Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West

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In collaboration with
Green Roofs for Healthy Cities
City and County of Denver
Environmental Protection Agency Region 8
Urban Drainage and Flood Control District
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Purpose

Contemporary green roofs have many benefits that are increasingly being identified, measured, and acknowledged by the general public. These benefits include: controlling quantity and quality of stormwater, cooling and cleaning the air, creating habitat for wildlife, conserving energy, extending the life of the roof, and improving aesthetic environments in work and home settings.

After reading this document you should understand the following:

1. The basic elements of a green roof
2. The benefits associated with green roofs
3. How to select the type of green roof for your project
4. The important technical issues necessary to address during design, implementation and maintenance
5. Maintenance issues which ensure longevity of the green roof
6. Detailed cost variables for green roofs
7. Examples of green roofs through several local case studies

Data and information used in the creation of the *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West* have been primarily generated from the following sources:

1. The FLL guidelines - green roof standards developed by the German Research Society for Landscape Development and Landscape Design (also known as Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.).
2. Green Roofs for Healthy Cities (GRHC), Study Material, Green Roof Professional (GRP) Accreditation Exam.
3. Collective design, implementation and maintenance experience from green roof professionals local to semi-arid and arid climates.

This document offers guidance on green roof design, implementation and maintenance. Acquiring the Green Roof Professional (GRP) Accreditation is strongly recommended for anyone interested in a more comprehensive understanding of these issues.

Disclaimer

Data and information used in the *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West* have been obtained from sources believed to be reliable. However, the various recommendations, regulations, standards and practices referenced in this document are subject to change, and this document is current only to its publication date. For updated recommendations, regulations and standards consult appropriate sources.

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Amendments

From time to time the author and all entities involved in the assembly of the *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West* may amend and/or update this document. Such updates and amendments may create significant differences among successive editions of the document. The *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West* is only as current as its publication date as indicated on the cover page.

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Foreword

A green roof is a living layer that holds the opportunity for discovery, absorption, filtration, release, decay and renewal. It has the ability to hide, to produce, to provide for respite, and to participate in changing culture over time. It is a layer in the urban context that often goes unnoticed as it carries out extremely important functions partaking in the circle of life.

The importances of living systems at different scales are closely interconnected. At an individual/personal scale, studies have show that we seem to be better balanced physically and psychologically, when we are aligned with our environment[1]. Patients with a view to nature recover faster than patients with a view of a brick wall.[2] Green roofs and vertical gardens - by nature - have great potential in urban settings, where enormous surfaces of wall and roof are available and open for vegetation to emerge, unfold and develop. These living layers holds a latent potential that we can tap into as we partner with nature. Green roof systems that help protect, insulate, filter, slow and clean water, provide for wildlife habitat, lower rising temperatures, and clean the air is already acknowledged, implemented and integrated across the nation and across the world.

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1 Kuo, F.E. & Sullivan, W.C. 2001. *Environment and crime in the inner city - Does vegetation reduce crime?* Environment and Behavior , 33 (3), 343-367.
2 Ulrich, R.S. 1984. *View through a window may influence recovery from surgery.* Science. 224:420–421.

To be in a garden high in the air, on top of a building, is the ultimate experience.
It is extraordinary because intuitively we know that here,
a garden is not supposed to be.
It is as if we have stepped into a fairy tale where everything is possible.
We feel that we might have come upon a secret
– upon a magical and mysterious place
that connects us to the unknown.

Leila Tolderlund

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1 INTRODUCTION

OVERVIEW

Intent

The *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West* establishes green roof design, implementation and maintenance recommendations and requirements which apply in general terms to green roofs in the semi-arid and arid regions.

This document is intended for use by professionals and local jurisdictions who are considering taking advantage of all the economic, social and environmental benefits green roofs offer. This includes using green roofs as a strategy to manage stormwater by reducing volumes and improving water quality. This document addresses design, implementation and maintenance principles for both the constructed and vegetated features of green roofs.

The primary purposes of this document are to:

- Establish basic guidelines for the design, implementation and maintenance of a green roof
- Identify and prioritize green roof design, implementation and maintenance tasks
- Quantify and qualify the amount of green roof maintenance necessary
- Provide strategies and checklists for regular green roof maintenance

Definitions

Green roofs are defined as a living system that is an extension of a roof. This green space can be below, at or above grade involving systems where plants are not planted in the ‘ground’. A green roof system contains a high quality waterproofing membrane and root barrier system, drainage system, filter fabric, a lightweight growing medium, and plants. Green roof systems can be modular layered systems already prepared in trays, including drainage layers, growing media and plants, or, each component of the system can be installed separately on top of the structure.

Green roof systems can be shallow (typically referred to as ‘extensive’) or deep (typically referred to as ‘intensive’). Shallow green roofs usually have as little as four to six inches of substrate and do not typically support a large diversity of plant species because of root zone limitations. Deeper green roof systems are more like rooftop gardens with six to eight inches to several feet of growing medium and a wide variety of plants. Some current buildings are not designed to withstand the additional weight load for deeper green roof systems. Consulting a structural engineer prior to design and installation of any type of green roof is strongly recommended and most often necessary.

A green roof is one of many stormwater management strategies and can help mimic pre-development conditions on a site. Many jurisdictions require stormwater quality Best Management Practices (BMP’s) for all new and redevelopment projects exceeding one-half acre. A variety of BMPs are needed to accommodate a wide range of projects. Green roofs preserve possible land development and have benefits that exceed those of stormwater quality.

Stormwater quality in semi-arid and arid climates can be positively impacted by green roofs. The rooftop vegetation retains and filters stormwater, subsequently reducing peak flows and improving the quality of stormwater released into city sewer systems.

Although green roofs have been used in Europe for decades and more recently in temperate areas of the United States, green roof design, implementation and performance parameters are not yet entirely understood in semi-arid and arid climates. In this area low annual precipitation, low average relative humidity, high solar radiation due to elevation, high wind velocities and predominantly sunny days make growing plants on a roof more difficult than in other climates. Because of this, specific design strategies, plant selection, growing media and supplemental irrigation requirements are key considerations for green roof project parameters to continue to evolve for the climate in the semi-arid and arid west.

2 GREEN ROOF TYPES

Shallow green roof systems (also referred to as 'extensive' green roofs[3]) include: **modular tray systems** (growing medium and vegetation in 'modules' or trays), **modular continuous systems** (rolls of growing medium and vegetation) and **loose laid systems** (varying depths of growing medium in traditional layers of green roof). These shallower green roofs have a depth of approximately 4-6" and are typically only accessible for maintenance and not for daily use.

To keep green roof systems shallower than 4" alive in semi arid and arid climates is a challenge. Creating greater plant diversity can also be a challenge for very shallow green roofs although some of these modular, continuous and loose laid systems have proven to be able to hold some diversity of plant species.

The typical weight of shallow green roofs are 15-55 lb/square foot (fully saturated). Some of the advantages include the following: low weight, low maintenance and low irrigation (depending on climate), low capital investment and might be appropriate for large areas. They are also easy to replace and might be more appropriate for retrofit projects.

Modular 4" tray system. Denver EPA.

Image 7.1 Photo courtesy Western Solutions.

Modular 4" continuous system . Denver Justice Center

Image 7.2 Photo courtesy Sempergreen

Loose laid 4-8" deep in areas. Denver Botanic Gardens.

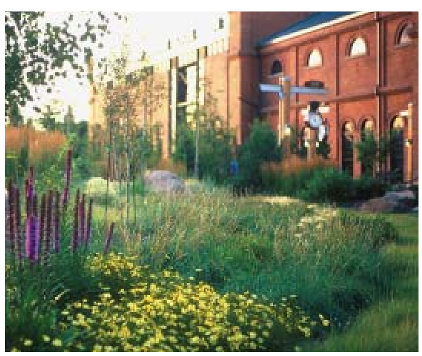
Image 7.3 Photo by Leila Tolderlund

Deeper green roof systems or green roof gardens (also referred to as 'intensive' green roofs[4]) are more than often loose laid systems and typically have a depth of growing medium that exceeds 6-8".

Deeper green roof systems allow for greater plant diversity but are also heavier. The typical weight of deeper green roofs are 80-150+ lb/square foot (fully saturated) and some of the advantages include the following: greater plant diversity and biodiversity, better storm water management and insulation properties, greater design opportunities and greater chance for variety, accessibility and daily use.

Green roof garden. One Riverfront, Downtown Denver.

Image 7.4 Photo by Leila Tolderlund



Green roof garden. REI, Downtown Denver.

Image 7.5 Photo courtesy Wenk Associates

Green roof garden. The Gathering Place, Denver.

Image 7.6 Photo by Leila Tolderlund

3 Dunnett NP, Kingsbury N. 2004. *Planting Green Roofs and Living Walls.* Portland (OR): Timber Press.
4 Idem

3 BENEFITS

Green roofs have many economic, social and environmental benefits. The following subcategories have been created with the understanding that many of these benefits could fit in several or all three categories. The benefits have been subdivided here to highlight significant aspects of these benefits.

ECONOMIC BENEFITS
- Energy Efficiency - Reducing heating and cooling cost for buildings
- Increased Solar Panel Efficiency
- Prolonged Membrane Durability and Longevity - Protecting the membrane
- Fire Prevention
- Local Job Creation
- Meeting Regulatory Requirements for Water Treatment of Urban Runoff
- Reduce Community Resistance to new Developments
- LEED and Opportunity for local, regional and national market exposure

ENVIRONMENTAL BENEFITS
- Creation and Preservation of Habitat and Increasing Biodiversity
- Temperature Regulation - Reduce 'urban heat island effect'
- Improve Air Quality - Filter clean the air
- Stormwater Management – Slow and minimize water runoff
- Water filtration - Filter particulates, pollutants and control temperature

COMMUNITY & SOCIAL BENEFITS
- Aesthetics & New Amenity / Recreational Space
- Improved Health and Horticultural Therapy
- Noise Reduction, Blocking Electromagnetic Radiation
- Creating Ballast against Wind Uplift
- Urban Agriculture - Food production in the city
- Public Education
- Reduction of Waste Volumes

ECONOMIC BENEFITS

Energy Efficiency

Poorly insulated roofs result in building inefficiencies by allowing warm air to escape in the winter and be absorbed in the summer. Green roofs are able to reduce the energy consumption to heat and cool the structure by moderating heat flow through the roofing system.[5] Studies at the National Research Council of Canada (2003) have shown that a green roof can reduced the heat flow through the roof by 70% to 90% in the summer and 10% to 30% in the winter, lowering the energy demand for space conditioning in the building up to 75%.[6] Not only does the green roof positively affect the conditions within the building, it also reduces the ambient temperature on the roof surface which results in better performing HVAC systems. Green roof savings and efficiency considerations include the following: cost of electricity, insulation thickness, HVAC efficiency, percentage of coverage, plant selection, medium depth, irrigation, climactic conditions and roof to wall ratio.

Solar Panel Efficiency - (Also see Chapter 6 for more information.) New studies are being conducted to explore the relationship between green roofs and solar panel efficiency. Keeping a constant temperature on the roof ensures a better efficiency of solar panel energy production.[7]

QUICK FACT

About Green Roofs in the Semi-Arid and Arid West

BENEFITS

- Reduce runoff rates & volumes.
- Reduces heat island effect in urban areas.
- May qualify for multiple LEED credits.
- Extend roof lifespan by reducing daily temperature fluctuations and providing shading from ultraviolet light.
- Provides energy savings from additional insulation & evapotranspirative cooling.
- Provides aesthetically pleasing open space in dense urban areas.

LIMITATIONS

- Limited experience in Colorado.
- Initial installation costs are greater than for a conventional roof (although lifecycle costs may be less).
- Supplemental irrigation required in semi-arid and arid climates.
- Maintenance during vegetation establishment (first two years) and throughout the life of the roof is significant

5 Krajčovičová D., Šprochová K. 2007. *Extensive roof garden as a thermal insulator,* Folia Oecologica, Institute of Forest Ecology, Zvolen; Slovakia. pp. 24-29.
Santamouris M., Pavlou C., Doukas P., Mihalakakou G., Synnefa A., Hatzibiros A., Patargias P. 2007. *Investigating and analysing the energy and environmental performance of an experimental green roof system installed in a nursery school building in Athens, Greece,* Energy (Oxford), Elsevier, Oxford; UK. pp. 1781-1788.
Spolek G. 2008. *Performance monitoring of three ecoroofs in Portland, Oregon*. Urban Ecosystems 11:349-359.
6 Liu, K.; Bass, B. 2005. *Performance of green roof systems*. National Research Council Canada, p.7.
7 Leonard T. and Leonard, J. 2005 *"The Green Roof Energy Performance – Rooftop Data Analyzed,"* Conference Proceedings Green Roofs for Healthy Cities, Washington.
Krauter. S.C.W, 2004. *Enhanced Integrated Solar Home System.* Proceedings of the 19th European Photovoltaic Solar Energy Conference & Exhibition, Paris.

Prolonged Membrane Durability and Longevity
Depending on the climate, waterproofing membrane, and region, a green roof can last up to 2.5-3.0 times as long as a traditional roofing installation. Some green roofs in Germany have lasted up to 30-40 years - sometimes longer, more than double the typical North American roof of 10-15 years. By additionally protecting the waterproofing membrane with a layer of organic and inorganic insulation, green roofs reduce the stress placed on the membrane by preventing severe fluctuations in temperature. This is especially important in semi-arid and arid climates where freeze-thaw cycles, day to night temperature differences and exposure to ultraviolet (UV) radiation can be extreme.

Fire Prevention
A well designed green roof can be successful in preventing the spread of fire. Though some plants may be less fire resistant than others (such as succulents retaining significant amounts of water versus grasses that seasonally dry out), layers of organic matter and even minimal moisture can be effective in preventing the spread of fire. It is important to maintain and provide appropriate fire breaks to limit flammability on all roofs. All green roofs should be in compliance with local fire codes. It should also be noted that some green roofs require a seasonal burn to ensure germination of the plants on the roof. This should be done with supervision from the local fire department and can become a seasonal safe and fun community event.

Local Job Creation
New employment related to the manufacturing, installation, design and maintenance of green roofs rose by over 80% between the years of 2004-2005. This rapidly emerging industry will require and create jobs, both within the profession and from the subsequent job creation of utilizing space in productive ways such as rooftop restaurants and recreational facilities.

Meeting Regulatory Requirements for Water Treatment of Urban Runoff
Urban runoff is water that has been polluted due to contaminants that are picked up on the way, such as motor oil, pet waste, pesticides and other waste. As our cities continue to grow, areas with concrete, asphalt and roof covers are increasing the volume and velocity of urban runoff. Green roofs are great for slowing down the speed of the runoff during events and can help clean the water in the process, before slowly releasing it to rivers and streams. As policies are being implemented to help slow and clean water at the source, green roofs can be a great investment to meet future requirements. Other benefits may happen as a result. For example at the EPA (Environmental Protection Agency) Region 8, a 20,000 square foot 4”deep modular green roof on top of the building helped downsize the required vault in their basement and in turn allowed for a few additional parking spots to be built in the area gained. Ongoing research to test the efficiency and rate at which the green roof is retaining and cleaning the water is currently being conducted. Depth and type of growing medium, type of plant species and type of drainage system are all factors that are important to consider when designing a green roof system for water treatment.

Reduce Community Resistance to New Developments
Cites are becoming more vertical and more dense. To introduce new high-rise buildings into the urban fabric can sometimes be very controversial. Green roofs can help reduce the resistance to new development in providing interesting views with aesthetic and seasonal value for adjacent residents and business owners.

LEED® and Opportunity for local, regional, national and global market exposure
The Leadership in Energy and Environmental Design (LEED®) Green Building Rating System is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. LEED® has become a trend in North American development and green roofs are increasingly being considered to help achieve points toward LEED® certification. Green roofs can help achieve up to 14 points in 5 different categories for LEED®.[8] By making a building more aesthetically and environmentally desirable, green roofs encourage increases in sales, lease outs, property values and employee recruiting.

