DESIGN GUIDELINES FOR GREEN ROOFS

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ABSTRACT

Green roof infrastructure promises to become an increasingly important option for building owners and community planners. As we move into the 21st century, green roofs can address many of the challenges facing urban residents. Life cycle costing indicates that green roofs cost the same or less than conventional roofing and they are an investment which provides a significant number of social, environmental and economic benefits that are both public and private in nature. These benefits include increased energy efficiency (from cooling in the summer and added insulation in the winter), longer roof membrane life span, sound insulation, and the ability to turn wasted roof space into various types of amenity space for building occupants. Green roofs filter particulate matter from the air, retain and cleanse storm water and provide new opportunities for biodiversity preservation and habitat creation. They generate aesthetic benefits and help to reduce the 'urban heat island effect' - the overheating of cities in the summer which contributes to air pollution and increased energy consumption.. This article provides an introduction to green roof infrastructure and describes how to implement and market a green roof, looks at costs, and presents three case studies.

Fig. 1– Pelgromhof Senior's Residence Green Roof Amersfort, Netherlands
Photograph courtesy of S. Marshall

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LEARNING OBJECTIVES

After reading this article you should understand:

1. The elements of a green roof
2. How to select the type of green roofs you should employ on your project
3. The public and private benefits and costs of green roofs
4. The important technical issues which must be addressed
5. Maintenance issues which ensure longevity
6. Detailed cost variables for green roofs
7. The potential of green roofs through several case studies

1.0 BACKGROUND

Green roofs are not a new phenomenon. They have been standard construction practice in many countries for hundreds, if not thousands, of years, mainly due to the excellent insulative qualities of the combined plant and soil layers (sod). In the cold climates of Iceland and Scandinavia sod roofs helped to retain a building's heat, while in warm countries such as Tanzania, they keep buildings cool. Canadian examples of early green roofs, imported by the Vikings and later the French colonists, can be found in the provinces of Newfoundland and Nova Scotia.

Fig. 2 – French Fisherman's Cottage
Fort Louisbourg, Nova Scotia, Canada
Photograph courtesy of M. Kuhn

Two modern advocates of green roof technology were the architects Le Corbusier and Frank Lloyd Wright. Although Le Corbusier encouraged rooftops as another location for urban green space, and Wright used green roofs as a tool to integrate his buildings more closely with the landscape, neither was aware of the profound environmental and economic impact that this technology could have on the urban landscape.

Until the mid-20th century, green roofs were viewed mainly as a vernacular building practice. However in the 1960's, rising concerns about the degraded quality of the urban environment and the rapid decline of green space in urban areas, renewed interest in green roofs as a "green solution" was sparked in Northern Europe. New technical research was carried out, ranging from studies on root-repelling agents, membranes, drainage, lightweight growing media, to plant suitability.

In Germany, the green roof market expanded quickly in the 1980's, with an annual growth rate of 15-20%, ballooning from one to ten million square metres. This growth was stimulated largely by state legislation, municipal grants and incentives of 35-40 Deutsch Marks/m^2 of roof greened.[3] Other European states have adopted similar types of support. Several cities now incorporate roof greening into regulations. Stuttgart, for example, requires green roofs on all new flat-roofed industrial buildings.[4] Vienna also provides subsidies and grants for new green roofs at the stages of planning, installation and 3 years post construction to ensure ongoing maintenance. Over 75 European municipalities currently provide incentives or requirements for green roof installation. A key motivator for this support has been the public benefits of storm water runoff reduction, air and water quality improvements. As a result, a new sector in the construction industry has been created, and green roofs have become a common feature in the urban landscape.

Canada and the United States are at least ten years behind Europe in investing in green roof infrastructure as a viable option for solving many quality of life challenges facing our cities. During the early 1990's several large European green roof manufacturers started to venture into the North American markets. However, the systems were hard to sell without public education, local research on technical performance, and accessible examples, especially in a cultural and political climate where many individuals, businesses, and governments do not readily invest in green technologies. This has started to change.

In Canada, landscape architect Cornelia Hahn Oberlander, architects Doug Pollard and Charles Simon, and engineers Greg Allen and Mario Kani, are some of the people who have helped to establish the first green roofs. These include the Boyne River Education Centre in Southern Ontario and Robson Square in Vancouver. More recently, a volunteer group called the *Rooftop Gardens Resource Group* and an industry group called *Green Roofs for Healthy Cities* have been working to develop the green roof market in North America. They provide information, implement demonstration projects and conduct technical research to show the benefits of this technology.

A partnership of the National Research Council's Institute for Research in Construction (IRC), Environment Canada , the City of Toronto, and *Green Roofs for Healthy Cities* has spearheaded research projects in Toronto, including the publicly-accessible roof of the City Hall.

At Laval University in Quebec, the roofing company Soprema is studying plant survivability in support of its Sopranature green roof product. A flurry of green roof-related research and demonstration activity is underway in Chicago, Portland, Winnipeg, and Ottawa. At IRC's Ottawa facilities a roof has been retrofitted to determine more detailed technical data on the performance of green roofs in areas such as energy efficiency and membrane life extension among others.

1.1 INTENSIVE AND EXTENSIVE GREEN ROOFS

A green roof is a green space created by adding layers of growing medium and plants on top of a traditional roofing system. This should not be confused with the traditional roof garden, where planting is done in freestanding containers and planters, located on an accessible roof terrace or deck. The layers of a contemporary green roof system, from the top down, include:

- the plants, often specially selected for particular applications,
- an engineered growing medium, which may not include soil,
- a landscape or filter cloth to contain the roots and the growing medium, while allowing for water penetration,
- a specialized drainage layer, sometimes with built-in water reservoirs,
- the waterproofing / roofing membrane, with an integral root repellent, and
- the roof structure, with traditional insulation either above or below.

