Lysimeter used to measure the amount of evapotransipiration released by plants.

The findings of this report are founded upon robust scientific evidence. Extensive research has provided a reliable understanding of the benefits and costs related to green roof installation and use. The ongoing evolution of the knowledge base is well-recognized, and uncertainties have been handled carefully through the cost-benefit analysis process.

A number of areas in which additional investigation may provide more clarity on some of the conclusions reached were identified during the study. The following sections summarize potential next steps for consideration.

The GSA encourages other federal agencies to more vigorously evaluate green roofs. Other agencies could be involved in data collection and performance modeling. Information gathered in this process could be used as an objective basis for decisions on whether to install a green roof on a particular building.

5.1 STORMWATER MANAGEMENT

1. LONG-TERM STORMWATER PERFORMANCE

Ample evidence supports conclusions of volume reductions in annual runoff from green roofs. However, there is little data to describe the long-term performance of these systems. Additional information on the influences of slope, drainage, and other moisture-retaining materials would support a better understanding of their performances in the field.

2. GREEN ROOFS AS A BEST MANAGEMENT PRACTICE (BMP)

Green roofs are often thought of and regulated with expectations that they may perform the role of traditional infiltration BMPs. However, because of the limited thickness of a typical extensive green roof and their lack of true infiltration capacity, green roofs have limited capacity to remove water from the urban water cycle for large and more frequent storms.

This study has highlighted that green roofs are better understood as runoff modulation measures that contribute to the restoration of naturalistic runoff patterns. Such patterns are characterized by lower rates, delayed peak development, and extended runoff times. These effects have positive consequences for flood control, CSO avoidance, and river base-flow nourishment. Future research should focus on validating runoff rates, delayed peak runoff and time of concentration so that these quantifications can be recognized as beneficial aspects of green roofs.

3. STORM DYNAMICS DATA

To incorporate large, commercial-scale green roof systems into stormwater management models at the watershed scale, additional data on storm dynamics should be gathered.

Most of the data for green roof stormwater performance comes from smaller roofs or from laboratory or field test beds. Although this data is useful, evidence from the few studies of larger roof areas suggests that the benefits of large roofs are greater than those suggested from the small-scale studies.

In addition, all of the available data for storm flow dynamics has been obtained in relatively short term studies (1–3 years). Gathering longer-term data from larger roofs may be beneficial to corroborate the conclusions reached in this study.

Such data would be useful to develop and calibrate algorithms that can more reliably predict runoff patterns from green roofs. Robust simulation algorithms tailored to the hydrology of green roofs are not available to support design innovation or the formulation of regulations. The use of algorithms developed for watersheds may not be accurate, especially because they process flow accumulation and infiltration in ways that are not specific to green roofs. Much of the runoff treated as infiltration in conventional runoff generation algorithms returns in a green roof as delayed and gradual runoff. Green roofs might be better understood and modeled as shallow groundwater systems. Experimental 2D unsaturated porous flow models have been used successfully to simulate runoff from green roofs.

4. FIELD MONITORING AND COMPUTER SIMULATION

New research, such as field-scale monitoring and computer simulation programming, is required to ensure that the design and regulation of green roofs will realize their potential. A centrally coordinated effort should be pursued, similar to that undertaken 50 years ago by the US Department of Agriculture, which resulted in the development of algorithms for modeling watershed hydrology. The cost of this work would be modest. The Department of Energy, USEPA, HUD and the Department of Commerce including NIST should be involved at a minimum in this effort.

5.2 BIODIVERSITY AND HABITAT

1. ESTABLISHING NATIVE PLANTS ON GREEN ROOFS

Establishing native plants is a major challenge when using green roofs to create habitat. This practice should be researched in more detail to reach a better understanding of techniques.

2. CREATING HABITAT FOR ENDANGERED FAUNA

Green roofs have been used in London and Basel to create habitat for endangered or rare fauna, but the "green roof as refugia" is a largely unexplored concept in most locales.

3. STRATEGIC SITING OF GREEN ROOFS

Further research may reach stronger conclusions about the appropriate siting of green roofs to enhance biodiversity: whether they should be located near other ecosystems to create a biodiversity "corridor" or isolated in an attempt to mimic the advantages of islands in protecting biodiversity. Existing studies show that surrounding habitat would influence plant diversity on a green roof. This could be examined in other locales to generate more robust conclusions.

