New Dirt on the Roof: Green Roofs for UMass Amherst

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Department of Landscape Architecture and Regional Planning
University of Massachusetts Amherst
Master's of Landscape Architecture Project
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TABLE OF CONTENTS

LIST OF FIGURES AND CREDITS

LIST OF TABLES

LIST OF APPENDICES

I. INTRODUCTION

Roofs make up a substantial portion of land cover in urban and suburban areas. In the United States, it is estimated that 71% to 95 % of industrial and commercial zoned areas are covered with impervious surfaces. This includes paved areas for parking, roads and building rooftops (Ferguson, 1998 in Getter and Rowe, 2006). In many areas 20 to 40% of urban areas are rooftops (Kloss and Calarusse, 2006; Wong, 2005). Impervious surfaces contribute to increased stormwater runoff, which has significant and dire consequences for water quality and hydrology. Green roof-tops provide an exciting opportunity to reduce impervious surfaces while at the same time providing other benefits, such as a reduction in the urban heat island effect, promotion of animal habitat, and reduction in heating and cooling costs.

Green roofs, also known as eco-roofs, vegetated roofs, and living roofs, involve the use of high quality waterproofing, a root-repellant layer, drainage systems, specialized growing media and specially selected plants on the roofs of buildings or other structures. Green roofs differ from roof gardens in that their primary objective is environmental enhancement, although recreation and human use may also be an objective of a green roof. Most green roofs also differ from roof gardens since they use a shallow depth of planting medium of 2-6” in depth. This shallow type of green roof is known as an extensive roof, and because of the shallow medium, the palette of plants is limited. When planting medium of greater depths is used, the green roof is referred to as a semi-intensive or intensive green roof. Intensive green roofs more closely resemble gardens on the ground. They may have a great variety of plants, shrubs, and small trees and are also usually accessible to humans.

This project examines opportunities for green roofs on the University of Massachusetts Amherst (UMA) campus. Founded in 1863 as a land grant agricultural college, UMA is the flagship campus of the state University system with an enrollment of nearly 24,000 students. While the campus is located in a small town setting in the Pioneer Valley of central Massachusetts, parts of the campus have an urban feel with tall buildings such as the W.E. DuBois Library and the Southwest Towers reaching more than 20 stories. The UMA campus has over 180 buildings located in the core campus area of approximately 900 acres. While UMA hold lands throughout the Pioneer Valley, this project examined opportunities for green roofs in the core campus area as shown in Figure 1.

Buildings cover seven percent of the

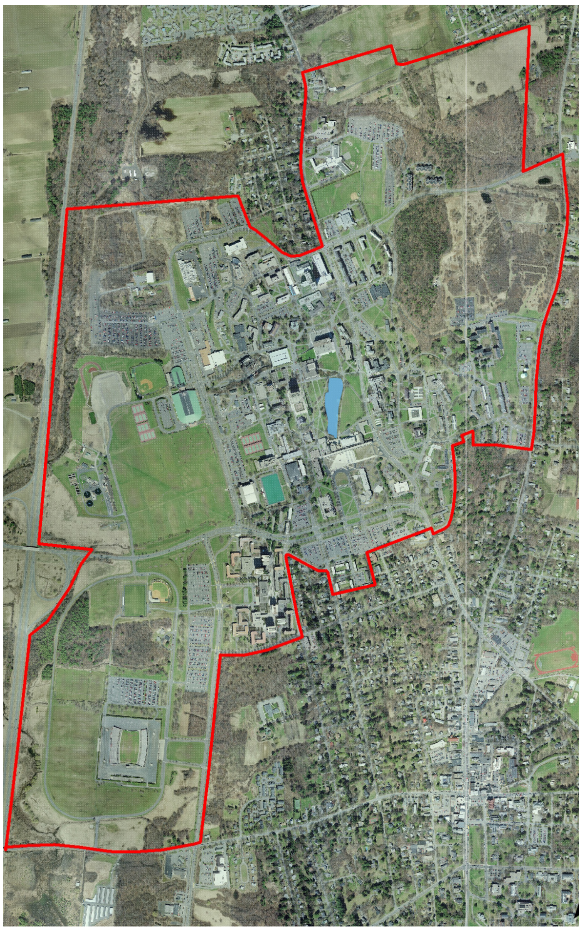

FIGURE 1: *The UMass Amherst campus study area, outlined in red, includes the core campus and adjacent athletic fields and wooded areas.*

surface area of the UMA campus study area and twenty-one percent of the campus is covered by other impervious surfaces such as parking lots, roads and walkways. Taken together pavement and buildings cover twenty-eight percent of the campus. This quantity of impervious surfaces has been proven to have a negative effect on water quality and quantity (Booth et al., 2002). Since water quality and quantity is an issue facing the UMA campus, the exploration of green roofs as a tool to mitigate the increasing urbanization of campus is useful information for campus planning efforts.

There are currently no green roofs on the UMA campus. There are examples of landscape on structure at the W.E. DuBois Library Courtyard and the Campus Center, but these roofs were not designed with environmental enhancement as the primary objective. A green roof is planned for the Integrated Sciences Building project, which is currently under construction and will be completed in the fall of 2008. This building is slated to have both an accessible, intensive roof and an extensive green roof with a shallow layer of planting medium located above the building's chiller plant. The first green roof on campus is an exciting milestone that should be celebrated, made visible, interpreted, and integrated into teaching and research. However, as this project shows, green roofs are most beneficial when significant areas of roofs are greened, which would require retrofitting existing buildings with green roofs.

With seventy acres of rooftop to manage, the UMA campus is faced with continual demands to repair and replace rooftops. According to a recent inventory of deferred maintenance on campus, ninety-nine buildings need work done on their roofs, and thirty-nine of the roofs were rated at Priority Level A and in need of replacement. Since the campus will be responsible for their buildings for centuries to come, the long-term maintenance cost

is an especially important consideration. Green roofs extend the life of a roof by two to three times. The Moos Water Filtration Plant in Zurich, Switzerland was constructed in 1914 with an earthen roof to help keep the water cool, and the waterproof membrane is still intact today with a thriving meadow plant community growing on it (Werthmann, 2007). In the long run, green roofs make economic sense in a campus environment where the institution is responsible for the long-term maintenance and operational costs of buildings. Green roofs currently cost at least double that of conventional roofs, but since green roofs also double the lifespan of the roof and reduce energy use, the overall cost over the life of the green roof is only about 10% more (Carter and Keeler, 2007, Paladino & Co., 2004). A twenty percent reduction in the cost of green roof materials and construction, which could result from increased demand or subsidies would make green roofs a better value than conventional roofs when evaluated over a forty year period (ibid, 2007).

Academic institutions can and must play a profound role in advancing acceptance of sustainable practices. UMA, like other colleges and universities, has great potential to increase people's understanding of sustainability through coursework, but also through its own actions, policies, and plans for the built environment. Many universities have implemented green roofs because they recognize the educational value of such a visible green building strategy. Appendix A lists known green roofs on university campuses.

UMA has begun to develop policies for green building. The Building Design Guidelines published in 2004 recognize the concept of green building and the importance of durability and maintainability over the life-time of the building. The guidelines note, "Extending the renewal cycles for building materials and reducing the consumption of energy and water have benefits for the natural environment, the quality of the campus built environment and the University's finances (p. 10)."

The Campus Sustainability Plan published in 2005 also recognizes the importance of green buildings and commits to resource and energy conservation through improvement in the design and construction of buildings. While green roofs are not specifically mentioned, the plan does include design to minimize life cycle costs and the design of buildings that minimize water and energy use as long-term sustainable solutions. The report also envisions the use of new spaces as educational opportunities for the campus, and a green roof would certainly provide such an educational space.

Recently constructed buildings on campus incorporate green features that reduce energy and water consumption. However, there has been a lack of

institutional leadership and commitment to push this concept and achieve recognition for exemplary green building. As the campus enters a new round of building and maintenance projects over the next ten years, it is time for UMA to demonstrate a true commitment to sustainability and education about sustainability by creating and renovating buildings in ways that demonstrate innovative solutions to environmental challenges.

Research is one of the cornerstones of UMA's mission, and there are exciting opportunities to perform research on green roofs. Michigan State University and Penn State University have become leaders in the field of green roof research, but there is a need for green roof research for the New England region. By incorporating green roofs on campus, faculty and students could be involved in research about this green building technology. Such research can lead to external funding, faculty publications and recognition, and undergraduate and graduate research experiences.

The goal of this project is to examine the campus's current roof tops to determine which buildings are the best candidates for green roofs and what those green roofs might look like. Two of the best candidates are studied in greater detail in order to create schematic designs for green roofs at those sites. In addition, this project explores the design of a potential new building to be constructed on campus with an intensive green roof and an extensive research green roof. When green roofs are incorporated in the design of a building from the onset, it is much easier to create a building that can support a more an accessible, intensive green roof with a greater variety of plant material and human uses. The project is intended to inform the UMA community as to which buildings are most suitable for green roofs, why green roofs should be included on campus, and how a green roof should be incorporated in a future building project.

II. STATE OF THE ART

The use of ornamental gardens on roofs dates back to the ancient civilizations located in the Tigris and Euphrates River valleys where the famous Hanging Gardens of Babylon were constructed in the 7th and 8th century B.C. (Clayton and Price, 1988). Grass or sod roofs have also been a feature of vernacular architecture for centuries in regions such as Scandinavia, Turkey, and Iran. This building technique utilized locally available and inexpensive materials and helped to keep homes cool in the summer and warm in the winter (Dunnett and Kingsbury, 2004).

FIGURE 2: *Sod roof on a log building at Norsk Folkemuseum, Sweden.*

In the 20th century several important modernist architects including Le Corbusier, Frank Lloyd Wright, and Walter Gropius incorporated planted terraces and roof gardens in their designs. While these buildings were often considered aesthetically successful, may of these flat roofs had problems with leaks which has contributed to skepticism and reluctance to implement modern day green roof technology. The widespread construction of flat roofs in cities such as Paris, New York, and London led to the proliferation of roof gardens, often on elite department stores and apartment buildings. Rockefeller Center in New York City and the Derry and Toms department store in London are examples of such intensive roof gardens. Twentieth century urban development also led to the construction of urban plazas that were often located over parking garages and roads, and the tradition of landscape on structure continues today with important civic projects such as Millennium Park in Chicago.

The modern green roof movement, however, differs from these related roof types because it places the environmental benefits of vegetation on roofs at the forefront. With the advancement in waterproofing materials over the past couple of decades, properly installed green roofs are not known to have problems with leaking unlike their predecessors from the early 20th century.

At UMA, there have been problems in the past with roof leaks on our modernist buildings including Lincoln Campus Center and the Fine Arts Center. While an analysis of the cause of these leaks is beyond the scope of this project, it is important to note that the green roofs

FIGURE 3: *An early green roof in Berlin was created for insulation to keep drinking water cool.*

being constructed today utilize recent technological advances to prevent leaks. Green roofers are now able to apply a variety of monolithic roofing membranes which means that there are no seams to fail under wet conditions. There are also new roofing materials on the market such as polyvinyl chloride (PVC), thermoplastic polyolefin (TPO), and ethylene-propylene-diene membrane (EPDM) with improved performance over traditional asphalt built up roofs. Along with seams, roof penetrations for mechanical equipment or vents are also common sites for roof failure, and experienced green roofers have developed construction details to address these potential problem areas. Many green roofing companies offer warranties on the green roof when applied by a certified installer, and a flood test or other waterproof membrane testing method is usually part of the warranty procedure (GRHC, 2006).

According to Dunnett and Kingsbury (2004), "Green-roof research began in Germany in the 1950's as part of a wider movement that recognized the ecological and environmental value of urban habitats...one of the urban habitats that received special attention was the spontaneous flora that developed on gravel or ballast covered flat roofs (p.15)." Germany's first green roofs were a result of the use of sand or gravel on roofs in the late 19th century to protect highly flammable tar pitch roofs from fire. As a result of Berlin's rapid growth in the 1880's, rows of cheaply constructed apartment blocks were constructed, and seeds eventually found their way into the hospitable environment of sand and gravel roofs on these buildings. Decades later researchers began to take note of this rooftop ecosystems and found that after seventy years and two world wars, the historic green roofs remained waterproof—impressive when compared to modern roofs which are typically worn out by sun exposure and heat expansion after 10-15 years (Earth Pledge, 2005).

In the 1970's German researchers established that roof greening had many benefits including energy conservation, stormwater management, and increased roof longevity. At the same time many German companies began to offer specialized roof greening services and developed products specifically for green roofs (Dunnett and Kingsbury, 2004). Many laws in Germany at both the state and federal level promoted the implementation of green roofs. Green

roof installation was one measure that met regulations that required development to avoid unnecessary damage to nature or the landscape through onsite mitigation. Green roofs became a popular mitigation technique since they do not require additional land use (ibid). Berlin and other cities also provided incentives for green roofs. Between 1983 and 1997, approximately 684,000 s.f. of green roofs were created in Berlin via a greening grant program that paid for almost half the cost of green roof installation. Cities also offered incentives for green roofing through the reduction of stormwater fees (Earth Pledge, 2005).

FIGURE 4: *Green roofs in Berlin which appear red during the winter.*

Current Green Roof Application

Even today, Germany continues as the international leader in the green roof movement. Through a combination of incentives and regulations, green roofs have been widely implemented. In Germany it is estimated that 14% of all flat roofs are green roofs (Kohler and Keeley, 2005). There has been a strong commitment to green roofing by the government as evidenced by the fact that half of the new government buildings in Berlin have green roofs (Earth Pledge, 2005) Over forty municipalities in Germany have regulations that mandate or encourage green roofs (Werthmann, 2007). The stormwater fee structure in Germany has also been a compelling reason for green roof installation. Many German water utilities now charge for both freshwater consumption and stormwater removal from the site based on impervious surface area. Because green roofs retain stormwater and delay runoff, they are accounted for when calculating the impervious surface total of the site and can lessen the stormwater fee for the property (Earth Pledge, 2005).

In 1978 a research group for green roof development and construction was founded in Germany to study and promote the ecological and aesthetic benefits of green roofs. In 1982, the Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL), published the first green roof

guidelines, and these guidelines have been continuously refined and updated (Werthmann, 2007). These guidelines and the work of the FLL have been an important part of the growth of the green roof industry. The guidelines help ensure correct green roof installation and help building owners feel confident about implementing a green roof.

Green roof implementation is on the rise in the North America, though the quantity of green roofs is far from that in Europe. Seven percent of newly built or resurfaced roofs are green roofs in Germany, while in the U.S. only .01% of annual roof construction is green (Werthmann, 2007). North American green roof implementation is on the rise. There was an over eighty percent increase in the square footage of green roofs installed in the U.S. between 2004 and 2005, a twenty-five percent increase between 2005 and 2006, and a thirty percent increase between 2006 and 2007 (GRHC, 2008). In 2006 alone, over 3 million square feet of green roofs were installed in North America as reported to Green Roofs for Healthy Cities in their annual industry survey.

The cities of Chicago, Illinois and Portland, Oregon have been leaders in green roofing in the United States. Both cities have established high-profile demonstration projects and developed regulations and incentives that promote green roof creation, although each city emphasizes a different environmental benefit to green roofing. Chicago emphasizes the cooling role of green roofs, while Portland emphasizes the stormwater management provided by green roofs.

Chicago has more green roofs than any other city in the United States, and Mayor Richard Daley has led the movement. Mayor Daley visited Hamburg, Germany, a sister city of Chicago, and was inspired by their extensive green roof network and how effectively they lowered the city's temperatures. Soon after his trip, Mayor Daley directed funds to green roof development. The funds came from a lawsuit settlement with the local electric company regarding the major power outages and a corresponding rise in heat-related illness and death in the summer of 1998.

Chicago City Hall, completed in 2001, is an early example of green roof technology in the United States that was constructed as a research and demonstration site for studies on the benefits of green roofs, plant selection, and different green roof typologies. The roof is not accessible to the public apart from tour groups, but it is visible from over thirty tall buildings in the center of Chicago (Earth Pledge, 2005). The 22,000 s.f. roof has over 150 varieties of plants arranged in starburst patterns in media depths of four inches, 6 inches, and eighteen inches. The roof cost $45.50 per square foot to construct,

and has been reported to save $10,000 per month in cooling costs (Eisenman, 2004). The city monitored the green roof's temperatures and those of an adjacent black tar roof and found them to be on average 70 degrees cooler on a 90°F summer day.

FIGURE 5: *Chicago City Hall's green roof is a combination of extensive and intensive green roofs created on a structure built in 1911.*

Along with the City Hall demonstration project, Chicago also created incentives for green roofs via grants of $5,000 to small businesses and home owners (City of Chicago, 2007), a zoning density bonus for adding a green roof, and revised building codes that mandate minimum standards for roof reflectivity and allow for green roofs or solar panels as an alternative (Earth Pledge, 2005). In 2006-2007, Chicago was the North American leader in green roof installation with over 517,000 s.f. of green roofs—an area equivalent to nine football fields (GRHC, 2008).

Portland battles combined sewer overflow (CSO) problems and water pollution as a result of stormwater runoff, which has impacted salmon stocks, an important industry for the city. Portland was an early pioneer in the green roof or 'eco roof' movement. The city's stormwater manual recognized green roofs as a best management practice for stormwater management in 1999, and the first two municipally funded green roofs in the country were also constructed in 1999 using stormwater fees. Monitoring efforts in Portland have found that green roofs are an effective tool for managing stormwater as they absorb an average of sixty-nine percent of the annual rainfall. Rainfall absorption rates were found to vary from 100% in the dry season to 10% in the wet season per storm (Earth Pledge, 2005). Developers are also encouraged to incorporate green roofs by being given opportunities to increase the permitted floor space of the building according to the area of green roof they put on the building (Dunnett and Kingsbury, 2004).