The two basic types of green roof systems - extensive and intensive - are differentiated mainly by the cost, depth of growing medium and the choice of plants.

Extensive green roofs are often not accessible and are characterized by:

- low weight,
- low capital cost,
- low plant diversity, and
- minimal maintenance requirements.

The growing medium, typically made up of a mineral-based mixture of sand, gravel, crushed brick, leca, peat, organic matter, and some soil, varies in depth between 5-15 cm (2-6") with a weight increase of between 72.6-169.4 kg / m^2 (16-35 lbs/sf) when fully saturated.[1] Due to the shallowness of the growing medium and the extreme desert-like microclimate on many roofs, plants must be low and hardy, typically alpine, dryland, or indigenous. Typically the plants are watered and fertilized only until they are established, and after the first year, maintenance consists of two visits a year for weeding of invasive species, safety and membrane inspections.[2]

Intensive green roofs are often accessible and are characterized by:

- deeper soil and greater weight,
- higher capital costs,
- increased plant diversity, and
- more maintenance requirements

Fig. 3 – Mountain Equipment Co-op Toronto, Ontario, Canada
Soprema System of Roofing, Curb, Drainage Layer, Filter Cloth and Bagged Growing Medium
Photograph courtesy of M. Kuhn

The growing medium is often soil based, ranging in depth from 20–60 cm (8-24"), with a saturated weight increase of between 290 - 967.7 kg/m^2 (60-200 lbs/sf). Due to the increased soil depth, the plant selection is more diverse and can include trees and shrubs, which allows for the development of a more complex ecosystem. Requirements for maintenance - especially watering - are more demanding and ongoing, and irrigation systems are usually specified. Structural and horticultural consultation and an experienced installer are recommended.

It should be noted that, depending on such site specific factors as location, structural capacity of the building, budget, client needs, and material and plant availability, each individual green roof will be different, likely a combination of both intensive and extensive systems. Table 1 summarizes the advantages and disadvantages of extensive and intensive green roof systems.

Table 1: Comparison of Extension and Intensive Green Roof Systems

EXTENSIVE GREEN ROOF	INTENSIVE GREEN ROOF
• Thin growing medium; little or no irrigation; stressful conditions for plants; low plant diversity.	• Deep soil; irrigation system; more favorable conditions for plants; high plant diversity; often accessible.
Advantages: • Lightweight; roof generally does not require reinforcement. • Suitable for large areas. • Duitable for roofs with 0 - 30° (slope). • Low maintenance and long life. • Often no need for irrigation and specialized drainage systems. • Less technical expertise needed. • Often suitable for retrofit projects. • Can leave vegetation to grow spontaneously. • Relatively inexpensive. • Looks more natural. • Easier for planning authority to demand as a condition of planning approvals. **Disadvantages:** • Less energy efficiency and storm water retention benefits. • More limited choice of plants. • Usually no access for recreation or other uses. • Unattractive to some, especially in winter.	**Advantages:** • Greater diversity of plants and habitats. • Good insulation properties. • Can simulate a wildlife garden on the ground. • Can be made very attractive visually. • Often accessible, with more diverse utilization of the roof. i.e. for recreation, growing food, as open space. • More energy efficiency and storm water retention capability. • Longer membrane life. **Disadvantages:** • Greater weight loading on roof. • Need for irrigation and drainage systems requiring energy, water, materials. • Higher capital & maintenance costs. • More complex systems and expertise.

Source: adapted from: "Greenbacks from Green Roofs: Forging a New Industry In Canada," CMHC. 1998.

Fig. 4– Queen's Quay Terminal Toronto, Ontario, Canada
Green Roof Courtyard with Skylights Architect: Zeidler Roberts
Photograph courtesy of M. Kuhn

2.0 SELLING THE CONCEPT - BENEFITS

One of the most valuable features of green roof infrastructure is that it generates a wide range of social, economic and environmental benefits, both public and private. Many of these are still being qualified in different North America climate zones through both field tests and the use of modeling. Since each green roof installation is unique, the key to success is finding the right mix of benefits for a particular client and for their project. The following describes some of the selling points of green roofs.

2.1 PRIVATE / BUILDING OWNER BENEFITS

2.1.1 ENERGY SAVINGS

In the summer, green roof planting shades the building from solar radiation and, through the process of evapotranspiration, can reduce, if not eliminate any net heat gain. This in turn helps to cool the surrounding area, as well as decreasing the amount of energy required to cool the building.

In the winter, the additional insulation provided by the growing medium helps to decrease the amount of energy required to heat the building. The extent of the energy cost savings impact is a function of:

- the size of the building,
- its location,
- the depth of the growing medium, and
- the type of plants and other variables.

Modeling research suggests that the reduced need for air conditioning in the summer is more substantial than the value of the added insulation in the winter. Building type is a key factor in determining overall cost savings. For example in one or two storey complexes where the roof is a large portion of the building envelope, the cooling energy savings in the summer have been modelled as high as 25%.(5) A 20 cm (8") layer of growing medium and a thick layer of plants has a combined insulative value of RSI 0.14 (R20).(6) Even when the growing media freezes, studies show that 30 cm (12") of growing medium will not experience temperature drops below 0° C (32° F), even when outside temperatures are, -20°(7) Depending on the climate zone, the implementation of a green roof may also allow for a reduction in the requirements for traditional insulation. IRC and Environment Canada research is working to develop a model that will more accurately predict the energy efficiency gains of various green roof systems on different building types.

