1. **Title:** The Potential for Reducing Impacts of Solar Radiation on a Crop Producing Green Roof, and Modifying Roof Microclimates, through the Utilization of an Adjacent Crop Producing Green Façade.

2. **Start Date:** Early summer 2017 for installation of study infrastructure, with crop production to start in summer 2017.

3. **End Date:** Late Fall/Winter 2018

4. **Principal Investigator(s):**

Dr. Susan Schaefer Kliman, Associate Professor
UDC Department of Urban Architecture and Community Planning
Susan.kliman@udc.edu
202.274.5774

Dr. Lorraine Clarke, Project Specialist
UDC Center for Urban Agriculture and Gardening Education
Lorraine.clarke@udc.edu
202-274-6494

5. **Abstract:**

The District of Columbia has millions of square feet of roof area. This roof area negatively impacts the urban environment and climate in several ways: the roof surface area absorbs a significant amount of heat, and is the greatest factor in residential energy consumption in certain climates (Kliman, 2001). Light colored roof coatings can ameliorate this problem by reducing the heat absorption; however, these coatings require regular maintenance, darken with dirt accumulation and age, and do nothing to address the increased runoff created when the previously vegetated site was replaced by an impermeable surface. These reflective roofs, coupled with the higher thermal mass of typical building materials like concrete and brick, are significant factors in the urban heat island in urban environments such as the District of Columbia.

Vegetated, or green, roofs can mitigate the effects of the urban heat island and water runoff in several ways. By improving the thermal performance of a building, a green roof can reduce the annual load for cooling the building (Garrison, 2012). A smaller mechanical system translates into reduced CO_2 emissions. The plants also reduce the radiation reflected back into the atmosphere from the roof. Finally, water retention and evapotranspiration of rainfall helps reduce runoff. These green roofs can contribute to an urban environment in other positive ways. A well-designed green roof can have park-like setting, and serve as a nice amenity for building users. A green roof can also be used to grow crop-producing plants. In this configuration, the roof serves as an important component in helping to ensure food security in an urban environment.

One of the challenges with fully utilizing the roof for cultivation of plants is the fact that many roofs have a penthouse for the mechanical system. This penthouse has solid vertical walls that reflect the sunlight and heat back onto the roof. The reflected light and heat is deleterious to the growth of many plants – particularly crops. This study proposes to determine the viability of using a three dimensional modular lattice system to support crop-producing vines that would cover the walls and reduce this reflected sunlight and heat.

The proposed research project is a parallel study that would utilize two existing green roofs – the one on the UDC campus, and one at a k-12 independent school located due west in McLean, Virginia. The UDC roof will test conditions and impacts in a dense urban environment, five floors above grade. The Virginia site will test conditions and impacts in a heavily vegetated suburban environment, two floors above grade. The test areas will be divided into three sections. The lattice on one section will support dense vine crops. The lattice on the second section will support moderately dense vine crops. The third section will serve as the control, with no lattice or vines. The roof area adjacent to the walls will be planted with micro greens. Measurements

will be taken at regular intervals away from the wall to determine temperature, relative humidity, and solar radiation.

It is anticipated that the dense vine crops will provide shading and reduce the reflected sunlight by as much as 20%. It is further anticipated that the air temperature adjacent to the vines will be reduced by 2-8°C (Connelly, 2012). These two variables should provide a better environment for the plants located in the adjacent shallow beds, and result in a higher crop density. With thriving crop producing vines, and an increase in the usable roof area for planter beds, the overall potential for increased food production on the roof is significant.

The ability to increase food security, while also mitigating the urban heat island and reducing the harmful runoff, simply by using existing roofs in the District has an enormous potential to positively impact the overall sustainability of the city. Furthermore, this condition of reflected heat is not limited to roofs with penthouses or partial floors on the same level. The results of this study will have relevance to the creation of urban farms, and even the homeowner with the garden plot. Student participation will provide hands-on learning experiences for college level and k-12 students, and there are numerous outreach opportunities through the activities of the Center for Urban Agriculture and the Co-operative extension services of UDC.

6. **Statement of District's or critical problem and the targeted NIFA and Sustainable DC Objectives:**

This proposal addresses the following targeted NIFA Objectives:

- Improve food security
- Mitigate climate change
- Improve water safety and management
- Expand alternative energy solutions

This proposal addresses the following Sustainable DC Objectives:

- Cut citywide greenhouse gas emission by 50%
- Cut energy consumption by 50% while increasing renewable energy by 50%
- Bring locally-grown food within a quarter mile of 75% of DC residents
- Capture rainwater and runoff from at least 75% of the landscape

Urban areas are significant contributors to climate change and environmental issues. Two of the greatest factors of these impacts are the urban heat island and increased runoff. Both of these factors are directly related to the key inputs from buildings and impervious paved areas. The specific heat of the materials used in buildings, sidewalks, and roads is high. The higher the specific heat value of a material, the more energy required to raise that material to a given temperature, the more heat it holds, and the longer it takes to cool down (Schiler and Moffat, 1981). In construction, materials with a high specific heat are identified as having a high mass. The development and growth of cities creates dense areas with a lot of mass, and results in an urban heat island.

Urban heat islands are areas where both the surface temperatures and ambient air temperatures are higher than those in the surrounding rural or less developed areas. The high mass, impervious materials used to construct the buildings and infrastructure, absorb and radiate heat back into the surrounding atmosphere. Garrison, et. al. (2009) have noted that on a hot, sunny day the surface of a conventional roof can exceed the ambient air temperature by up to 50°C (90°F). The radiation of heat back into the atmosphere can have an impact on a citywide scale. According to Garrison, et. al. (2009) daytime temperatures in highly developed urban cores in Northeast cities have recently been measured to be and average of 7°-9°C (13°-16°F) higher than the nearby rural areas. These temperature differences are often equally significant at night. Balling and Brazel (1986) observed significant nighttime temperature increases in Phoenix due to the urban heat island in that city. A 2014 report by Climate Central (http://www.climatecentral.org/news/urban-heat-islands-threaten-us-health-17919) identified Washington, DC as having the fourth most intense urban heat island in the U.S. The report noted that the District can be up to 12°C (21°F) warmer than in nearby rural areas, with the average difference being almost 2°C (5°F). Furthermore, the number of days above 32.2°C (90°F) in the urban core now exceeds those days in the adjacent rural areas by more than seventeen. The District ranks number six as having the greatest difference between urban and rural temperatures.

When considering the buildings themselves, the design and construction of the buildings is an important factor. In 2014, 41% of total energy consumption in the U.S. was from buildings (U.S. Energy Information Administration, 2016). Energy and heat loss through the roof and walls is a key component of this energy consumption. On a residential structure, the roof surface is the most critical for thermal transfer (Kliman, 2001). For a multi-story commercial structure, the exterior walls account for a greater percentage of the thermal transfer due to a larger ratio of wall area to roof area. Improving the thermal performance of any of these surfaces can be an important strategy for improving the building energy performance. A particularly good strategy for improving thermal performance of roofs is the installation of a green, or vegetated, roof.