8 Leadership in Energy and Environmental Design (**LEED®**) - <www.USGBC.org>

ENVIRONMENTAL BENEFITS

Image 11.1 Pollinator on EPA's Green Roof - 2009

Photo courtesy EPA Region 8, Tom Slabe.

Creation and Preservation of Habitat and Ecological Biodiversity

Urban sprawl has affected the health of ecologic systems by disrupting migration corridors and manipulating the resources and vegetation in natural environments. Green roofs can behave as an intermediate link for migration for species of insects and birds, using the urban environment as stepping stones for wildlife movement.[9] The potential for biodiversity depends on plant species and height, surface variation, food sources and building height.

Temperature Regulation - Reduction of Heat Island Effect

Inorganic surfaces such as buildings, standard roofs and parking lots that cover an urban environment are related to a rise in ambient temperature, known as the Urban Heat Island (UHI) Effect. Lack of vegetation, tall buildings and impermeable surfaces prevent natural cooling by wind and evapotranspiration. Consequently, cities reach higher temperatures and remain warmer longer than the surrounding environment.

This condition has demonstrated negative effects because of extreme heat in urban environments. In addition, chemical reactions of gaseous emissions caused by increased temperature have contributed to ground level ozone formation, causing respiratory and cardiac irritation. The rise in temperature also contributes to a greater demand in air conditioning and energy production.

The inclusion of green roofs can reduce UHI by introducing vegetation onto some of the hottest surfaces in urban areas. By means of evapotranspiration and simply covering the roof with a less absorbing surface, temperatures can be reduced. Green roof coverage will translate into significant economic gains by the reduction in energy costs associated with building cooling systems.[10]

The reduction in UHI can be affected by design factors such as the presence of moisture on the green roof, square footage, plant type, and depth and composition of growing medium. (See Chapter 4 for additional information.)

Improved Air Quality

The combination of cars, industrial pollutants and building emissions as well as elevated ambient temperatures result in poor air quality due to increased particulates and air contaminants. Air quality in cities in western states occasionally suffer temperature inversions where polluted air is trapped for periods of time causing a significant decrease in air quality.

Green roofs assist in combating poor air quality, making buildings more efficient and producing fewer emissions while reducing the summertime air temperature on the roof and absorbing gases and particulates through vegetation.[11] Depending on the type of plant, leaf surface and leaf tissue, the contribution to air quality by capturing and filtering airborne pollutants by vegetation can be significant.[12]

QUICK FACT

Urban Heat Island effect

Urban Heat Island (UHI) data collected from the EPA Region 8 office green roof in Denver, Colorado has shown about a 40% overall decrease in net radiative power on the green roof relative to the control roof for the month of July, 2009.

Water retained on the green roof in the substrate and plant material that would otherwise contribute to stormwater runoff and degrade aquatic ecosystems and water quality, is instead used for evaporative cooling for the building and the local environment.

9 Dunnett N., Hallam A., Nagase A. 2008. *The dynamics of planted and colonising species on a green roof over six growing seasons 2001-2006: influence of substrate depth.* Urban Ecosystems 11:373-384.

10 See Appendix A, EPA research provided by Tom Slabe, 2010.
Köhler M. 2004. *Studies of the ecological benefits of extensive green roofs. / Untersuchungen zu ökologischen Vorteilen extensiver Dachbegrünungen Wissenschaftliche Zeitschrift der Technischen Universität Dresden* 53:109-114.
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11 Clark C., Adriaens P., Talbot F.B. 2008. *Green roof valuation: a probabilistic economic analysis of environmental benefits.* Environmental Science & Technology 42:2155-2161.
Currie B., Bass B. 2008. *Estimates of air pollution mitigation with green plants and green roofs using the UFORE model.* Urban Ecosystems 11:409-422.

12 Additional benefit of green roofs is phyto-remediation of soil/growing media and water if designed properly.

Storm Water Management

The amount of impermeable surfaces in an urban environment is directly linked to volume and quality of storm water run-off. Because urban environments tend to have a low percentage of permeable surfaces, a larger volume of stormwater is sent through various management components (e.g. pipes, ditches and tunnels) that eventually lead to rivers, streams and lakes. This increase of runoff volume as well as the increased frequency of runoff causes pollution and erosion in our rivers and streams. Green roofs can help slow and minimize storm water run-off[13] as well as filter particulates, pollutants and control temperature.[14]

As Low Impact Development (LID) strategies have been increasingly promoted throughout the U.S., green roofs have been implemented in some parts of the country, most frequently in areas with humid climates and relatively high annual rainfall. Although there are some green roofs in the semi-arid and arid west, they have not yet been widely installed. Research is in progress regarding the best design approach and plant selection for semi-arid and arid climates. Because the technical community has expressed interest in exploring the water quality and volume reduction benefits of this technique, information on green roofs is provided in this document based on industry literature and academic research.

The runoff diversion for green roofs is both a function of the design and the rain pattern of the local climate. Efficiency of water run-off diversion is typically related to the depth of the system and media composition. The EPA Region 8 green roof is a 4" modular tray system and runoff hare been reduced by 85% for all storms 0.5" or less.[15]

COMMUNITY AND SOCIAL BENEFITS

Aesthetics & New Amenity / Recreational Space

In the past decade, many western cities have witnessed urban renewal with densification through urban infill projects. Sprawling subdivisions have been exchanged for the convenience of shopping, working and public transportation in the city. The urban environment has become visually uniform with little discrepancy in the shape and materials of the buildings that people use for working, living, shopping and playing.

Green roofs help encourage a more thoughtful approach to city planning by increasing amenity and green space, encouraging community gardens and food production and extending commercial and recreational space. By creating additional green space for urban dwellers, what may be perceived as an inorganic environment is given new life and purpose. The introduction of a green roof into the standard building palette creates a unique and desired quality of visual significance. It has been suggested that including greenery in the cityscape reduces stress and patient recovery time, increases property values and has been linked to a reduction in crime.[16]

Image 10.1 One Riverfront, Downtown Denver. Photo by Leila Tolderlund

Improved Health and Horticultural Therapy

The accessibility of outdoor space and views of natural settings has proven to have a positive impact on human health. Studies have found that even visual access to a natural environment results in a reduction of stress, sick leave and ailments and has improved overall health, job satisfaction and productivity.[17] The interaction of individuals with a natural environment has been shown to increase pride of place and encourage social and physical activity. Having a sense of place is a catalyst for community building and pride and has been correlated to a reduction in discriminatory behavior, violence and vandalism.[18]

13 Carter T., Jackson C.R. 2007. *Vegetated roofs for stormwater management at multiple spatial scales.* Landscape and Urban Planning 80:84-94.
14 Frazer-Williams R., Avery L., Winward G., Jeffrey P., Shirley-Smith C., Liu S., Memon F.A., Jefferson B. 2008. *Constructed wetlands for urban grey water recycling.* International Journal of Environment and Pollution 33:93-109.
Hathaway A.M., Jennings G.D., Hunt W.F. 2008. *A field study of green roof hydrologic and water quality performance.* Transactions of the American Society of Agricultural and Biological Engineers 51:37-44
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16 Kuo, F.E. & Sullivan, W.C. 2001. *Environment and crime in the inner city - Does vegetation reduce crime?* Environment and Behavior, 33 (3), 343-367.
Sullivan WC, Kuo FE, DePooter Sf. 2004.*The fruit of urban nature: Vital neighborhood spaces.* Environment and Behavior 36(5):678-700.
17 Ulrich, R.S. 1984. View through a window may influence recovery from surgery. Science. 224:420–421.
18 Fettig, T. 2006. *The Green Machine* [Video], (Director).
Kuo, F.E. & Sullivan, W.C. 2001. *Environment and crime in the inner city - Does vegetation reduce crime?* Environment and Behavior, 33 (3), 343-367.

Noise Reduction, Blocking Electromagnetic Radiation and creating Ballast against Wind Uplift
Though the effects of cell phone use and wireless devices on health and the environment have yet to be fully understood, some feel such technologies may increase the rate of cancer in certain conditions.[19] Green roofs have been tested and shown to reduce electromagnetic radiation up to 94% which may be encouraging for buildings with rooftop telecommunications equipment.[20]

A green roof (and green walls) can reduce the noise level within the building by 40-60 decibels. Such a reduction, coupled with other devices, can make buildings that are internally non-compliant with OSHA standards conform to sound quality levels. The thickness, plant type, growing medium and plant coverage can influence the effectiveness of the green roof (and green wall / vertical garden) to reduce noise levels.

Roofs in this region have to be designed to anticipate and manage wind uplift. This is particularly true for roof corners and along the edges of the perimeter of the roof. Green roof systems on top of the roof membrane can help as ballast against wind uplift.

Urban Agriculture
The proximity of urban centers to agricultural production has extended itself to the point that the average North American food product travels over 1350 miles before it reaches the consumer.[21] Because of the environmental burden that such distribution causes, a new movement of producing some of our food locally has emerged.

The synthesis of urban agriculture and green roofs has yet to be fully realized, but the additional available space that a roof can provide for food production should not be overlooked. By linking food production in urban areas, composting[22] and perimeter farming facilities together, locally produced food can enable cities to be independent of the massive food distribution model currently in place.

Green roofs cannot replace large scale farms, but can assist in developing a model for small scale food production. Community gardens located on rooftops can be places for education and local distribution, as well as a showcase for commercial endeavors such as restaurants utilizing the roof for kitchen gardens.

Green roofs for food production require little alteration from the standardized system, but a few issues need to be considered such as:
- The depth of the growing medium needs to be sufficient for anchoring and sustaining food plants
- Waterproofing membrane needs to be sufficiently protected from frequent use of gardening tools
- Fertilization may be required to sustain nutrient availability in heavily used growing medium
- Safety and quality of produce must be considered



Image 12.1, 12.2 and 12.3

Urban Agriculture and educational garden roof at The Gathering Place, Denver. Photos by Leila Tolderlund

19 Hyland, G, J. 2002. *How Exposure to GSM & TETRA Base-station Radiation can Adversely Affect Humans*. Department of Physics, University of Warwick, Coventry, UK and International Institute of Biophysics, Neuss-Holzheim, Germany.
20 Herman, R. (2003). *Green Roofs in Germany: Yesterday, Today and Tomorrow.* 1st North American Green Roof Conference: Greening rooftops for sustainable communities, Chicago, Il.
21 Pirog, Richard, and Andrew Benjamin. 2003. *Checking the Food Odometer: Comparing food miles for local versus conventional sales to Iowa Institutions.* Ames, IA: Leopold Center for Sustainable Agriculture, Iowa State University.
22 Sherman R. 2005. *Compost plays key role in green roof mixes.* BioCycle 46:29-32, 34.

Public Education

Like ordinary gardens, green roofs provide for a multitude of educational opportunities. For the public to understand that a green roof is not only a beautiful addition but a working system that positively affects the environment is invaluable. The educational aspect of green roofs is one of its most common functions and can provide an encouraging example for developers in other citywide applications.

The Gathering Place on Colfax Avenue and High Street in Denver (See case study page 40) has a playground and vegetable garden on the fourth floor. A tricycle path with letters and numbers wind its way through small planter areas where herbs, vegetables, fruits and flowers are grown. The children participate in seeding in the spring, tending the garden over the summer and harvesting in the fall. Produce from this garden is used on a daily basis in the kitchen at The Gathering Place during the summer months.

Image 13.1 Learning landscape at the Gathering Place, Denver. Herbs are grown in planter boxes and up onto the green screen walls. Planter edges additionally provide seating along edges.
Photo by Leila Tolderlund

Image 13.2 Learning landscape at the Gathering Place, Denver. This green roof play ground has play structure with running water and sand to teach kids about erosion. The garden additionally have planters with vegetables, fruit and herbs, a vertical green screen to provide shade and safety, and a tricycle path with letters and numbers stamped into the concrete.
Photo by Leila Tolderlund

Reduction of Waste Volumes

The simple act of building something to last for a prolonged period of time is one of the key ways to reduce the hundreds of millions of tons of waste that reach North American landfills every year. Green roofs are projected to last up to 2.5-3.0 times as long as traditional roofs by prolonging the life of the membrane, thereby diverting more than half of the materials for re-roofing in the lifetime of the structure. The improved efficiency of the heating and cooling systems of the building from the additional insulation of the green roof[23] may result in less frequent replacement of HVAC systems, also diverting waste from landfills. In addition, deliberate design and material selection can allow the roof to be comprised of the many recycled green roof components currently on the market. Thoughtful use of recycled green roof components ensures that they do not have any trace of toxins and heavy metals, nor any material with fine grained residue, as both create challenges for plant survival.

23 Sidwell et al. 2008. *Thermal Performance of Green Roofs.* Conference Proceedings. Green Roofs for Healthy Cities, Baltimore.
Saiz, S., Kennedy, C.A., Bass, B. and Pressnail K. 2006. *Comparative Life Cycle Assessment of Standard and Green Roofs, Environmental Science and Technology,* 40(13):4312-4316.

4 DESIGN AND IMPLEMENTATION

CONSIDERATIONS BEFORE STARTING A GREEN ROOF PROJECT

A comprehensive checklist of considerations before starting a green roof project has been provided in Appendix D in this document. Initial steps when beginning a green roof project are to determine the actual scope of work and from there determine appropriate consultants and professionals to include in the design team.

Determine Scope Of Work

Identifying the scope of work is essential when considering a green roof installation. Project goals need to be established, developing a plan for implementation, financial constraints, time-line and intent of the project. Issues that need to be addressed are as follows:

• Major design objectives:

The primary function of the roof and the relationship it will have with the building are integral to consequent design objectives. Structural load capacity, environmental considerations, aesthetics and type of use will determine the type of green roof that can be considered for a project.

• Budget:

Budget development is necessitated by a number of factors including accessibility, retrofitting, long-term maintenance, and market maturity. Unlike standard roofing systems[24], green roofs require forethought and a budget that extends beyond the initial phases and construction. Using Life Cycle Assessment (LCA) for green roofs might help shed light over the long term benefits of installing a green roof.[25]

• Accessibility:

The accessibility of the roof is a critical component of any green roof installation. The success of a green roof depends on the ease and safety of access during and after installation, whether for frequent visitors or occasional maintenance.

Assembly of an Appropriate Design Team

An integrated design process is advantageous especially in larger and more complex projects. A green roof is a whole system that will benefit from the contribution of all team players from the initial phases to the finished product. The required expertise depends on the size and scope of the project, from a large scale public installation to a single family residence. Design teams may include the following professionals:

Client	Civil Engineer	Roofing Consultant
Architect	Environmental Engineer	Cost Estimator
Landscape Architect	Mechanical Engineer	Leak detection specialist
Green Roof Consultant	General Contractor	Owners Testing Manager
Structural Engineer	Irrigation Specialist	Quality Assurance Manager
Roofing Consultant	Landscape Contractor	Landscape Maintenance Contractor
Growing Medium Consultant	Roofing Contractor	Future Maintenance Staff
Horticulturist/Agronomist	Manufacturers	Regulatory Agency Representative
Energy Manager	Stormwater Manager	

Determining factors for design team selection include budget, size of the project, time-line, system type and category, new or retrofit construction, and programmed use.

Collaboration between all trades is extremely important through the entire process, but particularly during the initial design stages to avoid costly mistakes, gaps in design, and the complete integration of systems.

24 Most standard roofing systems do require forethought. That is however often neglected.
25 See Green Roofs for Healthy Cities's GreenSave Calculator at <www.greenroofs.org/index.php/greensavecalc/>

SITE ANALYSIS AND SITE SELECTION

The building capacity, surrounding environment and climate are essential determinants of the success of a green roof. Especially important in the arid west are solar orientation, wind and slope considerations. The plant materials that thrive on a green roof need to be well adapted to adverse conditions.

Green roofs can be installed on commercial or residential buildings as well as on underground structures such as the REI parking garage shown in Chapter 10. Green roofs may be particularly well suited for dense urban areas where development is typically lot-line to lot-line and garden space is at a premium as shown in the One Riverfront case study in Chapter 10. Green roofs are especially valuable when their use extends to a place of enjoyment for those that inhabit the building. Several Colorado examples are provided at the end of this document. (See Chapter 10 - Case Studies.)

