

Green Roof Research Station: Rationale, Experimental Design, Equipment, and Estimated Costs

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A central component of our work is the development of a rooftop research station to collect data about green roof performance in New York City. The overall objective is to understand and document how green roofs function in New York. A specific goal is to gather applicable data from a rigorously instrumented site in New York to calibrate and validate our energy-balance and hydrology models over a range of weather and climate conditions. Other goals include developing a monitoring protocol to be shared with other green roof projects in order to facilitate characterizations and comparisons of green roof performance around the city and studying other aspects of green roofs such as their effects on biodiversity, air quality, and real-estate amenity values. The Green Roof Research Station would also provide educational opportunities for students at all levels, with a particular focus on high school and college-level research projects and theses.

The interaction of models and observations is a crucial component of the research design. It allows each sector to obtain results specifically applicable to New York City, and it also allows us to address complex cross-sector questions, such as the energy and water relations of a green roof.

Site Selection and Green Roof Construction

The first step is to select an appropriate research site – one that is accessible, not excessively shaded, and structurally sound. A structural engineer evaluates the proposed site and reviews plans to ensure that installation of a green roof does not threaten the integrity of

the existing roof, and that the experimental equipment does not cause stresses such as areas of freezing that may block drainage. We then work with a leading green roof manufacturer to select a waterproof membrane, green roof system, substrate, and vegetation (Table 1). For our initial experiments, lightweight, industrial-type configurations are likely to be chosen. The vegetation would likely include *sedums* and/or similar plants, which are drought-resistant, low-maintenance, hardy, and able to survive in a thin and lightweight growing medium. Follow-on work would include intensive plots with a wider array of vegetation.

Table 1. Green roof system components and estimated costs per square foot.

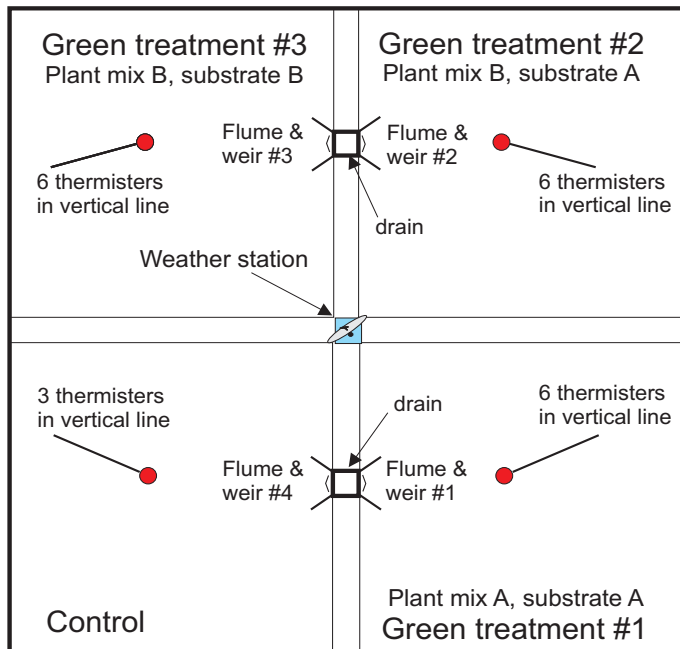
Green roof construction	Cost per sq. ft.
Green roof system	\$5-10
Waterproof membrane	\$10-15
Plants	\$1-3
Installation labor	\$3-8
Maintenance (per year)	\$1.50-2
Construction Total	\$20.50-38

*Additional costs could include structural engineering assessment, architecture and engineering services, and electrical and plumbing work to connect to monitoring equipment.

Experimental Design

Our experimental design for the research station requires a minimum of 3 green plots and 1 control plot, all with equal area (Figure 1). This design allows for comparison between a green roof and a standard roof as well as between two different substrate depths and two different plant mixes. It also allows us to run our models with different green roof configurations to determine the sensitivity to changes in variables – for example, soil depth or plant type.

The research station would be equipped



Experimental Design

The research roof is split into 4 quadrants of equal area. One quadrant serves as the control. Green Treatment #1 and #2 have the same substrate but different plant mix. Plant Mix A and Plant Mix B will be compared. Treatment #2 and #3 have the same plant mix but different substrates. Substrate A and Substrate B will be compared. All plants should be appropriate for extensive green roof design.

□ Drains With Flumes and Weirs (4 flumes, 4 weirs)

Each quadrant is fitted with one flume and weir to monitor runoff rate.

● Thermisters (21)

Vertical lines of thermisters are used to measure heat flux through the roof. Six thermisters are used in each green quadrant and three thermisters are used in the control quadrant.

☀ Weather Station

The weather station is located in the center of the roof. The weather station contains equipment for measuring temperature, rainfall, windspeed, wind direction, and a pyranometer to measure solar radiation.

