White Paper

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LIVING ARCHITECTURE: GREEN ROOFS FOR PUBLIC BUILDINGS

A Strategy for Smarter Roofing Decisions

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NOTE: This white paper was independently prepared by Amy Pevzner as a part of her GSA internship project and is to be used as a resource and guide, however it does not represent the official position of GSA on green roofs. If you wish to use or reproduce this white paper, please contact Amy Pevzner at amy.pevzner@gsa.gov

I. PREFACE

This document introduces green roofs as a practical and sustainable solution for improving the performance of the existing federal inventory. It demonstrates how green roof technology can enable Region 9 facilities to improve operational efficiency, meet agency goals, and reduce environmental impacts. This white paper was developed to support Region 9 project planning teams in the selection of optimum roofing strategies.

II. EXECUTIVE SUMMARY

The General Services Administration (GSA) must meet, and in many cases exceed, ambitious environmental, energy, and economic performance goals. For the largest real estate portfolio in the country to do so, solutions must be deliberate, flexible, and innovative. Conventional approaches to the built environment are no longer an option.

As an innovator in public service, GSA holds the responsibility of stewardship to not only change the way buildings are constructed and operated, but also lead the way for external agencies, commercial industry, and the private sector to do the same. These changes are accomplished through streamlining processes, stimulating reform, creating jobs, transferring technology, advancing market acceptance, and driving down costs of new technologies. GSA's solutions must be smart, sustainable, and offer considerable value from the start.

"Federal facility managers probably manage more resources and have more impact on the environment than any other group in the world. Entire changes in direction relative to energy and environmental quality are possible through their collective action" [2]

To optimize a large real estate portfolio, each building component must be examined individually then improved upon where possible. Roof maintenance and replacement is a costly and reoccurring expense for every facility. Expected to withstand years of abuse from the elements, a conventional roof must be dependable and functional for the duration of it predicted life of 15-20 years (per PM guidelines), until being removed, disposed of, then replaced. Throughout its lifecycle, a typical roof has great impacts on energy demands, building performance, and the environment.

If a more sustainable approach to the re-roofing process is achieved then replicated across government, commercial, and residential structures - ***the benefits will be significant***. Green roof technology has already proven to successfully enable many of the world's leading economic and environmentally advanced cities to meet increasing demands for building efficiency, waste diversion, and climate change adaptation.

Originating in Germany more than 40 years ago, green roof technology is now considered to be a widely accepted and sustainable strategy for improving building performance and helping to mitigate the effects of climate change. Although well established overseas, the green roof industry has only just recently begun to gain traction in North America. It is currently being supported through government incentives and mandates in cities such as Toronto, Washington D.C., Chicago, and Portland (35).

Common motivators for green roof applications include:

- **Storm water treatment and retention**
- **Sequestration of carbon emissions**
- **Mitigation of urban heat islands**
- **Increased building amenity values**
- **Increased life of roof membrane**
- **Reductions in energy demands**

GSA has long understood the potential for green roofs, with the first one entering the federal inventory in 1975. Today, GSA has installed a recorded 1,390,400 square feet of green roof at 36 of its buildings. [3] Although this number is promising, it comprises of only a small percentage of facilities that could potentially benefit from this technology.

Green roofs are living organisms and by nature, highly complex systems. To date, no single building system is available that can provide all that a green roof can. A green roof's benefits are extensive and many of these benefits can be difficult to quantify using traditional approaches to both business and policy decisions.

Green roof technology has thrived in every instance where government has established support through incentive programs and policies. [4] Numerous executive orders and directives issued by the President illustrate the necessity of preserving environmental integrity. However, Return on Investment (ROI), Net Present Value (NPV), and Lifecycle Costing (LC) calculations continue to remain at the forefront of government budget allocation determinations. Because sustainable design features cannot be universally quantified, a more holistic approach to decisions must be applied. GSA has been influential in defining the new standards for environmentally-sensitive decisions in government and is ideally positioned to set the standards for smarter roofing decisions.

Initial research uncovered studies already commissioned by and for GSA touting the advantages green roofs can offer federal buildings [5] [6] [7]. With only one green roof in Region 9's inventory, it is clear this information is not being adequately communicated to all individuals impacting GSA's reroofing projects. This disconnection between recommendation and application indicate these reports have not yet reached a wide enough audience to be effective.

This document intends to fill this gap by clearly communicating first the *need* and then demonstrating the *value* in order to substantiate the initial investment. By drawing on key concepts and presenting them within the context of GSA's needs, this document demonstrates how GREEN ROOF TECHNOLOGY:

- **Is a practical and effective solution for mitigating many effects of climate change**
- **Closely aligns with social, environmental, and economic agency goals**
- **Is an ideal solution for federal application and particularly well suited for many Region 9 facilities**

This paper is presented in two major sections: The ***technical overview*** focuses on identifying the systems involved in order to illustrate the "*need*". The ***business case*** identifies and defines the "*value*" of green roofs at federal facilities.

III. TECHNICAL OVERVIEW

KEY CONCEPTS:

- IDENTIFY EFFECTS OF CLIMATE CHANGE
- INTRODUCE GREEN ROOF TECHNOLOGY
- PROPOSE GREEN ROOFS AS A SOLUTION

A. EFFECTS OF CLIMATE CHANGE

"Although we must do everything in our power to slow down climate change, it is too late to prevent it entirely. All levels of government must begin preparing for and building resilience to the effects of climate change, an area of planning known as climate change adaptation" [8]

Global climate change is classified by political and social scientists as a "super wicked problem" [9], [10]. It is a concept not easily defined with its impacts unequally distributed across the globe. It has been said that the populations most responsible for causing climate change are also those in the most power to do something about it. Largely due to irregular weather patterns and technological advancements, these populations are the least impacted by the effects of climate change. According to social theory (and dictated by human nature), these same populations are also the least motivated to take action against it.

A broader understanding of climate change and its effects on a global scale could potentially address these obstacles.

Within the framework of public policy environmental law and its funding can be particularly challenging to uphold when motivations of time, budget, or agenda at stake [11]. Historically, environmental features are often the first compromised when encountering any project constraints. In the effort to counteract the problem of assigning universal values to the multi-dimensional facets of climate change, the focus of this first section is on the systems involved rather than employing more traditional costing methods.

I. TEMPERATURE AND HEAT ISLANDS

Cities and towns are on average 2-6°F warmer during the day and 18-22°F warmer at night than its immediately surrounding rural areas under the same climatic conditions. [12] This phenomenon is known as **urban heat island** effect**.**

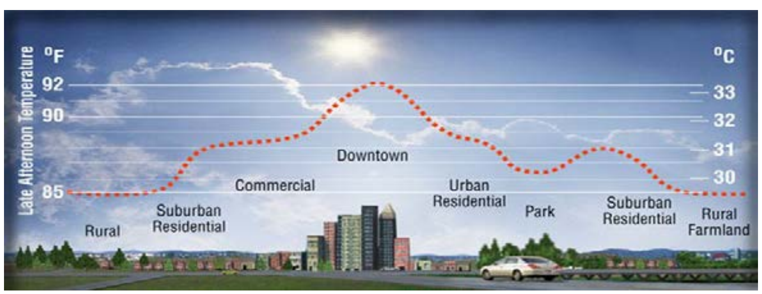

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Figure 1: Urban Heat Island effect on temperature rise

The increasing prevalence of paved surfaces typical to modern infrastructure is a primary cause for ambient temperature rise in urban areas. A site loses its natural capacity for storm water management, groundwater filtration, recharge, and purification once it is disturbed and paved over. The removal of the plant's supporting root structures lead to erosion and loss of nutrients to being brought back to the soil.

In a typical city 65% of impervious surfaces are due to transportation infrastructure; such as roads, parking lots, and sidewalks and **35% are from rooftops**. [14]

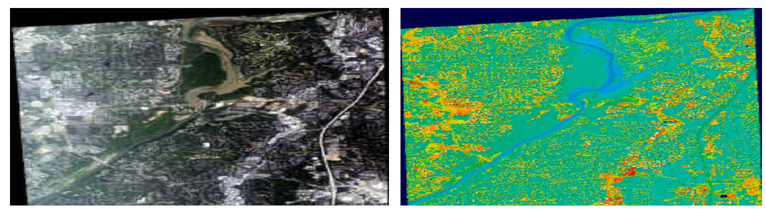
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Figure 2: Temperature variances between green-space and urban areas. – provided by Dr. Jeffrey C. Luvall, NASA

The sealed surfaces in urban hardscapes contribute to heat islands in two fundamental ways:

- Elevates evening temperatures by capturing and releasing previous day's accumulated heat.
- Inhibits the transfer of water from the air above, on, and below the earth's surface in order to cool and purify. This is also known as the *natural hydrological, or water cycle.*

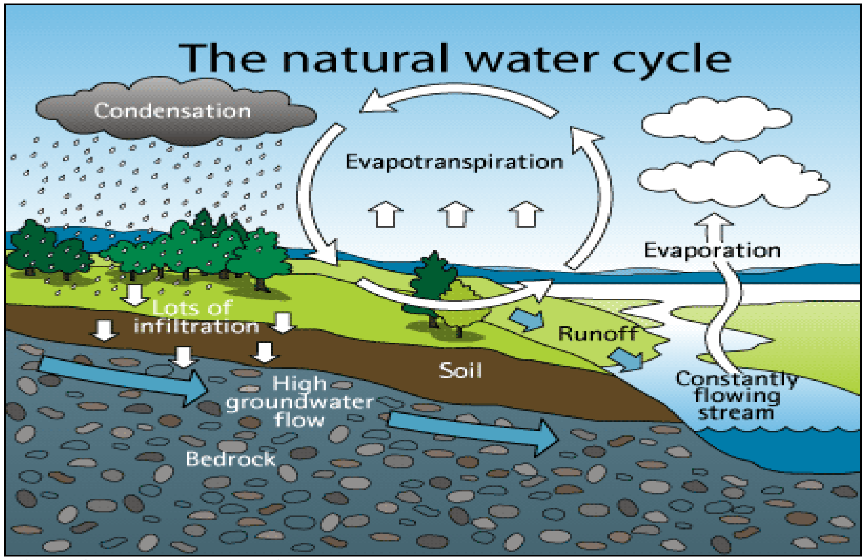

Figure 3: Natural hydrological cycle

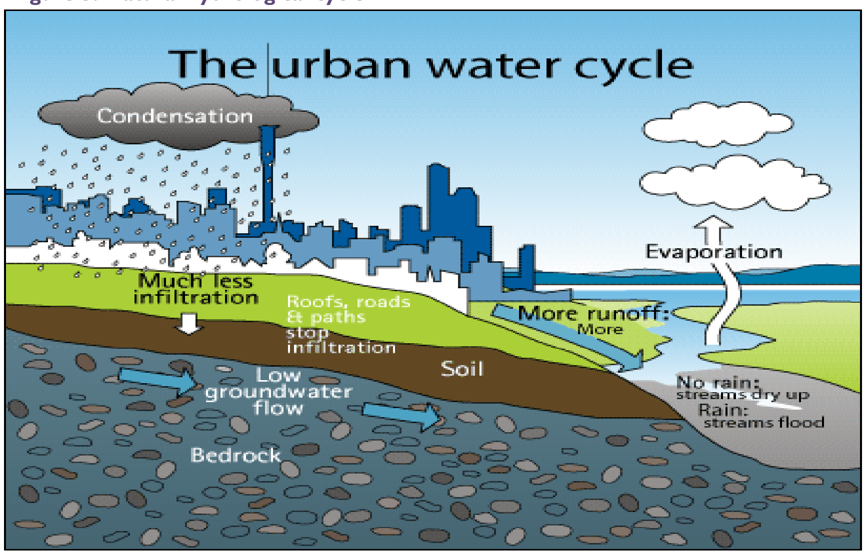

Figure 4: Paved surfaces interfere with the natural hydrological cycle

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2. STORM WATER MANAGEMENT

Storm water management is essential to the transfer of heat and water. Global temperature regulation, water distribution, and purification are able to take place through this natural water cycle.