2.1.2 ROOF MEMBRANE PROTECTION AND LIFE EXTENSION

Green roofs help to protect roofing membranes from extreme temperature fluctuations, the negative impact of ultraviolet radiation, and accidental damage from pedestrian traffic. European evidence indicates that green roofs will easily double the life span of a conventional roof, and thus decrease the need for re-roofing and the amount of waste material bound for landfill. These are direct operational cost savings for the building owner. Life cycle costing data which includes the cost of deferred maintenance and replacement suggests that green roofs cost the same or less than conventional roof systems.

2.1.3 SOUND INSULATION

Green roofs can be designed to insulate for sound, with the growing medium blocking lower frequencies of sound, and the plants blocking the higher frequencies. Tests show that 12 cm (5") of growing medium alone can reduce sound by 40 db.

2.1.4. FIRE RESISTANCE

There is evidence from European manufacturers suggesting that green roofs can help slow the spread of fire to and from the building through the roof, particularly where the growing medium is saturated. However, the plants themselves, if dry, can present a fire hazard. Similar to preventing grass fires at grade, the integration of "fire breaks" at regular intervals across the roof, at the roof perimeter, and around all roof penetrations is recommended. These breaks would be made of a non-combustible material such as gravel or concrete pavers, 60 cm (24") wide, and located every 40 m (130 feet) in all directions. Other options would be the use of "fire retardant plants", such as sedums, which have a high water content, or a sprinkler irrigation system connected to the fire alarm.

2.1.5 ADDITIONAL BENEFITS

There are many specialized applications that justify additional capital expenditures for a green roof, depending on which jurisdiction the building is located in and the occupancy. For example, accessible green roofs, which provide added amenity space for the occupants, can help to increase the unit value of condominiums. In addition to the increased marketability of office or residential suites for buyers, the installation of a green roof may also help gain planning approval for projects from local building officials, community members, and rate payers associations.

Public housing agencies can provide senior citizens and families with safe, accessible green space on top of housing projects, as well as improving their quality of life. School boards can integrate curricula and provide added green space for students – outdoor rooftop classrooms. A project to demonstrate this type of application in under development with Toronto Hydro Energy Services, Toronto Catholic School Board and *Green Roofs for Healthy Cities*. Governments generate publicly accessible park space on top of parking garages, like the new Roundhouse Park in downtown Toronto. It sits above the garage of the new convention centre. Even inaccessible green space on top of commercial buildings in residential areas has significant aesthetic value and may help to speed up the approvals process for new projects.

Fig. 5 – Mountain Equipment Co-op, Toronto, Ontario, Canada
Toit vert
Photographs courtesy of M. Kuhn

Fig. 6 – Roundhouse park, Toronto, Ontario, Canada
Green roof at grade

Hospitals and other health care facilities provide opportunities for horticultural therapy, a proven method of speeding recovery rates and reduction of drug use. A horticultural therapy green roof is currently planned for the roof of a head injury recovery centre in Northern Toronto.

Industrial buildings incorporate specialized green roofs for cooling, to provide amenity space for employees, or simply to improve the aesthetic surroundings for buildings that overlook the roof. Ecover Inc. is a Belgian manufacturer of biodegradable laundry products. Their 1992 factory, has a two-acre green roof with native grasses and wildflowers. Effluent produced by the factory is treated in an on-site sewage pond at grade and then filtered through the green roof, while at the same time acting as irrigation and nutrient source for the plants.

Green roofs are also be designed to generate urban agricultural opportunities for the production of high quality organic foods, and medicinal and ornamental plants. This has the advantage of reducing associated transportation and refrigeration costs, reducing the time and distance from field to table, ensuring ripeness at harvest, and providing new employment opportunities for city dwellers.

2.2 PUBLIC BENEFITS

Although green roofs provide many private benefits, European incentives and legislation for implementation are designed to promote the public benefits of these systems. The two most important of these public benefits are the reduction of the *urban heat island effect* and improved *storm water retention.*

Fig. 7 – Hazelburn Co-op, Toronto, Ontario, Canada
Rooftop Garden
Photograph courtesy of M. Kuhn

2.2.1 URBAN HEAT ISLAND EFFECT

The urban heat island is the overheating of urban and suburban areas, relative to the surrounding countryside, due to increased paved, built-over, and hard surface areas. Average summer temperatures in major cities across North America have been on the rise over the past decade. These artificially high summer temperatures have a range of direct and indirect negative impacts on our quality of life.

The urban heat island effect increases the use of more electricity for air conditioners and it increases the rate at which chemical processes generate pollutants such as ground level ozone. It also exacerbates heat-related illnesses. Green roofs intercept the solar radiation that would strike dark roof surfaces and be converted into heat, thereby improving energy conservation. Like urban forests and reflective roofing surfaces they absorb and/or deflect solar radiation so that it does not produce heat.

An ASHRAE simulation conducted by the City of Chicago of their City Hall green roof showed that every one degree Fahrenheit decrease in ambient air temperature results in a 1.2% drop in cooling energy use. The study suggests that if, over a period of ten years or more, all of the buildings in Chicago were retrofitted with green roofs, (30% of the total land area), this would yield savings of $100,000,000 annually from reduced cooling load requirements in all of the buildings in Chicago. The cooling would also slow the chemical processes that produce ground level ozone, nitrous oxides and smog, and help offset the production of sulphur dioxides from coal fired utilities.[8]

2.2.2 STORM WATER RETENTION

Green roofs can be designed for exceptional storm water retention capability. The plants capture and hold rainwater. Water stored in the growing media is released through evaporation and evapo-transpiration. Storm water retention rates are determined by saturated infiltration capacity, thickness of the growing media, field capacity, porosity, under-drainage layer water retention and flow, and relief drain spacing. A heavily vegetated green roof with a 20-40 cm (8-16") thick growing medium can hold between of water 10-15 cm (4-6").[9] A storm-water retention study for the City of Portland, Oregon found that if half of the buildings in the downtown area had green roofs, (219 acres), an estimated 66 million gallons of water would be retained annually. This would eliminate combined sewage overflows by 17 million gallons.[10] The study indicated that storm water discharges would be reduced between 11 and 15%.

