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The Potential for Green Roofs in Hawai‘i

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Modern urban landscapes include acres of rooftops that for the most part lie desolate and forgotten. As Thompson and Sorvig (2000) noted, at ground level the buildings that dominate these landscapes are alive and vibrant with shopping, commuting, plantings, and people, but at the roof level they are lifeless. Increased urbanization and density in Hawai‘i is creating more barren, harsh rooftops that detrimentally impact people, the economy, and the environment.

In response to concerns about increasing urbanization, cities around the world have invested in green roofs. The Hawai‘i Legislature expressed interest in green roofs by passing Senate Resolution LRB 06-2901 (SR-86) in 2006; it called for the University of Hawai‘i at Mānoa's College of Tropical Agriculture and Human Resources "to gauge the feasibility of rooftop landscaping and agriculture in urban districts."

This publication provides some basic information about green roofs, including their benefits and costs. Then, the potential for green roofs in downtown Honolulu, Waikiki, and Kaka‘ako is examined, and the result of an opinion poll about green roofs for residents and visitors is presented. Finally, some overall conclusions and recommendations are offered to assist property owners and decision-makers in looking toward the future of green roofs in Hawai‘i.

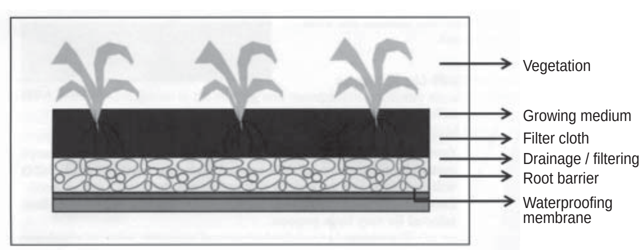
Green roof background and definitions

The term "green roof" is generally used to describe a built surface containing a substantial portion that sustains a permanent vegetative layer (Department of Environmental Affairs and County of Los Angeles 2006). However, some also use the term to describe reflective roofs. In this publication, green roof is a broad term used to describe ecological or vegetated roofs, which incorporates roof gardens as well as the new high-tech, thin profile vegetation surfaces. Although each green roof is unique, all green roof systems contain the same basic elements: a vegetative layer; a growing medium such as soil; fiber cloth; a layer for drainage, water storage, and aeration; a root barrier; and a waterproof membrane (Table 1, Figure 1, Moyer 2005).

Table 1. Green roof components.

Essential	*Optional*
High-quality waterproofing	Insulation
Root-repellant system	Membrane protection layer
Drainage	Leak-detection system
Filter cloth	Ponds and pools
Growing medium (substrate)	Irrigation system
Vegetation	Walkways
	Curbs and borders
	Railings
	Lighting

Figure 1. Overview of green roof components.



Green Roof 101 Design course: Green Roofs for Healthy Cities, 2005

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Table 2. Characteristics of green roofs by type.

Characteristic	***Extensive***	***Semi-intensive***	***Intensive***
Media depth	6 inches or less	Around 6 inches	More than 6 inches*
Accessibility	Often inaccessible	May be partially accessible	Usually accessible
Saturated weight	Low (10–35 lb/ft^2)	Varies (35–50 lb/ft^2)	High (50–300 lb/ft^2)
Plant diversity	Low	Greater	Greatest
Cost	Low	Varies	Highest
Maintenance	Minimal	Varies	Highest

*Unless they are primarily hardscapes

As more worldwide development brings about a decrease in green landscapes, the interest in green roofs is growing. The concept of green roofs has been around since the hanging gardens of Babylon and, therefore, is not new. The 1868 World Exhibition in Paris included a planted “nature roof” on concrete, the first of a series of high-end experimental projects. In the 1900s, green roofs were promoted by the leading modernist architects Le Corbusier, Roberto Burle Marx, and Frank Lloyd Wright. Wright designed a restaurant roof garden in Chicago in 1914 and the roof garden on the Rockefeller Center in New York in the 1930s; the latter still exists (Dunnett et al. 2004, Grant et al. 2003).