NATURAL WATER CYCLE

When heavy rains fall over areas of undisturbed soil, water is able to be absorbed into the ground where it is stored on site and then cleansed through the soil and vegetation. Once ambient temperatures rise, water is extracted from the soil, through the plants, and into the air in order to regulate the climate and purify the surrounding air of pollutants.

URBAN WATER CYCLE

When heavy rains fall over paved areas, water is unable to drain as it should. Instead of returning to the water table, it rushes across paved surfaces and gets deposited into nearby waterways. The initial surge of this *storm water runoff*, is called “first-flush”, and carries with it the highest concentrations of pollutants, chemicals, and debris that have accumulated on roofing and paved surfaces since the last rain event. The contaminants and pathogens that are picked up from rooftops and roadways pose serious threats to public health, ecosystems and wildlife.

COMBINED SEWER SYSTEMS

Combined sewer systems serve roughly 772 communities, containing about 40 million people in the U.S. [17] These systems collect both storm water and raw sewage into a single pipe that ultimately gets directed to the local water treatment facility. During periods of high precipitation, these wastewater systems frequently become overloaded. Usually only designed for a 2-5 year flood, once these systems reach their capacity, any of the excess untreated sewage, oil, toxics, and debris spills directly into nearby waterways via the system's overflow pipe.

Such events are called **combined sewage overflows (CSOs).** They contaminate waterways, wildlife, fish, marshlands, and public beaches with high concentrations of organic compounds, bacterial coliform, excess nutrients, suspended solids, and oils.

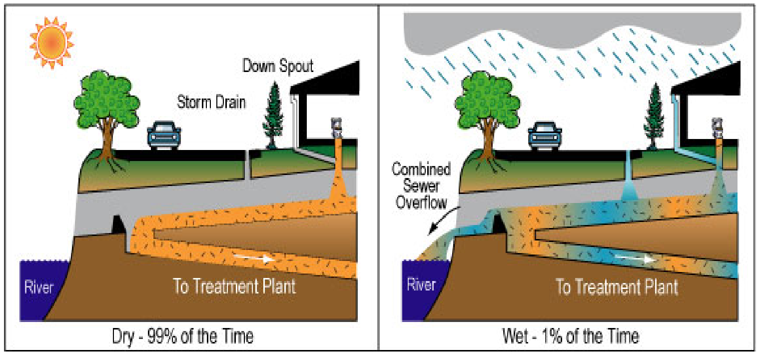

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Figure 5: Basic design of a combined sewer system (CSO)

"The city of San Francisco reportedly experiences <u>ten</u> combined sewer overflows per year and this number is likely to increase." [8]

According to the U.S. EPA, the most effective method for mitigating storm water overflows is to employ **low impact development (LID)** strategies to reduce the burden on the existing water treatment systems. This approach focuses on preserving and recreating naturally occurring landscapes in order to capture and treat local wastewater on site.

In order to combat the financial and environmental costs involved in wastewater treatment, utility companies are looking into charging facility owners for the percentage of impervious surface on their property. According to the EPA, these charges can be avoided by implementing LID techniques such as rain gardens, cisterns, ***green roofs***, and permeable pavements. It is noted that cost should not be the only driver when factoring in LID strategies since these often involve higher upfront project costs, with values realized later. [19]

Of all LID techniques, green roofs are the only ones that do not require the use of additional square footage at a facility's site. In urban areas, where property values are at a premium, green roofs are often the most viable option for storing and treating wastewater on site.

3. ATMOSPHERE AND AIR QUALITY

"Weather is the state of the atmosphere at any given time and place" [20]

Figure 6: Atmospheric carbon levels have nearly doubled since mid-century [21]

Naturally occurring atmospheric molecules such as Carbon Dioxide (CO_2), Nitrous Oxide (N_2O), Methane (CH_4), and water vapor (H_2O) are formed with atoms that are loosely bonded together. The spaces between the loose bonds enable the molecules to retain and emit solar radiation.

Of all *greenhouse gases*, water vapor is the most prevalent with the highest capacity for absorption. As temperatures rise, water vapor gets pulled from soil and vegetation where it is then able to retain even more emissions and heat than before. This cycle continues and each time its absorption and heat retaining capacities increase at an exponential rate. [21]. This process is temperature dependent; meaning the amount of emissions absorbed into the atmosphere, directly correlates to the current climatic conditions. Also known as a "positive feedback loop", these higher temperatures enable the atmosphere to retain and generate more contaminants, while exacerbating pollen counts.

SURFACE LEVEL OZONE

The *greenhouse effect* is a naturally occurring process and without it, the earth would be too cold to support life. Human activities have greatly increased the quantity and rate that these emissions are deposited into the atmosphere. Burning fossil fuels through energy consumption, transportation, industry, and agricultural practices are the major causes for this accumulation. In addition to gases; particulate matter, black carbon, pollens, and molds get trapped in the atmosphere at higher intensities. All of this buildup acts as a blanket holding in heat and suspending pollutants close to earth. This ground level smog contributes to poor air quality, increased maintenance and operation expense, health problems, and even death in susceptible populations.

STRATOSPHERIC OZONE

Chlorofluorocarbons (CFCs) and Hydrofluorocarbons (HFCs) are synthetic gases that were commonly used in refrigerants for their highly stable properties. Unlike the naturally occurring greenhouse gases that eventually break down in the atmosphere, these molecules remain intact and continue to rise up to the stratosphere. As they get closer to the sun's strong ultraviolet rays, the gases form into Chlorine (Cl) free-radicals.

OZONE DEPLETION

The particularly cold and windy conditions located above the earth's poles create an ideal environment for the formation of polar stratospheric clouds (PSCs). When Cl molecules arrive at these PSCs, they become highly reactive and extract oxygen atoms from the ozone (O_3) in order to re-stabilize. Ultimately forming into Chlorine Monoxide (ClO) molecules, these remain suspended in the stratosphere for long periods before eventually breaking down.

These synthetic gases are called ozone depleting substances (ODS), and they are now banned from production and in the process of being phased out under the Montreal Protocol [22]. This ban has succeeded in halting the rapid deterioration of the stratospheric ozone layer. However, it will take decades to begin to reverse all the damage that has occurred over the past 40 years.

Ozone depletion contributes to temperature rise by increasing the amount of solar radiation reaching the earth's surface. Among the many consequences of ozone depletion, the U.S. Environmental Protection Agency (EPA) has acknowledged strong correlations linking ozone depletion and rising cases of skin cancer and cataracts.

Ultraviolet radiation impacts are observed across all vital life systems. Changes in phytoplankton and damages to the early development of marine life have been well documented. Spikes in species extinctions are rising as a result of their inability to adapt fast enough to a climate that is changing at record speed. [23]

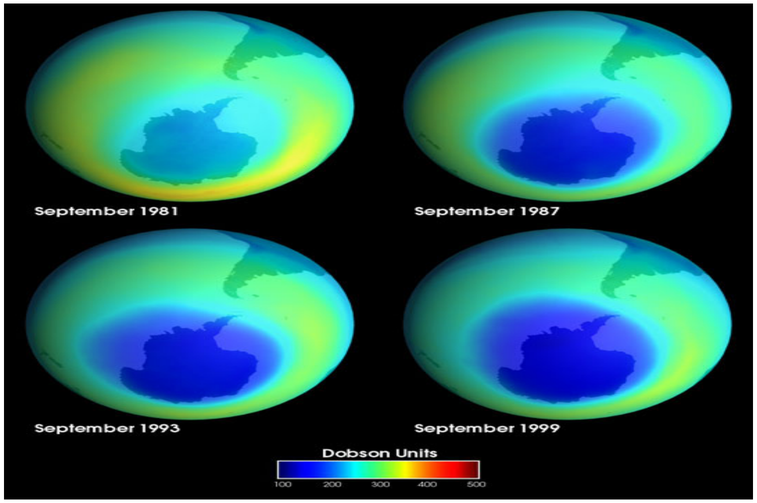

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Figure 7: NASA's Total Ozone Mapping Spectrometer (TOMS) show the depletion of ozone over Antarctica from 1979 to 1999. This "ozone hole" has extended to cover an area as large as 10.5 million square miles.

4. SEA LEVEL RISE

Figure 8: Sea level rise threatening to flood San Francisco's Embarcadero

"Sea levels in the San Francisco Bay are predicted to rise about 16 inches by 2050" [8]

Rising global temperatures lead to the rise in sea levels through thermal expansion and melting glaciers. As the ocean continues to absorb increasing quantities of CO_2, its average PH-levels are lowered. The result is ocean acidification. Consequences of sea level rise include flooding, erosion, erratic weather systems, spread of vector borne disease, and major threats to marine life.

FLOODING AND LAND EROSION

If all of the ice located at the poles were to melt today, global sea levels would rise by 220 feet. Although this is unlikely to occur soon, scientists indicate that if average global temperatures were to go up by only a few degrees (highly likely), sea levels are expected to rise 40 feet. [25] From studying fossils at elevated beaches, scientists can conservatively determine sea levels to rise five feet in the next 100-300 years. At this time, 6% of the San Francisco Bay will be permanently flooded. Most [26] of this expected flooding is concentrated over the second largest estuary in the nation. [8]

INSTENSIFIED WEATHER PATTERNS

The National Oceanic and Atmospheric Administration (NOAA), predicts major shifts in weather patterns due to rising sea levels. The ocean influences changes to hurricane patterns which alters the intensity and frequency of storms. Major weather events have been consistently climbing over the past four decades. [27]

VIRUS AND VECTOR BORNE DISEASE

Lyme disease and West Nile virus are proportionally linked to both atmosphere and sea level changes. The combination of warmer climates and stronger precipitation patterns contribute to the rise of tick and mosquito populations. Studies confirm risks of infection will increase as parasitic populations increase. [28]

B. INTRODUCTION TO GREEN ROOFS AND BENEFITS

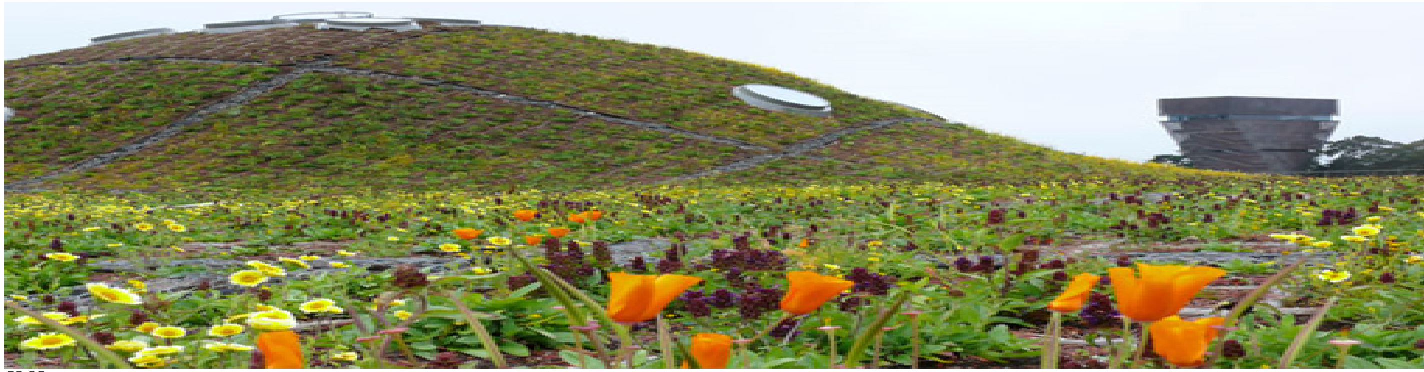

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Figure 9: San Francisco Academy of Science green roof

"A green roof system is an extension of the existing roof involving a high quality water proofing and root repellent system, a drainage system, filter cloth, a lightweight growing medium and plants." [30]

Benefits:

- ***Mitigates Heat Islands***
- ***Manages Storm Water***
- ***Reduces Peak Energy Demands***
- ***Improves Air and Water Quality***
- ***Extends Life of Roof Membrane***
- ***Attenuates Sound***
- ***Provides Insulation***
- ***Promotes Biodiversity***

Green roofs are categorized as either ***intensive*** or ***extensive***, depending on depth and the amount of maintenance required.

