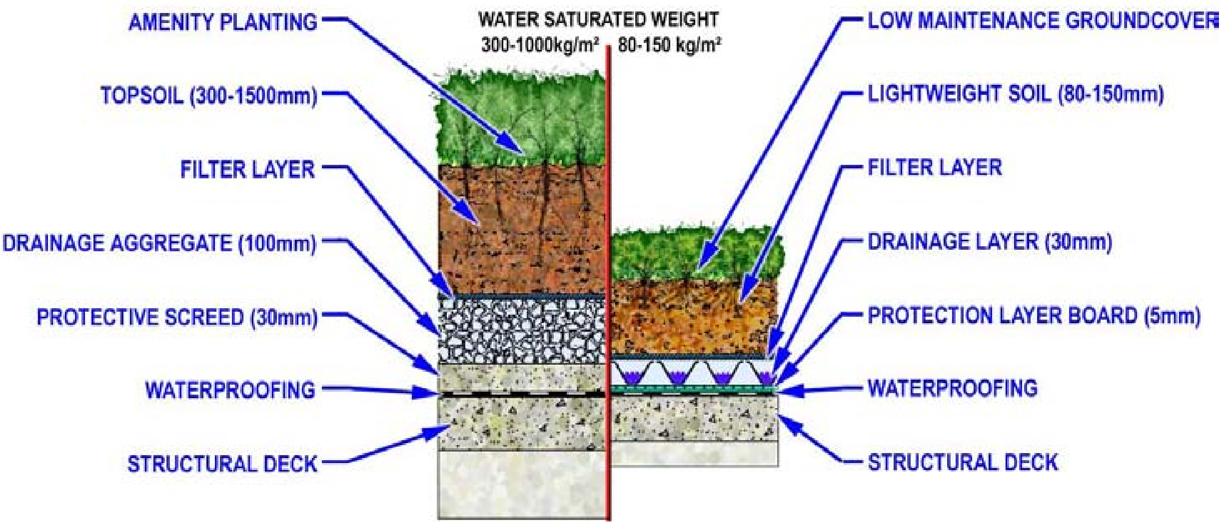
- weatherproofing the roof,
- protection of the roof surface from root penetration,
- drainage, and
- support and growth of the vegetation layer.

Figure 5.6 Basic Components of a Green Roof System (Intensive and Extensive)



(Source and copyright © Urbis Ltd., 2006)

Figure 5.7 Conventional (Intensive) and Lightweight (Extensive) Green Roof Systems



(Source and copyright © Urbis Ltd., 2006, Adapted from images from Greenlink Küsters Ltd.)
Note: Intensive green roof weights of 300-1000kg/m² refer to the most shallow soil depth needed for amenity groundcover or lawn grass (300mm). A soil depth conducive for successful tree growth (1500mm deep) is likely to weigh around 3300kg/m², excluding the weight and wind-loading pressure of the trees.

Waterproofing:

5.2.2 Waterproofing is arguably the most important pre-requisite of a green roofing system. For waterproofing to remain effective it must be root resistant over the long term and should fulfil the necessary standards (such as the German FLL standards). Alternatively, if the waterproofing is not root resistant then the *green roof system* must include a separate root barrier. Numerous waterproofing systems exist. These include:

- *Bitumen/asphalt roofing felt or bituminised fabrics*. These materials generally have a limited life span of 15 to 20 years and degrade from temperature changes and ultraviolet radiation (which are largely mitigated if greening is applied above). A separate root protection barrier must be applied with such membranes.
- *SBS modified bituminous membrane sheets set in SEBS polymer modified bitumen* and *coal tar pitch/polyester built-up systems.* These are a more robust system suitable for green roofs. However, they are only root resistant if a layer of copper is put inside the membrane or if it is treated with chemicals. This kind of waterproofing is commonly used in Europe for Intensive green roof application.
- *Fluid Applied Membranes*. These are available in hot or cold liquid form and are spray painted onto the surface. They do not suffer from jointing problems and are easier to apply vertically or to difficult shaped surfaces. Often a protection board (PVC sheet or expanded polystyrene) may be added above this layer. On flat roofs a layer of gravel, concrete slabs or sand may be added to protect the membrane from temperature fluctuations and UV radiation. (These gave rise to the observations of spontaneous plant colonization which sparked initial research on extensive roof greening in Germany.)
- *Single-ply roof membranes.* These membranes are rolled sheets (sometimes tiles) of inorganic plastic rubber material overlapped at the joints and sealed with heat, or with solvents if Ethylene Propylene diene monomer rubbers (EPDM) are used (requiring very clean and dry conditions). These membranes can be very effective if applied properly but are weakest at the seams between sheets and tiles. The PVC and butyl rubber are prone to UV degradation and should be covered at all locations. Thermoplastic polyolefins (TPOs) are also specified for green roof waterproofing and are often considered more environmentally acceptable. PVCs, EPDMs and TPOs are generally root-resistant. These kinds of membranes have a long proven track record in the green roof industry but rely on correct installation.
- *Concrete admixture water-proofing.* Concrete admixture waterproofing or *Hydrophobic Pore-blocking Ingredients* (HPI) are not well known in the green roof industry because they are applicable only to newly cast concrete roofs. From a construction and waterproofing viewpoint they perform better than PVC membranes and are generally cheaper too (see Table 8.2). With this system the concrete itself becomes permanently waterproofed in a more robust form which cannot be punctured, torn or damaged (a risk often associated with other waterproofing techniques when other sub-contractors are working on upper layers). Attachments to the roof slab (such as tree anchors) are also easy to install and do not form weak spots as they would through membrane waterproofing. However, when using HPIs it is important to find an admixture that; 1) is effective at limiting water-absorption, 2) has a long and proven track record, 3) is guaranteed for a long time and is guaranteed despite workmanship which may occur above the slab, 4) chemically does not break down over time, 5) does not leach out under pressure, and 6) does not compromise the performance of the concrete. Another type of concrete admixture is *crystal growth waterproofing* which works by growing crystals within the pores of the concrete matrix. It is best used as a concrete admixture when the concrete is being cast but can also be effectively used as coating which penetrates into existing concrete. As a coated waterproofing its effectiveness may be dependant on the type and porosity of the concrete used.

5.2.3 On new roofs the ideal is to double-waterproof the system using waterproofed concrete as well as a more flexible waterproofing layer above. Each waterproofing system has its own advantages and disadvantages but by combining the two systems far greater reliability is achieved. For example, although concrete admixtures are more robust and more repairable, the negative side of concrete waterproofing is that under certain conditions, where concrete expands and contracts, cracking is inevitable. These cracks would most likely be covered using a flexible system (PVC, etc). For existing roofs, where waterproofing the concrete system is impossible, it is still advisable that any levelling screed is also waterproofed.

5.2.4 On existing roofs it may be determined that the existing waterproofing is sufficient and that the green roof layers may be added without additional waterproofing. An assessment like this must be undertaken by a suitably qualified professional and/or the liability of failure removed from the green roof contractor's responsibility.

5.2.5 When using liquid or sheet membranes, attention needs to be given to the following locations where water leakage is often present[39]:

- *Right angled bends such as corners or at the junction between a roof slab & a parapet wall*: In these locations it is preferable to fix a triangular fillet prior to laying the membrane. This will form an obtuse angled junction, which is less likely to tear as a result of any subsequent movement that may take place, than a right angled one.
- *For the prevention of rising damp*: the membrane should be continued between 150mm & 300mm vertically up the side of a parapet wall at the perimeter of a roof, above the roof level & dressed into a horizontal groove & sealed. It should not just be stuck onto the side of the wall. The same principle applies to plinths & machine bases on the roof.
- *For pipe or service duct penetrations*: Carry any liquid waterproofing material up the side 150-300mm above the roof level. With sheet material, trim carefully around the base of the pipe & seal with a liquid applied sealant compatible with the membrane material. In some cases, suitable fasteners (such as jubilee clamps) may be used to secure the membrane to the pipe.
- *Where the parapet is made of block or brickwork, rather than concrete*: The waterproofing should be taken up the inner face of the parapet wall & beneath the coping on the top of the parapet. If this is not done, water will pass down through the brickwork & migrate behind the membrane at roof slab level.
- *Prevention of degradation*: The surface of the membrane may need to be covered with tiles, lightweight mortar screeds, or reflecting paint in order to prevent UV degradation & radiant heat absorption into the roof slab.
- *Surface abrasion tears*: Special care must be taken to ensure that waterproofing does not lie on a concrete/screed surface that is too rough. Expansion and contraction as well as the weight pushing the waterproofing onto this surface can cause punctures or abrasion holes. A separation layer is generally advisable.

Root Barrier

5.2.6 As mentioned above, a separate root protection barrier is needed if the waterproofing layer contains bitumen, asphalt, or any other organic material. It is important that this separation is continuous because any penetration of roots also provides access for micro-organisms which can actually attack these organic oil-based materials. Root Protection membranes are usually made of PVC rolls that are around 1mm thick. Intensive green roofs may need a far more robust root protection system capable of withstanding the penetration of tree roots. These are often thick hard plastic sheets or even metal sheets (usually copper) for exceptionally vigorous roots (such as from some Ficus trees or bamboos). For

(39) [39] Adapted from notes by Dr. Chris Stanley (May 2005, Hong Kong Concrete Repair Association).

extensive green roofs with limited rooting, a single layer of 0.4mm thick HDPE membrane can also be installed without welding as long as the overlap is at least 1.5m (FLL approved).

Protection Layer

5.2.7 Between the waterproofing and drainage layer a protection layer is often advised. This is usually a non-woven geo-textile that protects the waterproofing from mechanical damage. Extensive green roofs usually use a 300gr/m² polypropylene layer. A stronger protection layer (ranging from 400-800 gr/m²) is advised for green roofs with higher strain or loadings. The application of protection layers is more critical if the drainage layer uses a more primitive granular mix.

Drainage Layer

5.2.8 The main purpose of the drainage layer is to drain *exces*s water or underflow as rapidly as possible to prevent prolonged saturation. The operative word is excess, meaning that drainage is only necessary if the growing medium has reached saturation point. In fulfilling its main purpose, the drainage layer also protects the waterproof membrane. If drainage is inadequate then problems to the waterproof membrane may occur due to continuous contact with water or wet soil.

5.2.9 The drainage layer also helps to aerate the substrate. Providing internal airflow, below and through the substrate it also helps to reduce the vacuum which occurs due to wind uplift along the edges of an extensive green roof.

5.2.10 Green roof vegetation, particularly on extensive green roofs, is selected to be drought resistant and suited to free-draining soils. Prolonged saturation of the soil is likely to cause plant failure and rotting.

5.2.11 A permanently wet green roof is also likely to lose its thermal insulating properties.

5.2.12 The drainage layer may also double up, in some instances (as shown in the ***Figure 5.5***), as an irrigation mechanism, referred to as *irrigation by diffusion*. In such cases the troughs of the drainage layer, which are able to store water (away from the substrate), are actually able to provide water to the substrate through diffusion into the substrate which draws water up when dry.

5.2.13 Drainage layers are only applicable to flat or slightly angled surfaces (<5°). The addition of drainage layers on steeper slopes may in fact remove water too quickly and be disadvantageous to plant growth.

5.2.14 There are three main types of drainage materials:

- *Granular Materials.* These are usually coarse granules of gravel, stone chips, broken clay tiles, clinker, scoria (lava rock), pumice, expanded shale, or LECA. They contain large pockets of air or pore space between them when packed together in a layer or a space. It is this pore space that allows water to run freely through. This is the most low-tech drainage system but in some cases may be all that is necessary to lift the main substrate above the draining water. Often these layers may be lighter than the main growing substrate and can be used to lighten its overall load because they are still used as part of the root zone. A disadvantage of using granular materials (like LECA) is that they can easily be unevenly dispersed by workmanship occurring above. A wheel-barrow track, for instance, might cut into this layer completely compromising its function in that location.
- *Porous mats.* These mats operate in a similar way to horticultural capillary matting. They are made from numerous materials including recycled materials such as clothing and car seats and behave much like sponges, absorbing water into their structure. There is the danger that these materials may absorb too much moisture from the growing substrate or become too light when dry. Some materials (e.g. recycled foam) may decompose or shrink over time. Having no nutrient holding potential these materials may require continual fertilizing.
- *Lightweight plastic or polystyrene drainage modules*. A great variety of proprietary products exist

which operate in slightly different ways. Most are thinner than 25mm. Some include the ability to store water while others do not, and some can be filled with granular media. These interlocking modules are rigid enough to support the growing medium and vegetation which are kept away from the roof, and provide a permanent free-flowing lightweight drainage layer beneath. In some designs they store reserve water allowing plants to derive additional moisture. To prevent collapse during and after construction attention must be given to the strength that these drainage media offer. Thickened HDPE or High Impact Polystyrene (HIPS) may be considered in some circumstances.

5.2.15 Drainage outlets are an important consideration (existing roofs will already have their own drainage points installed). These need to be kept clear to fulfil their functions, especially from growing substrate. Drainage outlets should be connected by vertical piping to the surface of the growing medium so as to avoid and to clear blockages.

5.2.16 Drainage layers include a filter mat above, which prevents fine material being washed into the drainage which would negate its purpose and may also block the drainage outlets. Non-woven filter layers are ideal for most circumstances (having superior filtration) though woven versions may be considered for heavy duty applications. It is important that edges of the filter mat are taken up the edge of the planting medium.

5.2.17 If suitable soils are used, sloped green roofs (3°-10°) may drain naturally without the need for a drainage layer. For slopes above 10° it is advisable to include a drainage board that actually holds water in its specially designed pockets as the natural drainage may be too rapid.

Growing Medium / Substrate / Soils

5.2.18 Finding the right soil mix for roof gardens is a critical aspect to its success. The general requirements of all growing media are the same:

- efficient moisture retention,
- excess water is easily drained,
- well aerated
- able to absorb and supply nutrients,
- retains its volume over time; and
- provides adequate anchorage for plants.

5.2.19 Additional requirements that are important for green roof growing media include the following:

- light weight;
- water retention capacity;
- inert in a sub-tropical climate (i.e. artificial materials do not degrade); and
- fire resistant properties.

5.2.20 Light weight characteristics may be achieved using natural, artificial, or waste minerals. Lava (scoria) & pumice, perlite, vermiculite, light expanded clay aggregate (LECA), rockwool, diatomaceous earth (DE)[40] and numerous other materials are used. These may offer some other advantages, such as greater water absorption, but this light weight advantage usually comes at a cost, such as retaining soil volume or nutrient holding capabilities.

5.2.21 In extensive green roofs general garden soil or topsoil on its own is generally not suitable because it is too heavy and too fertile. However, thin layers of topsoil have been seen to be successful when used above lightweight, well-drained mediums below. Therefore, in the extensive green roofs developed in

(40) [40] Diatomaceous earth is a lightweight bio-mineral consisting of the fossilized remains of diatoms, a type of hard-shelled algae. It is similar to pumice with high water-retention and nutrient holding characteristics. It also has mechanical properties that act as natural insecticide (the fine silicate powder absorbs lipids from the waxy outer layer of insects' exoskeletons, causing them to dehydrate). This is a feature that might be considered desirable for extensive green roofs, which are designed to have high mineral and low organic soil contents.

Europe, substrates are geared towards light-weight alpine-like meadow vegetation (i.e. *Sedum* species). These prefer well-drained, low fertility soils where they have developed survival techniques to secure their niche. German research indicates that the ideal growing medium comprises 30%-40% substrate and 60%-70% percent pore space. Most commercial substrates are based on tailor-made non-organic mineral components. Clay and organic materials are sometimes added for their moisture and nutrient-holding capacities but noting the types of vegetation commonly used, and the negative aspects of these materials (potential clogging of the drainage systems and shrinkage of organic matter) these are usually applied sparingly.

5.2.22 Fire resistant properties are important, particularly for extensive green roofs where the maintenance regime may involve minimal irrigation permitting the roof to remain dry for long periods in the dry season.

5.2.23 The depth of growing medium/substrate or soil for various vegetation types is critical to its success. Common vegetation soil depths are illustrated below in *Table 5.2.* A list of the regular materials is presented in the *Table 5.3* below showing the characteristics of each. *Table 5.4* provides the weight characteristics of the various growing media as well as other green roof components for comparison.

Table 5.2a Standard Soil Depths for Basic Vegetation Types – Extensive Green Roofs

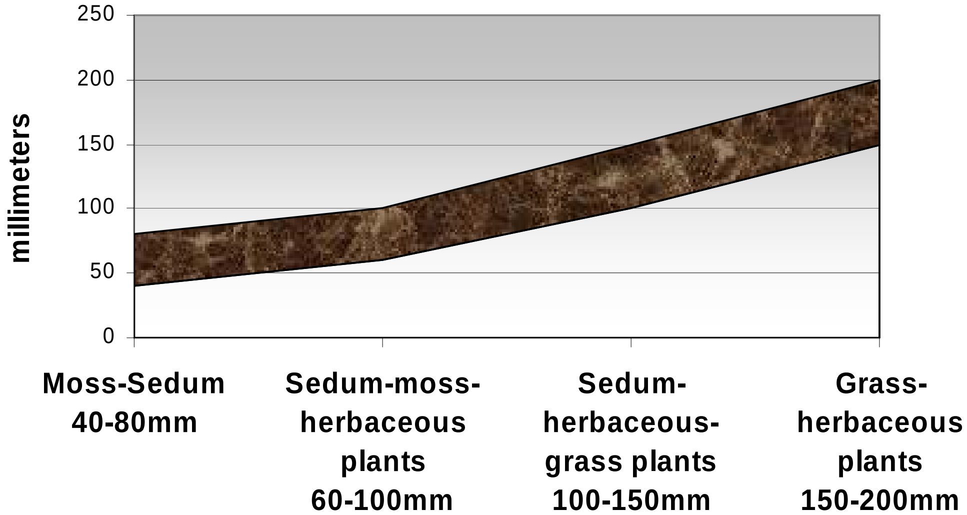
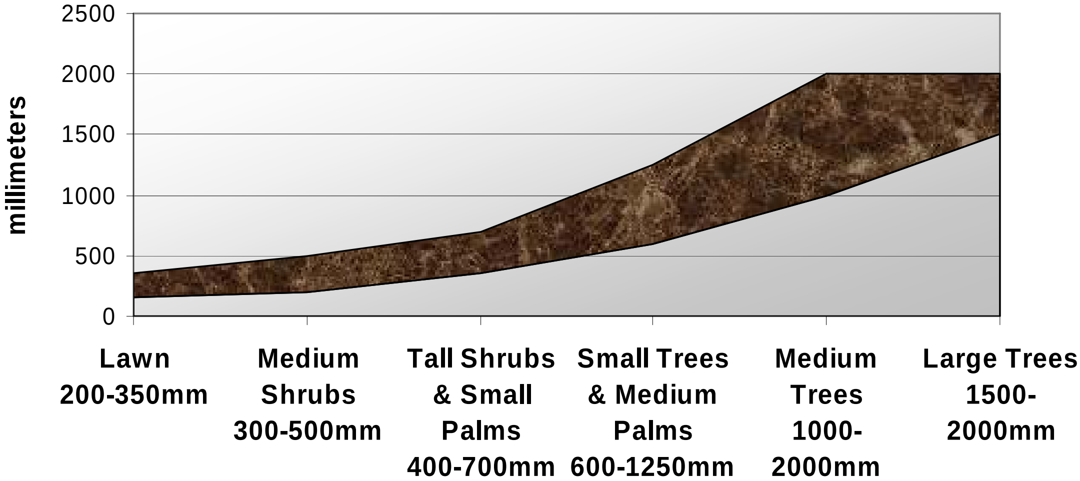


Table 5.2b Standard Soil Depths for Basic Vegetation Types – Intensive Green Roofs



(Source Adapted from the FLL's Guideline for the Planning, Execution and Upkeep of Green-Roof Sites)

Table 5.3 Characteristics of Inorganic Growing Media Components

Materials	Comments
Natural minerals	
Sand	Fine texture can result in lack of pore space and problems of saturation of the substrate if drainage is poor. Conversely, coarse sands can be so free-draining as to require constant irrigation.
Lava (scoria) & pumice	Lightweight and valuable if locally available.
Gravel	Relatively heavy.
Perlite	Particles tend to collapse over time (Hitchmough 1994).
Vermiculite	Very lightweight, but has no water- or nutrient-holding capacity and may disintegrate over time (Hitchmough 1994).
Artificial minerals	
Light expanded clay aggregate (LECA) Expanded shale	Lightweight, produce large amounts of pore space because of their size, and absorb water because of their porous nature.
Rockwool	Very lightweight but energy-intensive production and no nutrient-holding capacity.
Recycled or waste materials	
Crushed clay brick or tiles, brick rubble	Stable and uniform, some nutrient and moisture retention. Brick rubble may contain mortar and cement, which will raise the pH of the substrate.
Crushed concrete	Limited moisture retention and nutrient availability, alkaline. However, cheap and available in quantity as a demolition material.
Subsoil	Heavy, low fertility, readily available as by-product of construction.

