# Utilizing Green Technology and Research to Assess Green Roofing Benefits

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# Abstract

One emerging alternative to improving the state of inadequate, or decaying, infrastructure in urban environments, which does not involve a perpetuation of large scale, costly systems, is an approach known as low impact development (LID). LID interventions are small-scale changes or embellishments that are used at the building, lot or even neighborhood scale to conserve or reuse water, manage stormwater, and/or reduce energy demands. Because LID interventions are a distributed, rather than centralized, form of infrastructure, they also have the potential to build resilience into existing infrastructure systems. Furthermore, as less costly and more "nimble" infrastructures, LID interventions hold promise as urban adaptation strategies in the face of the uncertainty of climate change impacts. A current LID intervention that is increasingly being adopted in urban environments to manage storm-water impacts,

improve environmental conditions and reduce energy consumption, is green roof technology. Although modern green roofs have been in use for over thirty years in Germany, they are relatively new to North America. As a result, detailed understanding of green roof behavior, particularly within an urban context, is still lacking in many areas including; (i) the impact of different plant species and growing medium thickness on green roof behavior, (ii) the contribution of evapotranspiration to storm water retention/detention and reduction of urban heat island effects, (iii) the quality of green roof water run-off, and (iv) the ability of green roofs to trap air-borne particulates and take up other contaminants such as NO<sub>x</sub> and CO<sub>2</sub>.

A collaborative research project on the USPS-Morgan facility in NYC has started to monitor and understand the largest vegetated roof in all 5 boroughs in the NYC Region. The effort is lead by TectaAmerica Corp, USPS, Columbia University, and the URS Corp. The roof was also installed by industry experts in advance of any research potential, so this project stands to be a true example of real world analysis of green roof performance. The roof is equipped with equipment to record stormwater quality and quantity, heat flow comparisons, roof weather, and biodiversity. Columbia University has been instrumenting New York City green roofs for the past 6 years. Instrumentation on the USPS Morgan Facility began in 2010. The goal of this project is to scientifically quantify the performance of urban green roofs, in order to provide a basis for developing guidelines and standards that can ensure that the potential of this LID technology is fully realized.

Results from the project are and will directly contribute to strengthening the emerging U.S. green roof industry. Furthermore, they will help ensure that new policies and

decision making in this area support meaningful progress toward urban sustainability. In addition, the project will enhance the infrastructure for research and education by establishing an *Urban Green Roof Network* in New York City that can be used as a living laboratory for research and educational activities alike.

#### Author

Angle Durhman is the National Green Roof Manager for TectaAmerica Corporation, Skokie, IL. With over 150 green roofs installed, Durhman has managed a wide-variety of green roofs throughout the country including tough climates, elaborate designs, and logistical challenges. Ms. Durhman acts as the liaison with the Tecta project managers to make sure all warranties, water proofing, and maintenance is managed and executed properly with the overburden and vegetation. She also works creatively within the scope of the project to select the proper sustainable materials. Several award winning projects include Target Center (Minneapolis), USPS- Morgan (NYC), and ALSA Headquarters (Washington DC). Durhman frequently presents expertise utilizing a wide variety of speaking engagements and audiences: International Roofing Expo; local USGBC chapters; and AIA continuing education. She is a Green Roof Accredited Professional (GRP) and holds a Masters in Horticulture from Michigan State University, where she studied green roof plant performance and environmental sustainability. Angle is an active member nationally and locally for the USGBC, GRHC, NRCA, CEIR, and ANLA, and participates in UMN Extension courses. (acronyms: US Green Building Council, Green Roofs for Healthy Cities, National Roofing Contractors Assoc, Center for Environmentally Innovative Roofing, American Nursery and Landscape Assoc.).

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### Introduction

The percentage of the world's population living in urban centers is steadily rising. Recent data published by the United Nations indicate that by 2015, over three-quarters of the population living in developed countries, and close to a half of the population living in developing countries, will be located within urban centers. In both cases, about 10% of the urban population will be living in "mega-cities" of 10 million people or more.