In the second half of the 20th century, new technologies were developed that launched the modern green roof. Germany started developing extensive roof systems to restore nature in cities where development had significantly changed the character of views. The most recent trends in German green roofs include an increasing emphasis on recycled or recyclable materials and intensive applications similar to terrestrial spaces. Green roofs used to compete with other ecologically oriented systems, such as solar water heaters and energy panels, but today a combination of different forms of use is preferred in order to create synergy (Appl and Ansel 2004).

The two main types of green roofs are extensive and intensive (Table 2; Grant et al. 2003). Both types furnish similar benefits to the building and surrounding area, but they differ in their design, primarily in the depth of the growing medium and level of accessibility, and have other differences listed in Table 3. Semi-intensive roofs are typically intermediate in terms of the depth of growing medium.

Intensive green roofs are designed to provide the same recreation, relaxation, and food production services as a garden at ground level. They may be considered to be roof gardens. They typically require regular maintenance and irrigation. The need for accessibility and the soil depth requires that the underlying roof be structurally capable of bearing considerable weight (Department of Environmental Affairs and County of Los Angeles 2006).

Extensive green roofs are relatively self-sustaining after the establishment of the vegetative layer and are often constructed for their environmental and energy benefits. Access is only for maintenance purposes, and little to no supplemental irrigation occurs after the plants are established. The soil layer is thinner than on an intensive green roof, and the plants are generally herbaceous and chosen for drought-resistance. Some extensive green roofs are allowed to self-seed, or are planted with native vegetation (Grant et al. 2003).

The thin profile of extensive roof systems makes them light enough to be installed in some existing buildings with little or no additional structural support. However, some buildings will still require additional structural support. The vegetation is expected to survive in only a few inches of specialized soil substitutes, with very little organic matter. This growing medium is often very specifically designed for the plants and the conditions, making it tough for weeds to survive. Extensive gardens often cover the entire roof instead of just pockets, as some intensive gardens do, increasing their visual impact from higher viewing points. Extensive green roofs can be applied to flat roofs and to pitched or sloped roofs up to 35 degrees (Appl 2006).

A new generation of green roof technologies has vastly

Table 3. Advantages of green roofs by type.

Extensive	***Semi-intensive***	***Intensive***
Lightweight	Combines best features of extensive and intensive	Greater plant diversity
Suitable for large areas	Utilizes areas with greater loading capacity	Best insulation and rainwater management, unless they are primarily hardscapes
Low maintenance costs	Greater coverage at less cost than intensive	Greater range of design
No irrigation required	Average maintenance costs	Often accessible
Suitable for retrofit projects	Greater plant diversity than extensive	Greater variety of human uses
Lower capital costs	Greater opportunities for aesthetic design than extensive	Greater biodiversity potential
Easier to replace		

Green Roof 101 Design course: Green Roofs for Healthy Cities, 2005

expanded the ways in which vegetation can be integrated into the built spaces. Green walls or facades, roofs planted with sod or simple intensive green roofs, and hydroponic food production systems (Grant et al. 2003, Wilson 2002) are related approaches that bring green landscapes into urban areas. Fabric pockets attached to building walls can even support the cultivation of reed beds (Grant et al. 2003). Earth-sheltered structures, such as the parking garage near the State Capitol Building, already exist in Hawai'i. The term "green roof" also implies the use of environmentally sensitive technologies (Moyer 2005), with or without a vegetative layer, and embraces the concept of sustainability.

Benefits of green roofs

Green roofs provide a variety of private and public benefits that have been widely documented (Table 4). The private or direct benefits accrue solely to the property owner. These types of benefits generally include reduced energy consumption, increased roof life, fire retardation, and blockage of telecommunication radiation.