Where jurisdictions demand lot-level storm water charges, zero runoff policies, or a requirement for storm water management ponds, this ability to retain storm water may result in direct and indirect financial incentives. In Germany, 13 municipal governments allow for a reduction in storm water charges for green roof installations. This type of measure is being considered in several North American cities. Portland, Oregon has recently adopted an incentive which awards a density bonus of 3 square feet for every square foot of green roof installed, provided that 60% of the roof area is greened.

2.2.3 AIR CLEANING

Green roofs also filter out fine, airborne particulate matter as the air passes over the plants. Airborne particulates tend to get trapped in the surface areas of the greenery. Rain washes it into the growing medium below. Plants also absorb gaseous pollutants through photosynthesis and sequester them in their leaves (later to become humus).[11] Studies show that treed urban streets have 10-15% fewer dust particles than found than similar streets without trees.[12] In Frankfurt Germany, for example, a street without trees had an air pollution count of 10-20,000 dirt particles per litre of air and a treed street in the same neighborhood had an air pollution count of less than a third of that amount.[13] Based on data from trees, one estimate suggests that a grass roof with 2,000 m^2 of unmown grass (100 m^2 of leaf surface per m^2 of roof) could cleanse 4,000 kg of dirt from the air per year (2 kg per m^2 of roof). This estimate, is probably high since the lower portion of the grass layer is too dense to be in direct contact with the air. However, even if the amount were 1/10th of what trees could remove, 10 m^2 of grass roof could still take out the significant amount of 2 kg of dirt every year.[14]

2.2.4 CREATION OF HABITAT

Green roofs can be designed as acceptable alternative habitats for some species, although they should never be considered as a justification to destroy natural habitat at grade.[15] In Europe, two types of green roof habitats have been defined and implemented, as part of a larger system of wildlife corridors in urban areas. The first is a "stepping stone" habitat that connects natural isolated habitat pockets with each other. It is important to remember that this connection can be by air only (nesting and migrating birds, insects, airborne seeds). The second is an "island" habitat that remains isolated from habitat at grade. This type of habitat would be home to selected plant varieties whose seeds are not spread by air or over short distances.

Green roofs can also be specifically designed to mimic endangered ecosystems / habitats, including the prairie grasslands of the midwest United States or the rocky alvars of Manitoulin Island and the Great Lakes Region in Canada.[16] Extensive green roofs, with their lack of human intervention, are more protected and can become home to sensitive plants that are easily damaged by walking, and to birds species that only nest on the ground. Since the soil on an inaccessible green roof is also less likely to be disturbed, it becomes a safer habitat for insects as well. The deeper the soil the more insect diversity the green roof will support.

3.0 DESIGN & IMPLEMENTATION CONSIDERATIONS

The design and implementation of a green roof project is relatively straight forward, provided the following issues are considered and dealt with. It should be noted that just as each site, each building, each building owner, and each end user is different, so each individual green roof project will vary from the next.

3.1 USE

The primary functions a specific green roof is required to perform will have a profound effect on its overall design. For example, a green roof designed to retain storm water may look very different from one whose main purpose is to brighten a hospital courtyard. Along with the question of aesthetics are inherent differences in the required depth of growing medium, the ongoing maintenance program, and overall cost. This is not to say that a green roof designed to retain storm water cannot or should not also be aesthetically pleasing. Indeed, it can be both, but limiting factors in the budget or the building structure, among others, may concentrate the focus on one or another of these functions.

3.2 LOCATION

Location of the green roof plays an important role in the design process. The height of the roof above grade, its exposure to wind, the roof's orientation to the sun and shading by surrounding buildings during parts of the day will have an impact. The general climate of the area and the specific microclimate on the roof must also be considered. Views to and from the roof may also determine where certain elements are located for maximum effect.

3.3 CONSULTANTS

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

3.4 THE REGULATORY APPROVALS PROCESS

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

Although they are not specifically mentioned in the 1997 Ontario Building Code or the National Building Code, green roof systems are considered an extension of the roof system, and therefore must comply with requirements for structural loading and moisture protection. If the green roof is accessible for more than routine maintenance - in other words, if tenants or the public use the roof as an accessible outdoor green space - then the design must also comply with requirements for occupancy, exiting, lighting, guardrails, and barrier free access. This is not to say that a green roof project will be accepted without question provided that it conforms to the building code. Many of the plans examiners at the various building departments have never heard of this concept, let alone approved the plans for one, so an application for permit will often require an education component, along with a package of background information and test reports from product manufacturers and suppliers. Building codes vary from province to province so you should check the specific requirements prior to proceeding with a project.

3.5 STRUCTURE

Additional loading is one of the main factors in determining both the viability and the cost of a green roof installation. If a green roof is part of the initial design of the building, the additional loading can be accommodated easily and for a relatively minor cost. However, if a green roof is installed on an existing building, the design will be limited to the carrying capacity of the existing roof, unless the owner is prepared to upgrade the structure, which can be a significant investment.

