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Title: Green Roofs: Potential at LANL

Author(s): Elena M. Pacheco

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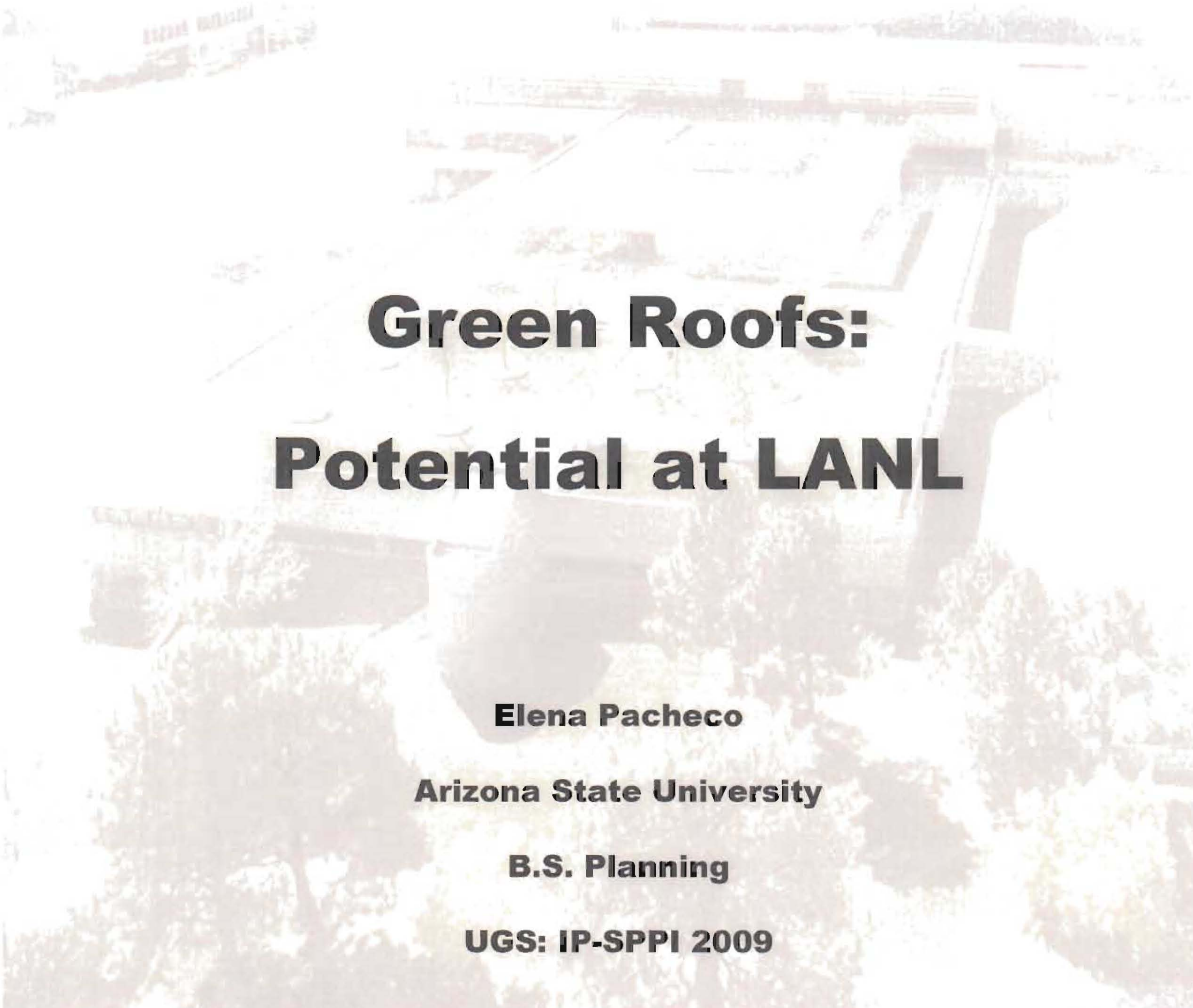

Green Roofs:

Potential at LANL

Elena Pacheco

Arizona State University

B.S. Planning

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Contents

Executive Summary

Green roofs, roof systems that support vegetation, are rapidly becoming one of the most popular sustainable methods to combat urban environmental problems in North America. An extensive list of literature has been published in the past three decades recording the ecological benefits of green roofs; and now those benefits have been measured in enumerated data as a means to analyze the costs and returns of green roof technology. Most recently several studies have made substantial progress quantifying the monetary savings associated with storm water mitigation, the lessoning of the Urban Heat Island, and reduction of building cooling demands due to the implementation of green roof systems.

Like any natural vegetation, a green roof is capable of absorbing the precipitation that falls on it. This capability has shown to significantly decrease the amount of storm water runoff produced by buildings as well as slow the rate at which runoff is dispensed. As a result of this reduction in volume and velocity, storm drains and sewage systems are relieved of any excess stress they might experience in a storm. For many municipalities and private building owners, any increase in storm water mitigation can result in major tax incentives and revenue that does not have to be spent on extra water treatments.

Along with absorption of water, vegetation on green roofs is also capable of transpiration, the process by which moisture is evaporated into the air to cool ambient temperatures. This natural process aims to minimize the Urban Heat Island Effect, a phenomenon brought on by the dark and paved surfaces that increases air temperatures in urban cores. As the sun

distributes solar radiation over a city's area, dark surfaces such as bitumen rooftops absorb solar rays and their heat. That heat is later released during the evening hours and the ambient temperatures do not cool as they normally would, creating an island of constant heat. Such excessively high temperatures induce heat strokes, heat exhaustion, and pollution that can agitate the respiratory system.

The most significant savings associated with green roofs is in the reduction of cooling demands due to the green roof's thermal mass and their insulating properties. Unlike a conventional roof system, a green roof does not absorb solar radiation and transfer that heat into the interior of a building. Instead the vegetation acts as a shade barrier and stabilizes the roof temperature so that interior temperatures remain comfortable for the occupants. Consequently there is less of a demand for air conditioning, and thus less money spent on energy.

At LANL the potential of green roof systems has already been realized with the construction of the accessible green roof on the Otowi building. To further explore the possibilities and prospective benefits of green roofs though, the initial capital costs must be invested. Three buildings, TA-03-1698, TA-03-0502, and TA-53-0031 have all been identified as sound candidates for a green roof retrofit project. It is recommended that LANL proceed with further analysis of these projects and implementation of the green roofs. Furthermore, it is recommended that an urban forestry program be initiated to provide supplemental support to the environmental goals of green roofs.

The obstacles barring green roof construction are most often budgetary and structural concerns. Given proper resources, however, the engineers and design professionals at LANL would surely succeed in the proper implementation of green roof systems so as to optimize their ecological and monetary benefits for the entire organization.

Introduction

The Los Alamos National Laboratory has quite often been noted for its achievement in innovative and cutting edge technologies. From the first atomic bomb to the world's fastest super computer, LANL has been home to projects that have not only benefitted the state of New Mexico, but the entire world. In the midst of a new social paradigm, one where the world is beginning to pay more attention to growing populations, decreasing natural resources, and a changing climate, LANL has been attempting to address some of these problems with continuing research on today's technologies that may help improve the standard of living for the global population. One of these technologies is the utilization of green roof or eco-roof systems. These systems support the growth of vegetation on the rooftops of buildings with an aim of achieving different goals unique to that location. Already, the Otowi building at LANL's TA-03 supports a green roof that is accessible to the building's occupants as seen in Figure 1. Specific case studies around the world, including most recently Chicago, Seattle, Portland, and Toronto will be included in this paper as well to provide examples of different strategies used to install, construct, and research green roofs.

Figure 1: Green roof at Otowi building

The purpose of this paper will be to present and analyze the attributes of green roof systems so as to determine their potential use, if any, at LANL. While green roofs have been commonplace throughout Europe for the last few decades, North America is just beginning its research and experimentation with the systems. Should LANL decide to begin experimenting with its own green roofs, either retrofitted on the current facilities and buildings or added into the design of new buildings, there are both costs and benefits to take into consideration. The following information will attempt to assess those costs and benefits specific to LANL.

What is a Green Roof?

As defined by Steven Peck, a well-known champion of the green roof industry, "A green roof is a green space created by adding layers of growing medium and plants on top of a traditional roofing system" (Peck 1). This basic definition can then, of course, be realized in countless design schemes for an innumerable amount of purposes. Though some die-hard advocates insist on specifically calling green roofs by that name, many titles can be used to refer to similar systems—eco-roofs, rooftop gardens, or even living roofs. What is important to mention, however, is the point that green roofs do not merely refer to roofs that are colored green or even roofs that are designed to ensure less energy consumption. The term "green roof" is specific to any roof that supports living vegetation and its preceding design scheme.