(Source: Adapted from Dunnett & Kingsbury (2004), p73)

Table 5.4 Material Weights of Soils and Other Green Roof Components

Materials Weight (Saturated Weights Where Applicable) - x 100 for kg/m³				
Soil Substrate Material	Weight of 1cm layer (kg/m²)		Other Materials	Weight of 1cm layer (kg/m²)
Gravel	16-19		Stone	23-30
Pebbles	19		Granite	26.6
Pumice	6.5		Concrete (precast)	21
Sand	18-22		Concrete (reinforced)	24
Crushed Brick	10-13		Brick (solid with mortar)	18
Sand and gravel mix	18		Concrete (lightweight)	13-16
Topsoil	17-20		Autoclaved Aerated Concrete	6.5
Topsoil (lightweight)	14		Lightweight Foamed Concrete	7
Water	10		Hardwood timber	7.3
Lava	8		Softwood timber	5.7
Perlite (expanded)	5		Cast iron	71
Vermiculite (expanded)	0.6-1.6		Steel	78
LECA	3-4		Aluminum	27
Rockwool	(1.7 dry) 10		Extruded Polystyrene fill	0.7

Note: the mixing of particles of different size will tend to make moisture capacities and final weights unpredictable. (Source: adapted from Dunnett & Kingsbury (2004), p60, Also refer to http://www.simetric.co.uk/si_materials.htm and Chapter 13, 'Reference Values for Design Loads' of the FLL Design Guidelines)

Light-weight fills and thermal insulating layers

5.2.24 Lightweight fills are used primarily on Intensive Green Roofs to create differences in level. Another use may be to create sculptural contours to hide utilities or to liven up the flat surfaces commonly associated with extensive green roofs.

5.2.25 Lightweight fills are usually made of some expanded material which has a lot of air in it. As such they are often very good thermal and acoustic insulators. In extensive green roofs they are sometimes used only for these reasons - as a *thermal insulating layer* (see **Figure** 7.1).

5.2.26 Most light-weight fills are relatively soft and are not physically durable enough to last over long periods if exposed to outside elements[41]. Lightweight fills can be made of a variety of materials:

- *Extruded Polystyrene Sheets* are the most established material. These are becoming less popular because of their environmental impacts during manufacture and eventual disposal. Polystyrene is also flammable. Its main benefit is its ease of handling, low cost and extremely light weight.
- *Polystyrene Cement* is the process of mixing polystyrene beads into cement. Traditionally this process produced an inconsistent material because the beads floated before the cement could set. Experiments using coated beads are proving more successful and may be on the market soon. This material is cheap and easy to produce and form on site but, depending on its composition, has a maximum depth (e.g. around 350mm).
- *Autoclaved Aerated Concrete (AAC)* is a special kind of pre-cast concrete. This material arrives on site in pre-cast panels or blocks. It is made from a mixture of cement, lime, water and sand that expands by adding aluminium powder, much like baking powder in cakes. It is then steam-cured in a pressurized chamber (an autoclave) at 300°C. It is often used as a walling system but is also perfectly suited as a lightweight fill for roofs. AAC's benefits are that it: 1) is easy to handle, work and shape (using only hand tools), 2) uses non-toxic natural materials which are completely recyclable, 3) is airtight, and 4) can be re-inforced with steel if needed to create additional load-bearing panels or roofs.
- *Foamed Concrete* is a special in-situ concrete which mixes foaming chemicals into the cement with a special mixer on site. The proportions of foam may be adjusted for various applications but care must be taken to produce a mix that is stable for its purposes (700kg/m^3 is considered stable, though foamed concrete may be pushed to 420kg/m^3 for other applications). From a density and workability point of view it is very similar to AAC but has the advantage of being poured in-situ if needed.
- *Other Cements (perlite, vermiculite, and LECA)* are other forms of lightweight cements. Perlite and vermiculite are mined mica minerals. Perlite, vermiculite and LECA are all expanded in a heating process much like popcorn. Being the constituents of clay, they all have nutrient-holding capacities (known as cation exchange capacity - CEC) and are therefore used effectively as lightweight soil mixes. However, perlite and vermiculite can also be mixed easily with concrete to create a very favourable lightweight fill. In Hong Kong these minerals are not readily available and/or are not of a high quality that expands well. Experiments using LECA in cement are currently being conducted and may prove to be an effective lightweight fill in the near future.

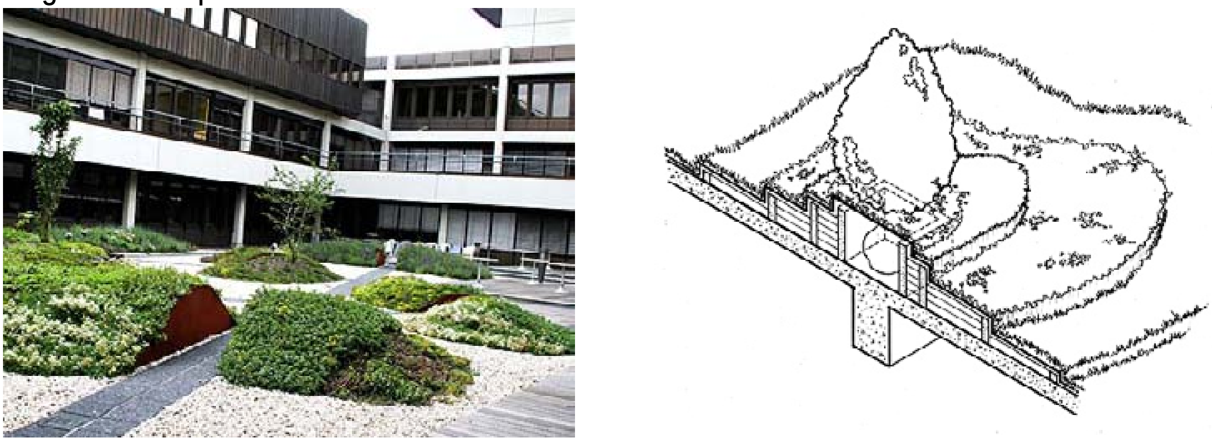
5.2.27 Composite concrete lightweight fills are physically more durable than other lightweight fills (polystyrene) but are much more porous than normal concrete. This makes them vulnerable to carbonation and other concrete weathering processes which makes waterproofing very important. Quality waterproofing is feasible on lightweight concretes using sterates.

(41) [41] Discussions with Redland Precast Concrete Products Limited and Dr. Chris Stanley of the Hong Kong Concrete Repair Association. Also see http://www.hkcra.com.hk/tech_waterproof_05.htm

Figure 5.8 Exploded View of Shaped Level Difference - Extensive Green Roofs

Recently opened HQ of American Society of Landscape Architects, ASLA (July 2006). The dullness of a flat roof (particularly on retro-fitted extensive green roofs or where little colour is possible) is often simply accepted without question. Lightweight constructions, as shown above, illustrate techniques for creating unique level differences for extensive roof gardens. These structures may be used for concealing rooftop utilities or, with enough area, may be used for defining elaborate spaces. They convert the flat canvas technique into an endless range of sculptural possibilities. (Adapted from images from ASLA, 2005)

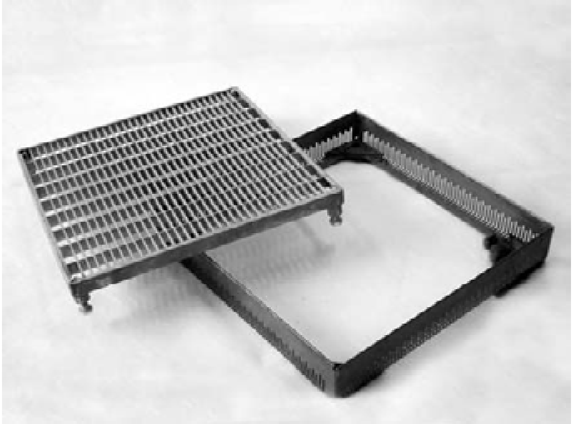
Figure 5.9 Shaped Level Difference - Extensive Green Roofs



Opportune structural beams may be used for spots of heavier loading where small shrubs, palms or trees may be planted with conventional soil while being surrounded by lightweight extensive green roof planting. Lightweight fills may be used to smooth out the level differences using slopes or terraced contours. Terraced contours allow for a distinct separation of planters if vigorous growth habits and competition between species is foreseeable.
(Left: Source and copyright © Greenlink Küsters Ltd.) (Right: source and copyright © Urbis Ltd., 2006)

Figure 5.10 Examples of Typical Green Roof Components

Inspection chamber for regular checking of the drainage layer. Drainage gullies should always have inspection chambers above.
(Source and copyright © Greenlink Küsters Ltd.)



Special paving drainage unit used if the drainage layer continues below the paving.
(Source and copyright © Greenlink Küsters Ltd.)

Protection layer/moisture retention mat being installed above the waterproofing/root barrier in Europe.
(Source and copyright © Greenlink Küsters Ltd.)

Drainage layers being installed at HKU
(Source and copyright © Cheung Shing Yuk Tong Co. Ltd., 2006)

Light weight fills or additional thermal insulation layers are usually installed below the drainage layer.
(Source and copyright © Earth Pledge, 2005)

Inorganic growing medium in Stuttgart, made from recycled construction and industrial waste, including crushed clay tiles and steel mill slag. (Source: Urbis Ltd)

Irrigation Systems

5.2.28 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. 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; and
- *Semi-Automatic Irrigation Systems* - a programmed system with various manual override options that are activated per day or as needs require.

5.2.29 Manual watering (with hose) is reliable, robust and tried-and-tested. Its main draw-back is its high labour costs. Automatic irrigation systems are systems that are controlled (usually electrically) to irrigate areas of planting without human intervention. They are able to deliver precise water quantities at very specific times.

Table 5.5 – Manual Irrigation Systems

ADVANTAGES	DISADVANTAGES
• Reliable and robust. • Tried-and-tested. • Low installation costs. • Labour does not need to be skilled.	• High labour costs. • Installation of water points may be needed. • Watering needs to occur during working hours when more evaporation occurs. • Water usage is not optimised and efficiency may be difficult to monitor. • Water dispersion may be unevenly distributed.

Table 5.6 – Automatic Irrigation Systems

ADVANTAGES	DISADVANTAGES
• Reasonably reliable. • Low recurrent costs. • Watering can occur at times best suited to minimize evaporation. • Water usage is optimised, is easier to control and to monitor.	• High installation costs. • Space required for pumps and other infrastructure such as electrical controllers. • Components are more delicate and planting of vegetation needs more care not to damage pipe-work. • Skilled operators are needed to understand programming of control systems.

5.2.30 The layouts of Automatic Irrigation Systems are dependent on a number of factors: the dispersion height, the irrigation length, the specific plant requirements and the soil volume needing saturation. Most critical are the dimensions of the planters to be irrigated. This affects the available water pressure, which in turn affects the irrigation pipe size, the need for booster-pumps, and in some cases special dispersal mechanisms.

5.2.31 For any automatic irrigation system the delivery or dispersal mechanism also needs to be considered. These are also largely dependent on site location, water supply, water pressure, maintenance access, size of planter, type of vegetation and expected lifespan. The two major dispersal mechanisms are described below:

- Sprinkler Heads - Sprinkler systems are generally cheaper and are used where water falling on leaves is desired (i.e. typically grasses, etc) or where long jets of water are the only means to irrigate a wide surface area. These range from small sprinklers called Bubblers to Spray Heads, to Rotary Nozzles, to Rotars, and eventually to high-volume delivery systems called Impacts for very large areas (mostly lawned sports fields). Sprinkler heads are not as accurate as other dispersal systems with water being lost due to wind and evaporation. Sprinkler Heads need to be elevated above their immediate vegetation to be able to spout to their desired distance. This makes them vulnerable to vandalism and damage where people may walk, which necessitates the need for pop-up versions. The smallest of this type of dispersal mechanism is a bubbler, which covers an area of about 1.2m delivering a high flow in a small area. Generally, Sprinkler heads do not perform efficiently in very windy locations, a constraint associated with many green roofs.
- Drip Irrigation – Drip Irrigation Systems are about 30-40% more expensive than sprinkler systems but offer a more efficient water dispersal method by delivering water at or near the plant root zone. For tree planting slotted subsoil pipes or special leaking pipes may be installed within the tree pits. For shrub and ground covers, they are normally installed above the soil (but below the mulch layer). By applying water directly to the soil, minimal water is lost through evaporation. Drip irrigation pipes laid on the soil surface are generally sufficiently concealed by the planting to avoid being visible to the public, but still visible enough to avoid damage during general plant maintenance. Drip irrigation delivers a low flow to a small area. Drip irrigation lines are vulnerable to UV light and if constantly exposed they need to be replaced approximately every 2 years. This is a constraint often associated with many green roofs.

Figure 5.11 Simple Sprinkler Head Irrigation System

A simple sprinkler head system with a very basic timer is low-cost and sometimes all that is needed. (Example shown at HKU) (Source and copyright © Cheung Shing Yuk Tong Co. Ltd., 2006)

5.2.32 The infrastructure associated with very large areas includes the following:

- Central Pump Room – This is usually situated at ground level with water being fed from municipal sources. The main pump provides any additional pressure that may be needed, which is especially relevant on elevated structures and very long planters. Space for this pump room needs to be adequately catered for during the initial design stage. The pump room needs space for maintenance, the actual pump, the reservoir tank and control systems. (The accurate dimensions of these components depend on the available water volume and pressure which cannot be determined until detail design investigations are initiated.)

- Primary Line - From the pump room, a primary line stretches along the longest length of the planter. This is usually a 2 inch PVC pipe buried within the planter.
- Lateral Emitter Lines - Attached to the primary line are the feeding lateral emitter lines to disperse the water. These lateral emitter lines would often be looped systems connected to the primary line. The total linear length of the entire loop must not exceed 45m. Emitter heads would be attached to the pipe at intervals appropriate for the desired dispersion. At the connecting point of each loop, a valve box is needed. Space for each valve box (approx. 500mm x 400mm x 300mm high, which includes a valve, filters and control mechanism) needs to be accommodated. An electrical cable (24V) also needs to be incorporated into the system to control each of these valves.

5.2.33 Semi-automatic Irrigation systems are constructed in much the same way. The only difference is that the control system is geared for manual override which means that an operator is responsible for turning it on every day as needs be. Another possible semi-automatic feature might be the manual control of the lateral feeder lines. This could be manually controlled electrically (i.e. the operator flips a switch for each line at the main controller situated in the pump room) or manually controlled at water valves along the route of the planter.

5.3 MAINTENANCE CONSIDERATIONS

5.3.1 Maintenance is an aspect that will determine the success of green roofs in Hong Kong. The maintenance requirements of green roofs are determined by many factors – height, micro-climate, soil types, soil depth, irrigation, species used and access (access is often the most crucial factor influencing maintenance costs. Green roof design should focus heavily on this aspect).

5.3.2 In the FLL, it is the maintenance requirements (not the soil depth) that determine whether a green roof is defined as being extensive, intensive or in-between (semi-intensive). Turf grass, for example, is considered a semi-intensive or intensive green roof, even if installed on a shallow lightweight growing medium.

5.3.3 Extensive green roofs are built for low-maintenance. Generally, the species used are native and adapted to harsh conditions (low water, exposed conditions) where they thrive and out-compete other species. This aspect of extensive green roofs is often misunderstood. A cavalier approach to maintenance, such as over-watering or over-fertilizing, may in fact change the growing environment making it more prone to weeds and ultimately adding to the green roofs maintenance requirements.

5.3.4 Intensive green roofs are directly comparable to the maintenance of amenity planting in at-grade locations and are not elaborated on in this study.

Table 5.7 Maintenance Procedures for Hong Kong Green Roof Types

Maintenance Procedure	Intensive: Podium	Intensive: 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.

5.4 GREEN ROOF DESIGN CHECKLIST SUITABLE FOR HONG KONG

5.4.1 Numerous decision-making steps need to occur before a green roof can be considered on any building. These ordered questions are presented below as a checklist for consideration:

Table 5.8 – Green Roof Design Checklist for Hong Kong: PLANNING AND FEASIBILITY

Category	Checklist Questions	Notes, Tips and References
a. 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?	See Section 8 for Capital and Recurrent Costs
	Who will see or appreciate the green roof?	Green roofs not visible to the public may be designed less for visual appeal and more for ecological or building efficiency performance.
	Is a green roof justified in the local context?	In some cases (such as rural areas, where the benefits of green roofs may not be appreciated) a thorough investigation into the needs for a green roof need to be assessed. At-grade planting may prove more effective in terms of visual results, and low capital and recurrent costs.

Table 5.8 – Green Roof Design Checklist for Hong Kong: PLANNING AND FEASIBILITY

Category	Checklist Questions	Notes, Tips and References
	Will the green roof be applied to special structures with special maintenance requirements or special access?	The greening proposals for Highways structures should be assessed on a case-by-case basis and should take into account local site conditions and also the guidelines provided in the Transport Planning and Design Manual.
b. 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?	A deteriorating roof may be the most opportune and most cost-effective time to replace the roof with a green roof.
c. 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?	Due consideration should be given to space needed for refuge floor areas.
	On new buildings, have the rooftop utilities been arranged to optimise the functional open space and to maximise the amount of greening?	
d. 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?	Drainage layers on some pitched roofs may not be necessary as the medium is able to drain very easily by itself. In some cases drainage through the medium may be too fast. The drainage requirements under these circumstances are best left to experienced specialists.
	Have the surface flows and water penetration rates been considered? Is the drainage layer below the growing substrate capable of removing excess water effectively?	Simple methods like timber battens and grids may be used to curb to problem up to pitches of 30 degrees. Steeper pitches may require special substrate mixes and devices.
e. Winds and Climate	Will severe winds be a problem?	
	Have the wind limits of the site been determined?	Some wind problems occur as a result of vortexes at the edge of the roof created by updrafts from the face of the building. From the outset, the building may be designed to limit this problem using irregular or 'rougher' faces (plant covered balconies, for example). High wind uplift is most severe near the edges and corners.
	Are the green roof layers vulnerable to wind shear?	
	Does the waterproofing layer need to be bonded to the roof beneath?	