FIGURE 6: *Hamilton Apartments in Portland, Oregon is the first affordable housing project in the U.S. to have a green roof.*

Types of Green Roofs

Green roofs fall into the following three categories: intensive, extensive and semi-intensive. The following table outlines the key differences:

CHARACTERISTIC	EXTENSIVE	SEMI-INTENSIVE	INTENSIVE
Planting Material Depth	6” or less	Above and below 6”	More than 6”
Accessibility	Often inaccessible	May be partially accessible	Usually accessible
Fully Saturated Weight	Low 10-35 lb/s.f.	Varies 35-50 lb/s.f.	High 50-100 lb/s.f.
Plant Diversity	Low	Greater	Greatest
Cost	Low ($12-20/s.f.)	Varies	$40 and up
Maintenance	Minimal	Varies	Highest

TABLE 1: *Types of Green Roofs (Adapted from Green Roof for Healthy Cities (GRHC), 2006)*

Extensive green roofs are the most appropriate for retrofit projects as they are lightweight and often require no additional structural support. They are also the most suitable for large areas such as manufacturing complexes and other flat roofed industrial buildings where human accessibility is not a priority. The Ford Rouge Center Truck Plant is the largest extensive green roof to date, covering over 450,000 square feet.

FIGURE 7: *Award winning extensive green roof Sanitation District No. 1, Ft. Wright, Kentucky*

Intensive roofs are often designed with human use in mind, which means that accessibility and safety issues must be addressed. Because this type of roof has the deepest planting medium, there are more opportunities for plant diversity and habitat creation. Intensive roofs also offer greater benefits in terms of stormwater management and insulation.

FIGURE 8: *Award winning intensive green roof-- The Louisa, 242 unit apartment building, Portland, Oregon*

A semi-intensive roof is a combination of extensive and intensive roofs, which achieves the benefits of both types of roofs in varying degrees. Often areas of the structure with the greatest loading capacity are utilized for more intensive roofs while extensive roofs are used in areas with low accessibility and to reduce the overall cost (GRHC, 2006). The benefits associated with green roofs depend on the type and overall design, and green roof designers should consider what benefits are most important for the client as part of the design process. Appendix B provides additional examples of green roofs from around the world.

FIGURE 9: *Award winning semi-intensive green roof-- Phillips Eco-Enterprise Center Minneapolis, Minnesota*

Green Roof Components

Modern day green roofs are an engineered system designed to allow plants to grow in challenging rooftop conditions. All green roofs share several common components:

- quality waterproof membrane
- root repellent layer (may be part of the waterproof membrane)
- drainage layer, filter fabric (to separate growing media from drainage layer)
- engineered growing media
- vegetation

In addition, there are several optional components found on many green roofs depending on the type of green roof and its use including:

- Irrigation system
- Leak detection system
- Insulation
- Additional waterproof membrane protection layer
- Safety features such as railings or a harness attachment system
- Other features as found in a garden: lighting, walkways, curbs and borders, pools and ponds.

Green roof growing media

Green roof growing media is not regular topsoil. It is an engineered soil mixture designed specifically for green roofs to be lightweight, provide good drainage, and water retention capabilities. The German FLL guidelines have established rigorous standards for the quality of green roof soil, as a successful green roof is largely dependent on this medium, and these standards are being adopted in the United States (GRHC, 2006). The growing medium needs to be free of material that can degrade, clog or corrode the drainage system and waterproof membrane. Other important characteristics of green roof growing media are the ability to maintain vertical integrity and avoid shrinkages, the ability to hold nutrients and water, and the ability to anchor plants (Snodgrass and Snodgrass, 2007). The lightweight nature of the growing medium can be attributed to the use of lightweight aggregate such as expanded shale and pumice. In an extensive planting medium lightweight aggregate makes up 75-90% of the mixture, and the remainder of the medium is organic matter and coarse sand. This type of medium weighs between 5 and 6 pounds per square foot per inch of depth.

Green roof plants

Successful green roof plants must be able to withstand drought conditions and be water tolerant, long-lived or self-propagating, require minimal nutrients and maintenance, and be able to withstand the harsh conditions of a rooftop. Highly flammable plants, plants that develop large root systems and biomass, and plants that require a lot of water should not be used on green roofs (Snodgrass and Snodgrass, 2007). Years of experience in Germany

have shown that varieties of the Sedum genus are some of the most successful green roof plants. These plants and other types of hardy succulents such as Sempervivum, Talinum, and Delosperma have exceptional abilities to withstand drought and windy conditions. There are over 600 varieties of Sedum and according to Snodgrass and Snodgrass (2007), " Sedums bloom profusely with a wide variety of bloom and leaf color and textures, are non-invasive, and are well loved by insects and birds" (p. 56).

In addition to Sedum, grasses and herbs can be used on green roofs when there is at least six inches of planting medium. Grasses bring exciting motion and texture to green roofs, and they can provide bird and insect habitat. However, grasses can attain a larger biomass than the hardy succulents and can pose a fire hazard during winter dormancy, and undergo a dormant period creating brown spots in the roofscape (Snodgrass and Snodgrass, 2007). Herbs and herbaceous perennials will need irrigation in order to become established on a green roof, and they may need irrigation throughout their lifespan. Allium, Phlox, Origanum, and Dianthus are low-growing and shallow-rooted, and they have proven to be successful on green roofs. A successful extensive green roof mixes Sedum varieties with other accent plants to create an interesting palette. At least 75% of the plantings should be Sedum and more than six varieties of Sedum should be used (Green Roof Service, 2008).

Careful plant selection is an important part of a beautiful green roof. Plant selections should be both attractive and practical, meaning that the plant is well-suited to the conditions and maintenance regime of the green roof. When designing an intensive green roof, there are many more options for plants, but the choices are not the same as for a garden on the ground. The micro-climate and soil conditions on a roof are different, and plant selection must take these factors into account. There is a need for more information about successful green roof plants in each North American climate zone, as much of the information currently available is based on the experiences of German green roofs. There are exciting opportunities to expand the planting palette to reflect regional plants and biodiversity goals.

Literature Review

There is growing interest in green roofs in the United States as more information becomes available on their benefits, but there are still barriers to the widespread adoption of this technology (Hendricks and Calkins, 2006). This review looks at literature on the benefits of and barriers to green roofs.

There were several challenges in writing this literature review. Much research about green roofs has been conducted in Germany and very little is available in English. Many primary sources were not accessible and had to be reviewed based on their discussion in another source. Much research regarding green roofs that is available in English is in the form of conference proceedings, especially the annual Greening Rooftops for Sustainable Communities Conference organized by Green Roofs for Healthy Cities (GRHC) for the past six years. There is also a body of literature regarding green roofs that is published by the GRHC non-profit group's director and colleagues. Since GRHC is an advocacy group for industry growth of green roofs in North America, their literature may exaggerate the benefits of green roofs. Finally, the variable nature of green roofs themselves make it difficult to compare literature and synthesis results as studies often consider green roofs with different depths of planting medium, plant types, and climatic conditions.

There are many research questions about green roofs that need to be explored further. Fortunately, the past couple of years have seen an increase in the peer-reviewed literature on green roofs and their benefits. This can largely be attributed to the establishment of green roof research programs at several North American universities including Penn State, North Carolina State, and Michigan State Universities. By installing green roofs at UMA, researchers here could also study this technology and publish high quality, peer reviewed research with a focus on New England's climate and plant species.

Apart from journal and magazine articles, there are three well-illustrated and easy to understand books about green roofs, which can help to educate potential adopters of green roofs. Dunnett and Kingsbury (2004), British authors, are biased to Europe and the U.K., especially in the plant species list suitable for extensive green roofs. However, they do offer an excellent review of the benefits of green roofs, the components of a green roof, and how to plant on roofs. Earth Pledge (2006) provides much less technical information and research, but it does have over 30 case studies with excellent photographs and design details. Snodgrass and Snodgrass (2006) provide the first illustrated guide to green roof plants focused on North America. The

book is an excellent resource for selecting plants that will be successful on a green roof and includes a useful discussion of the challenges that plants face on roofs. These three books complement each other and all provide comprehensive information and bibliographies.

Green Roof Benefits

The benefits of green roofs can be divided into the following two categories: community benefits and building benefits. Community benefits are those that have an impact on the greater good, while the owner or occupants of the building only enjoy building benefits. Many of the benefits associated with green roofs are quantifiable and will continue to be quantified with greater accuracy as research in the field continues. However, several of the benefits of green roofs cannot currently be measured or assigned a dollar value.

The following chart outlines the benefits associated with green roofs and evaluates the amount of research and documentation of the benefit as high, medium, and low. Each benefit is discussed further based on currently available research and literature.

Community Benefits	Quality of Research	Building Benefits	Quality of Research
Stormwater quantity management	High	Increased roof life	High
Biodiversity	High	LEED points	High
Urban heat island	Medium	Reduced heating and cooling	Medium
Stormwater quality	Medium	Life-cycle benefit	Medium
Air quality	Low	Biophilia	Medium
Job creation	Low	Noise reduction	Low
		Increased rental rates and occupancy	Low

TABLE 2: *Green Roof Benefits*

Community Benefits

Stormwater management (SWM)

Green roofs help to reduce the volume of stormwater runoff in urban areas where impervious surfaces of an individual building site can be as great at nearly 100%. Mentens et al. (2006) performed a literature review on the current data on runoff from green roofs. It was found that the amount of water retained depended on the structure of the green roof, climatic conditions and precipitation. On a yearly-basis intensive roofs retained 75% of rainfall and extensive roofs retained 45%. It was also found that retention is significantly lower in winter than in summer. Green roofs were found to reduce overall flow volumes, but they were not as effective at reducing storm flow peaks. The authors suggest that green roofs should be part of a repertoire of stormwater management strategies such as stormwater ponds and wetlands, rainwater cisterns, porous pavements, and vegetated swales, and further study should be done to investigate the integration of these strategies. They point out, however, that green roofs do have an important advantage over other stormwater strategies such as ponds and open channels since they do not make use of previously unused space and thus do not limit the demand of people for "open space" on the ground. In urban areas, there is often not sufficient space for ponds and open channels making green roofs a more desirable option in these areas.

Following Mentens et al. (2006), Carter and Rasmussen (2006) found the green roofs in their study to retain just under 90% of rainfall for small storm events (<2.54 cm) and 50% for larger storms (>7.62 cm). VanWoert et al. (2005) found that green roofs retained an average of 82.8% of rainfall. This study also compared green roofs to gravel ballast roofs and unvegetated green roofs (growing media only). They found the experimental vegetated roof platforms retained significantly more rainfall than the gravel ballast roof; however, the effect of vegetation was minimal when compared to the growing media only platforms. This indicates that the primary retention capability of green roofs comes from the growing media and water retention mat as opposed to the plants themselves.

Carter and Rasmussen (2006) point to the need for greater scientific data on stormwater BMPs in light of recent EPA regulations targeting non-point source pollution including the Clean Water Act Section 319. One facet of their study was to establish a protocol for testing and monitoring the stormwater retention of green roofs so that further research could be conducted (see Appendix C

for a description of the protocol). They found that green roofs retained more water during small storms and that runoff from the green roof was delayed when compared to a traditional roof. Green roofs have more complex runoff behavior as their response to a storm depends on existing moisture conditions in the planting medium. The authors point out that green roofs are essentially a retention system. This can be viewed as a detriment to the watershed in some areas as the water is not infiltrated. However, in urban areas, little rainfall infiltrates and returns to the stream as base flow, and the runoff reaching water bodies in urban areas has high pollutant loads. In urban areas retention and use of the rainfall by the vegetation is considered beneficial. The authors also note that the increased evapotranspiration rates in the roof surface reduce surface and air temperature.

Stormwater quality

Green roofs have the potential to improve water quality and to mitigate the pollution derived from conventional roof runoff. However, there is contradictory research in this area. Moran et al (2004) found that, contradictory to their hypothesis, the green roofs' runoff had higher quantities of nitrogen and phosphorous than rain water from a conventional roof. Research in Berlin, Germany at Potsdamer Platz has shown that when green roofs are designed with water quality in mind, they can be very effective at reducing nutrient loading of runoff, which has an important role in improving aquatic habitat. The type of planting medium is the most important factor in runoff quality along with the degree of plant establishment. A coarser planting medium and well-established plants are best at reducing the percentage of nitrogen, phosphorous, and heavy metals in runoff (Kohler and Schmidt, 2003).

The main drawback to green roofs as a best management practice for SWM is that it can sometimes be very costly for the amount of stormwater quality and quantity improvements it provides, especially since the cost for green roofs is so high in North America today and because of the additional cost of creating a roof structure that can support the green roof load. Depending on the site, it is possible that only a small amount of overall site stormwater can be managed by a green roof (e.g., areas with large amounts of surface parking lots). However, in urban areas where rooftops constitute a high percentage of the impervious area, green roofs are a more viable best management practice.

Stormwater modeling

There is no consensus about the best way to model the stormwater response of green roofs, and this is an area in which greater research is required in order to create accessible and accurate

models. Stormwater models are an important tool for planners and engineers to make decisions about what practices to employ to manage stormwater. One of the challenges of modeling the hydraulic response of green roofs is the fact that a green roof acts as a retention area until it reaches its saturation point, at which point stormwater begins to run off the roof. The amount of water that a green roof can retain or absorb depends on the moisture level of the planting medium at the time of the storm event, and this can be widely variable depending on preceding conditions such as previous storm events and amount of evapotranspiration (Teemusk and Mander, 2007).

Another factor that makes green roof stormwater modeling a challenge is the variability in depth of planting medium from roof to roof. The deeper the planting medium, the greater the stormwater retention capability (Van Woert et al.,2005). The fact that planting medium depth is not a constant in green roofs means that stormwater models need to adjust for this variable. To date, there is no such model available to the public in the United States.

The commonly used and readily available TR-20 stormwater model is not well-adapted for predicting the runoff from green roofs since it was developed to describe surface runoff, does not take into account the physical percolation of water that characterizes green roof hydrology, and is not accurate for smaller areas. The NRCS Curve Method is another widely used model that is more appropriate for green roof modeling. Researchers have been working to determine a curve number for green roofs, and they have calculated a runoff curve number (RCN) for a planting medium of about three inches for a two year and ten year storm. This can be used to estimate the stormwater response for individual storm events and can be useful for describing runoff characteristics on a larger scale (not just an individual building). However, as described before, one of the weaknesses of this model is that it does not incorporate the amount of existing moisture in the planting medium when the storm occurs.

Miller (2006) calculated an RCN of 66 for a two-year storm and 72 for a ten-year storm based on an analysis of a 3.2 inch green roof using rainfall information for the mid-Atlantic region. Carter and Rasmussen (2006) calculated a green roof curve number of 86 based on a study of a three-inch roofing system in Georgia. The difference in curve numbers could be attributed to the difference in climate between the two regions, the slight variation in media depth as well as the composition of the green roof---the Georgia study describes a drainage layer mat that could impact runoff quantity.

Urban heat island

The amount of impervious surfaces and black tar or asphalt roofs found in urban areas causes these areas to absorb heat energy, store it in dense building materials such as concrete and steel, and radiate it back into the air resulting in increased air temperatures. Urban areas lack trees, other vegetation and pervious surfaces which cool the air through the evaporation and transpiration of water from soil and plants. The increased temperatures found in urban areas is known as the urban heat island effect (UHI). UHI may also increase convection currents over cities, which generates more rainfall (which urban areas are less able to absorb). Convection currents are also associated with increasing the amount of dust in the air (Dunnett and Kingsbury, 2004).

New York City is typically 3.6° F to 5.4° F warmer than its suburbs (Rosenzweig et al., 2006). Urban areas are on average 2-8 degrees warmer than surrounding areas (Akbari et al., 1992). The increase in temperature places greater demand on cooling systems, which in turn requires greater energy use, which results in greater pollution and global warming. Since one-sixth of electricity consumed in the U.S. goes to cool buildings, it follows that reducing the cooling need in large areas would have a significant impact on energy use. Along with reduced energy use, mitigation of UHI can improve the health of urban residents especially those likely to suffer during a heat wave. Research shows that the mortality rate during a heat wave increases exponentially with the maximum temperature (Buechley et al., 1972), so a reduction of 1-2 degrees could have an important impact on health and safety.

Along with other strategies to reduce impervious surfaces in urban areas, green roofs can contribute to reducing temperatures in urban areas. In order for this to happen, however, there needs to be a significant amount of green roofs in a given area. Ryerson University (2005) found that if green roofs were commonly used throughout Toronto, there would be a reduction in the heat island effect. A 1° C drop in temperature would be obtained over one third of the city if 50% of the buildings had green roofs.

The amount of energy that a surface reflects determines how hot it will become. The higher the reflectivity, the less heat is absorbed. Materials are given an albedo (reflectivity) value from 0 to 1 (hottest to coolest). The albedo of a black tar roof is 0.08 compared to 0.25 for grass and 0.6 for reflective roofing (Earth Pledge, 2006). By increasing the albedo of surfaces in cities, the urban heat island effect can be reduced. Green vegetated roofs and lighter colored or reflective roofing are strategies to reduce UHI. Light-colored or reflective roofing

costs less than vegetated roofs, but it does not provide the other environmental benefits associated with vegetation on roofs. Vegetated roofs also help to reduce temperatures more than reflective roofing because of the evapotranspiration of plants (Gaffin et al., 2006)

Air quality

Green roof advocates frequently promote the ability of green roofs to mitigate air pollution. However, there is no peer-reviewed literature documenting the effect of green roofs on air quality. One challenge is the fact that different types of plants can filter and clean the air in varying degrees. Trees, grasses, and shrubs filter pollutants much differently from the Sedum plant species usually found on green roofs, and therefore research on trees, grasses, and shrubs cannot be directly applied to the green roof context. Traditional green roof plantings have a low leaf area index when compared to trees which means that one meter of tree canopy has much greater air quality benefits than one meter of Sedum green roof.