Installing such a system is hardly a new idea blossomed out of 21st century thinking, however. An ancient wonder of the world, the Hanging Gardens of Babylon were built by King Nebuchadnezzar II around 600 B.C. in a series of terraces with lush trees, vines and other vegetation (Wark 2).

Figure 2: French cottage in Nova Scotia (Peck)

Sod roofs were developed in Scandinavia to provide extra insulation against the harsh Nordic winters. This idea was later adopted by the French colonists of Canada to combat similar conditions in Nova Scotia and Newfoundland as seen in Figure 2. A visionary architect, Le Corbusier incorporated roof gardens into his five elements of modern architecture. In his famous Ville Savoy, Le Corbusier enhanced the accessible roof with native French shrubs and other vegetation to compliment the modernist architecture. The famous Frank Lloyd Wright often tried to incorporate rooftop gardens in many of his projects, most notably Midway Gardens that was built in the beginning of the 20th century (Peck 2).

Beginning in the 1980s, Germany led the way in the green roof industry when it established legislation and several incentives for the development and construction of green roofs in order to deal with excessive stress on sewage systems from heavy rainfall. Data shows that there is approximately 150 million square feet green roof installed every year in the country (Taber). To date, the German FLL Guideline for Planning, Execution, and Upkeep of Green Roof Sites

(***F**orschungsgesellschaft **L**andschaftsentwicklung **L**andschaftsbau e.V.*) is the only reliable source for building codes and design specifications concerning green roofs. While the American Standards and Testing Materials (ASTM), is thought to be in the beginning stages of drafting some sort of green roof standard to be issued in North America, the engineering and design of green roofs is still largely in the hands of individual clients and companies on this continent (FLL). As climate change and environmental reform begin to gain more public and political leverage, however, green roof installation trends have been increasing all around the world including North American cities such as Chicago, Toronto, and Portland. With growing interest and research, standard industry practices are surely going to be agreed upon in the near future.

Already agreed upon amongst the entire green roof industry, are the two different types of green roof systems—Extensive and Intensive green roofs. Though built with the same components, these two systems have unique requirements that result in unique costs and benefits as well. While the extensive green roof system is characterized by its lighter weight and shallower growing medium, an intensive system can support vegetation with much deeper roots because of its added depth in growing medium. Consequently, an intensive green roof will add a significantly greater amount of weight to be supported by the roof and underlying building structure. Extensive green roofs will also require far less maintenance compared to an intensive system. Both systems can be constructed out of several layers that are secured to the rooftop or in a more flexible modular form that contains square units of vegetation and growing medium. These construction and implementation types will be further described and analyzed in the proceeding sections.

Components

No matter which type of green roof system is selected for implementation, there are basic components that must be included so that the green roof performs at optimal capacity, with as few problems as possible. Several companies sell these components separately, or only have individual parts of the green roof system. In past applications, however, cities and corporations that have incorporated green roofs into the design of their buildings have found it more cost effective and less time consuming to use companies that engineer and install complete systems with all components included (Peck 13).

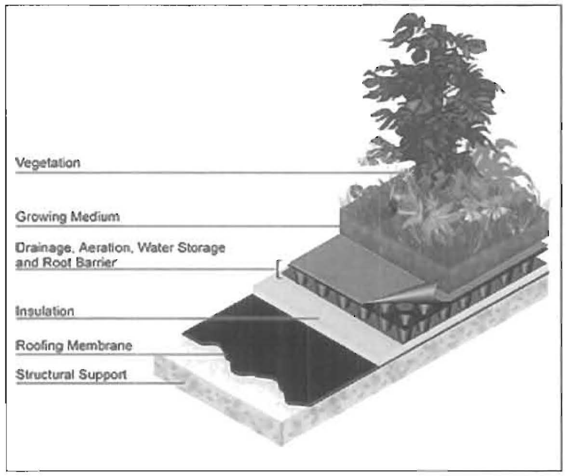


Figure 3: Green Roof components (Toronto)

Roofing Membrane

Most often built from the bottom up, the roofing membrane is always the first component to be installed when adding a green roof to a building's roof top. This roof membrane is often cited as the most important component of a green roof because of its crucial role in protecting the roof from water damage. In fact, many manufacturers will not provide a warranty of a green roof system if a new membrane is not applied (Peck 12). Though different manufacturers may have unique compositions of materials in their membranes, the waterproofing technology is often composed of hot, rubberized asphalt which should have self-sealing capabilities (Green Roof Assemblies). Some new roof membranes, specifically developed for green roof applications, also contain root-deterring chemicals to ensure that any bitumen or organic-material included in the membrane is not susceptible to root penetration (Peck 13).

Insulation

Many studies have proven the effectiveness of green roofs and their top components to provide ample thermal insulation for buildings on their own. This is especially true in warmer climates. However, where the average temperatures are colder or perhaps more extreme in the winter time, building codes will usually specify required levels of added insulation (Wark 5). With temperatures that regularly average in the low 20s in winter months, insulation on LANL buildings is undoubtedly still necessary.

Protection Layer

As mentioned previously, a roof membrane needs protection particularly from root penetration as well as from damage during roof installation. According to *Green Roof Specifications and Standards* by Christopher and Wendy Wark, the materials by which a protective layer can be constructed and applied vary from project to project depending on the design parameters: "The protective layer can be a slab of light weight concrete, sheet of rigid insulation, thick plastic sheet,

Figure 4: Installation of protective layer in Fairbanks, Alaska (CCHRC)

copper foil, or a combination of these…" (Wark 5). In Fairbanks, Alaska the Cold Climate Housing Research (CCHRC) building's roof incorporated a green roof. The construction of the roof was photographed and documented, including the application of a rubberized protective membrane as seen in Figure 4.

Drainage Layer

Located between the planting medium and the roof membrane, the drainage component accomplishes a number of essential objectives for a green roof system. Designed in a shape very similar to that of an egg carton like Hydrotech USA's patented Gardendrain, the drainage layer allows water to flow to the building's drainage system from any point of the green roof (Wark 5). Commonly made of recycled polyethylene panels, the retention cups and drainage channels provide aeration of the system and evaporation of excess water into the above soil and vegetation layers (Green Roof Assemblies). Applicable for both extensive and intensive green roofs, the drainage cups are easily manipulated to fit the design's requirements so as not to interfere with any of the roof's other entities such as drains or flashing (Green Roof Assemblies).

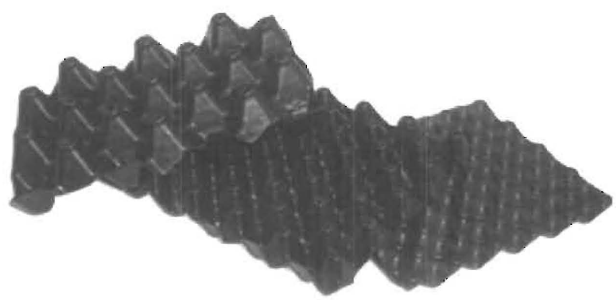


Figure 5: Hydrotech USA Gardendrain (Hydrotech)

Fabric Filter

Yet another layer intended to protect the roof from root penetration is the filter layer most often made of non-woven geo-textile material (Wark 5).

The fabric is rolled over the entire drainage layer and is often times treated with some type of root inhibitor like copper or a mild herbicide. The filter can also reduce erosion of the planting media (Green Roof Assemblies).

Planting/Growing Medium

Critical to any growing life form, the soil of a green roof is actually not soil but an engineered ‘recipe’ of minerals that produce a synthetic clay, known as growing media that is far less dense and more absorbent than natural soil minerals (Wark 4). This engineered element relieves the roof structure of unnecessary stress from an abundance of planting soil while still providing the above vegetation with essential nutrients and water and oxygen (Green Roof Assemblies). It should be noted that soil is still used for high-maintenance roof gardens, but the engineered clay produced by many companies has proven to be just as effective in supplying a stable structure for the anchorage of roots for any plant (Green Roof Assemblies).

Figure 6: Growing medium in Fairbanks, Alaska (CCHRC)

Vegetation

The component that almost literally defines a green roof, the vegetation selected to plant on a roof is entirely subjective to the client and design of the system. Because green roofs are often built with a shallow soil layer, only 4cm in many extensive systems, the plants must be able to thrive in such conditions and often with little to no maintenance (Wark 2).