Typical wet soil weighs approximately 1,597 kg per cubic metre (100 lbs per cubic foot). This is a lot, considering that in Ontario, Canada, existing roofs are typically designed for a live load of only 40 lbs per square foot (195 kg per square metre), which includes the snow load. The green roof industry has responded by developing various types of lightweight growing media. The green roof on the new library in Vancouver, British Columbia, Canada, has a 35.6 cm. (14") layer of lightweight substrate made up of sand, pumice, and compost. This weighs only 292.6 kg per square metre (60 lbs/sf) when fully saturated and did not require structural upgrading beyond the standard requirements of the British Columbia Building Code.[17]

Recent editions of the Ontario Building Code have changed requirements for snow loading. In areas like Toronto, a general snow load of only 107 kg per square metre (22 lbs/sf down from 40lbs in earlier editions) must be accommodated on the roof, with capacity for higher snow loading required only in specific areas on the roof which are subject to drifting and build-up.

This leaves 88 kg per square metre (18 lbs/sf) for a green roof installation, - enough for a simple extensive system. On inverted roof applications, where the waterproofing membrane has been applied underneath the loose-laid insulation and a layer of ballast, usually gravel or concrete pavers, the green roof can be used to replace the ballast, thereby effectively allowing an increase in the load bearing capacity of the roof by eliminating the dead load of the ballast material. A thorough analysis of the roof structure may also reveal areas where point loading can be increased - perhaps over a column or along a bearing wall, thus allowing for a combination extensive and intensive system (semi-extensive), with specific areas for deeper growing medium and larger plants. Please note that owners, tenants, and building managers should be made aware of the roof's loading restrictions, through a plan or as a part of a maintenance manual, to avoid future improper relocation or additional plantings in areas which cannot accommodate the weight.

3.6 ACCESS AND EXITS

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

3.7 ROOFING

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

Green roofs can be applied on inverted or traditional roofing systems. If the existing system is inverted, then one needs to determine whether the insulation can be replaced by an equivalent R- value of growing medium. If the insulation is to remain, then good drainage must be ensured to prevent continuous contact with water, and subsequent damage.

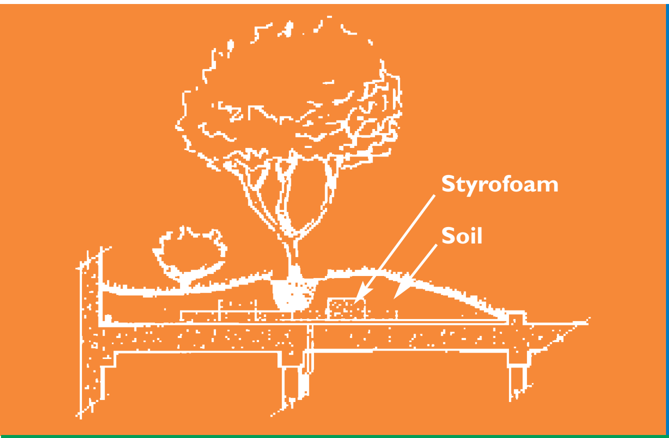


Fig. 8 – Deep Soil over Structural Column

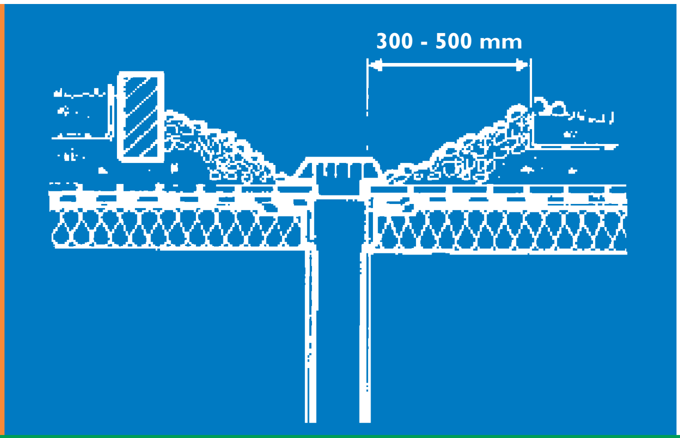


Fig. 9 – Gravel Skirt and Vegetation Barrier Around Roof Drain

Illustrations courtesy of R. Hippolite, based on Grundlagen der Dachbegruenung, Patser Verag, Berlin, 1989.

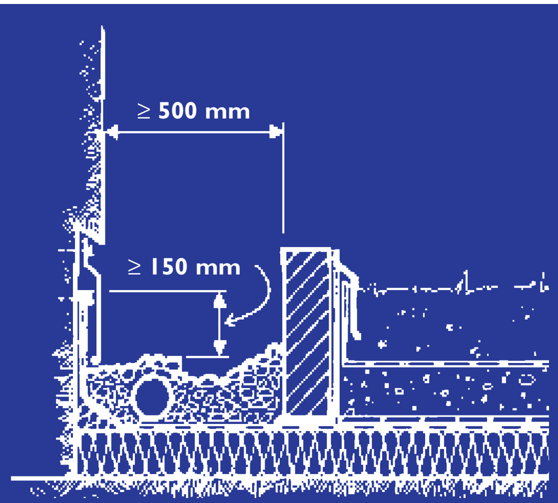
If the membrane, existing or new, contains bitumen or any other organic material, it is crucial to maintain a continuous separation between the membrane and the plant layer, since the membrane will be susceptible to root penetration and micro-organic activity. Some of the new membranes developed specifically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

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

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

3.8 PLANTS

Location, wind, rainfall, air pollution, building height, shade, and soil depth are all factors in determining what plants can be grown and where. The ability of plants to survive on a green roof is directly proportional to the amount of maintenance time and budget allocated to the project, particularly in the first two years when they are getting established. Climatic conditions on a rooftop are often extreme. Unless one is willing to provide shading devices, irrigation, and fertilization, the choice of planting material should be limited to hardier or indigenous varieties of grasses and sedums. Root size and depth should also be considered in determining whether the plant will stabilize in 10 cm (4") or in 60 cm (24") of growing medium. It is vital to know where the plants were previously grown and if the growing conditions were comparable to the ones on the roof to ensure their ability to adapt and flourish. Typically, extensive green roofs rely on a mixture of grasses, mosses, sedums, sempervivums, festucas, irises, and wildflowers - plants that are native to drylands, tundras, alvars, and alpine slopes. On an intensive green roof, with few exceptions, the choices are limitless.