A green roof adds layers of insulation, which reduces the amount of energy needed to cool the building. Research suggests that the energy savings can be maximized by targeting medium- to low-density areas in which the roof area is greater than the building's square footage of internal space (Alcazar and Bass 2006). Therefore, a high-rise building likely will not benefit as much as a low-rise building because the cooling effect of the green roof does not extend past about six stories. Large, one-story establishments such as Costco, Kmart, and Home Depot are considered to be good candidates for green roofs. A green roof system also protects a roof's structural elements from the environment and, therefore, gives the roof a longer life than conventional roofing technology. However, specific projects may increase accessibility, building value, building management efficiencies, and community, customer, and employee satisfaction.

The public or indirect benefits of green roofs are much more wide-ranging. They include improved rainwater management, reduction in urban heat, improved air quality, increase in green space, increase in local food supply, increased wildlife habitat and native plants communities, and noise abatement. While the public benefits from green roofs are many, they are difficult to quantify because their monetary value is hard to assess.

Determining the value of improved rainwater management, for example, requires that the actual improvement that can be attributed to a green roof be determined. Due to the large number of factors that can affect water quality and quantity in a given area, this information is not easily obtained. Then, this improvement must be given a monetary value in order to facilitate the calculation of total benefits across all possible benefits. Normally, monetary value is obtained using market prices.

Table 4. Public and private benefits of green roofs.

Public benefits		*Private benefits*	
Common	***Project-specific***	***Common***	***Project-specific***
Aesthetics	Aesthetics	Aesthetics	Aesthetics
Noise reduction	Noise reduction	Noise reduction	Noise reduction
Rainwater management	Additional green space	Energy savings	Accessibility
Reduction of urban heat island effect	Multiple uses of limited space	Extended roof life	Increased building management efficiencies
Improved air quality	Biodiversity	Fire retardation	Increased community acceptance, customer and employee satisfaction
Local job creation	Community or commercial gardens		Blockage of telecommunication radiation
Horticultural therapy	Leverage private roofing investment for public good with incentives		Increased building value
Improved "liveability"	Use of local, reused and recycled materials		
Waste diversion			

Adapted from: Green Roofs Infrastructure, Participant's Manual, Green Roofs for Healthy Cities, 2006.

Thus, the value of an improvement in quality is measured by the price of the lower-quality item minus the price of the higher-quality item. However, because the water quality in a stream or ocean is not a good or service sold in a market, no market price for it exists. Various non-market valuation techniques exist, but extensive research would be required to quantify each public benefit before totaling the public and private benefits.

The literature contains a few examples that quantify all the private and public benefits of green roofs in a specific city. A study conducted by Ryerson University estimated the public and private benefits of green roof technology for Toronto, Canada, and these are summarized in Table 5.

A number of factors influence the benefits that will accrue to a green roof. These include:

Roof design: Type, size, components, and plants

Environment: Building site, climate

Building design: The degree to the roof is integrated with other building systems

Type of building: Industrial, commercial, residential, new vs. retrofit

Existence of supportive public policies: Desired public benefits.

Some benefits are common to all projects, while others result from the green roof's specific design and the property owner's objective. Designs that are integrated overall with the building are likely to achieve maximum benefits.

Costs

The overall out-of-pocket investment in a green roof differs from a conventional roof based on two types of costs. The installation cost of a green roof is larger than a conventional roof, as are the maintenance costs. The literature provides some information about relative levels for each type of cost between the two roofing systems. However, the exact cost of a green roof will depend on a variety of factors, as indicated in Table 6.

Extensive roof systems cost less to install than either semi-intensive or extensive gardens, although intensive

Table 5. Public and private benefits for Toronto, Canada, from the installation of 6,000 hectares of green roofs.