Sedum, which is a succulent ground cover, is a very popular choice due to its low maintenance and natural drought resistance. The characteristic of drought resistance would be especially important to consider here in the Southwest United States where annual rainfall rarely reaches even 10 in. /yr. (Annual). Native plants would undoubtedly be the optimal choice in any consideration, but as seen in Figures 7 through Figure 9, the possibilities concerning vegetation on a green roof are limitless

Figure 7: Extensive grass roof in Amersfort, Netherlands (Peck)

Figure 8: Wildflower roof in Fairbanks, Alaska

Figure 9: Intensive green roof system in Salt Lake City, Utah (Roofscapes)

Extensive and Intensive Green Roof Systems

Extensive Green Roofs

Characterized by their lower capital costs, low weight, and minimal maintenance, extensive green roof systems are ideal for an existing building that cannot carry a large additional dead load or a project with more conservative budget (Peck 4). Contrary to the more extravagant intensive roof, the typical extensive system's soil depth ranges from 5-15cm and has a weight increase that ranges from 16 lbs/sq. ft. to roughly 35lbs/sq. ft. when completely saturated (Peck 4). With the selection of hardy plants that require little to no maintenance, extensive roofs are commonly implemented to reduce both storm water runoff and the "urban heat island effect", as opposed to providing an additional recreational or therapeutic relief like an intensive roof (Green Roof Assemblies). Extensive roofs are generally not designed for public access. Their purpose is most often a practical one rather such as thermal energy savings. Despite the lack of public access, an attribute many corporations and municipalities value, the ecological benefits prove to be a significant incentive for developers and designers to accommodate the added capital cost of an extensive green roof into their budgets.

Intensive Green Roofs

With a growing medium ranging from 20-60cm, intensive green roof systems allow for the growth of a more diverse plant life including trees and larger shrub bushes (Peck 5). When municipalities and developers intend on providing an active space on their roofs that include rooftop gardens, intensive green roof systems provide a plethora of opportunity for creativity. Hospitals around the globe also have begun looking at the benefits of horticulture therapy and physical therapy associated with intensive rooftop gardens. This added depth and denser vegetation as seen in Figure 10 heightens the effects of an extensive green roof, providing increased thermal energy savings and even more reduction in the "urban heat island effect". Additionally, the amount of storm water mitigated also significantly increases with more vegetation. Because of the added growing medium and larger vegetation, however, it is critical to take into account the added weight an intensive green roof will distribute over a roof.

Figure 10: Intensive green roof system in Chicago, IL

The saturated weight increase of an intensive system ranges from 60-200 lbs/ sq. ft. in some cases (Peck 5). Such a considerable weight increase nearly eliminates the possibility for retrofitting a roof with an intensive green roof system. Hence, the cost to retrofit any LANL building with an intensive green roof simply would not be justified by the end results.

Comparisons of Green Roof Systems

Table 1: Advantages adn disadvantages outline by Steven Peck (Peck)

Table 1: Comparison of Extension and Intensive Green Roof Systems	
EXTENSIVE GREEN ROOF	INTENSIVE GREEN ROOF
• Thin growing medium; little or no irrigation; stressful conditions for plants; low plant diversity.	• Deep soil; irrigation system; more favorable conditions for plants; high plant diversity; often accessible.
Advantages: • Lightweight; roof generally does not require reinforcement. • Suitable for large areas. • Duitable for roofs with 0 - 30° (slope). • Low maintenance and long life. • Often no need for irrigation and specialized drainage systems. • Less technical expertise needed. • Often suitable for retrofit projects. • Can leave vegetation to grow spontaneously. • Relatively inexpensive. • Looks more natural. • Easier for planning authority to demand as a condition of planning approvals.	**Advantages:** • Greater diversity of plants and habitats. • Good insulation properties. • Can simulate a wildlife garden on the ground. • Can be made very attractive visually. • Often accessible, with more diverse utilization of the roof. i.e. for recreation, growing food, as open space. • More energy efficiency and storm water retention capability. • Longer membrane life.
Disadvantages: • Less energy efficiency and storm water retention benefits. • More limited choice of plants. • Usually no access for recreation or other uses. • Unattractive to some, especially in winter.	**Disadvantages:** • Greater weight loading on roof. • Need for irrigation and drainage systems requiring energy, water, materials. • Higher capital & maintenance costs. • More complex systems and expertise.

In Steven Peck's *Design Guidelines for Green Roofs,* the advantages and disadvantages of extensive and intensive green roofs systems are compared (Table 1). These basic attributes are imperative to know and understand when taking the design of a green roof into consideration. For LANL, including green roofs in the design of new buildings or retrofitting present facilities with green roofs should be a cooperative initiative between engineers, architects, and site planners. Utilizing the capabilities of these professionals and the resources from other relevant groups would provide LANL and the community of Los Alamos a much more meaningful and efficient project that produces more significant results. Understanding the below comparisons of the two types of green roof systems is the first benchmark in the realization of that process.

Modular (Container) Green Roofs

In addition to the two basic types of green roof systems, there exists a third, sub category system which is referred to as a modular green roof system. This system, though not unique in its aim, offers a different method by which to install a green roof. In a paper written by Linda Velazquez, an ASLA associate, modular green roof technology is defined and compared to those of the other two systems: " With a modular system, the drainage, soil substrate or media, and the plants are self-

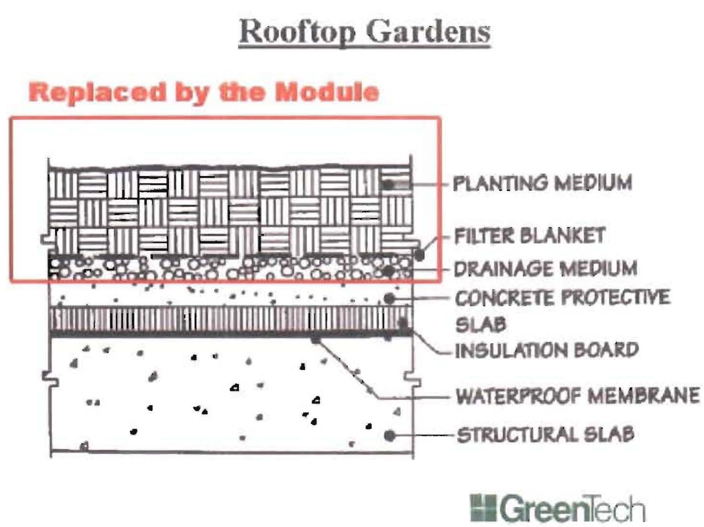


Figure 11: Modular green roof system (Velasquez)

contained within a lightweight high-density polyethylene (HDPE) module of varying dimensions" (Velazquez 1). Thus, in essence, what the modular system aims to do is to replace the top three components of a green roof system (Figure 9) and relieve the roof of excessive weight brought on by the blanket membranes and layers seen in the alternate green roof systems. When put together in a continuous pattern, the modules allow for satisfactory drainage and roof protection comparable to any other green roof (Velazquez 1)

The simplicity and flexibility of a modular system is ideal for retrofitting an existing building with a green roof. While the containers or fabric modules can support both extensive and intensive designs, there are some companies that offer especially light weight modules that when fully saturated only adds an extra 11-13 lbs/sq. ft. to the roof's dead load (Green Grid). Because structural concerns are the most pressing in any retrofit project this fact should not be overlooked. Green Grid and GreenTech are two prominent companies known in the modular green roof industry. These two companies, presented by Velazquez, offered very similar services including off-site planting and efficient installation; in one case GreenTech installed an entire system on top of a family's condominium in just two days (Velazquez 9).

Another company called Green Paks, provides the same services, but with a different type of module. While companies like Green Grid and GreenTech install modules that are made out of plastic trays, Green Paks' modules are made of, "high-density polyethylene knit fabric" (International). Each pack covers roughly 4.5 sq. ft. and has a saturated weight range of 11-17 lbs/sq. ft. Once positioned on the roof, openings are cut in the fabric and eventually the vegetation will grow and cover the unit in which it is growing out of (Greenpaks). Both types of modules are seen below.

Figure 12: Green Pak modular system (GreenPaks)

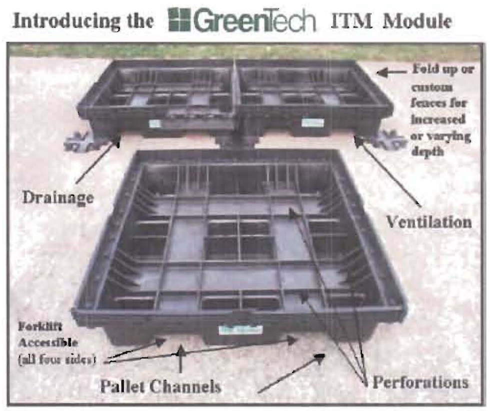


Figure 13: Green Tech modular system (GreenTech)

Potential for LANL

Should green roofs become a reality for LANL, retrofitting older buildings would certainly be taken into consideration. In those circumstances modular technology is seemingly the one of the most pragmatic solutions. With the least amount of added weight, and likely the least expensive choice, modular systems could efficiently be installed.