3.9 CONSTRUCTION/INSTALLATION

Be aware of installation issues. The installers should have experience with green roof systems. In fact, it may be preferable to have one company handle the whole project, from re-roofing to planting, thus avoiding scheduling conflicts and damage claims between the various trades. It will also bring single point responsibility post-construction. Methods for getting the materials up to the roof should be discussed to determine cost and potential equipment rentals. Timing is also important.

Fig. 10 – Flashing and Gravel Barrier with Drainage Pipe at a Wall/Roof Connection
Illustration courtesy of R. Hippolite, based on Grundlagen der Dachbegruenung, Patser Verag, Berlin, 1989.

Depending on the local climate, planting in high summer requires extra irrigation to get the plants through the heat before they are established. Fall planting will depend on the availability of suitable plant stock and time enough to allow for the plants to get established before the cold weather sets in. Some plants can be installed while dormant. If you prepare everything in the fall for spring planting there may be some erosion of the growing medium through winter wind and runoff. Covering the roof with burlap or some other material could reduce this problem. Compartmentalization of the green roof into sections may allow for easier access to the membrane and the roof drains, for inspection and maintenance, without having to pull up the whole installation.

3.10 MAINTENANCE

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

Maintenance and visual inspections of the waterproofing membrane can be complicated by the fact that the green roof system completely covers the membrane. Although the green roof protects the membrane from puncture damage and solar radiation, doubling its lifespan, leaks can still occur at joints, penetrations, and flashings, due more to sloppy installation than to material failure. Regular maintenance inspections should be scheduled as for a standard roof installation, especially just before the warranty period expires. Some companies are recommending the incorporation of an electronic leak detection system between or underneath the waterproofing membrane to pinpoint the exact location of water leaks. Access strategies include keeping the sensitive areas free of plants and growing medium (gravel skirts, etc), and dividing the green roof into distinct compartments for ease of removal. Eventually, after 30-50 years, the membrane will have to be replaced. Depending on the roof size, building height, type of planting, and depth of growing medium, the system will either be removed and reinstalled over the new membrane, or replaced entirely. If the green roof can be removed and stored on the roof while the membrane is being replaced in sections, then the additional cost is "labour" only, and comparable to the original installation cost; if the green roof has to be moved off the roof, and then brought back up, costs will increase accordingly, and the arguments for starting fresh, with new growing medium and plants, become more convincing.

3.11 INSURANCE & LIABILITY

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

4.0 DETAILED COST ESTIMATES AND VARIABLES

Although all green roof systems share common components, there are no standard costs for implementation. The two tables below give a range of component costs and identify some of the key variables that determine those costs.

4.1 INACCESSIBLE EXTENSIVE GREEN ROOF

(Costs assume an existing building with sufficient loading capacity; roof hatch and ladder access only. The larger the green roof, the cheaper the cost on a square metre basis.)

	Component	Cost	Notes & Variables
a)	Design & Specifications	5% - 10% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
b)	Project Administration & Site Review	2.5% - 5% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
c)	Re-roofing with root-repelling membrane	$100.00 - $160.00 per sm. ($10.00 - $15.00 per sf.)	Cost factors include type of existing roofing to be removed, type of new roofing system to be installed, ease of roof access, and nature of flashing required.
d)	Green Roof System (curbing, drainage layer, filter cloth, and growing medium).	$55.00 - $110.00 per sm. ($5.00 - $10.00 per sf.)	Cost factors include type and depth of growing medium, type of curbing, and size of project.
e)	Plants	$11.00 - $32.00 per sm. ($1.00 - $3.00 per sf.)	Cost factors include time of year, type of plant, and size of plant - seed, plug, or pot.
f)	Installation / Labour	$32.00 - $86.00 per sm ($3.00 - $8.00 per sf.)	Cost factors include equipment rental to move materials to and on the roof (rental of a crane could cost as much as $4,000.00 per day), size of project, complexity of design, and planting techniques used.
g)	Maintenance	$13.00 - $21.00 per sm ($1.25 - $2.00 per sf) for the first 2 years only.	Costs factors include size of project, timing of installation, irrigation system, and size and type of plants used.
h)	Irrigation System	$21.00 - $43.00 per sm. ($2.00 - $4.00 per sf).	*Optional, since the roof could be watered by hand. Cost factors include type of system used.

4.2 ACCESSIBLE INTENSIVE GREEN ROOF

(Costs assume an existing building with sufficient loading capacity; roof hatch and ladder access only. The larger the green roof, the cheaper the cost on a square metre basis.)