The most commonly referenced statistics about green roofs and air quality are derived from research on turf roofs in Toronto. Peck and Kuhn (2001) found that turf roofs can remove 0.2 kg of particulates per year per square meter. As air passes over the plant, airborne particles settle on the leaf and stem surfaces. This material is then washed off into the soil via rainwater. Yok and Sia (2005) found a 37% reduction of sulfur dioxide and 21% reduction of nitrous acid directly above a newly planted green roof.

Plants affect air quality in a variety of ways: plants take up carbon dioxide and nitrogen oxide, filter particulate matter, and can reduce volatile organic compounds and ozone in certain environments. The complexity of the relationship between plants and air quality makes it difficult to evaluate the benefits of green roofs for air quality. It is also difficult to determine a monetary value for the air pollution removal service of green roofs. Peer-reviewed research has evaluated the nitrogen uptake of the Crassulaceae family of which Sedum is a part (Morikawa, et al, 1998). Based on this information, Clark et al (2005) quantified the economic value of green roofs as part of a cap and trade emissions credit system. Using the 2005 market value for NO emission credits of $3375 per ton, the authors estimated the credit for Sedum green roof to be $0.11 per square meter. NO uptake can also be quantified in terms of public health benefits. Using U.S. Environmental Protection Agency (EPA) estimation methods, a green roof of 2,000 square meters had a public health benefit of between $890 and $3390 per year (Clark et al, 2008). The wide variance in these results points to the lack of proven methods for this type

of economic analysis. Further peer-reviewed research is required as well as comparative analysis of plant species to enhance the air quality benefits of green roofs.

Biodiversity

A quantity of green roofs in one area also maximizes the benefits to wildlife as it increases habitat and can also contribute to a habitat network. Kim (2004) explores the idea of an urban biosphere reserve and suggests that green roofs can play an important role. Kim describes the UNESCO Green Roof Top in Seoul that was created with the goal of securing biotopes, i.e. functional ecosystems, in the downtown. A variety of habitats were created on the roof including a wetland, meadow, scrub, and woodland. This roof functions as a "building- integrated habitat specifically for biodiversity conservation." The benefit for wildlife has also been shown, however, on roofs that are not specifically designed for biodiversity. In a biodiversity study in Basel, Switzerland, 78 spider and 254 beetle species were found on 17 green roofs. Eighteen percent of the spiders and eleven percent of the beetles were listed as endangered (Brenneisen, 2003). Birds have also been recorded using green roofs as food habitats for insects and seeds in the USA, Canada, England, Switzerland, and Germany (Brenneisen, 2005 and Gedge, 2003). Researchers in Switzerland have also documented nesting on green roofs and are investigating how we can begin to design green roofs as ecologically valuable habitat for bird species (Baumann, 2006). On the Ford Rouge Truck Plant green roof with a planting media of 7.6 cm, 29 insect species, seven spider species, and two bird species were identified within the first two years after construction (Coffman and Davis, 2005).

As an alternative to planting vegetated green roofs with nursery stock, "brown roofs" or "rubble roofs" use soil from the displaced site or nearby to the site, and the roof is allowed to self colonize through windblown seeds and birds. The rubble roof movement is growing in London, England where biodiversity is challenged by urban growth. Several rubble roofs have been installed and 100,000 square meters are planned to provide habitat for black redstart, an endangered bird species (Earth Pledge, 2005).

FIGURE 10: *A killdeer nests on a green roof near Washington, D.C.*

A new law in Basel, Switzerland requires green roofs on all new buildings with flat roofs, and the law also requires that the planting medium on green roofs greater than 500 square meters be composed of natural soils from the region and be of varying depths in order to promote biodiversity (Brenneisen, 2006). This law recognized that the biodiversity potential of green roofs was not being realized by the use of 'technical' planting media developed specifically for green roofs.

Kohler (2006) observed over 100 plant species over a 20-year period on extensive green roofs in Berlin. However, only 15 of these species were commonly present. The author suggests that plant diversity can be increased by planting a greater variety of species during the establishment period, creating microclimates (shady and sunny areas), and the presence of surrounding vegetation.

While green roofs clearly provide more biodiversity than traditional roofs, there is much to learn about how to maximize the biodiversity of this unique environment. Many species cannot adapt to the extreme conditions or do not have the required mobility to get to a green roof. A green roof will never replicate the biodiversity of the undisturbed ground-plane, but in the context of urban ecological planning, a green roof can have an important role especially when the roof is designed with biodiversity in mind.

Job creation

In Germany, the growth of the green roof industry has created a multi-million dollar market for services and products related to green roofs. In 1997, the industry made 700 million deutsche mark (5.6 million dollars), and since then the annual square footage of green roofs installed has significantly increased (GRHC, 2005). Nurseries growing green roof plants will have the most to gain. When the Ford Motor Company installed a 450,000 s.f. green roof in Michigan on an existing building, it is estimated to have resulted in $200,000 of orders for plant material from Michigan nurseries (Rowe, 2003). Researchers in Canada estimated that if 6% of Toronto's roofs were greened over ten years, it would lead to direct and indirect job creation of 1350 jobs per year (Peck et al, 1999).

Building Benefits

Building level benefits relate to the long term economic benefits of green roofs that can be assigned a monetary value, and the human benefits associated with the enjoyment of green space that cannot easily be assigned a monetary value. However, research has shown that buildings with green space and green design are able to charge higher rent and attract customers or buyers (CoStar Group, 2008).

Reduction in heating and cooling costs

Research has shown the green roofs play a greater role in helping to keep a building cool than in reducing the need for heat in the winter (Liu, 2003). This is due to the fact that green roofs reduce the surface and air temperature on a roof, which has an effect on air conditioning use, and the overall need for HVAC equipment. However, the research on this benefit has produced varied results. One study found that a green roof was 39 degrees Fahrenheit cooler than a conventional roof on a summer day resulting in the need for roughly 700-Watt hours less energy for cooling. The authors also point out that over time a green roof will further reduce heat gains as the vegetation spreads; a conventional roof becomes darker over time as it collects dirt which increases heat gains (Sonne, 2006).

Saiz et al (2006) also found that the lower solar absorption and greater evaportranspiration on green roofs cause lower surface temperatures, which results in annual energy savings of just over 1%. Summer cooling loads were reduced by 6% and reductions in peak hour cooling on the upper floors of an eight-story building reached 25%. Spala et al. (2007) found an even greater reduction in the building cooling load, with a green roof providing a forty percent reduction during the summer period.

Green roofs do provide additional insulation which reduces heating costs. A 3-inch deep extensive green roof provides an additional R-value of 2.8 which is equivalent to one inch of fiberboard or fiberglass insulation. On a single-story, 10,000 s.f. building researchers found the green roof provided an energy savings of 3.3 % (Carter and Keeler, 2007). Liu (2003) found that a six-inch extensive green roof reduced heat loss by 26% and heat gains by 95%. The economic benefit associated with this additional insulation depends on heating and cooling costs at the location of the green roof and these costs will change over time.

Increased roof life

Many people believe that since green roofs hold water, they will increase the likelihood of leaks. In fact, the opposite is true since green roofs hold water away from the waterproof membrane in the

planting media and drainage layer. Water is more likely to pool rather than runoff on conventional roofs than green roofs. This pooling allows water time to exploit weaknesses in the waterproof membrane, which can lead to leaks in conventional roofs (Dunnett and Kingsbury, 2004).

If constructed properly green roofs have been proven to last longer than conventional roofs, which has significant cost benefits. Green roofs prevent damaging ultraviolet (UV) rays from reaching the roof membrane, which extends the lifespan of this membrane. UV rays can change the chemical composition and degrade the mechanical properties of bituminous roofing materials (Dunnett & Kingsbury, 2004). Green roofs also protect the roofing membrane from extreme fluctuations in temperature, which can cause warping and cracking of the roof membrane (Snodgrass, 2006). Green roofs in Germany have lasted more than 50 years and a roof garden in London has lasted more than 70 years (Peck et al., 1999). Based on European research, green roofs can be expected to more than double the life span of a roof membrane and pay for itself in the long run since re-roofing costs are avoided (Peck and Kuhn, 2000).

Noise reduction

Hard surfaces are more likely to reflect sound while green roof plants and substrate have been shown to absorb sound. However, researchers do not agree to what degree green roofs can contribute to a reduction in noise pollution. German researchers found that a four -inch green roof on the airport in Frankfurt Germany reduced sound transmission into the building by five decibels (Dunnett and Kingsbury, 2004). Dunnett and Kingsbury (2004) find the claims made by Peck and Kuhn (2001) that a green roof with 4.8 inches of substrate can diminish noise by 40 decibels to be “extravagant.”

There are other factors in building construction that also contribute to noise reduction including the density of wall insulation and the quality of windows, so research needs to establish what the role of the green roof is in reducing noise. Further peer-reviewed research needs to be completed in the area before green roof advocates can realistically include noise reduction as a significant benefit of green roofing.

Life-cycle analysis

Saiz et al (2006) were the first to also examine green roof benefits using environmental life-cycle assessment (LCA). They investigated the life cycle impacts due to the change in energy use in the building and found that environmental impacts were reduced in all categories by 1.0% to 5.3%. Categories include abiotic depletion, global warming, human toxicity, and several others. They also point out that the increased longevity of a green

roof has an impact on the maintenance phase of LCA as use of a green roof alleviates production and transportation of roof materials including PVC. The authors also note that the percentage change when comparing a green roof with a conventional roof may not seem very high, but their study was conducted on a building in which the green roof only covered 16% of the building's exposed surface. Greater energy savings would occur with a larger roof-to-envelope ratio, such as with low-rise buildings. The authors also found that if there was a 1° C drop in temperature, as suggested to be possible with widespread roof greening by Ryerson University (2005), it would reduce the building's summer cooling load by 33%, leading to reduction in life cycle impacts that are five times greater than those previously discussed. In order to maximize the private building benefits of green roofs, it is necessary to create city-wide policies to help achieve a critical mass of green roofs.

Kosareo and Ries (2007) assessed the life-cycle environmental cost of a 12,000 s.f. conventional stone ballast roof, an extensive green roof, and intensive green roof to compare the environmental impacts associated with constructing, maintaining and disposing of each type of roof. Factors used in the analysis included materials used in construction, the transportation required for materials, energy use, and water runoff quality and quantity. The study found that green roofs have a noteworthy impact on the life-cycle assessment. While green roofs require additional resources in the beginning, the results showed that extensive green roofs are the environmentally preferable choice due to the small reduction in energy demand each year and the increased life of the roof.

Carter and Keeler (2007) performed a benefit cost analysis (BCA) for the life cycle of an extensive green roof when compared to a traditional roof. Unlike the environmental life cycle assessment performed by Kosareo and Ries, this study assigns monetary value to the environmental benefits of green roofs and compares the cost over forty years of the two scenarios by comparing their net present values (NPV). This analysis discounts the effects of inflation over the forty-year period using an interest rate of four percent. The analysis assumed that a green roof would last forty years while a conventional roof would need to be re-roofed at year twenty. Monetary value was assigned for stormwater management with the assumption that the cost of another stormwater best management practice or stormwater utility fee would be avoided. An economic value was also calculated for the air quality benefits of green roofs based on the market value for NO emission credits as part of a cap and trade emissions credit system. Finally, the savings associated with reduced heating and cooling costs were also calculated. Using current construction

costs for green roofs and current energy costs, the researchers found that a green roof is 10% to 14% more expensive than a conventional roof. However, by changing reasonable assumptions in the analysis such as the cost of energy (which is projected to increase) and the cost of green roofs (expected to decrease), the net present value of the green roof is less than the conventional roof.

A similar type of analysis was used by Clark et al. (2008). The researchers recognized that greater up front costs is a deterrent to investment in green roof technology, and they sought to quantitatively integrate a range of green roof benefits in an economic model at the building level scale. The benefits that were quantified in the study include reduced stormwater, reduced energy use, and air pollution reduction. Using an up front cost for a green roof that was 39% higher than the conventional roof, the researchers found that the NPV of the green roof was 20-40% less than the NPV for the conventional roof over forty years depending on which variables were incorporated in the analysis. Their method showed that an investment in a green roof in the Midwest may break even in 14 to 22 years. The researchers found that a 21,527 s.f. green roof would result in $180 less in stormwater fees, $710-$1670 less in energy costs, and $890-3390 less health care costs related to bronchitis and premature deaths per year. The researchers point out that the information regarding the air pollution uptake capacity of green roofs was based on plants in a green house, and they point to the need for further research on specific plant uptake potential as green roof plants might behave differently under more stressed conditions.

Life cycle analysis and economic analysis of environmental benefits are useful for quantifying the environmental benefits of green roofs and may help to persuade decision makers who are concerned about long-term costs to implement green roofs. However, as a review of the research on this topic has indicated, there are a wide range of results which are often based on research that is not as rigorous as one might like. Green roof skeptics might not be convinced by these analyses, but they are a starting point for an important discussion about the need for a broader understanding of the costs associated with buildings.

Biophilia

Biophilia is the idea put forth by E.O. Wilson that humans have a unique affinity with nature and love of living things (Wilson, 1984). While there is no specific literature on this phenomenon related to green roofs, Ulrich and Simmons (1986) show that views of nature including plants and trees have positive influences on emotional and physiological states. The benefits of seeing trees and other vegetation may also be greatest for

individuals experiencing stress or anxiety. Kaplan et al (1998) reported that employees who had a view of nature were less stressed, had greater job satisfaction, and had fewer health problems.

Kats (2004) found worker productivity in green buildings to be much higher than in buildings that are less environmentally friendly, though the study did not separate out green roofs from other green building features. Further research is needed to determine the unique human response to green roofs.

FIGURE 11: *View of a green roof from an office.*

LEED points

Leadership in Energy and Environmental Design (LEED) rating is a useful marketing tool for attracting residents to buildings and decreasing vacancy rates, which can have economic benefits at the building level. Green roofs can contribute as many as 15 credits, depending on the design and level of integration with other building systems such as gray water. Green roofs can earn direct credits in the following categories (Kula, 2005):

- SS credit 5.1: Protect or Restore Habitat
- SS credit 6.1: Stormwater Quantity Control
- SS credit 6.2: Stormwater Quality Control
- SS credit 7.2: Heat Island Effect: Roof
- WE credit 1.1: Water Efficient Landscaping
- Innovation in Design

Increased occupancy rates and rent

Green buildings with LEED or Energy Star ratings have been proven to achieve higher rents, occupancy rates, and prices per square foot (CoStar, 2008). This research does not specifically address green roofs as a part of green building, but green roofs are one of the most visible green building strategies, making them an important part of green building marketing.

Barriers to Green Roofs

Despite the benefits just described, there are barriers to the implementation of green roofs in the United States. Getter and Rowe (2006) point out that the same barriers existed and have been overcome in Germany and Switzerland and that the United States can learn from Europe to help overcome barriers in this country. The barriers identified are lack of awareness regarding green roods, higher initial cost, lack of quantifiable

data on the benefits of green roofs, and lack of technical information on how to build them (Getter and Rowe, 2006). Other barriers identified include concerns about roof failure, leaks, weight, and lack of long-term performance information (Hendricks and Calkins, 2006).

A survey of building owners and architects in the Midwest found that they do not see enough benefit to outweigh perceived costs of implementing green roofs. However, both groups also indicated that incentives would increase their likelihood of implementing green roofs (Hendricks and Calkins, 2006). Getter and Rowe (2006) point to incentive programs in Germany, Tokyo, Chicago, Atlanta and Portland that have facilitated more green roofs. Many German cities help to pay for the cost of installing a new green roof, and other cities significantly reduce stormwater fees.

In order to hasten the adoption of green roof technology in the United States, the cost benefit ratio needs to improve. This can be achieved by reducing the cost of green roof materials and installation. As green roofs become more common the cost of materials and installation will be reduced. In Germany green roofs cost only 10% of what they cost in the Unites States. An average extensive green roof in Germany costs approximately 12.00 €/m2 ($1.33 per square foot) not including the waterproofing and $4-13 per s.f. including waterproofing (Phillipi, 2006). Cost reductions in the U.S. market can be achieved with standardization of green roof products, complete systems, greater training and specialization by installers, and the introduction of specialized technology such as blower trucks to get planting medium on the roof.

In addition to reducing installation costs, there is a need for comprehensive and well-disseminated information on economic, environmental, functional, and aesthetic performance of green roofs in order to reduce uncertainty about the technology and improve the perceived cost benefit ratio. Hendricks and Calkins (2006) note that "misconceptions of green roof technology have led to the perception of greater costs and less benefits than actually exist." The authors suggest that education and information efforts aimed at a wide variety of potential adopters is necessary for green roofs to become more widespread in this country.

Conclusion

The environmental and economic benefits of green roofs need to be further quantified in order to convince developers and building decision makers to implement green roofs. Greater research is needed to understand the role of green roofs in stormwater management in order to convince people that green roofs can effectively reduce run off from a site and prevent the need for costly underground drain and pipe structures. Since

stormwater management is the potential benefit with the greatest overall value, especially in our climate, future research at UMA or other institutions in the area should be focused on quantifying the effects of green roofs on stormwater and creating accurate stormwater modeling tools. Further research is also needed on the pollution uptake ability of green roofs and their ability to mitigate the urban heat island effect. Finally, there needs to be more information gathered and made available about the long term performance and maintenance of green roofs so that risk averse decision makers can feel at ease.

While further research on green roofs is needed, it is important to note that unlike other environmental solutions such as stormwater detention basins and solar panels, green roofs provide multiple benefits. Green roofs impact air quality, water quality, and energy use while providing habitat and visually pleasing spaces. In order to address the environmental challenges of the future, it is important to implement multi-functional solutions such as green roofs.