The biogeophysical environment of urban regions is substantially different from that of rural areas. As a result, the growing expansion of urban centers is having significant impact on urban ecosystem services and the human communities dependent on these services. For example, large amounts of clean water are imported, consumed and ultimately exported as wastewater by urban communities, altering the hydrologic cycle of exurban (or outside the city limits) watersheds. In addition, widespread imperviousness within urban areas themselves is radically modifying the local water balance, by substantially decreasing groundwater recharge and increasing surface water runoff. Urban centers also modify the local climate, as urban night-time temperatures are higher, relative to surrounding rural areas, due to the release of sensible heat from artificial surfaces warmed by solar energy during the day. Atmospheric particulates in urban areas are generating rain-inducing condensation nuclei that result in increased precipitation in, and downwind, of a city, while urban air itself contains increased concentrations of pollutants such as CO<sub>2</sub>, nitrogen oxides, sulfur oxides, ozone and other volatile organic compounds. Finally, increased abundance of exotic plant species in urban areas is contributing to significant changes in plant species composition in urban ecosystems.

Conventionally and historically, urban environments in counties such as the United States (U.S.), have been built around large and costly infrastructure systems. The dense urban environment of New York City (NYC) is no exception. The drinking water supply system comprises 3 upstate reservoir systems in the Catskills and Delaware River watersheds, encompassing 19 reservoirs and 3 control lakes that gravity feed to NYC's massive underground water tunnels, from which water is pumped up to

consumers. The city's waste water system comprises over 6,000 miles of sewer pipes, 135,000 sewer catch basins, 93 wastewater pumping stations and 14 wastewater treatment plants. The system is a combined sewer system (CSS), meaning that the system collects sanitary sewage and storm-water in the same piping infrastructure, and feeds both to a wastewater treatment plant. In precipitation events that exceed twice the "dry weather flow", the waste water treatments plants are overwhelmed, and 494 permitted outfalls directly discharge a combination of sewage and storm-water into the City's local water bodies. In an average year, these overflows are responsible for releasing approximately 40 billion gallons of untreated wastewater into the environment, violating the Clean Water Act. As a final example; although NYC is one of the most energy efficient cities in the U.S., existing transmission limitations in the City mean that, without new power generation capacity, New York City cannot meet reliability requirements given current energy usage at times of peak load, increasing the probability of rolling blackouts during high demand periods. As climate change impacts magnify the effects of NYC's urban heat island, this problem will only worsen.

The American Society of Civil Engineers (ASCE) 2009 report card for America's Infrastructure, estimates that \$2.2 trillion is needed to bring the nation's infrastructure to a good condition; this is up from the 2005 estimate of \$1.6 trillion. The report card provides an average rating of D for all infrastructure categories, noting that since the rating system began, infrastructure "grades" have, at best, remained flat in some categories. However, in many categories grades have actually deteriorated. Indeed, the report card specifically states that; "In 2009, all signs point to an infrastructure that is

poorly maintained, unable to meet current and future demands, and in some cases, unsafe".

One emerging alternative to improving the state of inadequate, or decaying, infrastructure in urban environments, which does not involve a perpetuation of large scale, costly systems, is an approach known as low impact development (LID). LID interventions are small-scale interventions that be used at the building, lot or even neighborhood scale to conserve or reuse water, mange storm-water – thereby reducing flows to combined sewer systems - and/or reduce energy demands. Because LID interventions are a distributed, rather than centralized, form of infrastructure, they also have the potential to build resilience into existing infrastructure systems. Furthermore, as less costly and more "nimble" infrastructures, LID interventions might hold great promise as urban adaptation strategies in the face of uncertain of climate change impacts.

A current LID intervention that is increasingly being adopted in urban environments to manage storm-water impacts and reduce energy consumption is green roof technology. Other management practices include the use of 'white' roofs to enhance the albedo and 'blue' roofs to just take advantage of water retention and detention. A green roof is an environmental system that incorporates layers of specialized waterproofing and root-resistant materials, drainage or water storage layers, and a growing medium to support vegetation on a structure's roof. In many respects, green roofs are similar in cross-section to the traditional landfill covers familiar to many geo-environmental engineers. There are two main categories of green roof systems; extensive and intensive. Extensive green roofs are generally 1-4 inches thick and planted with drought-resistant

plants such as sedums, Figure 1. Intensive green roofs are deeper than 4 inches and can support more diverse plant life. Extensive green roofs are more common than intensive green roofs due to their weight advantage and cost; notably extensive roofs only have a maximum density of about 5 lbs/ft<sup>2</sup> when saturated with water. An extensive green roof can be applied to many existing buildings with few structural modifications and require little maintenance, while intensive roofs require more tending-to, and irrigation during periods of low rainfall. The USPS roof is a combination of the two types; sedums are the dominant plant, although Tecta installed berms to support grasses and perennials. There are also nine (9) trees designed into the benches.