INTENSIVE GREEN ROOFS can have anywhere from 8 inches to several feet of growing media and include plantings with deep woody roots such as bushes and trees. These types of roofs are often used as community gardens and public parks. The higher costs, structural, and maintenance requirements make them less practical for federal building retrofit applications.

EXTENSIVE GREEN ROOFS are characterized as having approximately 3-6 inches of growing media with plantings of low-growing, hardy sedums. These are generally not intended for public access, have limited structural load requirements, and following the initial establishment period of 2-4 years, require little to no maintenance. Extensive green roofs provide the greatest value with numerous direct and indirect benefits making them ideal for federal applications.

Extensive green roof systems offer the greatest value/benefit potential, and therefore will be the only type of green roof examined in this document.

"The waterproofing membrane must be fully bonded to the substrate, seamless with an overburden consisting of a protection course, root barrier, drainage layer, insulation, moisture-retention layer, reservoir layer, filter fabric, and engineered soil-based growth medium with plantings". [31]

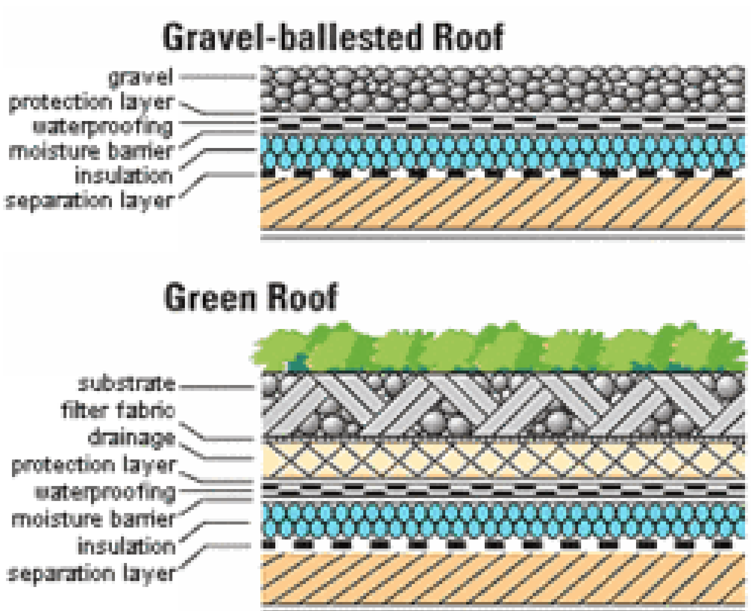


Figure 10: Instead of the gravel as on a conventional roof, a green roof has a drainage layer, filter fabric, and substrate with planting media and sedum. [5]

Typical Green Roof Material Layers:

Waterproofing Membrane

Waterproof membranes are required for all roofs types. For this reason, the membrane should be removed from any cost-analysis comparisons when determining between different types of roof to install. Missing this step will result in inaccurate cost assessments.

Drainage

The drainage layer is engineered to ensure water flows away from the roof. A properly designed green roof will not have water sitting on top of it – any stored water will reside in the soil and vegetation.

Root-resistant Fabric

This layer is critical to ensuring roots cannot puncture the waterproof membrane.

Soil Media

Actual soil is not used on today's green roofs. In order to limit roof loads, a composite material, such as light-weight clay, is used.

Vegetation

Grass is not used on green roofs. Low-growing sedums are often planted. Sedums can survive harsher environments of higher elevations and also perform as a fire-break on the roof.

I. TEMPERATURE AND HEAT ISLANDS

The foliage of a green roof is constantly self-regulating by utilizing all available forms of heat transfer as required; solar radiation, reflected solar radiation, long wave radiation, convection, evaporation, conduction, and absorption. This intricate system involving temperature control, regulation of air and water quantity and quality, along with the capacity for regeneration is what sets a living system apart from any engineered product on the market.

Green roofs transfer heat in the following ways:

1. **Solar radiation -** Heat is absorbed through the leaves and stems of plant foliage.
2. **Reflected solar radiation -** Heat is reflected outward.
3. **Long wave radiation -** Heat is reflected back into the atmosphere.
4. **Convection -** Air movement across the leaves speeds the process of cooling or heating.
5. **Evaporation -** This is the removal of excess heat through the removal of water
6. **Conduction -** Heat transfer through a roofs system
7. **Heat absorbed or released by high mass layers** – Thermal mass or insulation has the same effect.

A green roof is aptly described by energy expert Christopher Wark, as "smart" because it understands how to adapt to its surroundings. When it is too hot, a green roof releases water vapors via evapotranspiration. When it is too cold, the dormant vegetation flattens its roots and stems close to the roof to expand surface volume exposed to the sun.

In comparison to a green roof, he explains that a shingle (or any other roof system) is "stupid" because it is unable to react to its environment. "Like a car parked in the hot sun, it just sits there continuing to get hotter." [32]

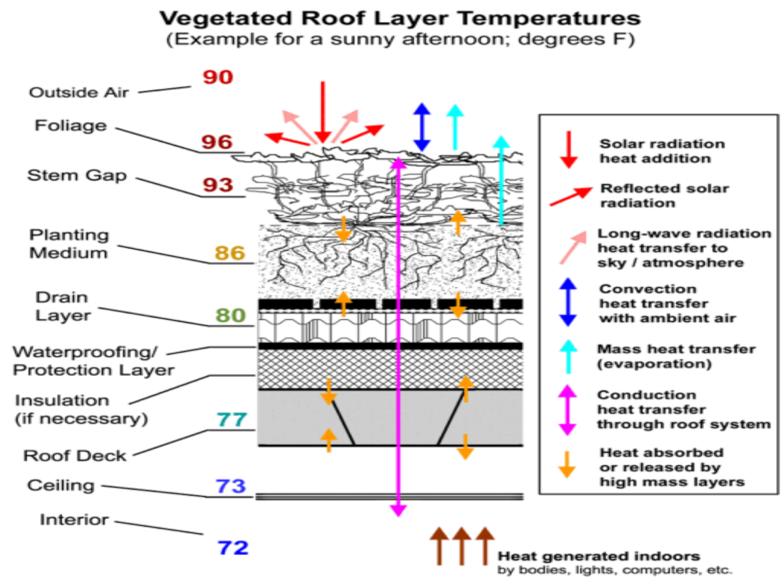


Figure 11: Temperature analysis of vegetated roof surfaces [32]

Temperature Reductions

When compared to white or black roofs, green roofs have been observed to reduce surface temperatures significantly. Columbia University's monitoring results of the Con Edison Learning Center in Long Island City reveal a white roof's membrane temperature peaks to average out at 30 degrees cooler than black roofs and **green roofs averaged 60 degrees cooler than black roofs**.

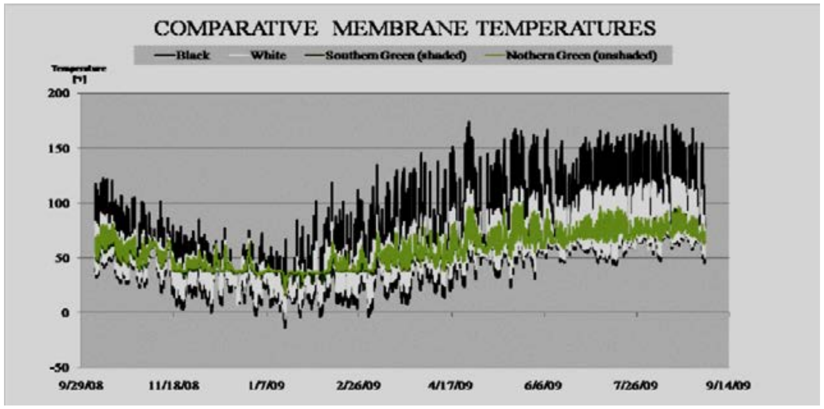


Figure 12: Con Edison roof temperature monitoring reveals green roofs to be 60 degrees cooler than black roofs [33]

A study, performed by the city of Toronto found that "***if only 6 percent of Toronto's roofs (1,600 acres) were green roofs, summer temperatures could be reduced by 1.8°F to 3.6°F***." [5]

Reduced ambient temperatures directly impact energy loads by minimizing demands for engineered cooling. This benefits a facility owner directly by saving on utility bills and overall operational costs. At a municipal level, there is potential to avoid significant energy production at power plants. This in turn, conserves water (used to create power) and minimizes the creation of ground-level ozone, and ultimately reducing city-wide energy dependence.

Insulation

The thickness, or *thermal mass,* of a green roof provides building insulation, retains heat, and reduces energy loads, while also acting as a barrier protecting the roof membrane from exposure.

When internal building temperatures increase (server rooms, lighting, people, etc.), a green roof transfers excess heat through its membrane, media, and plants where it is then cooled through evaporation, conduction, and convection. ***Researchers identified indoor temperatures to be at least 38 degrees (F) lower than outside air temperatures of 83 degrees (F).*** [34] [35] Conversely, a conventional roof's insulation holds the generated heat inside the building and increasing requirements for cooling.

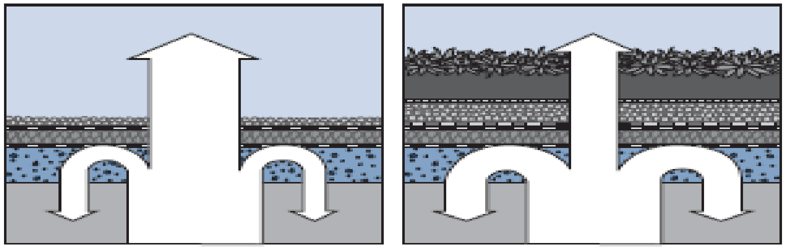


Figure 13: Illustration of heat loss through a conventional and a green roof [5]

Thermal Stress

Reduced temperature fluctuations reduce thermal stress. Benefits of a green roof are realized through the extended life of the roof membrane, nearby equipment, and its related systems. These benefits will carry over to cooling fans and PV panels.

Roof Membrane

A conventional roof lasts 15-20 years, and a green roof typically 40+. The extended roof life means that a significantly higher return on investment can be expected. As more green roofs are installed, reroofing activities will become less frequent. This results in saved money, time, and resources (through funding requests, contracting, design, oversight, etc.). Re-roofing half as often also saves "embodied energy". This includes diversion of waste and reduction in all carbon forming activities involved in the re-roofing process such as manufacture, transportation, installation and disposal of materials.

Building Systems

HVAC and cooling fans are less likely to become overworked while operating under more controlled climate conditions. These benefits are further enhanced if the air intakes are located on the roof. Equipment and energy preservation translates directly into lower utility-use charges and less required capital needed for building equipment in terms of size and costs.