Building - Design and Implementation Considerations

For existing buildings, structural integrity of the building **must** be verified prior to consideration of retrofitting the building with a green roof. For both existing and new construction, it is essential that a multi-disciplinary team of structural engineers, civil engineers, architects and landscape architects be involved early in the process to ensure that the buildings structural characteristics and site conditions are appropriate for green roof installation.

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

Structural load bearing capacity analysis should include the following:
- Waterproofing membrane - green roof retrofit will also more than likely need a new membrane
- Plant weight at maturity
- Fully saturated growing medium and drainage layers
- Weight of all components including dead and live weights for all phases of the green roof

Structural load bearing capacity will determine the following:

Access
Growing medium type and depth
Function and type of green roof
Replacement and repair strategies
Plant selection

Image 15.1, Example of temporary dead and live loads during installation at the Gathering Place, Denver. Photo by Leila Tolderlund

Typical weight (dead load) of fully saturated green roof systems:

Shallow (extensive) 4-6” green roof systems, including modular, continuous and loose laid systems is 15 - 55 lb/square foot.
Deeper (intensive) green roof systems with depths exceeding 6-8” is 75 - 150 lb/square foot.

As different types of green roofs require differing loading capacity, it is possible to mix types of roofs on one installation to accommodate the structural load. For instance, heavier materials such as trees can be placed on higher weight bearing areas, such as columns or roof perimeters. This is especially important in retrofit projects where it may be necessary to be creative in the location and use of heavier structures. (See Denver Botanic Garden’s green roof - Chapter 10.)

PROVIDING STORMWATER TREATMENT AND SLOW RELEASE

The Urban Drainage and Flood Control District (UDFCD) works with local governments to solve and prevent multi-jurisdictional drainage and flood control challenges in order to protect people, property, and the environment. UDFCD leads the region and the nation in implementing innovative thinking and technology and by promoting wise use of public and private lands, while providing unsurpassed service to the community.

UDFCD provides stormwater management guidance in Volume 3 of the Urban Storm Drainage Criteria Manual (USDCM). The USDCM is frequently used to design Best Management Practices (BMP's) for stormwater quality and quantity. New development and significant re-development projects typically require new BMP's, designed to treat specific volume of runoff from all runoff producing storms. The USDCM includes design of green roofs for treatment of the Water Quality Capture Volume (WQCV), the volume of stormwater associated with the 80th percentile storm. For example, in the Denver Metropolitan area the WQCV is the volume of runoff associated with approximately 0.6 inches of rain.

Based on the data that the EPA has collected to date from the green roof at its Wynkoop Street Regional office, it appears that the EPA green roof retains 98-100% of the WQCV without restricting the flow of water at the outlet. There are a few exceptions which may be attributed to successive rain events. For this reason UDFCD recommends that WQCV-credit be given for the area of the green roof without constructing a controlled release at the outlet. This should be granted for roofs that meet or exceed the EPA green roof section, which is a modular system using trays with four inches (4") of growing media. Systems deeper than 4" should also be considered to capture and retain the WQCV and can be designed to do so more efficiently than a shallow green roof system.

A green roof can also be designed to accept runoff from a traditional roof. This could be done for additional water quality and/or irrigation benefits or, if designed with a slow controlled release, the green roof would provide a WQCV for an area in excess of the area of the green roof. Use Figure (16.1) to determine the WQCV using a 12-hour drain time. This figure provides a WQCV for the Denver metropolitan area which has an annual storm precipitation depth (P6) of 0.43 inches. For use in other areas, the WQCV from the figure can be multiplied by ratio of the local P6 to the P6 in the Denver metropolitan area (P6 for the local area/0.43). The volume should be provided within the void space of the drainage layer and the growing media. This is a function of the material selected. The outlet can be controlled by an orifice or orifices located at one central location or at each roof drain. This is also a function of the overall drainage design.[26]

26 See Appendix A for EPA research quotes.

QUICK FACT

Volume Reduction Data for the EPA Green Roof in Denver

Stormwater performance data collected from the EPA Region 8 office green roof in Denver, Colorado has shown that green roofs can be effective at retaining and infiltrating stormwater runoff. This is especially true for snowmelt events and for smaller precipitation events (generally <1" rainfall in a 24-hour period).
Data from the EPA green roof is available for download and analysis at:
www.epa.gov/region8/building/green_roof.html
This data may be useful in considering additional volume reductions associated with the growing media and evapotranspiration from the vegetation.

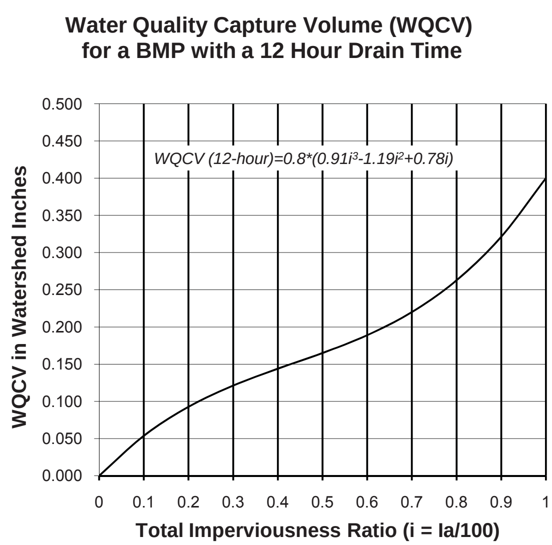


figure 16.1

$$Design\ Volume = \left[\frac{WQCV}{12}\right] * Area$$

ACCESSIBILITY AND SAFETY

All green roofs require some degree of accessibility. Some green roofs might only be accessible for maintenance and other green roof gardens are designed specifically for daily use and high traffic volumes of visitors and users. Types of access may be an elevator, stairs, a stairwell with doorways or a hatch.

During the design phase of the project, access for installation and maintenance must be included and meet job site safety standards and building code requirements. Occupational Safety and Health Administration (OSHA) 29 CFR 1910 Subpart D (general industry standards) and 29 CFR 1926 Subpart M (construction standards) can provide a guide to safety and accessibility requirements. Rules differ according to state or local regulations and type of use.

Designing for Maintenance
A comprehensive checklist for green roof maintenance is provided in Appendix B and general maintenance issues are addressed in Chapter 8. At a minimum, the following should be considered during design development to ensure ease of maintenance for green roofs during and after installation:

- Access for equipment and inspections following construction.

- Access for water is in most green roofs imperative. Irrigation system, growing media and plant selection are critical factors determining long-term maintenance requirements and survival of the green roof vegetation under hot, dry conditions; otherwise, vegetation may have to be repeatedly replanted and/or the irrigation system replaced. Ease of access to multi-functional irrigation timers is recommended.

- If an under-drain system is used, provide a clean-out for both inspection and maintenance. There is potential over the long term for the roof under-drain system to become clogged with growing medium and organic matter that migrates down beneath the plant root zone. The ability to access the under-drain system, flashings, drains, etc for clean-out is essential.

SLOPED ROOFS

The most critical component of any sloped green roof is the confinement system, which holds the growing medium in place during the roof's early stages of development. A pitched vegetated roof can erode and slip under heavy rain, excessive irrigation, or poor plant growth if not properly secured. This is especially true the higher the pitch of the roof. Different strategies can be employed to distribute the weight. Some of the considerations that need to be addressed are inconsistent drainage, irrigation imbalance, and sheer force of gravity, potentially causing the roofing system to be unstable. Vertical 'green roofs' are usually referred to as green walls and are typically divided into two categories - **Living Walls** (plants embedded/growing in the wall) or **Green Walls**/green facades (plants growing from ground level reaching/climbing up onto the wall).

Image 17.1, Example of a steep slope roof.
Photo courtesy American Hydrotech, Inc.

The product shown below (images 18.1, 18.2 and 18.3) provides for drainage as well as distributes the weight of the growing medium through a series of cable tendons to a central engineered connection at the top of the slope. An example where this application was used, is on the American Society of Landscape Architects (ASLA) Head Quarters Green Roof in Washington, DC. A great experience and interesting views are achieved by using sloped green roofs. These forms additionally hide the mechanical systems and are designed with a path around the perimeter to provide for easy maintenance access.

Image 18.1, 18.2 and 18.2

Photo courtesy American Hydrotech, Inc.

Moisture Retention on sloped roofs
Most roofs are designed with a minimum slope of 1-2% to ensure proper drainage (although some roofs are designed to be completely flat). Plants in sloped green roof systems will face greater inconsistency in conditions, as roof line conditions may be excessively dry or water logged near the eaves.

To address disproportionate conditions, irrigation techniques or planting schemes will need to be incorporated such as drought tolerant plants near the ridge or multiple irrigation zones to allow for custom schedules.

Wind/Solar Exposure
A sloped roof is subject to more adverse conditions than a flat roof that may have protection from parapet walls or other sheltering devices. It is essential to analyze sloped roofs for solar and wind exposure and the variability that may affect the roofing system.

Areas of intense sun or shade will change throughout the year. It is necessary to choose plant materials that can acclimate to the extremes in temperature and light in highly variable areas.

Wind may cause the growing medium to erode while plant cover is being established and it may be beneficial to include an erosion protection layer (See Chapter 4 - Green Roof Components).

SYSTEMS AND APPROACHES

Green roofs are typically **modular** (trays or continuous mat) **or loose laid/built-up**.

Modular Systems – Typically ready made flexible (vegetative mats into a woven fabric) or firm (metal or recycled plastic) trays or modules. These ready-made modules typically have the essential components of the system already combined (except irrigation), including:

- Drainage
- Growing medium
- Root barrier layer
- Borders
- Plants

Loose Laid / Built-Up Systems:

Typically are separate installation of green roof components
Typically increase design opportunities, biodiversity and experience
Typically use various subcontractors for design and installation

Loose laid systems are currently the most popular type of installation both in Europe and the US. The majority of work completed in the US and Europe are build-up assemblies. An approach may be to use one system or the other exclusively. However, the components may work together on the same roof to achieve a design goal.

GREEN ROOF COMPONENTS

A green roof is a complex system of layers that work in conjunction to provide aesthetic and performance goals. When designing a green roof, it is critical to make educated and informed decisions about the inclusion or exclusion of certain layers of the system. As with any chain, the weakest link will dictate its performance. Separate components typically only operate properly when the whole system is functioning. Some layers are absolutely necessary in green roof systems (* listed in bold below) and others are optional. Optional layers can be beneficial to the green roof system and design details and objectives may require their inclusion.

Although sometimes not composed, designed and built in this particular order for various reasons such as performance, site constraints or cost, this section of the document will expand on each layer in the following order:

- **Waterproofing Membrane*)**
- **Root Barrier*)**
- **Protection Board*)**
- Insulation and Insulation used as Lightweight Fill
- **Drainage and Flashing*)**
- Water Retention
- Erosion Control
- **Filter Fabric*)**
- **Growing Medium*)**
- **Vegetation*)** and Vegetation Free Zones
- **Irrigation*)** [27]
- Additional Elements and Features

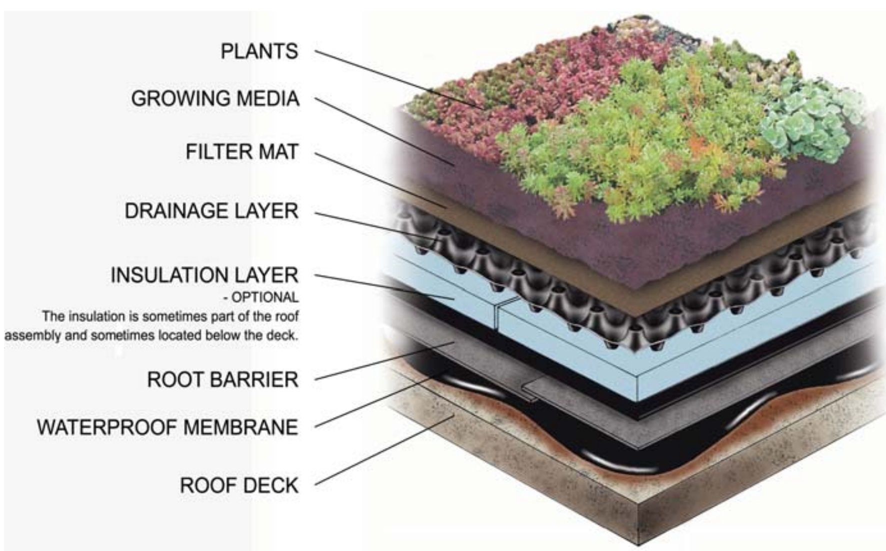
*) Necessary layers

Image 19.1

Typical green roof system layers.

Note: insulation is an optional layer (but usually required by building standard code) and can occur:
- under the slab/roof deck
- under the waterproof membrane - or as shown here above the waterproof membrane.
See Chapter 4 for more information.

Photo courtesy: American Hydrotech, Inc.



27 Due to extreme temperatures in this climate it is essential to the success of most green roofs to have at least a minimum of irrigation during drought periods.

Waterproofing Membrane

The most critical component of a green roof, or any roof, is its ability to prevent water from entering the building. The waterproofing membrane prohibits water from penetrating the building while also facilitating run-off. It is comprised of a material able to withstand hydrostatic pressure (ponding water) for extended periods of time.

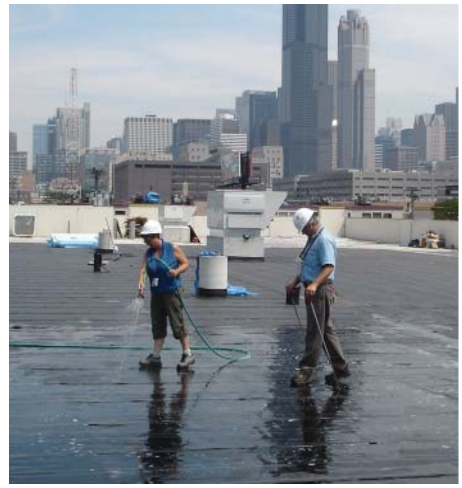


Image 20.1 Waterproofing membrane.
Photo courtesy American Hydrotech, Inc.

The membrane needs to be installed by a professional experienced in green roof applications as this layer is essential to the success of the system. The warranty of the product and the installation, restrictions, and obligations should be understood by all parties at the design and/or specification stage.

As the industry is relatively new in the North American market, design should include membranes that are guaranteed when submerged in water. In semi-arid and arid climates, it is necessary to consider the membrane's durability during storm events where a large amount of precipitation may occur over a short period of time.

Retrofitting over an older membrane may require specific considerations such as roof structural capacity, age and condition. It may be necessary to test the membrane (See Chapter 5 - Leak Detection) and investigate the limitations of the existing roof's warranty.

Image 20.2.
Example of membrane installation.
Photo by Leila Tolderlund

Types of membranes include the following:

- Built-up or modified bitumen
- Rubberized asphalt (completely adhered to the deck)
- Thermoplastic membranes of polyvinyl chloride (PVC)
- Thermoplastic olefin (TPO) (sheets with seams)
- Elastomeric membranes: Ethylene propelyne diene membrane (EPDM) (sheets with seams)

New products on the market include active bi-polymers and urethanes.

Membrane Application:

The waterproofing membrane can be applied to the roof using a number of methods, outlined below. The membrane's ability to withstand moisture infiltration is necessitated by the type, thickness, method of attachment, and the quality of installation and materials used.

Types of ways to apply the membrane are as follows:

- Bonded – hot or cold application
- Torch application
- Self-adhering
- Mechanically attached
- Loose laid – with temporary ballast during application

After installation of the waterproofing membrane a flood test should be done to verify that the membrane has no leaks and is in fact waterproof. (See Chapter 5 for more information on leak detection.)

Root Barrier
The root barrier protects the integrity of the waterproofing membrane by preventing unwanted plant roots from reaching the layer and the supporting structure. Because root systems in semi-arid and arid climates tend to be aggressive for the purpose of survival, this layer is extremely important for any green roof.