	Component	Cost	Notes & Variables
a)	Design & Specifications	5% - 10% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
b)	Project Administration & Site Review	2.5% - 5% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
c)	Re-roofing with root-repelling membrane	$100.00 - $160.00 per sm. ($10.00 - $15.00 per sf.)	Cost factors include type of existing roofing to be removed, type of new roofing system to be installed, ease of roof access, and nature of flashing required.
d)	Green Roof System (curbing, drainage layer, filter cloth, growing medium, decking and walkways)	$160.00 - $320.00 per sm. ($15.00 - $30.00 per sf.)	Cost factors include type and depth of growing medium, type and height of curbing, type of decking, and size of project. (cost does not include freestanding planter boxes.)
e)	Plants	$54.00 - $2,150.00 per sm. ($5.00 - $200.00 per sf.)	Cost is completely dependent on the type and size of plant chosen, since virtually any type of plant suitable to the local climate can be accommodated (one tree may cost between $200.00 - $500.00.
f)	Irrigation System	$21.00 - $43.00 per sm. ($2.00 - $4.00 per sf.)	Cost factors include type of system used and size of project.
g)	Guardrail / Fencing	$65.00 - $130.00 per lin.m. ($20.00 - $40.00 per lin. ft.)	Cost factors include type of fencing, attachment to roof, and size of project / length required.
h)	Installation / Labor	$85.00 - $195.00 per sm. ($8.00 - $18.00 per sf.)	Cost factors include equipment rental to move materials to and on roof, size of project, complexity of design, and planting techniques used.
i)	Maintenance	$13.50 - $21.50 per sm ($1.25 - $2.00 per sf) annually.	Costs factors include size of project, irrigation system, and size and type of plants used.

5.0 PUBLIC INCENTIVES FOR IMPLEMENTATION

Unlike Europe, few North American public policies provide direct financial incentives or regulatory requirements for green roofs in North America. Despite this, there are a number of avenues described below that may be worth pursuing on behalf of your client. These will vary considerably by jurisdiction.

5.1 STORMWATER MANAGEMENT

Some jurisdictions may reduce water and sewerage charges, or may provide financial incentives to developers or building owners who retain storm water on site. In other jurisdictions, no storm water runoff is permitted in re-developments, particularly in areas where the sewer/ storm water drainage systems are at capacity or the area has a combined sewer system. In jurisdictions that require the construction of storm water management ponds for new developments, green roofs can help to reduce the size of the ponds that would normally be required, thereby saving valuable land for other purposes.

5.2 ENERGY EFFICIENCY

Some governments have programs that provide financial support for the identification and implementation of technologies that generate energy efficiencies beyond a minimum standard, as found in the local building code. Calculation of increased R values and resulting energy reductions will be required.

5.3 OPEN SPACE REQUIREMENTS

Under the planning act and zoning by-laws, many jurisdictions require a certain percentage of the developed property to be landscaped open space and/or publicly accessible green space. Green roofs may provide opportunities to satisfy or partially satisfy these conditions, or provide a bargaining tool for additional density or other desired features that must be negotiated with the local authorities.

5.4 AESTHETIC BENEFITS

In a location where many buildings look down upon a roof, there may be opportunities to speed the approvals process or, reduce public opposition to a project, by incorporating a green roof system and designing it specifically for maximum aesthetic enjoyment.

6.0 CONCLUSION/RESOURCES

Green roofs are a proven technology that provide building owners with opportunities to utilize often wasted roof spaces for energy efficiency, storm water management, sound insulation, and aesthetic improvements. Accessible green roof systems can confer significant added value to a building's occupants or to the general public with benefits ranging from enhanced educational opportunities in schools, private "roofparks" for condominium owners, public parkland, horticultural therapy and even food production. Each green roof system should be tailored to the specific needs of the client, with the variables determining costs. As more governments come to recognize the wide range of public benefits of green roofs and how they can help to address many of the challenges facing cities, they will increasingly look to providing incentives for private building owners to undertake the additional capital costs associated with these systems. Until then, there are many niche opportunities to implement green roof systems and to help demonstrate the many benefits of this technology, including lifestyle benefits amenities.

For more information on green roofs, please visit the following web sites:

- Green Roofs for Healthy Cities
  www.greenroofs.ca
- Rooftop Gardens Resource Group
  www.interlog.com/~rooftop/
- CMHC official web site:
  Research Highlight: Technical Series:
  Greenbacks from Green Roofs Report.
  www.cmhc-schl.gc.ca/publications/en/rh-pr/tech/01-101_e.pdf
  Buildings Innovation
  www.cmhc-schl.gc.ca/en/burema/himu/buin/buin_009.cfm

7.0 CASE STUDIES

MOUNTAIN EQUIPMENT CO-OP, TORONTO, ONTARIO, CANADA

Overview: This inaccessible green roof garden located on downtown Toronto corporate headquarters of the Mountain Equipment Co-op. The 903 m^2 green roof area surrounds a skylight located on the second floor of the building.The roof has full sun exposure and a load capacity of 40 PSF. The green roof uses Soprema SOPRADRAIN PSE for drainage, a Soprema SOPRAFILTRE filter, and Soprema SOPRAFLOR-X growing medium. The vegetation is a wild flower meadow mix of sun flower seeds and perennial plants (contained in 4 inch pots, plantation at a density of 14 plants/m^2).

Owner: Mountain Equipment Co-op

Construction: Installation of the green roof took place in May 1998 and the building was constructed during Fall 1997- Winter 1998.

Partners: Architect: Stone Kohn McQuire Vogt (SKMV) Architects,
Landscape Architect: Ferris + Quinn (with recommendations from Marie-Anne Boivin of Soprema, Inc.)

Structural Engineer: Read Jones Christopherson, Ltd.

Mechanical Engineer: Keen Engineering Co., Ltd.

Landscape Contractor: Top Nature

Drivers: Some items in the program had no quantifiable economic benefit, but to the owner they contributed to social and community leadership. The building was intended to encourage discussion and debate about environmental issues and the green roof has contributed to this.