FIGURE 12: *Award winning green roof--Life Expression Wellness Center, Sugarloaf, Pennsylvania*

Local Site Visits and Interviews

In order to gain a better understanding of the state of the art of green roofs, I visited three local green roofs and talked to the people involved in their construction and maintenance. All three were built on new buildings, as I was unable to locate any examples of retrofit green roofs in the area. I also talked to people involved with the green roof that will be installed next year at Smith College. Common factors with these green roofs were an institutional commitment to the environment and excitement about the teaching/research potential of green roofs. All of the green roofs were also installed or will be installed as modular, loose-laid systems meaning that one company provided all of the components and oversaw the installation.

Pequot Museum

The Mashantucket Pequot Museum in Mashantucket, Connecticut has a large intensive green roof, though most visitors would not realize that the building has such a roof. Constructed in 1993, the green roof is an integral part of the architectural concept of fitting the building in to the landscape.

Size: 52,000 s.f.

Type: Intensive (accessible)

Manufacturer: American Hydrotech

Program: The roof is used regularly for museum functions and educational programs.

Maintenance: There was a problem with the roof leaking shortly after construction. The leaks were quickly repaired and the museum has not had any problems with the green roof since then. The regular grounds-keeping crew maintains the roof which demands the same amount of time as other manicured/lawn areas.

Notes: While the museum is proud of the award winning green roof design, they do not advertise the fact that they have a green roof or include green roofs in their educational/outreach programs. The original design for the roof was done by Dan Kiley's office, but it was redesigned to be less geometric and formal a couple of years after construction. The museum is interested in further refining the design to incorporate larger swaths of native plants and an ethno-botany component.

FIGURE 13: *Mashantucket Pequot Museum Intensive Green Roof*

Holyoke Community College (HCC)

HCC in Holyoke, MA has a small inaccessible extensive green roof on the Kittredge Center building which has housed the Center for Business and Professional Development since its construction in 2006.

Size: 2,400 s.f.

Type: Extensive (inaccessible)

Manufacturer: Sarnafil

Program: The roof is inaccessible, but it can be viewed from several offices and group work rooms. Due to the topography of the site, the roof is also visible from the campus core.

Maintenance: HCC was told by the manufacturer that this extensive green roof does not require maintenance. Due to the inaccessibility (a maintenance worked would have to climb through a window; there are no handrails), weeding or plant replacement is not possible.

Notes: The green roof was proposed by the architect as it would be visible from many points on campus and merge with the athletic fields in the background. The fact that the roof is inaccessible, even to maintenance crews, limits the educational potential of the roof. HCC is an example of a state–owned institution that was able to successfully implement a green roof. While the exact cost of the green roof was not available, the additional upfront cost was modest and not difficult to justify.

FIGURE 14: *HCC's green roof is visible from the central courtyard on campus.*

FIGURE 15: *HCC's can be seen from study areas and offices.*

Deerfield Academy

This private boarding school, located in Deerfield, Massachusetts, recently completed construction of a green science building, which includes two levels of green roofs. The building is LEED Gold certified, and the green roofs were an important part of achieving this certification. The school was dedicated to constructing a nationally recognized green building to show their commitment to sustainability.

Size: There are several separate green roofs as part of the building totaling 27,000 s.f.

Type: Extensive (accessible and inaccessible)

Manufacturer: American Hydrotech

Program: Classrooms have doors opening directly onto the green roofs and faculty plan to incorporate the green roof into biology and ecology lessons. The primary roof is almost entirely a green roof and is only accessible for maintenance. However, there is a viewing area that is accessible to students.

Notes: The facilities manager has not had any problems with the green roof, though the building has had problems with leaks in areas around skylights (not related to the green roof). The plants appear to be establishing well as they were manually watered for the first growing season. The school anticipates minimal maintenance of the roof most of which will be biannual weeding.

FIGURE 16: *The uppermost green roof is the largest and can be seen from a viewing area.*

FIGURE 17: *Several green roofs can be accessed via doors from classrooms.*

Smith College

Smith College will complete their first green roof in the spring of 2009 on Ford Hall, the new 140,000 s.f. science and engineering building. The school is planning to achieve LEED certification with this building and sees the green roof and green building as an important opportunity to showcase the campus's commitment to sustainability and involving students in research related to sustainability.

Size: 20,000 s.f. extensive, 1,000 s.f intensive

Type: Extensive (partially accessible) and intensive (accessible)

Manufacturer: American Hydrotech

Program: The intensive portion of the roof will act as a small garden space for school community. The extensive portion will be used for some research by science classes including stormwater retention, temperature variation and plant viability.

Notes: The green roof was incorporated from the initial building design discussions and is considered to be an important tool to gain LEED certification. Faculty and staff have been supportive of the green roof as they see it as a potential teaching laboratory. The physical plant was initially concerned about the maintenance of the roof, but when they understood that the extensive portion of the roof would require minimal maintenance, they were supportive. The extensive portion is designed to not require watering or fertilizer, so the only maintenance is weeding. The smaller intensive section will be treated as one of the campus flower beds with irrigation connected to the buildings gray water.

III. METHODS

One objective of this project is to determine which existing buildings at UMA would be most suitable for green roofs. For the purpose of this project, the study area was limited to the core contiguous area of the UMA campus (Figure 18). While there are benefits to green roofs no matter where they are located, there are greater benefits in more central-urbanized areas such as the core of the UMA campus when compared to outlying areas such as the Tilson or Hadley Farm. These areas have less buildings, parking lots and impervious surfaces. The number of users of these areas is also significantly less than in the core area of campus, which would limit the educational potential.

FIGURE 18: *The project study area outlined in red is over 900 acres.*

Building Selection Method

A three-step approach looking at individual buildings and campus-wide factors was used to prioritize buildings with the potential for green roofs. Suitable buildings were identified in the preliminary building analysis and then narrowed down further based on the campus wide analysis. Individual buildings were then examined in greater detail to determine suitability based on structural characteristics, visibility, accessibility, and other building specific factors such as roof condition, replacement schedule, and building use.

This approach was chosen to minimize the number of buildings subjected to detailed analysis, thereby reducing the number of buildings that would need to be reviewed by a structural engineer.

Step One: Preliminary Building Analysis

Buildings within the study area were first sorted into two categories: flat roof and sloped roof. While green roofs can be installed on a roof with a slope up to 45 degrees, only flat roofs were considered

for this study because installation is easier and less costly, a greater variety of vegetation is possible and because there will likely be a research/educational component to the green roof that would require an accessible flat roof.

The flat roofs were further sorted, and dormitories and campus owned housing were eliminated. Dormitories/housing are only accessible to residents and their guests, so a green roof on a dormitory would not provide equal benefit to the entire community. However, if a wide-spread roof greening program were going to be implemented at UMA, dormitories should be included since they constitute a significant percentage of roof area (many dormitories on campus, however, have sloped roofs). Green roofs on dormitories would provide students with a unique living and educational experience as they would be living directly under a green roof.

From the remaining flat, non-residential buildings within the study area, buildings over six stories tall and buildings with large amounts of mechanical equipment on the rooftop were eliminated. The tallest building cannot be viewed from other buildings and also have a lower roof/building envelope percentage which reduces green roof heating/cooling benefits; large amounts of mechanical equipment reduces the surface area that can be greened on a roof and therefore reduces the benefits. Buildings that are scheduled to be demolished based on information from UMA Facilities Planning were also eliminated.

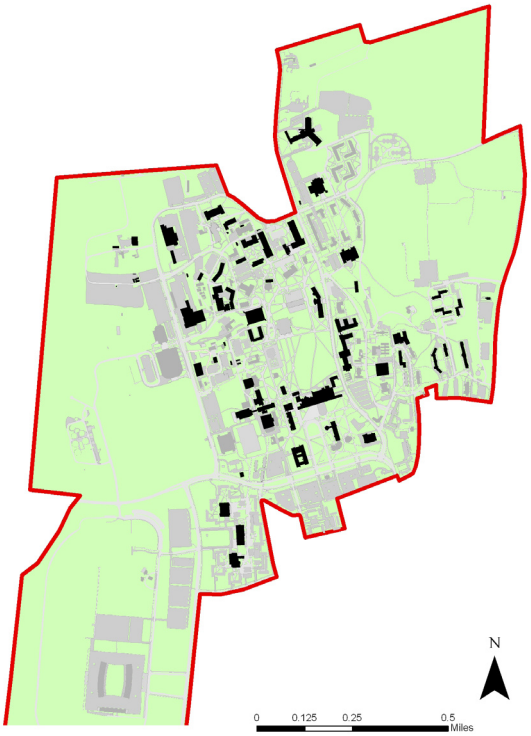

FIGURE 19: *Flat buildings excluding buildings greater than six stories, dormitories, buildings scheduled to be demolished, and buildings with significant mechanical equipment.*

Step Two: Campus Scale Analysis

A campus scale analysis was used to further narrow down the potential green roof buildings. This broader scale analysis considered which locations on the campus had the greatest potential for optimization of green roof environmental benefits and was based on the methods described in the City of Waterloo's Green Roof Feasibility Study (2004). Two green roof environmental benefit areas were mapped, and by overlaying these maps it

is possible to see which areas of campus were most in need of the environmental benefits of green roofs. The following two environmental benefits areas were mapped:

Urban Heat Island and High Impervious Areas

Figure 20 shows the areas with the greatest amounts of impervious surfaces including roofs, roadways, and parking. Surface temperatures are expected to be higher in these areas relative to other parts of campus, and green roofs could help to reduce the temperature. These areas are also in the greatest need of best management practices (BMP) for stormwater runoff due to the high percentage of impervious surfaces, and green roofs are one type of BMP for stormwater.

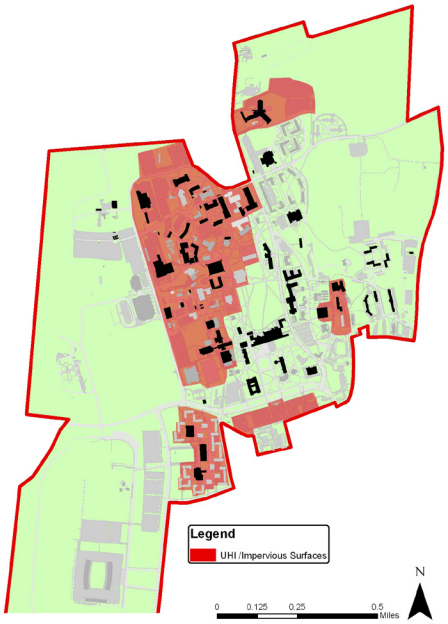

FIGURE 20: *The red area shows parts of campus with high impervious surfaces and urban heat island.*

Lack of Green Space

Figure 21 shows areas of campus where green space is lacking relative to the rest of campus. Green roofs have the potential to increase the amount of usable or viewable green space in these areas of need.

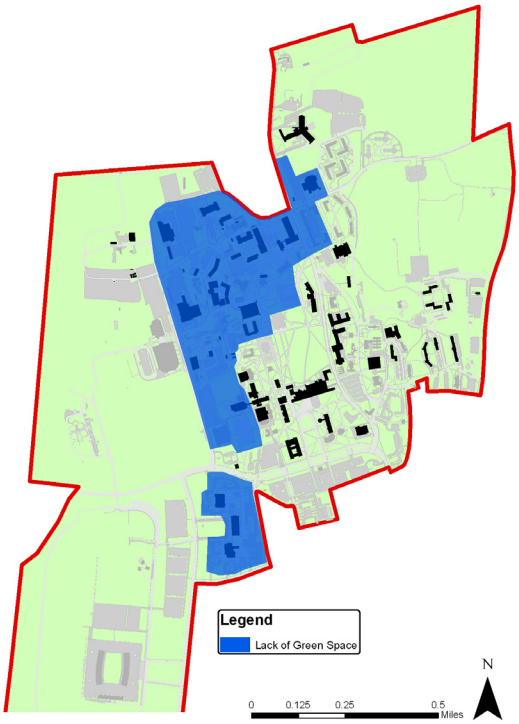

FIGURE 21: *The blue area shows parts of campus with that lack quality green and views of green space when compared to other parts of campus.*

These two maps were overlaid in order to determine the areas of that would benefit the most from green roofs. Figure 22 show the thirty three buildings which are the best candidates for green roofs based on environmental need. This method is a tool for understanding the environmental benefits of green roofs for existing buildings and for future buildings on campus. It provides a basis for comparing sites, which can inform decisions about where to incorporate

green roofs when funding for retrofitting the roof becomes available. The individual maps and overlay combinations can help decision makers maximize the desired environmental benefits based on the priorities of the time.

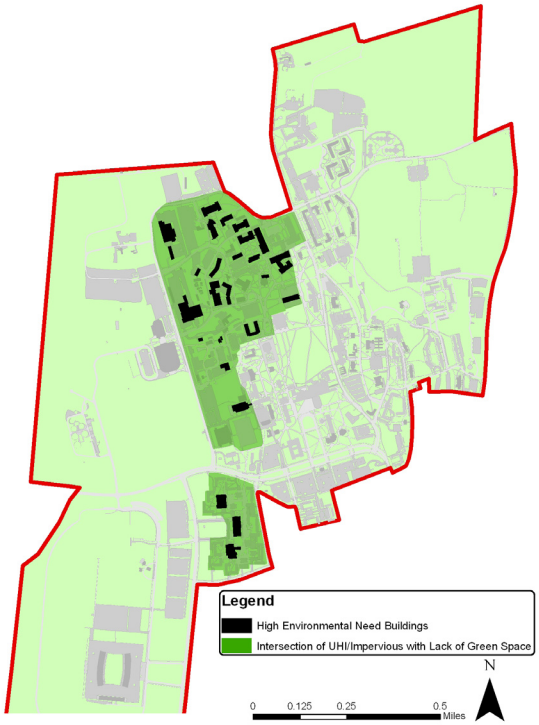

FIGURE 22: *The green area shows the intersection of Figures 20 and 21. The highlighted buildings have the greatest environmental need for green roofs.*

Step Three: In-Depth Building Analysis

The priority buildings shown in Figure 22 were further reviewed to determine their suitability for a green roof retrofit. Visibility, roof condition, accessibility, and existing parapet wall were evaluated. Each building received a visibility rating from zero to five based on the number of other buildings that could see the roof. A score of three means that three other buildings can view the roof. Accessibility was rated as either yes or no, depending on whether or not there is stair access to the roof. Parapet walls were rated as none, low-wall, medium-wall, high-wall. Roof condition was evaluated based on information from UMA Facilities and Campus Planning regarding deferred maintenance of roofs. The color of the roof was also noted as lighter colored roofs would be less of a priority than dark roofs since lighter roofs also help to reduce the urban heat island. See Appendix D for a complete building list and evaluation. Appendix E summarizes the deferred maintenance information for roofs on campus.

From this list of buildings, those with a visibility score of three or greater, stairs to the roof, and at least a low parapet wall were selected. The priority buildings based on this rating system are the following:

- Engineering Shops Buildings
- Gunness Laboratory
- Holdsworth Hall

- Lederle (Low Rise)
- Marston Hall
- Paige Laboratory
- Tobin Hall
- Berkshire Dining Hall (SW)
- Hampden Dining Hall (SW)
- Hampshire Dining Hall (SW)
- PVTA Bus Facility Building
- Engineering Laboratory II

From these twelve buildings, the most centrally located were identified along with the buildings in which the current academic program could benefit from a green roof as a research/teaching tool. These buildings were then discussed with a structural engineering student to determine the load bearing capacity of the roof in order to establish the design constraints for the green roof.

Structural Engineer Input

A senior structural engineering student, Andrew Stone, reviewed building plans and existing conditions to determine the approximate excess dead-load bearing capacity of Hampden Dining Hall in Southwest, Marston Hall in the Engineering Quad, and the Lederle Low-Rise buildings. The original building plans were obtained from UMA Facilities and Campus Planning. For each building, the student reviewed the plans and analyzed the structure using a computer program.

The structural engineering student determined that the three buildings could each hold an additional 15-20 lbs/s.f. of dead load. This assumes that the original roofing material would be removed and replaced with a new waterproof membrane. In a retrofit application, the existing roofing material can play a role in how much of a green roof load can be added. For example when a roof already has a gravel ballast roof, the ballast will be removed for the green roof, and the green roof itself can incorporate the weight of the ballast. The structural engineering student suspects that Marston has concrete pavers on the roof, and by calculating the weight of those pavers, it is possible to arrive at a potentially greater allowable green roof weight.

Since the structural engineering analysis was completed by a student, it only provides an estimate of the excess load capacity of the building. If green roofs are to be considered for these buildings, it will be necessary to hire a licensed structural engineer. A discussion with structural engineering students and faculty revealed that a comprehensive structural analysis for a green roof retrofit project would require approximately forty hours of work with an estimated cost of $6,000.

Exploration of Green Roofs that Meet Load Restriction

While the green roof literature mentions that green roofs are possible with an

additional dead-load of as little as 10 lb/s.f. (GRHC 2006), much of the literature indicates that plants are most successful when there is at least 3 inches of planting media (Boivin et al., 2001, Durham et al., 2007) which would have a weight of nearly 20 lb/s.f. With retrofit applications, the structural restrictions of the roof can be a limiting factor that severely restricts growing media depth and subsequently limits plant choice. Three different manufacturers were found that provide green roofs systems with three inches of growing media that are less than 20 lbs/s.f. Each of these systems includes a waterproof membrane, root barrier, a thin drainage layer, filter fabric, lightweight planting medium, and plants.

The weight of each component is provided below:

- Sedum & low growing perennials: 1-2 lbs/s.f.
- Lightweight planting medium: 5 lbs./s.f. per inch (when saturated)
- Filter fabric: .03 lbs/s.f. (wet)
- Drainage layer: 1 lbs/s.f. (wet)
- Waterproof membrane: 1.5 lbs./s.f.