4. SYNERGIES BETWEEN BIODIVERSITY AND OTHER GREEN ROOF BENEFITS

Plant diversity has been demonstrated to enhance other green roof benefits in some circumstances, but this research has not yet been replicated in other locales. Research should be expanded to generate more robust conclusions across geographies.

5.3 URBAN HEAT ISLAND

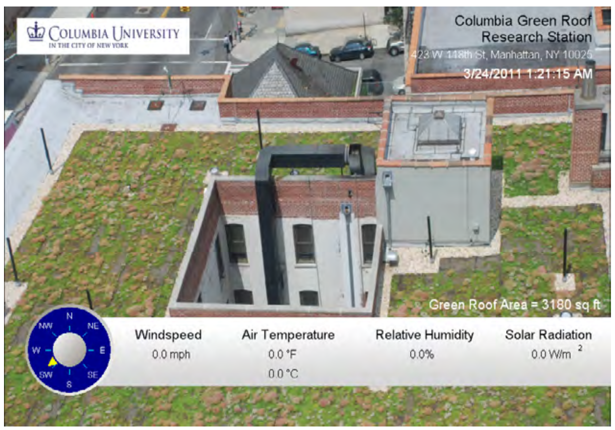
Most conclusions about the impacts of green roofs on the UHI are based on extrapolation of observations from a few roofs or are the results of simulation models. Two of the biggest challenges are confirming the impact of green roofs on the UHI and validating model output when green roofs are added to buildings. The following steps should be taken.

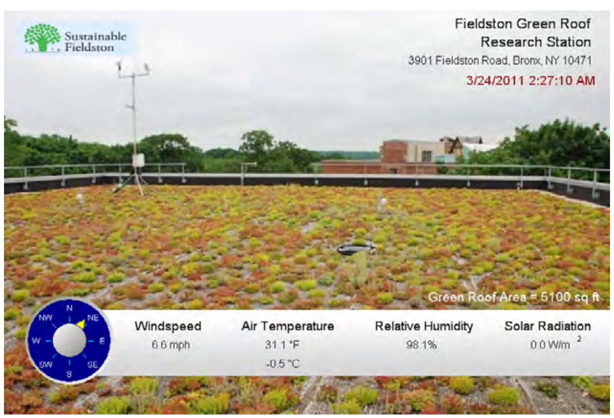
1. ADDRESS THE LACK OF LONG-TERM OBSERVATIONS

A set of temperature transects should be collected over a few days—before and after green roof coverage—supplemented by infrared imagery of the area and by simulation modeling. This data collection should be done in representative urban areas of at most 250 acres (1 square kilometer), to minimize cost and to make use of tools like ENVI-Met (a micro-climatological, high-resolution simulation model for urban areas that has been used for UHI research). The challenge in this research is coordination, so that the UHI is measured before the green roof is large enough to have an effect.

Image courtesy Stuart Gaffin

Data logger during the installation of an experimental green roof





Green roof dashboards

2. REPRESENT SEDUMS IN ATMOSPHERIC SIMULATION MODELS

Data from sedum roofs should be gathered to match the plant and soil parameterizations required in an atmospheric simulation model, thereby enabling green roof impacts on UHI to be modeled through existing tools. For example, ENVI-Met would require details of plant features and characteristics, soil profiles, and soil types. Much of this information is not yet available for sedums and other succulents.

3. POTENTIAL SYNERGY BETWEEN UHI AND SOCIAL BENEFITS OF GREEN ROOFS

A green roof must be of considerable size if it is to influence the UHI. A green area of sufficient size would offer other community-wide or city-wide benefits such as urban biodiversity, stormwater runoff attenuation, air quality improvements, urban agriculture, and green amenity space.

5.4 ENERGY

1. INFLUENCE ON BUILDING ENERGY USE

Additional research should be undertaken to determine the potential for cooler green roof surface temperatures to reduce the air intake temperature and related energy usage for rooftop heating and cooling units.

Future studies should focus on determining the insulative and other thermal properties of different types of vegetation and of different types and depths of growing media. The impact of design modifications to encourage energy savings (such as maintaining higher minimum moisture content to promote evaporative cooling) would also be valuable to study. Additional research on these topics would enable more efficient green roof design in cases where energy savings are a key objective.

The relationship between the size of green roofs and the magnitude of energy savings should also be explored further.

Research should be conducted on the energy consumption, urban heat island impacts, and other factors relating to building and landscaper performance as they relate to green roofs, reflective roofs, heating and cooling systems (HVAC), water retention, evaporative cooling, materials lifespan, etc.