A green roof is created when plants are grown on the rooftops. These plants replace the traditional roof membrane, and are intended to replace the vegetated footprint that was destroyed when the building was constructed. According to the International Green Roof Association (2016), green roofs can be categorized as 'intensive', 'semi-intensive' or 'extensive' systems. The category of a specific roof depends on the plant materials installed and use of that roof.

Intensive green roofs incorporate a wide variety of plant species, may include trees and shrubs, lawns and perennials, and are often used to create garden or park-like conditions. These installations require a system build-up height, defined as the overall thickness of the green roof layer of the overall roof system, of between 150-400 mm (5.9-15.7 in.), are costly, and require high maintenance with regular irrigation. These roofs are typically flat. The Convention Center of the Church of Jesus Christ of Latter-day Saints in Salt Lake City, Utah is an example of an intensive roof (figure 1).

Figure 1. Convention Center of the Church of Jesus Christ of Latter-day Saints in Salt Lake City Utah.
http://www.hrt.msu.edu/greenroof/what-is-green-roof/index.html

Semi-intensive roofs are typically designed green roofs, with little to no public access. These semi-intensive roofs are planted with grass, herbs and shrubs. They require a system build-up height of 120 – 250 mm (4.7-9.8 in.), are moderate in cost, and require periodic maintenance and irrigation. An example of a semi-intensive green roof is the Vancouver Convention Center (figure 2).

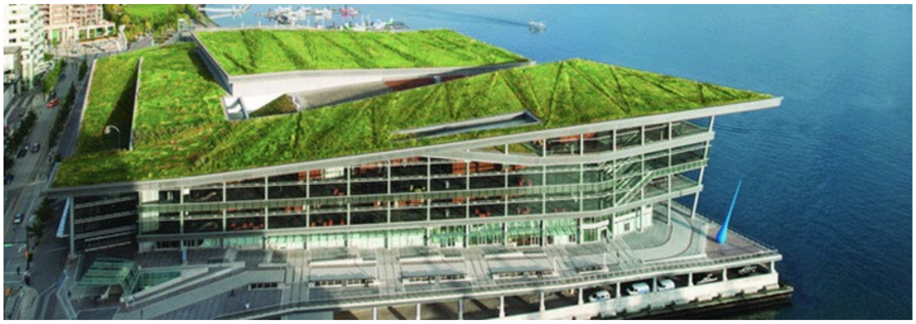


Figure 2. Vancouver Convention Center
http://www.vancouverconventioncentre.com/facility

Extensive green roofs are planted with herbs, grasses, mosses, and drought tolerant succulents such as Sedum. These extensive roofs are generally intended to serve as an ecological protection layer. They require a system build-up height of 60-200 mm (2.4-7.9 in.) are relatively low cost, require low maintenance and no irrigation. These roofs are generally not accessible to the public.

Green roofs impact the thermal performance of a building in three ways. First, they create an additional layer of insulation, which reduces the heat gain through the roof by conduction. Second, the canopy of plants provides shade on the roof surface, reducing the heat gain through radiation. Third, the transpiration from the plants provides cooling of the air right above the roof through convection, which lowers the temperature differential between the exterior and interior air temperatures and further lowers the heat gain by conduction. Research by Berghage, et. al. (2009) determined that in addition to providing additional insulation, green roofs are capable of removing 50% of the annual rainfall volume from a roof through retention and evapotranspiration.

Green roofs have gained increasing popularity. According to the Michigan State University Green Roof Research team (2016), Germany is widely considered to be the leader in green roof research, technology and usage, with over 12% of flat roofs in the country being green roofs. Further, the green roof industry in Germany is growing at a rate of 10-12% per year. Increasingly, cities, building owners and architects in the U.S. are turning to green roofs as a sustainable design strategy. The City of Chicago, an early leader in the implementation of green roofs, has 509 vegetated roofs within the city limits, according to the City of Chicago Planning and Development Department. Many green roof projects across the country are being installed by private owners and developers. Green Roofs for Healthy Cities reported in the 2014 Green Roof Industry Survey that more square feet of green roof were installed on private projects than public projects (Greenroofs.org, 2014). Of particular note is the fact that a vast majority of these installed green roofs are ornamental in nature. There are very few green roofs where the plants produce food. UDC has one such food-producing roof.

As of 2010, the District of Columbia had approx. 20% of open space as a percentage of total land area (NCPC, 2010). That figure translates into over 54 square miles of paved surfaces or buildings. Converting even a fraction of these surfaces to more porous and less heat absorbing/re-radiating surfaces through the installation of green roofs would have a significant impact on urban heat island in the District. The ability to mitigate the climatic and environmental impacts of these areas, while also helping to ensure food security for residents of the District is an important step toward ensuring the sustainability of city.

The plants and growing medium provide shade, thermal insulation, and evaporative cooling. All of these factors reduce the temperatures on the roof surface as well as the building interior below. As previously mentioned, temperatures on the surface of the roof can be significantly higher than the ambient air temperature on a sunny day. Coatings intended to ‘cool’ the roof have limitations because they require regular maintenance to keep them clean or they become darker and more absorptive. These coatings must also be reapplied on a regular basis, at an expense to the building owner. Much of the heat absorbed by the roof is transferred into the building’s interior. Green roofs, aided by the benefits of evapotranspiration can actually be cooler than the surrounding ambient air. According to Garrison, et. al. (2009) green roofs significantly impact the floor below the roof, reducing the energy needed for building cooling in that portion of the building by 50 percent or more. This reduced energy load translates into a smaller HVAC system and lower CO2 emissions.

Converting standard roof surfaces into green roofs provides additional insulation, while also reducing water runoff. Having those green areas used for crop production provides and important food source, while also improving the thermal performance of the building. On commercial buildings, one of the challenges is that there is typically a penthouse with mechanical equipment. The walls from this penthouse reflect the sunlight back onto the roof surface, thereby creating conditions that are not conducive for growing most plants. The standard sedum used on most green roofs is capable of withstanding this reflected heat and sunlight; however, crops that grow in relatively shallow beds, such as micro greens, cannot endure the increased temperatures and light. Figure 3 shows a diagram for the specularly reflected light from a vertical surface in the District. A design solution that reduces building energy consumption while increasing the viable area for crop production will solve two critical problems at the same time. Further, there are hundreds of urban gardeners in the District. The problem of reflected heat and sunlight is not unique to roofs. The results from this study will improve strategies for installing, planning, and producing crops on green roofs, and have a positive effect on urban food production and local urban heat island effects.