Figure 1. Cross-sections through common extensive green roof systems from Oberndorfer et al. (2007). (a) Complete system where each green roof component is a part of the roofing system; (b) Modular system where pre-cultivated vegetation trays are installed above an existing roofing system, and (c) Precultivated Vegetation Blanket, which is installed by rolling the blanket onto the existing roofing system.

V = vegetation, M = growing medium, F = filter membrane, D = drainage layer, W = waterproofing/ root barrier, I = insulation, S = structural support.

Although modern green roofs have been in use for over thirty years in Germany, they are relatively new to North America. Nonetheless, green roofs are rapidly gaining popular attention in the U.S. and have recently become a high-profile component of sustainable building construction: They are lauded for provision of multiple benefits in the urban environment, including stormwater management, building energy savings, mitigation of the urban heat island effect and urban air pollution, and provision of habitat and aesthetic amenity. It is, however, important to note that construction specifications and local environmental conditions greatly impact the ability of green roofs to provide these services. Furthermore, detailed understanding of green roof behavior within an urban context is still lacking in many areas including; (i) the impact of different plant species and growing medium thickness on green roof behavior, (ii) the contribution of evapotranspiration to stormwater retention and reduction of urban heat island effects, (iii) the quality of green roof water run-off, and (iv) the ability of green roofs to trap airborne particulates and take up other contaminants such as NO<sub>x</sub> and CO<sub>2</sub>. Understanding in all of these areas is key if green roofs are to become meaningful components of an appropriately functioning network of urban LID interventions.

#### **Objectives**

Because of their growing popularity in the U.S., many authorities have begun to provide building owners incentives to install green roofs on their properties [e.g., the 2008 New York State Green Roof Tax Abatement Program]. Unfortunately, the majority of these incentives are based on the green roof typology and area, and not on performance metrics that might lead to sustainable development. The goal of this project is to scientifically quantify the performance of urban green roofs, in order to provide a basis for developing guidelines and standards that can ensure that this LID technology

meaningfully contributes to urban sustainability. In order to meet this goal, the project uses the USPS in the New York Urban center and compare with the other full-scale green roof installations in New York City to quantify the fundamental behavior of different extensive green roof technologies with respect to stormwater management, urban heat island mitigation and air quality improvement. Stormwater management, urban heat island mitigation and air quality improvement are emphasized because these metrics are cited as the key environmental benefits of green roof systems. Furthermore, urban regions, like NYC, are predicted to face increased challenges in each of these areas under projected climate change impacts. Hence, an understanding of the capacity of extensive green roofs to improve stormwater management, the rate of urban cooling and urban air quality will assist in determining whether or not this LID technology is a promising strategy for urban climate change adaptation.

Numerous groups in the U.S. have ongoing research programs to investigate green roof behaviors e.g., the *Center for Green Roof Research at Penn State* and the *Michigan State Green Roof Research Program*, to name but two. These groups are using instrumented model roofs, green roof platforms and larger-scale green roofs on buildings in rural and peri-urban environments to further understanding of green roof performance under a variety of different conditions. In addition, organizations such as *Green Roofs for Healthy Cities* are building on-line databases that aggregate research papers reporting green roof performances in order to "increase general knowledge of green roof benefits". The unique contribution of this project to this body of ongoing effort is the quantification of green roof behavior in a dense urban environment, where the complexities of local eco- and climatic conditions, coupled with building density, are

likely to significantly impact green roof performance. The project is also unique in its development of an *Urban Green Roof Network*, which encompasses all three extensive green roof systems illustrated in Figure 1, as part of a living research laboratory.