2. CLIMATIC CONTEXT

Further research should consider the energy performance of green roofs in a wider variety of climates. Most of the studies analyzed for this report were conducted in temperate climates with warm-to-hot, moist summers and with cold winters (North America, Sweden, Germany, etc.). A few were conducted in tropical locations (Singapore, Brazil, and India), a few were in subtropical locations (China and Japan), and three were in Mediterranean climates (Spain, Greece, and Italy). Understanding the performance impact of individual weather variables, such as windspeed, humidity and cloud cover, would allow owners to better identify regions and sites where green roofs would provide greater benefit.

Existing research does not sufficiently assess the performance of green roofs in winter conditions, or the heating benefits of green roofs in a cold climate. These areas should be investigated further to provide a stronger basis for conclusions.

3. WHITE ROOFS VERSUS GREEN ROOFS

The energy performance of white roofs ("cool roofs") as compared with that of green roofs should be assessed in more depth (although studies exist), especially with respect to their influence on energy demand reduction.

4. IRRIGATED GREEN ROOFS

Further research is needed on irrigated green roofs in the summer, particularly in dry climates.

5. INTERACTION WITH SOLAR PANELS

Few studies have been published that look at solar panel installations in conjunction with green roofs. The positive synergies between energy production, temperature reductions and plant protection below the solar panel from the green roof should be researched.

5.5 ACOUSTICS

ACOUSTIC PROPERTIES

Increased attention should be applied to the acoustic properties of each individual layer of a green roof to provide a stronger understanding of acoustic performance and of methods to optimize performance through design.

5.6 URBAN AGRICULTURE

1. ECONOMICS OF ROOFTOP AGRICULTURE

Additional economic evaluation of rooftop agriculture projects can provide stronger data to underpin cost-benefit analyses.

2. LIFE CYCLE ASSESSMENT OF ROOFTOP AGRICULTURE

An assessment of the expenditure of resources required to provide food using local rooftop agriculture versus remote conventional farming would be valuable. Criteria of interest include water and energy use and greenhouse gas emissions.

3. CASE STUDY DEVELOPMENT

A library of rooftop agriculture case studies could help local governments streamline policy and code requirements.

5.7 AIR QUALITY

AIR QUALITY IMPROVEMENTS

Increased research could help to determine the ability of green roof planting to reduce particulate matter, volatile organic compounds and other air pollutants.

5.8 JOB GENERATION AND ECONOMIC DEVELOPMENT

1. EMPLOYMENT ANALYSES

Economic studies of the abilities of green roof technologies to stimulate a new green jobs market should compare the labor requirements of conventional roofs with those of green roofs.

2. REGULATORY INCENTIVES

An evaluation of policy and incentives in cities such as Portland OR, Toronto, Canada, Chicago IL, Washington DC, and Seattle WA should be compared to job generation statistics and changes in the economic values of retrofitted buildings.

3. RENT ANALYSIS

An analysis of the rents of commercial buildings with green roofs that GSA leases compared to those without green roofs.

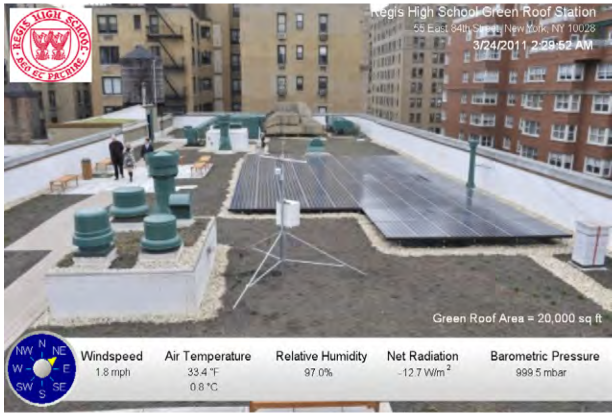
5.9 AESTHETICS AND QUALITY OF LIFE

1. SOCIAL WELLBEING AND PRODUCTIVITY SURVEYS

Limited studies have been undertaken about the health, wellbeing, and work productivity of people with a green view from their window. Additional studies would be valuable particularly in office environments, as most existing studies focus on healthcare. These studies should be augmented by the impact of new green roof installments in urban environments.

2. EVALUATION OF AMENITY VALUE

The evaluation of amenity and productivity benefits is notoriously difficult to do reliably, yet could be an area for future development to enhance green roof analyses.



Green roof dashboards

GSA Region 5 - 10 West Jackson Street Building, Chicago, Illinois

A 12,000 square foot extensive green roof replacement of an existing, modified bitumen (black) roof.