Types of root barriers include the following:

- High density polyethylene (HDPE) (various thicknesses)
- Impregnated copper hydroxide
- Impervious concrete
- PVC
- TPO

Additionally, a new Swedish EPDM recently passed the FLL (German green roof construction guidelines, also known as Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V) root barrier test.

Root barrier standards (FM Global) require a thickness of 0.8 mm when used in conjunction with asphalt and bituminous membranes and in assemblies with over 6” of growing medium. Seams need to overlap by 6” and be welded a minimum of 1.5”. Some are overlapped and tapped with a root protection tap.

Every effort should be made to overcompensate in the root barrier. The root barrier should be carried into flashings. Roots, if given enough time and a place to go, will seek moisture and nutrients beyond the growing medium. Eventually they will cause damage to the waterproofing layer, drainage outlets and possibly the structure.

Protection Board
Understanding what happens to the membrane AFTER installation and water proofing testing is crucial. Creating a plan to protect the membrane until all components are installed on top, is essential and a membrane protection board is often used. The typical thickness of a membrane protection board is 1/8 - 1/4 inch and is typically made of a durable material that does not deteriorate in water.

Educating all crew members and personnel who might be on-site during the implementation stages is recommended. It is important to avoid running equipment and machinery that is too heavy for the membrane, installing components, or mis-using of sharp objects, as these might puncture and/or compromise the membrane during construction.

Insulation
Insulation is required by code in the building industry and conserves energy through reduced heat loss or gain. The effectiveness of insulation is measured in its R-value and is a measure for how well a certain material resists thermal influence of heat or cold. In winter, insulation can prevent heat loss and help maintain a consistent soil temperature in the frequent freeze/thaw cycles of semi-arid and arid areas, as well as reducing the demand for air conditioning in the summer.

Most commonly used types of insulation include the following:

- Polyurethane foam
- Polystyrene foam (Expanded and Extruded)
- Fiberglass

Other types of insulation are as follows: expanded perlite, vegetable fiber and isocyanurate foam

Insulation can be installed under the structural slab, right below the membrane or above the membrane as indicated in the graphic on page 19. Due to condensation and efficiency, the preferred location is above the membrane. When insulation is installed in this location, the assembly is often referred to as a protected or inverted roofing membrane assembly (IRMA).

Although insulation with a certain R-value is required for buildings, there is no code for the insulation needed for growing medium and plants. Plants above structure in planters and plants in shallow green roof systems are susceptible to root damage, created by extreme freeze-thaw cycles in semi-arid and arid climates. Especially in the Rocky Mountain region, it is recommended to include 2-3 inches of insulation below the growing medium and along the side edges of planters above structure.

Insulation material such as expanded or extruded polystyrene foam is often used to create lightweight landforms on green roofs where the creation of large volumes of growing medium or other fill material would otherwise have been needed. Using polystyrene products is an alternative that is lightweight, easy to handle, easy to cut and shape on site, inexpensive and readily available. It is necessary to ensure the insulation has drainage grooves (chamfers) and/or is installed with a pitch or tapered toward the drainage outlets to avoid ponding of water on the insulation layer.

Drainage

The drainage layer is a network of boards, pipes and drains intended to remove additional water that might find its way to the waterproofing layer. It allows enough moisture to remain and sustain plant life. Additional functions may be to act as an additional layer to the root barrier or membrane and augment the compressive strength and thermal capacity of the insulation layer.

Types of drainage layers and drainage components include the following:

Granular media (crushed stone, pea gravel or river rock washed and free of small particles)
Rigid drain board (often used for modular systems)
Porous mats of polystyrene, plastic or organic material
Roof drains
Gutters, eaves and troughs
Moisture retention mats
Drain pipes

All components of the drainage system must be kept free of debris and plant material in order to properly convey drainage. The image below (22.1) shows metal edging where a stainless steel plate separates growing media from the rock that surrounds the roof drains. This provides both material separation as well as a root barrier. Landscape edging typically comes with metal stakes. For shallow growing media depths full length stakes must not be used in order to avoid damage to the waterproofing membrane. The metal edging typically used on green roofs is L-shaped and can be held in place by growing media. The metal edging is furthermore perforated at the bottom to allow the growing media to drain as shown in image 22.2 below. A drainage barrier should also be used at the roof’s border with the parapet wall and for any joints where the roof is penetrated or joins with vertical structures.

Image 22.1. Stainless steel plate around the perimeter of a roof drain
Photo courtesy: Urban Drainage and Flood Control District

Image 22.2. Stainless steel edge / steel plate detail.
Photo by Leila Tolderlund

While sloped roofs have the advantage of gravity and a basic gutter system, green roofs with a minimum slope require a more complex drainage scheme which may need to be coordinated with the building's system. Larger systems may require a number of drainage applications to transport water to pipes and downspouts.

Water retention for further uptake by the planting medium and to reduce storm water runoff may be held for a while in the drainage layer. Some drainage boards have been designed as concave systems that improve the ability of the drainage layer to both transport and temporarily retain water. Local building codes will specify the drainage and storage requirement.[28]

Flashing
Flashing is necessary to seal the waterproofing membrane at points of interruption, penetration or termination, such as walls, drains or features. Base flashings cover the edges of the membrane; counter-flashing seals the upper edges of the base flashing. Flashing should be made from corrosive resistant materials such as stainless steel. The root barrier should also be carried into the flashings.

The majority of leaks in a green roof (as with any roof) are not found in the membrane field, but in points of interruption, such as flashing, drainage and anchors. It is vital that these places of weakness be properly designed, installed and maintained.

Water Retention
The water retention layer captures water and retains moisture delivered to the growing medium through evapotranspiration. It may augment the water retention capacity of the drainage layer and increase the performance of the irrigation system.

Types of water retention layer are as follows:

- Plastic sheeting with depression cups
- Urethane foam matting
- Absorbent fleece

Image 26.1. Example of water retention cups.

Photo courtesy American Hydrotech, Inc.

Erosion Control
Special consideration is needed for sloped green roofs (See Chapter 4 - Sloped Roofs for more information). During periods when the vegetation is being established, where the roof is left unplanted or in areas with high winds, an erosion protection layer may be beneficial and sometimes necessary.

Types of protection layer material include the following:

- Protective, non-woven fabric or mats
- Mulch
- Aggregate
- Jute mats
- Protective sheeting

28 It should be noted that water detention is not allowed in Colorado but water retention is. These retention systems slow and release water after rainfall and irrigation.

Filter Fabric

Filter fabric is a lightweight and durable material that prevents the infiltration of particulates into the drainage layer and behaves as a protective barrier to prevent clogging in the drainage system.

Types of filter fabric include:

- Landscape fabric, non-woven, non-biodegradable
- Polyester fiber matting
- Polypropylene-polyethylene matting

Growing Medium

When designing a green roof, special consideration needs to be paid to the formula of the growing medium as it will play a major role in the success or failure of the vegetation. Growing medium is typically a combination of inorganic matter, organic matter, air and water.

Examples of inorganic matter: sand, gravel or lightweight aggregate.

Examples of organic matter: peat, compost, clippings or worm castings.

Some of the characteristics of the growing medium are (in varying degrees, dependent on the requirements of the vegetative layer):

- Good drainage and aeration
- Water holding capacity
- Durability
- Nutrient cycling capacity
- Weight – dry/saturated
- Filtration

The growing medium needs to be specifically formulated to meet the requirements of the vegetation it is intended for as well as be compositionally satisfactory for the intended structural, slope, drainage and climatic conditions. The growing medium anchors the vegetation, giving it nutrients for growth and sustenance. Unlike soils at grade, the green roof growing medium needs to be engineered to meet specific functions of drainage and weight. The medium is specifically developed for a certain application and varies according to the roof's condition. When considering highly specialized applications, it may be necessary to consult a soil scientist.

Green roofs typically require a lightweight growing medium with several features. These features must be balanced carefully in order to provide healthy support systems for plant success. The growing medium must:

- Retain necessary amounts of air and water for plant roots
- Allow water to permeate through planting media
- Provide root stability and plant support
- Resist compaction and maintain integrity
- Drain well enough so that roots are not consistently saturated.
- Be able to resist and stay in place during wind gusts.

Example of typical growing medium composition for semi arid and arid green roofs includes 85-95% expanded shale and 5-15% organic matter.

QUICK FACT

Growing Media Research by Colorado State University at the EPA Green Roof in Denver

CSU researchers are evaluating alternative growing media for green roofs and report: "Most extensive green roof media is predominantly made up of expanded slate, shale or clay. While these materials are very well-drained, lightweight but do not blow away and do not break down like organic materials, they do have some limitations. They typically drain too quickly (too much macro-pore space, not enough micro-pore space) and do not hold nutrients very well (low cation exchange capacity - CEC). A material that has all of the benefits of expanded slate, shale and clay, while having more micro-pore space and higher CEC is ideal. One example of a material that may fit this description is zeolite. Zeolites are currently being utilized as amendments for shallow, well-drained golfgreens."

http://greenroof.agsci.colostate.edu/

Other ratios also can work, for example:

For deeper (also referred to as intensive) applications:

Coarse, lightweight aggregate	30-60%
Sand or fine aggregate	25-45%
Organic matter	5-15%
Air content at maximum water capacity	15% at 45% H_2O

For shallower (also referred to as extensive) applications:

Coarse, lightweight aggregate	50-90%
Sand or fine aggregate	0-35%
Organic matter	0-20%
Air content at maximum water capacity	10% at 35% H_2O

Vegetation

The plant selection is the most distinctive component of a green roof. Designs vary widely to incorporate different plant species and aesthetic functions, but the vegetative layer needs to be carefully considered for the conditions and the projected goals. In many cases, that means considering plants that are native to semi-arid and arid areas or from a region with a similar climate. It also typically means selecting low-water use plants. It is recommended to keep in mind that Hardiness Zones only describe cold extremes and do not take into account the heat zones and warm extremes which are typically experienced in semi-arid and arid climates.

Many green roofs have a shallow and light weight growing medium layer. This results in a composition that is unable to provide stability for larger shrubs and trees. Furthermore, this can be exacerbated as plants grow and windloads increase. Deadmen, or other custom guying systems may be needed in these circumstances.

Plant selection objectives are dependent upon the design goals of the roof, whether the goals are related to function, performance, education or aesthetics. Horticulturists might recommend hardy and adaptable[29] perennial plants with rather shallow, spreading and fibrous root systems. If the green roof is located in an urban setting, these plants must also be able to withstand excess heat and dryness. More aspects to consider in the semi-arid and arid west include the factors of wind and light. Excessive wind, especially on the roofs of skyscrapers and tall buildings, will increase the speed at which moisture is lost from plants as well as from the planting media itself. Intense sunlight, light reflection and heat reflection from surrounding buildings will affect plant health.

Ideal plant characteristics include:

- Lasting, thriving or active through the year and through the seasons or through many years (perennial plants)
- Lateral and adaptable[7] root system (fibrous or woody root system, without a deep tap root)
- Low nutritional requirements
- Low maintenance
- Light weight at maturity
- Drought resistant in both cold dry winters and hot dry summers
- Wind resistant
- Non invasive
- Low, compact, spreading growth habit
- Low dry matter content to alleviate fire safety concerns

29 Adaptable meaning with a root system that is capable of spreading/changing direction when meeting an edge.

Plants that have root systems with the ability to change direction when encountering resistance might have a higher chance of survival. The installation needs to be timed according to suppliers' availability and done during the spring or early fall. Case studies from the Colorado region, with corresponding plant selections, are listed at the end of this document and may prove helpful during the design process. (See Chapter 10 - Case Studies.)

Local conditions have to be considered for any green roof project in semi-arid and arid climates. The rooftop environment, especially in the Rocky Mountain region, is harsh, with extremes of temperature, moisture and solar exposure. In areas with higher elevation, factors such as daily and seasonal temperature change, vegetation cover, plant guilds and oxygen availability should be taken into account. Plants typically suited for semi-arid and arid conditions may thrive in at-grade soils, but may struggle in a similar condition on a roof. When using native plant species, consider that 'native' to the ground is not 'native' to a certain floor on top of a roof or on an underground structure. Various species and cultivars of plants well suited for the green roof environment have been and continue to be tested in this region. When designing a green roof, it is necessary to retain the expertise of a consultant versed in the current palette of plants deemed successful for green roofs in the Rocky Mountain region. Though a particular species may be proven to thrive on green roofs in other areas, the arid climate and temperature fluctuations of the mountain west need special consideration for the vegetative layer. A variety of green roof case studies are provided at the end of this document to give initial guidance.

The extreme nature of the green roof environment and the number of microclimates it produces need to be the foremost consideration when selecting plant species. Though the majority of a roof may be in full sun for the duration of a day, small overhangs and walls may create a period of shade that will affect the plant's performance. Plants adjacent to walls with highly reflective material such as windows or metal panels might experience extremes in temperature or solar reflection during specific hours of the day and during specific times of the year. Likewise, the orientation of a building may be detrimental to some species in that there may be a series of months in the winter where an area of the roof will receive little sunlight and the growing medium may remain frozen.

The structural loading capacity is crucial when considering the type and placement of differing components of the vegetative layer. Larger trees and shrubs (calculated at maturity) may be strategically placed over columns, near the parapet or over/near support structures to increase design flexibility. Lightweight Styrofoam blocks can be considered to achieve variable depth and mounding of surfaces beneath the growing medium.

Larger plants/trees are considerably more expensive to purchase as well as transport to the site. If considering larger trees, additional funds need to be allocated for a crane or conveyance system. Modular systems are more expensive than seeds or cuttings, but the initial impact is sometimes greater.

A four-season, mature roof planting will be more costly than using smaller containers and calipers. It may be necessary to include annuals in the first couple of year's growth to maintain aesthetic qualities while the roof is becoming established.

The underlying structure may influence the success of the vegetative layer. Thermal conductivity differs between materials (i.e. wood verses steel) and the increase in temperature needs to be accounted for as well as in areas near heating, ventilation and air conditioning (HVAC) vents. Green roofs above unheated structures such as a parking garage or a bridge will more than likely experience colder temperatures than green roofs above heated structures.

Factors for consideration when making plant selections:

Growth rates	Nutrient requirements	Sensitivity to pollution
Wind resistance	Solar exposure	Fire resistance
Drought tolerance		

Vegetation Free Zones:
Creating 12 inch vegetation-free zones around the perimeter of a green roof, around drainage zones, flashing areas and other penetration areas (roof top structures, skylights, play equipment, etc) are highly recommended. This zone helps with fire prevention, creates passage in case of a fire, creates accessibility for maintenance and helps prevent roots reaching and damaging the membrane and flashings at these locations. Wind turbulence at roof edges can displace light weight growing medium and is another reason for providing vegetation free zones. The vegetation free zone can be created by material, such as concrete pavers, crushed gravel, pebbles or pavers. For very large green roof areas, vegetation free zones are also recommended to divide the roof into smaller zones in case of a leak or system failure.

Photo 27.1 Example of 12" vegetation free zone at the perimeter of a green roof with vegetation mat. Photo on the right is one month after installation.
Photo courtesy Andy Creath

Irrigation
Green roof environments in the semi-arid and arid west are at times extremely challenging. Conditions can become severe with high winds, extremes temperature fluctuations and drought conditions. Conditions on a 2nd or 3rd story roof are very different than conditions on a 30 or 40 story roof.

Some drought resistant plants can survive without supplemental water, once established. Nevertheless, it is more than likely necessary to include irrigation as part of the establishment stage for green roof systems in semi-arid and arid climates. Though it may be possible to reduce or eliminate irrigation, only very specific plant types can survive in this climate without irrigation. An irrigation system (temporary and/or permanent) should be integral to the design's success and additional watering in times of extreme heat and drought will, in all likelihood be necessary.