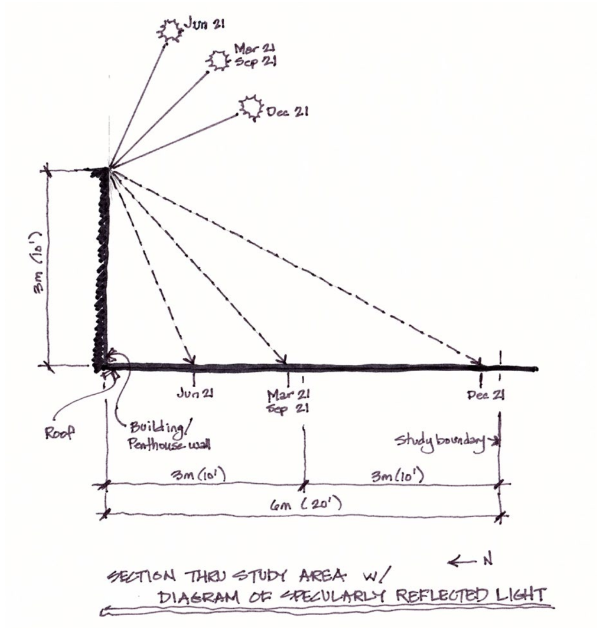


Figure 3. Section through study area showing the specularly reflected light from the building/penthouse wall onto the roof surface.

7. **Statement of results or benefits of Expected outcomes:**
The primary goal of this study is to determine whether the installation of a green façade, constructed with a commercially available three-dimensional modular trellis system, can successfully to reduce the reflected heat and light from building penthouses located at the same level as the green roof on the adjacent roof surfaces/planters. Solar insolation values and temperatures at the roof penthouse walls and regular intervals

away from the wall will provide valuable data regarding the potential of the façade to impact the microclimate on the adjacent roof.

By altering the density of the foliage on the green façade, the research will measure and observe whether the reduction reflected light and heat and modifications to the microclimate are sufficient to allow for the successful production of crops, such as micro greens, on the roof surface adjacent to the wall. The data will also provide information regarding the ideal density of the green façade. Further, the study will test the viability of crop producing vines in this type of installation. A series of measurements will document the magnitude and extent of microclimate modification from the green façade. Crop densities will also be measured on the adjacent green roof.

Based on previous studies, it is anticipated that a dense crop-producing vine will reduce the air temperature adjacent to the wall by 2-8°C, as well as the reflected light that typically overwhelms any crops within close proximity of the vertical surface by 5-20%. The magnitude and extent of the impact that will be determined by this study are important variables that can be used in the implementation of new green roofs, as more urban environments tackle solutions to food security. Further, by comparing the results of the two different microclimate conditions of the study sites, it may be possible to make inferences on a broader scale. The potential to ameliorate the deleterious impacts of radiant and solar gain from vertical building surfaces on adjacent horizontal garden plots is significant. Urban gardens and farms throughout urban areas – including the Urban Food Hubs being implemented across the District by UDC – will be able to benefit from the knowledge of strategies that will allow for greater flexibility in design, and maximum use of the available land. It is anticipated that the results gained from this study can be disseminated not only in research publications, but also in many of the outreach activities of the CAUSES Center for Urban Agriculture.

8. **Nature, scope, and objectives of the research/outreach project:**

While many green roofs are being implemented in urban areas as a means of improving building energy performance, and mitigating the urban heat island, very few of these roofs are planted to produce crops. Typically a green roof is planted with sedum. These plants, which are succulents, are capable of withstanding relatively high temperatures and high levels of solar radiation. The horizontal beds of a roof, with their relatively shallow depths, are perfect locations to grow crops such as micro-greens. Unfortunately, those crops are very susceptible to the impacts of radiant heat and light, thereby limiting the ability to plant these crops in locations where there are penthouse walls. It should be noted that the same conditions apply to planters on the ground, in typical household gardens. This situation is especially prominent on south facing walls with adjacent planters.

The project proposes a solution by installing a three dimensional lattice system to support a crop-producing vine. It is intended that the vine will reduce the impact of the light and heat gains from the reflected sun on the adjacent roof surface. The research will explore different densities of foliage and their impacts on the radiation values and air temperatures at regular intervals away from the vertical wall. The results will provide valuable information for both the design and installation of crop producing green roofs, as well as the design and creation of the typical household garden.

The objectives of the proposed project are:
Objective 1: To determine the potential for implementing a green façade as a means of ameliorating the impacts of reflected light and heat on adjacent horizontal planting beds.
Objective 2: To determine the optimal plant density of the vine crops for reducing the negative impacts of the reflected light and heat.
Objective 3: To determine whether certain vine crops are capable of growing in these harsh conditions, and which crops are best suited for this purpose.

Objective 4: To determine whether the impacts/benefits of the green façade vary by the larger microclimate within which the roof is located, and whether the results can be translated to the typical household garden or urban farm/food hub.
Objective 5: To evaluate the results of the study, and optimize the design.

To broaden the impact of the project, the following outreach plan is proposed: 1. Tours of the study sites showcasing the research, as well as signage at each site. Regular tours of the green roof are given at both study locations. 2. Special tours to local high school students at UDC on-campus recruiting events. The student research assistants will be used to give these tours. 3. The results obtained from this research project will be disseminated through conference posters/workshop presentations and journal publications.

This study is expected to last three years and will adhere to the following timeline to achieving the above objectives:

Table 1. Timeline of activities for the proposed project.

#	Description of Activities	Timeline in Years											
		Year 1				Year 2				Year 3			
Task 1	Install the three-dimensional modular trellis system on the walls of both study sites, prepare planters for vine crops, prepare beds on horizontal roof												
Task 2	Plant vine crops and micro greens												
Task 3	Measure solar radiation, temperature values, crop densities												
Task 4	Evaluate performance and optimize the system								*				

* At the end of year two we will evaluate the performance of the system; however, no modifications will be made to ensure two years' (growing seasons) worth of data for analysis

9. **Methods, procedures, and facilities:**
This study will be a parallel study with two research sites. Portions of both the UDC green roof, and the existing green roof at The Potomac School in McLean, VA will be used. These sites were selected for access and location. As previously mentioned, the green roof at UDC is one of the few crop –producing roofs in the U.S. Completed just over a year ago, the roof has large sections which are not yet allocated for crops, and have good potential for research. The location on the main campus of UDC makes the roof easily accessible for the PIs and the student assistants. The second roof is located at a K-12 independent school in McLean, Virginia. Dr. Kliman has volunteered at the school for several years, and currently serves as the co-chair of the Parents for Environmental Action Committee. This committee is actively engaged in connecting the students with the environment through the curriculum. The school has a green roof, which was installed eleven years ago, but has never been used as its intended function of an outdoor classroom because of several design issues. This project will turn the roof into a learning laboratory. This school is relatively close to the UDC site, and there is a core of faculty members who are very interested in participating in the research project, and engaging students. Support from the upper administration will facilitate easy access to this site. Student and faculty participation will help ensure the success of this portion of the study.