Buildings Under Construction

UMA is in the middle of several major building projects. Since these buildings are not complete at the time of this project, they were not considered in the above analysis. The green roof potential of these buildings is discussed below and is based on information gathered about these buildings through interviews with construction managers.

Integrated Science Building
(To be completed in Fall 2008)

This building has a flat roof, but it has significant mechanical equipment on the roof and a stepped roof design. Part of this building project includes a green roof, which is located on the adjacent chiller plant. The second story entrance on the eastern side of the building is via a green roof. This green roof provides physical plant and maintenance the opportunity to learn about green roofs in a low risk building (an unoccupied mechanical area).

Recreation Center
(To be completed in Spring 2009)

The Recreation Center's flat roof will be a white Energy Star rated roof with a warranty of 20 years. Since the building has large rooms for recreation activities, the building is not a candidate for a retrofit as the large spans could not support the additional load of a green roof.

Other Campus-Scale Analysis Opportunities

When looking at a broad scale such as a campus or a city, it may also be useful to consider energy efficiency and pollution as a criterion to narrow down potential green roof sites. These criteria were explored on the UMA campus, and while they were not included in the final method,

they are described for informational purposes. Since reduction in energy use and air pollution mitigation of green roofs are research areas that require significant further study, these criteria should only be used in conjunction with other more proven benefits such as stormwater management .

Areas with the highest concentration of older buildings are likely to have the least energy efficiency since energy consumption was not a concern when these buildings were constructed. Older buildings can best make use of the energy saving benefits of green roofs. Areas close to roadways and industrial uses are likely to have poorer air quality, which could be mitigated by an increase in vegetation from green roofs. Proximity to air pollution sources and areas with older buildings could be mapped and combined with other environmental benefit overlay maps to make decisions about priority green roof sites.

IV: APPLICATION: SCHEMATIC GREEN ROOF DESIGNS

Schematic designs were created for three green roofs in order to present the UMA community with ideas about how green roofs would have a positive visual impact on campus along with the other environmental benefits associated with green roofs. Each building has different characteristics that influenced the design, but the design concepts could easily be adapted to other buildings on campus. Plan and perspective views are presented for each of the designs along with a suggested planting palette.

Hampden Dining Commons Extensive Green Roof

Constructed in 1967, Hampden Dining Commons is a low building located in the center of the Southwest residential area. The roof of the building is visible from the adjacent high-rise dormitories and also visible from Sunset Avenue. The building no longer functions as a dining hall. It currently houses a convenience store, art galleries, and other residential life program space.

The building has the original roof from 1967 which has been subject to regular patches and repairs. This roof is considered an "A" level priority roof for replacement according to the Integrated Facilities Plan (IFP), a facilities audit completed in 2007. The roof is accessible via stairs and an elevator, and it has a low parapet wall. The current roofing material is tar pitch with gravel ballast. According to the roofers on campus, the insulation layer has sustained water damage and there have been leaks in the building.

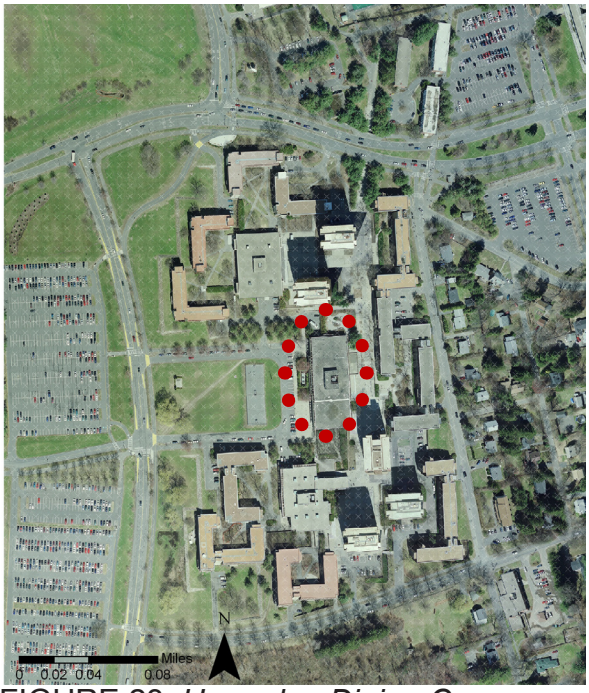

FIGURE 23: *Hampden Dining Commons is centrally located in the Southwest Residential Area.*

FIGURE 24: *The Hampden Dining Commons roof is visible from the adjacent towers.*

Based on the estimated excess loading capacity of the building, the green roof must be less than 20 lbs/s.f. when saturated. In order to achieve this weight, it is possible to put three inches of lightweight planting media on the roof. This depth of medium can support Sedum varieties and some leafy perennials such as Allium and Delosperma (Snodgrass and Snodgrass, 2006).

Design Concept

The Southwest residential area is one of the densest parts of campus with five high-rise dormitories and eleven low-rise buildings located in an area less than thirty acres. Over 5500 students live in the area which is just under half of the total population housed on campus. The area has a uniquely urban feel when compared to other parts of campus with modern architecture, plazas and rectilinear forms. Since Southwest also lacks green space and vegetation, the proposed green roof at the center of the space will bring over 30,000 new square feet of vegetation to the area.

The vegetation on the green roof will be planted so that flowing swathes of white will be perceived when viewed from above. The biomorphic form of the swath is influenced by the Holyoke Mountain Range which is visible from the campus, and it is intended to introduce more natural geometries to space. The planting of varieties of white flowering Sedum within the swath area creates the mountain range form. All other parts of the green roof will be planted with plant varieties that do not have white flowers. See Appendix F for planting plan.

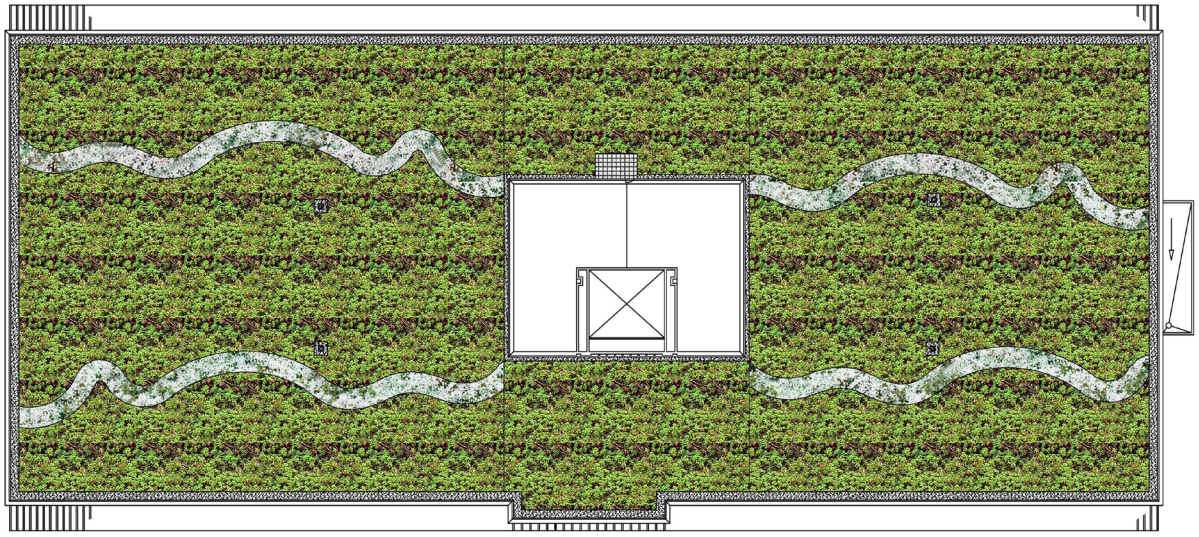

FIGURE 25: *Rendered plan view of Hampden Dining Commons green roof*

FIGURE 26: *Perspective view of green roof.*

FIGURE 28: *View of the green roof from adjacent building.*

FIGURE 27: *The Hampden Dining Commons green roof would be visible from Sunset Avenue.*

FIGURE 29: *Perspective view of green roof.*

A small paved area is proposed immediately outside the access door to provide an area for maintenance personnel to gather without damaging the plants. The plants proposed for the green roof can withstand moderate foot traffic, but high-use areas such as access point should incorporate paving material instead of plants.

Planting Palette

The following table identifies thirteen varieties of plants that are hearty to zone five and will provide seasonal interest throughout the year. All of these plants have been identified as successful green roof plants by *Green Roof Plants: A Resource and Planting Guide* (Snodgrass and Snodgrass, 2006). While many varieties of Sedum flower in the summer, careful attention was paid to selecting varieties that bloom in the spring and fall since students will be on campus to enjoy the flowering during these times. See Appendix G for selected plant images.

Sedum/Groundcover Mix				
Botanical Name	Size	Spacing	Height	Bloom Time/ Color
Sedum hybridum var. Czar's Gold	2" plug	8 " O.C.	6"	Spring/ Yellow
Sedum spurium var. 'Fuldagut'	2" plug	8" O.C.	6"	Summer/Pink
Sedum kamtschaticum var. floriferum	2" plug	8" O.C.	6"	Summer/ Yellow
Sedum sexangulare	2" plug	8" O.C.	6"	Summer/Yellow
Delopsperma nubigenum 'Basuto-land'	2" plug	12" O.C.	3"	Spring/Yellow
Accent Plants				
Botanical Name	Size	Spacing	Height	Bloom Time/ Color
Allium oreophilum	Bulb	6" O.C.	6"	Spring/Purple
Allium senescens	2" plug	8" O.C.	8"	Fall/Pink
Sedum aizoon 'Euphorioides'	2" plug	8" O.C.	10"	Summer/Yellow
Sedum sichotense	2" plug	8" O.C.	6"	Summer/Yellow
White Flowering Plants				
Botanical Name	Size	Spacing	Height	Bloom Time/ Color
Sedum ternatum	2" plug	8" O.C.	6"	Spring/White
Sedum spurium var. white form	2" plug	8" O.C.	6"	Fall/ White
Sedum telephioides	2" plug	8" O.C.	6"	Fall/White
Sedum album	2" plug	8" O.C.	6"	Summer/White

TABLE 3: *Planting list for 3" growing medium.*

Marston Hall Extensive Green Roof

Marston Hall was constructed in 1950, and it currently houses the Environmental and Structural Engineering Departments. This three-story brick building forms one edge of the engineering quadrangle and is visible from the W.E. DuBois Library, Conte Polymer Science Building, and the Lederle High-Rise. The building is also low enough that some green roof plants will be visible from the ground.

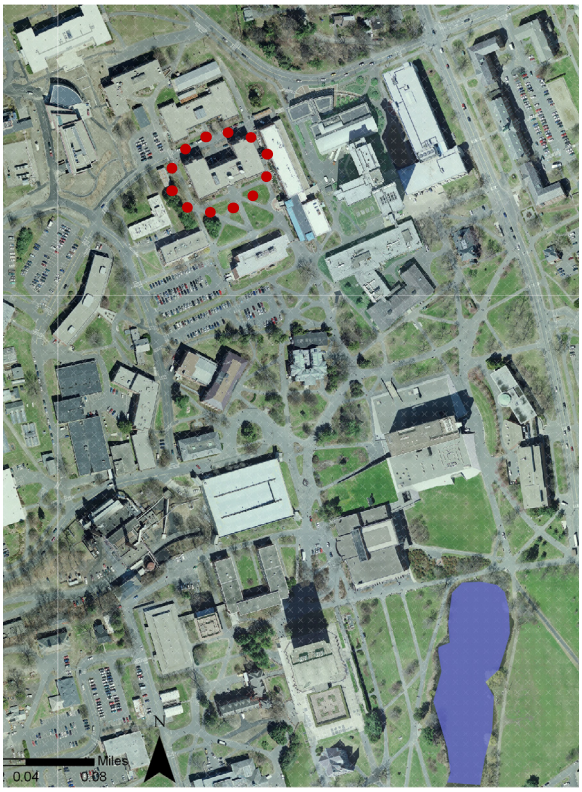

FIGURE 30: *Marston Hall is located in the enginnering quadrangle.*

The roof is accessible via two spiral stairways and the building has a low parapet wall. The roof was replaced in 1987, but it is listed as an "A" level priority for replacement according to the Integrated Facilities Plan (IFP), a facilities audit completed in 2007. The roof is an inverted construction with a singe ply membrane beneath the insulation layer. The insulation layer is ballasted on the roof using concrete pavers. A recent visit to the roof revealed that vegetation is beginning to grow between the concrete pavers, many of which are cracked and falling apart. There have been no reported leak problems, but the building is likely to undergo a major renovation in which the roof and windows would be replaced. The roof currently has two non-functional satellite dishes that will be removed when renovations occur.

FIGURE 31: *Marston Hall's roof is visible from several buildings.*

FIGURE 32: *Vegetation is already growing between the concrete pavers.*

The structural engineering student suspected that the Marston Roof might have greater excess loading capacity than the Hampden Dining Common because of the structure of the building and the existing concrete pavers. After visiting the roof, the presence of concrete pavers was confirmed, but the pavers were less than 1" thick which would add 8-10 lbs/s.f., bringing the estimated excess loading capacity to 30 lbs/s.f. For the purposes of this project, it was decided to use an excess loading capacity for the Marston roof of 40 lbs/s.f., which would allow for 6" of planting media. When a green roof has 6" of planting media, there are significantly more options for plant species that will thrive including grasses, herbs, and a wider variety of herbaceous perennials (Snodgrass and Snodgrass, 2006).

Design Concept

As with the Hampden Dining Common green roof, small paved areas are provided at access points to the roof. The Marston Hall green roof uses un-vegetated paths to create an attractive pattern of geometric shapes that can be perceived from above and also provide areas for maintenance workers to walk. The diamond pattern was inspired by traditional parterre geometry, but in this case, the hedges are replaced with paths and the absence of vegetation. The geometric forms are also appropriate for an engineering building. There are a variety of edging material available for use on green roofs that can separate the pathway area from the vegetated areas. Straight paths were chosen to aid in the ease of installation of the edging material.

The formal geometry of the paths and planted zones also allows for informal research on the roof. The design is symmetrical which means that several zones have the same area and can therefore be compared over time. The entire roof is planted with the same palette of six Sedum, but within each of the eight zones a different accent plant will be mixed in. Overtime it will be possible to study which accent plants do the best on green roofs in this region as each plant will be confined to one zone. See Appendix H for the planting plan.

FIGURE 33: *North facing perspective of green roof.*

FIGURE 34: *West facing perspective of green roof.*

FIGURE 35: *View of Marston roof from Conte.*

FIGURE 36: *View of Marston roof from Lederle.*

Planting Palette

The Sedum groundcover plant mix has plants that bloom throughout the year and also have attractive winter foliage (Table 4). The accent plants used in each of the eight zones will also selected for their attractive foliage and flower. Taller plants were placed closer to the front of the building where they will be partially visible from the ground. Galium verum and Dianthus alpinus were selected because they are both known to attract butterflies and moths. The accent plants will bloom at different times of the year. Figure 37 shows what would be blooming in the spring, summer, and fall.

Appendix I has additional images of the planting palette.

Sedum/ Groundcover Mix				
Botanical Name	Size	Spacing	Height	Bloom Time/Color
Sedum hybridum var. Czar's Gold	2" plug	8 " O.C.	6"	Spring/ Yellow
Sedum album	2" plug	8" O.C.	6"	Summer/White
Sedum spurium var. 'Fuldagut'	2" plug	8" O.C.	6"	Summer/Pink
Sedum kamtschaticum var. floriferum	2" plug	8" O.C.	6"	Summer/ Yellow
Sedum stefco	2" plug	8" O.C.	2"	Fall/White
Sedum spurium var. album	2" plug	8" O.C.	6"	Fall/ White
Accent Plants				
Botanical Name	Size	Spacing	Height	Bloom Time/Color
Zone A				
Aster oblongifolius	2" plug	15" O.C.	30"	Fall/Purple
Zone B				
Aster alpinus	2" plug	6" O.C.	9"	Spring/Purple
Zone C				
Dianthus alpinus*	2" plug	10" O.C.	6"	Summer/Pink
Zone D				
Galium verum*	2" plug	8" O.C.	12"	Spring-Fall/Yellow
Zone E				
Achillea tomentosa	2" plug	6" O.C.	8"	Summer/Yellow
Zone F				
Chrysopsis mariana	2" plug	12" O.C.	24"	Fall/Yellow
Zone G				
Lavandula angustifolia	2" plug	10" O.C.	16"	Summer/Purple
Allium senescens	2" plug	8" O.C.	8"	Fall/Pink
Zone H				
Arenaria montana	2" plug	10" O.C.	4"	Summer/White
Allium schoenoprasum	2" plug	6" O.C.	10"	Spring/Pink

TABLE 4: *Planting list for 6" growing medium.* *= *Attracts butterflies and moths*