# **Experimental Section**

# Urban Network of Instrumented Green Roofs

In order to build the capacity to understand green roof behavior in an urban environment, the project instruments a suite of full-scale extensive green roofs that have been recently installed on seven NYC buildings (Figure 2). The location, size and roof type for each system is summarized in Table 1. As shown, the roof systems in the *Urban Green Roof Network* encompass all common extensive roof types, include both sedum and native plants and have a range of growing medium thicknesses. Three of the seven roofs (Roof 2 to 3) are on Columbia University property.



Figure 2: Location map for the 7 green roof monitoring sites. Fieldston (1) at 40.901058 N, -73.905716 W; Columbia University  $115^{th}$  (2) at 40.808007 N, -73.965867 W; Columbia University  $118^{th}$  (3) at 40.808178 N, -73.959795 W; United States Postal Service (4) at 40.751236 N, -73.999942 W; Queens Botanical Gardens (5) at 40.751114 N, -73.827685 W; Con Edison (6): at 40.751695 N, -73.952837 W; and Regis High School (7): 40.779743 N, -73.958743 W.

The seven sites are: (1) The Ethical Culture Fieldston School, Bronx, NY; (2) Columbia University 115; NY, NY; (3) Columbia University 118; NY, NY; (4) The United States Postal Service Morgan Distribution Hub; NY, NY; (5) Queens Botanical Gardens, Flushing, Queens; (6) The Con Edison Learning Facility, Long Island City, NY; and (7) the Regis High School: NY, NY. These locations span a range of environments and neighborhoods in the New York City area, including multiple watersheds. Most of the New York City boroughs are represented. The sites range from areas that are somewhat greener and forested (Fieldston), to dense urban residential (Columbia), to industrial warehouse stock (Con Ed), to predominantly residential areas (Queens Botanical). The spatial separation is also fairly uniform. One practical factor about the

locations is that they are all accessible by New York City's subway system which does allow a rapid, low cost researcher transportation option for regular site visits.

	Name	Location	Area (ft <sup>2</sup> )	Туре	Medium	H (in)	Plants	Age
1	Fieldston	Bronx	5,100	built-up	Mineral	4	Sedum	3
2	Columbia West 118	Manhattan	3,200	matt Xeroflora	Mineral	1	Sedum	2
3	Columbia West 115	Manhattan	650	matt Xeroflora	Mineral	1	Sedum	2
4	US Postal Service	Manhattan	108,900	built-up Tecta Green	Mineral	4-6	Sedum and Natives	1
5	Queens Botanical Garden	Queens	2,900	built-up	Mineral	6	Semi Natives	4
6	Con Edison	Long Island City	10,000	Modular Green Grid	Mineral	4	Sedum	2
7	Regis High School	Manhattan	20,000	built-up Greensulate	Mineral	4-6	Sedum and Native	0.2

# Table 1: New York City Green Roof Network

# Monitoring a US Postal Service Green Roof

Energy balance methods for research

Understanding the building energy benefits and urban heat island benefits ultimately requires quantifying surface and air temperature energy balance fluxes. Energy balance is a powerful technique which forms the basis of climate modeling, among other applications. The major energy fluxes at the surface of the Earth are well known and include shortwave and longwave radiation fluxes, convective air flows, latent heat flows and surface heat conduction. High-precision field equipment is available to quantify each of these terms and includes familiar weather station sensors (air temperature,

relative humidity, wind speeds, rain gauges), surface contact thermistors, up and down shortwave and longwave radiometers.

#### Water balance methods for research

In exact analogy with energy flows, the fundamental approach to understanding water flows is water balance theory. There are a variety of techniques to quantifying the water balance and to estimate the retention and detention at a variety of timescales. These include: (i) energy balance equipment to deduce the latent heat flows, which are equivalent to the 'retention.' This approach uses the same equipment as described for energy balance above. (ii) Direct drain flow rate meters that are installed within the drains on the roof. We have used a variety of flow meters due to the challenges of capturing both high and low flow rates; and (iii) direct evapotranspiration approaches that are placed on the green roof and monitor water vapor release from the surface – this data is again equivalent to retention.