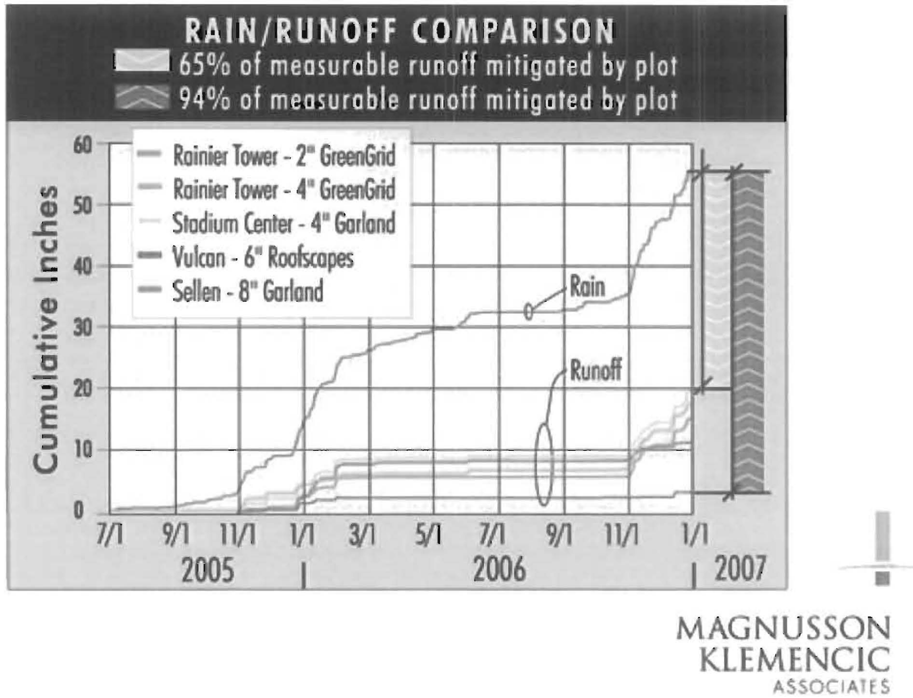
Benefits of Green Roof Systems

Roof Protection and Extended Lifespan

Green roofs, with whatever system is implemented, are terrific barriers for conventional roofs, preventing UV radiation exposure and temperature fluctuations. As a result of this innate protective attribute, the life of the roof on which the vegetation rests is significantly extended. A case study done concerning the DfES building in Sheffield, U.K. noted the damage a maintenance worker observed on the building's conventional roof: "…when visiting the roof, it is easy to see deterioration of the asphalt around the parapet edges, where it is exposed to the sun" (Munby 27). This kind of decline is not uncommon in even the best quality conventional roofs. Subsequently, the roofs of older buildings must then be replaced and refurbished, usually causing many inconveniences to the tenants of that building and a costly expenditure to the landlord. Green roofs relieve this stress by extending the life-span of a roof by up to an extra 30 years in some experts' estimations ("Cost benefit"). Even more conservative estimates suggest that a green roof will easily double the lifespan of a roof membrane, which directly affects the operational costs for the better, and will result in a reduced life-cycle cost compared to that of a conventional roof system (Peck 6). Research done by Beatrice Munby at the University of Sheffield presents clear evidence of this fact: "In Germany, it is estimated that the cost to install a green roof and maintain it over 40 years is about 43 Euros (£29) per m^2, compared to a possible saving of 70 Euros (£48) per m^2 from the reduced maintenance, energy saving, city water fee and increased life" (Herman: 2003 in Munby 39).

Storm water Mitigation

An important benefit of green roofs that would be especially relevant to the Los Alamos area and LANL is the ability to reduce the volume of storm water runoff and delay the rate at which runoff is produced. When increasingly large amounts of rain or snowmelt run off buildings, storm drains can be put under excessive stress and sewage systems can overflow. As evidence is published by more and more research groups around the country, green roofs are proving to be an extremely effective strategy to resolve these issues. With monsoon seasons that can produce fairly severe storms at times and winters that result in feet of snow in any given year, storm water runoff should certainly be given substantial thought considering how many buildings LANL has under its management.



Graph 1: Seattle runoff mitigation (Gangnes)

In Seattle, Washington, a place synonymous with grey skies and rainy days, a research study was conducted under the supervision of Drew Gangnes that evaluated the effectiveness of green roofs to mitigate storm water runoff. After two years of observations the final report showed very impressive results: "…despite record breaking rainfall events, cumulative measurable runoff mitigation ranged from 65% to 94%!" (Gangnes 1). Data collected off of five different green roofs, each differing in either soil depth or maker, showed that even with an average Seattle precipitation cycle (55.4 inches of cumulative rainfall) the green roofs performed at an optimal level (Graph 1).

The scientists also recorded the amount of reduction in peak flow that the green roofs on the five Seattle buildings achieved during one of the most volatile storms of the winter on December 14, 2006. Gangnes cited the table of percentages seen in Table 2 that this particular storm, "...was more intense than the standard Seattle design storms used to size detention tanks" (Gangnes 2). Perhaps the most notable performance was the Vulcan plot that retained nearly all of the rainfall of the November month (Table 2). The volume-reduction trends of this report were repeated in another Northwest city. Portland, Oregon conducted a storm water retention study and discovered that were half the buildings in downtown Portland to have green roofs, it is estimated that 66 million gallons of water would be retained on a yearly basis; that would relieve the city's storm sewage system of 17 million gallons in combined sewage overflows (Peck 9).

RUNOFF MITIGATION SUMMARY NOVEMBER 2006		
Plot	Volume Reduction (total for month)	Peak Flow Reduction (for worst storm)
Rainier Tower 2"	81%	27%
Rainier Tower 4"	47%	21%
Stadium Center 4"	52%	6%
Vulcan 6"	99%	79%
Sellen 8"	56%	52%

Table 2: Runoff reduction in Seattle, WA (Gangnes)

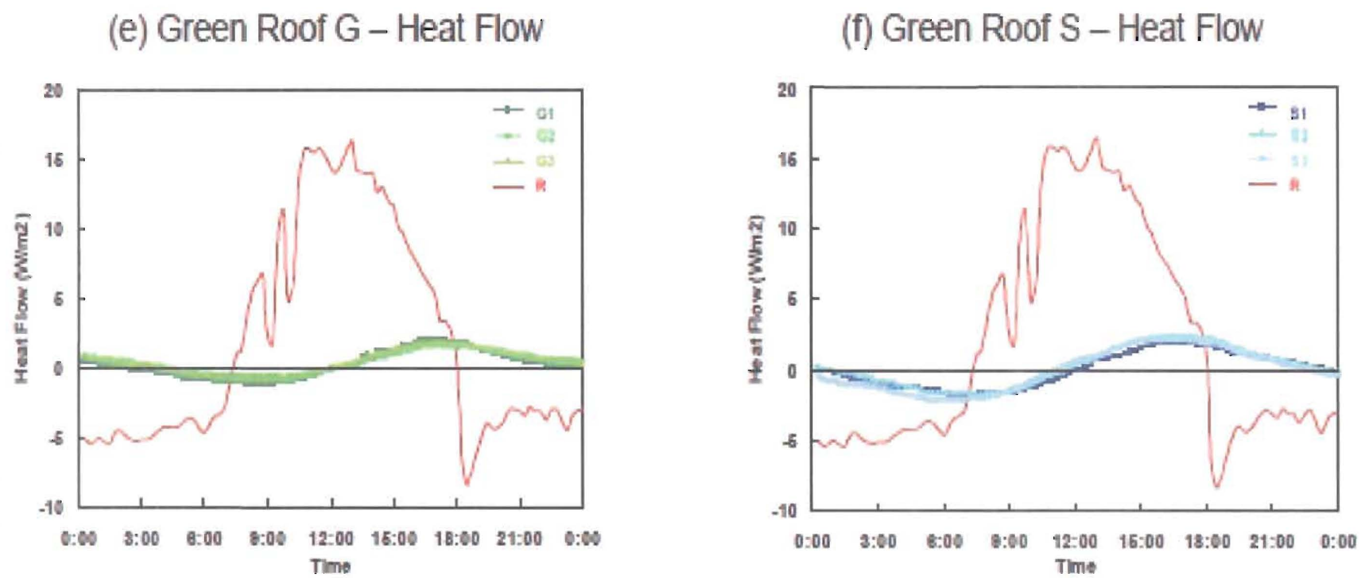
Energy Savings

Perhaps the most tangible and concrete benefit of green roofs concerns the energy they have proven to save for their selected buildings. This attribute is an especially important benefit to take into consideration for large organizations like LANL because heating and cooling bills can become a large expenditure in the budget with so many facilities. Published every year by Energy Information Administration, the Annual Energy Review recorded that in 2008 alone, the United States' buildings accounted for 70% of the total energy consumed in the entire nation (Energy Information Administration). Decreasing that statistic should be a primary concern for any organization, and green roofs are a valid strategy to combat the problem.