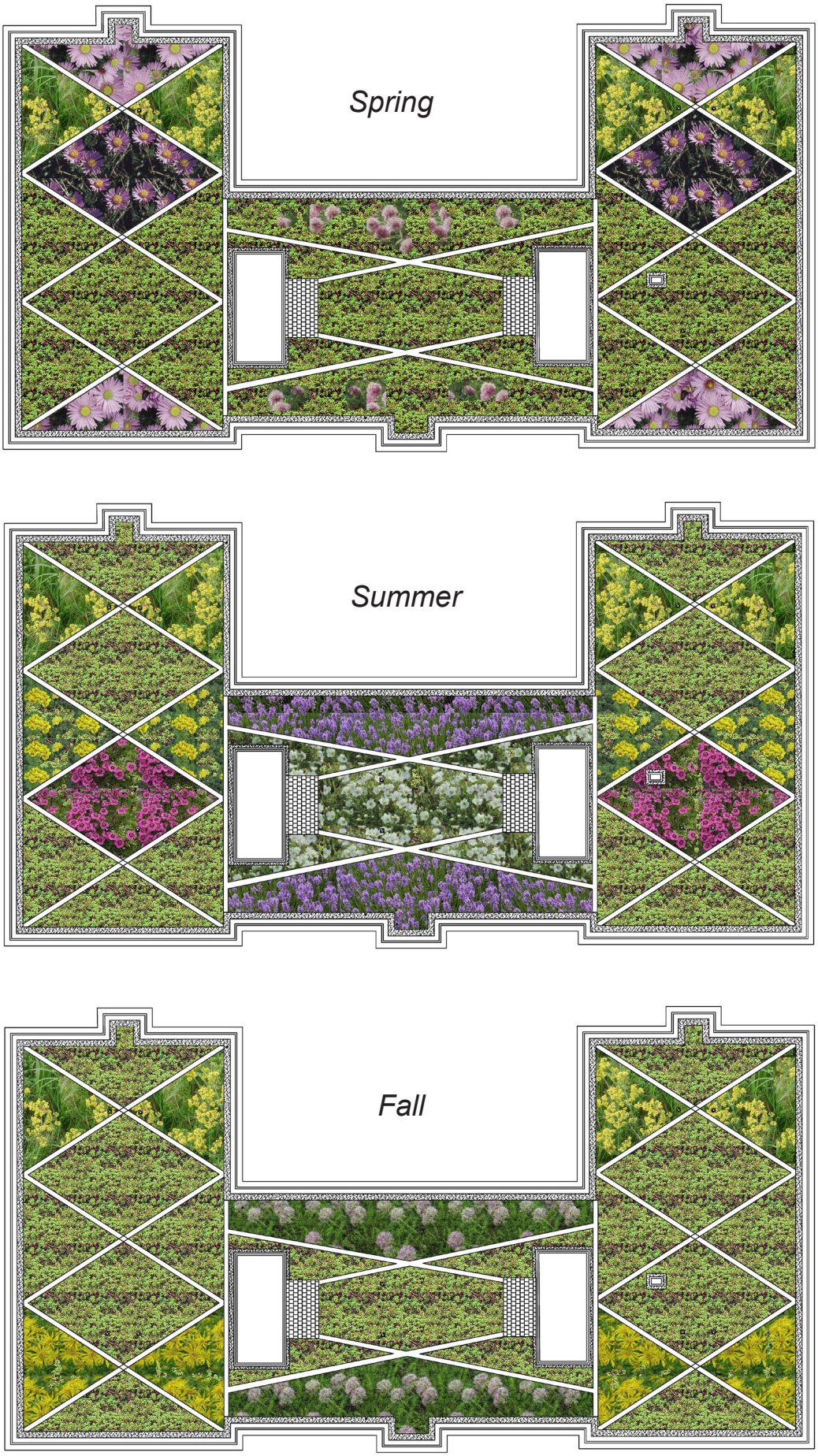

FIGURE 37: *Spring, summer, and fall views of planting zones and accent plants.*

Maintenance

This green roof will only be accessible to Physical Plant staff or members of the campus who will be assisting in the maintenance of the green roof under their supervision. When the roof is installed, it is recommended that a safety attachment system be included so that volunteer members of the campus can also be involved on the roof with less liability issues.

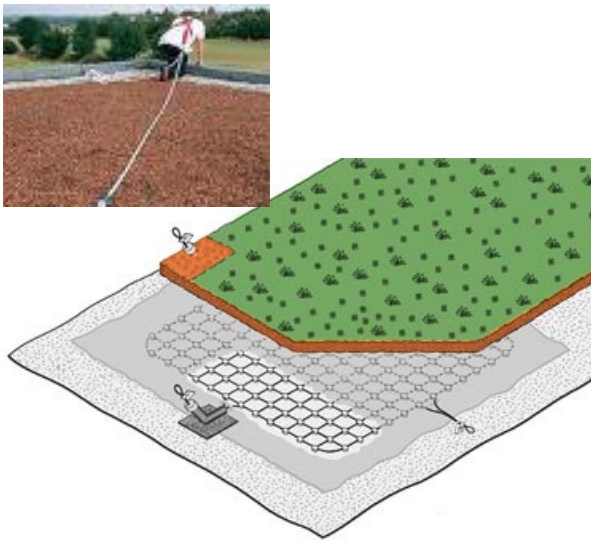

FIGURE 38: *This safety system uses a wire mesh that is applied below the planting medium and allows workers to be attached to the roof via a harness and rope. The system does not require penetrations to the roofing membrane.*

Maintenance is critical to the success of the green roof especially during the first two years while the plants are becoming established and spreading to cover the entire planting medium area (Snodgrass and Snodgrass, 2006, GRHC, 2006). The three primary maintenance tasks for green roofs are weeding, watering and fertilizing.

Weeding

When the green roof is planted there will be space between plants in which weeds can begin to grow. The green roof should be visually inspected and hand-weeded at least three times during the first two growing seasons while plants establish. Once the green roof is established less weeding will be required, but the green roof should still be inspected twice a year to be sure that drains are free of debris.

Watering and Fertilizing

During the first two growing seasons, the green roof must be irrigated if there is not sufficient rainfall. Young plants require sufficient water in order to become established. The young green roof will require approximately ¼" of rainfall at one to two week intervals (GRHC, 2006). Drip tube hoses or standard sprinklers can be used and then removed from the roof once the plants are established.

Fertilization is not required in the first year, but a slow release fertilizer should be applied in the early spring a year after planting and also in subsequent years depending on the health of the plants (Snodgrass and Snodgrass, 2006).

Both of the extensive green roofs will be planted following a planting plan. Over time, it will require maintenance to preserve the forms from the original planting plan as plants will naturally migrate throughout

the roof. Decisions about whether or not to maintain the original planting plan can be made at a later date and may depend on available staff and volunteers. Based on the interest expressed in green roofs by students at the time of the writing of this report, there will likely be an ample supply of volunteers who would be excited to participate in green roof maintenance and can provide the necessary labor to preserve the planting plans.

Estimated Costs

The three manufacturers consulted regarding extensive retrofit green roofs all provided similar cost estimates for green roofs of $12-20/s.f. Using this range, the Hampden green roof would cost between $370,857 and $617,140 and the Marston green roof would cost between $254,520 and $424,200. The table on the following page shows the difference in cost for a traditional roof and a green roof when the energy savings and re-roofing costs are included. The yellow column shows the green roof costs less the traditional roof cost, re-roofing cost, and energy savings over forty years at three different energy inflation rates. Using an annual interest rate of 3% and an annual energy inflation of 4%, 6%, or 8%, the net present value of the Hampden green roof is less than a traditional roof when energy costs rise by 6% per year. The Marston green roof is between $114,000 and $31,000 more expensive than the traditional roof depending on annual energy inflation. However, when a lower green roof cost is used ($12/s.f.) both green roofs have a lower net present value.

Annual energy savings were calculated using current energy use audits and a kilowatt/hour rate of $0.08. The green roof was assumed to provide a 3% savings in energy. As Table 5 shows the annual energy savings for Hampden is much greater as the building currently uses much more energy than Marston.

TABLE 5: *Traditional and green roof cost comparison*

	HAMPDEN			MARSTON		
	Traditional Roof ($6/s.f.)	Green Roof ($20/ s.f)	Difference	Traditional Roof ($6/s.f.)	Green Roof ($20/ s.f.)	Difference
Initial cost	$185,142	$617,140		$127,260	$424,200	
Replacement cost after 20 years	$185,142			$127,260		
Interest rate = 3%						
Energy Scenarios						
Annual Energy Savings		$3,867			$1,132	
Energy inflation = 4%:						
Total Savings (NPV)		$189,737	$57,119		$55,542	$114,138
Energy inflation = 6%:						
Total Savings (NPV)		$294,194	$(47,338)		$86,120	$83,560
Energy inflation = 8%:						
Total Savings (NPV)		$472,747	$(225,891)		$138,388	$31,292
		Green roof ($12/ s.f)	Difference		Green Roof ($12/s.f)	Difference
		$370,284			$254,520	
Energy inflation = 4% Total Savings (NPV)			$(189,737)			$(55,542)
Energy inflation = 6% Total Savings (NPV)			$(294,194)			$(86,120)
Energy inflation = 8% Total Savings (NPV)			$(472,747)			$(138,388)

Prospective Building

The Plant, Soil and Insect Science (PSIS) Department is scattered across campus in multiple buildings. Bringing the department together under one "green" roof would provide greater opportunities for collaboration, research, and sharing of resources. When a new PSIS building is constructed, it is recommended to have a green roof (both intensive and extensive). Since the building has yet to be designed, it is the ideal time to plan for a green roof, especially an intensive green roof. By deciding that a green roof will be part of the building from the onset,

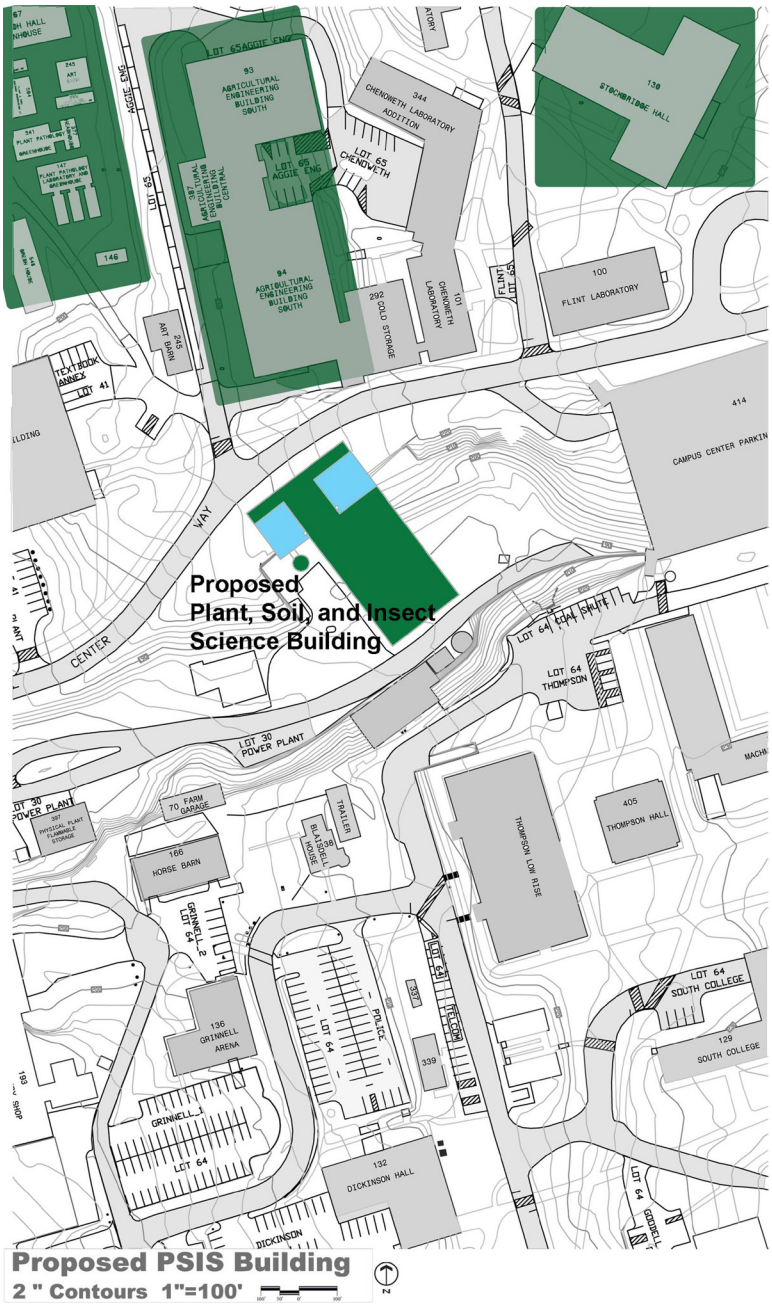

FIGURE 40: *The existing Power Plant is scheduled to be demolished in 2009.*

FIGURE 39: *Site of the proposed building. The green areas indicate other buildings in the area that are also in the College of Natural Resources and the Environment.*

there is an opportunity for it to contribute to a powerful overall green concept that connect the architecture of the building with the mission of the department that inhabits it.

Design Concept

The prospective building could be located on several open parcels on campus, and the design concept described below can be adapted to any building location. There is an exciting opportunity to site a new gateway building at the site of the former power plant on Campus Center Way, adjacent to the parking garage. This site is close to other buildings in the College of Natural Resources and the Environment, and it is also a premier site for visitors to the campus who enter via Campus Center Way. When the power plant is demolished, a similarly sized footprint can be used for the new PSIS building. There are currently three smoke stacks associated with the power plant that have become a well-known part of the UMA skyline. When the new PSIS building is constructed, one of the smoke stacks should be preserved and utilized as a green façade. Visitors to campus would be greeted by an ivy tower and a new building with vegetation cascading off the roof and green houses on the roof, glimmering in the sun.

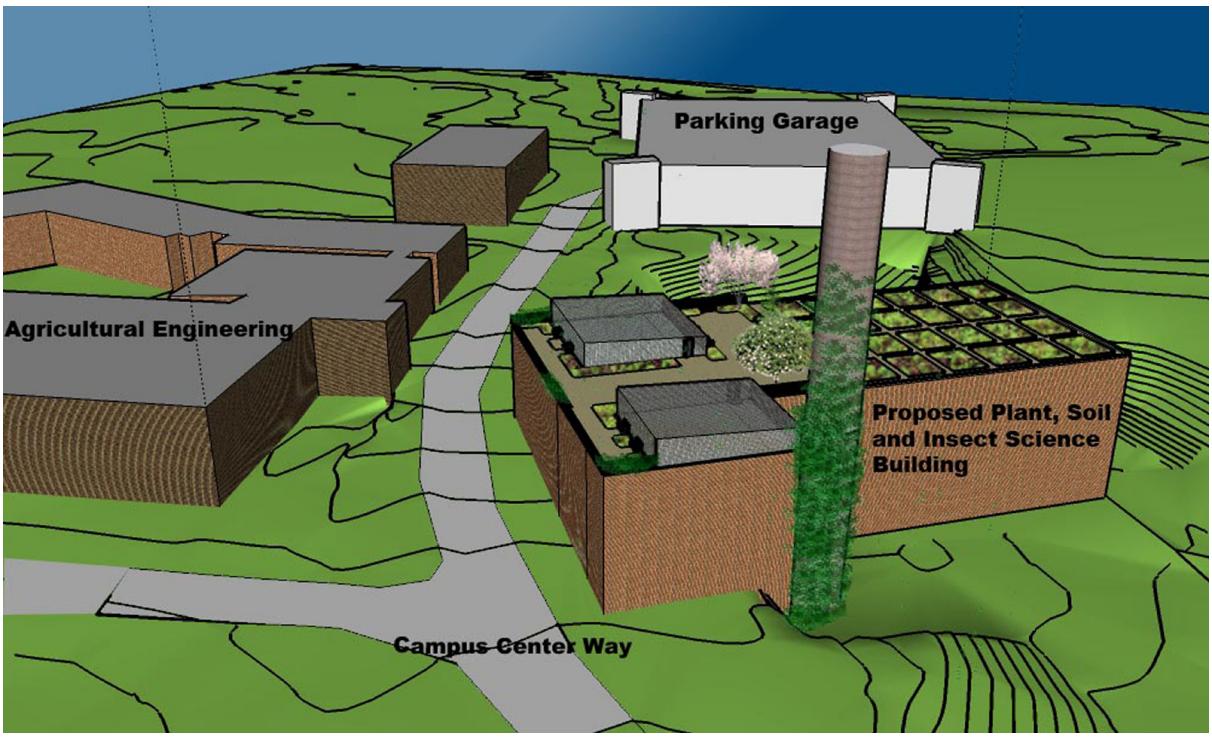

FIGURE 41: *3D model showing the location of the proposed building and green roof.*

The proposed PSIS green roof will have the following program elements:

- Flexible extensive green roof research area (since extensive green roofs are the most widely used, they are the most important type to research and understand better)
- Intensive insect garden area (butterflies, moths etc.)
- Intensive garden area for human enjoyment
- Small gathering space for faculty and student discussion, lunch, outdoor enjoyment
- Handicapped accessibility

The green roof can be reached via stairwells and an elevator through two green houses located on the roof. Upon entering the green roof, the user may visit the northern intensive garden that overlooks Campus Center Way. This area is home to shade tolerant species, benches, and climbing plants that climb from the planting beds over the railings. The plantings will be visible from the roadway and pathways below. There is another intensive garden area to the south of the green houses with more benches, small trees, and sun-loving plants. The intensive green roof area has between 12" and 24" of planting media which allows for a wide variety of perennials, shrubs, and small trees.

FIGURE 42: *The north facing balcony is visible from Campus Center Way.*

On the intensive portion of the roof, studies could be set up to look at green roofs as habitat for insects and birds since a wider variety of plants are possible. The intensive area would also serve a shared garden space for the PSIS department and the campus. Ample seating and open space can be used for both informal and formal gatherings as needed by the campus.

The extensive portion of the green roof is set up for research. According to Dr. Bradley Rowe, Assistant Professor of Horticulture at Michigan State University, who focuses on green roof technology, there are several desirable characteristics for an extensive research green roof including self-contained roof sections with their own drain and a method to measure the quantity of runoff (weir system, magnetic flowmeters), an electrical and water source, and a minimum of four plots for each variable being tested (via e-mail, 2008).

The proposed green roof has six rows with four plots in each row for a total of 24 plots. Each plot is 18'x14' (252 s.f.) and set up with its own drain with a flow meter that can measure stormwater runoff. These plots are larger than those used at Michigan State University and other research programs, but they can be subdivided depending on the goals of the research. The most important characteristic is that each plot is self-contained and has its own drain.