Types of irrigation include the following:
- Overhead spray
- Drip
- Hose bib or hose
- Capillary

The decision to use drip or spray irrigation is based on growing medium characteristics and plant needs. Drip irrigation might prove insufficient if the growing medium restricts lateral movement of water. Custom detailing of irrigation systems may be necessary to avoid damage to the waterproofing membrane because of the shallow depths of growing medium. For example, typical concrete thrust blocks for irrigation mainlines may have to be detailed differently. Drip irrigation is sometimes more effective when installed below the vegetation layer to avoid heating of the drip line and to get a more effective watering of the roots. Spray irrigation should be considered for shallow depth applications as drip irrigation may not spread laterally when applied over a rapidly draining medium. Current Colorado State University experiments are determining the extent of irrigation requirements for various plants. Initial results suggest non-succulents dry out faster (need more frequent irrigation), whereas succulent plants require less frequent irrigation. However, succulents tend to die rather than go dormant during prolonged dry periods. Installation of irrigation monitoring equipment such as timers, flow meters, sensors, runoff monitors and precipitation monitoring equipment can vastly improve irrigation procedures and conserve water.

Additional Elements and Features typically used on green roofs are as follows**:**

Curbs and borders
Furniture and shade structures
Lighting
Planters and seat walls
Railings and green screens
Vents and pipes
Walkways , stepping stones and paths.
Water features

Curbs and borders separate vegetated areas from walls, drains, skylights and walkways. They may also serve as a fire break and protection from wind. Planter edges can double as seating and create confined area. It is important to ensure that any contained area has a drain (or several drains if needed) and a strategy for overflow. It is also important to ensure easy access for maintenance of these interior drains. Examples of curbs and borders are pre-cast concrete curbs, planter boxes, aluminum edging and timbers.

Furniture and shade structures (including benches, trash cans, trellis systems and play equipment) have to be fastened to the roof. It is extremely important that any penetration point is waterproof and have flashing to ensure the membrane is not compromised over time. Lighting offers illumination along paths and features to guide the user as well as adding focus to design features.

Walkways, such as pavers-on-pedestals or cast-in-place paths are helpful as a means of encouraging circulation and maintenance. They direct and control movement where necessary. Pavers can also be placed directly on top of growing medium. Examples of walkways are pre-cast concrete pavers, natural stone, recycled plastic decking, gravel, crusher fines, concrete slabs and wood.

Water features, such as ponds, fountains and waterfalls can be incorporated into the drainage system. It might be helpful to have separate waterproofing systems for these water features as extra prevention against leakage. Water features can be integrated into storm water management or mechanical cooling systems.

Railings and green screens are important safety components and often a code requirement. Railings and green screens provide protection from falls during construction, as well as during normal use. They can also function as privacy screens, provide shade and be an aesthetic addition to a green roof as shown here.



Photo 28.1, 28.2 and 28.3 Example of green screens and parapet planters at The Gathering Place, Denver.

Photos by Leila Toderlund

5 LEAK DETECTION

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

Types of flood tests usually used for leak detection are **flood test (**typically 2" of water is temporarily retained for 24-48 hours to determine effectiveness of the water proofing system) and **flowing test** (flowing water continuously over the surface of the waterproofing membrane for a minimum of 24 hours without closing the drains or erecting dams). Other strategies for detecting leaks include electric field vector mapping, infrared (IR) thermal imaging, nuclear testing, capacitance test and moisture sensors.

Photo 29.1 Example of flood test at the Denver Botanic Garden green roof.
Photo courtesy Mark Fusco

Photo 29.2 Example of flood test at a Denver residential green roof.
Photo courtesy Andy Creath

Photo 29.2 Example of flood electric field vector mapping
Photo courtesy American Hydrotech, Inc

6 INTEGRATION OF SOLAR PANELS ON GREEN ROOFS

A new and quite successful trend is to integrate solar panels on green roofs. Studies have shown[30] that there is a symbiotic beneficial relationship between green roofs and solar panels. The green roof will lower the temperature of the roof and ultimately ensure a greater solar panel efficiency. In turn, the solar panels provides shade for the green roof below, creating interesting micro-climates and providing temporary relief from the sun.

Image 30.1 Integration of solar panels on a green roof. EPA, Region 8, Denver. Photo by Leila Tolderlund

7 INSURANCE/ WARRANTY AND LIABILITY

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

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

30 Leonard T. and Leonard, J. 2005 *"The Green Roof Energy Performance – Rooftop Data Analyzed,"* Greening Rooftops for Sustainable Communities Conference Proceedings. Green Roofs for Healthy Cities, Washington.

8 DESIGNING FOR MAINTENANCE

GREEN ROOF MAINTENANCE

A maintenance plan should be established prior to the completion of all new green roofs. Both plant maintenance and inspection of membrane flashing points and various roof structural elements are regularly required.

Green roof plants require regular attention and care including irrigation, weeding, fertilizing, pruning and replanting. (See APPENDIX B for a Green Roof Maintenance Manual Checklist.) Some maintenance procedures should be scheduled after events (such as floods and storms) while others can be scheduled according to seasonal events (such as germination period, season for certain invasive and unwanted species and in the fall after leaf fall).

MEMBRANE MAINTENANCE

The waterproofing roof membrane is the most vital aspect of green roof longevity and success. There are areas where regular inspections are advised at least three times per year. These include all joints, borders or other features penetrating the roof, such as all abutting vertical walls, roof vent pipes, outlets, air conditioning units and perimeter areas.

In addition:

- Joints must offer open access for inspection, maintenance and upkeep.
- Any areas or joints (such as vents, ducts, drains and expansion joints, etc) where the roof is penetrated should be regularly inspected and kept free of roots, leaves, rocks and debris.
- A vegetation free zone 12-18 inch around the perimeter of the roof and around all drainage locations is recommended. (See Chapter 4 - Vegetation). The vegetation free zone typically has rocks, stone or gravel as seen on image 31.1 below.

DRAIN INSPECTION

Plants are susceptible to insufficient drainage in the soil. If too much water is present and unable to drain, the plants will drown or rot. Regular inspections of drains should take place approximately three times per year, with additional inspections advised after major weather events.

All drains must remain free of vegetation and foreign objects. Inspection of drainage flow paths is crucial because of the severe consequences of drainage back-ups. In order to allow for regular inspections and maintenance, every drain on a green roof must remain permanently accessible. Roof outlets, drains, interior gutters, and emergency overflows should be kept free from obstruction by either providing a drainage barrier (e.g., a gravel barrier between the green roof and the emergency overflows) or they should be equipped with an inspection shaft.

Image 31.1. Vegetation free zone around roof drain being cleaned out. Photo courtesy: Urban Drainage and Flood Control District.

If an under-drain system is used, provide a clean-out for both inspection and maintenance. There is potential over the long term for the roof under-drain system to become clogged and the ability to access the under-drain system for clean-out is imperative.

SURROUNDS AND ROOFTOP STRUCTURES

Surrounds must be designed and installed with consideration for the structural integrity of the roof membrane and for water drainage. Drainage outlets may be installed at the foot of the surrounds, depending on layout of the roof regarding paved and vegetated areas.

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

PLANTS AND GROWING MEDIUM

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

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

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

IRRIGATION

The irrigation system needs to be flushed out completely before the first winter freeze. It is recommended to check emitters and spray heads at spring start-up and throughout the season. If you have a drip irrigation system, hand watering can be used during the plant establishing period. Installing or adding a main line hose spicket might be considered for additional hand watering during establishment periods, during dry seasons and during fall and spring, while irrigation is off and for cleaning.

9 COST

OPPORTUNITIES AND CONSTRAINTS

In the past, the cost related to the installation of a green roof has been high. As this industry develops, the initial cost of implementation may be reduced with standardized practices and programs that allow consistent availability of products, suppliers and installers. Additionally, incentives at the public and municipal level, technology advances and integrated building designs may decrease the project cost and make green roofs more cost effective and attractive to a wider range of clients.

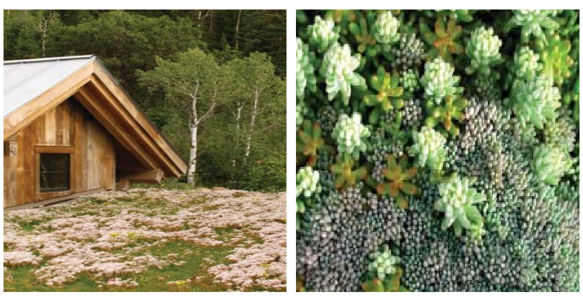
LOCAL PROJECT EXAMPLES

A vide variety of green roof case studies are included in Chapter 10 to provide examples of cost associated with different sizes and types of green roofs. Each case study includes the list of elements that were included as the general project square footage price was calculated. Examples of selected case studies are as follows:

Project Name: EPA Region 8 Headquarters Green Roof.

Cost: $15.50 per square foot.

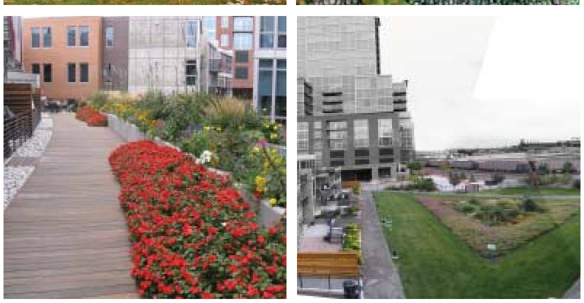
See Chapter 10 for a more detailed list of items included in this price.



Project Name: Elkin's Meadow Residence.

Cost: $21.00 per square foot.

See Chapter 10 for a more detailed list of items included in this price.



Project Name: One River Front.

Cost: $45 - $ 55 per square foot.

See Chapter 10 for a more detailed list of items included in this price.

Major variables that influence the overall project cost are as follows:

- Retrofit versus new construction, potential structural upgrades and/or re-roofing
- Type of green roof - shallow or deeper (extensive versus intensive)
- Accessibility
- Maintenance
- Market maturity

COMPONENTS AND VARIABLES

Buying separate layers from different vendors or buying a whole-system from one supplier can greatly effect cost. Additionally as described in Chapter 7 - Insurance / Warranty and Liability, some manufacturers might not give you a warranty on something they do not sell. This presents a challenge as green roofs are layered systems. Warranty and liability might be compromised and/or lost with some manufactures if their product is used and combined with other products.

To be cost effective during design and implementation is often necessary and should be done thoughtfully and without compromising the system performance for the life of the roof. Cost factors are generally project scope and building dependent. If the project is new, the significant expense of a structural retrofit may be eliminated. The following cost ranges are generated based on prices in the Denver Metro area. Prices and availability will vary depending on where you are in the region.

Structural Evaluation: $ 0 (if new) - $ 3,500 for larger commercial projects. Structural reinforcement on a current building can be expensive and unnecessary depending on the current structural load bearing capacity. Consult a structural engineer for advice. If the project is new, no additional cost for the structural evaluation is needed. It will automatically be part of the fee for the structural engineer as the project goes through conceptual design, design development, construction documentation and implementation.

For smaller scale projects such as a shed, a garage or a minor residential green roof project, structural analysis can usually be acquired in the range of $ 150 - $ 175 per hour.

Design: 0 - 15% of the overall project cost.
- If the project is a shallower modular system with trays or a vegetative mat system, there might not be an actual design cost, as these modules and mats most often are pre-planted and pre-grown.

- If the project is a shallow (extensive) or deep (intensive) loose laid system, design fees can reach 10-15% (or more) depending on the complexity of the project. Planting plan, materials plan, grading plan and lighting plan corresponding to the architectural roof plan and site survey findings plus analysis from the structural engineering plan more than likely have to be generated.

General consulting on green roofs systems usually can be acquired at $ 100 - $ 120 per hour, depending on the size and complexity of the project.

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

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

Waterproofing Membrane: $ 7.50-12.50 per square foot. Depends on the size of the project, product availability, number of penetrations, edge conditions and accessibility.

Root Barrier: $ 0 - 0.75 per square foot. Some membranes function both as the water proofing membranes and root barrier because of material type and thickness. If such a membrane type is used, there is no actual additional cost for the root barrier. If the membrane does not function as both, it is essential to add a root barrier to the system.

Protection Board: $ 0 - 1.75 per square foot*)
Insulation: $ 0 - 3.00 per square foot*)
Drainage and Water Retention: $ 1.50 - 6.00 per square foot*)
Filter Fabric: $ 0 - 0.35 per square foot*)
*)Depends on the size of the project, product availability, type of product, access and the number of potential membrane penetrations needed. Some of these layers may not be needed.

Erosion Control: $ 0 - 0.50 per square foot. Depends on the size of the project, product availability, type of product, access and the number of potential membrane penetrations needed. Some of these layers may not be needed. For less steep slopes biodegradable straw mat can be found at approximately $ 0.45 per square foot. For steeper slopes more complex erosion control systems can also be found. Typically the more complex the system the higher the cost.

Growing Medium: $ 75 - $ 200 cubic yard. Depends on the size of the project, product availability, type of product (type of specific mix), access and method of conveyance to the roof (crane, blower, truck, manual, etc).

Vegetation:
Modular systems (including plants, growing medium and root repellant): $ 12 - 25 per square foot.
Shallower (extensive) loose laid systems: $ 2.00 - 6.00 per square foot.
Deeper (intensive) loose laid systems: $ 4.00 - $ 20.00 (or more) per square foot.
Depends on the size of the project, type and the size/maturity of plants, seeds, cuttings, plugs, mats, plant availability, method of conveyance to the roof (crane, blower, truck, manual, etc) and type of container/anchorage for support of larger types of vegetation. Just one plant, shrub or tree can cost several hundred dollars and a field of meadow grasses can be seeded for as little as 2 ¢ per square foot.

Landscaping is sometimes calculated as 2.5 - 3 x vegetation purchase price and might include plant warranty for a certain period of time, plant replacement in case something dies within the warranty time given and initial replacement installation.

Irrigation: $ 2.00 - 5.00 per linear foot. Depends on the size of the project, access and the type of irrigation used. Drip irrigation can be installed at approximately $ 1.50 - $ 2.00 per square foot (excluding plumbing to the roof) and again depends on the size of project and access.

Walkways, Edges, Borders and Paths: $ 0 - 20.00 per square foot/linear foot. Depends on the size of the project, product availability, material (pre-cast pavers, pre-cast concrete edges, metal/wood/aluminum/gravel/timber edges, natural stone, decking, recycled products), access and number of penetrations to the waterproofing membrane.

Security Railing or Green Screens: $ 0 - 75.00 per linear foot. Depends on the size of the project, product availability, material used (metal, wood, aluminum, iron, steel, etc), access and number of penetrations to the waterproofing membrane.

Maintenance: $ 20 - $ 40 per hour. Depends on the size of the project, types of plants and elements used, access, irrigation, frequency of maintenance visits required and level of expectation. The above mentioned hourly cost most times includes fertilization, pesticides and removal of debris such as clippings and leaves.

10 CASE STUDIES

While the case studies included in this document focus on Colorado, mostly the Denver area, the principles can easily be applied to other areas in the west with similar climates. A variety of projects have been selected to represent the array of possibilities for green roofs in semi-arid and arid climates.

Greenroofs.com - an internet news media organization - provides a global green roof and green wall projects searchable database online at: www.greenroofs.com/projects/plist.php

Image 36.1. Photo by Leila Tolderlund

Project Name: Denver Botanic Gardens Green Roof
Client: Denver Botanic Gardens
Project Location: Denver Botanic Gardens, 909 York St. Denver, CO
Completion date: Installed November 2007
Green Roof Category: Combination of shallow and deep (semi-intensive)
New or retrofit: Retrofit
Size: 2100 square feet
Media Depth: 4" – 12"
Type of Membrane: American Permaquick
Cost: Green roof garden: $12.75 per square foot
(This includes all material and installation of components above roof membrane)

Green roof hardscape: $39.00 -$41.00 per square foot
(This includes Bison modular decking, knee wall, interpretation signs and door retrofit)
Many materials and most labor were donated by Bison Innovative products and DBG staff

Landscape Designer: Civitas Inc
Horticulturist and Growing Medium Consultant: Mark Fusco
Irrigation Design: Mark Fusco and Devin Riles
Roofing Consultant: Wis Janney Elstner Associates
Structural Engineering: Sam McGlammery
General Contractor: Project Manager Mark Fusco with Denver Botanic Gardens Staff
Warranties: Waterproofing

General Project Description: This green roof is a semi-intensive roof that is a retrofit onto a 1950's structure. The main purposes of this roof are to identify a broader palette of plants that may be feasible for Colorado green roofs and experiment with irrigation amounts and frequency. Staff report that an objective is irrigating about 10-12 times per year with about ¼" of water. Researchers are also examining which plants become dormant versus which plants die without irrigation. The current green roof is designed with varying irrigation zones to conduct this research.