### Water quality and air quality methods for research

With respect to the water quality sampling, monthly discrete samples are obtained during a precipitation event at a number of locations on the roof. This allows monthly water quality measurements at each site to provide seasonal and annual variability. For the purpose of runoff data, a storm event will be considered to be any event which results in more than .02 in of rain preceded and followed by a minimum of 6hr without measurable precipitation. Sampling and monitoring include environmental conditions/weather, roof conditions, runoff, water quality. The discrete sampling is a

manual collection of rainwater and runoff. The discrete samples of rainwater and runoff water are obtained by sampling the water during a rain event. Samples are collected using washed 4 gallon plastic containers on site. Sample water from these plastic containers are portioned into sterilized plastic vials for laboratory analysis and into an in situ 1 guart measurement chamber made of washed plastic. Runoff water samples are obtained by placing a pint sized washed glass beaker in the outflow stream and filled. These runoff water samples are then used for water quality analysis in the in situ 1 quart measurement chamber and the small plastic vials. For rainwater and runoff water guality measurements of Nitrates and lons an auto-analyzer located in a Columbia University Laboratory is used. Four of the small plastic vials are filled from the in situ water collection and used for this analysis. In situ probes include a conductivity sensor, turbidity sensor, and pH sensor. The field probes are calibrated in the laboratory for pH, conductivity, and turbidity using manufacturer standards and deionized water. Autoanalyzer samples are frozen after sampling and run in the auto-analyzer within one week.

Air quality measurements focus on key atmospheric species including carbon dioxide  $(CO_2)$ , carbon monoxide (CO) and ozone  $(O_3)$ . Automated sensors are available to detect these criteria species and can be integrated with the automated energy and water balance equipment. The sensor deployment plan will require further site visits and information but in general we will want to detect differences in ambient air quality well within the boundaries of the green roof as compared to the neighboring street locations.

Biodiversity benefits methods

Several techniques are being used to study the insect communities. These methods include Pan traps, which are bowls filled with soapy water, sweep netting and observations of specific plants.

The pan traps consist of bowls of three different colors, white, yellow and blue, in order to attract insects that see ultra violet light. The bowls are placed in a grid across several areas of the roof for three days on three separate occasions during the summer.

The sweep netting and observations occur while the bowls are on the roof. Sweep nets are cloth nets on sticks that allow for the capture of a wide variety of insects. A set pattern "sweeping" for insects is performed. The observations entail observing specific pollinator friendly plants for a set period of time. For proper identification of insects samples of insects are collected that visit the plants.

#### United States Postal Service Study Site

The green roof study is performed on the United States Postal Service Morgan Processing and Distribution Center, New York, New York (Figure 3). This semiintensive roof is installed on the 7<sup>th</sup> floor and has an area of 109,000 square feet. This is currently the largest green roof in New York. The original roof needed replacing and the roof structure was deemed strong enough to support the additional weight of the soil and plants/vegetation of a green roof. Plants and vegetation that are native to the region comprise approximately 59% of the roof. Nearly 90% of the original roof materials were recycled and reused on the roof.

Built in 1933, the USPS building is designated a historical landmark. It's also as big as a city block and serves as a major mail sorting facility that operates 24 hours a day. When the existing built-up asphalt roof began to fail, the USPS looked at options to reduce energy usage as part of its goal to reduce energy use by 30 percent by 2015. The objective was to incorporate a vegetated roof without straining the budget and recycle or reuse as much of the material as possible — all without disrupting normal operations at the facility.

Working closely with the USPS, the construction and design teams from Turner Construction, URS Corp., and Tecta America's J.P. Patti Roofing installed nearly 2.5 acres of green roof as part of the 109,000 ft<sup>2</sup> overall roofing project. The project was completed on time, under budget, and without interrupting the facility's operation.

#### System and Material

The new roof system consists of 80-mil PVC loose laid membrane installed over 1/4inch DensDeck® board and 3 inches of extruded polystyrene insulation. The planted area was over 65,000 ft<sup>2</sup>. Although the original design called for 12 -18 inches of soil, it was reduced to the 4-inch and 8 inch growing media profiles to fit the project's budget. A variety of plants were chosen that would thrive in the local environment, including sedum, drought-tolerant grasses and perennial flowers, including coreopsis. Serviceberry trees were in a planter in the center of the roof. Plants were irrigated during the establishment period, but there is no permanent irrigation system. The plugs grew in quickly, only about eight months were needed to achieve 80 percent coverage.