Nearby Equipment

Green roofs reduce airborne particulates and cool the surrounding air. White roofs and PV (solar) panels require regular maintenance to ensure proper functioning. The vegetation on a green roof removes fine particulates, black carbon, and pollen out of the air. Improved air quality and minimized temperature swings of a green roof will likely increase performance of periphery solar equipment.

2. STORM WATER MANAGEMENT

"In April 2011, the United States experienced record-breaking floods, tornadoes, drought, and wildfires all in a single month." [36]

Effective storm water management should be a high priority for most communities. Frequency and intensity of storm events are predicted to increase in the upcoming decades. If storm water is not properly managed on site, the consequences to public health and marine life evident through increases in urban and coastal flooding, droughts, power outages, and loss of soil integrity will be disastrous.

Green roofs are proven to be extremely successful at retaining storm water and delaying runoff rates. Studies indicate multiple green roofs minimize volumes of wastewater that would otherwise be sent to be treatment plants.

Storm water Attenuation

"A typical green roof will absorb, filter, retain and store up to 75% of all annual precipitation that falls on it under conditions prevalent in most areas of the U.S." [5]

Green roofs have been recorded to capture on average 100% of storm-water runoff volume during lower intensity rain events of about one inch and have an average retention rate of 67% at higher intensities. [37] [38]. This is equivalent to about 0.6 gallons of water per square foot of green roof area.

Peak Runoff Rates

A monitoring project on green roof water quality and quantity of a 3,000 square foot ASLA green roof in Washington D.C. that was performed in accordance with the U.S. EPA collection standards determined the roof retained approximately 75% of the total rainfall volume (29 in.) that fell over the ten month period [39], keeping **27,512.4 gallons** of wastewater out of the city sewer system.

> ***Over an average year of typical Washington DC rainfall, such a green roof would retain about 15 gallons of storm water per square foot of coverage."*** [62]

Peak Energy Demands

According to Energy Star, "the nation's wastewater plants and drinking water systems spend about $4 billion per year on energy to treat wastewater. Individually, these operating costs can add up to one-third of a municipality's total energy bill." [40]

3. ATMOSPHERE AND AIR QUALITY

Green roofs contribute to improved air quality by capturing greenhouse gases, particulates, pollens, and molds. The vegetation on a green roof cools ambient air temperatures and consequently promotes reductions in urban heat islands and greenhouse gas production.

While a single green roof provides many benefits to the facility owner, it may not necessarily provide much impact at a city-level. Clustering installations are an effective strategy to increase these impacts significantly.

Referred as the "master control knob" to the earth's climate, human-generated CO_2 emissions have been likened by scientists as the equivalent of people "essentially twisting the earth's thermostat hard to the right" [41]

Carbon Sequestration

Pollen counts and emission levels are sharply rising. Vegetation performs as an extremely effective carbon sink by cleansing the air of excess emissions. Additionally, temperature regulation is achieved through the transfer of heat and water vapor. Air quality and public health subsequently improves as the amount of emissions and irritants are cleared.

A study measuring carbon levels in plant and soil samples were collected from 13 green roofs in Michigan and Maryland over a two year period. The researchers determined green roofing an urban area of about one million people will capture more than 55,000 tons of carbon- this is an amount ***"similar to removing more than 10,000 mid-sized SUV or trucks off the road a year,"*** [42]

Energy Reduction

Fewer emissions and the cooling of ambient air temperatures reduce the potential for ground-level ozone production. Reduced concentrations of pollutant intensities minimize opportunities for smog formation, and consequently reducing demand requirements for air conditioned space and relieving extra energy burdens of city-wide demands.

Figure 14: Typical L.A. day seen through the haze of ground-level ozone and smog [43]

An energy modeling study on peak summertime cooling demands and CO_2 reductions at the city level was performed by Ryerson University. They calculated the impacts of urban heat islands and smog reductions using the city of Los Angeles, CA. They determined that the **city of L.A. could realize a savings of $100 million a year by greening 75% of its eligible rooftops**. [44]

As green roofs continue to expand across North America, more data can be collected for analysis. Such energy modeling calculations are scientifically backed methods. However, they often can raise questions to their validity because of the continued to reliance on valuation assignments of multi-faceted systems as related to climate change.

4. SEA LEVEL RISE

"Almost half of the CO_2 produced in the past 200 years from the burning of fossil fuels and cement manufacture has been absorbed by the oceans. [45]*"*

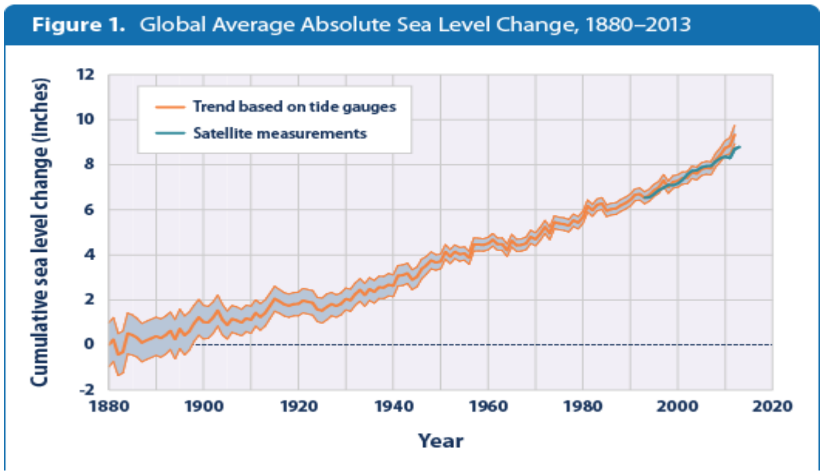


Figure 15: Absolute global sea level rise since 2013 [46]

Prevention of greenhouse gas production will reduce the quantity of CO_2 being absorbed into the ocean. Prioritizing efficiency, renewable energy, and carbon sequestration into all construction, maintenance, and operational decisions can effectively mitigate the sea level's predicted sharp trajectory (see graph above). Promotion of green roof installations on a wide-scale will facilitate reductions in the federal government's environmental footprint, while at the same time inspiring and enabling others to do the same.

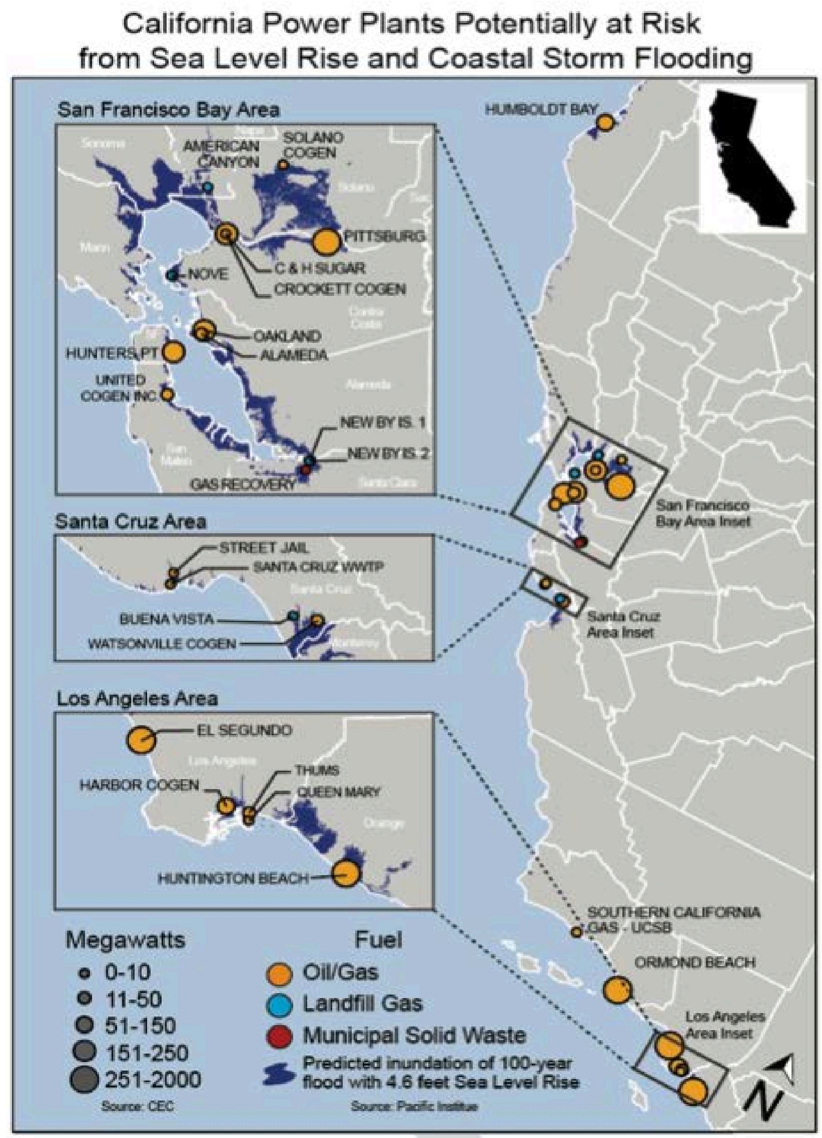


Figure 16: Power plants along California's coast susceptible to sea level rise [47]

IV. BUSINESS CASE FOR GREEN ROOFS

KEY CONCEPTS:

- ALIGNS WITH AGENCY GOALS
- IMPLEMENTATION BARRIERS
- GREEN ROOFS FOR REGION 9

A. AGENCY GOALS

The application of green roofs has proven to provide many social, environmental, and fiscal benefits. This relationship is reciprocal in that the implementation of green roofs in the federal inventory happens to align with GSA's agency-wide priorities. Dan Tangerhlini, GSA Acting Administrator released a statement in January 2013. GSA must focus on the following six agency priorities:

GSA's KEY PRIORITIES

- Deliver Better Value and Savings
- Serve Our Partners
- Expand Opportunities for Small Businesses
- Make a More Sustainable Government
- Lead with Innovation
- Build a Stronger GSA

I. DELIVER VALUE AND SAVINGS

GSA must deliver value to customer agencies and taxpayers. The value of installing a green roof can quantified through return on investment calculations of operational costs that consider many benefits. A green roof's tangible and intangible benefits have also been found to positively impact properties values.