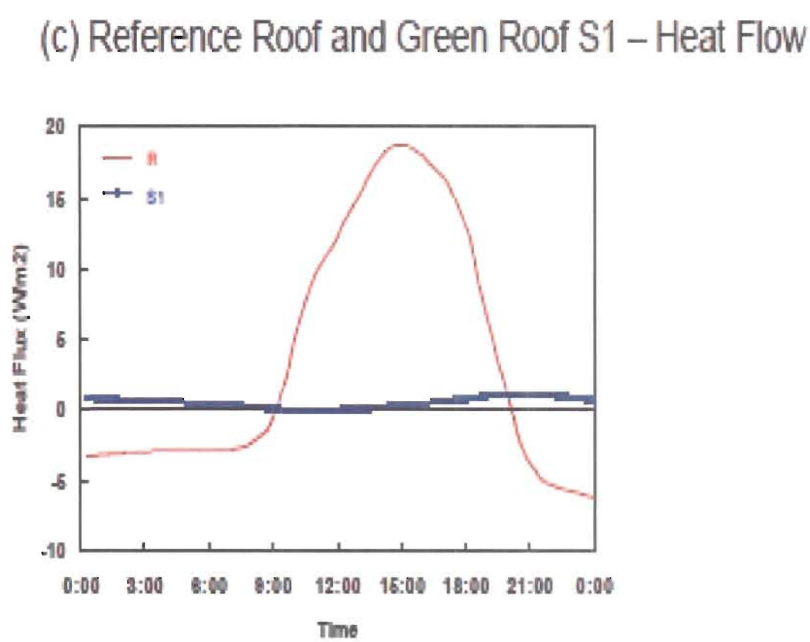
A report published by the Institute for Research in Construction, documents the results of a comprehensive study done to calculate the thermal performance of extensive green roofs. The findings of the report show that green roofs significantly reduce heat flow in and out of the roof, lower the roof's temperature, and delay the peak temperature of the roof all of which reduce the demand for space conditioning in an occupied building (Liu 8).

One of the locations studied by the institute was Eastview Neighborhood Community Centre in Toronto, Canada. The community center was constructed with a conventional roofing system above a maintenance room, and two different green roofs above their gymnasium (Green Roof S and Green Roof G). The conventional system at Eastview was used as the reference roof in the study. In the summer months it was easy to compare the heat flow of the reference roof and the green roofs under investigation: "Heat started to enter through the Reference Roof not long after sunrise (around 06:00)...and continued until the evening shortly before sunset (around 18:00), at which time heat gain changed to heat loss" (Liu 3). The report continues by describing the heat flow activity on the green roofs, which contrasted drastically to the conventional roof system: "Note that both Green Roofs lost heat in the morning and did not start to gain heat until the afternoon, after the peak solar intensity has been reached (Liu 3). This information was recorded with heat flow profiles seen below.

Graph 2: Heat flow profiles of Eastview Community Center green roofs (Liu)



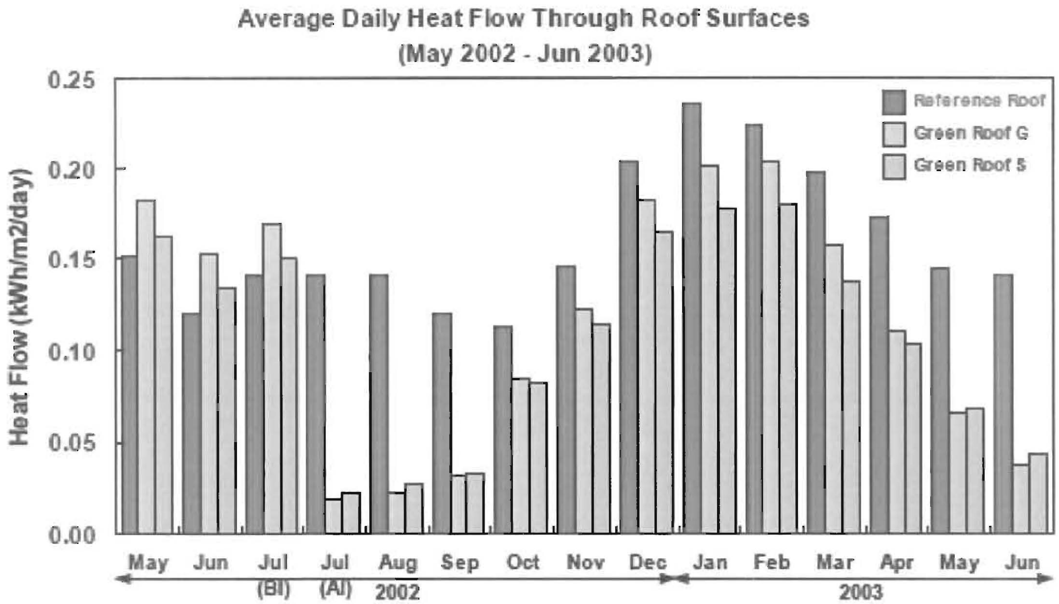
It is obvious from the graphs that both Green Roof G and Green Roof S, represented by the green or blue lines, significantly outperformed the reference roof, represented by the red line. The same clear profile was recorded at Toronto City Hall, represented by the third heat profile of Green Roof S1 seen in Graph 3. Liu notes that, "Green Roof S1 significantly reduced the heat flow through the roofing systems to a peak intensity of 1W/m²" (Liu 4). As a result of the green



Graph 3: Heat profile on Toronto City Hall (Liu)

roofs' effective insulating properties and thermal mass, the building experienced less of a heat flux, thus reducing the cooling demand, which saves energy and money.

The heat flow was also recorded through the winter months, though the results yielded less of an impact concerning heat loss: "The Green Roofs consistently reduced the average daily heat flow through the roof throughout the year—more in the summer (70-90%) and less in the winter (10-30%)" (Liu 5). The average daily heat flow was monitored and recorded in the first year of the experiment for the Reference Roof, Green Roof G, which had 100 mm of lightweight growing medium, and Green Roof S, which had 75mm of growing medium (See Graph 4: Liu 2, 7). Obviously, the higher the average daily heat flow, the greater the demand for space conditioning becomes in order to stabilize the indoor temperature for the occupants, and as a result, the money spent on energy increases. There is not one month where the traditional roofing system outperforms either green roof.



Graph 4: Average daily heat flows of green roofs and reference roof at Eastview Community Center. Note that the green roofs were installed late July 2002 (BI = before installation AI = after installation)

Reducing the Urban Heat Island Effect

The urban heat island effect is a phenomenon that has been of increasing concern throughout North America's cities in recent years. As more land is built-over and paved, the temperature in a city core begins to become considerably warmer than that of the surrounding countryside. The reflective properties of bitumen roofs and asphalt actually absorb the solar radiation of the sun and then radiate it later at night, making the temperature of a city center very warm, sometimes rising 22° F above the temperature of the hinterlands (Basic Information). This overheating of urban and suburban areas has many negative consequences including the increased demand for cooling energy and excessive emissions from buildings into the atmosphere. As a result of the higher localized temperatures, plants and trees can be damaged and their ability to photosynthesize can be dramatically reduced, thus only fueling the vicious cycle already in play.

Such artificially high temperatures, as seen in Figure 14, also induce more pollution, which then increases the likelihood of respiratory problems for people and heat-related incidents such as heat stroke or heat exhaustion. In the United states alone, there is an average of 1,000 deaths due to heat related problems annually (Peck: 2009).