Some of the plants studied -
- Delosperma nubigenum
- Hesperaloe parviflora
- Opuntia sp
- Penstemon pinifoliu
- Agave parryi

Image 37.1. Photo by Leila Tolderlund

Project Name: Denver Public Library
Client: City of Denver
Project Location: At Civic Center, 10 W 14th Avenue Pky, Denver, CO
Completion date: Installed in 2008
Green Roof Category: Deep / green roof garden (‘intensive’)
Size: ~860 square feet
Media Depth: 8”
Total project cost: $ 86,000. (This includes actual repair of the roof that had to be replaced anyway, removal of all pavers, a fully adhered sealant, planters and waterproofing of planters, drainage and irrigation. Some growing medium and plants were donated. The approximate cost of the green roof part itself: $ $40,000).

A number of entities donated time and materials to make this project happen. Among them are as follows:
City of Denver
Green by Nature
Green Print Denver
EPA

Landscape Architect: Lime Green Design
Horticulturist: Denver Botanic Gardens
Architect: Bennett Wagner and Grody
Irrigation Design: Rain Bird
Irrigation installation: Green by Nature
Roofing Consultant: Rooftech Consultants
Structural Engineering: S. A. Miro
General Contractor: White Construction Group

Warranties: Membrane warranty held with Roof Tech Consultants
Maintenance: The green roof is maintained by Denver Public Library employees

General Project Description:
This project is a small extensive green roof with pedestal on pavers and planter areas with edges that also function as seating. The green roof is not open to the public but can be reserved and made available for events when renting the adjacent event room. The green roof is irrigated with a sub-surface drip irrigation system.

Plants used - Mesa Verde Ice Plant, Silver Mound Sage, Blue Mist Beardtongue, Coronado Hyssop, Shenandoah Switchgrass, Mersea Yellow Pine Leaf Penstemon, Blue Buckle Penstemon, Panchito Manzanita, Hybrid Stonecrop.

Image 38.1. Photo by Leila Tolderlund

Image 37.2. Photo courtesy Jennifer Bousselot.

Project Name: Environmental Protection Agency Region 8 Headquarters Green Roof
Client: GSA/EPA/Government Properties Trust (building owner)
Project Location: 1595 Wynkoop Street Denver, CO
Completion date: Installed in 2006
Green Roof Category: Shallow ('extensive')
New or retrofit: New
Size: ~20,000 square feet
Media Depth: 4 inches
Type of Membrane: EPDM
Cost: $15.50 per square foot. (This includes waterproofing, modular systems, irrigation and two years of maintenance/guaranteed plant survival.)

Horticulturist: Weston Solutions
Growing Medium Consultant: Weston Solutions
Architect: Zimmer Gunsul Frasca Architects LLP
Irrigation Design: Larry Keeson
MEP Engineering: Syska Hennessy Group
General Contractor: Opus Northwest for building, Weston Solutions for green roof
Maintenance Company: Weston Solutions

General Project Description: Extensive modular tray system. The primary objective of EPA's green roof is to absorb the precipitation which contacts the roof surfaces, and to release it at a reduced and measured pace. The green roof is expected to reduce peak flow and runoff volumes from rain and snow-melt events to mimic a more natural landscape. Reducing the peak flow will minimize impact to the South Platte River from concentrated stormwater runoff.

Plants used in modular system - Sedum acre, Sedum album, Sedum kamtchaticum, Sedum spurium 'Dragon's Blood', Sedum spurium 'John Creech', and Sedum spurium 'Red Carpet'

This is a research project for EPA. Current research includes a study of biological performance of native and adapted plants. Plants currently being tested by CSU, Jennifer Bousselot: Antennaria parvifolia, Bouteloua gracilis, Delosperma cooperi, Eriogonum umbellatum, Opuntia fragilis and Sedum lanceolatum. Additional research includes analysis of urban heat island effect (UHI) and stormwater benefits. The EPA roof is accessible to the public through tours, scheduled by appointment through the EPA Region 8 website.

Image 39.1, 39.2 and 39.3. Photo courtesy Sarah Maas

Project Name: REI flagship store: Denver
Client: REI
Project Location: 1416 Platte St, Denver, CO
Completion date: Installed in 2000
Green Roof Category: Deeper / green roof garden (‘intensive’)
New or retrofit: New (addition to historical building)
Size: 1 Acre
Media Depth: varies 30” - 42”
Type of Membrane: Poured rubber membrane 1”-2”, protective drainage board on top
Total project cost $ 1.2 Million
Landscape Architect: Wenk Associates
Horticulturist: Wenk Associates
Growing Medium Consultant: Wenk Associates
Architect: Mithun Partners
Irrigation Design: HydroSystems-KDI, Inc
Roofing Consultant: HydroSystems-KDI, Inc
Structural Engineering: Martin Martin Engineering
General Contractor: Hensel Phelps
Historic Preservation: Semple Brown (historic preservation restoration of structural and windows)
Maintenance Company: CoCal Landscape

General Project Description: The REI Flagship Store is an outstanding example of adaptive reuse in design and a major contribution to the redevelopment of Denver’s Central Platte Valley. The store is located in the Tramway Building, the former City trolley system power plant that had stood under-utilized for years, verging on being derelict. The landscape design works to promote REI’s corporate image, while contributing to the City of Denver’s urban design goals for redeveloping the Central Platte Valley. The entrance to the store is set in an intensive green roof garden above a parking structure and features a 75-foot re-circulated creek. The green roof landscape recalls Colorado’s alpine landscapes and includes a bike test track and a rock climbing feature. The green roof garden also provides the public with access to the South Platte River and serves Greenway trail users and boaters.

Plants used -	Lanceleaf cottonwood	Ponderosa off structure
	Aspen on structure	Combination of shrubs and perennials
	Blue grama based seed mix	

Image 40.1 and 40.2. Photos by Leila Tolderlund

Project Name: One River Front
Client: East West Partners
Project Location: 1620 Little Raven Street, Downtown Denver, CO
Completion date: Courtyard 2007
Completion date: Park 2008
Green Roof Category: Deeper / green roof garden ('intensive')
New or retrofit: New
Size: 18,500 square feet (green roof only)
Media Depth: Varies 6-24"
Cost: $ 45 - $55 per square foot. (Includes waterproof membrane, growing media, irrigation and plants)

Landscape Architect: Design Workshop, Inc
Architect: 4240 Architecture
Irrigation Design: HydroSystems-KDI, Inc
Civil Engineer: 68 West Engineering, Inc
Structural Engineering: S.A. Miro
MEP Engineering: ABS
General Contractor: Pinkard Construction
Landscape installation: Western Proscapes
Maintenance Company: East West Urban Management

General Project Description: One Riverfront (www.oneriverfront.com), one of Lower Downtown Denver's newest additions to urban living, is a great example of an interior courtyard and park above structure. It provides residents with a secluded interior private park and garden. Broker Associate Scott Leggett states that this green roof 'private/shared' gardens made the units more desirable and increased sales rates. One Riverfront is a combination of town homes, a mid-rise condo building, an interior courtyard and a semi-private/semi-public park over a parking garage.

Plants used - Trees - Autumn Purple Ash Fraxinus americana, Tulip Tree Liriodendron tulipifera, Purpleleaf Plum Prunus cerasifera, Crabapple (sp), Colorado Blue Spruce Picea pungens, Pinion Pine Pinus edulis, Austrian Pine Pinus edulis Shrubs - Flowering Almond Prunus glandulosa, Althea-Rose of Sharon Hibiscus syriacus, Barberry Berberis thunbergii, Dogwood, Variegated Cornus alba, Dogwood, Isanti Cornus sericea, Forsythia (sp), Cotoneaster Cotoneaster divaricatus, Manhattan Euonymus E. kiautschovica 'Manhattan', Chokecherry Prunus virginiana, Serviceberry Amelanchier Canadensis, Roses, shrub (sp), Sandcherry, Purple Leaf Prunus x cistena, Golden Vickery Privet Ligustrum x vicaryi, Hosta (sp) Perennials - Yarrow (sp), Lupine Lupinus 'Russell Strain', Coreopsis Coreopsis verticillata 'Moonbeam', Delphinium (sp), Bee Balm Monarda didyma, Hibiscus, Disco Belle H. moscheutos 'Disco Belle' Grasses - Maiden Grass, Dwarf Miscanthus sinensis, Feather Reed Grass Calamagrostis acutiflora 'Karl Foerster' Annuals - Mixed Zinnias, Purple Wave Petunia



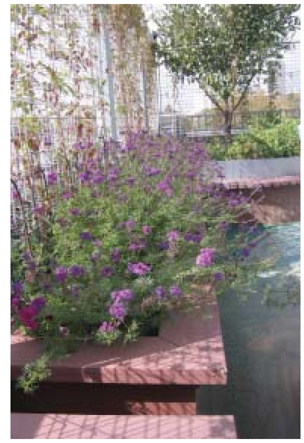


Image 41.1, 41.2 and 41.3. Photos by Leila Tolderlund

Project Name: The Gathering Place
Client: The Gathering Place
Project Location: 1535 High Street, Denver, CO
Completion date: Installed in 2006
Green Roof Category: Deeper / green roof garden ('intensive')
New or retrofit: New
Size: 3505 square feet. (Includes vestibule and storage room)
Media Depth: Varies: 6" - 18"
Type of Membrane: Monolithic Membrane 6125 Garden Roof by American Hydrotech, Inc
Cost: $ 58.00 per square foot. (This includes everything above the slab, also playground equipment. It does not include HVAC and solar panels)

Landscape Architect: Design Workshop Inc
Growing Medium: Lightweight Hydrotech Soil
Architect: Burkett Design
Irrigation Design: HydroSystems-KDI, Inc
Roofing Consultant: Douglass Roofing Co
Waterproofing: Wiss Janey Elster & Associates
Structural Engineering: Martin / Martin Consulting Engineers
MEP Engineering: 360 Engineering Inc. and Centerline Resources Inc
General Contractor: Turner Construction
Other trades included: CRESA Partners, Architectural Energy Corp, Green Screen, American Hydrotech and Colorado Garden Show, Inc
Warranties: Metecno USA and CEI Roofing
Landscape Installation: Columbine Design & Urban Farmer
Maintenance Company: Urban Farmer and staff of The Gathering Place
Landscape Installation: Columbine Design, Urban Farmer and the women, children and friends of The Gathering Place

General Project Description: Denver's only daytime drop-in center for women and children who are experiencing homelessness or poverty. It is a great example of a safe and fun rooftop and playground garden. The Gathering Place produces and uses some of its own fruits, herbs and vegetables in the kitchen. Children are involved in the seeding, planting, caring and harvesting for educational purposes, and for fun. The laughter yoga also meets weekly on the roof top garden during the Spring, Summer and Fall.

Plants used - Tomatoes (Heirloom, Plum and Beef Steak), Cilantro, Parsley, Thyme, Rosemary, Sage, Basil, Cabbage, Peppers (Bell, Jalapeño, Anaheim) , Wee Be Little Pumpkins, Peas, Beans, Bibb lettuce, Spinach, Impatiences, Wild Flowers, Roses, Marigolds, Red Delicious Apples, Cherry (Montmorency), Virginia Creeper, Clematis, Daylilies, Echinacea, Victoria Blue and Daises



Image 42.1, 42.2 and 42.3. Photos by Leila Tolderlund

Project Name: Museum of Contemporary Art
Client: Cydney Payton
Project Location: 1485 Delgany St, Denver
Completion date: Installed Oct 2007
Green Roof Category: Combination of shallow and deep (semi-intensive)
New or retrofit: New
Size: 250 square feet
Media Depth: 1'-2'
Type of Membrane: Hydrotech
Cost: $ 920 per square foot. (Includes all steel fabrication, water feature, decking, bench, lighting, waterproofing, media, plants, irrigation and drainage)

Landscape Designer: Karla Dakin, K. Dakin Design Inc
Horticulturist: Mark Fusco, Senior Horticulturalist, Denver Botanic Gardens
Irrigation Design: Mark Fusco and Greg Alvarado, Green By Nature
Technical Consulting: Mark Fusco
Structural Engineering: Tom Moe and Charles Keyes, Martin / Martin Consulting Engineers
MEP Engineering: General Contractor: Greg Alvarado, Green By Nature
Warranties: Hydrotech, 10 Year
Maintenance Company: Green By Nature
General Project Description: Art Commission - www.mcadenver.org

Plants used -

Shrubs:	Chilopsis linearis 'Warren Jones'	Daphne cenorum 'Dr. Lawrence Crocker'
	Rosa 'Darlos Enigma'	Paxistema canbyii
Perennials:	Aubrieta	Acantholimon hohenackeri
	Aethionema schistosoma	Androsace sarmentosa v chumbyii
	Armeria trojana	Artemisia virdis
	Asclepias tuberosa	Dalea purpurea Stefani
	Delosperma kelaidis	Delphinium nelsonii or d.virescens/larkspur
	Dianthus anatolicus	Eriogonum umbellatum 'Kenna Creek'
	Draba hopeana	Heterotheca jonesii
	Liatrus punctata	Ipomopsis rubra agregata / Standing Cypress
	Opuntia phaeacantha	Physaria Bellii
	Penstemon Davidson Menziesi	Penstemon Linaroides
	Penstemon Mensarum	Phlox condensata
Grasses:	Bouteloua gracilis, Koeleria Glauca, Sesleria Autumnalis and Sesleria Heufleriana	
Bulbs / Tubers:	Allium Azureum , Allium Hair, Allium Schubertii	
Annuals:	Phacelia campanularia	

Image 43.1 and 43.2. Photo courtesy Sempergreen

Project: Denver Justice Center
Client: City of Denver
Project Location: 400 West Colfax Ave. Denver, CO
Completion date: Installed in 2009
Green Roof Category: Shallow (‘extensive’)
New or retrofit: New
Size: 7500 square feet
Media Depth: Minimum of 4” with max at 6”
Type Of Membrane: Hot fluid applied
Cost: $19.35 per square foot

Cost includes (from the deck up): Surface Conditioner, MM6125 – 90 mils, Flex Flash Reinforcing, M6125 – 125 mils, Hydroflex 30 protection sheet, Root Stop, 4” 40 psi Dow Styrofoam, Garden Drain 15, System Filter, 4” Lite Top Growing Media (w/ 12” o.c. drip irrigation) with a sedum mat on top - this is a Hydrotech Garden Roof Assembly.

Landscape Architect: none
Horticulturist: Sempergreen
Growing Medium Consultant: American Hydrotech
Architect: Klipp Architecture
Irrigation Design: Urban Farmer Landscaping Inc
Subsurface Drip Irrigation: Netafim in place, 12” spacing
Roofing Consultant: American Hydrotech
General Contractor: Hensel Phelps
Warranties: Sempergreen plant warranty

General Project Description: Extensive green roof with continuous mat of plants

Plants used - Sempergreen sedum mat with:
Sedum acre ‘Gold Moss’
Sedum album ‘Coral Carpet’
Sedum floriferum ‘Weighenstephaner Gold’
Sedum hispanicum ‘Purple Form’
Sedum kamschaticum
Sedum ‘Angelina’
Sedum spurium ‘Red Carpet’
Sedum spurium ‘Tricolor’
Sedum ‘John Creech’

Image 44.1, 44.2 and 44.3. Photo courtesy Andy Creath

Project Name: South St. Paul
Client: Anderman Family
Project Location: Bonnie Brae, Denver, CO
Completion date: September 2009
Green Roof Category: Shallow ('extensive')
New or retrofit: New
Size: 500 square feet
Media Depth: 6"
Type of Membrane: 90 mil EPDM
Cost: $ 25 - $ 35 per square foot
(This cost includes a drip irrigation system, plant consultation with LA, green roof layers and edging, plants, labor, 2 years maintenance, product design and install of custom recycled pickle barrel deck.)