OPERATIONAL EFFICIENY AND SAVINGS

In a report prepared for GSA, ARUP determined the Net Present Value (NPV) for installing a green roof at a federal facility:

- Installation, replacement, and maintenance of a green roof has the greatest negative impact at a **cost** of approximately **$18 per square foot of roof**
- Storm water and energy savings provide a **benefit** of approximately **$19 per square foot** of roof.
- Benefits to the community have the greatest positive impact at a **savings of almost $38 per square foot** [48]

The chart on the following page illustrates ARUP's findings on installing a green roof over a conventional black roof. Details of this study can also be found in the Supplemental section of this document here: Research Data

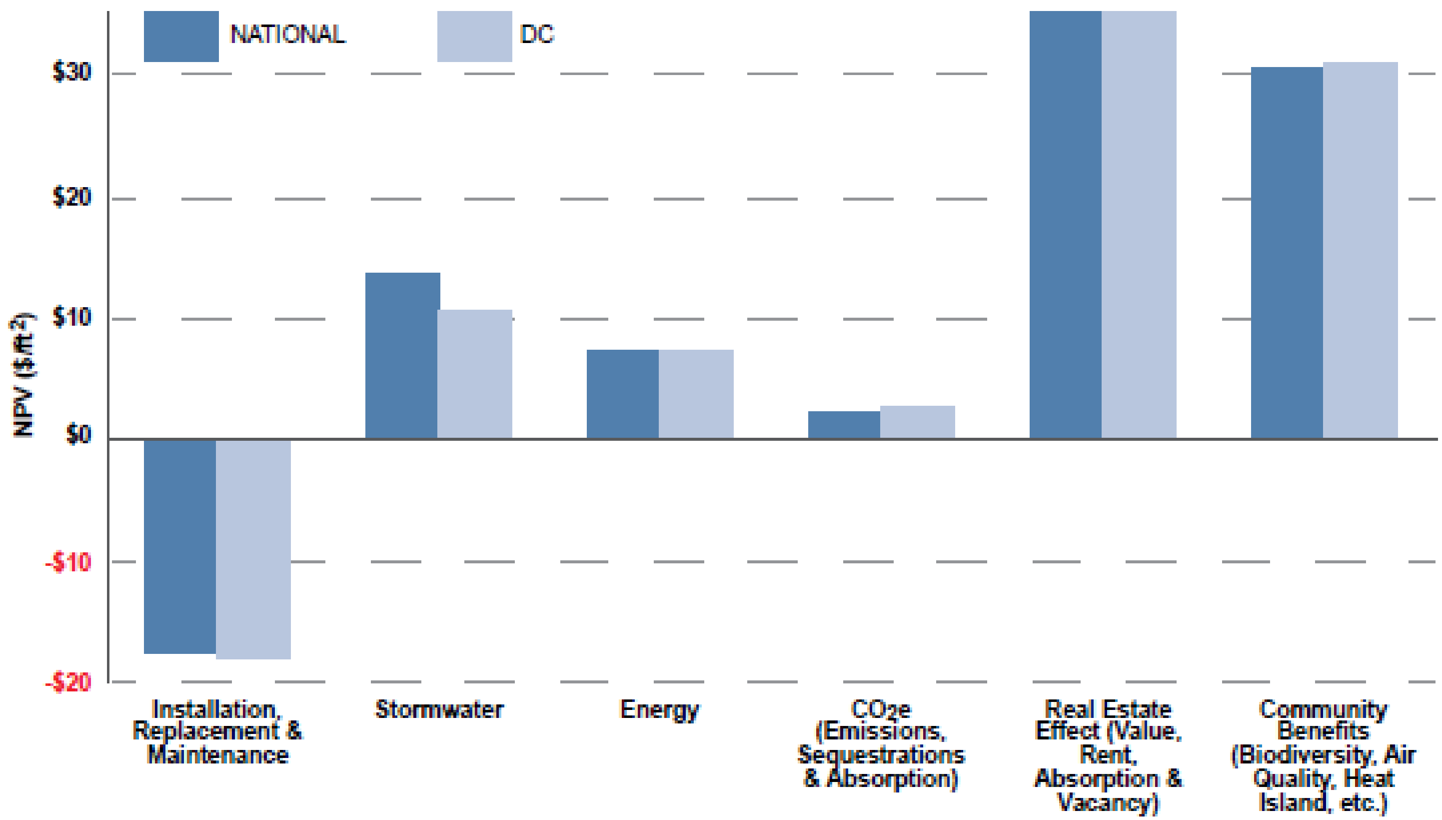


Figure 22: NPV cost-benefit analysis results of green roof versus black roofs

[48]

Figure 17 Itemization of the Costs and Benefits of installing a green roof at a federal facility

The study at Ryerson University, determined the following green roof benefits have the ***highest quantifiable monetary value***:

- Storm water management
- Improvement in air quality
- Reduction in direct energy use
- Reduction in urban heat island effect

It was estimated ***if 75% of existing buildings in the city of Toronto were greened, (538,195,000 sq ft) that it would save the city $313,100,000 initially and $37,130,000 annually***. [44]

Benefit	Initial Savings	Annual Savings
Storm water	$118,000,000	
Combined Sewer Overflow	$46,600,000	$750,000
Air Quality	$2,500,000	
Building Energy	$68,700,000	$21,560,000
Urban Heat Island	$79,800,000	$12,320,000
Total	**$313,100,000**	**$37,130,000**

Figure 18: Cost breakdown of savings if 75% of existing buildings in the city of Toronto had a green roof [44]

Increases in solar UVB levels are proven to shorten the life of man-made materials that are stored outside [20]. Green roofs provide both a physical barrier and protect the membrane and nearby equipment from thermal stress. Because vegetation regenerates there is generally no degradation of roof material. Wide-scale implementation of green roofs brings significant value to federal investments, community improvements, and for property disposal.

PROPERTY VALUES

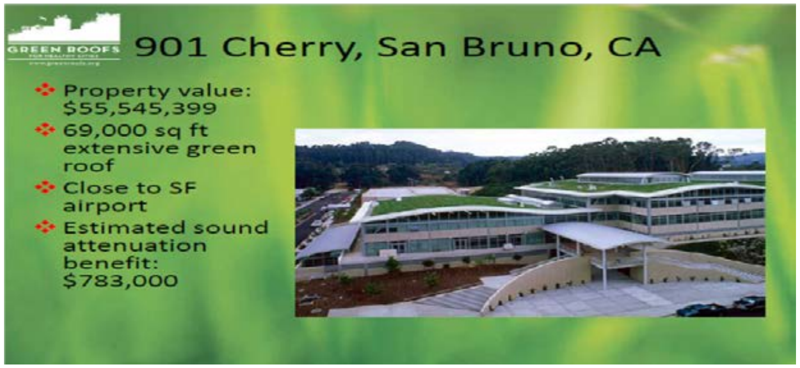


Figure 19: Green roofs increase property values [49]

Although the following qualitative benefits may not necessarily translate into direct savings, they do increase amenity value to a property, its tenants:

- Sound attenuation
- Improved aesthetics
- Re-creation of natural habitats

The 2011 study performed by ARUP, determined that **facilities with green roofs validate higher rental premiums of 2.5% nationally** and 3.3% in Washington D.C [48]

SOUND ATTENUATION

An eight inch green roof can reduce traffic noise by 46 decibels. [50] Where noise is a concern at a GSA facility (ex: Courthouse) planting a green roof with a depth of 6 inches or more can add a significant amenity value to the property. This method could be useful for properties near freeways or airports (ex: Ports of Entry).

IMPROVES AESTHETICS

Enhancing urban landscapes and increasing human connections to natural landscapes has proven to successfully reduce stress and enhance worker productivity. Key buildings in GSA's portfolio function to symbolize national strength and leadership. Green roofs are an effective visual tool to demonstrate green building practices to the public. Studies conducted at hospitals reveal patients healed faster when were they were given access to views of nature. [51]

RE-CREATES NATIVE HABITATS

Green roofs provide the opportunity to restore a buildings existing footprint by replicating the previously undisturbed site. Birds, butterflies, bees, and other invertebrates get displaced as the urban environment expands. Green roofs provide a much needed resting place for these creatures that are so vital to maintaining the delicate balance of the eco-system.

"To the extent that we value a diverse food supply with minimized trauma to the environments where it is produced, we will place a high value indeed on honey bees and other pollinators." [52]

Pollination is essential to plant bio-diversity. Significant reductions in plant species will result in homogenization of plants and crops. Reductions in plant and species diversity will require heavier reliance on engineered methods, often involving chemicals, for plant establishment.

2. SERVE OUR PARTNERS

GSA plays a key role is in providing support and services to its partners and customer agencies. GSA can best help agencies focus on their missions by increasing comfort and efficiency through the services it provides.

INCREASE OCCUPANT COMFORT

The term "*biophilia*", meaning love of nature, is increasingly being used in high performance green building design. The goal of biomimicry is to recreate natural environments in order to increase the human/nature connection. Employee satisfaction and productivity has been found to increase, while the number of "sick days" decreased where organizations have integrated biomimicry into the workplace. [53]

10% of employee absences can be attributed to architecture with no connection to nature. [54]

Building occupant health and comfort is enhanced when both air quality and temperature are properly controlled. Green roofs contribute both directly; through filtration and regulation, and indirectly; by reducing peak energy demands and storm water overflows.

3. SMALL BUSINESS SUPPORT

*"Greater building efficiency can meet 85% of future U.S. demand for energy, and a **national commitment to green building has the potential to generate 2.5 million American jobs.**"* [61]

There are only a handful of cities in the United States that have begun to engage in the early stages of green roof policy development. [4] Currently, Portland, Oregon is the only "west coast" city to have advanced in the arena of green roof policy and industry development. Incidentally, the installations of green roofs are found to be particularly beneficial for California climates (for more information: Green Roofs for Region 9).

There is real opportunity for growth of new industries and helping to support small businesses through GSA's dedicated contracting efforts. Acting as the "voice" of the government through its purchases, GSA can effectively leverage its buying power to support the advancement of business growth and job creation in the arena of design, material, oversight, and data-collection for federal green roof projects.

In doing so, these efforts will help to lay the groundwork for industry standards, while driving down costs for green roof materials and installations. Supporting business development and growth the of green roof industries overlaps with the following GSA priorities: ***sustainable development, leading with innovation, and building a stronger GSA***.

4. SUSTAINABLE GOVERNMENT

The U.S. building sector is responsible for consuming 19% of the global primary energy; right on the heels of China's 20% – A nation whose total population is more than tripled that of the U.S.

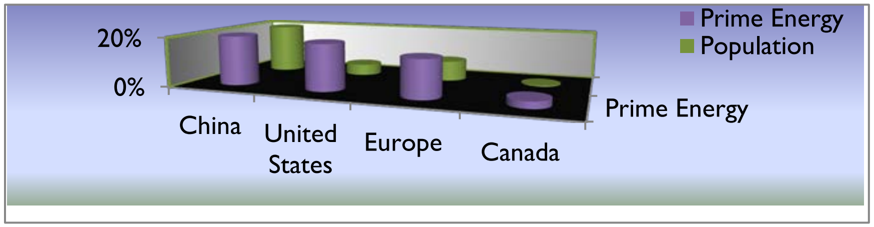


Figure 20: US building sector consumes almost as much energy as China [55]

The federal government owns 374 million square feet of floor space [56] and GSA is one of five federal agencies responsible for **83% of all federal building primary energy consumption**. [55].

According to the *Whole Building Design Guide* (WBDG), sustainable design must include an increased commitment to environmental stewardship by achieving an optimal balance of cost, environmental, societal, and human benefits and meeting the mission and function of the intended facility or infrastructure. [57]

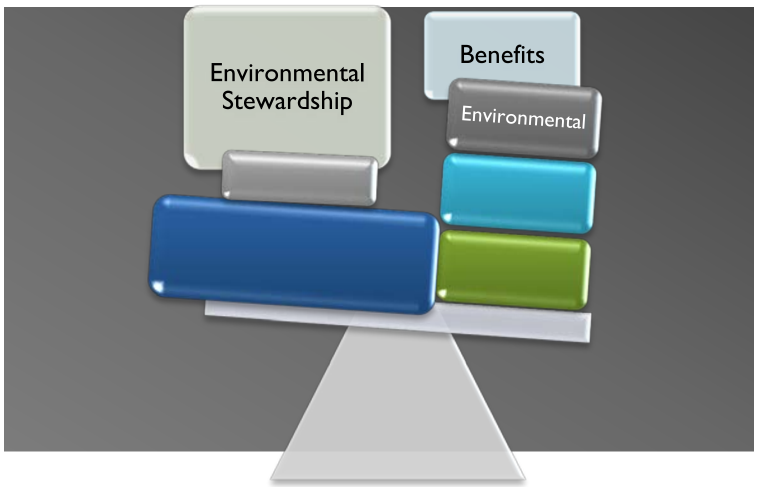


Figure 21: Sustainable Design is achieved through a balance of factors [57]

"Buildings in the United States account for 72% of total electricity consumption and 38.9 percent of the nation's total carbon dioxide emissions." [55]

Government-wide support of sustainable products, services, and activities is imperative if we are to effectively mitigate the escalating effects associated with climate change. This can only be achieved by re-introducing nature back into *our environments* on a large scale.