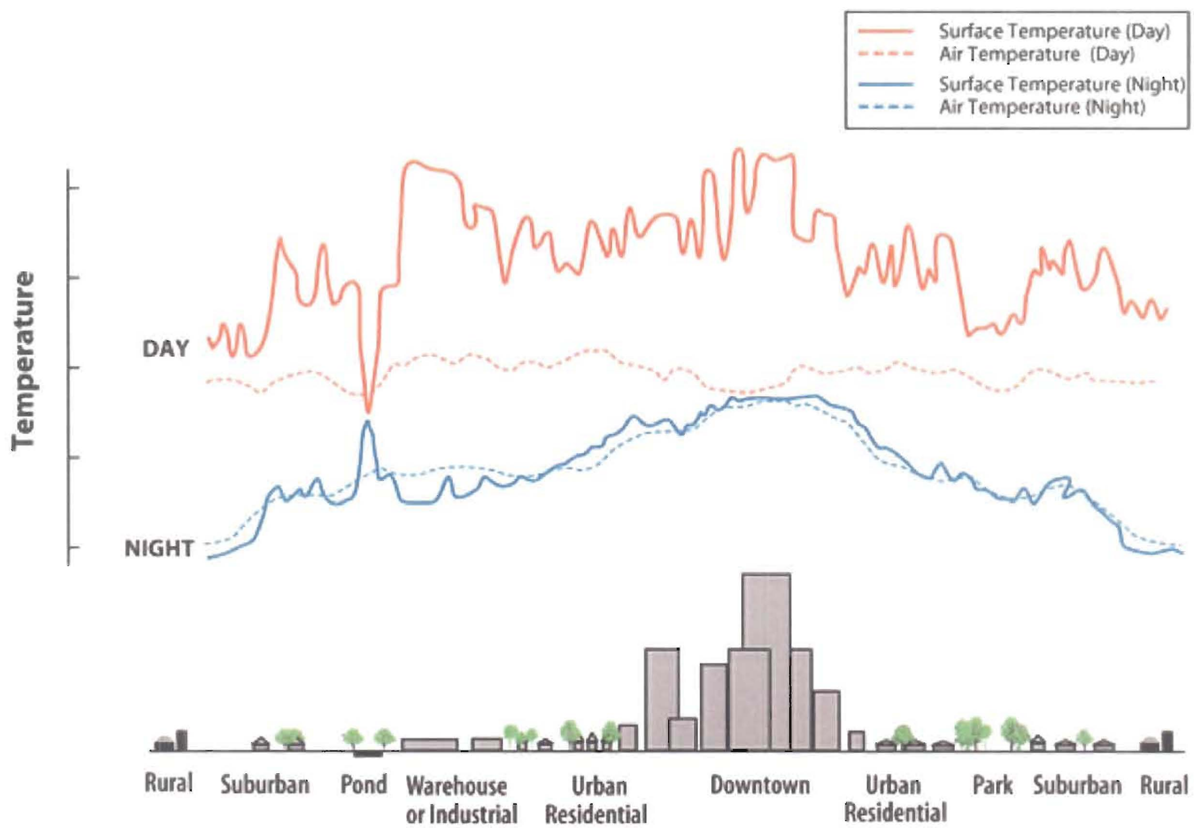


Figure 14: Urban Heat Island profile (EPA)

Vegetative roofs intercept the solar radiation that would otherwise be absorbed by a conventional roof. This shade barrier provides for a much cooler and stable roof temperature and a more comfortable microclimate for the occupants of the building. Figure 15 displays the amount of heat and energy emitted from or absorbed in a building's roof when it is constructed in the conventional design and the benefits of adding a green roof.

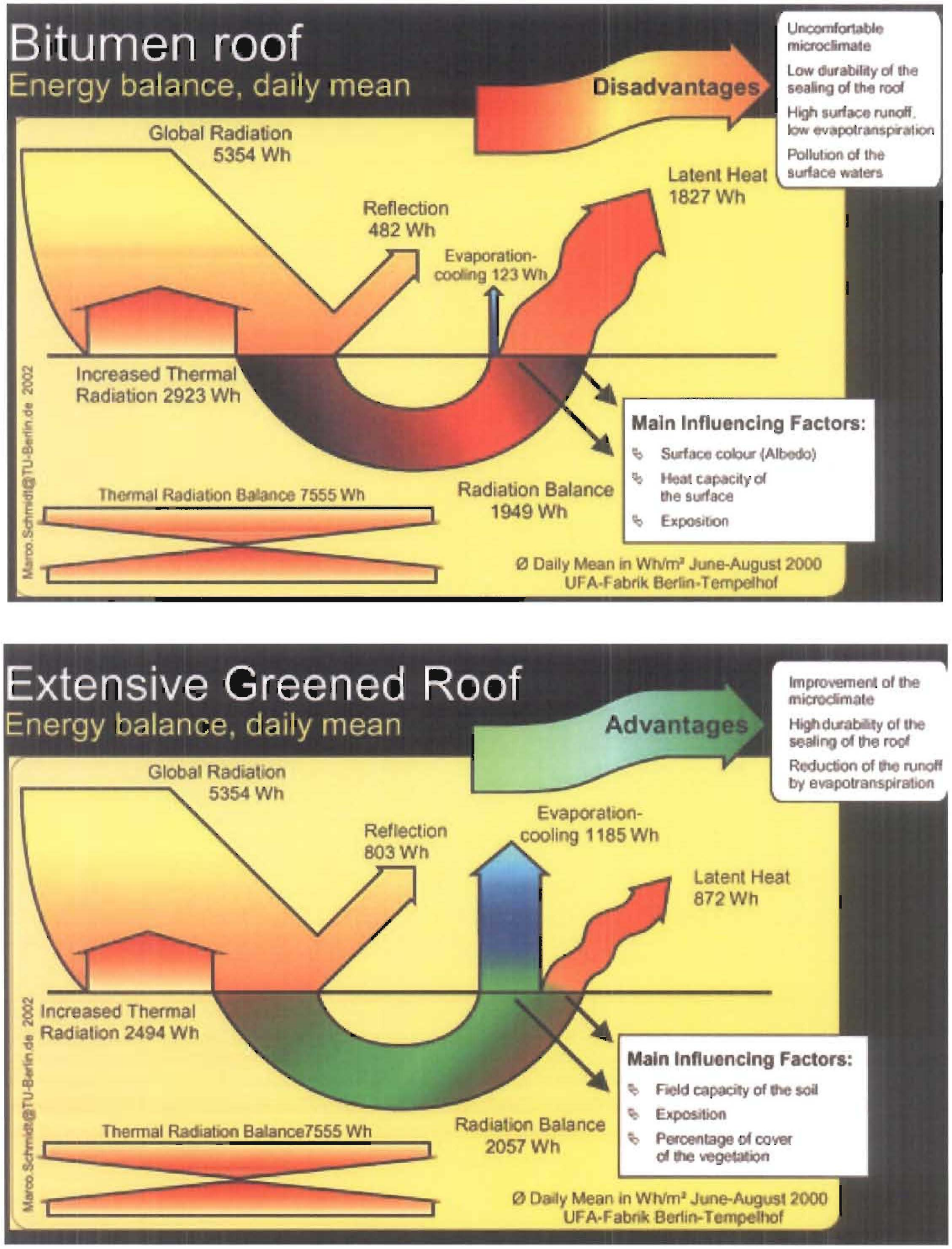


Figure 15: Bitumen and Green Roof daily energy balance (Greenroof.com)

Along with being a shade barrier, the evapotranspiration process plants naturally go through also sustains a cooler air temperature. Evapotranspiration begins when plant leaves “transpire” water through the stomata, which are similar to a person’s pores. The water on the leaves then evaporates into the atmosphere attracting heat molecules and cooling the air (ASLA). As previously stated, cooler air temperatures then result in less energy used in warmer months by buildings. With a bitumen roof, however, such a process is impossible because the average asphalt roof normally absorbs the solar radiation it receives and transfers that heat to the interior of the building. In the city of Chicago, the urban heat island was a primary factor motivating the city’s officials to instigate their green roof initiatives. Steven Peck noted a simulation conducted by ASHRAE that said, “...that every one degree in Fahrenheit decrease in ambient air temperature results in a 1.2% drop in cooling energy use” (Peck 9). With that calculation it was subsequently suggested that if in the next ten years or more the city of Chicago retrofitted every building with a green roof, the yielded savings would be $100,000,000 annually from reduced cooling demands in the city (Peck 9). Reducing the urban heat island effect does not merely result in a healthier environment, but a healthier budget as well.

In congruence with its green roof efforts, Chicago as well as other cities such as Phoenix have initiated an entire urban forest program. The projects make efforts to plant trees in parking lots and along thoroughfares so that the Urban Heat Island is

Figure 16: Urban forestry (U.S. Forest Service)

reduced in all areas surrounding the urban core. Shading the bitumen surfaces of the city and increasing the surface area of vegetation has proven to be an excellent strategy to combat these ecological problems while also beautifying the cities which would normally be characterized as grey and unsightly. Green roofs, as sound evidence in Chicago proves, serve as an excellent complimentary tool to an urban forest program.