Table 5.8 – Green Roof Design Checklist for Hong Kong: PLANNING AND FEASIBILITY

Category	Checklist Questions	Notes, Tips and References
	Has the wind erosion of the soil mix been considered?	Lightweight media like LECA, Vermiculite and Perlite are considered by some to be too light for green roof applications. However, if these are covered with heavier topsoil then this risk is minimised. Wind vortex problems may also be mitigated by angling and extending the shape of the parapet coping. Erosion problems may necessitate the use of anti-erosion netting placed just below the soil surface. These are the same systems commonly used on slopes in Hong Kong.
	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?	
f. Acces-sibility	Is or will the roof be accessible or inaccessible?	Accessibility and safety for maintenance also needs to be considered. Difficult or unsafe access during construction and maintenance may increase the labour insurance premiums.
	How will the roof be accessed?	Special cases may require the erecting of temporary scaffolding for maintenance.
	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?	
g. Structural Limits	What are the structural loading limits of the roof?	The typical loadings of extensive green roofs range from 80 to 150kg/m² while intensive green roofs range from 300 to 1000 kg/m².
	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?	I.e. loading directly above support beams and walls may allow for significant increase in soil depth (See Figure 5.8)
	Are polystyrene or other lightweight materials being used to increased depth without adding significant weight?	(e.g. Autoclaved Aerated Concrete, Foamed Concrete, Extruded Polystyrene, etc.)
	Has the green roof manufacturer provided detailed information and attested to the fully saturated weight?	

Table 5.8 – Green Roof Design Checklist for Hong Kong: PLANNING AND FEASIBILITY

Category	Checklist Questions	Notes, Tips and References
	Will any roofing components be removed from the roof which allows for additional weight?	In Hong Kong 'air-gap' tiles with elevated points are often laid above the structural slab and sealed together. Their construction and condition might determine whether they are removed for a retro-fitted green roof which may affect the weight calculations.
h. General Design	Have structural joints been incorporated into the green roof design from the beginning?	Structural movement joints need to be accessible for maintenance. Roof gardens on bridges may require large concrete slabs on either side of the joint which should be recognised early in the design stage.
	Have maintenance paths been incorporated as part of the design?	Maintenance paths are especially relevant for extensive green roofs because they often create a distinctly visible intersection within the green roof canvas.

Table 5.9 – Green Roof Design Checklist for Hong Kong: COMPONENTS

Category	Checklist questions	Notes, Tips and References
i. Insulation and Light-weight fills	Is additional thermal Insulation necessary?	
	Are lightweight fills needed or desired to create level differences?	
	What kind of insulation or lightweight fill is required?	Polystyrene (flammable, not environmentally friendly but very lightweight) or lightweight cement mixtures (heavier, more robust and environmentally friendly). See Section 5.2.25
j. Water-proofing	What kind of waterproofing will be used?	Membrane tanking or concrete admixtures, see Section 5.2.2.
	Are leak detection tests planned prior to installation?	
	Does the waterproofing have any guarantee? With different contractors building the green roof-scape layers above the waterproofing is this guarantee still valid?	
	How is waterproofing quality control ensured? How will the various sub-contractors co-ordinate to ensure that the water-proofing layer is not compromised during their construction?	A protection board above the waterproofing may be considered.
k. Root Barrier	Does the green roof system need an additional root barrier? Or does the waterproof membrane fulfil this purpose?	
	Are the root barriers tied into flashings and roofing terminations?	
	How effective is the root barrier?	If laid loose root barriers should overlap at least 1.5m to prevent lateral root growth.
	Has the root repellent system been tested or approved by a relevant overseas body, the FLL for example?	
l. Drainage Layers and Drainage	If the slope is more than 21° have mechanisms such been installed to prevent slippage of the layers?	
	What will the drainage layer be made of?	Cheaper but heavier granular layers, lightweight plastic drainage mats made for water storage, or more robust plastic drainage grids engineered for rapid removal of excess water and for heavy loads.

Table 5.8 – Green Roof Design Checklist for Hong Kong: PLANNING AND FEASIBILITY

Category	Checklist Questions	Notes, Tips and References
	Has the drainage been designed for major storm events? Are there at least two roof outlets or overflow drains? In the event of a major storm event will the vegetation be drowned? If so, for how long?	
	Does the drainage capacity increase closer to the drains?	
	Has the drainage layer adequately catered for the average rainfall events?	With heavier downpours (such as occur in Hong Kong) a thicker drainage layer is recommended, i.e. 25mm thick rather than 12mm, used abroad.
	Has a drainage specialist investigated the impacts?	
	If rain water is being retained within the substrate (moisture reservoir layer) or drainage layer, how long will it last? Will it last till the next rainfall or will irrigation be needed in-between?	
	If the drainage layer stores water, has its loading capacity been considered during the structural calculations?	
m.Filter Layer	Is the filter layer lightweight, rot-proof, inexpensive, easy-to-install and permanent?	
	Is the filter layer effective? Non-woven is preferable.	
	At the edges and seams, is the filter cloth appropriately overlapped?	
	Is the filter layer designed to properly deal with the edges and curbs?	
n. Growing Medium / Substrate	Has the growing media been specified by an experienced professional?	
	Has the medium been well-established and tested?	
	Does the growing medium have the characteristics specific to the green roof design? (weight, water absorption, stability, resistance, drainage and surface area)	See Section 5.2.18
	How is the growing media being transported to the roof?	
o. Plant Selection	Has the plant material been specified by an experienced professional?	See Table 7.2 for potential species suitable for extensive green roofs in Hong Kong. Also see Table 6.1 for a list of known trees that are suitable for use in Hong Kong's Podium Gardens and Sky Gardens.
	Will any new plants be introduced into Hong Kong? Have these been approved by AFCD?	
	Will any new plants be imported into Hong Kong? Have the necessary Plant Import Licences / Phytosanitary documents been acquired from AFCD?	Plants from countries other than mainland China may need to fulfil more stringent requirements.
	Do the selected plants work in the local area and specific rooftop environment?	
	Has full consideration been given to growth rates, sensitivity to airborne pollutants, ability to withstand wind, drought tolerance, and fire resistance?	
	Are they readily available for supply? If not how long?	
	Will seeds be used, cuttings, mats, modules plugs or fully grown plants?	These affect the price but mature at different rates.
	On lower areas, has the sun exposure hours and shade hours been considered?	This is particularly relevant to podium gardens and green roofs proposed on elevated walkways within the city.
p. Irrigation	Have the irrigation needs been established, particularly during the dry season?	

Table 5.8 – Green Roof Design Checklist for Hong Kong: PLANNING AND FEASIBILITY

Category	Checklist Questions	Notes, Tips and References
	Will additional roof-top water points be needed? Or will tanks and pumps be needed?	
	What kind of irrigation system is needed?	Sprinklers are cheaper but are inefficient in windy conditions. Surface drip irrigation is more expensive and is vulnerable to UV
	How will irrigation be timed?	(automatic, semi-automatic or manual)

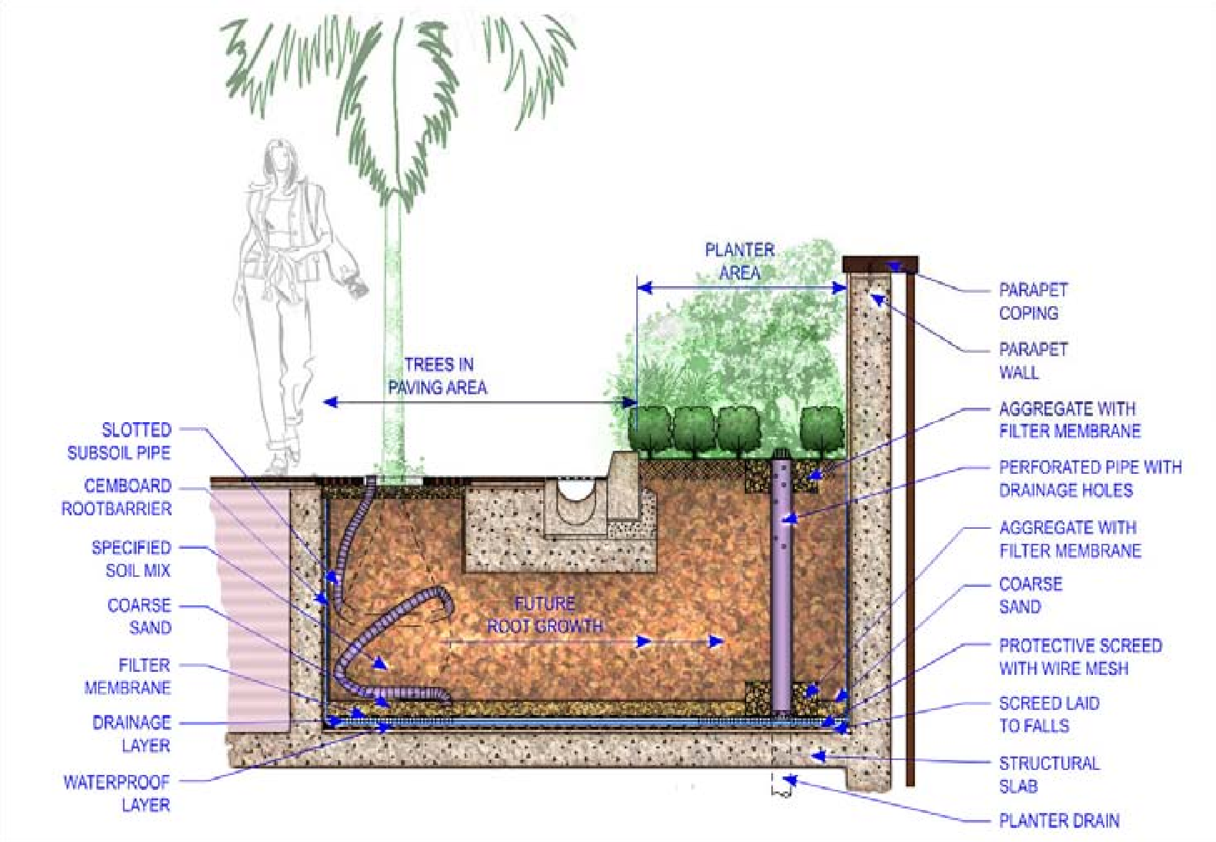
Table 5.10 – Green Roof Design Checklist for Hong Kong: MAINTENANCE & MANAGEMENT

Category	Checklist questions	Notes, Tips and References
q. Management	Has a detailed management plan and budget been established?	
	Are any special arrangements required for access? (e.g. scaffolding)	
	Who is responsible for management and maintenance?	In government projects the agents responsible are not necessarily LCSD by default. For clarification refer to ETWB TCW No. 2/2004 (Maintenance of Vegetation and Hard Landscape Features http://www.etwb.gov.hk/UtilManager/tc/C-2004-02-0-1.pdf). It is advisable to resolve maintenance responsibilities before implementation.
	How will access be managed?	Access for maintenance and the public needs to be controlled. Green roofs not intended for public access might attract curiosity visitors.
	Will horticultural training be necessary	Dedicated horticultural maintenance staff are usually required for intensive green roofs. Maintenance for Extensive green roofs is easy enough for building maintenance staff to be done. In most cases an introductory lecture of 2 hours by an experienced green roof contractor is all that is necessary.
	Will litter bins and associated maintenance be required?	
	Will temperature reductions be measured to determine building energy efficiency changes? Who will co-ordinate measurements and data collection?	Baseline measurements before construction need to be taken. Teams or qualified professionals may use pyrometers, scintillometers, infra-red cameras or thermal imaging cameras (very expensive) to determine building temperatures.
r. Maintenance	How will the plant species selection affect maintenance?	
	How often will drains be inspected?	
	How often will plant health be inspected?	
	How often will the building's waterproofing be checked?	
	How often will irrigation need to be switched on? How often will the irrigation system need to be checked?	
	How often will weeding be necessary?	
	How often will fertilizing be necessary	
	How often will tree-staking need to be checked?	
	How often will mowing need to be done?	

6 INTENSIVE GREEN ROOFS (SKY GARDENS & PODIUM GARDENS) IN HONG KONG

6.1 CONSTRUCTION DETAILS

Figure 6.1 Details of Typical Intensive Roof Garden



(Source: adapted from drawings of PTI roof garden park, CNR Chatham & Salisbury Road, TST. copyright © Urbis 2006 and adapted from drawings from LF Sam Ltd.)

6.2 SPECIAL CONSIDERATIONS FOR PODIUM GARDENS & SKY GARDENS

The Importance of Trees

6.2.1 Any urban greening proposals, including green roofs, should consider the inclusion of trees. Compared to other types of greening, trees are generally the most effective in terms of:

- the amount of greenery they provide versus the ground surface area they occupy (though roots may occupy substantial underground space);
- their provision of shade;
- their rates of evapo-transpiration;
- their total leaf surface area and ability to filter air-bourne particulates and gaseous pollutants;
- their life-expectancy;
- their sensitivity to climatic and air quality fluctuations
- their visual mass;
- the ecological habitats they create;
- their long term maintenance and water requirements; and
- their price

6.2.2 Trees greatly enhance the various benefits offered by green roofs. Trees define spaces and provide micro-climates conducive to the creation of amenity spaces on rooftops, which may ultimately enhance the value of the property. A plant selection matrix of trees, palms and palm-like trees applicable for intensive green roofs in Hong Kong is presented in Appendix II.

Trees in Roof Gardens

6.2.3 When including trees in roof gardens the following key aspects should be considered.

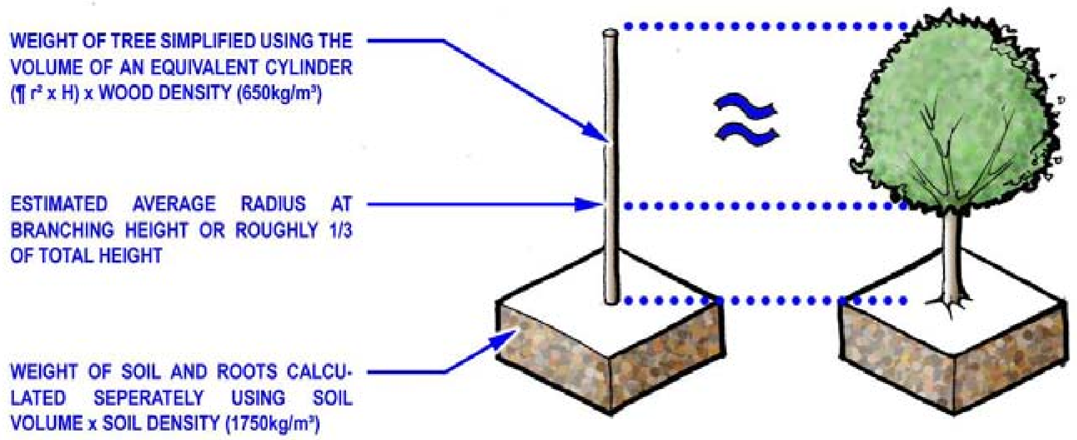
- Provision of adequate soil volume for healthy growth and anchorage is critical. A simple rule of thumb is that 1.2m soil depth should be provided, although smaller trees may grow in shallower depths, provided that the lateral extent of soil is widened to compensate.
- Soil depth may be locally deepened at tree locations (either by mounding the soil surface or locally deepening the planter). Trees may be located over structural columns to take advantage of loading efficiency.
- Tree anchoring may be by staking or tying down of the root ball but in all cases must not interfere with the integrity of the waterproofing.
- Species selection is critical. Trees need to be selected which have a strong branching system, are flexible in high winds and have leaves that do not appear battered when exposed to strong winds.

Calculating Plant Weights

6.2.4 Calculating plant weights at maturity (particularly for trees) is an important consideration during the initial design stages of a green roof. There is no industry standard for calculating tree weights. The simple method presented below in Figure 6.2 was adapted from the successful techniques used for the importing, transporting, and installing of large trees to Penny's Bay and Hong Kong Disneyland.

6.2.5 Tree weight calculations consists of three components; stems, branches and roots. Weight calculations for roots can simply use the entire volume of the soil multiplied by an average soil density (1750kg/m^3). The proportion of the roots (around 20%) can be ignored because the heavier density of soil builds in an adequate safety margin. The above-soil weight calculations are based on a tree being simplified into a consistent cylinder, where the volume is easy to calculate (¶.r^2 x H), multiplied by the density of hardwood (650kg/m^3). The estimated radius at the branching height (usually ⅓ of the estimated total height) is considered a usable average for the volumetric calculations of the assumed cylinder.

Figure 6.2 Calculating Plant Weights at Maturity



Note: The technique presented is for general reference only.

6.2.6 It should be noted that the above calculations do not factor in wind loading which needs to be added to the weight loading calculations. Additional wind loading results from the horizontal force of the wind being transferred to the roots of the tree, resulting in a downward pressure on one side and an upward pressure on the other side. This is best left for suitably qualified engineers and experts to determine. Also not included are tree supports and anchorage which may become exceedingly heavy with larger trees.

6.2.7 Determining plant weights during construction is also important. These weights need to be calculated to determine labour and transport costs and to ensure the balancing of cranes that may be used to lift heavy trees. Table 6.2 below presents a very general indication of typical weights for a variety of plant materials.