"About 20% of the national cooling demand can be avoided through a large-scale implementation of heat-island mitigation measures. This amounts to 40 TWh/year savings, worth over $4B per year by 2015 in cooling-electricity savings alone. Once the benefits of smog reduction are accounted for, the ***total savings could add up to over $10B per year****."* [12]

5. LEAD WITH INNOVATION

"In North America, the benefits of green roof technologies are poorly understood and the market remains immature, despite the efforts of several industry leaders. In Europe however, these technologies have become very well established. This has been the direct result of government legislative and financial support.... Such support recognizes the many tangible and intangible public benefits of green roofs." [49]

Lack of industry standard has been one of the major barriers inhibiting growth of green roofs today. U.S. Policy support of green roofs is widely adopted throughout Germany, France, Austria, Switzerland, and Canada with great success and is in its early development in Chicago, D.C., and Portland. Without industry standards established, pricing, expertise and outcomes will be inconsistent at best.

Acting as stewards, GSA can to effectively help other agencies understand green roof technology. Where determined feasible, the greening of federal facilities could begin as demonstration projects at key buildings to further the education about green building to customers and taxpayers.

6. BUILDING A STRONGER GSA

Training and resources to its employees is critical to agency success. GSA must be at the forefront of green building technologies to effectively *lead with innovation.*

Increased data collection opportunities through continuous monitoring and analysis are imperative for smart building design. Developing industries, such as green roofs, require data collection in order to further progress.

The benefits of green infrastructure increase exponentially, so potentially teaming up with local and state governments such as the Public Utilities Commission and San Francisco's Planning and Urban Development could strengthen the efforts of all involved.

B. COMMON IMPLEMENTATION BARRIERS

Living systems, with its highly complex functions are not always readily or simply understood. The majority of a green roof's implementation barriers stem from information being communicated partially or inaccurately. A project mistake resulting from inexperience and occurring in an un-standardized industry can easily perpetuate stigmas surrounding lesser understood technologies such as green roofs. The following major implementation barriers are identified and the possible strategies to overcome them are included below:

1. STRUCTURAL CONCERNS

ROOF LEAKS

"The fear of leaks appears to be the single greatest barrier to implementation and can even outweigh the realization that a green roof provides numerous cumulative benefits, both direct and indirect, to facilities, occupants, and outdoor and indoor environments. " [5]

Strategy

To minimize the potential of roof leaks, schedule the installation immediately after the new waterproof membrane is applied and limit roof access to avoid damaging the waterproof membrane. Integrate leak detection into the green roof design, such as an Electronic Vector Mapping (EVM) system.

LOAD CALCULATIONS

A green roof installation can be prematurely rejected for the belief that major structural designs must accompany every retrofit project.

Strategy

The U.S. Department of Energy reported that most extensive green roofs often do not require additional structural support:

> *"The weight added by an extensive green roof is comparable to that of the gravel ballast on a conventional roof— about 15 to 30 pounds per square foot, depending on the soil media, the depth of the soil layer, and the weight and depth of any additional layers."* [5]

1. INDUSTRY STANDARDS

DESIGN AND CONSTRUCTION GUIDELINES

Lack of technical knowledge, designers, data, and marketplace acceptance are reasons why this industry has taken longer to catch on in North America. The federal government has the resources to streamline industry standards while still protecting its assets.

Strategy

Lump the project under one performance-based contract to ensure plant establishment and guarantees on product and performance.

2. COST AND DATA COLLECTION

INITIAL COSTS

According the Department of Energy, green roofs typically cost $15-20 sq ft as opposed to the $8-10 sq ft for a conventional cool roof [5]. Government buildings typically remain in the portfolio for many years. The probability that GSA will realize the full financial benefits of a green roof's pay-back period is extremely likely.

Strategy

Inaccurate data collection methods can lead to making premature and costly re-roofing decisions. Decisions concerning multifaceted designs must examine all factors involved.

STANDARDIZED MEASUREMENTS

One dimensional industry-assigned valuation cannot accurately gauge all potential benefits of a green roof system. An R-value or albedo is a single function-not a true measurement of performance.

Strategy

When comparing performance between different types of roof, all angles must be taken into account. Figure 14 illustrates the ways a green roof's performance can be evaluated.

OVERESTIMATIONS

A common mistake when making decisions based on cost is including the waterproof membrane in the price of a green roof but not the alternate roof.

Strategy

The waterproof membrane is component that must be included regardless of roof type. In order to ensure accurate cost analyses, the price of the roof's membrane must be included decisions are often made by analyzing the bottom line.

3. COOL ROOFS

Researchers have determined the combination of green roofs and cool roofs are often an optimal choice at a municipal level. A full examination of a cool roof's benefits is beyond the scope of this document. They are discussed only to the extent that their performance compares to a green roof.

Cool roofs work by reflecting solar radiation back into the atmosphere. In doing so, less heat gets absorbed into the building. Although the upfront cost for a cool roof are much less than that of a green roof, once full benefits are factored in, the green roof becomes a much better value.

When comparing the performance results of a conventional roof to a cool roof, a cool roof is extremely effective in its ability to reduce a building's cooling demands. The cool roof's reflective properties (albedo) degrade in efficacy (by about 70%) typically within the first two years of installation. In addition, the remaining percentage of light that does get reflected, does so at a continuous rate back into the atmosphere (or to neighboring buildings), regardless of the current temperature – this means heat loss will continue during cold months and even likely result in potential energy deficits.

	Extensive Green Roof	Average Cool Roof
Reflectivity	summer: 0.15 - 0.5 winter: 0.1 - 0.3	summer: 0.7 winter: 0.7
Emissivity	summer: 0.8 - 0.99 winter: 0.5 - 0.7	summer: 0.95 winter: 0.95
Convection (wind cooling)	fairly significant at any wind speed	highly dependent on wind speed and roof configuration
Evapotranspiration	fairly significant, depending on water availability and temperature	none
Seasonal Adjustment	significant	none
Embodied Energy	high initially, then insignificant	Standard initially, then periodic with replacement

Figure 22 Performance comparisons of a green roof and cool roof [32]

Even when it is cold outside, a white roof maintains the same degree of solar reflection (albedo) into the atmosphere. For this reason it is possible for white roofs to increase energy loads during the winter months because the sun is not able to warm the building.

C. GREEN ROOFS FOR REGION 9

"The waterproofing of a roof on a GSA-managed building is typically replaced every 15 to 25 years. Even if a green roof only doubles the lifetime of the waterproofing system, the resulting savings could significantly offset the initial costs of the roof. Savings to the federal government could be considerable. For example, the federal government owns or manages more than 500,000 facilities nationwide and spends about $8 to $10 per square foot to replace a roof and dispose of old materials every 15 to 35 years. Assuming that the average roof surface of each building is 10,000 square feet, the savings from green roofs could amount to $80,000 to $100,000 per building in roof replacement costs alone. This is roughly equivalent to the initial capital investment in a green roof system, excluding maintenance. If only half of all government facilities were retrofitted with green roofs, the savings could be in the millions of dollars over 15 to 25 years, despite additional maintenance expenses. To minimize extra costs, green roofs could be installed on existing buildings to coincide with the next waterproofing replacement. The potential savings and environmental impact of such a phased-in approach are significant. If only 50 percent of all buildings are suitable for a green roof application, approximately 2.5 billion square feet, or nearly 60,000 acres, of green roof installations could be completed within the next 15 to 25 years on government buildings alone." [5]

Green roofs are an ideal solution for federal applications and particularly well suited for GSA Region 9 facilities. The weather and coastal proximity of many of its buildings are reported to be prime locations for obtaining the maximum amount of environmental and energy saving benefits from a green roof application. To be specific, the most ideal locations include the warm and dry climates of southern California coast, and one or two valleys in from the coast of northern California to Washington State. [32]

The green roof currently in construction at 50 United Nations Plaza (50 UNP) in San Francisco, CA is the only application in Region 9's portfolio. Buildings with larger footprints (roof/wall ratios) that have low-sloped roofs, are fewer than 5 stories, and require normal air exchanges (unlike labs) can most benefit from the application of a green roof. They are particularly valuable to a building owner in terms of direct savings and quicker returns on investment.

Each potential project site must be evaluated by an engineer to better predict plant viability and energy performance. Some factors to consider include examining the particular micro-climates and orientation to the sun, as well as to other buildings. If there are urban canyons contributing to significant shading or there are high winds, some additional engineering may be required.

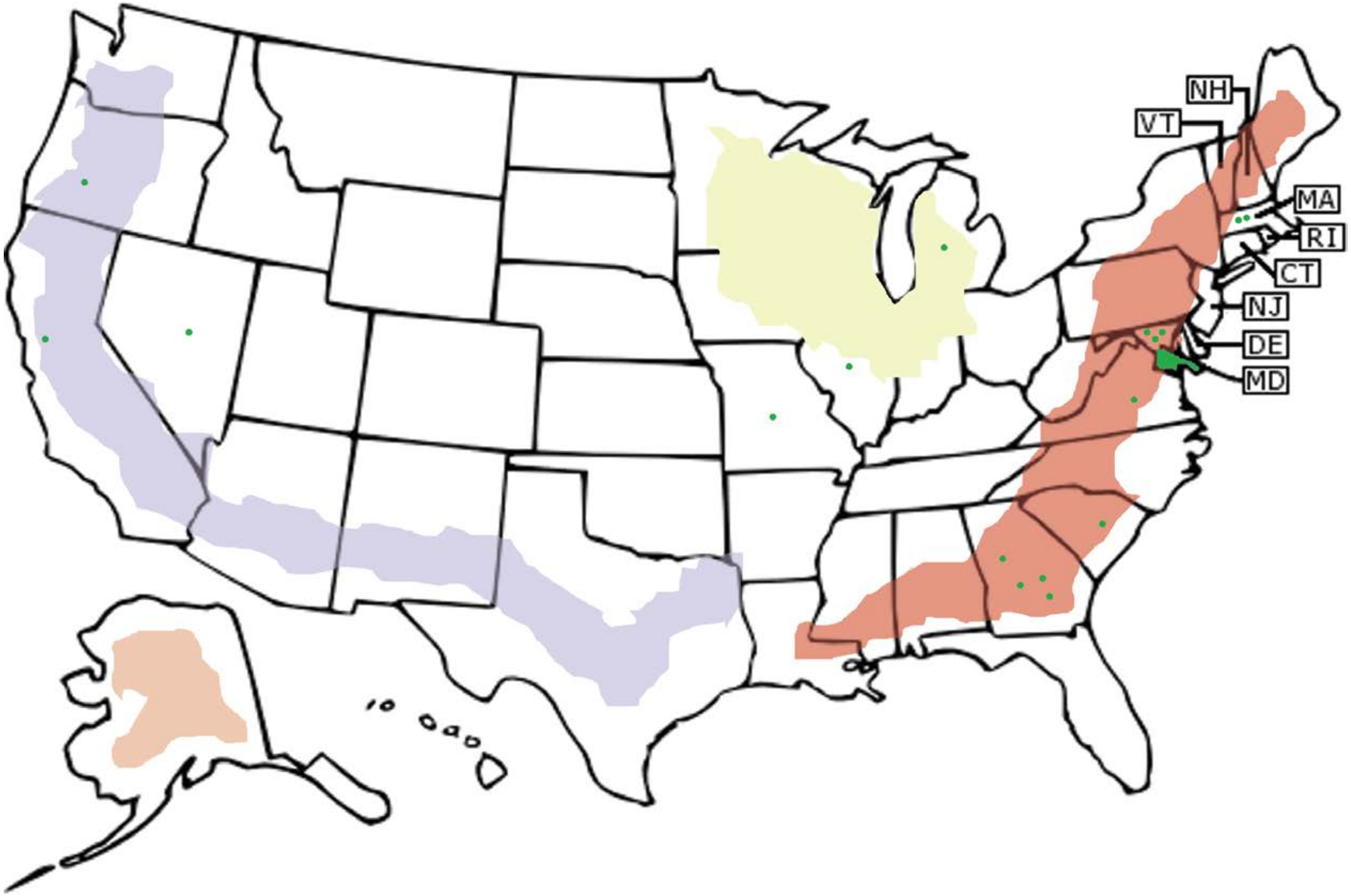
V. SUMMARY

GSA aims to do more with less. Properly designed green roofs fulfill the primary functions of protecting a building as effectively as a conventional roof. The additional benefits a green roof provides a building owner, its tenants, community, and the environment are the reason they are and will continue to be integrated into modern building design.