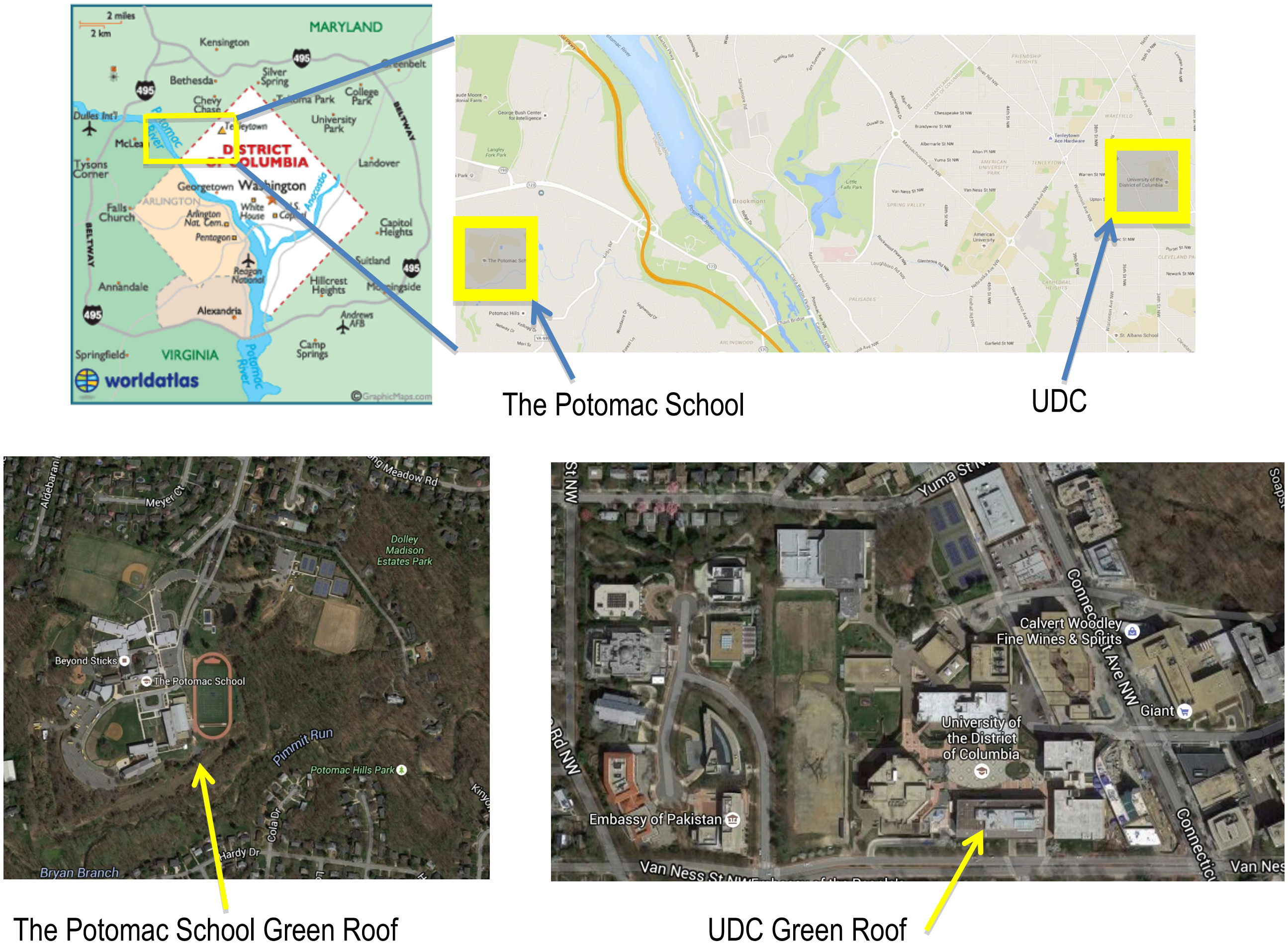


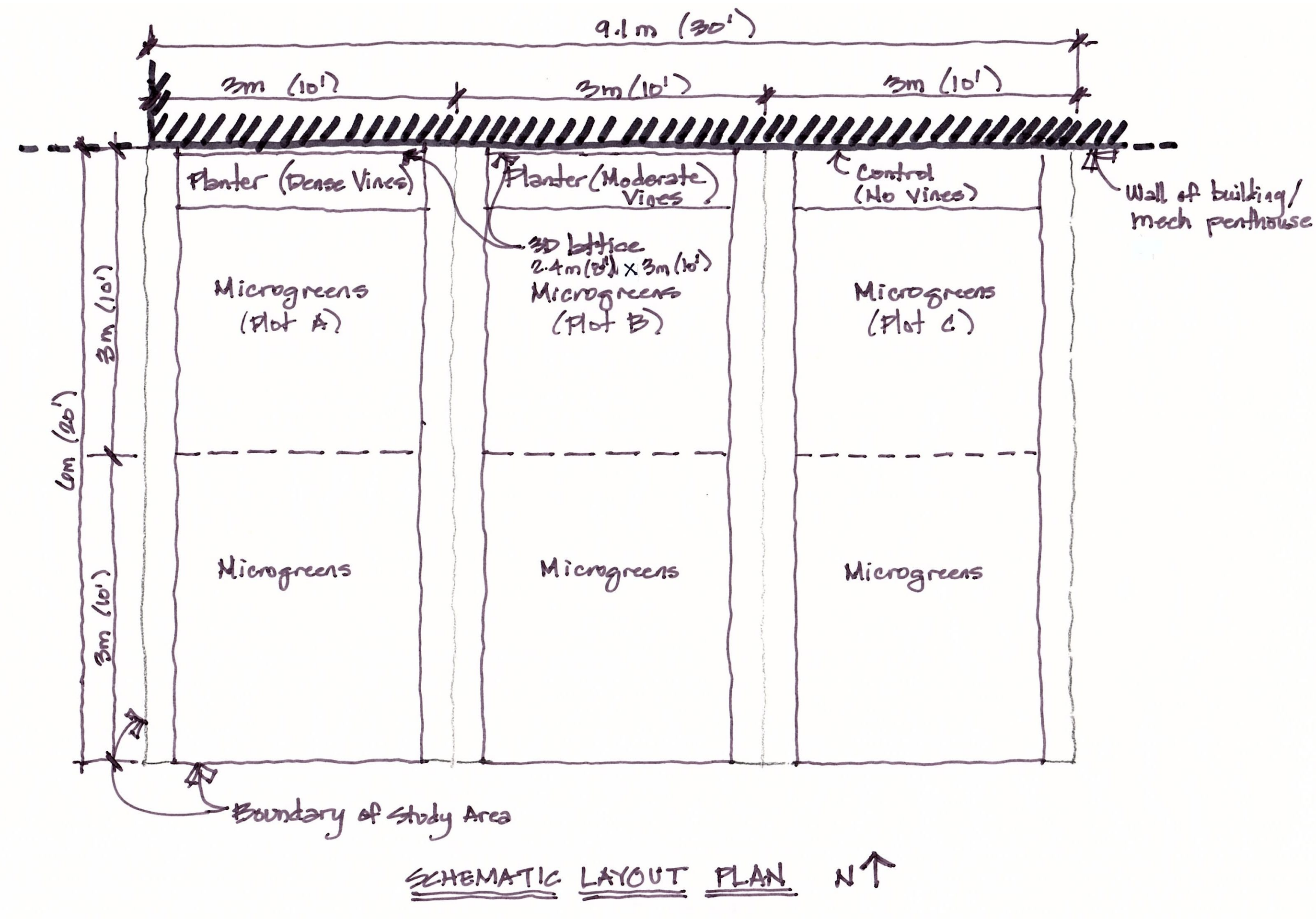
Figure 4. Research Project Location. Parallel study with two sites.