Costs of Green Roofs

Capital Costs

While the benefits of green roof installation are plenty and well worth any extra effort to many developers and designers, there are costs involved with the green roof construction process which should be taken into consideration. One of the primary apprehensions that the green roof industry is challenged with is the capital costs of a green roof. It is difficult to gauge the exact costs of green roofs due to their ability to uniquely fit certain needs and requirements. In several case studies that were retrofitting green roofs to existing buildings, the ranges of initial cost were said to be anywhere from 20-180% more expensive than the installation of a new conventional roof (Munby 39). With such a large range, and seemingly a lack of precedence, many individuals are reluctant to invest in a green roof for their building.

Developers are especially cynical of green roof designs. While analyzing the perceived barriers of green roofs in her report, Beatrice Munby noted, "A survey of various professionals carried out in London showed that…92% of developers agreed that 'the physical structure of many buildings prevents the establishment of green roofs'" (Munby 40).

This sentiment seems to be the case in Toronto currently, now that the government has passed a bill mandating that all new buildings 2000 m² or greater in size be fitted with green roofs that cover 20-60% of the roof depending on several factors (Belford). Many developers like Scott Addison, who works for a major Toronto real estate broker, say that such demands create an even greater burden on an industry already facing overwhelming economic stresses: "On the office and industrial side you already have tenants pressing for lower rents; construction costs are rising; there is fierce competition for development in surrounding municipalities" (Addison in Belford). The difficulties of overcoming budget problems can sometimes be the only thing barring a project from including a green roof in the design so it is imperative that every aspect is reviewed and all stakeholders be informed before implementation. The city of Toronto made a conscious effort to include the opinions of all parties potentially affected by the ordinance as seen in Figure 17.

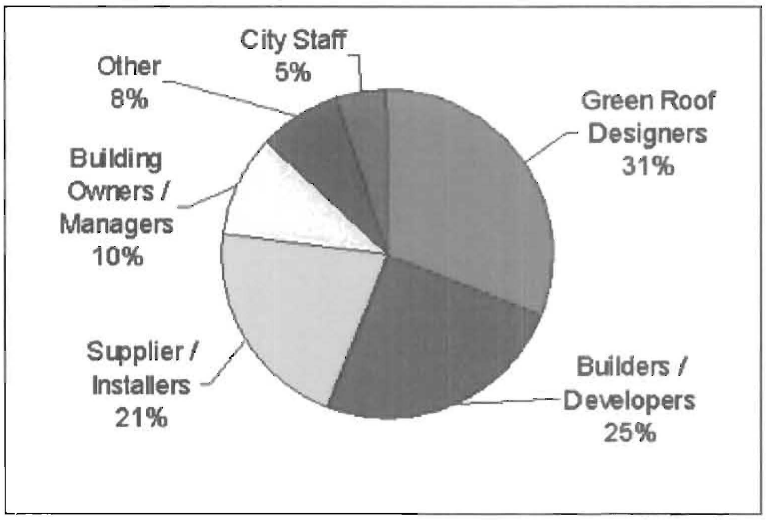


Figure 17: Industry participants in Toronto policy making process (Toronto)

Steven Peck has identified some major components that all green roofs share to try and create a range of costs that a client might expect when considering an extensive or intensive green roof (Table 3 & Table 4).

4.1 INACCESSIBLE EXTENSIVE GREEN ROOF

(Costs assume an existing building with sufficient loading capacity; roof hatch and ladder access only. The larger the green roof, the cheaper the cost on a square metre basis.)

Component		Cost	Notes & Variables
a)	Design & Specifications	5% - 10% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
b)	Project Administration & Site Review	2.5% - 5% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
c)	Re-roofing with root-repelling membrane	$100.00 - $160.00 per sm. ($10.00 - $15.00 per sf.)	Cost factors include type of existing roofing to be removed, type of new roofing system to be installed, ease of roof access, and nature of flashing required.
d)	Green Roof System (curbing, drainage layer, filter cloth, and growing medium).	$55.00 - $110.00 per sm. ($5.00 - $10.00 per sf.)	Cost factors include type and depth of growing medium, type of curbing, and size of project.
e)	Plants	$11.00 - $32.00 per sm. ($1.00 - $3.00 per sf.)	Cost factors include time of year, type of plant, and size of plant - seed, plug, or pot.
f)	Installation / Labour	$32.00 - $86.00 per sm ($3.00 - $8.00 per sf.)	Cost factors include equipment rental to move materials to and on the roof (rental of a crane could cost as much as $4,000.00 per day), size of project, complexity of design, and planting techniques used.
g)	Maintenance	$13.00 - $21.00 per sm ($1.25 - $2.00 per sf) for the first 2 years only.	Costs factors include size of project, timing of installation, irrigation system, and size and type of plants used.
h)	Irrigation System	$21.00 - $43.00 per sm. ($2.00 - $4.00 per sf).	*Optional, since the roof could be watered by hand. Cost factors include type of system used.

Table 3: Cost estimates for Extensive green roof system (Peck)

4.2 ACCESSIBLE INTENSIVE GREEN ROOF

(Costs assume an existing building with sufficient loading capacity; roof hatch and ladder access only. The larger the green roof, the cheaper the cost on a square metre basis.)

	Component	Cost	Notes & Variables
a)	Design & Specifications	5% - 10% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
b)	Project Administration & Site Review	2.5% - 5% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
c)	Re-roofing with root-repelling membrane	$100.00 - $160.00 per sm. ($10.00 - $15.00 per sf.)	Cost factors include type of existing roofing to be removed, type of new roofing system to be installed, ease of roof access, and nature of flashing required.
d)	Green Roof System (curbing, drainage layer, filter cloth, growing medium, decking and walkways)	$160.00 - $320.00 per sm. ($15.00 - $30.00 per sf.)	Cost factors include type and depth of growing medium, type and height of curbing, type of decking, and size of project. (cost does not include freestanding planter boxes.)
e)	Plants	$54.00 - $2,150.00 per sm. ($5.00 - $200.00 per sf.)	Cost is completely dependent on the type and size of plant chosen, since virtually any type of plant suitable to the local climate can be accommodated (one tree may cost between $200.00 - $500.00.
f)	Irrigation System	$21.00 - $43.00 per sm. ($2.00 - $4.00 per sf.)	Cost factors include type of system used and size of project.
g)	Guardrail / Fencing	$65.00 - $130.00 per lin.m. ($20.00 - $40.00 per lin. ft.)	Cost factors include type of fencing, attachment to roof, and size of project / length required.
h)	Installation / Labor	$85.00 - $195.00 per sm. ($8.00 - $18.00 per sf.)	Cost factors include equipment rental to move materials to and on roof, size of project, complexity of design, and planting techniques used.
i)	Maintenance	$13.50 - $21.50 per sm ($1.25 - $2.00 per sf) annually.	Costs factors include size of project, irrigation system, and size and type of plants used.

Table 4: Cost estimates for Intensive green roof system (Peck)

Lack of Design Standards

Having a tremendous effect on the cost of constructing a green roof, is the fact that in North America there are no standard design specifications for such projects. While certain companies and organizations have provided unique standards for individual projects, there has yet to be an internationally recognized entity that green roof construction must adhere to. Without a minimum, quantifiable level of expertise in the area of green roof construction many developers and clients find it extremely difficult to calculate the reliability of a green roof system even with substantial research. Such apprehensions are understandable especially as building managers begin to assess insurance and warranty information. Trying to guarantee products or insure a major institution's roof without standard guidelines to reference, reasonably, can discourage the developers and municipalities from recommending or allowing the construction of green roofs. Noting a paradox in the green roof industry Christopher and Wendy Wark of Shade Consulting LLC comment, "The paradox surrounding green roof standards is the lack of official guidelines keeps some specifiers from recommending green roofs for their projects, but without a substantial number of projects, there is little need to establish those standards" (Wark 10). In Europe this adversity is not as relevant due to the widespread publication of the FLL (***F**orschungsgesellschaft **L**andschaftsentwicklung **L**andschaftsbau e.V.*) standards originally engineered in Germany. The incentives and codes that they have established could certainly supplement a foundation for the initiation of North American standards. Until then contractors and developers must work with their project's clients and engineers to construct the optimal green roof system for those unique needs.

Retrofitting and Structural Concerns

While designing a green roof system for a new project is a relatively easy task for an architect or engineer, retrofitting such a system to an existing building is quite often cited as an entirely different task. The pivotal point Beatrice Munby of The University of Sheffield noted in her final report, *Feasibility Study for the Retrofitting of Green Roofs*, as being the "make it or break it" concern was the structural capacity of a building. With any new construction that includes existing facilities, it is often the case that those buildings are brought up to current building codes. Because building codes are constantly evolving and changing, engineers and architects find it especially difficult and often times extremely costly to upgrade a building even in the smallest ways.