Table 6.2 Plant Weights

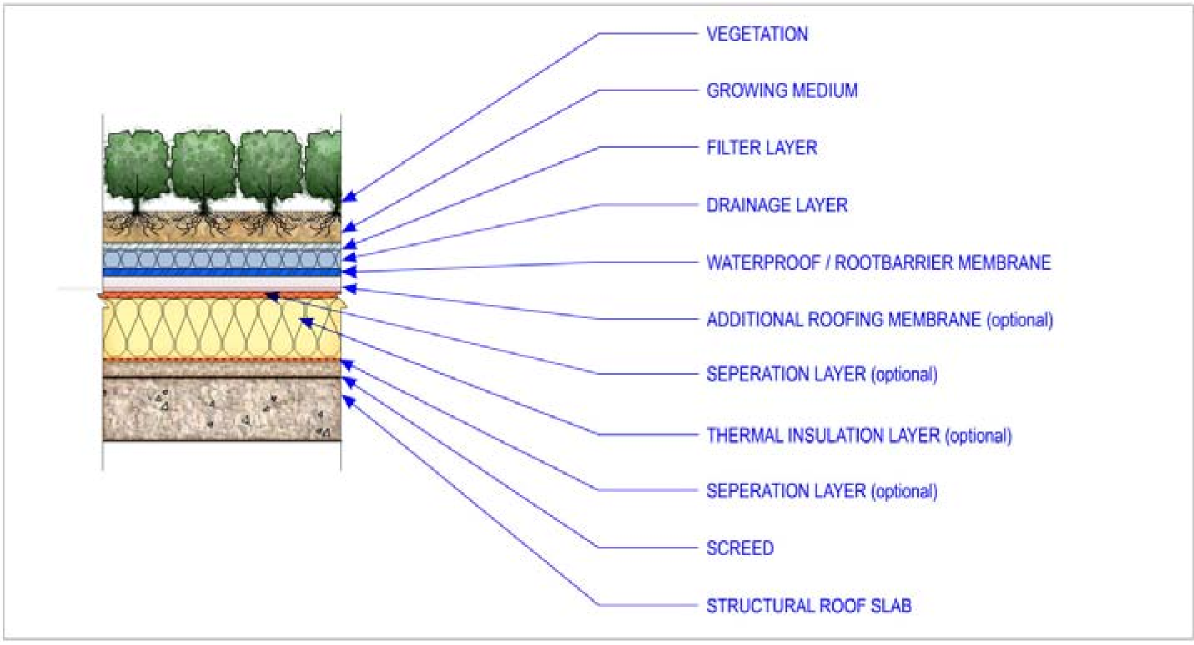
Plant Type	Description	Root Ball Size and Depth	Estimated Planting Weight
TREES			
Light Standard Tree	Stem dia. 35mm, total height 2.5m	Root ball dia. 350mm, depth 300mm	54 kg
Standard Tree	Stem dia. 60mm, total height 3.5m	Root ball dia. 350mm, depth 300mm	58 kg
Heavy Stand. Tree	Stem dia. 150mm, total height 3.5m	Root ball dia. 400mm, depth 350mm	119 kg
Semi-mature Tree	Stem dia. 200mm, total height 5.5m	Root ball dia. 1000mm, depth 600mm	961 kg
Specimen Trees	Stem dia. 200mm, total height 7.0m	Root ball dia. 1000mm, depth 600mm	991 kg
	Stem dia. 250mm, total height 8.0m	Root ball dia. 1200mm, depth 800mm	1884 kg
	Stem dia. 300mm, total height 10m	Root ball dia. 1500mm, depth 1000mm	3640 kg
PALMS & BAMBOO	(well formed and with good fronds)		
Palms	Stem dia. 30mm, clear trunk ht. 300mm	Root ball 200mm, depth 250mm	14 kg
	Stem dia. 40mm, clear trunk ht. 700mm	Root ball 200mm, depth 250mm	15 kg
	Stem dia. 80mm, clear trunk ht. 1500mm	Root ball 350mm, depth 300mm	57 kg
	Stem dia. 100mm, clear trunk ht. 3000mm	Root ball 500mm, depth 450mm	174 kg
	Stem dia. 120mm, clear trunk ht. 4500mm	Root ball 1000mm, depth 600mm	881 kg
	Stem dia. 150mm, clear trunk ht. 7500mm	Root ball 1300mm, depth 800mm	1997 kg
	Stem dia. 170mm, clear trunk ht. 9500mm	Root ball 1800mm, depth 1000mm	4721 kg
Bamboo Palms	Stem dia. 175mm, clear trunk ht. 1500mm	Root ball 350mm, depth 300mm	75 kg
	Stem dia. 210mm, clear trunk ht. 2000mm	Root ball 350mm, depth 300mm	97 kg
Bamboo	Stem dia. 50mm, overall height 600mm	container dia 400mm, depth 450mm	103 kg
SHRUBS			
Small Shrub	Stem dia. 10mm, Overall height. 400mm	container dia 130mm, depth 150mm	4 kg
Medium Shrub	Stem dia. 15mm, Overall height. 600mm	container dia 150mm, depth 200mm	6 kg
GROUND COVERS			
Small Gnd covers	Average dia. 350mm	Pot grown dia.125mm, depth 150mm	3 kg
Medium Gnd covers	Average dia. 500mm	Pot grown dia.150mm, depth 200mm	6 kg
Large Gnd covers	Average dia. 1200mm	Pot grown dia.200mm, depth 300mm	17 kg

Note: Calculations use thick-diameter trees, a wood density of 650kg/m³ and soil density of 1750kg/m³.
(Source: Adapted from values provided by Asia Landscaping Ltd.)

7 EXTENSIVE GREEN ROOFS (ECO-ROOFS) IN HONG KONG

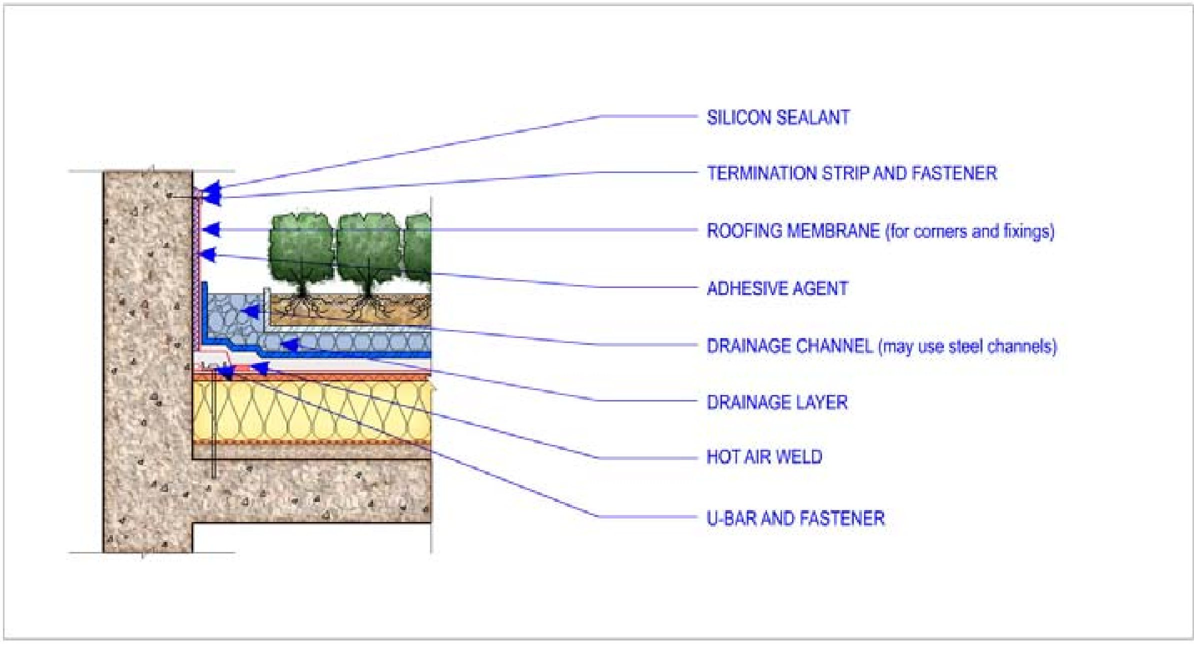
7.1 CONSTRUCTION DETAILS

Figure 7.1 Details of General Roof Build-up



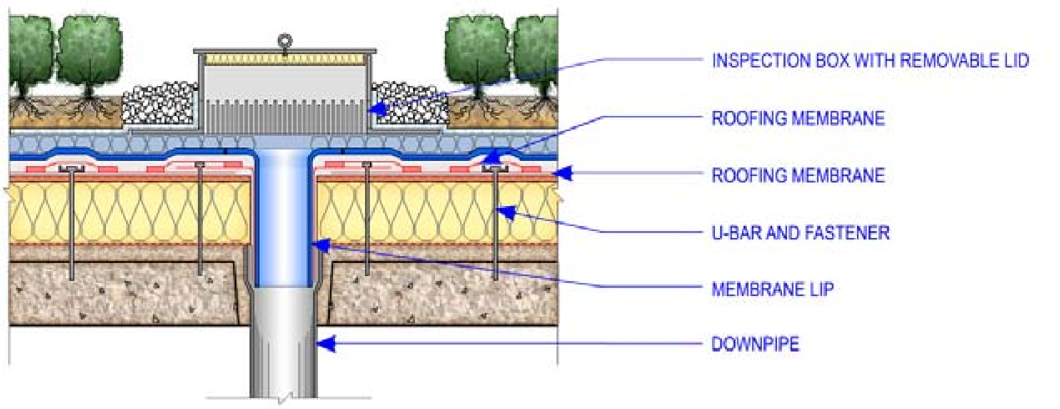
(Source: Adapted from technical drawings for Eco Park, Hong Kong, from Sarnafil Ltd.)

Figure 7.2 Details of Parapet Edge Treatment



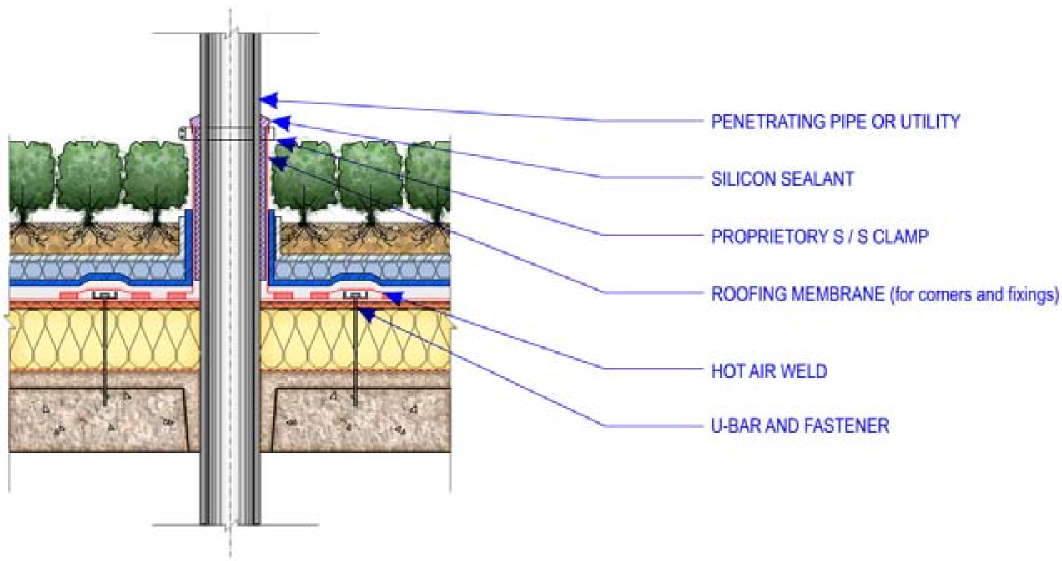
(Source: Adapted from technical drawings for Eco Park, Hong Kong, from Sarnafil Ltd.)

Figure 7.3 Details of Typical Drainage Inspection Chamber



(Source: Adapted from technical drawings for Eco Park, Hong Kong, from Sarnafil Ltd.)

Figure 7.4 Detail of Typical Penetration of Roof-top Utilities

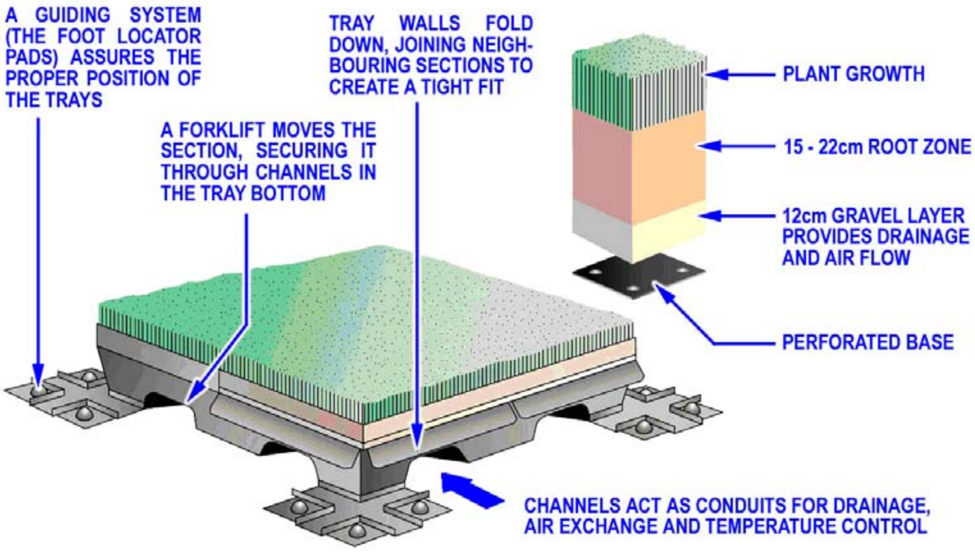


(Source: Adapted from technical drawings for Eco Park, Hong Kong, from Sarnafil Ltd.)

7.2 MODULAR TRAY SYSTEMS

7.2.1 Recent years have seen the introduction of tray systems into the extensive green roof market. These come in a variety of shapes and sizes and offer some advantages, particularly for maintenance. Figure 7.5 illustrates a typical large tray system (1.17m x 1.17m) needing equipment to install but being tightly connected to allow for additional soil to be installed above the bounds of the tray. Figure 7.6 illustrates a smaller and possibly more versatile system that can be installed manually. It appears to be completely self-contained and has drainage connected directly to roof outflow pipes rather than relying on the existing waterproofing. Although planting designs may be restricted by the rigidity of a grid system, well-designed plant variety, as seen below in Figure 7.7, needs to be used to create a pleasant design.

Figure 7.5 Typical Extensive Green Roof Tray Systems



(Source: adapted from GreenTech ITM™ Module by GreenTech, Inc.)

Figure 7.6 Prefabricated Extensive Greenroof (PEG) Tray System Developed in Singapore

(Source and copyright © ZinCo Singapore Pte Ltd., using a patented design developed by Singapore's Housing & Development Board and United Premas Ltd.)

Figure 7.7 Aesthetic Potential of Extensive Green Roof Tray Systems

GreenGrid™ modular rooftop garden
(Source and copyright © Weston Solutions, Inc.)

7.2.2 Tray Systems, like extensive green roofs in general, are suitable for retro-fitted green roofs. Despite the apparent ease of construction, tray systems have negative characteristics which must be also be considered.

Table 7.1 - Advantages and Disadvantages of Tray Systems

Advantages	Disadvantages
♦ If the growing medium is completely contained, then the modules (only if small enough) can easily be removed and put back in place without disturbing the plants. ♦ Plants are pre-planted and may be used for instant effect. Seasonal or festive effects may make use of this advantage though it would be a costly exercise. ♦ Onsite installation is quicker. Downtime due to inclement weather is reduced. ♦ Onsite installation can be done by less experienced labour as quality is maintained more at the plant propagation nursery rather than by the onsite contractors. ♦ Alterations may be easier and installation in stages is easier. ♦ Concerns over various sub-contractors (if different) interfering with each other's layers, such as the waterproofing layer, are reduced. ♦ Tray systems may be well suited to sloped roofs. ♦ Trays systems may be well suited to being specially mounted above some roof top utilities (e.g. pipe work). ♦ Designers may experiment or refine the planting design on site by mixing and matching the different pre-grown planting modules.	♦ In years to come, older module designs may not be available making replacing of parts difficult. ♦ Plastic trays will eventually deteriorate in the sun, even UV-resistant plastic. This compromises the aging benefits that green roofs offer over conventional roofs. There is also the possibility that cheap copies using inferior short-aged plastics may flood the market. ♦ Transportation and stacking difficulties and expenses may be higher, especially for larger tray systems. Larger cranes may be needed in many cases. (Only onsite installation may be quicker). ♦ Being self-contained, trays may be slightly more prone to drying out, requiring more watering and care. (Tray systems must have adequate soil depth and water reservoir layering to overcome this). ♦ Some tray systems have fixed soil depths which limits the overall design. ♦ Planting designs and maintenance pathways layout are largely dictated by the uniform squares of the trays. The exposed grids lines may also detract from the aesthetic qualities of a continuous landscape. ♦ As trays may be easier to dismantle they may invite developers to be only half-committed to green roofing. ♦ If modules are rigidly connected or buried with soil above then the removal may be as cumbersome as normal extensive green roofs. ♦ There is the possibility of roots growing through drainage holes in open module systems and compromising the roof slab below (particularly from undesirable self-seeding weed trees). ♦ Uneven roof surfaces below the tray system may collect water. As this water may not evaporate away fast enough it may create breeding grounds for mosquitoes.

7.2.3 Major conditions/scenarios for choosing a modular tray system might include the following:

- ♦ If regular removal for inspection is foreseeable;
- ♦ If the plastic used is guaranteed over the long term;
- ♦ If long-term roofing cost benefits are not a concern;
- ♦ If an instant effect is needed; and/or
- ♦ If liability issues between sub-contractors is a concern.

7.3 PLANT SELECTION FOR EXTENSIVE GREEN ROOFS

7.3.1 In the early days of roof greening in central Europe the species used were generally the more showy or resilient components of dry meadow communities or species chosen from the extensive flora popular as rock-garden plants. Trialling of species for their suitability for roof greening was a major part of the early research work. German researchers set up trials, with plants being evaluated by a panel, which assessed them for appearance of growth and ground coverage. Sedums consistently rated high, along with low-growing grasses such as many *Festuca* and *Koeleria* species. Sedums have since become the standard plant for shallow-substrate roof-greening systems due to their drought tolerance, year-round good looks, ease of propagation, and suitability for shallow substrates. The trials also revealed surprises. Some species were found to be unsuitable for their sensitivity to competition with grasses. Others were excluded for the opposite reason – invasiveness.[42]

7.3.2 The task of selecting suitable plant species for roof greening has arguably hardly begun, and it offers potentially enormous rewards.[43] Unfortunately, there has been a limited range of research into widening the planting possibilities on roofs. While many German green-roof companies carried out their own research into suitable species for low-input green roofs, they are now doing very little additional research. In parts of the world where green roofs are a new phenomenon, there is a tendency to repeat the use of these species.[44] It is essential for proper local investigations to be done to find the most appropriate species.

7.3.3 It is important to note that new technologies are emerging, especially in the field of façade walls. Although the maintenance of these systems is largely unknown (probably notably higher than extensive green roofs), they do offer an urban greening method that uses epiphytes, of which Hong Kong has many suitable species.

7.3.4 A collection of species that have extensive green roof potential are listed in Appendix II. Year-round greenery is theoretically possible in all plant species presented. This is dependant on the local conditions, maintenance and watering. Plants adapt and grow well in ideal and consistent environments. Highly responsive maintenance/irrigation regimes aims to ameliorate stressful impacts (excessive heat and dry periods for example) allowing plants to flourish. Maintenance and irrigation that responds poorly to extreme conditions might result in plants appearing less desirable during such periods. Plants listed in Appendix II generally look well even during harsh conditions, allowing appearance to be maintained with minimal maintenance. However, some species will perform better than others. Species with succulent-type characteristics (i.e. those with C4-photosynthesis or CAM- photosynthesis), which have special mechanisms for preserving water, generally appear better during extreme periods. Plant family names are also included in Appendix II as these reveal such features. Succulents-type plants include Crassulaceae, Agavaceae, Cactaceae, Dracaenaceae and Portulacaceae.