As part of a whole building design approach, a green roof's features and benefits are fully integrated with the building's other major systems. In effect, one small change can alter performance of other components within a building. It is for this reason that several building-specific factors must be examined in order to determine exactly *how* measurably beneficial a green roof's application will be at a particular facility. A building's construction, use, climate, sun exposure, and precipitation patterns are just a few of the features that must be examined prior being able to determine its potential benefits.

Green roofs are a practical and effective solution for lessening the impacts of climate change. A regional green roof implementation plan closely aligns with social, environmental, and economic agency goals. The primary function of this document is to encourage green roof consideration for all future re-roofing opportunities at all Region 9 eligible facilities. A potential next step would be to use this information as a starting point to initiate the groundwork for the future development of a pre-screening tool to assist decision-makers in identifying key factors in determining a building's candidacy for a green roof.

As feasibility studies and requests for information (RFIs) for green roofs at GSA facilities increases, the research in the field of green roof technology will progress. These advancements will help to set clearer industry standards, create new jobs, drive down costs, stimulate local incentive programs, and eventually make this technology more accessible to commercial and private sectors. In doing so, GSA could be a key contributor in reducing our national energy dependence and mitigating many of effects of climate change, while leading others to do the same.



[58]

Figure 23 Data map where the green dots represent GSA's green roofs and the color-blocked areas represent ideal geographic locations to obtain the most ENERGY benefits of a green roof. GSA's Region 9 facility locations are ideal locations for a green roof application

VI. SUPPLEMENTAL INFORMATION

A. ASTM STANDARDS DEVELOPED FOR GREEN ROOFS

E2396-05 Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Green Roof Systems

E2397-05 Standard Practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems

E2398-05 Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems

E2399-05 Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems

E2400-06 Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems

B. POTENTIAL LEED CREDITS FOR GREEN ROOFS

Storm water Management: SS Credit 6 – Green roofs may reduce storm water discharge by more than 25% (rate and quantity). Green roofs may also be considered as storm water treatment through their ability to remove suspended solids and other pollutants. Potential Points: 1 point

Heat Island Reduction: Roof – SS Credit 7.2 – Green roofs can reduce roof temperatures from summertime highs of up to 180°F to less than 80°F, especially in cities. The USGBC specifies green roofs as a way to meet this objective, when the green roof installation covers at least 50% of the roof surface. Potential Points: 1 point

Water Efficient Landscaping – WE Credit 3.1-3.3 – Green roofs can be designed so that irrigation is not required. Drought-resistant plants can be selected or greywater systems can be directed onto the roof to irrigate. As an added benefit, runoff from the green roof is filtered by the vegetation and soil media, so this water can be used to irrigate other landscaping features without pretreatment. Potential Points: 1 to 3 points

Energy and Atmosphere
Optimize Energy Performance – EA Credit 1 – Because of their heat absorption properties, green roofs have been shown to reduce energy demand by more than 50% annually in certain types of structures, geography and configurations. Reduced demand and increased efficiency may also lead to smaller cooling systems and lower capital costs. Potential Points: 1 to 15 points, depending on total energy reduction levels and other factors.

Innovation and Design Process
Green roofs may qualify for innovation and design credits by improving the workplace environment, creating an educational laboratory, or a recreational space. Potential Points: 1 point

C. EXECUTIVE ORDERS RELEVANT TO GREEN ROOF SYSTEMS

E1946, Standard Practice for Measuring Cost Risk of Buildings and Building Systems

E1980, Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces

E2396, Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Green Roof Systems

E2397, Standard Practice for Determination of Dead Loads and Live Loads Associated with Green Roof Systems

E2398, Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems

E2399, Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems

E2400, Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems

D. CITIES WITH EXISTING GREEN ROOF POLICIES

CITY	GREEN ROOF POLICIES
Basel	building regulations
Beijing	policy targets
Berlin	financial incentives and mandatory policy requirements
Chicago	building regulations and financial incentives
Cologne	financial incentives
Linz	planning policy and financial incentives
Munster	financial incentives
Portland	financial incentives
Seattle	mandatory policy requirements
Tokyo	planning policy and financial incentives
Toronto	financial incentives
Vancouver	planning policy and building bylaws

[59]

U.S. Postal Service Morgan Processing and Distribution Center, NY, New York

Building Facts:

- Built in 1933 and designated a historical landmark in 1986
- 22.2 million interior square feet and 1600 windows
- Nearly 90 percent of the original roof was **recycled and reused**
- Vegetation comprises 59% of roof

The U.S. Postal Service estimates that the plants' ability to cool the roof in summer and insulate it in winter will reduce the building's energy costs by $30,000 a year.

- **Postal Service projected a savings of $30,000 annually in HVAC costs resulting from green roof installation**
- **$1 million saved in the first year due to green roof and other energy enhancements**
- **Storm water runoff reduced by as much as 75 percent in summer and 40 percent in winter**
- **40 % reduction in energy use**
- **15 % average decrease in energy expenses** [60]

F. RESEARCH DATA

ARUP NET PRESENT VALUE CALCULATIONS

NATIONAL LEVEL RESULTS	ROOF SIZE (ft²)		
	5,000	10,000	50,000
Impact on Owners/Occupants/Investors			
Initial Premium, $/ft² of roof (extra cost of installing a green roof instead of a black roof)	-$12.6	-$11.4	-$9.7
NPV of Installation, Replacement, & Maintenance, $/ft² of roof	-$18.2	-$17.7	-$17.0
NPV of Stormwater, $/ft² of roof (savings from reduced infrastructure improvements and/or stormwater fees)	$14.1	$13.6	$13.2
NPV of Energy, $/ft² of roof (energy savings from cooling and heating)	$6.6	$6.8	$8.2
Net Present Value (installation, replacement & maintenance + stormwater + energy NPV)	$2.5	$2.7	$4.5
Internal Rate of Return (IRR)	*5.0%*	*5.2%*	*5.9%*
Payback, years	*6.4*	*6.2*	*5.6*
Return on Investment (ROI)	*220%*	*224%*	*247%*
Other Financial Impacts (less realizable)			
NPV of CO_2e, $/ft² of roof (emissions, sequestration & absorption)	$2.1	$2.1	$2.1
NPV of Real Estate Effect, $/ft² of roof (value, rent, absorption & vacancy)	$120.1	$111.3	$99.1
NPV of Community Benefits, $/ft² of roof (biodiversity, air quality, heat island, etc.)	$30.4	$30.4	$30.4

WASHINGTON DC RESULTS	ROOF SIZE (ft²)		
	5,000	10,000	50,000
Impact on Owners/Occupants/Investors			
Initial Premium, $/ft² of roof (extra cost of installing a green roof instead of a black roof)	-$10.7	-$9.5	-$8.0
NPV of Installation, Replacement, & Maintenance, $/ft² of roof	-$18.1	-$17.9	-$17.7
NPV of Stormwater, $/ft² of roof (savings from reduced infrastructure improvements and/or stormwater fees)	$11.0	$10.5	$10.2
NPV of Energy, $/ft² of roof (energy savings from cooling and heating)	$6.8	$6.8	$8.3
Net Present Value (installation, replacement & maintenance + stormwater + energy NPV)	-$0.2	-$0.6	$0.7
Internal Rate of Return (IRR)	*4.3%*	*4.2%*	*4.7%*
Payback, years	*6.6*	*6.5*	*6.0*
Return on Investment (ROI)	*198%*	*194%*	*209%*
Other Financial Impacts (less realizable)			
NPV of CO_2e, $/ft² of roof (emissions, sequestration & absorption)	$2.6	$2.6	$2.6
NPV of Real Estate Effect, $/ft² of roof (value, rent, absorption & vacancy)	$98.4	$88.2	$74.1
NPV of Community Benefits, $/ft² of roof (biodiversity, air quality, heat island, etc.)	$30.9	$30.9	$30.9

[6]

ARUP GREEN ROOF PERFORMANCE DATA

Table B2: Assumptions

GENERAL ASSUMPTIONS	
Discount Rate, %	4.4%
Investment Outlook, years	50
Green Roof Medium, inches	3-6"
Green Roof Size, sf	10,000
NOMINAL GROWTH RATES	
Labor and Materials	4.91%
Stormwater Costs	4.09%
Energy Prices	2.40%
Carbon (included in price of carbon)	0.00%
Community Benefits (Inflation)	2.49%
Rent, Absorb and Retention	(5.00%)
Green Roof Risk Contingency	2.34%

Table B3: Variables

PERFORMANCE VARIABLES	NATIONAL		WASHINGTON DC		
	GREEN	BLACK	GREEN	BLACK	
Installation, Maintenance & Replacement					
Average Installation cost, $/sf of roof	$24.50	$8.99	$23.95	$9.66	*initial/replacement*
Replacement premium, %	33.5%	0%	33.5%	0%	*replacement*
Maintenance costs, $/sf of roof	$0.27	$0.06	$0.36	$0.06	*annual*
Roof longevity, years	40	17	40	16	
Disposal costs, $/sf of roof	$0.12	$0.37	$0.12	$0.37	*initial/replacement*
Stormwater Management					
Stormwater equipment Cost, $/sf of roof	$0.00	$4.15	$0.00	$4.77	*onetime/ replacement*
BMP maintenance Cost, $/sf of roof	$0.00	$0.13	$0.00	$0.13	*annual*
Stormwater surcharges, $/sf of roof	($0.084)	$0.00	n/a	$0.00	*annual*
Energy					
Electricity Price, $/kWh	$0.1118		$0.1100		
Natural gas price, $/MCF	$12.08		$12.54		
Heating/cooling costs, $/sf of roof	($0.166)	$0.00	($0.169)	$0.00	*annual*
Air Quality, CO_2e					
Embodied carbon, tonnes of CO_2e/sf of roof	0.0006	0.0000	0.0006	0.0000	*onetime/ replacement*
Carbon offset, metric tonnes of CO_2e	0.0002	0.0000	0.0002	0.0000	*annual*
Carbon savings from heating/cooling	0.0006	0.0000	0.0007	0.0000	*annual*
Community Benefits					
Stormwater energy savings, $/sf of roof	$0.0004	n/a	$0.0004	n/a	*annual*
Biodiversity & habitat, $/sf of roof	$0.42	n/a	$0.42	n/a	*annual*
Air quality, $/sf of roof	$0.035	n/a	$0.035	n/a	*annual*
Heat island energy savings	$0.030	n/a	$0.045	n/a	*annual*
Heat island peak shaving savings	$0.200	n/a	$0.200	n/a	*annual*
Heat island air quality effect (7.5x)	$0.30	n/a	$0.30	n/a	*annual*
Real Estate					
Avg. rent, $/sf/yr	$21.78	$21.25	$15.02	$14.54	*annual*
Avg. value, $/sf	$254	$248	$182	$176	
Average vacancy, %	16.97%	17.40%	6.32%	6.54%	
Cap rate, %	7.38%	7.55%	6.40%	6.61%	
Absorption, months	7.8	8.0	5.8	6.0	
Tenant retention, months	53.1	52.6	53.3	52.6	
Other (Used in Real Estate Analysis)					
Green building performance improvement	5.7%	n/a	7.4%	n/a	
Green roof proportion of green bldg benefits	44.2%	n/a	44.4%	n/a	