Proposed as a possible solution to these adversities, replacing a ballasted roof system with an extensive green roof is a strategy that seems promising. Noted by Mumby in the feasibility report, should the ballasting of an existing building be removed so as to implement the construction of a green roof, the replacement would likely not add any additional weight on the roof: "Typically, stone chippings weigh 2Kn/m² per 100 mm depth and a

Figure 18: Accessible green roof combined with inverted ballasted roof in Tyrone, Pennsylvania (Extensive Green Roofs)

paving slab of 50mm weighs 1.2kn/m². Even if a thinner layer of chippings were used, a green roof weighing 0.6Kn/m² could easily be retrofitted" (Mumby 21). After mathematical conversions, Munby's calculations translate to roughly a 42lbs/sq. ft. allowance on a typical ballasted roof. This amount of given weight would easily allow for an extensive green roof system that could replace the ballasting without any trouble. Some instances have shown that a green roof and ballasting can easily exist together as see in Figure 17. In an inventory of buildings and facilities, LANL has several roofs covered with ballasting. Each of these buildings could undeniably be considered as an appropriate candidate for green roof construction given the proper capital investment.

Such buildings include:

Building Name	Tech Area	Roof Area (sq. ft)
Material Science Laboratory	TA-03-1698	35,442
Space Science Laboratory	TA-03-0502	13,359
Office	TA-53-0031	15,633

Life Cycle Analysis

In order to test the relevant value of a green roof system at LANL, life cycle analyses were conducted to show the return on investment (ROI) on a green roof based solely on initial capital costs and estimated energy saved for the Material Science Lab and the Space Science Lab. The office building could not reliably be tested because it lacks proper energy metering systems. It should be noted that these buildings were chosen because their current roof systems include ballasting, which can be easily replaced with an extensive green roof. Unknown retrofitting and upgrade costs were not included. A more comprehensive cost calculation should be done for all buildings in the future.

Figure 19: Materials Science Laboratory TA-03-1698

Figure 20: Space Science Laboratory TA-03-0502

Figure 21: NPB Technical support office building TA-53-0031

Life Cycle Analysis

Material Science Laboratory TA-03-1698 (Green Roof)

Component	Price ($/sq. ft.)	Sq. Footage	Subtotal
Reroofing	12.5	35,442	$443,025
Green Roof System	7.5	35,442	$265,815
Plants	2	35,442	$70,884
Labor	5.5	35,442	$194,931
Maintenance	1.5	35,442	$53,163
Irrigation	3	35,442	$106,326
Component	**Price ($/kWh)**	**kWh**	**Subtotal**
Energy Consumption at 15 years	0.064	13,670,947.5	$874,940.64
TOTAL			$2,009,084.64

Material Science Laboratory TA-03-1698 (Conventional Roof)

Component	Price ($/sq. ft)	Sq. Footage	Subtotal
Reroofing	4	35,442	$141,768
Labor	5.5	35,442	$194,931
Maintenance	1.5	35,442	$53,163
Roof Replacement at 15 years	4	35,442	$141,768
Labor	5.5	35,442	$194,931
Maintenance	1.5	35,442	$53,163
Component	**Price ($/kWh)**	**kWh**	**Subtotal**
Energy Consumption at 15 years	0.064	19,529,925	$1,249,915.2
TOTAL			$2,029,639.2

SAVINGS	$20,554.56

Life Cycle Analysis

Space Science Laboratory (Green Roof)

Component	Price ($/sq.ft)	Sq. Footage	Subtotal
Reroofing	12.5	13,359	$166,987.5
Green Roof System	7.5	13,359	$100,192.5
Plants	2	13,359	$26,718
Labor	5.5	13,359	$73,474.5
Maintenance	1.5	13,359	$20,038.5
Irrigation	3	13,359	$40,077
Component	**Price $/kWh**	**kWh**	**Subtotal**
Energy Consumption at 15 years	0.064	9,602,950	$614,588.8
TOTAL			$1,042,077

Space Science Laboratory (Conventional Roof)

Component	Price ($/sq.ft)	Sq. Footage	Subtotal
Reroofing	4	13,359	$53,436
Labor	5.5	13,359	$73,474.5
Maintenance	1.5	13,359	$20,038.5
Roof Replacement at 15 years	4	13,359	$53,436
Labor	5.5	13,359	$73,474.5
Maintenance	1.5	13,359	$20,038.5
Component	**Price ($/kWh)**	**kWh**	**Subtotal**
Energy Consumption at 15 years	0.064	13,718,500	$8,77,984
TOTAL			$1,171,882
SAVINGS			$129,805

The cost analysis was based on the assumption that a conventional roof would have a 15 year warranty and have to be replaced at that time. The energy demands were based on an annual running meter system, which monitors the energy consumed in kWh and records the readings every month. To calculate the potential energy consumption of the same buildings with a green roof it was assumed that the thermal mass of the vegetation would decrease the building's energy demand by 30%. This approximation represents the average savings of the many findings and claims found during the research process. The costs of each component were averages of Steven Peck's estimates for an extensive green roof system as seen in *Costs:* Table 3.

By adding up the estimated installation costs along with the energy costs, the total lifecycle cost for a green roof on the Materials Science Lab was $2,009,084.64 while the conventional roof system totaled $2,029,639.20. That is a savings of $20,554.56 in favor of the green roof system in 15 years. At $129,805 the savings were six times that for the Space Science Laboratory where the cost for each roof and their energy consumption totaled $1,021,056 and $1,141,852 respectively. What these totals indicate is that, in the case of a retrofit project, the value of a green roof peaks at an optimal roof area before it then starts to diminish and the monetary value of the benefits no longer outweigh those of the costs. While the MSL building showed a savings, calculations suggest that at $20,555 every 15 years it would take nearly 260 years before the initial cost gap could be paid off. On the other hand, if the Space Science Lab showed consistent savings of $120,796 every 15 years, the green roof system would have an ROI in the first 16 years. Assessing these variables would be critical for anyone considering a green roof project, especially a retrofit. What is also essential to consider, is that these approximations merely take into account the immediately accessible, and easily quantifiable data of the current facilities. The indirect benefits of a green roof, like the reduction of the Urban Heat Island Effect or storm water mitigation, would have to be further researched and documented in those 15 years so they too could be added to the increased value of the green roof.

Conclusions

The gaining popularity and advancing technology of the green roof industry cannot be disputed. Every year there is more research and development dedicated to green roof systems; and every year more contractors and developers are willing to invest in their production. Municipalities such as Toronto and Chicago have initiated legislative efforts to try to implement dedicated green roof programs in their cities. Seattle and Portland have conducted diligent research on different aspects of green roofs, taking advantage of their uniquely abundant amounts of rainfall. Despite the higher initial investment, all research indicates that the benefits of green roofs are significant enough to provide a fairly efficient return on investment, especially when the system is planned for at the beginning stages of the design process.

These benefits include the lessening of the Urban Heat Island, the reduction of storm water runoff volumes, and most significantly the decrease in energy consumption and demand by buildings. Combined, all these advantages add to the value of a green roof system and increase the financial gains of the stakeholders. These profits cannot only be realized through monetary gains, but through greater worker efficiency due to a more comfortable interior environment. Less tangible, but no less significant are the ecological paybacks that facilities and organizations can benefit from as well.

Still barring green roofs from becoming a regular consideration of builders and developers is the fact that there exist few examples of standard design specifications. LANL can have a significant part in making that a reality. Should LANL ever choose to integrate green roofs into the design considerations for future buildings or retrofit any existing facilities, it would undoubtedly provide a noteworthy example of the costs and benefits associated with green roofs. Applied to those buildings with roof areas that prove to give a reasonable ROI, LANL should try to develop standard building codes to integrate into the engineering standards that could help engineers and designers more easily construct green roof systems.

At LANL the potential of green roof systems has already been realized with the construction of the accessible green roof on the Otowi building. To further explore the possibilities and prospective benefits of green roofs though, the initial capital costs must be invested. Three buildings, TA-03-1698, TA-03-0502, and TA-53-0031 have all been identified as sound candidates for a green roof retrofit project. It is recommended that LANL proceed with further analysis of these projects and implementation of the green roofs. Furthermore, it is recommended that an urban forestry program be initiated to provide supplemental support to the environmental goals of green roofs.

Under federal jurisdiction green roofs can help meet government regulations for LANL buildings like those issued for High Performance Buildings; they can be used to attain points in the LEED program, and they can be the foundation for further scientific experimentation. All of these features, along with the monetary savings, make green roofs a relevant topic of consideration for the LANL facility's designers and the rest of the nation.

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