Benefit category	***Initial benefit ($)***	***Annual benefit ($)***
Rainwater		
Best management practice	79,000,000	
Pollution control savings	14,000,000	
Erosion control savings	25,000,000	
Sewer		
Storage cost savings	46,600,000	
Reduced beach closures		750,000
Air quality		
Reduction in CO, NO_2, O_3, PM_{10},SO_2		2,500,000
Building energy		
Energy cost saving		21,000,000
Peak demand reduction	68,700,000	
Savings from CO_2 reduction		563,000
Urban heat island		
Energy cost saving		12,000,000
Peak demand reduction	79,800,000	
Savings from CO_2 reduction		322,000

Adapted from Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto. Ryerson University, 2005

systems offer a greater return on investment due to the increased energy savings, primarily cooling, and improved water and air management. Intensive systems are more costly than extensive systems because of the increased structural support needed to support the additional weight. Costs can vary substantially, particularly for intensive systems, based on the design, as indicated in Table 6. One reference indicated that the cost of a semi-intensive green roof was $45.50 per square foot in 2001 (Earth Pledge 2005).

Costs will likely go down as the standardization and certification of green roof systems increase. The United States will likely see costs coming down to a fraction of their 2006 prices, perhaps approaching Germany’s, which are currently 20 percent of U.S. costs. The benefit-to-cost ratio is greatly improved by using extensive roof systems, which is why over 80 percent of green roofs in Germany are extensive (Philippi 2006).

Currently, anyone installing a green roof in Hawai‘i would need to purchase each component separately, which increases the buyer’s concern that the system will not be reliable. Purchasing the pieces separately increases the possibility for confusion about liability to occur should one part of the system fail. Green roofs in Germany are produced according to generally accepted standards and guidelines (Appl 2006). Currently, five standards for green roofs are published, and they are currently being written for North America through the American Society for Testing and Materials International (ASTM).

By combining the waterproofing, insulation, and vegetation into one system that is purchased as a kit, the client will have some assurance that the system will function as designed. In order for green roof installation to be as efficient and effective as possible, manufacturers of systems must be developed. The technical issues would then be in the hands of manufacturers rather than the consultants, which would result in better adoption rates and lower prices, which are key to green roofs spreading across Hawai‘i.

The local availability of lightweight materials such as lava rock and pumice will help to reduce costs, while increasing transportation rates for supplies that must be shipped in, such as growing media, will raise costs. A derivative of volcanic rock, “Grodan,” has been used in Denmark as a growing medium on green roofs for more than 20 years (Thompson and Sorvig 2000). Hawai‘i may have an opportunity to develop green roof materi-

Table 6. Cost ranges and factors for green roofs.

Element	***Price range***	***Cost factors***
Design	4–8% of project cost	Size and complexity of project
Project administration	6–12% of project cost	Size and complexity of project, number of professionals
Initial structural evaluation	$0–$1000	Building type, quality of documentation
Re-roofing with high-quality membranes	$0–$12/ft^2	Size, accessibility, number of roof penetrations
Drainage	$1–$5.50/ft^2	Type of drainage layer, size of project
Filter cloth	$0–$.50/ ft^{22}	
Growing medium	Extensive: $2–$12/ft^3 Intensive: $2–$20/ft^3	Volume and type of medium, transportation costs
Vegetation	Extensive: $0.20–$5.00/ft^2 Intensive: $1.25–$10/ft^2	Type and size of plants, Time of year
Installation	Extensive: $2.40–$6.40/ft^2 Intensive: $6.40–$14.40/ft^2	Project size, design, type of planting, type of roof access
Modular system	Extensive: 10^+$/ft^2 Intensive: 13^+$/ft^2	Design, shipping, installation, plant species, density
Reinforcement of existing roof	Depends on the structure	May not be necessary. Load-carrying capacity of roof
Curbing/borders	$0–$20/ft	May not be necessary. Type, length
Walkways	$0–$10.20/ft^2	May not be necessary. Type, length
Railings	$0–$65.45/ft	May not be necessary. Thickness of rail, number of rails, roof deck penetration
Irrigation system	$0–$5.00 /ft	May not be necessary. Type of system, size of project
Maintenance	Extensive: $0.25–$4.10/ft^2 for first two years Intensive: $1.00–$4.10/ft^2	Size of roof, types of plants, nature of access

Adapted from Green Roof 101 Design, Participant’s Manuel, Green Roofs for Healthy Cities, 2006.

als such as this, which could be exported to North America and Asia. Specializing in volcanic growing media for green roofs will be highly technical and important in the years to come.