Landscape Architect: Nancy Eastman, Art of the Land
Horticulturist: Mark Fusco
Growing Medium Consultant: Green Roofs of Colorado, LLC
Architect: Virginia DuBrucq
Irrigation Design: Green Roofs of Colorado, LLC
Structural Engineering: Foothills Engineering
General Contractor: Old Greenwich Builders
Warranties: Membrane and Plant with Maintenance contract
Maintenance Company: held with Green Roofs of Colorado, LLC

General Project Description: Residential intensive green roof
This is an accessible deck space designed for relaxation and beauty with a portion being a recycled pickle barrel decking with seating. The other is a designed green roof space serving as a display area for a George Rickey sculpture.

Plants used -

- Sedum
- Penstemum
- Blue grama
- Veronica
- Blue fescue
- Delosperma
- Sage
- Daisy and
- Sulfur flower



Image 45.1, 45.2 and 45.3. Photo courtesy Lisa Benjamin

Project Name: Elkin's Meadow Residence
Client: Laurie Reed
Project Location: Steamboat Springs
Completion date: May 2009
Green Roof Category: Shallow sedum mat ('extensive')
Size: 1755 square feet
Media Depth: 3.5 inches/ 1.5 inch mat = 5 inch system
New or retrofit: New
Cost: $ 25-30 per square foot

(This cost includes drip irrigation system, plants, travel, labor, edging, green roof consultation and delivery. The roofing company laid the drainage and root barrier layers. High end includes maintenance and estimated cost for layers.)

Landscape Designer: Evo Design, LLC
Growing Medium Consultant: Greenroofs of Colorado, LLC
Architect: Jeff Gerber, Hawkins Architects
Irrigation Design: Kyle Pietras / Green Roofs of Colorado, LLC
General Contractor: Habitat Construction
Warranties: Sempergreen plant warranty
Maintenance Manual provided - no
Maintenance Company - residents

General Project Description: This is a residential extensive green roof with a continuous alpine sedum carpet.

Plants used -

Sempergreen sedum mat with
Sedum acre 'Gold Moss'
Sedum album 'Coral Carpet'
Sedum floriferum 'Weighenstephaner Gold'
Sedum hispanicum 'Purple Form'
Sedum kamschaticum
Sedum 'Angelina'
Sedum spurium 'Red Carpet'
Sedum spurium 'Tricolor'
Sedum 'John Creech'



Image 46.1, 46.2 and 46.3. Photo courtesy Anthony Mazzeo

Project Name: UMB Stapleton
Client: UMB
Project Location: 35th and Quebec, Denver CO
Completion date: October, 2007
Green Roof Category: Shallow ('extensive')
New or retro-fit: New
Size: 2100 square feet
Media Depth: 4"
Type of Membrane: NA GreenGrid System
Cost: $ 20 per square foot
Total Project Cost $40,444

Landscape Architect: GroundWorks
Architect: GroundWorks
Irrigation Design: Hines Irrigation
Roofing Consultant: Carlisle (Weston Solutions)
Structural Engineering: MES
General Contractor: JE Dunn
Landscape Contractor, installed/maintained GreenGrid System: Shultz Industry
Warranties: Carlisle (Weston Solutions)
Maintenance Manual - no
Maintenance Company - Shultz Industry

General Project Description: This is a commercial extensive green roof. The Branch Bank (1200 SF) w/ drive-up facility for UMB is unique in that the green roof sits over the drive-up canopy.

Plants used -

Sedum acre
Sedum album
Sedum album Murale
Sedum ellacombianum
Sedum Green Spruce
Sedum kamtschaticum
Sedum rupestre 'Forsteranum'
Sedum spurium 'Bailey's Gold'
Sedum spurium Eco Mt. Emei
Sedum spurium John Creech
Sedum spurium Summer Glory
Sedum spurium White Form
Sedum acre Aureum
Sedum album 'Chloroticum'
Sedum cauticola Lidakense
Sedum floriferum 'Weihestephaner Gold'
Sedum hybridum 'Immergrauch'
Sedum reflexum
Sedum sexangulare
Sedum spurium 'Dragon's Blood'
Sedum spurium Fuldaglut
Sedum spurium Roseum
Sedum spurium 'Tricolor'

11 ADDITIONAL DESIGN GUIDANCE

Additional Design Guidance: Until more experience is gained in semi-arid and arid climates with regard to green roofs, the following design guidance documents may provide additional assistance. These guidelines may need adjustment for any local climate.

“FLL Guidelines”: The FLL Guidelines are green roof standards developed by the German Research Society for Landscape Development and Landscape Design. These guidelines include the planning, execution and upkeep of green-roof sites. The 2002 edition of these widely consulted guidelines is available in English from the German organization - Research Society for Landscape Development and Landscape Design (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. - FFL) online at -http://www.roofmeadow.com/technical/fll.shtml

Green Roofs for Healthy Cities: National Green Roof Accreditation - Seminars and manuals provided by Green Roofs for Healthy Cities - For more information go to: www.greenroofs.org.

ASTM Book of Standards, v. 04-12, 2005: ASTM International, originally known as the American Society for Testing and Materials, is one of the largest voluntary standards development organizations in the world. The Annual Book of ASTM Standards can be consulted in the Science Reference collection of the Library of Congress. ASTM standards can also be purchased through ASTM International at - http://www.astm.org. See v. 4.12 for standards related to green roofs.

Selected ASTM standards related to green roofs include the following:

ASTM: E2397-05	Standard Practice for Determination of Dead Loads and Live Loads Associated with Green Roof Systems. ASTM book of standards, v. 04-12, 2005
ASTM E2396-05	Standard Test Method for Saturated Water Permeability of Granular Drainage Media (falling-head method) for Green Roof Systems
ASTM E2398-05	Standard Test Method for Water Capture and Media Retention Standards of Geocomposite Drain Layers for Green Roof Systems
ASTM E2397-05	Standard practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems
ASTM E2400-06	Standard Test Method for Maximum Media Density of Dead Load Analysis of Green Roof Systems
ASTM E2396/E2399-05	Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roofs

ASTM has recently developed a new set of standards for green roofs; however, it is important to recognize that these standards have been developed outside of Colorado

Leadership in Energy and Environmental Design (LEED®):
The Leadership in Energy and Environmental Design (LEED®) Green Building Rating System is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. Attainment of a desired LEED® building rating (e.g., silver, gold, platinum) is based on accumulation of “points” addressing eight different credit categories:

- Location and Planning
- Sustainable Sites
- Water Efficiency
- Energy and Atmosphere
- Materials and Resources
- Indoor Environmental Quality
- Innovation and Design Process
- Regional Priority

LEED® standards are available through the U.S. Green Building Council: http://www.usgbc.org**/.**

FM Global is not a standard setting entity; rather it is a commercial and industrial property insurance risk management organization which is a large player in the construction industry. FM Global has published Property Loss Prevention Data Sheet 1-35: Green Roofs, which is based on the FFL guidelines. It should be noted that local ordinances and building codes should be followed foremost, and supported with guidelines and standards.

BOCA Codes: Building Officials and Code Administrators International Inc. (BOCA), now known as the **International Code Council (ICC),** publishes codes that establish minimum performance requirements for all aspects of the construction industry. BOCA or ICC codes at the Library of Congress are located in the Law Library Reading Room. Some state codes are available at no cost through the eCodes sections of the ICC Website, while others must be purchased: http://www.iccsafe.org/.

Low Impact Development (LID) Urban Design Tools
LID technology is an alternative comprehensive approach to stormwater management. Integrating a green roof into a project is an excellent example of applying low impact development (LID) principles. This page from the Low Impact Development Center has links to Integrated Management Practices (IMP) standards and specifications: http://www.lid-stormwater.net/

Recommended Books
Weiler, Susan K. and Scholz-Barth, Katrin. 2009. *Green Roof Systems.* John Miley & Sons, Inc
ISBN 978-0-471-67495-5. 2004
Dunnett, Nigel and Kingsbury. Noel. 2008. *Planting Green Roofs and Living Walls.* Timber Press, Inc
ISBN-13: 9780881929119
Margolis, Liat and Robinson, Alexander. 2007. *Living Systems.* Birkhauser Verlag AG
ISBN 978-3-7643-7700-7
Dunnett, Nigel, and Noel Kingsbury. 2004. *Planting Green Roofs and Living Walls.* Timber Press, Inc
ISBN 0-8819-2-640-X
Snodgrass, Edmund C. and Snodgrass, Lucie L. 2006. *Green Roof Plants.* Timber Press, Inc
ISBN 0881927872
Earth Pledge. 2005. *Green Roofs - Ecological Design and Construction.* Shiffer Books
ISBN 0-7643-2189-7
Osmundson, Theodore. 1999. *Roof Gardens: History, Design, and Construction.* New York, W. W. Norton
ISBN 0-393-73012-3

Information and Projects from Local, State, and Federal Government Agencies
Environmental Protection Agency Region 8 - Green roofs -
http://www.epa.gov/region8/greenroof/index.html

Environmental Protection Agency Region 8 - Heat Island Effect: Green Roofs. Basics on green roofs, with some illustrations and examples, from the U.S. Environmental Protection Agency -
http://www.epa.gov/heatisland/index.html

Boston City Hall Green Roof Project. Press release, September 2005, describes the Boston project -
http://www.cityofboston.gov/bra/press/PressDisplay.asp?pressID=285

Chicago City Hall Green Roof. American Society of Landscape Architects, 2002 Merit Award - Design winner -
http://www.asla.org/meetings/awards/awds02/chicagocityhall.html

City of Chicago Green Roofs -
http://www.explorechicago.org/city/en/about_the_city/green_chicago/Green_Roofs_.html

City Hall Greenroof, City of Atlanta Online. The first city-owned green roof in the Southeast -
http://www.atlantaga.gov/mayor/energyconservationgreenroof.aspx

Information and Projects from Local, State, and Federal Government Agencies - continued
City of Portland Ecoroof blog -
http://www.portlandonline.com/bes/index.cfm?c=50716

Green Roof Examples and Green Roof Tracker. From the U.S. General Services Administration, examples of green roofs on Government buildings -
http://www.gsa.gov/portal/content/103493

Green Roof Project, Albemarle County, Virginia. Pictures and a brief description of the project, completed in July 2005 -
http://www.albemarle.org/department.asp?department=planning&relpage=6879

Heat Island Group. The Heat Island Group at Lawrence Berkeley National Laboratory conducts research on the summer warming trends occurring in urban areas, the so-called 'heat island' effect -
http://eetd.lbl.gov/HeatIsland/graphic.html

Stormwater Management and Green Roof Technology, from the Maryland Dept. of the Environment -
http://www.mde.maryland.gov/assets/document/sedimentstormwater/swm_greenroof.pdf

Organizations, Research Centers and Research Programs
Casey Trees Endowment: Green Roof Initiative, preserving green infrastructure in Washington, DC -
http://www.caseytrees.org/planning/greener-development/gbo/index.php

Earth Pledge Initiative: EPF Green Roofs - supports vegetated rooftops in urban areas to prevent stormwater runoff pollution, lower urban temperatures, and improve air quality -
http://www.earthpledge.org/gr

Toronto Green Roofs. Study findings and other material -
http://www.toronto.ca/greenroofs/index.htm

Lady Bird Johnson Wildflower Center/University of Texas at Austin -
http://www.wildflower.org/

Pennsylvania State University - Center for Green Roof Research at Penn State University, information on research, news, industry, and many links -
http://horticulture.psu.edu/node/235

Michigan State University - Green Roof Research Program at Michigan State University, descriptions and photographs of several projects, along with a list of publications, industry links, and other information - http://www.hrt.msu.edu/greenroof/

North Carolina State University Biological and Agricultural Engineering Green Roof Research -
http://www.bae.ncsu.edu/greenroofs/

Southern Illinois University -
http://www.greenroofs.com/projects/pview.php?id=454

Scandinavian Green Roof Institute - Augustenborg's Roof Garden, Malmö, Sweden -
http://www.greenroof.se

The University of British Columbia - Greenskins Lab -
http://www.greenskinslab.sala.ubc.ca/

Other Recommended Websites

Independent U.K. site, promotes green roofs and provides information and advice - http://livingroofs.org

National Public Radio: Story on Green Roofs. Includes links and photos - http://www.npr.org/templates/story/story.php?storyId=1970286

Peggy Notebaert Nature Museum: Thinking Green. Offers suggestions for homeowners, as well as many links, images, and audio - http://www.naturemuseum.org/greenroof/index.html

Whole Building Design Guide. A web-based portal providing government and industry practitioners with information from a whole building's perspective. This is a collaborative effort among federal agencies, private sector companies, non-profit organizations and educational institutions - http://www.wbdg.org/

'Roof Deck Design Guidelines.' Central Mortgage and Housing Corporations. Ottawa, Ontario 1979 - http://egov.cityofchicago.org/webportal/COCWebPortal/COC_ATTACH/Design_guidelines_for_green_roofs.pdf

'Green Roof Handbook.' Resource Conservation Technology. Document available online at http://conservationtechnology.com/documents/GreenRoofHandbook1008.pdf

German Green Roof Association (FBB) - http://www.fbb.de/en/

Forschungsgesellschaft FLL (Research and Guideline Society) - http://www.fll.de/

European Federation of Green Roof Associations (EFB) - http://www.efb-greenroof.eu/

www.worldgreenroof.org - World Green Infrastructure Network
www.greenroofs.org and www.greenroofs.net - Green Roofs for Healthy Cities
www.growwest.com - GrowWest - Annual green roof symposium in Colorado
www.greenroofs.com - Greenroof industry portal for resources and information
www.epa.gov/ord/sciencenews/scinews_grr.htm - EPA green roof research
www.ucdenver.edu/greenroof - University of Colorado Denver green roof research project
www.greenroof.agsci.colostate.edu - Colorado State University
www.botanicgardens.org/content/green-roof - Denver Botanic Gardens green roof
www.land.asla.org/050205/greenroofcentral.html - American Society of Landscape Architects green roof
www.greenroofs.com (www.greenroofs.com/projects/plist.php)
www.igra-world.com - International Green Roof Association
www.greenroofplants.com - Emory Knoll Farms
www.roofscapes.com
www.greengridroofs.com
www.verticalgardenpatrickblanc.com
www.g-sky.com
www.hydrotechusa.com
www.tectaamerica.com
www.greenroofsco.com

APPENDIX A

Research Quotes:

“The green roof at EPA Region 8 has been shown to be effective in terms of runoff reduction and treating the Water Quality Capture Volume. New developments in Denver that exceed 1/2 acre in size are required to be designed to treat the Water Quality Capture Volume. Generally speaking, the WQCV correlates to the 0.6” storm and capture/infiltration/ retention of the WQCV represents treatment of the 80% percentile storm event. At the EPA Region 8 green roof, runoff has been reduced by 85% for all storms 0.5” or less. Therefore, EPA’s roof is an appropriate management practice for treatment of the WQCV or the first flush of runoff. For larger storms exceeding 1” in rainfall, capture of runoff from EPA’s green roof has been less than 50%. This is expected since saturation of the media will decrease performance in terms of capture and treatment of runoff.