7.4 EXTENSIVE GREEN ROOF PLANTING APPROACHES

7.4.1 This section suggests planting options commonly associated with extensive green roofs. Extensive green roofs are designed for their low maintenance and/or ecological functioning and generally follow four basic approaches:

- Mono-culture Planting. This type of planting is simple and usually uses one plant species en masse. 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

(42) [42] Dunnett & Kingsbury (2004) p102

(43) [43] Dunnett & Kingsbury (2004) p103

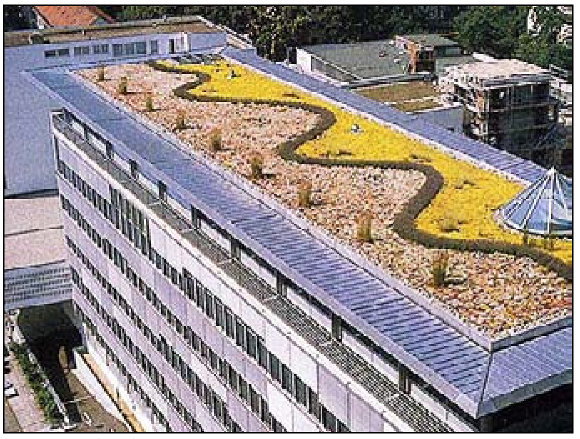
(44) [44] Dunnett & Kingsbury (2004) p80

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 there 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 fulfil a green roof's maximum ecological potential.

Figure 7.8 Extensive Green Roof Planting Approaches

Monoculture planting (Source: Urbis Ltd.)



Pattern Planting
(copyright © Earth Pledge, 2005, photo Peter Philippi)

Mixed Planting
(Source and copyright © Earth Pledge, 2005, photo by City of Portland)

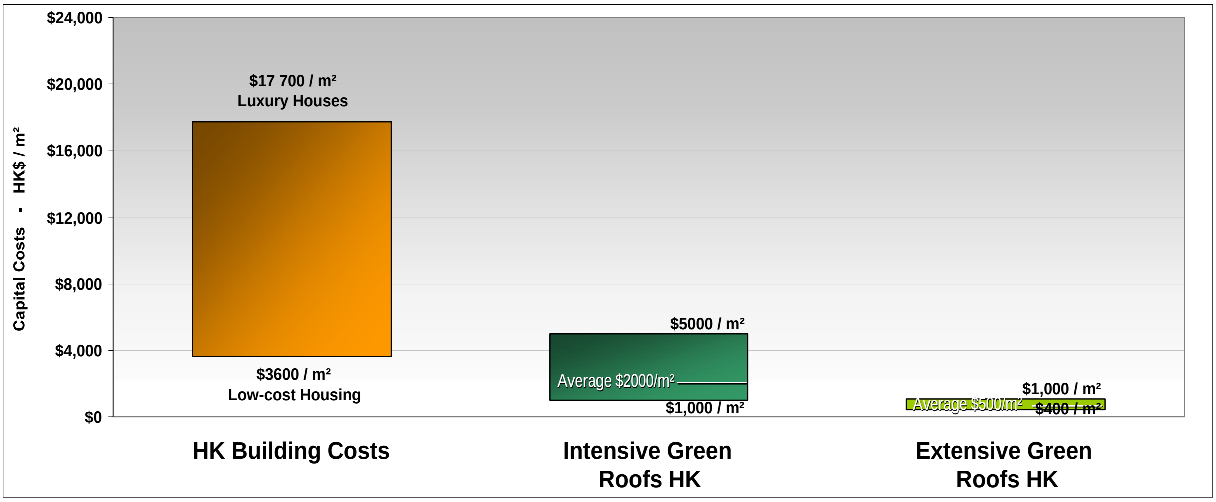
Plant Communities Planting - planting design by Dunnett.
(Source and copyright © Dunnett & Kingsbury (2004), p101)

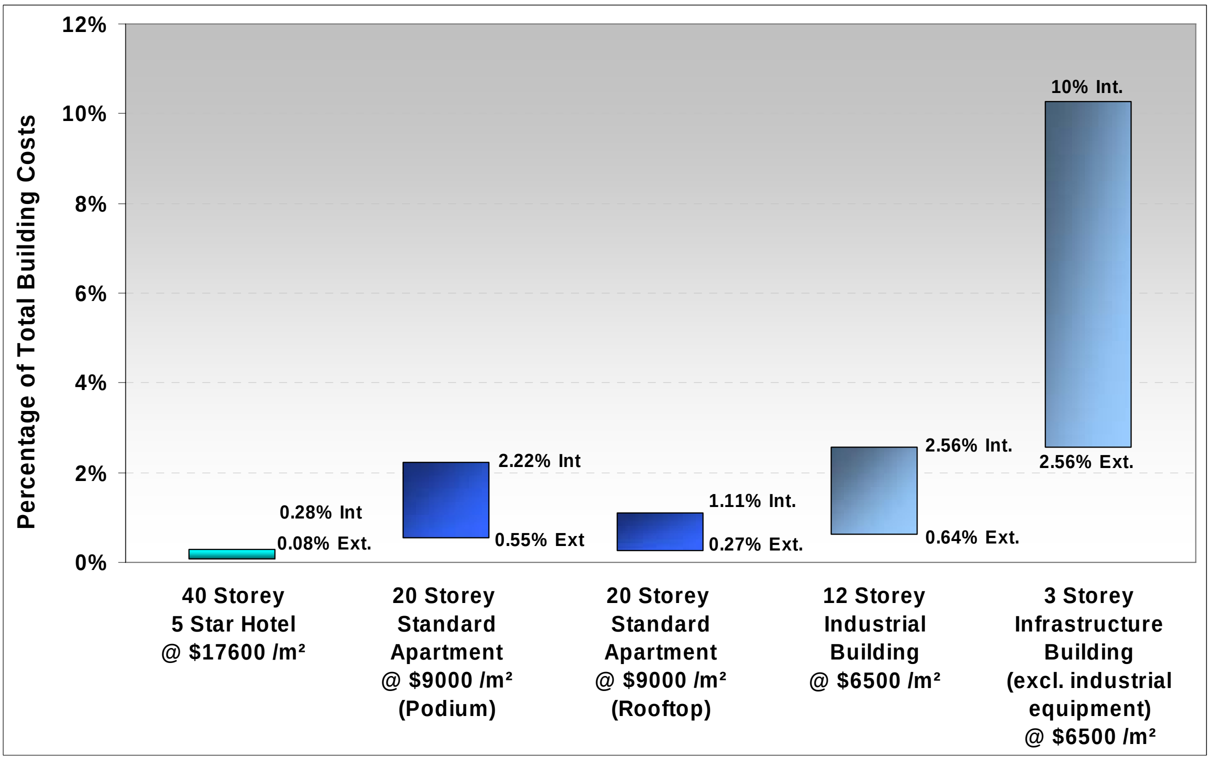
8 GREEN ROOF COST ESTIMATES FOR HONG KONG

8.1 CAPITAL COSTS

8.1.1 Capital Costs are largely dependent on labour, materials and access difficulties. However, compared with entire building costs in Hong Kong[45], green roofs costs, both intensive and retrofitted extensive, are very small. This is illustrated in **Table 8.1** below.

Table 8.1 Comparison between Building and Green Roof Costs in Hong Kong





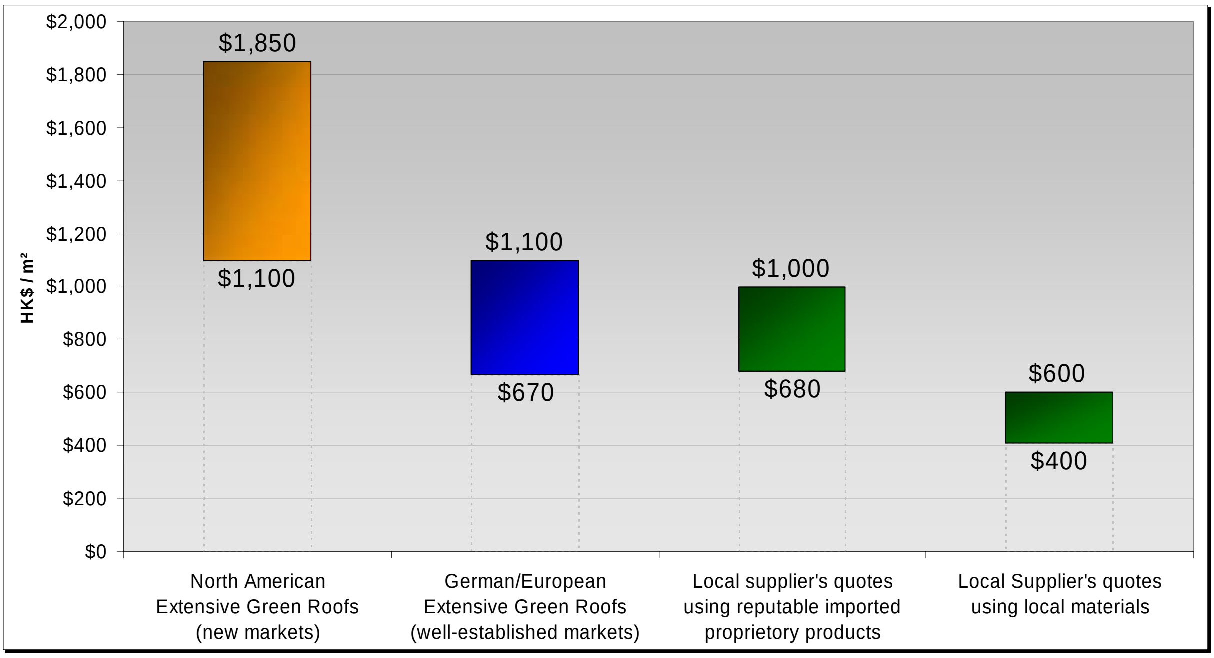
The lower table illustrates the range that green roofs will play in the overall costs of buildings ($500/m² for extensive green roofs, and $2000/m² for intensive green roofs). It illustrates that on luxury skyscraper buildings, green roof costs are virtually insignificant. On low-rise infrastructure buildings green roof costs might reach 10% of the total costs if elaborate Intensive Green Roofs are considered).

(45) [45] Approximate Building Costs in Hong Kong, 1st Quarter 2006 (Davis Langdon & Seah, Quantity Surveyors) http://www.dlsqs.com/modules.php?name=News&file=article&sid=279

Extensive Green Roof Capital Costs

8.1.2 **Table 8.2** shows the range of capital costs for extensive green roofs in North America, Germany and Hong Kong. A range of **$400/m² to $1000/m²** (average $500/m²) is estimated for Local Extensive Green Roof costs[46] and relates to retrofitting costs. The costs for *new construction extensive green roofs* currently have no precedents in Hong Kong. However, American research[47] indicates that *new construction extensive green roofs* costs are around 60 to 70% that of retro-fitted projects.

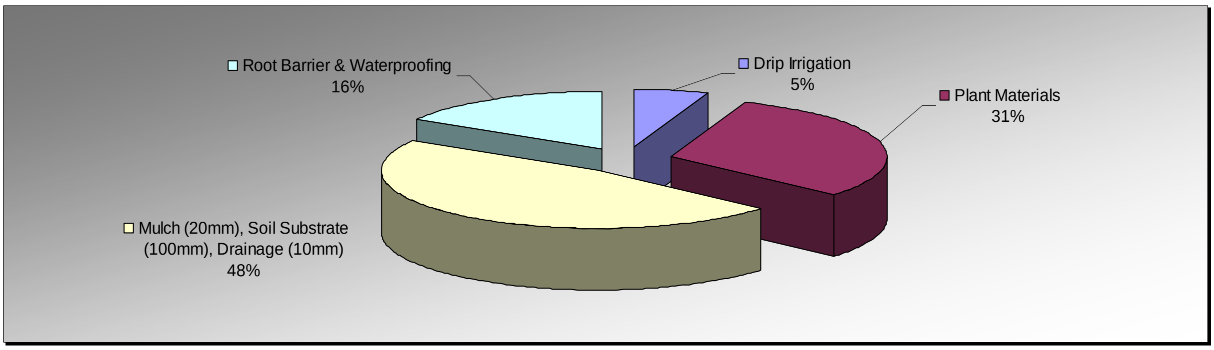
Table 8.2 Comparison of International and Local Extensive Green Roof Cost Ranges



Note: All costs quoted in Hong Kong Dollars

8.1.3 A typical breakdown of the costs involved is illustrated below in **Table 8.3**. The specialised growing substrate is clearly the most expensive part.

Table 8.3 Typical Extensive Green Roof Capital Cost Breakdown (example from USA)



(Source: calculated from component priced at www.greenrooftops.com)

(46) [46] Figures based on quotes from local suppliers with some experience in Hong Kong and in China

(47) [47] Portland Bureau of Environmental Services (2002), indicates that a new construction would cost around HK$800/m² to HK$1200/m² (US$10/ft²-US$15/ft²) while a retrofitted green roof might cost around HK$1200/m² to HK$2000/m² (US$15/ft²-US$25/ft²).

8.1.4 The costs of extensive green roofs are generally affected by the following:

- Access constraints to the site during construction
- Whether the project is a new construction or a retro-fit project.
- The slope of the roof.
- Status of the existing roof (if a retro-fit project).
- The number and arrangement of rooftop utilities, affecting labour and wastage.
- The materials used, and the type of plant material used. This affects labour costs (plants may be individually planted, seeded, or have pre-grown sedum or turf mats applied).
- Irrigation needs.
- Growing medium depth.
- Access or safety components that need to be added

Intensive Green Roof Capital Costs

8.1.5 The costs of intensive green roofs are highly variable and therefore difficult to assess[48]. They are estimated to be at least double the cost of an extensive green roof (if only soft-landscaping costs are considered).

8.1.6 Costs for intensive green roofs can be divided into two broad categories – soft-landscaping (with a unit cost of \$800/m²)[49] and hard-landscaping (with unit costs of \$3200/m²)[50] which together give a **general value of \$2000/m²** for easily accessed intensive green roofs. The lowest value, with very easy access and mostly soft-landscaping is estimated to be around \$1000/m². The general high-end range has been assessed at \$5000/m² and is based on a green roof having a highly thematic design, difficult access (5 storey podium) and where the landscaping contract and crane operations are brought in separately.[51]

8.1.7 The costs of intensive green roofs are generally affected by the following:

- 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 (large cranes, reaching a 6 storey high podium, will cost about \$400,000 to erect and dismantle, and will have a running cost of \$100,000 per month)[52].
- 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
- Access or safety components that need to be added

(48) [48] Green roof garden design and soil depth might dramatically influence the structural design of a building with cost implications that are not possible to separate. The green roof cost range provided does not consider such extreme cases and is based on costs occurring above the roof slab.

(49) [49] Costs based on two public accessible roof gardens being currently being built above new KCRC and MTR stations

(50) [50] Costs based on hard-landscaping costs of a new publicly accessible roof gardens currently being built above an MTR station

(51) [51] Costs based on elaborate and thematic roof garden being built as part of Macau's casino complex

(52) [52] Based on construction costs of a new casino complex in Macau

General Green Roof Capital Cost Breakdown

8.1.8 Table 8.4 below offers a typical breakdown of the costs involved for intensive and extensive green roofs. Although this table may provide a good indication for budgetary purposes, it should be noted that pricing of green roofing is normally by a global rate or item, rather than by each individual component of the green roof design.

Table 8.4 Costs Breakdown and Commercial Availability of Components in Hong Kong (HK$)

Basic Green Roof Components	Supply Costs HK$	Install & Labour Costs HK$	Additional Costs ‡ - due to height and access constraints, etc.	Additional Notes & Descriptions
PLANT MATERIALS				
Trees (Standard Size)	$180 / tree	$100 / tree	$200 / tree	Cost is dramatically influenced by size of trees and site access. Semi-mature trees may need external cranes.
Shrubs	$20 / shrub	$10 / shrub	$20 / shrub	
Climbers	$10 / plant	$10 / plant	$20 / plant	
Groundcovers	$8 / plant	$6 / plant	$6 / plant	
Sedums (Specialized species)	$60 / m²	$10 / m²	$20 / m²	
Grasses	$40 / m²	$10 / m²	$20 / m²	
GROWING MEDIUM				
Mulch (50mm)	$20 / m²	$10 / m²	+$20 / m²	
Topsoil	$170 / m³	$160 / m³	+$100 / m³	3:1 (CDG: conditioner)
Sand	$100 / m³	$160 / m³	+$350/m³	River Sand
Lava (scoria) and Pumice	$500 / m³	$160 / m³	+$350/m³	(Sourced from Inner Mongolia)
Gravel	$180 / m³	$160 / m³	+$350/m³	
Perlite	$1500 / m³	$160 / m³	+$350/m³	
Vermiculite	$480 / m³	Included	+$350 / m³	100mm Vermiculite pellets (3mm - 6mm) with 300mm soil mix - Supply, mix and lay to Ground level works only.
LECA (Light Expanded Clay Aggregate)	$530 / m³	Included	+$350/m³	100mm LECA with 300mm soil mix - Supply, mix and lay to Ground level works only.
Crushed clay Brick or tiles, Brick rubble			+$350/m³	Price depends on availability of brick rubble in the area which is crushed on site.
Moisture Reservoir Panel within growing medium (40mm THK)	$200 / m²	Included	Included	
PROTECTION & DRAINAGE LAYERS				
Filter Layer	$10/m²	Included	Included	Non-woven fabric is better. Filter layer is often built onto the drainage layer.
Drainage Layer	$120 / m² $84 / m² $60 / m²	Included	Included	The more expensive layers with specialized dimples is to be used specifically when water retention is required. Other lower costs systems are made for more rugged situations and are designed for very heavy loading and rapid removal of excess water.

Basic Green Roof Components	Supply Costs HK$	Install & Labour Costs HK$	Additional Costs ‡ - due to height and access constraints, etc.	Additional Notes & Descriptions
Separate Root Barrier / Root herbicide layer	$60 / m²	Included	Included	OPTIONAL. - Seperate root barrier is needed if waterproofing layer does not provide this function
Waterproof Layer (PVC membrane) and root layer.	$130 / m²	Included	Included	PVC layer. Costs include Moisture retention mat above and separation layer below
Integrated Cement Waterproofing (Admixtures and Impregnations)	$34 - $68/m² (150mm slab)	None	None	Robust and effective when used as an admixture to concrete (i.e. for new roofs). Needs a concrete layer of 150mm for effective guarantee.
Thermal Insulation Layer (Expanded Polystyrene)	$45 / m²	Included	Included	OPTIONAL. May be needed if additional thermal insulation is desired.
OTHER COMPONENTS				
Paved areas	$200 - $800 /m²	Included	Included	
Autoclaved Aerated Concrete	$650 /m³	$350 /m³	Included	Commonly termed Y-Tong blocks in Hong Kong
Lightweight Foaming Concrete	$800-1000 /m³	Included	Included	
Concrete roof slab	$1650 /m³	Included	Included	
Concrete roof beams	$3050 /m³	Included	Included	
Extension of Concrete Columns	$2700 /m³	Included	Included	
Concrete walls	$2000 /m³	Included	Included	
Railings added to parapet	$1000 / ln.m	Included	Included	Standard S/S Railings. Free-standing railings with concrete footings = $1200 / ln.m
Drip Irrigation System	$70/m² to $100/m²	Included	Included	Price does not include additional tanks and pumping systems. It includes dispersal mechanism, controllers, timers and rain sensors.
Sprinkler Irrigation System	$55/m² to $70/m²	Included	Included	

Note ‡ - Additional Costs due to height & access constraints, are based on a typical 20 storey residential block in Hong Kong.