The potential for green roofs in Hawai‘i

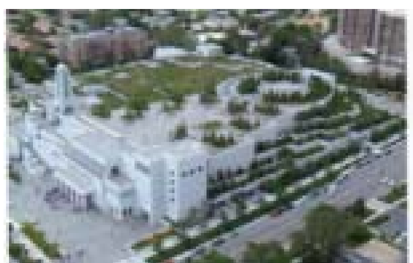
For existing buildings in Hawai‘i, intensive green roof installation may not be as feasible as extensive green roof systems because intensive roofs would require structural reinforcement. This structural assessment would need to be completed on a case-by-case basis, and the associated costs would likely be prohibitive in most situations.

Because the savings associated with deferred maintenance and reduced energy consumption of extensive green roofs have been shown to offset the initial capital and ongoing maintenance costs, these systems are expected to be feasible for Hawai‘i for private landowners (Green Roofs for Healthy Cities 2006). However, as was the case in other countries or states, private property owners may not perceive that the private benefits are greater than the private costs, making it imperative that policymakers consider various legislative instruments to adjust the benefit and cost structure in order to assure that private owners perceive that the benefits outweigh the costs.

Figure 2. Examples of green roofs.

Ford assembly plant (July 2003).

An intensive green roof on a restaurant in Lansi Michigan.

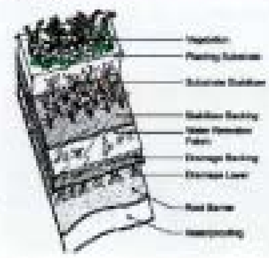


The convention center of the Church of Jesus Christ of Latter-day Saints in Salt Lake City, Utah.

Rowe doghouse for Finnegan and Cooper in Mason, Michigan (August 2003).

Rowe doghouse (July 2006).

Photograph showing Xero Flor System installation and cross section (Adapted from Xero Flor Canada)



Chicago City Hall. (Roofscapes, Inc.).

(Behrens Systementwick)

Photos courtesy of www.hrt.msu.edu/greenroof.

Various policy instruments aimed at increasing the use of green roofs have been used around the world. Researchers have concluded that policy makers should not mandate a particular solution but instead should adopt policies that ultimately make cities more sustainable (Chellsen 2006). The regulatory approach appears to be much more effective than incentives, although incentives that mitigate the cost of installing a green roof are generally effective. The regulations that were most stringent and applied to any project receiving public assistance or those in special management areas were the most effective. While regulations do have the highest effectiveness in terms of number of green roofs implemented, the researchers noted two points. First, the regulations should not mandate green roofs as the solution, but rather identify a problem such as storm water, water quality, or urban heat-island effect, and then be flexible in which solutions meet the goals, and second, without proper buy-in from the public, resentment occurs (Chellsen 2006).

Clearly, O'ahu has the bulk of the development found in Hawai'i and, therefore, represents the area with the most potential for green roofs in the state. In order to investigate the potential for green roofs on O'ahu, more

Figure 3. Waikiki without green roofs (above) and with 75 percent green roof coverage (below).

Figure 4. Downtown Honolulu without green roofs (above) and with 75 percent green roof coverage (below).

Figure 5. Kaka'ako without green roofs (above) and with 75 percent green roof coverage (below).

information is needed about the existing roof area that could be converted to an extensive green roof. Then the actual amount of green roof that could be developed on existing buildings in this area is estimated. The net benefits discussed above would accrue to all roof space that is converted to a green roof.

Study areas characteristics

Three highly developed areas, Waikiki, Downtown, and Kaka‘ako on the island of O‘ahu, were selected for study in this report. Waikiki, selected due to its commercial and multi-family development, is largely dominated by hotels on the makai (ocean) side and by multi-family buildings on the mauka (mountain) side, along the Ala Wai canal. The Downtown and Kaka‘ako areas were selected because they represent the state's commercial and industrial areas, respectively.