Further data will help determine a saturation point of the roof as defined by the point at which the capture of runoff reduces significantly. It should be noted though, that the saturation point will not be a static number. Factors such as back-to-back storms, cloud cover, and wind speed all affect the evapotranspiration and uptake capacity of the roof. Regardless, for all storm events monitored over a two year period thus far, capture of runoff has exceeded 80% for all storm events less than or equal to 0.5”. This demonstrates that the green roof has significant potential for capture the first flush that is associated with most stormwater pollution, and the green roof is a reliable BMP for capturing the WQCV as defined by the Urban Drainage and Flood Control District”

Greg Davis
EPA Region 8 Storm Water Coordinator
Mailcode: 8P-W-WW
1595 Wynkoop Street
Denver, CO 80202-1129
Phone: 303-312-6314
http://www.epa.gov/region8/water/stormwater

“In the Urban Heat Island (UHI) data collected from the EPA Region 8 office green roof in Denver, Colorado has shown about a 40% overall decrease in net radiative power on the green roof relative to the control roof for only July, 2009. Net radiative power varies from month to month and does not include sensible, conductive, convective, and latent heat fluxes. In our calculations the radiative capacity constitutes on average about 10% of net total solar radiation recorded on the roof.

In addition, the water retained on the green roof in the substrate and plant material that would otherwise contribute to stormwater runoff and degrade aquatic ecosystems and water quality, is instead used for evaporative cooling for the building and the local environment. There is one ton of cooling with the evaporation of 35 gallons of water. One ton of cooling is equivalent to the amount of energy required to melt 2,000 pounds of ice. The cooling from evapotranspiration produces a self-reinforcing feedback response that modulates temperatures of roof surfaces within a range that supports plant life, and the plant parts store water, sequester carbon, engage in evapotranspiration, and support other ecological functions, such as developing canopy structure that helps shade the substrate surface, all of which sustain the roof cooling processes.”

Thomas J. Slabe, Biologist
Laboratory Services Program 8TMS-L
Office of Technical & Management Services
Region 8, U.S. Environmental Protection Agency
16194 West 45th Drive
Golden, Colorado 80403
Phone: 303-312-7797 (office)
Fax: 303-312-7800 (fax)
Cell: 216-403-2600 (cell)
slabe.thomas@epa.gov

APPENDIX B

GREEN ROOF MAINTENANCE CHECK LIST

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

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

PRUNING:
How often will plant material be pruned and dead headed?
Will clippings and dead leaves be composted? Where?

WEED CONTROL:
The time to prepare for the oncoming of weeds is in the dormant season by applications of pre-emergence applications.
How often will planters be manually weeded?

CLEAN UP:
How often will drainage outlets, water features and filters be cleaned?
How often will entrances, planter edges, paths, etc be cleaned?

MAINTENANCE OF FURNITURE, PATHS, DECKING, PLANTERS and RAILINGS, ETC
What products are recommended for upkeep of planter edges, furniture, decking, etc?
What products are NOT recommended due to potential chemical effect on other components of the roof assembly?
What are specific recommendations for what tools to use (and not use) for the upkeep and maintenance?
Where are maintenance tools, ladder, hoses, security harnesses and other equipment stored?

WATERING:
How will the roof plants be irrigated – hand watering and/or irrigation system?
How frequently will the roof plants be irrigated – during the summer?
Will there be hand watering during the winter? How frequently?
How often will the controller system and operating system be checked?
Are irrigation systems installed with a back-flow preventer valve that can be drained in case of a freeze?
Are there any specific requirements for upkeep and clean-up of water features?
What is the typical lifespan of plants used on the green roof?

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

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

APPENDIX C

TYPICAL REASONS FOR GREEN ROOF FAILURE

MAINTENANCE - is the number one reason for premature green roof problems. It is highly recommended to create a maintenance manual that the entire design team signs off on. See suggestions in Appendix B – the maintenance manual check list.

FAULTY DESIGN and INSTALLATION - often has costly ramifications. Design and implementation deficiencies can be a result of inexperienced green roof professionals or misunderstood and/or ignored essential building and site requirements. To correct errors usually requires a roof replacement.

Examples of faulty design and faulty installation include the following:

- Improper membrane protection during installation
- Structure movement and membrane failure as a result of stretching and splitting
- Green roof system sliding due to insufficient distribution of green roof load related to roof slope
- Unintentional ponding of water due to insufficient location and/or number of drains
- Lack or insufficient expansion/contraction joints between changes in green roof materials (decking, planters, paths, etc) and/or at edges where incompatible materials meet.

PENETRATIONS - through the roof membrane needs to be flashed.
Typical penetration flashing failures are as follows:

- Improper design and/or installation of the flashing at the penetration point
- Seam failures (metal edges, concrete curbs, etc) due to expansion and contraction
- Movement between the penetration component (pipe, vent, etc) and the flashing
- Improper priming and stripping of penetration components made of metal
- Missing or deteriorated counter flashing
- Standing water behind or at the penetration point due to improper design and/or installation

FAILURES AT FLASHINGS - is one of the most common failures for green roofs. Most flashing failures happen because of faulty flashing design and/or improper flashing construction. It is strongly recommended to have flashings carefully inspected during the green roof installation and include regular flashing inspections in the maintenance manual for the life of the roof.

DRAINS - are installed to prevent retention of water on the roof by removing the water. It is important that the drainage system is designed and installed correctly to ensure the continuous flow of water. Creating a sufficient seating pocket for the roof drains and ensuring that the drain is indeed the lowest point of the roof is often ignored and can lead to ponding of water that over time might compromise the membrane. Furthermore, the number of drains, overflow scuppers in parapet walls and roof slope are imperative to prevent water collecting and ponding during rain events. Any collected and ponded water is an indication of inadequate drainage. Regularly inspections of drains are recommended to ensure the drains are free from debris.

APPENDIX C

WEATHERING - is a critical component in the deterioration of a roof. This is especially true in semi-arid and arid climates with high UV rays from the sun, extreme freeze-thaw cycles and at times, air pollutants and hail. A green roof can help extend the life of the roof and protect it from some of these conditions, but it is also susceptible to permanent damage under extreme conditions.

WIND - and flying debris can damage green roofs. Winds of hurricane and tornado intensity can permanently damage a green roof. Moderate winds with 50-75 miles per hour gusts can also cause damage. Green roof components, including plants, growing medium, insulation and water proofing membrane should be adequately fastened to the roof and the perimeter of the roof.

GREEN ROOF COMPONENTS - such as HVAC, other mechanical systems, solar panels, antennas, signs, flag poles, bracings, etc should be carefully considered when placed on the roof. These components should be mounted to a support structure or a raised curb-type structure using curb flashings. That way the roof is kept water tight during repair and upkeep of equipment and the roof can be recovered or replaced without disturbing or removing these components.

For proper mounting and flashing of these items use the ARI/NRCA/SMACNA Guidelines for Roof-Mounted Outdoor Air- Conditioner Installations, and the roof membrane manufacturer for recommendations.

GRAVEL STOPS, VEGETATION FREE ZONE EDGES AND METAL EDGE STRIPS – are used to close off the edges of the roof to prevent wind damage and blow offs; to prevent the loss of aggregate near the perimeter; as a root repellant; and sometimes to create easy maintenance access. The metal retention edge often sits on the drainage mat. This allows water to freely drain under it and it also provides a cushion of the membrane for the metal of the retention edge and the drainage rock on the non-vegetated side of the border. Placing filter fabric with a spacer (such as a drainage mat) in the vertical soil-side face of the metal retention edge prevents soil extrusion through the perforations.

It is recommended to inspect metal edges, edges at the vegetation free zone and edges at the gravel stop areas after major events (such as heavy rainfalls, floods, storms, etc). A typical problem with these areas are leakage through open or broken joints and edges. One way to prevent this is to raise the gravel stops and metal edge strips above the waterline or, if interior drainage is not an option and water will drain over the metal edges, scupper cutouts can be used.

APPENDIX D

CHECKLIST FOR CONSIDERATIONS BEFORE STARTING A GREEN ROOF

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

APPENDIX E - GLOSSARY

Amenity Space - A place for social gathering.

Anchor (point) - Point where a tree ie. is tied off.

Annuals - A plant that completes its life cycle in one growing season.

Biodiversity - Biological diversity in an environment as indicated by numbers of different species of plants and animals.

Built Up Roof Membrane - A continuous, semi-flexible roof membrane assembly, consisting of layers of saturated felts, coated felts, fabrics or mats between which alternate layers of bitumen are applied, generally surfaced with mineral aggregate, bituminous materials, or a granule-surfaced roofing sheet.

Caliper - Standard measurement of the diameter of the trunk of a tree.

Compressive Strength - The ability of materials and components to resist deformation or other damage caused by the weight of compression of either live or dead loads.

Confinement System - A system designed with specific limits.

Counter Flashing - Formed metal or elastomeric sheeting secured on or into a wall, curb, pipe, rooftop unit or other surface, to cover and protect the upper edge of a base flashing and its associated fasteners.

Dead Loads - Non-moving rooftop loads, such as mechanical equipment, air conditioning units, and the roof deck itself.

Deck - The structural surface to which the roofing or waterproofing system is applied.

Drain - A device that allows for the flow of water from a roof area.

Drainage Layer System - Comprised of drainage boards, drains, and/or pipes which removes enough water from the roof so as to not compromise the waterproofing system and building, while allowing enough water to remain in the system to sustain plant life.

Elastomeric - Having elastic, or rubber-like properties of a material. (RCI)

Electromagnetic Radiation - Electromagnetic radiation is classified into several types according to the frequency of its wave; these types include (in order of increasing frequency and decreasing wavelength): radio waves, microwaves, terahertz radiation, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays.

Energy Efficiency - Using less energy to provide the same level of energy service.

EPA - Environmental Protection Agency is an agency of the federal government of the United States charged to protect human health and the environment, by writing and enforcing regulations based on laws passed by Congress.

Erosion Layer - Protective sheeting or woven fabric placed on top of growing medium to protect it from wind erosion while plants are being established.

Evapotranspiration - The loss of water from the soil both by evaporation and by transpiration from the plants growing in the soil.

Exposure - Traverse dimension of a roofing element not overlapped by an adjacent element in any roof system. The exposure of any ply in a membrane may be computed by dividing the felt width minus 2 inches by the number of shingled layers; thus, the exposure of 36 inch-wide felt in a shingled, four-ply membrane should be 8 1/2 inches; - time during which a portion of a roofing element is exposed to the weather.

Extensive Green Roof - Typically refers to a shallower (4 - 6 inch) green roof system.

Filter Fabric Cloth - A lightweight, rot-proof material laid over or included as a part of the drainage layer to prevent blockage of the drainage system and keep the growing medium in place.

Fire Resistance - The ability of a building component to act as a barrier to the spread of fire and confine it to the area of origin. (NRCA/SPFA)

Flashing - System used to seal membrane edges at walls, expansion joints, drains, gravel stops, and other places where the membrane is interrupted or terminated. Base flashing covers the edge of the membrane. Cap flashing or counter flashing shields the upper edges of the base flashing.

Geotextile Fabric - Geotextile fabrics are permeable fabrics which, when used in association with soil, have the ability to separate, filter, reinforce, protect, or drain.

Green Roof - A "contained" green/living systems on top of a building whether this green space is below, at or above grade, and it involves systems where plants are not planted in the "ground'.

Growing Medium - The particulate matter or substrate that anchors the plant roots to sustain the plant growth.

HVAC Systems - Controls the ambient environment (temperature, humidity, air flow, and air filtering) of a building and must be planned for and operated along with other data center components such as computing hardware, cabling, data storage, fire protection, physical security systems, and power.

Hydrostatic Membrane - A membrane that is able to withstand pressure exerted by a fluid due to its weight.

In fill Projects - In the urban planning and development industries, in fill is the use of land within a built-up area for further construction, especially as part of a community redevelopment or growth management program or as part of smart growth. It focuses on the reuse and repositioning of obsolete or under utilized buildings and sites. This type of development is essential to renewing blighted neighborhoods and knitting them back together with more prosperous communities.

Infiltrating - To pass into or through (a substance) by filtering or permeating.

Insulation - A material applied to reduce the flow of heat (RCI).

Intensive Green Roof - typically refers to a deeper (6-8 inch or more)green roof system.

Irrigation System - Systems which deliver moisture to the growing medium making it available for plant use. Not all green roofs require an irrigation system.

Life Cycle Analysis (LCA) - The assessment of a product's full environmental costs, from raw material to final disposal, in terms of consumption of resources, energy and waste.

Live Loads - All equipment and people on the roof. They are not permanent elements and cause the weight on the roof to fluctuate.

Loose Laid Green Roof System - (aka Built-Up Systems) - A green roof which is constructed with one component installed upon the next.

Low Impact Development (LID) - A sustainable landscaping approach that can be used to replicate or restore natural watershed functions and/or address targeted watershed goals and objectives.

Membrane Protection Layer - A material used to protect the waterproofing membrane and/or insulation layer during the installation of a green roof.

Micro Climate - The essentially uniform local climate of a usually small site or habitat.

Modified Bitumen - A bitumen modified through the inclusion of one or more polymers (e.g. atactic polypropylene, styrene butadiene styrene. etc.)

Modular Green Roof System - A green roof system which combines one or more layers of the assembly into a single product (e.g. drainage, growing mediums, and plants).

Moisture Retention Layer - Layer installed above the drainage layer which stores water for plants' use after a rain event, usually made of felt or other absorbent recycled materials.

Nutrient Cycling - The circulation of nitrogen in nature, consisting of a cycle of chemical reaction which atmospheric nitrogen is compounded, dissolved in rain, and deposited in the soil, where it is assimilated and metabolized by bacteria and plants, eventually, returning to the atmosphere by bacteria decomposition of organic matter.

Occupational Safety and Health Administration (OSHA) - Occupational Safety and Health Administration

Parapet - A part of any wall entirely above the roof.
Perennials - A plant that lives for more than two years.

Permeability - The rate at which liquids pass through soil or other materials in a specified direction.

Retrofit - When a green roof is built on to an existing roof.
Roofing Membrane - A flexible or semi-flexible roof covering or waterproofing layer, whose primary function is the exclusion of water.

Root Repellent - The ability of a waterproofing membrane to prevent the growth of plant roots.

Root Barrier - A physical or chemical barrier that prevents unwanted plants from compromising the waterproofing over the long term, particularly species with aggressive root system resistance (Kirby 2006).

Saturated (growing medium) - When all the voids in the growing medium are filled with water.

Sedums - are members of the Crassulaceae family (aka Orpine) family - succulent flowering plants.

Semi-Arid Climate - Characterized by light rainfall; especially having from about 10 to 20 inches (25 to 51 centimeters) of annual precipitation.

Semi-Intensive Green Roof - A semi- intensive green roof system is one with growing medium of a depth 25% more or less than 6".

Slope - A change in altitude in a surface, rise over run.

Stormwater - Is a term used to describe water that originates during precipitation events. It may also be used to apply to water that originates with snow melt or runoff water from over watering that enters the stormwater system. Stormwater that does not soak into the ground becomes surface runoff, which either flows directly into surface waterways or is channeled into storm sewers, which eventually discharge to surface waters. Stormwater can carry pollutants into waterways.

BMP's - Best Management Procedures is a term used to describe water quality and quantity control strategies.

Thermal Insulation - A material applied to reduce the flow of heat.

Thermoplastic Polyolifen (TPO) Membrane - A blend of polypropylene and ethylene polymers, colorants, flame retardants (non-halogenated preferred), UV absorbers, antioxidants and other proprietary substances that may be blended with the TPO to achieve the desired physical properties. Membrane used for roofing is reinforced with polyester fabric. Non-reinforced membrane is available for other applications (low compaction sub-grade waterproofing, root barriers, etc.)

Urban Agriculture - The practice of cultivating, processing and distributing food in, or around a village, town or city. Urban agriculture in addition can also involve animal husbandry, aquaculture, agro-forestry and horticulture.

Urban heat island effect (UHI) - This phenomenon describes urban and suburban temperatures that are 2° to 10°F (1° to 6°C) warmer than nearby rural areas. For more information, visit EPA's Heat Island Web Site.

Waste Diversion - Reducing the amount of waste that goes into landfills by recycling and composting.

WQCV - Water Quality Control Volume - a specific volume of stormwater runoff to be captured and treated.

Waterproofing - Treatment of a surface or structure to prevent the passage of water under hydrostatic pressure.

Watershed - The land area that drains into a stream; the watershed for a major river may encompass a number of smaller watersheds that ultimately combine at a common point.