FIGURE 43: *A southern facing seating area uses the green house wall to create an warm, intimate space.*

The plots will also be set up to have three inches of planting media on grade with the flexibility to add three inches of additional media in a raised bed. Experiments can therefore be conducted with anywhere from 3-6” of planting media.

UMA recently instituted a professional master’s program in green building through the Building Materials and Wood Technology Department. Research and teaching about green roofs would complement this degree program along with the degree offerings of PSIS. The extensive green roof could be used for research on the stormwater management ability of green roofs by looking at variables such as type of planting medium, depth, and plant species. Information could be gathered to create accurate stormwater models for green roofs in New England’s climate. Different plant species could also be studied for their viability in green roof applications in New England. To this date, there has not been research on the viability of Massachusetts’s native species on green roofs. Researchers could examine evapotranspiration rates of different types of green roofs plants and set up experiments to evaluate the building level benefits such as reduced heating and cooling loads. Since there are soil scientists in the department, research could examine green roof planting media with a focus on using local and affordable materials while maintaining quality and consistency.

FIGURE 44: *An extensive green roof research area can be viewed from the intensive garden area .*

FIGURE 45: *Schematic planting plan of the proposed intensive and extensive research green roof.*

Planting Palette

The following plants were selected for the intensive areas of the green roof because they are either native to Massachusetts, attractive to insects, birds (and people), or well-suited to the conditions of a green roof. The plant species that can be used in an intensive roof garden are much broader than the choices for an extensive green roof. Since an intensive green roof more closely resembles a garden on the ground, there is not published information about the viability of different plants for intensive green roofs. In general, the plants should be able tolerate poor soil conditions and low water conditions. Wetland species, for example would not be a good choice for a green roof, while species known to thrive in alpine conditions would be a good choice. The planting scheme is divided into the following four areas:

Small Trees--Three small trees are planned for the green roof including two small flowering trees and a small evergreen. These trees were selected for multi-season, low growing habit, and adaptability to extreme conditions.

Zone A--Since this zone has a southern and/or western exposure, plants for this area include sun-loving shrubs and perennials.

Zone B-- This zone faces east and is moderately shaded. Shrubs and perennials for this area tolerate partial shade.

Zone C-- On the north side of the building, this zone also faces Campus Center Way. Plants in this area tolerate shady conditions and many will climb onto the railing and be visible from the road.

Existing Smoke Stack

Three varieties of climbing plants will green the façade of the smoke stack. Parthenocissus quinquefolia (Virginia creeper) and Hedera helix (English Ivy) will be planted on the ground adjacent to the preserved smoke stack. Over time these plants can reach heights in excess of 98 feet and require no additional support (Dunnett and Kingsbury, 2004). These plants are self-clingers that are able to attach to rough surfaces such as brick. Virginia creeper is deciduous and produces berries that are attractive to birds while English Ivy is an evergreen that will provide year-round interest.

Since the smoke stack will no longer be in use, it is also possible to suspend planter boxes from the top of the stack so that plants could also cascade downward. Species such as Campsis radicans (Common Trumpetcreeper) and Cotoneaster dammeri (Bearberry cotoneaster) would attract birds and insects and create a colorful show on the top of the smokestack.

Small Trees			
Botanical Name	*Common Name*	*Habit*	*Comment*
Magnolia stellata	Star Magnolia	15-20' tall	Showy spring flowers
Ilex penduculosa	Longstalk Holly	20-30' tall	Evergreen, showy berries
Cercis canadensis	Eastern Redbud	20-30' tall	Showy spring flowers
Zone A			
Spiraea tomentosa	Steeplebush	2' tall	Attractive to insects
Vaccinium angustifolium	Low bush blueberry	2' tall	Attractive to insects and birds
Aquilegia vulgaris	Columbine	36" tall	Attractive to insects and birds
Sedum 'herbstfreude'	Autumn Joy	24" tall	Fall flower, attractive to insects
Limomium platyphyllum	Sea lavender	24" tall	Mid-summer bloom,attractive to insects
Lupinus perennis	Wild Lupine	24" tall	Attractive to insects
Eragrostis spectabilis	Purple lovegrass	24" tall	Attracts rare insects, rare plant
Zone B			
Botanical Name	*Common Name*	*Habit*	*Comment*
Spiraea alba	White meadowsweet	2-6' tall	Attractive to insects and birds
Leucothoe racemosa	Sweetbells Leucothoe	4-6' tall	White flowers, nice fall color
Arctoctaphylos uva-ursi	Bearberry	4" tall	Evergreen, fall berries
Zone C			
Hydrangea anomala	Climbing hydrangea	Climber	Multi-season interest
Actinidia arguta	Bower Actinidia	Climber	Attractive to insects and birds
Osmunda claytoniana	Interrupted Fern	36" tall	Tolerates dry conditions,light green color
Hosta halycon	Hosta	14-16" tall	
Galium oderatum	Sweet Woodruff	18" tall	Fast growing
Heuchera micrantha	Coral Bells	30" tall	Attractive to bees

TABLE 6: *Selected planting list for intensive green roof.*

FIGURE 46: *Rendered plan of proposed intensive and extensive research green roof.*

V. CONCLUSION

As this project has shown, green roofs have the potential to provide environmental, financial, and educational benefits to the community. The amount of environmental benefits depends on the scale of green roof implementation. Green roofs should be evaluated as an option for all re-roofing projects on campus so that over time a significant portion of roofs on campus will be green. In short, if the building can support the extra weight of a green roof, a green roof should replace the existing system instead of a traditional roof. New construction on campus should incorporate green roofs as an integrated green design feature and maximize green roof visibility and accessibility.

By implementing green roofs on thirty-three buildings for a total area of thirteen acres of green roofs, the campus could prevent stormwater runoff equivalent to eight feet in depth over the area of a football field during a storm event of 2.7 inches. If green roofs were implemented on Marston Hall and Hampden Dining Commons, nine inches of water covering a football field would be prevented from running off for the same storm event. Green roofs also provide habitat for insects and birds and make a positive contribution to air quality.

Since green roofs extend the life of the waterproof membrane and reduce heating and cooling costs, they can save the university money in the long-term, especially if green roof costs go down and energy costs go up. As an institution, UMA must be concerned with the long-term costs to own and operate their facilities and should be willing to implement building techniques that have greater initial costs, but lower long-term costs.

UMA is dedicated to education and research and green roofs on campus help fulfill the mission of the university. Research about green buildings and sustainability is a growing area of interest for students and faculty, and several of the university's schools and departments could readily become involved in green roof research if research sites were built on campus. Both undergraduate and graduate students could be involved in research about green roofs—an exciting area of study because it is interdisciplinary, novel, and highly visible. Through a green roof research program, UMA could become a resource for the implementation of this building strategy in the northeast.

As an educational institution, UMA has the important role of demonstrating appropriate, innovative and sustainable solutions that mitigate the impact of buildings on the environment. More than 4,000 students graduate from UMA

each year, and green roofs in the core of campus are a highly visible example of sustainable practices that will influence and inform the next generation of citizens and professionals.

There is great potential for green roofs on the UMA campus, and the fact that over 180 buildings are owned by the same institution facilitates the rapid implementation of this technology. The building selection method described in this project gives the university a place to begin with green roofs. The schematic designs are intended to spark the interest of campus decision makers by showing the aesthetic benefits of green roofs on our buildings. And finally, a review of the current literature on green roofs shows that while we have much to learn about this exciting technology, we know enough to be sure that green roofs provide benefits, monetary and otherwise, that exceed their cost.

FIGURE 47: *California Academy of Sciences, San Francisco, California*

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APPENDIX A: Green roofs at colleges and universities

The following information was obtained from www.greenroofs.com, a website with a searchable registry of green roofs. Since green roof projects must be submitted to the site, there are green roof projects at educational institutions that might not be listed.

Calhoun School Green Roof Learning Center, New York, NY
Green roof Type: Semi-Intensive, Test/ Research
Roof Size: 2500 sq.ft.
Roof Slope: 1.25%
Access: Accessible

Carleton College Green Roof Project, Northfield, MN
Green roof Type: Extensive, Test/ Research
Roof Size: 666 sq.ft.
Roof Slope: 1.5%
Access: Accessible

Cornell University Dept. of Horticulture Ithaca, NY
Building Type: Educational
Green roof Type: Extensive
Roof Size: 120 sq.ft.
Roof Slope: 0%
Access: Accessible

Cornell University Dining Hall, Ithaca, NY
Green roof Type: Extensive
Roof Size: 10000 sq.ft.
Roof Slope: 1.5%
Access: Inaccessible

Duke Marine Laboratory Beaufort, NC
Green roof Type: Extensive
Roof Size: 2500 sq.ft.
Roof Slope: 1.5%
Access: Accessible

Durham College, Toronto, Ontario
Green roof Type: Extensive
Roof Size: 5000 sq.ft.
Roof Slope: 1.5%
Access: Inaccessible

Evergreen State College Olympia, WA
Green roof Type: Extensive
Roof Size: 24000 sq.ft.
Roof Slope: 1.25%
Access: Accessible

University of Georgia, Athens, GA
Green roof Type: Extensive, Test/ Research
Roof Size: 500 sq.ft.
Roof Slope: 1%
Access: Accessible

Harford Community College - Joppa Hall, Belair, MD
Green roof Type: Extensive
Roof Size: 3000 sq.ft.
Roof Slope: 1.5%
Access: Accessible

Harvard Graduate Student Housing, Cambridge, MA
Green roof Type: Extensive
Roof Size: 10000 sq.ft.
Roof Slope: 1.5%
Access: Accessible

University of Maryland Medical School, College Park, MD
Green roof Type: Extensive
Roof Size: 20000 sq.ft.
Roof Slope: 1.5%
Access: Inaccessible

Oberlin College, Cincinnati, OH
Green roof Type: Extensive, Test/ Research
Roof Size: 404 sq.ft.
Roof Slope: 1%
Access: Accessible

Pace University Brooklyn, NY
Green roof Type: Extensive
Roof Size: 30000 sq.ft.
Roof Slope: 1.5%
Access: Inaccessible

St. Louis Community College, Wildwood, MO
Green roof Type: Extensive
Roof Size: 73000 sq.ft.
Roof Slope: 1%
Access: Inaccessible

Swarthmore College, Swarthmore, PA
Green roof Type: Extensive
Roof Size: 900 sq.ft.
Roof Slope: 1.5%
Access: Accessible

Swarthmore College Residence Hall, Swarthmore, PA
Green roof Type: Extensive
Roof Size: 6500 sq.ft.
Roof Slope: 1.5%
Access: Inaccessible

University of Syracuse, Baker Lab Syracuse, NY
Green roof Type: Extensive
Roof Size: 7000 sq.ft.
Roof Slope: 1.5%
Access: Accessible

Temple University Ambler, PA
Green roof Type: Extensive
Roof Size: 4000 sq.ft.
Roof Slope: 1.5%
Access: Accessible

University of VA - Rouse Hall, Charlottesville, VA
Green roof Type: Extensive
Roof Size: 4900 sq.ft.
Roof Slope: 1.5%
Access: Inaccessible

University of Waterloo Waterloo, Ontario
Green roof Type: Extensive
Roof Size: 10000 sq.ft.
Roof Slope: 1.5%
Access: Accessible

Williams College, Williamstown, MA
Green roof Type: Extensive
Roof Size: 2500 sq.ft.
Roof Slope: 0%
Access: Inaccessible

University of Wisconsin-Milwaukee Great Lakes Water Institute, Milwaukee, WI
Green roof Type: Extensive & Intensive, Test/Research
Roof Size: 6480 sq.ft.
Roof Slope: 1.5%
Access: Accessible

APPENDIX B:

Green roofs examples from around the world.

AUGUSTENBORG BOTANICAL ROOF GARDEN 95,000 s.f.

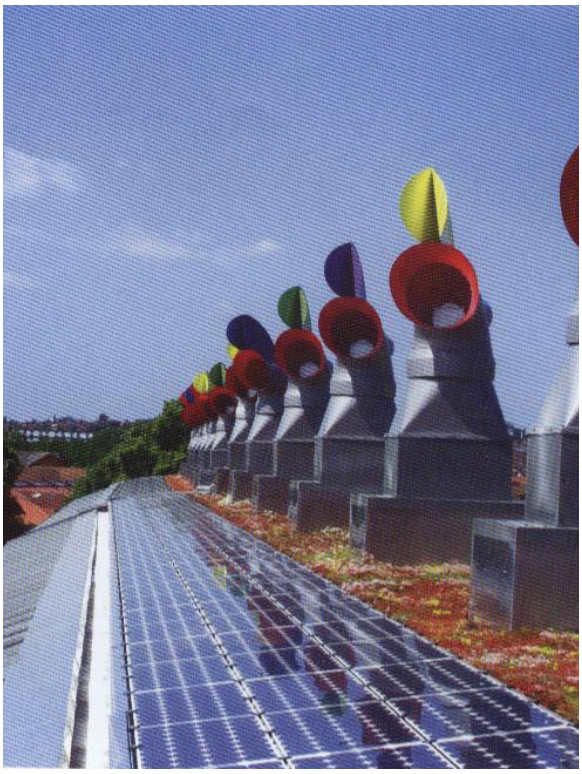
Malmo, Sweden Completed 2001

Largest green roof in Scandinavia. Used for research testing and short term demonstration gardens.

Source: Green Roofs: Ecological Design and Construction. Earth Pledge, 2005.

BEDDINGTON ZERO EMISSION DEVELOPMENT 333,518 s.f.

London, England Completed 2002



First large scale carbon neutral community has green roofs, passive solar, and photovoltaics. Each unit has its own garden space.

Source: Green Roofs: Ecological Design and Construction. Earth Pledge, 2005.

FORD ROUGE CENTER TRUCK PLANT 454,000 s.f

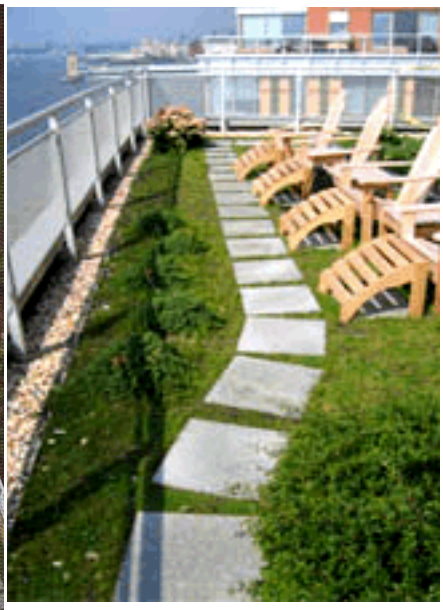
Dearborn, MI Completed 2003

The largest green roof in the world--10.4 acres. The planting media is only 2 inches deep, but it still retains about 50% of the annual rainfall. The green roof was installed using green roof mats which are rolled out like carpet.

Source: Green Roofs: Ecological Design and Construction. Earth Pledge, 2005.

THE SOLAIRE BUILDING 9,400 s.f.

New York, NY Completed 2003



This LEED Gold high-rise apartment building has two green roofs: an accessible intensive roof (shown in the photos) and an inaccessible extensive roof with only 3 " of planting media. Water not absorbed by the green roof is collected in a gray water system and used for irrigation when necessary. Bamboo and other lush plantings hide mechanical equipment.

Sources: Green Roofs: Ecological Design and Construction. Earth Pledge, 2005. http://www.greenroofs.com/projects/pview.php?id=464

PRIMARY AND SECONDARY SCHOOL 15,000 s.f.

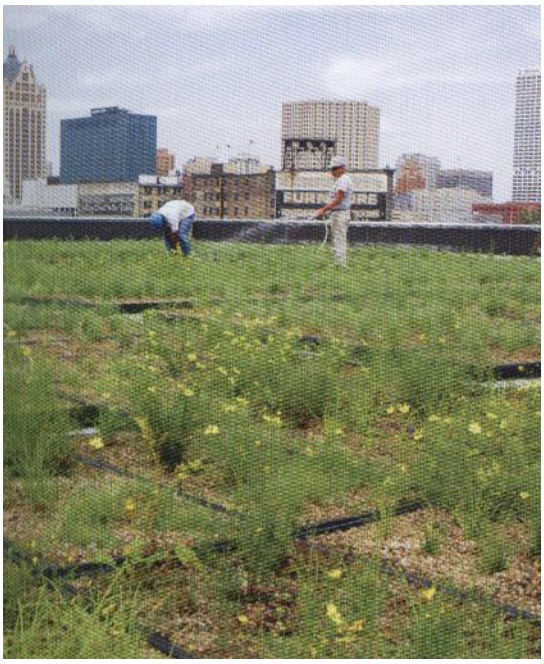
Unterensingen, Germany Completed 2002

The green roof and solar panels are part of the school's curriculum. Research shows that solar panels function better at lower temperatures, and green roofs help to keep temperatures down on roofs. The green roof plants also like the shade. The photo above shows an efficient way to get planing media on a roof with a blower truck.

Source: Green Roofs: Ecological Design and Construction. Earth Pledge, 2005.

MILWAUKEE METROPOLITAN SEWAGE DISTRICT 3,800 s.f.