The two sites are ideally configured for a parallel study. Both roofs have south-facing walls approximately 3m(8ft) tall and 9m(30ft) long adjacent to shallow horizontal planting beds. They are located nearly due east west from one another (figure 4). The UDC roof is located in a very urban environment, five stories above the ground. The Potomac School roof is two stories above the ground on southern edge of the campus, a 92-acre heavily vegetated/forested site located in a suburban environment. The campus also has the Pimmit Run stream running through it just to the south of the classroom buildings. In using these two sites for a parallel study, the research will determine whether the results vary based on the microclimate in which the roof is located.

The walls at each site will be divided into three sections. Three-dimensional modular lattice systems, 2.4m (8ft) wide x 2.4m (8ft) tall will be installed on two sections of each wall. The third section will serve as the control. One section of lattice will be vegetated with a dense vine crop (zucchini or other squash). The second section of lattice will be vegetated with a moderately dense vine crop (Pole beans or other legumes). Planting beds 2.4m (8ft) wide by 6m (20ft) in length away from the wall will contain micro greens (figures 5 and 6). The vine planters will be self-watering. The beds for micro greens will incorporate drip irrigation tape. It is recognized that micro greens are not a nutrient dense crop. They were selected for the study based on the fact that they are fast growing, and do not require deep beds, which is an important consideration for when dealing with existing roofs where the structure was not designed for the weight of a green roof.

HOBO RX3000 Remote Monitoring Station Data loggers will be used at each site. These data loggers will be connected to HOBO Silicon Pyranometer Sensors and HOBO Temperature/RH Smart Sensors. These sensors will be located in the center of vine planter adjacent to the wall for each section, and then at the center of the micro green beds at 3m (9.8ft) intervals away from the wall. The sensors will collect hourly data on insolation values, as well as temperature and relative humidity. Visual inspection and photos will be used to measure crop density on both the horizontal and vertical surfaces.

Data collected from the data loggers will be uploaded wirelessly to a computer file. Using the software provided by the sensor data logger manufacturer, the files will be stored, and the downloaded and used by the PIs and student research assistants for statistical analysis. The results of the first growing season will be used to make adjustments as necessary with respect to crops, watering patterns, and sensor locations, for years two and three of the study. The results will be evaluated again at the end of the second year; however, the configurations for years two and three will remain consistent to ensure replication over time and changing seasonal conditions. All data will be analyzed to determine overall results.



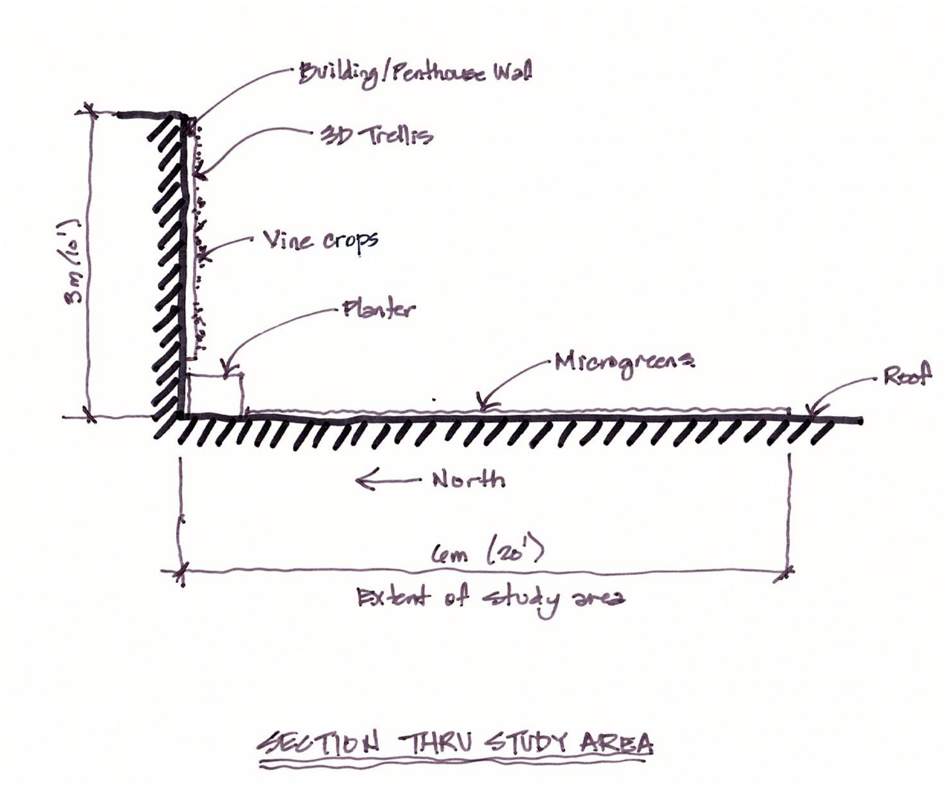


Figure 6. Sections through the study area showing project layout.

The exact configuration of the lattice and control sections will be evaluated at the time of installation. Consideration will be given to the optimal layout for minimizing the influences of the adjacent wall sections on the horizontal plots. A configuration where the control section is in the center may prove to be a better option. Further evaluations will be made at the end of the first study year.

10. **Related Research:**

Several studies have looked at the benefits of green roofs and provided documentation regarding the improved thermal performance of buildings, the potential for the creation of microclimates and the reduction of runoff. There have also been a few studies related to the climatic impacts of green facades on the thermal performance and rainfall shielding of a building. To date, no studies of green facades have measured the impacts of reduced heat/light radiation on adjacent surfaces, particularly with the use of crop producing vines. The following studies, many referenced above, provide relevant information with respect to green roofs and urban climatology.

Arizona State University, Center for Environmental Studies. 1977. Microclimate, Architecture and Landscaping Relationships in an Arid Region, Phoenix, Arizona: Final Report. Arizona State University, Tempe.

Aronin, J.E. 1953. Climate & Architecture. Reinhold Publishing Corporation, New York.

ASHRAE. 2013. Handbook of Fundamentals. American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE),

Balling, R.C. and S.W.Brazel. 1986. "New weather in Phoenix? Myths and realities. Weatherwise 39(2):86-90.

Bennett, I. and R. A. Nelson. 1960. Nighttime influence of irrigation upon desert humidities. U.S.