A geographic information system (GIS) layer of building footprints and heights was obtained from the City and County of Honolulu's Department of Planning and Permitting (http://gis.hicentral.com). The building footprint and height data were retrieved from stereo aerial photos acquired by Air Survey Hawaii on January 7, 2004 (Pennington et al. 2004). The GIS layer was not updated for buildings demolished and/or constructed after that date.

The descriptions for facilities included in the layer's attribute table were reclassified from the original 61 classes into 6 classes: commercial, hotel, industrial, multi-family, others, and unknown. Several buildings that did not have a facility description attribute value were labeled "unknown." The GIS layer was then divided into a subset for the Waikiki, Downtown, and Kaka‘ako areas. The building footprints for each class were totaled in each study area. The buildings were further reclassified into two height categories: (1) less than 48 feet and (2) greater than 48 feet and less than 144 feet. These heights correspond to the approximate height of 6-story and 12-story buildings, respectively. Buildings less than 48 feet are likely to reap a larger benefit in terms of decreased energy costs than building between 48 and 144 feet.

Green roofs are at risk of being peeled off by a strong wind, but no information is currently available that addresses the maximum wind that an extensive green roof can withstand. Monthly mean wind speed data for a maximum of two minutes and a maximum of 5-second gusts from 1998 thru 2006 recorded at the Honolulu International Airport were obtained from the National Oceanic and Atmospheric Administration National Climate Data Center (see Appendix, p. 16). Because wind gusts equal to 50 mph were recorded, any building taller than 144 feet was excluded from the study area because the wind above this height is assumed to be too strong. Because Hawai‘i has unique climate characteristics such as varying wind velocities, demonstration sites are needed to test different green roof systems to address these unknown factors.

As Table 7 indicates, the study area contained a total square footage of 10,216,310 for buildings 48 feet tall or less. This footage is considered to be the most attractive area in which to install green roofs in existing buildings. The buildings between 48 and 144 feet tall in the study area, which account for 7,386,870 square feet, are not likely to glean the same energy cost savings per square foot because the cooling benefits of green roofs do not extend past 48 feet. Therefore, the taller buildings have less potential for conversion. This square footage information can be used by policymakers to estimate the cost of any green roof legislation that may be enacted to encourage the installation of green roofs in existing buildings.

To illustrate the visual impact of installing green roofs in Honolulu, green roof installations covering 75 percent of the roofs were simulated in a photo of the area. As shown in Figures 3, 4, and 5, the urban landscape is significantly enhanced by the installation of green roofs. While increasing green roof coverage by 75 percent is a challenging goal, the benefits to the public are readily apparent in the illustrations.

Green roof installation would also affect the amount of impervious surface in an area. A decrease in impervious surface is expected to increase the public benefits associated with water management. In order to more fully understand the impact of changes in impervious surface in each study area, the current situation was investigated.

For each area, three sets of 100 random points from orthorectified, digital EarthData imagery of each location were selected for a total of 300 points for each area. The EarthData images were acquired in February and May of 2004 and April and May of 2005 at a flight altitude of 10,000 feet above mean terrain, resulting in a photo scale of 1:19,200 with a 1-foot spatial resolution (EarthData International 2005). The cover surface of vegetation, roof-

Table 7. The square footage for various types of space less than 48 feet tall and between 48 and 144 feet tall in each study area.

Space location and type	*Square footage of buildings less than 48 feet tall*	*Square footage of buildings between 48 and 144 feet tall*
Waikiki		
Commercial	589,673	340,776
Hotel	701,525	1,743,958
Industrial	24,274	
Multi-family	1,337,847	1,346,848
Downtown		
Commercial	3,499,437	831,949
Hotel	27,163	
Industrial	33,269	
Multi-family	198,189	43,800
Kaka‘ako		
Commercial	2,023,260	2,322,028
Hotel		107,548
Industrial	1,686,694	
Multi-family	94,979	649,963
Totals		
Commercial	6,112,370	3,494,753
Hotel	728,688	1,851,506
Industrial	1,744,237	
Multi-family	1,631,015	2,040,611
Total square footage	10,216,310	7,386,870

top, or any impervious surface other than rooftop was visually identified at every point. This information was used to calculate how much of each type of surface was in each study area, as indicated in Table 8.