8.2 RECURRENT COSTS

8.2.1 Maintenance requirements for Intensive green roofs are directly comparable to the maintenance of at-grade parks, except for the difficulties associated with height access by maintenance staff. These proportions may vary considerably but are generally in the order of 30% which brings the local maintenance costs for intensive green roofs to between $6.5 per m² per year to $44 per m² per year[53].

8.2.2 Estimated maintenance costs for extensive green roofs are based on industry experience in Beijing and Shanghai (Shanghai is considered a close approximation to Hong Kong)[54]. If installed as a proper Extensive Green Roof, maintenance should only require 1 minute per m² per year. This may increase but will very rarely exceed 3 minutes per m² per year. Translated into local labour costs this equates to between $0.8 per m² per year and $2.25 per m² per year. These values are typical for typical building rooftops. Very difficult access (such as on some highways structures) may have even higher maintenance

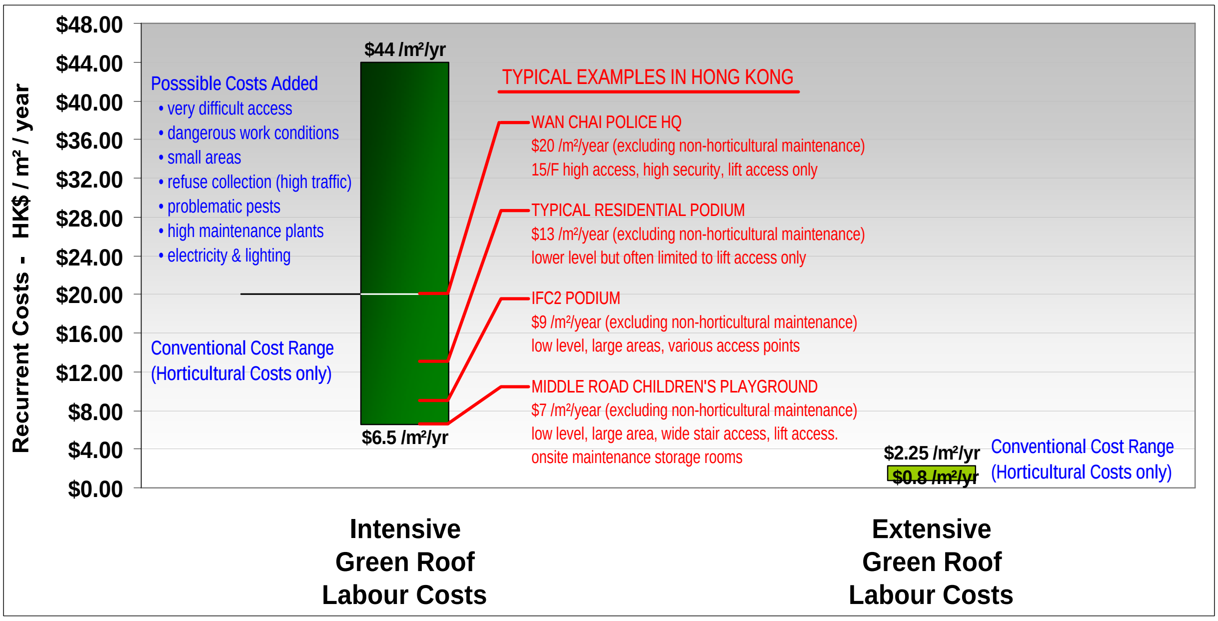
(53) [53] Based on LCSD Term Contract rates and discussions with Tarzan Ltd.

(54) [54] Discussions with Peter Küsters (FLL representative in Asia) of Greenlink Küsters.

values for extensive green roofs.

8.2.3 It is estimated that the maintenance of hybrid or semi-intensive green roofs, where more common amenity planting is used on thin lightweight substrates, will result in a maintenance cost range above true extensive green roofs but below the lowest range of Intensive green roofs, i.e. between \$2.25 per m² per year to \$6.5 per m² per year. Examples might include the turf grass and *Duranta repens* planted at HKU (see **Figure** 4.2), the amenity planting tried on bus shelters (see **Figure** 4.3) and the turf grass planted at Kadoorie Farm (see **Figure** 4.4).

Table 8.5 Comparison of Local Intensive and Extensive Green Roof Maintenance Cost Ranges



PART 3

Conclusions and the Way Forward

9 SUMMARY OF THE STUDY

9.1 BACKGROUND

9.1.1 There are two main types of green roofs:

- **Intensive Green Roofs** (with deep soils, wide plant choice but requiring more capital and maintenance resources); and
- **Extensive Green Roofs** (that are lightweight, have a narrow plant range, and are geared for low maintenance).

9.1.2 The Study finds that the green roof industry is well established in Europe, particularly Germany and is rapidly becoming popular in North America and in some parts of Asia.

9.1.3 In Hong Kong *Intensive Green Roofs* are already well-established in the form of podium gardens. *Extensive Green Roofs*, on the other hand, are better-suited to retro-fitting projects which have their own technical constraints, and are not yet well-established in Hong Kong. Despite Intensive Green Roofs being well-established, a consolidated approach to green roof techniques and standards is still needed.

9.1.4 The benefits of Green Roofs are numerous and well-researched overseas. All of the benefits are of some value to Hong Kong, in varying degrees. These benefits include:

- **Amenity and Aesthetic Benefits** including:
  - Leisure and Functional Open Space
  - Visual Amenity Value; and
  - Health and Therapeutic Value
- **Environmental Benefits** including:
  - Ecological and Wildlife Value,
  - Water Management,
  - Reducing the Urban Heat Island Effect, and
  - Air Quality.
- **Economic Benefits** including:
  - Increased Roof Life,
  - Building Insulation & Energy Efficiency,
  - Green Building Assessment & Public Relations)

9.1.5 Although all green roof benefits will be noticeable, the major benefits for Hong Kong are considered to be:

- Increased *Leisure and Functional Open Space*.
- Increased *Visual Amenity*.
- Improved *Building Insulation & Energy Efficiency*.[55]
- Green roofs at a significant scale also contribute towards numerous city-wide environmental benefits. These include improved water-management, air quality and mitigation of the urban heat island effect.[56]

(55) [55] Research by ZHAO Ding-guo (2005 at the Environmental Science Research Institute, SAAS, Shanghai, 201106, China) & XUE Wei-cheng shows that a **reduction of 2°C for internal room temperatures** can be expected, though other research claims values of 4°C to 5°C under different circumstances. Research by N.H.WONG (2005, National University of Singapore) shows a **net annual saving of 15% for air-conditioning costs** on a 5 storey building. Local findings show similar results and indicate that the surface temperature of a vegetated area can be about 10°C to 15°C lower than that of a concrete roof on a sunny day in November/December (readings at EMSD HQ building) and about 18°C to 26°C lower during August (readings at HKU).

(56) [56] Research (Green Roofs for Healthy Cities Coalition, 2002) indicates that **1 square meter of grass can remove 0.2 kg of airborne particles per year**. Research on the ACROS building in Fukuoko, Japan illustrates that the environmental benefits of intensive green roofs extend beyond the building footprint and may play a significant role in mitigating the urban heat island effect.

9.2 GREEN ROOF OPPORTUNITIES, CONSTRAINTS & CONSIDERATIONS FOR IMPLEMENTATION

Opportunities

9.2.1 Hong Kong's urban form, context and climate are unique. In the CBD, buildings are tall and finger-like, providing minimal roof-greening opportunities. However, other parts of the city have larger street blocks and buildings with more suitable roof greening opportunities. Hong Kong also has numerous roof-greening opportunities on other infrastructure buildings, such as covered walkways, noise enclosures, ferry piers, pumping stations and vent buildings. Typical Building types in Hong have been listed in **Table** 4.4.

9.2.2 Consequently, the potential opportunities for green roofs in Hong Kong may be broadly categorised into three main green roof scenarios – Sky Gardens, Podium Gardens (New Buildings) and Existing / Low Maintenance Buildings:

- Sky Gardens are found on top of any high-rise buildings (usually 20 storeys and above). Sky Gardens are usually designed as part of the building and may be **intensive or extensive green roofs** depending on usage.
- Podium Gardens are usually 2 to 5 storeys up forming the base of a residential or office tower. These gardens are usually intended for full access by the building occupants or the public and are therefore always **intensive green roofs.**
- Existing and low-maintenance buildings include existing office and residential towers and other buildings such as public infrastructure buildings. Due to weight constraints and the need for low maintenance **extensive green roofs** would generally be prescribed.

Figure 9.1 Some Typical Urban Forms in Hong Kong




(Source and copyright © 2006 Urbis Ltd.)

Constraints

9.2.3 As intensive green roofs are widely occurring in Hong Kong it is apparent that any constraints presented by the construction of intensive green roofs have already been overcome. The technical issues associated with *intensive green roofs* are well understood by the local construction industry. On the other hand, with no incentive and minimal knowledge about the emerging technologies, there are very few examples of *extensive green roofs* in Hong Kong.

9.2.4 The constraints or barriers against the development of green roofs (which apply in Hong Kong to differing degrees for intensive and extensive green roofs), fall into four categories, namely:

- *Lack of knowledge and awareness* – There is generally a lack of knowledge about extensive green roofs. Also, knowledge of the benefits of all green roofs has previously never been consolidated and used effectively in building design decision making. Greenery in the city is generally approached from an amenity and cosmetic point of view only.
- *Lack of incentive / statutory mandate* - Many of the benefits would not accrue to property developers who build and sell immediately;
- *Economic constraints* - There is a lack of understanding about direct tangible and long-term economic benefits of extensive green roofs. Green roof structural loading requirements require additional capital expenditure. Additional maintenance costs may be required.
- *Lack of available roof area* – Many of Hong Kong's buildings, especially the tall finger-like buildings in the CBD, are often so cluttered with roof-top utilities that green roofs may be impractical.
- *Technical issues and risks associated with uncertainty* – This is particularly relevant for extensive green roofs (especially the retro-fitting of existing green roofs).

Considerations for implementation in Hong Kong

9.2.5 From a physical and climatic point of view, Green Roofs in Hong Kong have their own unique difficulties. These include:

- high winds,
- high summer rainfall with low winter rainfall,
- high & exposed buildings, and
- Hong Kong has little experience in using low-maintenance plant species that fit the defining criteria of extensive green roofs.

9.2.6 Other major considerations for implementation include capital and recurrent costs.

Capital Costs in Hong Kong

9.2.7 In Hong Kong, green roof costs (for both Extensive and Intensive Green Roofs) are not high relative to total building costs, which range from \$ 3,600 /m² (for low-cost housing) to \$ 17,700 /m² (for luxury houses). For comparison, green roof prices are listed below and include all components above the roof slab, and all hard- and soft-landscaping components.

- Intensive Green Roofs usually range from \$ 1,000 /m² to \$5,000 /m² (market average: \$2000/m²).
- Extensive Green Roofs usually range from \$ 400 /m² to \$ 1,000 /m² (market average: \$500/m²).

Recurrent Costs in Hong Kong

9.2.8 Recurrent costs are notably also not high. The labour associated with intensive green roofs is directly comparable with the maintenance associated with at-grade park operations which range from easily accessed sites to very inaccessible or remote sites. The maintenance requirements for extensive green roofs are untested in Hong Kong. Beijing and Shanghai experience shows that as little as 1 to 3 minutes per m² per year is needed for extensive green roofs (if designed correctly and with low-maintenance plants). These facts translate into the following figures:

- Intensive Green Roofs usually range from $6.5 /m²/year to $44 /m²/year (average: $20/m²/year).
- Extensive Green Roofs are estimated to range from $0.8 /m²/year to $ 2.25 /m²/year.

9.3 GREEN ROOF DIRECTIONS IN HONG KONG

9.3.1 The application of green roofs should be based on a rational evaluation of the specific needs of each building and its users, while still striving to accomplish the city's environmental needs. A balanced understanding of green roof costs and effectiveness is required.

9.3.2 This study has comprehensively covered the costs and technical aspects of green roofs, showing that green roofs (extensive and intensive) are economically and practically feasible in Hong Kong. However, the effectiveness of some benefits of green roofs is unfortunately more difficult to quantify. This is because they deal with aspects, such as some environmental and economic benefits, which are difficult to quantify.

- The <u>social benefits</u> (i.e. Amenity and Aesthetic benefits) of green roofs are generally well understood, with the public and planners commonly identifying and emphasizing the need for more hospitable, pedestrian-friendly and greened environments in Hong Kong.
- Unfortunately, some <u>environmental benefits</u> of green roofs, such as *improving air quality* and *reducing the Urban Heat Island effect*, are extremely complex issues to quantify. To know all the causes of these urban problems is difficult enough, let alone determining what scale of mitigating impact green roofs would have. Further research in this field is essential.
- Some <u>economic benefits</u> of green roofs, such as *building insulation and energy efficiencies*, also require more in-depth local knowledge before they can be fully factored into any cost-benefit assessment. Of all the technologies available (solar panels, double skins, green roofs etc.), it remains to be determined which will be the most cost-effective for Hong Kong's context.

9.3.3 However, it is considered unwise to delay the implementation and encouragement of green roofs simply because of these unknowns, especially when one considers the following points:

- Of all the technologies that a city or building might employ to solve its problems it would appear that green roofs offer the most benefits. The aesthetic and amenity benefits of green roofs are also a major aspect that other technologies are not likely to contribute to the city.
- Early research (with regards to pollution control and mitigation of the urban heat island effect) is already beginning to prove that green roofs on a large enough scale can noticeably improve a city's environment. Overseas research in this field is ongoing and is likely to deliver useful results in the near future.
- Early research from a building-energy-saving's point of view shows that green roofs, as a living skin, are more cost-effective than the whitest surface possible (see Section 2.2.69). Green roofs also help to lower ambient temperatures, making solar panels more effective, which suggests that green roofs are likely to be an integral part of this technology if adopted (see Section 2.2.70). It should also be noted that green roofs <u>reduce</u> energy demands, which in the field of resource efficiencies, is considered more sound than simply adding additional components and

maintenance to a building to cater for high energy demands.

- It is intuitively felt that a return to natural systems (in whatever small way) should be of some environmental benefit to the city.

9.3.4 Considering the above, it is apparent that Green Roofs offer noticeable benefits for Hong Kong and could become an integral part of the city's solutions. For now, the main benefits to aim for are considered to be:

- An improvement to the city's appearance and amenity,
- An increase in the usable green space, and
- An improvement on building energy savings.

9.3.5 As such, it is considered that *Intensive Green Roofs* should be promoted as the prime direction for the future of green roofs in Hong Kong. *Extensive Green Roofs* could be considered for retro-fitting projects and situations where Intensive Green Roofs are not practical.

9.3.6 The long term objective of green roofs is to achieve collective environmental benefits through city-wide application of green roofs. Various steps are needed to achieve this. They are presented below and are divided into Short, Medium and Long Term Goals.

9.4 RECOMMENDATIONS AND THE WAY FORWARD

Short Term Recommendations

9.4.1 *Dissemination of information* through the media is recommended to actively promote green roofs and to foster better understanding of their potential benefits.

9.4.2 *Trade Shows* demonstrating green roof technologies are recommended for Hong Kong.

9.4.3 *Engaging with stakeholders* (including real estate professionals, construction industry representatives, developers and suppliers) is recommended to encourage green roof development in Hong Kong.

9.4.4 *Government should lead by example* by continuing to implement green roofs on all new buildings, and to review the retro-fitting of green roofs for existing roofs.

9.4.5 *Introducing rating systems and elements of competition* should be maintained and strengthened by expanding the role of green roofs in CEPAS and HK-BEAM labelling systems, especially after local data and research on building efficiencies is available.

9.4.6 *Pilot schemes and further research* is needed to fulfil the need for more local information. Information is needed to more accurately determine: 1) changes to ambient temperature, building surface and interior temperatures; 2) changes in pollution and particulate levels; and 3) changes in water runoff. The goal is to accurately determine building energy efficiencies applicable to Hong Kong's unique climate and building forms. Further horticultural research is also needed to determine the viability of different species for extensive green roofs.

Medium and Long Term Recommendations

9.4.7 *Collating citywide scientific data* on green roofs is recommended. This would involve doing cost-benefit analysis studies to establish the geographical extent to which green roofing could be achieved in Hong Kong, and the resultant benefits that would be enjoyed by the community. This could take the form of a G.I.S. study. Monitoring of green roofs on a regular basis is also recommended. This would provide knowledge of the progress over time and would assist the formulation of effective policies and incentives to promote green roofs.

9.4.8 *Developing reliable standards* (e.g. similar to Germany's FLL Guidelines) is suggested to promote industry confidence and to prevent low-quality products and construction from entering the market.

Although podium gardens are well-established in Hong Kong, there are still no standards ensuring quality in this field. The development of standards should cover extensive and intensive green roofs.

9.4.9 Reviewing Government policy is suggested to maximise the amount of greening possible in the city, after collective environmental/economic benefits have been proven and supported by public consultations. There are numerous green roof policies around the world that may be considered and adapted for Hong Kong's needs. These policies used abroad should always be viewed in the context of each city's physical composition, social values and individual case settings. The approaches adopted elsewhere should not necessarily be copied directly in Hong Kong. Also, Hong Kong requires a thorough understanding of the costs and benefits, technical standards, horticultural requirements and unique market forces before evaluating the need and direction of policy and regulations. It is therefore premature, at this stage, to make recommendations on policy. There are many concepts tried elsewhere that may be considered. These include: 1) *Direct Incentives to the Private Sector*, such as cash grants towards capital costs, 2) *Indirect Incentives to the Private Sector,* such as GFA bonuses for the provision of green roofs, or even 3) the introduction of the *Polluters Pay Concept,* based on the "eco-tax/carbon tax" concept against polluters, where the provision of a green roof might be used to reduce this tax because of its contribution towards energy efficiency.