Quartermaster Research and Engineering Center, Natick, Mass., Environmental Protection Research Division, Technical Report EP-136. 42 p.
Berghage, et. al., 2009. Green Roofs for Stormwater Runoff Control. Final report from EPA/600/R-09/026
Bernatzky, A. 1982. The Contribution of Trees and Green Spaces to a Town Climate. Energy and Buildings 5:1-10.
Brazel, S. W., and D. M. Johnson, 1980. Land use effects on temperature and humidity in the Salt River Valley, Arizona. Journal of the Arizona-Nevada Academy of Science 15:54
City of Chicago, Planning and Development (2016). Chicago Green Roofs. Retrieved from (2016).(http://www.cityofchicago.org/city/en/depts/dcd/supp_info/chicago_green_roofs.html
Climate Central (2014). Cities Are Hot and Getting Hotter. Retrieved from http://www.climatecentral.org/news/urban-heat-islands-threaten-us-health-17919
Connelly, Maureen, et. Al, 2012. Rainwater Interception Capacity of Green Facades. Final Report from the Center for Architectural Ecology, BCIT School of Construction and the Environment.
Cook, J. 1984. Cool Houses for Desert Suburbs, Optimizing Heating & Cooling for Arizona Builders. Arizona Solar Energy Commission, Phoenix.
de Vries, D. A. 1958. The influence of irrigation on the energy balance and climate near the ground. Journal of Meteorology 16:256-270.
Garrison, Noah, et. al. 2012. "Looking Up: How Green Roofs and Cool Roofs can Reduce Energy Use, Address Climate Change, and Protect Water Resources in Southern California. NRDC Report R:12*06*B
Geiger, R. 1965. The Climate Near the Ground. Harvard University Press, Cambridge.
Huang, Y. J., Akbari, H., Taha, H., and Rosenfeld, A. H. 1987. The Potential of Vegetation in Reducing Summer Cooling Loads in Residential Buildings. Journal of Climate and Applied Meteorology. 26:1103-1116.
Jones, H. G. 1983. Plants and Microclimate. Cambridge, Cambridge University Press.
International Green Roof Association (2016). Green Roof Types. Retrieved from (http://www.igra-world.com/types_of_green_roofs/
Kirby, SF and W.D. Sellers. 1987. Cold air drainage and urban heating in Tucson, Arizona. Journal of the Arizona-Nevada Academy of Science 22(2):123-128.
Kliman, S. S. 2001. Effects of Vegetation, Structural and Human Factors on the Thermal Performance of Residences in a Semi-Arid Environment. Doctoral Dissertation. The University of Arizona, Tucson.
Lechner, N. 1991. Heating, Cooling, Lighting: Design Methods for Architects. John Wiley & Sons, New York.
Livingston, M. 1990. Effects of Three landscape Treatments on Building Microclimates, and energy and Water Use. University of Arizona, Tucson.
Mastalerz, J. W., and Oliver, C. S. 1974. Microclimatic Modification: Development and Application in the Urban Environment. HortScience 9(6):560-563.
McClenon, ed. 1977. Landscape Planning for Energy Conservation. Environmental Design Press, Reston.
McPhereson, E. G., ed. 1984. Energy-Conserving Site Design. American Society of Landscape Architects, Washington.
Michigan University Research Team (2016). What is a Green Roof? Retrieved from http://www.hrt.msu.edu/greenroof/what-is-green-roof/index.html
Morgan, D., L. Myrup, D. Rogers, and R. Baskett. 1977. Microclimates within an urban area. Annals of the Association of American Geographers 67:55-65.
Monteith, J. L. 1981. Evaporation and Surface Temperature. Quarterly Journal of the Royal

Meteorological Society. 107, 1-27.
National Capital Planning Commission (2016), Ideas to Achieve the Full Potential of Washington's Parks and Open Space. Retrieved from http://www.ncpc.gov/DocumentDepot/Publications/CapitalSpace/CapitalSpace_Plan.pdf
Ohman, H. L. and R. L. Pratt. 1956. The daytime influence of irrigation upon desert humidities. U.S. Quartermaster Research and Engineering Center, Natick, Mass. Environmental Protection Research Division, Technical Report EP-35. 30p.
Oke, T. R., 1992. Boundary Layer Climates. New York, Routledge
Olgyay, V. 1992. Design With Climate: a Bioclimatic Approach to Architectural Regionalism. Van Nostrand Reinhold, New York.
Ramsey/Sleeper. 2015 Architectural Graphic Standards, Twelfth Edition. John Wiley & Sons, New York.
Sealy, A. 1979. Introduction to Building Climatology. Commonwealth Association of Architects, London
Sellers, W. D. 1965. Physical Climatology. University of Chicago Press, Chicago.
Suckling, P. W. 1980. The energy balance microclimate of a suburban lawn. Journal of Applied Meteorology 19:606-608.
Sutcliffe, J. 1977. Plants and Temperature. The Institute of Biology's Studies in Biology no. 86. Southampton, Great Britain, The Camelot Press, Ltd.
Terjung, W. H. and O'Rourke, P. A. 1981. Relative Influence of Vegetation on Urban Energy Budgets and Surface Temperatures. Boundary-Layer Meteorology 21:255-263.
U.S. Energy Information Administration (2016). How Much Energy is Consumed in Residential and Commercial Buildings in the United States? Retrieved from www.eia.gov/tools/faqs/faq.cf?id=86&t=1.
van Straaten, J.F. 1967. Thermal Performance of Buildings. Elsevier Publishing Company, New York.
Van Wijk, W. R., ed. 1963. Physics of Plant Environment. Amsterdam, North-Holland Publishing Company.
Watson, D., FAIA and K. Labs. 1983. Climatic Design, Energy-Efficient Building Principles and Practices. McGraw-Hill Book Company, New York.
Watson, D. FAIA, ed. 1993. The Energy Design Handbook. The American Institute of Architects, Washington, D.C.

11. **Training potential:**

It is anticipated that for the first year of the study, there would be one UDC architecture student participating in the study. For the second two years, three UDC undergraduate architecture students would participate in the study. These students would assist with the measuring and monitoring of the solar radiation and microclimate impacts. At the Virginia site, at least one high school student per year would participate, with guidance from a faculty advisor, to measure the solar radiation and microclimate impacts. The Potomac School has several curricular and extra-curricular options for student engagement in the research. The school has a specific Science and Engineering Research Curriculum (SERC), where students are actively engaged in a two-year research project, and must conduct, document and present their work. These students are partnered with local organizations outside of the school, and work closely with their industry partner. This project would provide an opportunity for one or more of these students to spend time on the UDC campus. Students from both sites would interact with one another, and the PIs.

Given the nature of this research project as a parallel study with two sites, and the number of annual visitors to each site, this project would have tremendous training potential through the duration of the study, and a much broader impact once the results of the study are published. It is anticipated that students from both project sites would participate in the preparation of papers and presentations, and would have the opportunity to present this research at conferences. Signage and handouts of the research project will be prepared to explain the research to site visitors. It is further anticipated that a part of the research could be incorporated into a graduate thesis project in the architecture department.

12. **Budget Breakdown**:
The Budget Breakdown below is complete and included for each year.