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GSA GREEN ROOF BENEFITS AND CHALLENGES APPENDIX B PAGE 113

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GREEN ROOF KEY FINDINGS DOCUMENTED BY RYERSON UNIVERSITY TORONTO, CANADA

Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto

Table 2.1 – Summary of key findings from literature review related to heat transfer, energy use and green roofs

Study	Location	Monitoring	Qualitative/Quantitative Changes due to green roof	Study recommendations	Conversion to costs or benefits
Kohler et al. (2002)	Berlin, Germany	As early as 1984 surface temperatures of a green roof were monitored. The surface temp; shadowed surface temp of gravel; shadowed surface temp of green roof; temp of substrate; ambient air temp. were all measured	Green roof reduced surface temp. but also more importantly reduced the max. temp. amplitude by half.	The complex composition of green roofs represents a decisive additional buffer zone; the lowering roof temp. and added insulation effect are undeniably positive for indoor climate; the durability of flat roof is increased significantly	
Sailor (1995)	Los Angeles	Three-dimensional meteorological simulation of urban surface characteristics i.e. increasing albedo and or vegetative cover.	Increasing the albedo over the downtown L.A. area by 0.14 decreased summer time temperatures by 1.5°C. Increasing the vegetative cover by using green roofs showed similar results.	Preliminary evidence suggests that albedo and vegetation increases would benefit cities by reducing air temp. and energy demand. A thorough cost-benefit analysis for modifying urban surfaces for other geographical locations is needed; feasibility issues for large scale implementation must be resolved	A reduction of 1°C in summer time afternoon air temp for L.A. corresponds to a 2% energy savings
Del Barrio (1998)	Mediterranean region	Mathematical model	Green roofs do not act as cooling devices but as insulation, reducing the heat flux through the roof	Soil density, thickness and moisture content are identified as relevant for green roof design parameters.	
Eumorfopoulu (1998)	Athens, Greece	Mathematical model to determine the thermal behaviour of planted roofs and the thermal protection	Of the total solar radiation absorbed by the planted roof, 27% is reflected, 60% is absorbed by the plants and the soil through evaporation and 13% is transmitted into the soils; Evidently, the insulation value is in both the plants and the layer of substrates.	Green roofs block solar radiation, reduce daily temp. variations and thermal ranges between winter and summer; planted roofs contribute to the thermal protection of a building, but do not replace the insulation layer.	

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GREEN ROOF KEY FINDINGS DOCUMENTED BY RYERSON UNIVERSITY TORONTO, CANADA (continued)

Table 2.1 – Summary of key findings from literature review related to heat transfer, energy use and green roofs (continued)

Study	Location	Monitoring	Qualitative/Quantitative Changes due to green roof	Study recommendations	Conversion to costs or benefits
Onmura et al..(2001)	Japan	Field measurements; wind tunnel experiment; numerical calculations.	The evaporative cooling effect of a roof lawn garden showed a 50% reduction in heat flux in the rooms below the garden. A reduction in surface temperature from 60 to 30°C during day time led to the conclusion that evaporative component is an important role in reducing the heat flux.	Evaporation was dependent on the moisture content in the lawn	
Liu and Baskaran (2003); Bass and Baskaran (2003)	Ottawa, Canada	A green roof and a reference bituminous roof were instrumented to allow direct comparison of thermal performance	The green roof was more effective at reducing heat gain than heat loss. The green roof reduced temperature fluctuations and also modified heat flow through the roofing system by more than 75%	During the observation period, the green roof reduced 95% of the heat gain and 26% of the heat loss as compared to the reference roof. Then it is expected that its effectiveness will be more significant in warmer regions	A reduction from 6.0-7.5 kWh/day to less than 1.5kWh/day which corresponds to a 75% reduction and the potential for savings.
Alcazar and Bass, (2005)	Madrid, Spain	The energy performance of three roofing systems is compared. Thermal and optical characteristics are monitored ESP-r energy simulation software is used to compare annual energy consumption	The study show that the installation of a green roof in the building provides savings in annual and peak energy consumption; The green roof resulted in a total annual energy consumption reduction of 1% with a 0.5 % reduction in the heating season and a 6 % reduction in the cooling season.	This reduction was not homogeneous throughout the building. Below the third storey, under the roof, no savings were achieved. .	A total annual energy reduction of 1%
Bass et al. (2002)	Toronto, Canada	A mathematical model (MC2) was used to quantify the mitigation of the urban heat Island	Low level air temperatures were simulated for 48 hours in June 2001. With a 50% green roof coverage a 1°C reduction in low level air temperatures was observed. Irrigation of the green roofs produced a cooling of 2°C	Further research is needed in this area. The model operated well, however, unexpectedly low reductions in air temperature may have been caused by unknown underlying assumptions.	

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Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto

Table 2.6 – Summary of key findings from a literature review related to stormwater and green roofs

Study	Location	Monitoring System and Duration	Water Quality Sampling	Flow Interval	Events	Qualitative Changes	Quantitative Changes	Costs/ Benefits	Recommendation s
Jennings, et al, 2002	North Carolina	Runoff quantity and quality; Sigma 900Max TM automatic samplers; 5 months	Tritest, Inc. Lab	5 min.	6	yes	yes		Plant species
Hutchinson, et al, 2002, 2003	Portland, Oregon	Runoff quantity and quality analysis; Sigma model 950 bubbler-type flow meter; 15 months	Bureau of Environmental Sevices			yes	yes		Strategic selection of soils/growing media
Rowe, et al, 2002, 2003	Michigan	Slope and substrate depth influence on runoff quantity; Model TE525WS tipping bucket rain gauges; 2 months		5 min.	24		yes		
Graham and Kim, 2003	Vancouver	Evaluating the stormwater management benefits; water balance Modmel					yes		Retrofit to counteract climate change and land use densification, to restore watershed
Cunning, 2001	Winnipeg	Runoff quantity analysis; Kulching's Rational Formula; 5-, 20- and 50- yr storms					yes	yes	Durability of green roofing needs research; plant list needed
Monterusso, 2003	Michigan	Species selection and stormwater runoff quantity analysis; autoregressive type 1(AR1) error structure	Michigan State University Soil Testing Lab		4	yes	yes		Research fertilizer needs
VanWoert, 2002, 2003	Michigan	Runoff quantity analysis; Model TE525WS tipping bucket rain gauges; 430 days		5 min.	162 days		yes		Sedum
Liu, 2002, 2003	Eastview	Runoff quantity; Campbell Scientific CR23X data acquisition system; 13 months		15 min.			yes	yes	Research thermal efficiency in winter
Liu, 2000, 2002	Ottawa	Runoff quantity; tipping bucket mechanism; HP VXI data acquisition system; 1 year		15 min.			yes		
TRCA 2005	Toronto	Rainfall; runoff volume and water quality, soil	TRCA	15	23	Yes	Yes		Seed green roof

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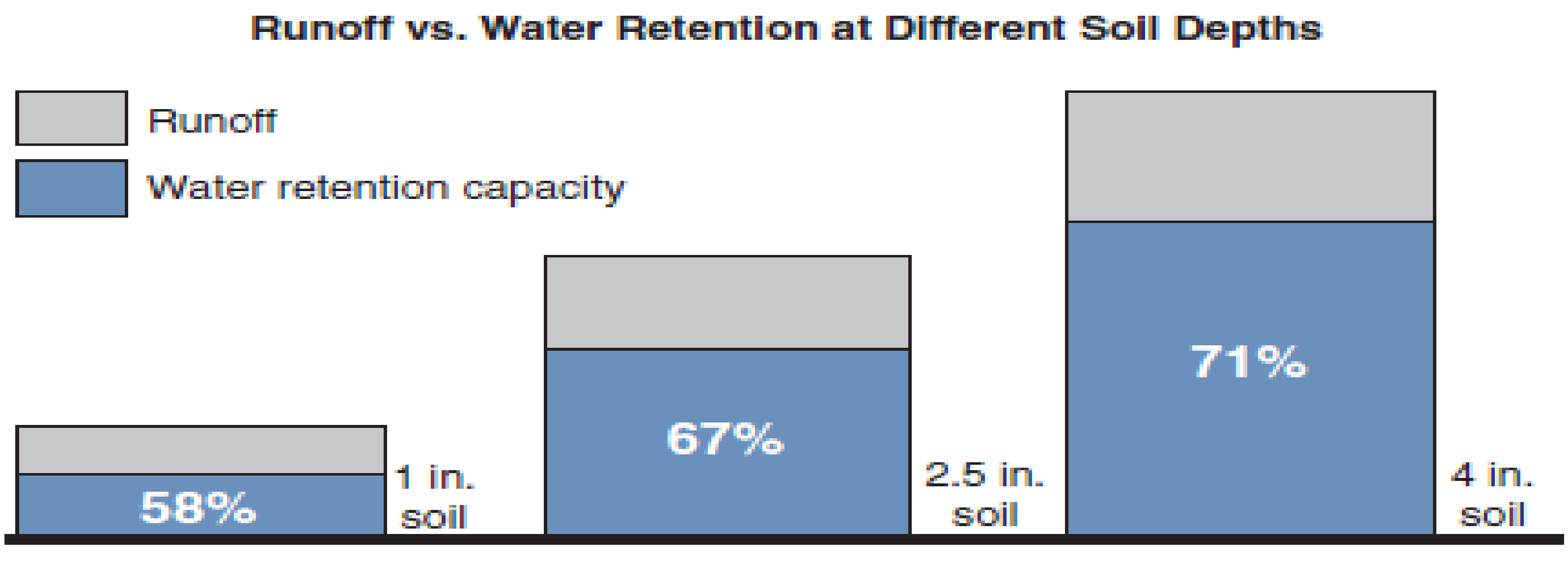
RYERSON UNIVERSITY'S CALCULATION METHOD FOR LOS ANGELES AIR QUALITY STUDY

"It is well known that smog forms when nitrogen oxides (NOx) react with volatile organic compounds, a process that is accelerated by higher ambient temperatures. In the report by Rosenfeld, et al. (1998), which looked at strategies to cool urban areas and reduce the heat island effect and smog in Los Angeles, it was noted that on a typical summer day in Los Angeles, 1350 tons of NOx and 1500 tons of volatile organic compounds (VOCs) react to form ground level ozone. By calculating the small NOx savings from avoiding air conditioning electricity use and combining it with the NOx avoided by cooling Los Angeles up to 3 degrees, these researchers estimated that a 10% reduction in smog is equivalent to reducing precursors by about 25%, that is, reducing NOx releases by 350 tons per day. Los Angeles has a smog offset trading mark that trades NOx at $US 3,000 per ton. To convert this to c/kWh of peak power they multiplied it by 0.5kg/MWH to get .15c/kWh. Hence, the 350 tons/day of avoided "equivalent" NOx is then worth about $US 1,000,000 per day to Los Angeles. The researchers then converted this saving to a yearly value, to find, on average, the 100 smog days experienced might provide a $US 100 million per year saving to a city as large as Los Angeles." [44]

DEPARTMENT OF ENERGY: FEDERAL ENERGY MANAGEMENT PROGRAM STORM WATER RETENTION



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