Milwaukee, Wisconsin Completed 2003

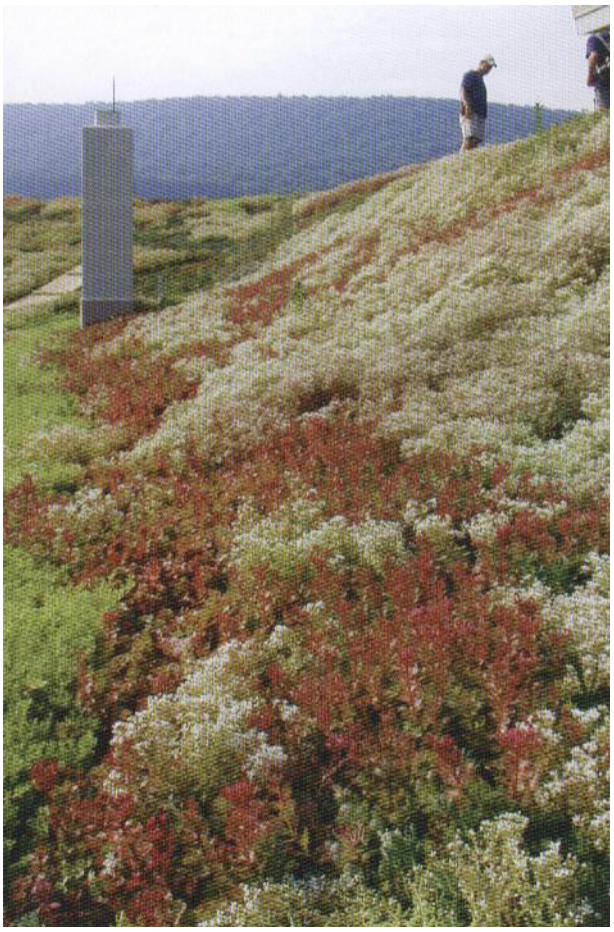


Milwaukee faces significant stormwater problems. The goal of this roof is to demonstrate the feasibility of green roofs as a best management practice for urban stormwater. This modular system is easy to install, flexible, and made from recycled plastics.

Source: Green Roofs: Ecological Design and Construction. Earth Pledge, 2005.

LIFE EXPRESSION CHIROPRACTIC CENTER 6,000 s.f.

Sugarloaf, PA Completed 2001

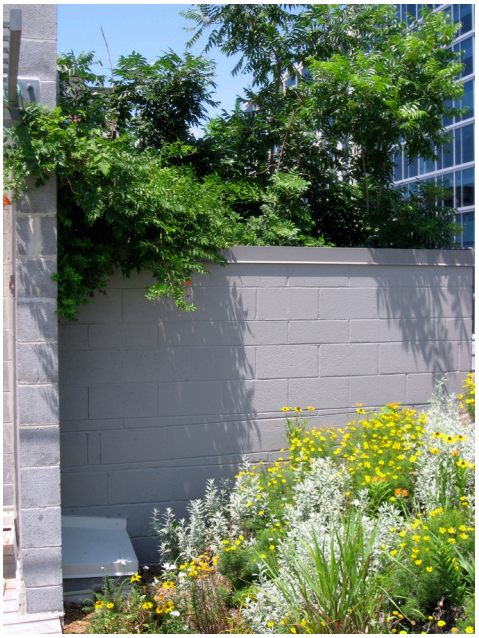


Green roofs can work on slopes such as this one of 30 degrees. While the plants were establishing, a photodegradable mesh helped to keep them in place.

Source: Green Roofs: Ecological Design and Construction. Earth Pledge, 2005.

AMERICAN SOCIETY OF LANDSCAPE ARCHITECTS HEADQUARTERS
3,300 s.f. Washington, D.C. Completed 2006

This green roof, designed by Michael Van Valkenburgh Associates, serves as a demonstration project for the environmental benefits of green roofs and the contribution of landscape architects to the field. Lightweight styrofoam waves cover mechanical equipment and the metal grating allows foot traffic with plantings underneath Stormwater retention, plant growth, temperature, and water quality are monitored.



Source: ASLA

APPENDIX C:
Protocol for testing and monitoring stormwater retention performance of green roofs as described by Carter and Rasmussen (2006).

1. Test plots chosen on existing flat roof that is accessible and highly visible (for public education).

2. Test plots isolated from the rest of roof using pressure treated lumber and additional waterproofing material.

3.Each test plot connected to its own drain.

4.Each drain disconnected and rerouted through two 120 cm by 30 cm by 30 cm stainless steel weirs. The weirs were located in the basement of the building directly below the test plots.

5.Druck PDCR 1800 pressure transducers were mounted to the base of each weir and linked to Campbell Scienitific CR23x Datalogger. Data logger was programmed to record data every 20 minutes during quiescent periods and every 30 seconds during storm events

6.Texas Electroniocs TR525M tipping bucket rain gauges located within test plots also linked to data logger.

7.Weir discharges calculated using the known orifice size and weir stage

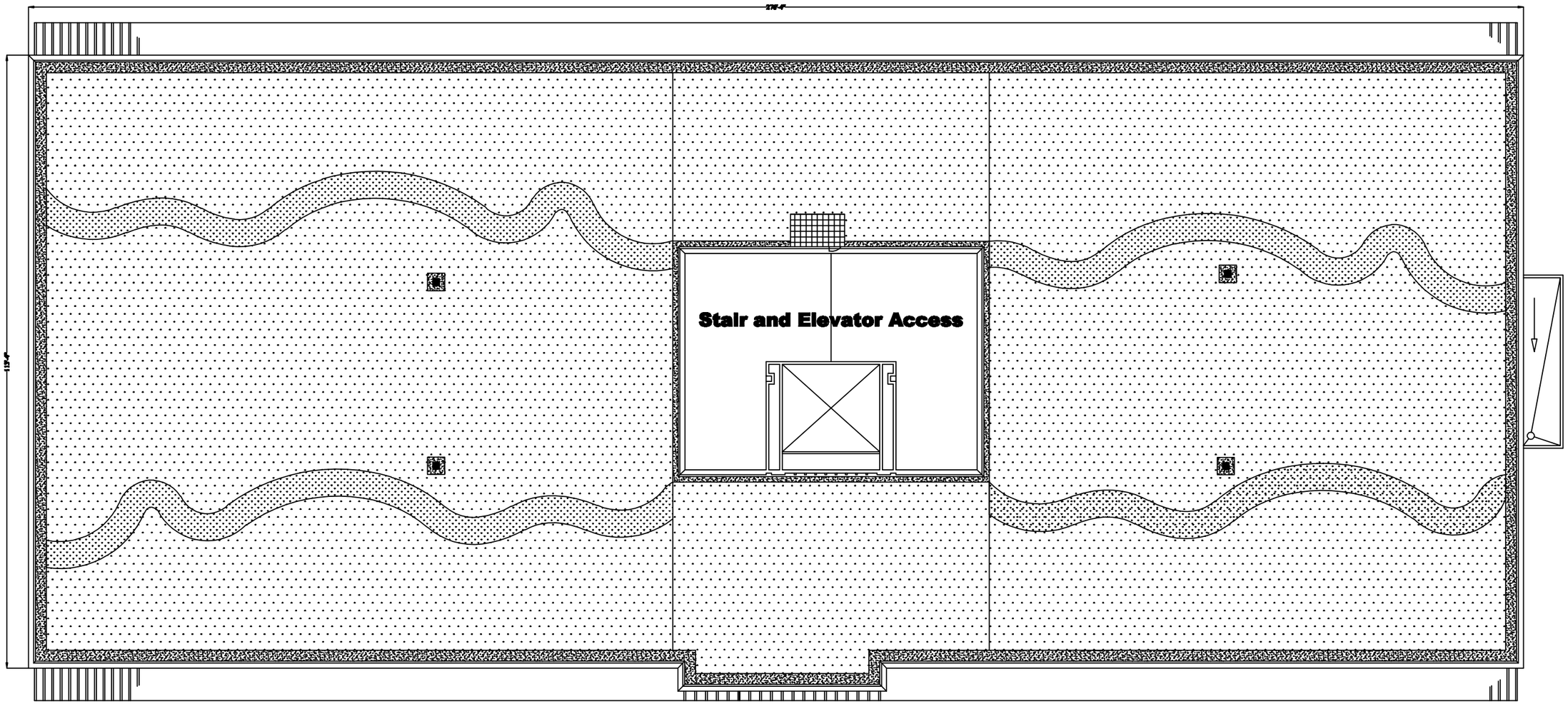
8.Storm events monitored for 13 month period

APPENDIX D: Priority Building Evaluation Table

Bldg#	Name	SF	Access	Railing	Condition	Viewing	# Views
293	Engineering Shops Building	13836	Yes	No	Good White	Lib/Led/Conte	3
91	Gunness Laboratory	20494	Yes	Low wall	Fair	Marston/Led/Conte	3
296	Holdsworth Hall	15457	Yes	Low Wall	Fair	Lib/Led/Conte	3
412	Lederle (Low Rise)		Yes	Low Wall	Under const.	Lib/Led/Conte	3
92	Marston Hall	53949	Yes	Low Wall	Fair	Lib/Led/Conte	3
120	Paige Laboratory	7669	Yes	Low Wall	Poor	Lib/Led/Conte	3
415	Tobin Hall		Yes 3 Tiers	Med Wall	Gravel Many tubes	Lib/Southwest?	3
399	Berkshire Dining Hall (SW)	28164	Yes	Low wall	Good	Towers	5+
382	Hampden Dining Hall (SW)	30857	Yes	Low wall	Poor	All towers, roadway	5+
357	Hampshire Dining Hall (SW)	26225	Yes	Low wall	Good	Towers	5+
546	PVTA Bus Facility Building	46397	Yes	Low wall	Good	Lib/Led/Conte	3
657	Engineering Laboratory II	21832	Yes	Med Wall	Good	Lib/Led/Conte	3

APPENDIX E: Inventory of required roof maintenance according to IFP Sightlines Facilities Audit.

Priority A	Priority B	Priority C
W.E. DuBois	Dickinson	Admissions Bldg.
New Africa House	Chadborne	Hills House
Goodell Addition	East Experiment Station	Isenberg SOM
University Apartments	Greenough	Mahar
Baker	Knowlton	Arnold
Lincoln Apartments #3	Van Meter	Alfond
Parking Garage Tunnel	Hamlin	Eng. and Comp. Sci.
Stadium	Lewis	Hicks
Flint	Munson	Knowles
Hatch	Munson Annex	Middlesex
Bodwitch	Tahtcher	Physical Plant and Addi-tion
Hampshire House	Agricultural Eng. Cent	University Health Serv. and Addition
Hasbrook Addition	Goessman	Mather
Marcus Hall	Brown	Grinnell
Totman	Cashin	Hicks
Bartlett	Dickinson	Mullins
Cold Storage	Field House	Hadley Farm
Morrill I-IV	Grayson	Boyden
Lincoln Apartments # 5	McNamara	Gunness
Lincoln Apartments # 1	Lincoln Apartments # 2	Herter
University Apts. Garage	Johnson House	Holdsworth
Enigneering Shops	Agriculturan Eng/ North	Whitmore
Lincoln Campus Center	Agricultural Eng/ South	Lincoln Apartments # 10
Draper Annex	Conte	Berkshire House
Marston Hall	PVTA Buidlng	Hasbrook
Admissions Building	Bodwitch Greenhouse	Furcolo
Student Union	Fine Arts Center	Thompson
Worcester D.C. Addition	Wilder Hall	Auxillary Services
Hampden D.C.	Hampshire D.C.	Paige Lab
West Experiment Station		Tobin
Crampton House		
Goodell		
Butterfield		
John Quincy		
Draper Hall		
Agricultral Eng. Central		
Machmer		



3" Extensive Green Roof System (See Planting Zone Details)

3" Extensive Green Roof System with White Flowers (5' wide)

Lightweight Aggregate (1.5' width to edge of parapet wall)

Lightweight Pavers

Hampden Dining Commons
3" Extensive Green Roof Plan

Issue Date: May 2008

Building No: 382

GRAPHIC SCALE
(IN FEET)
20 0 10 20 40

N

Planting Palette

Hampden (Southwest)

3 inch planting media depth

Sedum varieties for year-round interest with a focus on spring and fall bloomers.

Source: Green Roof Plants (2006) by E.C. and L.L.Snodgrass and greenroofplants.com (Emory Knoll Farm)

SPRING

Sedum hybridum var. 'Czar's Gold'
Yellow flowers
Green foliage
Good color for winter interest.

Allium oreophilum
Purple flowers
Green foliage
Usually planted as bulb

Sedum ternatum
White flowers
green foliage
Needs protection from full sun.

SUMMER

Sedum spurium var. 'Fuldaglut
Pink flowers
Green to red foliage
Foliage turns red in fall/ winter. Very tough plant.

Sedum sexangulare
Yellow flowers
Green foliage
Foliage turns russet in winter.
Highly adaptable plant.

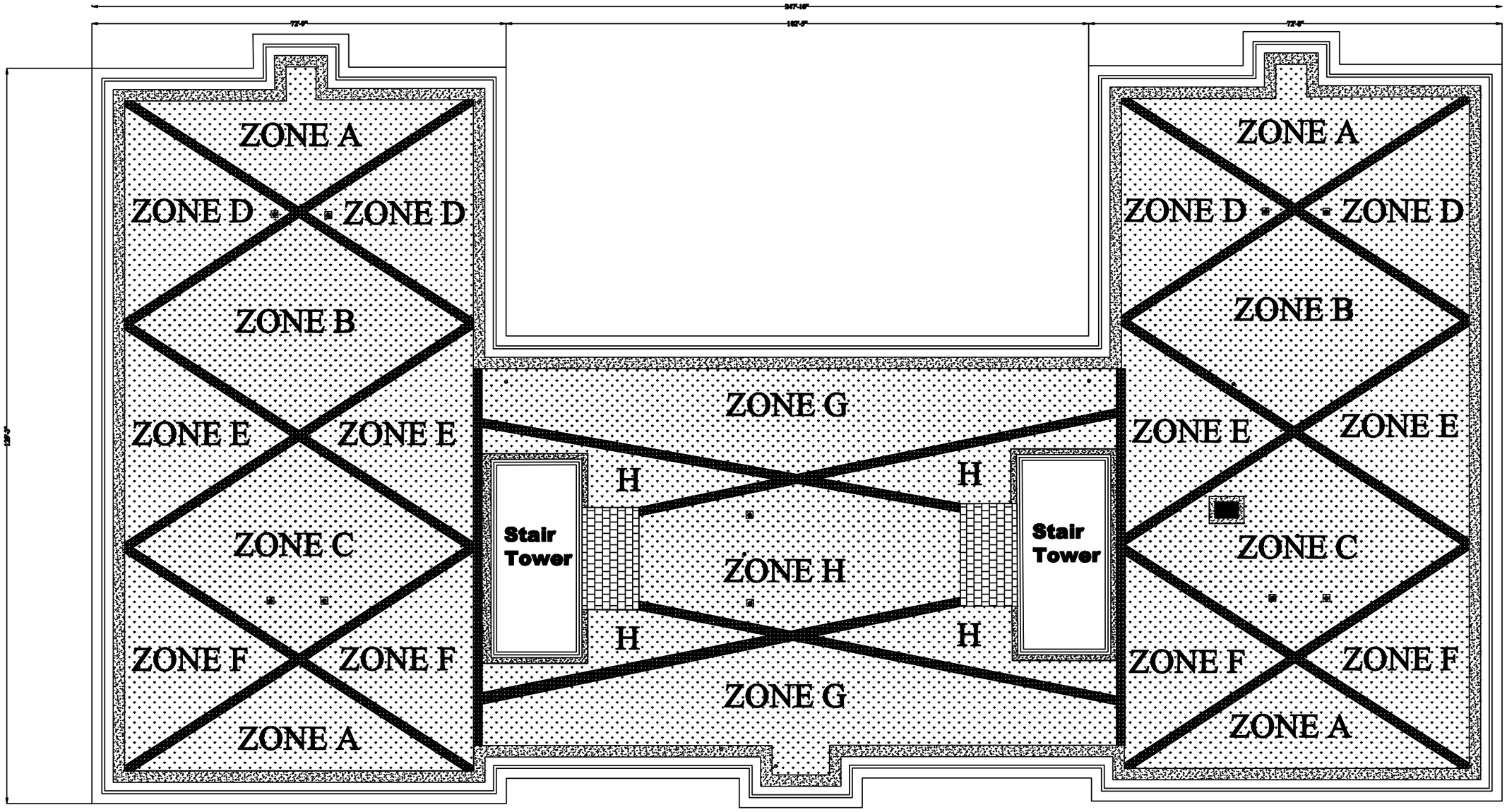
Sedum kamtschaticum
Yellow flowers
Green foliage
Very drought tolerant.

FALL

Sedum stefco
White flowers
Green/red foliage
Vivid winter color

Sedum telephioides
White flowers
Blue-green foliage

Sedum spurium var. 'White Form
White flowers
Green foliage



6" Extensive Green Roof System (See Planting Zone Details)

Lightweight Aggregate with edging (1.5' wide)

Lightweight Aggregate (1.5' width to edge of parapet wall)

Lightweight Pavers

Marston Hall
6" Extensive Green Roof Plan

May 2008

Building No:92

GRAPHIC SCALE
(IN FEET)
20 0 10 20 40

N

Planting Palette

Marston Hall

6 inch planting media depth

Sedum varieties for year-round interest with accent plants suitable for deeper planting media and a nod to one of Frank Waugh's favorites: aster.

Source: Green Roof Plants (2006) by E.C. and L.L.Snodgrass and greenroofplants.com (Emory Knoll Farm)

SPRING

Sedum hybridum var. 'Czar's Gold'
Yellow flowers
Green foliage
Good color for winter interest.

Phlox subulata
Purple flowers
Green foliage
Early season bloomer.

Aster alpinus
Purple flowers
green foliage
Showy flower

SUMMER

Sedum spurium var. 'Fuldaglut
Pink flowers
Green to red foliage
Foliage turns red in fall/ winter. Very tough plant.

Arenaria montana
White flowers
Green foliage
Grows in mounds

Artemesia ludoviciana
Yellow flowers
Gray foliage
Grows up to 22 inches

FALL

Sedum stefco
White flowers
Green/red foliage
Vivid winter color

Aster oblongifolius
Blue-purple flowers
Green foliage
Aromatic and showy

Galium verum
Yellow flowers
Green foliage
Blooms late spring to early fall.
Good plant for habitat creation (moths).