-

Proposed Start Date: 1 May 2016		**Proposed Completion Date:** 1 November 2019		
Project Title: The Potential for Reducing Impacts of Solar Radiation on a Crop Producing Green Roof, and Modifying Roof Microclimates, through the Utilization of an Adjacent Crop Producing Green Façade.				
Principle Investigator: Susan Schaefer Kliman, PhD **Co-Principle Investigator**; Lorraine W. Clarke, PhD				
Cost Category	Year 1	Year2	Year 3	Total
1. Salaries and Wages:	$	$	$	$
-Principal Investigator(s)				
Student Research Assistants	$ 1,500	$ 13,500	$ 13,500	$ 28,500
Total Salaries and Wages	$ 1,500	$ 13,500	$ 13,500	$ 28,500
2. Fringe Benefits	$ 0	$ 0	$ 0	$ 0
3. Supplies	$13,500	$ 4,000	$ 2,600	$ 20,100
4. Equipment	$ 0	$ 0	$ 0	$ 0
5. Services and/or Consultants	$ 5,000	$ 0	$ 0	$ 5,000
6. Travel	$ 0	$ 2,500	$ 3,900	$ 6,400
7. Other Direct Costs	$ 0	$ 0	$ 0	$ 0
8. Total Direct Costs	$ 18,500	$ 6,500	$ 6,500	$ 31,500
11. Total Estimated Cost	$ 20,000	$ 20,000	$ 20,000	$ 60,000

* The manufacturer of the 3D modular lattice system, Green Screen, has agreed to donate all materials necessary for both research sites. Those materials are valued at $ 3,500.

13. **Budget Justification:**
The budget required for each of these categories is estimated on the basis of minimum requirements to perform the proposed research. The PIs, Dr. Kliman and Dr. Clarke, will be directly involved in the research activities.

- $ 28,500 in wages to pay one undergraduate student intern for one semester the first year and 3 undergraduate students for the second two years @ $ 1,500 per semester (including summer) per student, to complete literature review, help oversee installation of lattice system and plantings, monitor growth process, harvest crops, download climate data, climate and process for analysis.
- $ 20,100 for supplies for data loggers and sensors ($13,000),2 laptop computers for data processing and analysis and preparation of posters and presentations associated with dissemination of results and outreach ($ 4,500), freight charges for the lattice system from CA to UDC ($ 1,200), containers and irrigation systems at both sites, engineered soil for VA research site for first year, and plant materials, and nutrients at both sites for all three years ($1,300). Any additional supply funds will be used for educational signage and handouts.
- $ 5,000 for first year to pay local subcontractor to install the trellis and irrigation systems at both study sites

- $ 6,400 for PI and co-PI and/or students to present at a regional or national conferences for two years (AIA national convention, regional AIA conferences, and other potential climate-related conferences)

14. **Investigator's qualifications:**
    Resumes are included on the following pages.

Susan Schaefer Kliman, PhD

Chair

University of the District of Columbia (UDC), Department of Architecture and Urban Sustainability; College of Agriculture Urban Sustainability and Environmental Sciences (CAUSES), Washington, DC

Education

Ph.D.	University of Arizona. Arid Lands Resource Sciences with a minor in Geography.
M.Arch.	University of Arizona. Department of Architecture, Desert Architecture Track.
B.Arch.	Cornell University.

Professional Experience

2015-Present	Chair, Department of Architecture and Urban Sustainability, CAUSES, University of the District of Columbia, Washington, DC
2014	Adjunct Professor, Department of Urban Architecture and Community Planning, CAUSES, University of the District of Columbia, Washington, DC
2007-Present	Principal, Klimatic Architecture, LLC, McLean, VA and Tucson, AZ
2005-2009	Internship Supervisor, Guest Studio Critic, and Guest Lecturer, University of Arizona, Tucson, AZ
2005-2007	Principal and Managing Partner, bright/kliman Architects, PLC, Tucson, AZ
1994-2005	Principal, Klimatic Architectural Design, LLC, Tucson, AZ
1994	Graduate Teaching Assistant and Graduate Research Assistant, University of Arizona, Tucson, AZ
1991-1993	Job Captain, Project Manager, Pedersen Associated Architects, Inc. Tucson, AZ
1989-1991	Designer/Project Manager, HAS Architects, Inc., Las Vegas, NV
1988-1989	Designer, Richard Luke Architect, Las Vegas, NV
1986-1988	Project Manager, Giuliani Associates Architects, Washington, DC
1986	Intern Architect, Kemnitzer, Reid and Haffler, Washington, DC

Selected Publications and Presentations

Kliman, S.S. and Comrie, A. 2004. Effects of Vegetation on Residential Energy Consumption. *Home Energy* 21(4): 38-42.

Kliman, S. S. 2001. Effects of Vegetation, Structural and Human Factors on the Thermal Performance of Residences in a Semi-Arid Environment. Doctoral Dissertation. The University of Arizona, Tucson.

Kliman, S. S. 1994. The Effects of Orientation and Regional Climatic Variations on the Thermal Performance of a House. Master's Thesis. University of Arizona, Tucson.

Schaefer, S. M. 1986. A Center for Creative Photography at the University of Arizona, Bachelor's Thesis. Cornell University, Ithaca.

"Building on Current and Previous Work--Programs and Initiatives Relevant for Arid Cities in Changing Climates Project". Arid Cities in Changing Climates: Urban Land and Water Use in the Desert Southwest Workshop, Tucson, Arizona. December 2010. Panel Participant.

" IDP 2.0 - Still Rolling", 2010 NCARB Annual Meeting Workshop, San Francisco, California. June 2010. Joint Presentation with Nick Serfass, AIA of NCARB.

"Double Your 'Green' with Sustainable Residential Design". AIA/Southern Arizona Chapter, Public Lecture Series. Tucson, Arizona. October 2009.

"Code Officials, Registrants and the Arizona Board of Technical Registration: Regulations, Interactions, Etc.". ICC/Southern Arizona Chapter, monthly chapter meeting. Marana, Arizona, September 2009.

"Licensure & Your Career: IDP, ARE & Certification", AIA/Arizona Associates Conference, Phoenix, Arizona. August 2009. Joint Presentation with Nick Serfass, AIA of NCARB.

“Saving Dollars with ‘Green’ Remodeling”. AIA/Southern Arizona Chapter, Public Lecture Series. Tucson, Arizona, October 2008.

“Preliminary Results on AIA S/DAT for Tucson”, 2007 Community Sustainability Forum: Building Partnerships and Tools to Advance Local Sustainability. Tucson, Arizona. October 2007.

“Caution: Remodeling Ahead”. AIA/Southern Arizona Chapter, Public Lecture Series. Tucson, Arizona, October 2006. Joint Presentation with Philip Rosenberg of PGR Construction.

“Living Green in the Desert”. AIA/Southern Arizona Chapter, Public Lecture Series. Tucson, Arizona, October 2004.

“The Effects of Vegetation, Structural and Human Factors on the Thermal Performance of Residences in a Semi-Arid Environment.” Hot Topics Cool Solutions 2001, The Sustaining Desert: Building Livable Futures. Tucson, Arizona, September 2001.