Fig. 11 – Mountain Equipment Co-op
Toronto, Ontario, Canada
Soprema Green Roof Installation and Planting
Photograph courtesy of M. Kuhn

Barriers:	The possibility of added costs of structural redesign allowing for employee accessibility were barriers. Since the roof structure would have had to be further upgraded to accommodate live loads, accessibility was not incorporated into the design.
Cost:	Labour and materials: $115,000 and structural upgrade: $55,000
Benefits:	The green roof does have environmental and community benefits. It will also have some operating cost benefit due to thermal inertia of mass of growing medium. Successful in the establishment of the vegetation and wildlife (birds, butterflies, insects, etc.). Local developers are considering similar initiatives.
Changes:	Include green roof in original design scope to cut costs. Design to provide limited access by employees for added benefit.

VANCOUVER PUBLIC LIBRARY, BRITISH COLUMBIA, CANADA

Overview:	This extensive 2 400 m^2 green roof in Vancouver can be viewed from surrounding downtown office towers. The inaccessible roof is located on top the 7 storey library. It is oriented toward the city and the harbour. Four different types of trees, green and blue/green tufted fescues are planted in a lightweight growing medium which is composed of reconstituted vegetable waste, sand and pumice.
Owner:	City of Vancouver
Construction:	Building and green roof were constructed in 1995
Partners:	Architects: Moshe Safdie and Associates and, Downs Archambault & Partners
Landscape Architect:	Cornelia Hahn Oberlander
Landscape Contractor:	Jackway Landscaping
Drivers:	Environmental and aesthetic purposes
Barriers:	None
Cost:	Total cost of library green roof : approximately $250,000 ($104/sm.)
Benefits:	The green roof was a great success but no quantifiable data collected

Fig. 12 – Vancouver Public Library Green Roof
Vancouver, British Columbia, Canada
Photograph courtesy of Hydrotech

CITY HALL, TORONTO, ONTARIO, CANADA.

Overview:	This demonstration project is located on the first floor podium roof of the Toronto City Hall building at 100 Queen Street West. The green roof is accessible to the public. It features eight different plots that represent a variety of green roof applications. Two green roof systems were manufactured by Garland and Soprema. The eight plots include: • 2 semi-extensive systems demonstrating a variety of plant types and landscaping techniques • Reproduction of the now rare black oak savannah prairie ecosystem type with native plants drawn from nearby High Par • A bird and butterfly garden with a mixture of native and non-native material • 2 extensive green roof plots demonstrating a wide variety of plants • 2 urban agricultural plots, one of which demonstrates some of the principles and plant types associated with permaculture
Owner:	The City of Toronto
Construction:	Re-roofing and green roof were constructed in the fall of 2000
Partners:	City of Toronto, IRC, Environment Canada and the member companies of *Green Roofs for Healthy Cities* (Flynn Canada, Deboer Environmental Concepts, IRC Building Sciences, Sheridan Nurseries, Soprema and Garland)
Landscape Architect:	Julien Marton
Drivers:	Need for Technical research on performance and demonstration
Barriers:	Many constituencies were involved and needed to be accommodated in order to implement the green roof.
Cost:	Total cost of green roof and reroofing was approximately $265,000, which was shared by Green Roofs for Healthy Cities, the Toronto Atmospheric Fund and the federal government's Climate Change Action Fund. The City of Toronto paid for the value of traditional re-roofing which was scheduled to be replaced in 2004.
Benefits:	The green roof provides an excellent opportunity for public and professional access to a variety of different types of applications in one place.

ENDNOTES

1. Soprema Roofing Inc., 1996 – marketing information.
2. Thompson, 1998, p. 49, in "Greenbacks from Green Roofs" (GBGR) see below.
3. Boivin, 1992, in GBGR.
4. Johnston, 1996, p. 48, in GBGR.
5. Pers. Com. Dr. Brad Bass, Environment Canada, Adaptation and Impacts Research Group, February 2001.
6. Bass, B., Kuhn, M., Peck S., "Greenbacks from Green Roofs: Forging a New Industry in Canada" (GBGR), CMHC. 1998 p. 24. – see for a pdf file of the report.
7. "Vegetative Roof Covers: A New Method for Controlling Urban Runoff in Urbanized Areas", C. Miller. Villanova University, October 1998.)
8. GBGR, p. 30.
9. "Urban Heat Island Initiative Pilot Project: Final Report", Prepared for City of Chicago by Roy F. Weston et. al., May 9, 2000.
10. Beckman, S.; Jones, S.; Liburdy, K. and Peters, C., "Greening Our Cities: An Analysis of the Benefits and Barriers Associated with Green Roofs". Portland State University, Planning Workshop, 1997, p. 26.
11. Minke, 1982, p. 11, in GBGR.
12. Johnston, 1996, p. 10, in GBGR.
13. Minke, 1982, p. 11, in GBGR.
14. ibid., p. 11.
15. Johnston, 1996, p. 49, in GBGR.
16. North American Wetland Engineering, 1998; and Reid, 1996.
17. Thompson, 1998, p. 49, in GBGR.

Q&A'S

1. Why are the ongoing maintenance requirements for extensive green roofs different from those required for intensive green roofs?

2. What are the environmental benefits of green roof installations for municipalities?

3. What are the cost saving benefits for building owners and developers?

4. What are the social benefits for building occupants?

5. What are the advantages of including a green roof in the design phase of a project, rather than in a retrofit situation?

6. Which areas within the Ontario Building Code regulate green roof systems?

7. Why is it recommended to separate the growing medium from the waterproofing membrane?

8. What are three reasons to create a separation between the plants and any roof penetrations?

9. Can green roof systems be installed on a sloped roof?

10. What happens to the green roof system when the waterproofing membrane reaches the end of its life cycle?

For the answers to these questions, please refer to your professional association's Web page.