Optional Additional Equipment

- Evaporimeter
- Surface soil moisture sensor
- Net radiometer

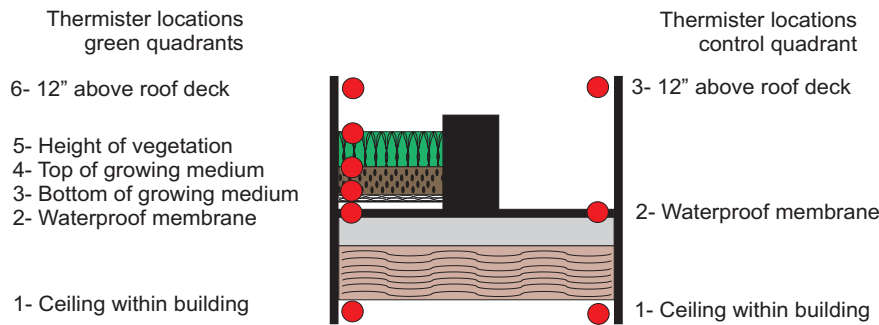


Figure 1. Green Roof Research Station experimental design.

with a weather station and each plot would be instrumented with monitoring equipment relevant to the energy and hydrology research sectors. This includes equipment for monitoring heat flux through the roof, as well as water retention and detention capacity (Table 2). The heat flux data, as well as data from a rooftop weather station, would be used in the energy-balance model to compare greened and non-greened vertical roof profiles and to correlate the results with heating and cooling requirements. Runoff rates, evaporation data, and precipitation data would be used in the hydrological model. Results from both energy and hydrology

simulations would be used as inputs into the cost-benefit model. Measurements would be taken at regular time intervals – likely every 5 minutes – and would be recorded by an on-site data logger and then transferred remotely to an off-site computer.

Monitoring Protocols

Using the research station as a laboratory, we will design and test monitoring protocols that can be easily and inexpensively replicated at other green roof sites, even if the sites are dissimilar. We will then offer a monitoring package to

Table 2. Equipment list and costs based on a 4-plot experimental design, with 3 plots greened and 1 plot control. This list is included for illustrative purposes; actual equipment chosen and costs depend on roof conditions, green roof design, and project budget.

Measurement	Equipment	Cost per item	Total
Weather station			
Outdoor temperature	Thermocouple reference	1 @ \$48.50 each	\$48.50
Rainfall	Heated rain gauge	1 @ \$1,045.50 each	\$1,045.50
Wind speed/direction	Anemometer	1 @ \$195.00 each	\$195.00
Solar Radiation	Pyranometer	1 @ \$275.00 each	\$275.00
Energy balance			
Roof temperature profile	Roll of thermocouple wire	21 @ \$790.00 total	\$790.00
Heat flux	Soil heat flux plate	4 @ \$315.00 each	\$1,260.00
Soil water content	Water content reflectometer	3 @ \$175.00 each	\$525.00
Surface temperature	Infrared thermocouple	1 @ \$745.00 each	\$745.00
Stormwater runoff	Flume & weir	4 @ \$750 each	\$3,000.00
(Alternative)	(Pressure transducer)	(4 @ \$900 each)	(\$3,600.00)
Health – indoor air temp	Thermister	4 @ \$80 each	\$320.00
Compile data	Datalogger	1 @ \$1,154.30	\$1,154.30
	Datalogger support software	1 @ \$85.00	\$85.00
	Multiplexer	1 @ \$868.15	\$868.15
Download and interpret data	Laptop computer	1 @ \$1,500	\$1,500.00
	Modem, software		\$733.95
Connection equipment	Mounts, cables, power		\$1,333.35
On-site installation			\$7,000.00
Freight			\$162.00
Miscellaneous expenses			\$3,959.30
Equipment total			\$25,000-25,600

* Funds for research personnel are not included.

others developing green roof projects in the New York metropolitan region. This will allow the developer to monitor green roof performance and will allow us access to a larger data pool from a wider spatial area. The additional data will be used to refine the models, compare the performance of different types of green roofs installed on different types of buildings, and study the effect of green roofs on the urban heat island effect and combined sewage overflows at scales beyond that of an individual building.

The success of such monitoring will depend on close collaboration between green-roof adopters and the research group from an early stage in the design process.

Further Research

As initial research questions regarding energy and hydrology become resolved, the Green Roof Research Station will continue to provide a laboratory for researching new questions in the coming years. These could involve not only

further aspects of green roofs, such as their effects on biodiversity (e.g., How do green roofs affect local populations of insects and birds? How do green roofs affect neighborhood and regional air quality?), but other aspects of ecological infrastructure as well. For example,

How might vegetated walls and awnings affect New Yorkers and the buildings they live in? The green roof Research Station will be a resource for a broad group of scientists in the New York metropolitan region and beyond.