Scholarly, Professional and Community Service

- **UDC CAUSES**
    - FY15 LGP Grant Review Committee
- **National Council of Architectural Registration Boards (NCARB)–** Member Board Member, 2007-2012
    - ARE Task Force FY2016
    - US/AU/NZ MOA Task Force FY15 and FY16
    - Broadly Experienced Architect Committee, FY15 and FY14
    - NCARB Liaison to the AIA National Associates Committee, FY14 and FY13
    - NAAB Accreditation Team Pool, 2009-present (appointed through 2017)
    - Accreditation Visits, 2011, 2012, 2013, 2015, 2016
    - WCARB Executive Committee, 2010-2012, Vice Chair, FY12
    - Internship Committee Chair FY13 and FY12
    - IDP Advisory Committee, FY13 and FY12
    - Procedures and Documents Committee FY13 and FY12
    - Practice Analysis Task Force, FY12
    - IDP Committee Member, FY11
    - IDP Program Development Task Force, FY10
    - Integrated Project Delivery Task Force, FY09
- **Arizona Board of Technical Registration** - Board Member 2007-2012
    - Chair, 2008-2009.
    - Secretary, 2007-2008, 2009-2011
    - Legislative and Rules Committee, 2007-2012
- **American Institutes of Architects –** member since 1988
    - AIA/Southern Arizona 2007 S/DAT – Grant Co-Author and Steering Committee Chair
    - Board Member, Arizona State Chapter 2006-2007
    - President, Southern Arizona Chapter, 2006
    - President-elect, Southern Arizona Chapter, 2005
    - Secretary, Southern Arizona Chapter, 2003-2004
    - Tucson Gateway Masterplan Charrette**,** Planning Committee/Team Leader 1996-1997
- **City of Tucson Solar Stakeholder Committee, 2008-2009**
    - Recruited by Deputy Director, Development Services to help write new residential solar readiness ordinance and development standards for hydronic and photovoltaic systems for Tucson.
- **Tucson’s Leading Women in Business, Government, Science & the Arts –** member, 2006-2011
- **Tucson Institute for Sustainable Communities**
    - Board Member, 1998-2000
    - Hot Topics/Cool Solutions II Conference Committee 1999.

Lorraine W. Clarke, PhD

Lorraine Weller Clarke
Center for Urban Agriculture and Gardening Education
College of Urban Agriculture, Sustainablity and Environmental Science
University of the District of Columbia
Phone: (202) 274-6494 - Email: lorraine.clarke@udc.edu

Education and Training:
2014: Ph.D. in Plant Ecology (Urban Ecology): Under the direction of G. Darrel Jenerette; UC Riverside
2010: M.S. in Plant Ecology; UC Riverside
2006: B.A. in Environmental Science; Fresno Pacific University

RESEARCH AND WORK EXPERIENCE:
Project Specialist in Urban Agriculture September 2014-present
University of The District of Columbia, CAUSES

- Managing Specialty Crop Block Grant through USDA AMS with multiple non-profit partners across DC.
- Research projects active:
    - Permaculture project, beginning in April 2016. Testing soil/plant interactions in a long term perennial polyculture project.
    - Analysis comparing soil characteristics and plant nutrient density at UDC's research farm, with the goal of creating more nutrient dense crops through soil management

Assistant Project Scientist April 2014-August 2014
University of California at Riverside, Dept. of Botany and Plant Sciences

Graduate Student Researcher June 2008-March 2014
University of California at Riverside, Dept. of Botany and Plant Sciences

Visiting Researcher Summer 2012
China Agricultural University, Beijing, China

TEACHING EXPERIENCE
Professor of Agroecology
University of the District of Columbia 2015-Present

Graduate Teaching Assistant with Dr. Walling and Dr. Ellstrand Mar. 2012-June 2012
University of California at Riverside, Dept. of Botany and Plant Sciences
Grading and section TA: California's Cornucopia

PUBLICATIONS:

1. Jenerette, G.D.; Clarke, L.W.; Avolio, M.; Pataki, D.E.; Gillespie, T.; Pincetl, S.; Nowak, D.; Hutrya, L.; McFadden, J.; McHale, M.; Alonzo, M. Environmental Filters and Trait Choices Shape Urban Tree Biodiversity. (*In Review at Global Ecology and Biogeography)*

2. Avolio, M.; Pataki, D.E.; Gillespie, T.; Jenerette, G.D; McCarthy, H.R.; Pincetl, S.; Clarke, L.W. 2015. Tree diversity in southern California's urban forest: the interacting roles of social and environmental variables. Frontiers in Ecology and Evolution (*doi: 10.339/fevo.2015.00073)*
3. Rossi, RJ, Bain, DJ, Jenerette, GD, Clarke, LW. Responses of roadside soil cation pools to vehicular emission deposition in southern California. 2015. Biogeochemistry 124;1-3(131-144).
4. Clarke, L.W., Jenerette, G.D., Bain, D.J. 2015. Urban legacies and soil management affect the concentration and speciation of trace metals in Los Angeles community garden soils. Environmental Pollution, 197:1-12.
5. Clarke, L.W., Jenerette, G.D. 2015. Biodiversity and direct ecosystem service regulation in the community gardens of Los Angeles, CA. Landscape Ecology, 30(4): 637-65
6. Clarke, L.W.; Li, L.; Jenerette, G.D.; Yu, Z. 2014. Drivers of plant biodiversity and ecosystem service production in home gardens across the Beijing Municipality of China. Urban Ecosystems 17: 741-760
7. Clarke, L. W., Jenerette G.D., and Davila, A. 2013. The luxury of vegetation and the legacy of tree biodiversity in Los Angeles, CA. Landscape and Urban Planning 116:48-59
8. Nowak, David J.; Hoehn, Robert E. III; Crane, Daniel E.; Weller, Lorraine; Davila, Antonio. 2011. Assessing urban forest effects and values, Los Angeles' urban forest. Resource Bulletin NRS-47. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 1-30.

GRANTS AND AWARDS*:*

Specialty Crop Multi-State Grant

- Submitted December 2015, Pending

Beginning Farmer Rancher Training Program

- Submitted March 2015, January 2016
- Not funded in 2015
- Pending 2016 funding

UCR Dissertation Year Program Fellowship

- Submitted January 2013
- Awarded May 2013
- Funded: $7,000 stipend and tuition waiver for Fall 2013 and Winter 2014

NSF Doctoral Dissertation Improvement Grant

- Submitted November 2011: "Dissertation Research: The effect of human management and soil properties on heavy metal content of Los Angeles Community Garden soils"
- Funded: $14,800 research grant for activities during the period of June 1, 2012-May 14, 2014.

NSF East Asia-Pacific Summer Institute Fellowship

- Submitted November 2011 "Drivers of plant biodiversity in urban, suburban, and rural home gardens across the Beijing Municipality of China"
- Funded: $5,000 stipend, travel costs to Beijing China and living expenses to do research in China during the period of June 11-August 5th, 2012