APPENDIX I

Examples of Public Buildings in Hong Kong with Green Roofs

Appendix I

Examples of Public Buildings in Hong Kong with Green Roofs

APPENDIX I: EXAMPLES OF PUBLIC BUILDINGS IN HONG KONG WITH GREEN ROOFS

DISTRICT		NAME OF FACILITY	TYPE OF BUILDING	TOTAL AREA m^2	PHOTO
1. Central & Western	1.1.	Roof top planters along covered walkway	High Court	90	
	1.2.	Roof top garden at Pier 2	Pier	1,318	✓
	1.3.	Roof top garden at Pier 3	Pier	1,640	✓
	1.4.	Roof-top garden at Arbuthnot Road FEHD Refuse Collection Building	Refuse Collection Station	91	
	1.5.	Sitting-out Area at Centre Street Market	Market	800	
	1.6.	Joint Users Building at Rock Hill Street, Kennedy Town			
2. Wan Chai	2.1.	Bowrington Road Market Roof-top Children's Playground	Market Complex	1,200	✓
	2.2.	New Police Headquarters, Wan Chai (at 15/F)			✓
	2.3.	Tang Shiu Kin Hospital	Hospital		✓
3. Eastern	3.1.	Sitting-out Area at 2 Podium Levels (not open for public)	Municipal Services Building	892 m^2 at 6/F 338 m^2 at 8/F	
	3.2.	North Point Government Offices			✓
	3.3.	Meng Tak Primary School at Chai Wan			
	3.4.	Braemar Hill Fire Station			
	3.5.	Roof-top garden at Ex-Chai Wan	Refuse Collection Point	44	
	3.6.	Meng Tak Primary School, Cheung Man Road, Chai Wan	School		✓
	3.7.	Lei Yu Mun Museum	Museum		
4. Southern	4.1.	Roof-Top Garden at Stanley Sports Centre	Municipal Services Building	470	
	4.2.	Water Sports Centre at Stanley Main Beach			
	4.3.	Wah Fu Fresh Water Service Reservoir	Service Reservoir		✓
5. Yau Tsim Mong	5.1.	Amenity Plot at the Podium of 3/F, Fa Yuen Street Sports Complex	Municipal Services Building	38	
	5.2.	Roof Top Garden Phase 1,II, III at Kowloon Park	Kowloon Park	4,928	
	5.3.	Middle Road Children's Playground	At the roof-top of KCRC East Tsim Sha Tsui Station	5,671	✓
	5.4.	Transport Link in Tsim Sha Tsui East			
	5.5.	Tsim Sha Tsui Promenade Beautification			
	5.6.	Reprovisioning of CAS & FSD Facilities, West Kowloon Reclamation	Municipal Services Building		✓
6. Kowloon City	6.1.	Kowloon Hospital – Phase 1 Redevelopment			✓
	6.2.	New EMSD Headquarters			✓
	6.3.	Education Resource Centre cum Transport Interchange			
	6.4.	Kowloon Tong Fire Station, Ambulance Depot & Fire Command HQ			
	6.5.	Podium garden, Civil Engineering and Development Department (Ho Man Tin)	Government Office	1,043 (planted area)	
	6.6.	Podium garden at Hung Hom Phase 1	Residential	471	
	6.7.	Podium garden at Homantin South Phase 1B	Residential	87	

DISTRICT		NAME OF FACILITY	TYPE OF BUILDING	TOTAL AREA m²	PHOTO
	6.8.	Primary School at Sheung Shing Street, Ho Man Tin	School		✓
	6.9.	Education Resource Centre cum Transport Interchange	School / PTI		✓
7. Wong Tai Sin	7.1.	Ngau Chi Wan Market Roof Top Children's Playground	Municipal Services Building	1,450	
	7.2.	A 36-classroom Primary School in Sze Mei Street, San Po Kong	School		✓
	7.3.	Special School for Physically Handicapped Children at Ngau Chi Wan	School		
	7.4.	Diamond Hill Crematorium	Crematorium	800	
	7.5.	Podium garden at Lok Fu Phase 7	Carport	480	
	7.6.	Podium garden at Wang Tau Hom Phase 12	Commercial	30	
	7.7.	Podium garden at Wang Tau Hom Phase 13	Residential	533	
	7.8.	Podium garden at Wang Tau Hom Phase 14	Residential	502	
8. Kwun Tong	8.1.	Tsun Yip Street Cooked Food Market Roof-top Rest Garden	Market	1,100	
	8.2.	Yee On Street Market Rest Garden	Complex	1,400	
	8.3.	Podium at 2/F in Ngau Tau Kok Municipal Services Building	Municipal Services Building	2,212	
	8.4.	Shun Lee Departmental Quarter			✓
	8.5.	Lei Yue Mun Museum			
	8.6.	Podium garden at Lam Tin Phase 7 & 8	Residential	998	
	8.7.	Podium garden at Lei On Court at Lei Yue Mun	Residential		✓
	8.8.	Podium garden at Lei Yue Mun Phase 1	Residential		✓
	8.9.	Podium garden at Sau Mau Ping Commercial Centre	Commercial	590	
	8.10.	Two 36-classroom Primary Schools in the Eastern Harbour Crossing, Yau Tong	School		
	8.11.	Special School for Physically Handicapped Children at Ngau Chi Wan	School		
9. Sham Shui Po	9.1.	Public Health Laboratory at Nam Chong Street, Shamshuipo	Medical Facility		
	9.2.	Re-provisioning of MHAHK Pak Tin Children Centre at Cornwall Street, Sham Shui Po	School		
	9.3.	Primary School at Site 10, West Kowloon Reclamation	School		
	9.4.	Secondary School at Site 10, West Kowloon Reclamation	School		
	9.5.	Podium garden at Un Chau Street Phase 1	Carport	1177	
	9.6.	Podium garden at Un Chau Street Phase 3	Residential	282	
	9.7.	Secondary School at Lai Hong Road	School		
10. Kwai Tsing	10.1.	Wo Yi Hop Road Cooked Food Market Roof-top Sitting-out Area	Cooked Food Market	1,160	
	10.2.	Lai King Departmental Quarter	Municipal Building		✓
	10.3.	Princess Margaret Hospital Lai King Building	Hospital		✓
	10.4.	Public Mortuary at Area 26E, Kwai Chung			
	10.5.	An 18-Classroom Primary School at Tai Pak Tin Street, Kwai Chung (Non-Standard)	School		

DISTRICT	NAME OF FACILITY		TYPE OF BUILDING	TOTAL AREA m²	PHOTO
	10.6.	Infectious Disease Centre Attached to Prince Margaret Hospital	Hospital		
	10.7.	Re-provisioning of Victoria Prison at Lai Chi Kok Old Staff Quarter	Prison		
	10.8.	Podium garden at Kwai Chung Estate 5 & 7	Planting on Footbridge	50	
	10.9.	Roof-top garden at Shek Lei Phase 10	Refuse Collection Point	126	
	10.10.	Kwai-Chung Ambulance Depot	Hospital Facility		✓
	10.11.	Public Mortuary at Area 26E, Kwai Chung			✓
	10.12.	Improvement Works to Departmental Quarters for the Disciplined Services in Kwai Chung & Kwai Yung Court, Kwai Chung	Municipal Building		
	10.13.	Princess Margaret Hospital Radiotherapy and Accident & Emergency Department	Hospital		✓
	10.14.	Welfare Complex at Lai King Headland, Kwai Tsing	Public Facility		
11.Islands	11.1.	Praya Street Sports Centre Roof-Top Sitting-out Area	Municipal Services Building	411	
	11.2.	Primary School in Area 20, Tung Chung	School		
	11.3.	Secondary School in Area 20, Tung Chung	School		
	11.4.	Secondary School in Area 40, Tung Chung	School		
	11.5.	Second Secondary School in Area 40, Tung Chung	School		
12.Tuen Mun	12.1.	Kwong Choi Market Root-top Garden	Kwong Choi Market	1,450	
	12.2.	Tuen Mun Riverside Park	Roof-top Garden	21,800	
	12.3.	Tuen Mun Cultural Square	Town Hall Complex	13,700	
	12.4.	Tuen Mun Hospital	Hospital		✓
	12.5.	Castle Peak Hospital	Hospital		✓
	12.6.	Primary School at Hing Ping Road	School		
	12.7.	Immigration Services Training School & Perowne Immigration Centre	Municipal Building		
	12.8.	Primary School in So Kwun Wat, Area 55A	School		
	12.9.	Second Primary School in So Kwun Wat, Area 55A	School		
	12.10.	Community Complex at Tseng Choi Street	Public Facility		
	12.11.	Rehabilitation Complex at J/O Tsun Wen Road & Leung Shun Street, Tuen Mun			
	12.12.	Primary School at Hing Ping Road, Tuen Mun	School		
13.Yuen Long	13.1.	Tai Kiu Market Sitting-out-area	Government offices cum market complex	1,480	
	13.2.	Yuen Long Civic Centre	Public Facility		
	13.3.	International Wetland Park & Visitors Centre in Tin Shui Wai	Eco-tourist centre	10,000	✓
	13.4.	Primary and Secondary school at Tin Shui Wai	School		
	13.5.	A Special School in Area 32, Tin Shui Wai	School		
	13.6.	Primary School in Area 12, Yuen Long	School		
	13.7.	Boundary Crossing Facilities in Shekou China, Shenzhen w. Corridor/Deep Bay Link			
	13.8.	Podium garden at Tin Shui Wai Area 101 Phase 1	Residential	128	

DISTRICT		NAME OF FACILITY	TYPE OF BUILDING	TOTAL AREA m²	PHOTO
	13.9.	Podium garden at Tin Shui Wai Area 102 Phase 7	Commercial Centre and Carport	840	✓
	13.10.	Yuen Long Civic Centre	Public Facility		
14.Tsuen Wan	14.1.	Tsuen King Circuit Children Playground	Market Complex	2,525	
	14.2.	Primary School in Ma Wan	School		
	14.3.	NT South Regional Police Headquarters & Operation Base, Tsuen Wan	Government Offices		
	14.4.	Podium garden at Lei Muk Shue Phase 3 & 4	Commercial & Carport	678.4	
15.Sha Tin	15.1.	Sha Tin Government Office	Government Offices		✓
	15.2.	New Laboratory Building at Shatin Sewage Treatment Works	Municipal Facility		
	15.3.	Podium garden at Shatin Area 11 – Shek Mun	Residential	102	
	15.4.	Podium garden at Shatin Area 14B Phase 2	Carport Building	670	✓
	15.5.	Podium garden at Shatin Area 14B Phase 5	Commercial Centre	580	✓
	15.6.	Podium garden at Shatin Area 4D Phase 2	Carport Building	570	
	15.7.	Science Park at Pek Shek Kok Phase 1C - Building 9)			✓
	15.8.	Science Park at Pek Shek Kok Phase 1C - Buildings 7 & 8			✓
	15.9.	Science Park at Pek Shek Kok Phase 1C - Building 6			
	15.10.	Science Park at Pek Shek Kok Phase 1B - Building 4			
	15.11.	Science Park at Pek Shek Kok Phase 1A - Building 1			✓
	15.12.	New Lab. Building at Shatin Sewage Treatment Works	Municipal Facility		
	15.13.	Government Complex in Lee On Estate, Area 108, Ma On Shan	Government Offices		
	15.14.	Roof garden at Primary School in Shatin Area 11	School		✓
	15.15.	Roof garden at Primary School in Shatin Area 11	School		✓
16.North	16.1.	Shek Wu Hui Complex Podium Garden	Municipal Services Building.	2380	
	16.2.	Fanling Departmental Quarter	Government Offices		✓
	16.3.	Fanling Magistracy Building	Government Offices		✓
	16.4.	Retro-fitting of Air-conditioning and General Improvement Works to Shek Wu			
	16.5.	Tai Lung Veterinary Laboratory	Medical Facility		✓
17.Tai Po	17.1.	Amenity area at the podium of Tai Po Complex (landscape area 500 m²)	Complex	2,830	
	17.2.	Market Complex at Area 1, Tai Po	Market		
	17.3.	Refuse Collection Point, Fong Ma Po, Tai Po	Refuse Collection Point		
	17.4.	Redevelopment of Hong Chi Pinehill Schools	School		
18.Sai Kung	18.1.	Sai Kung Waterfront Park	Podium of the park	1216	
	18.2.	Primary School in Area 65, Tseung Kwan O	School		✓
	18.3.	Secondary School in Area 50, Tseung Kwan O	School		✓
	18.4.	Podium garden at Tseung Kwan O Area 73A Phase 1	Commercial Centre	435	✓

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(Central & Western District)
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1.3 – Roof top Garden at Pier 3
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3.2 – North Point Government Offices
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Selected Images of Public Buildings in Hong Kong with Green Roofs

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10.11 – Public Mortuary at Area 26E
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10.12 – Princess Margaret Hospital,
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13.3 – International Wetland Park
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13.9 – Podium Garden, Tin Shui Wai Area 102
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15.1 – Sha Tin Government Office
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15.4 - Podium Garden, Sha Tin Area 14B, Phase 2
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15.14 – Primary School in Area 11, Shatin
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15.15 – Primary School in Area 11, Shatin
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16.5 – Veterinary Lab. at Tai Lung Farm
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18.2 – Prim School, Area 65, Tseung Kwan O
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18.3 – Sec. School, Area 50, Tseung Kwan O
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18.4 – Tseung Kwan O Area 73A, Phase 1
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APPENDIX II
Plant Selection Matrix for Green Roofs (Intensive & Extensive)

Appendix II

PLANT SELECTION MATRIX
FOR GREEN ROOFS
(INTENSIVE & EXTENSIVE)

APPENDIX II: PLANT SELECTION MATRIX FOR GREEN ROOFS (INTENSIVE & EXTENSIVE)

APPENDIX II - PLANT SELECTION MATRIX FOR GREEN ROOFS (INTENSIVE)

Species Name	Common Name (Chinese Name)	Size MEDIUM	Size SMALL	Wind Tolerant	Pollution Tolerant	Evergreen	Deciduous	Fast Growing	Medium Growing	Slow Growing	Conspicuous Flowers	Interesting Foliage	Interesting Fragrance
Trees													
Araucaria heterophylla	Norfolk Island Pine (南洋杉)	✓		H	M	✓				✓		✓	
Callistemon viminalis	Tall Bottle-brush (串錢柳)		✓	M	M	✓				✓	✓		
Cassia surattensis	Sunshine Tree (黃槐)		✓	M	M	✓		✓			✓		
Cinnamomum burmannii	Cinnamon Tree (陰香)	✓		M	M	✓			✓				
Eleaocarpus hainanensis	Hainan Elaeocarpus (水石榕)		✓	M	L	✓				✓			
Ficus benjamina	Weeping Fig (垂榕)	✓		H	H	✓			✓				
Ficus microcarpa 'Golden Leaf'	Golden Chinese Banyan (黃金榕)		✓	H	H	✓			✓				✓
Garcinia spicata	Fortune Tree (福木)		✓	H	H	✓				✓			
Hibiscus tiliaceus	Sea Hibiscus (黃槿)	✓		H	H	✓		✓			✓		
Juniperus chinenisis cv.Kaizuca	Dragon Juniper (龍柏)		✓	H	M	✓				✓			
Koelreuteria bipinnata	Golden Rain Tree (複葉欒樹)	✓		M	L		✓		✓		✓		
Lagerstroemia speciosa	Queen Crape Myrtle (大花紫薇)	✓		M	M		✓	✓			✓		
Magnolia grandiflora	Southern Magnolia (荷花玉蘭)	✓		M	L	✓				✓			✓
Michelia x *alba*	White Jade Orchid Tree (白玉蘭)	✓		M	M	✓			✓				✓
Michelia champaca	Yellow Jade Orchid Tree (黃玉蘭)		✓	M	L	✓			✓				✓
Nageia nagi (syn. Podocarpus nagi)	Nagi (竹柏)		✓	M	L	✓				✓		✓	
Pongamia pinnata	Wild Bean (水黃皮)	✓		H	M	✓			✓		✓		
Podocarpus macrophyllus	Buddhist Pine (羅漢松)		✓	M	L	✓				✓			
Schefflera actinophylla	Umbrella Tree (傘樹)		✓	M	M	✓		✓					
Syzygium jambos	Rose Apple (蒲桃)	✓		M	M	✓			✓				
Thuja orientalis	Chinese Arborvitae (扁柏)		✓	M	L	✓				✓			
Thespesia populnea	Portia Tree (恆 春 黃槿)	✓		H	M	✓			✓		✓		

H - High, M - Medium, L – Low,
Unless other-wise noted, plant photos are sourced from Urbis' plant library.

APPENDIX II - PLANT SELECTION MATRIX FOR GREEN ROOFS (INTENSIVE)

Trees

Araucaria heterophylla
Norfolk Island Pine
(南洋杉)

Callistemon viminalis
Tall Bottle-brush
(串錢柳)

Cassia surattensis
Sunshine Tree
(黃槐)

Cinnamomum burmannii
Cinnamon Tree
(陰香)

Eleaocarpus hainanensis
Hainan Elaeocarpus
(水石榕)

Ficus Benjamina
Weeping Fig
(垂榕)

Ficus microcarpa 'Golden Leaf'
Golden Chinese Banyan
(黃金榕)

Garcinia spicata
Fortune Tree
(福木)

Hibiscus tiliaceus
Sea Hibiscus
(黃槿)

APPENDIX II - PLANT SELECTION MATRIX FOR GREEN ROOFS (INTENSIVE)

Trees

Juniperus chinenisis cv.Kaizuca
Dragon Juniper
(龍柏)

Koelreuteria bipinnata
Golden Rain Tree
(複葉欒樹)

Lagerstroemia speciosa
Queen Crape Myrtle
(大花紫薇)

Magnolia grandiflora
Southern Magnolia
(荷花玉蘭)

Michelia x alba
White Jade Orchid Tree
(白玉蘭)

Michelia champaca
Yellow Jade Orchid Tree
(黃玉蘭)

Nageia nagi
(syn. Podocarpus nagi)
Nagi
(竹柏)

Pongamia pinnata
Wild Bean
(水黃皮)

Podocarpus macrophyllus
Buddhist Pine
(羅漢松)

APPENDIX II - PLANT SELECTION MATRIX FOR GREEN ROOFS (INTENSIVE)

Trees

Schefflera actinophylla
Umbrella Tree
(鴨腳木)

Syzygium jambos
Rose Apple
(蒲桃)

Thespesia populnea
Portia Tree
(恆 春 黃槿)

Thuja orientalis
Chinese Arborvitae
(扁柏)

APPENDIX II - PLANT SELECTION MATRIX FOR GREEN ROOFS (INTENSIVE)

Species Name	Common Name (Chinese Name)	Size MEDIUM	Size SMALL	Wind Tolerant	Pollution Tolerant	Evergreen	Deciduous	Fast Growing	Medium Growing	Slow Growing	Conspicuous Flowers	Interesting Foliage	Interesting Fragrance
Palms & Palm-like Trees													
Areca catechu	Betel Palm (檳榔)		✓	H	H	✓			✓			✓	
Bismarckia nobilis	Bismarck Palm (霸王棕)	✓		H	M	✓			✓			✓	
Cocos nucifera	Coconut Palm (椰子)	✓		H	M	✓			✓			✓	
Cycas revoluta	Sago Palm (蘇鐵)		✓	H	M	✓				✓		✓	
Hyophorbe lagenicaulis	Bottle Palm (酒瓶椰子)		✓	H	M	✓			✓			✓	
Hyophorbe verschaffeltii	Spindle Palm (棍棒椰子)	✓		H	M	✓			✓			✓	
Neodypsis decaryi	Triangle Palm (三角椰子)		✓	H	M	✓			✓			✓	
Pandanus veitchii	Veitch Screwpine (露兜)		✓	H	M	✓				✓		✓	
Phoenix dactylifera	Edible Date Palm (中東海棗)	✓		H	M	✓				✓		✓	
Phoenix hanceana	Date Palm (刺葵)	✓		H	M	✓				✓		✓	
Phoenix sylvestris	Silver Date Palm (銀海棗)	✓		H	M	✓				✓		✓	
Phoenix roebelenii	Dwarf Date Palm (日本葵)		✓	H	H	✓			✓			✓	
Livistona chinensis	Chinese Fan Palm (蒲葵)	✓		H	H	✓			✓			✓	
Wodyetia bifurcata	Foxtail Palm (狐尾棕)		✓	H	M	✓				✓		✓	
Washingtonia robusta	Washington Palm (華盛頓葵)			H	M	✓				✓		✓	

H - High, M - Medium, L – Low,
Unless otherwise noted, plant photos are sourced from Urbis' plant library.