Figure 3: Meteorological sensor system on USPS that uses boundary layer methods to measure evapotranspiration, sensible heating, weather, and carbon dioxide exchange.

# **Results and Discussion**

All systems but Roof 2 are instrumented with weather stations that record the local wind-speed, gust speed, wind direction, air temperature, relative humidity, solar radiation, and precipitation. Addition systems installed on each roof also measure albedo as well as temperature and moisture gradients within the green roof growing medium. Custom made weir systems to measure the run-off from Roof 2-7 are calibrated and installed. Data from all afore-mentioned measurement devices are continuously logged and transmitted in real time to a secure data archive, which can be remotely accessed by the project investigators and their students via a password protected web-site. Gas and moisture flux sensing devices, hand-held particle counters, sonic anemometers and acoustic velocimeters are used on the USPS (4) roof. To date, these devices have been moved from roof to roof to make measurements as needed.



Figure 4. Comparison of green roof temperature (green line) with paver temperature (silver line = control roof).

On all roofs, but Roof 3, a section of roof area has been set aside and instrumented as a control area (i.e., a non-green roof area), in order that observed green roof performance can be compared to that of a standard black, silver painted or concrete paver roof surface.



Figure 5. Average diurnal  $CO_2$  flux for the green roof type over several weeks. A negative flux indicates  $CO_2$  sequestration by the green roof. Zero diurnal time of day is equivalent to midnight.



Figure 6. Average evapotranspiration for green roof over several weeks in the Fall. Zero diurnal time of day is equivalent t o midnight.

Figures 4, 5 and 6 provide example data collected on green roofs. Figure 4 illustrates that, as expected, the average green roof temperature is less than that of the silver control roof. In addition, the silver roof experiences significant temperature cycling in comparison to the green roof membrane. Hence, the green roof not only insulates the building, it likely extends the life of the roofing membrane by dampening temperature fatigue. Figure 5 illustrates a small CO<sub>2</sub> sequestration by the roof growing substrate, a positive ecosystem service. Based on a literature review, it is hypothesize that the magnitude of green roof CO<sub>2</sub> sequestration is much greater for a native plant system that can be tested on the USPS building. Finally, Figure 6 illustrates the evaporative cooling power of the green roof, which peaks when the difference between plant moisture content and atmospheric moisture content is at a maximum.

### Summary

Vegetated roofing designs are a green roof technology that is being used in building Green roofs offer important ecosystem services to address sustainability designs. needs, particularly in urban areas. Green roofs are used to mitigate watershed runoff, ameliorate air temperatures, increase building heating and cooling efficiency, clean up atmospheric wet and dry deposition, increase biodiversity of insects and birds, extend roof life cycle, and absorb atmospheric carbon dioxide. The USPS Morgan facility has built the largest individual green roof surface in New York City. While research on the performance of the USPS green roof is in initial phases, preliminary scientific findings have been made. The presence of the green roof provides significant detention and retention of precipitation from the storm drains and sewer systems of New York City. The retained precipitation evaporates which also provides cooling and air temperature reduction. The amount of water retained and evaporated is as high as 2 inches per month. This is significant considering that New York City receives about 3 inches per month on average. The acidic rain in New York City (pH ~ 4) is significantly altered as the green roof filtrates and changes the water quality of the rain that does ultimately reach the sewer system and waste water treatment plants. The rain water at USPS is more than neutralized. The pH has been found to increase to over 8, where a neutral pH is 7. The rain water does gain some turbidity and nutrients. These constituents are added to the run off. Work is currently in progress to assess the storm event, monthly, and seasonal variability of the total discharge to the sewage system, the subsequent building cooling and air temperature reduction, and the additional mitigation and increase in water quality. Finally, the Tecta America green roof on the USPS building in

New York City has provided a much needed laboratory in the study of Green Roofs in a major urban area with serious sustainability issues around temperature, wastewater management as population and climate patterns change.