Palms and Palm-like Trees

Areca catechu
Betel Palm
(檳榔)

Bismarckia nobilis
Bismarck Palm
(霸王棕)

Cocos nucifera
Coconut Palm
(椰子)

Cycas revoluta
Sago Palm
(蘇鐵)

Hyophorbe lagenicaulis
Bottle Palm
(酒瓶椰子)

Hyophorbe verschaffeltii
Spindle Palm
(棍棒椰子)

Neodypsis decaryi
Triangle Palm
(三角椰子)

Pandanus veitchii
Veitch Screwpine
(露兜)

Phoenix dactylifera
Edible Date Palm
(中東海棗)

Palms and Palm-like Trees

Phoenix hanceana
Date Palm
(刺葵)

Phoenix sylvestris
Silver Date Palm
(銀海棗)

Phoenix roebelenii
Dwarf Date Palm
(日本葵)

Livistona chinensis
Chinese Fan Palm
(蒲葵)

Wodyetia bifurcate
Foxtail Palm
(狐尾棕)

Washingtonia robusta
Washington Palm
(華盛頓葵)

Plant Selection Matrix for Extensive Green Roofs

This list is derived from existing local knowledge and other overseas sources with humid climatic conditions similar to Hong Kong. It should be noted that plants from these overseas sources (Singapore) do not encounter the dry winters that Hong Kong experiences, making the species they use, possibly not suitable for Hong Kong. They are presented below as having a good chance for success in Hong Kong and also as worthy candidates for planting trials in Hong Kong. This list also includes grasses, ornamentals and annuals even though these vegetation types may not have the ecological functions and low-maintenance features which characterize extensive green roofs. Plant species are listed according to low-maintenance, soil depth, wind tolerance and pollution tolerance - the order of characteristics that best defines extensive green roofs.

APPENDIX II - PLANT SELECTION MATRIX FOR GREEN ROOFS (EXTENSIVE)

Species Name	Family Name	Common Name (Chinese Name)	Minimum Soil Depth (cm)	Maintenance (H / M / L)	Wind Tolerant	Pollution Tolerant	Growth Rate (F / M / S)	Conspicuous Flowers	Interesting Foliage	USED in HONG KONG	ADDITIONAL NOTES (Special Requirements, Location of known use on Extensive Green Roofs, etc.)
Low-maintenance Groundcovers											
Zephyranthes~candida	AMARYLLIDACEAE	Autumn Zephyr-lily (葱蘭)	**8**	**L**	**H**	**M**	F	✓		✓	
Zephyranthes grandiflora	AMARYLLIDACEAE	Rose-pink Zephyr-lily (風雨花)	**8**	**L**	**H**	**M**	F	✓		✓	
Bryophyllum ‘Crenatodaigremontianum’	CRASSULACEAE	Dancing Butterfly (森之蝶舞)	**8**	**L**	**H**	**H**	F		✓	✗	Singapore
Bryophylum fedtschenkoi	CRASSULACEAE	Lavender Scallop, Grey Sedum (花葉落地生根)	**8**	**L**	**H**	**H**	F		✓	✗	Singapore
Furcraea foetida ‘Mediopicta’	AGAVACEAE	Mauritius Hemp, Green Aloe (黄紋萬年麻)	**8**	**L**	**H**	**M**	M		✓	✓	
Kalanchoe tomentosa	CRASSULACEAE	Panda Plant, Pussy Ears (月兔耳)	**8**	**L**	**H**	**H**	M	✓		✗	Singapore
Liriope muscari	CONVALLARIACEAE	Variegated Lily Turf (闊葉麥門冬)	**8**	**L**	**H**	**M**	F			✗	Singapore
Portulaca oleracea	PORTULACACEAE	Purslane (馬齒莧)	**8**	**L**	**H**	**M**	F	✓		✓	Native to HK but not common, Singapore
Portulaca pilosa	PORTULACACEAE	Kiss-Me-Quick, Shaggy Purslane (毛馬齒莧)	**8**	**L**	**H**	**M**	F	✓		✓	Native to HK but not common, Singapore
Rhipsalis mesembryanthemoides	CACTACEAE	Clumpy Mistletoe Cactus	**8**	**L**	**H**	**M**	F		✓	✗	Singapore
Sansevieria trifasciata ‘Golden Hahnii’	DRACAENACEAE	Golden Birdsnest (金邊短葉虎尾蘭)	**8**	**L**	**H**	**H**	M		✓	✓	
Sansevieria trifasciata ‘Hahnii’	DRACAENACEAE	Bird Nest Sansevieria (短葉虎尾蘭)	**8**	**L**	**H**	**H**	M		✓	✓	
Sansevieria trifasciata ‘Laurentii’	DRACAENACEAE	(金邊虎尾蘭)	**8**	**L**	**H**	**H**	M		✓	✓	
Sedum acre	CRASSULACEAE	Biting Stonecrop, Wall Pepper, Golden Moss (金氈景天)	**8**	**L**	**H**	**H**	F		✓	✗	Singapore

APPENDIX II - PLANT SELECTION MATRIX FOR GREEN ROOFS (EXTENSIVE)

Species Name	Family Name	Common Name (Chinese Name)	Minimum Soil Depth (cm)	Maintenance (H / M / L)	Wind Tolerant	Pollution Tolerant	Growth Rate (F / M / S)	Conspicuous Flowers	Interesting Foliage	USED in HONG KONG	ADDITIONAL NOTES (Special Requirements, Location of known use on Extensive Green Roofs, etc.)
Sedum lineare	CRASSULACEAE	Variegated stonecrop (佛甲草)	8	L	H	H	F			✗	Singapore and Shenzhen
Sedum lineare 'Variegatum'	CRASSULACEAE	Variegated Sedum (白佛甲草)	8	L	H	H	F		✓	✗	Singapore
Sedum mexicanum	CRASSULACEAE	Mexicum Sedum (松葉佛甲草)	8	L	H	H	F		✓	✗	Singapore
Sedum nussbaumerianum	CRASSULACEAE	Coppertone sedum (銘月)	8	L	H	H	F		✓	✗	Singapore
Sedum sarmentosum	CRASSULACEAE	Stringy stonecrop (垂盆草)	8	L	H	H	F		✓	✗	Singapore
Sedum sexangulare	CRASSULACEAE	Tasteless Stonecrop (六楞景天)	8	L	H	H	F		✓	✗	Singapore
Sesuvium portulacastum	AIZOCEA	Sea Purslane (海馬齒)	8	L	H	H	F			✓	Native to HK but not common, Singapore
Tradescantia pallida 'Purpurea' New:*Setcreasea purpurea*	COMMELINACEA	Purple Heart (紫鴨跖草)	8	L	H	H	F			✓	
Tulbaghia violacea	ALLIACEAE	Wild Garlic, Society Garlic (蒜味草)	8	L	H	H	F			✗	Singapore
Zephyranthes rosea	AMARYLLIDACEAE	Fairy Lily, Cuban Zephyr-lily (玫瑰葱蓮)	8	L	H	M	F	✓		✗	Singapore
Alternanthera ficoidea 'White Carpet'	AMARANTHACEA	Alternanthera 'White Carpet' (白莧草)	8	L	M	M	F		✓	✗	Singapore
Commelina diffusa	COMMELINACEA	Diffuse Dayflower (節節草)	8	L	M	M	F			✓	
Murdannia nudiflora	COMMELINACEA	Naked Flowered Murdannia (裸花水竹草)	8	L	M	M	F			✓	Native to HK but not common, Singapore
Murdannia vaginata	COMMELINACEA	Sheathed Murdannia (細柄水竹葉)	8	L	M	M	F		✓	✓	Native to HK but not common, Singapore
Portulaca grandiflora	PORTULACACEAE	Ross-moss (松葉牡丹)	8	L	M	M	F	✓		✓	
Arachis duranensis	FABACEAE	Groundnut (蔓花生)	10	L	H	H	F	✓		✓	
Arachis pintoi	FABACEAE	Amarillo (多年生花生草)	10	L	H	H	F	✓		✓	
Axonopus compressus	POACEAE	Carpet Grass (地毯草)	10	L	H	H	F			✓	Grass
Stenotaphrum dimidiatum	POACEAE	Glabrous Stenotaphrums (光鈍葉草)	10	L	H	H	F		✓	✓	
Wedelia chinensis	ASTERACEAE (COMPOSITAE)	Wedelia (蟛蜞菊)	10	L	H	H	F	✓		✓	
Wedelia trilobata	ASTERACEAE (COMPOSITAE)	Wedelia (三裂葉蟛蜞菊)	10	L	H	H	F	✓		✓	
Scutellaria indica	LAMIACEAE	Skullcap (韓信草)	10	L	H	M	M			✓	Native to Hong Kong

APPENDIX II - PLANT SELECTION MATRIX FOR GREEN ROOFS (EXTENSIVE)											
Species Name	Family Name	Common Name (Chinese Name)	Minimum Soil Depth (cm)	Maintenance (H / M / L)	Wind Tolerant	Pollution Tolerant	Growth Rate (F / M / S)	Conspicuous Flowers	Interesting Foliage	USED in HONG KONG	ADDITIONAL NOTES (Special Requirements, Location of known use on Extensive Green Roofs, etc.)
Melastoma dodecandrum	MELA-STOMATACEAE	12-stamened melastoma (地菍)	10	L	M	M	M			✓	For shady areas, Native to HK
Vitex rotundifolia	VERBENACEAE	Beach Vitex (單葉蔓荊)	15	L	H	H	F			✓	Native to Hong Kong
Crinum asiaticum var. sinicum	LILIACEAE	Chinese Crinum (文殊蘭)	15	L	H	M	M	✓		✓	Native to Hong Kong
Hymenocallis littoralis	LILIACEAE	Spider lily (蜘蛛蘭)	15	L	H	H	F	✓		✓	
Osbeckia chinensis	MELA-STOMATACEAE	Chinese Osbeckia (金錦香)	15	L	H	M	M			✓	Native to Hong Kong
Sansevieria trifasciata	AGAVACEAE	Spear sansevieria (虎尾蘭)	15	L	H	H	M			✓	
Alternanthera bettzickiana	AMARANTHACEAE	Calico-plant (紅草)	15	L	M	M	F		✓	✓	
Cyathula prostrate 'Blood-red Leaves'	AMARANTHACEAE	Blood-red Leaves (紫杯莧)	15	L	M	M	F		✓	✓	
Lantana sellowiana	VERBENACEAE	Lantana (馬纓丹)	15	L	M	H	F	✓		✓	
Nephrolepis exaltata	NEPHROLEPIDACEAE	Sword-fern (腎蕨)	15	L	M	M	M			✓	
Ophiopogon jaburan	LILIACEAE	Jaburan Lily-turf (花葉沿階草)	15	L	M	M	F		✓	✓	
Ophiopogon japonicus	LILIACEAE	Blue Grass (沿階草)	15	L	M	M	F			✓	Native to Hong Kong
Asparagus densiflorus cv. Sprengeri	LILIACEAE	Springer Asparagus (天冬)	20	L	H	H	F			✓	
Baeckea frutescens	MYRTACEAE	Dwarf Mountain Pine (崗松)	20	L	H	H	F			✓	Native to Hong Kong
Callisia repens	COMMELINACEA	Creeping Basketplant (舖地錦竹草)	8	M	M	M	F		✓	✗	Singapore
Plectranthus verticillatus	LABIATAE	Swedish ivy (瑞士常春藤)	8	M	M	M	F		✓	✗	Singapore
Rhoeo discolor	COMMELINACEAE	Oyster Plant (蚌花)	10	M	M	M	F		✓	✓	
Rhoeo discolor 'Compacta'	COMMELINACEAE	Dwarf Oyster Plant (矮蚌)	10	M	M	M	F		✓	✓	
Cuphea hyssopifolia	LYTHRACEAE	False Heather (細葉萼距花)	15	M	M	M	F	✓		✓	
Iris tectorum	IRIDACEAE	Crested iris (鳶尾)	15	M	M	M	M	✓		✓	
Liriope spicata	LILIACEAE	Lily turf (山麥冬)	15	M	M	M	F			✓	Native to Hong Kong
Epipremnum aureum (old name: *Scindapsus aureus*)	ARACEAE	Ivy-arum (綠蘿)	15	M	L	M	F			✓	Requires semi-shade and high water requirements
Aerve songuinolenta	AMARANTHACEAE	Songuinea	20	M	M	M	F		✓	✓	

APPENDIX II - PLANT SELECTION MATRIX FOR GREEN ROOFS (EXTENSIVE)

Species Name	Family Name	Common Name (Chinese Name)	Minimum Soil Depth (cm)	Maintenance (H / M / L)	Wind Tolerant	Pollution Tolerant	Growth Rate (F / M / S)	Conspicuous Flowers	Interesting Foliage	USED in HONG KONG	ADDITIONAL NOTES (Special Requirements, Location of known use on Extensive Green Roofs, etc.)
		(血莧草)									
Zoysia japonica	POACEAE	Zoysia Grass (朝鮮草)	20	H	H	M	F			✓	Grass

Note 1: L=Low, M=Medium, H=High, F=Fast, M=Medium, S=Slow.
Note 2: Annotations reading "Native to HK but not common, Singapore" refers to species that are indigenous to Hong Kong (Checklist of Hong Kong Plants, 2004, AFCD) but are not yet widely used and/or may not be commercially available yet. These species have been successful in Extensive Green Roof planting trials in Singapore. As they are indigenous, these species have a very good chance of also being successful on Extensive Green Roofs in Hong Kong.

APPENDIX II - PLANT SELECTION MATRIX FOR GREEN ROOFS (EXTENSIVE)

Aerve songuinolenta
Songuinea
(血莧草)

Alternanthera bettzickiana
Calico-plant
(紅草)

Alternanthera ficoidea 'White Carpet'
Alternanthera 'White Carpet'
(白莧草)

Arachis duranensis
Groundnut
(蔓花生)

Arachis pintoi
Amarillo
(多年生花生草)

Asparagus densiflorus cv. Sprengeri
Springer Asparagus
(天冬)

Axonopus compressus
Carpet Grass
(地毯草)

Baeckea frutescens
Dwarf Mountain Pine
(崗松)

Bryophyllum 'Crenatodaigremontianum' †
Dancing Butterfly
(森之蝶舞)

Bryophylum fedtschenkoi †
Lavender Scallop, Grey Sedum
(花葉落地生根)

Callisia repens
Creeping Basketplant
(舖地錦竹草)

Commelina diffusa
Diffuse Dayflower
(節節草)

Crinum asiaticum var. sinicum
Chinese Crinum
(文殊蘭)

Cuphea hyssopifolia
False Heather
(細葉萼距花)

Cyathula prostrate 'Blood-red Leaves'
Blood-red Leaves
(紫杯莧)

APPENDIX II - PLANT SELECTION MATRIX FOR GREEN ROOFS (EXTENSIVE)

Epipremnum aureum
(old name: *Scindapsus aureus*)
Ivy-arum
(綠蘿)

Furcraea foetida 'Mediopicta' †
Mauritius Hemp, Green Aloe
(黃紋萬年麻)

Hymenocallis littoralis
Spider lily
(蜘蛛蘭)

Iris tectorum
Crested iris
(鳶尾)

Kalanchoe tomentosa †
Panda Plant, Pussy Ears
(月兔耳)

Lantana sellowiana
Lantana
(馬纓丹)

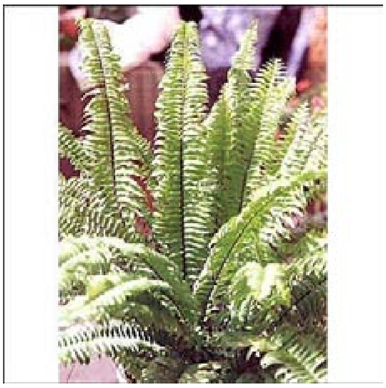
Liriope muscari †
Variegated Lily Turf
(闊葉麥門冬)

Liriope spicata
Lily turf
(山麥冬)

Melastoma dodecandrum
12-stamened melastoma
(地菍)

Murdannia nudiflora †
Naked Flowered Murdannia
(裸花水竹草)

Murdannia vaginata †
Sheathed Murdannia
(細柄水竹葉)



Nephrolepis exaltata
Sword-fern
(腎蕨)

Ophiopogon jaburan
Jaburan Lily-turf
(花葉沿階草)

Ophiopogon japonicus
Blue Grass
(沿階草)

Osbeckia chinensis
Chinese Osbeckia
(金錦香)

Plectranthus verticillatus †
Swedish ivy
(瑞士常春藤)

Portulaca grandiflora †
Ross-moss
(松葉牡丹)

Portulaca oleracea †
Purslane
(馬齒莧)

Portulaca pilosa †

Kiss-Me-Quick, Shaggy Purslane

(毛馬齒莧)

Rhipsalis mesembryanthemoides †

Clumpy Mistletoe Cactus

Rhoeo discolor

Oyster Plant

(蚌花)

Sansevieria trifasciata

Spear sansevieria

(虎尾蘭)

Sansevieria trifasciata 'Golden Hahnii' †

Golden Birdsnest

(金邊短葉虎尾蘭)

Sansevieria trifasciata 'Hahnii' †

Bird Nest Sansevieria

(短葉虎尾蘭)

Sansevieria trifasciata 'Laurentii' †

(金邊虎尾蘭)

Scutellaria indica

Skullcap

(韓信草)

Sedum acre †

Biting Stonecrop, Wall Pepper, Golden Moss

(金氈景天)

Sedum lineare
Variegated stonecrop
(佛甲草)

Sedum lineare 'Variegatum'
Variegated Sedum
(白佛甲草)

Sedum mexicanum †
Mexicum Sedum
(松葉佛甲草)

Sedum nussbaumerianum †
Coppertone sedum
(銘月)

Sedum sarmentosum †
Stringy stonecrop
(垂盆草)

Sedum sexangulare †
Tasteless Stonecrop
(六楞景天)

Sesuvium portulacastum †
Sea Purslane
(海馬齒)

Stenotaphrum dimidiatum ‡
Glabrous Stenotaphrums
(光鈍葉草)

Tradescantia pallida 'Purpurea'
(New name: Setcreasea purpurea)
Purple Heart
(紫鴨跖草)

APPENDIX II - PLANT SELECTION MATRIX FOR GREEN ROOFS (EXTENSIVE)

Tulbaghia violacea †
Wild Garlic, Society Garlic
(蒜味草)

Vitex rotundifolia
Beach Vitex
(單葉蔓荊)

Wedelia chinensis
Wedelia
(蟛蜞菊)

Wedelia trilobata
Wedelia
(三裂葉蟛蜞菊)

Zephyranthes candida †
Autumn Zephyr-lily
(蔥蘭)

Zephyranthes grandiflora †
Rose-pink Zephyr-lily
(風雨花)

Zephyranthes rosea †
Fairy Lily, Cuban Zephyr-lily
(玫瑰蔥蓮)

Zoysia japonica
Zoysia Grass
(朝鮮草)

† Plant photos from Selection of Plants for Green Roofs in Singapore*, copyright © 2005, National Parks Board of Singapore*
http://www.nparks.gov.sg/book_1.asp   *‡ copyright © 2004 Antonie Van Den Boss*

APPENDIX III

References & Bibliography

Appendix III

References & Bibliography

APPENDIX III: REFERENCES AND BIBLIOGRAPHY

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