Clearly, the study area has a large amount of impervious surface and a relatively small amount of vegetation, especially Kaka‘ako. This situation has contributed to the problems that have been reported for the Ala Wai, Honolulu Harbor, Ke‘ehi Lagoon, and Kewalo Basin (Scorecard 2006). If less rainwater moves onto the parking lots and roadways because green roofs have decreased the number of impervious surfaces, then less runoff to the ocean will occur. Work done at Michigan State University found that green roofs retained 60 to 100 percent of the rainwater (Nicholaus et al. 2005). The conversion of the rooftops in each study area to green roof is thus expected to have an impact on water quality in these coastal zones.

Public attitude survey

While commercial property owners are motivated by return on investment, residents and visitors are members of the public who are likely to be interested in scenic views and be willing to pay more for locations that have these views. At the same time, the public is also likely to be concerned with environmental quality. While the short time-frame allotted to complete this report precluded research into the willingness of residents and visitors to pay for views of green roofs, a short attitude survey was conducted to determine if these groups would find the idea attractive. This provides policymakers with a general overview of public opinion.

Residents were surveyed at Kahala Mall on November 26, and visitors were surveyed in Waikiki on December 1. The survey instrument is described on p. 16. Of 118 people surveyed, 53 percent were residents and 47 percent were visitors. Of those surveyed, 36 percent

Table 8. Percent of surface cover in each study area.

Area	*Roof top*	*Other impervious surface*	*Vegetation*
Waikiki	35.3	37.6	27.0
Downtown	37.6	44.0	18.3
Kaka‘ako	40.3	51.0	8.6

had heard of green roofs and 61 percent had not, with the remainder having no answer. Of those who had heard of green roofs, only 9 percent were very familiar with them and 23 percent were somewhat somewhat familiar with them.

As far as having the local or state government promote green roofs, a large majority of the respondents, 48 percent, was very much in favor, with 29 percent somewhat in favor, 20 percent being neutral, and 3 percent being somewhat or very much opposed. Twenty-three percent of respondents were very much in favor of the local or state government mandating green roofs, while 25 percent were somewhat in favor, 36 percent were neutral and 16 percent were somewhat or very much opposed.

As Table 9 indicates, a large majority of respondents felt that the benefits of green roofs are very important or somewhat important. Survey results show that 81 percent of the respondents indicated that improvement in air quality from green roofs would be very important to them. Likewise, 79 percent of respondents believed that improved water quality was a very important benefit from green roofs, and 77 percent believed that green roofs' ability to reduce energy consumption was a very important benefit. When asked if food production was an important benefit to be derived from green roofs, 63 percent of respondents replied it was very important. The provision of outdoor recreation was the benefit that the respondents felt was relatively less important compared to the others listed in Table 9. Clearly, the public benefits of green roofs are known and valued by residents and visitors.

Demonstration sites are commonly used as a means of providing education about green roofs and a means of conducting on-site research. Hawai‘i has no such demonstration sites, and the state faces a significant challenge given the lack of research in tropical green roofs. In response to a query about the important features of a demonstration site in Table 10, 79 percent of respondents indicated that an educational program or tour was very important or somewhat important. The next most important feature, with 72 percent of respondents indicating it very important or somewhat important, is variety of types and plants. While the location of the demonstration site was very important and somewhat important to many respondents, it was generally ranked lower than the leading two factors.

Forty-seven percent of respondents would like to learn more about green roofs for possible installation at home, and 30 percent would like to learn for possible installation at work. Clearly, more educational outreach is of interest to survey respondents, as reflected by a 79 percent agreement that it is very to somewhat important.

Conclusions and recommendations

Increased urbanization and density in Hawai‘i is creating more barren, harsh rooftops that affect the people, the economy, and the environment. Since some countries and states are aggressively encouraging green roof construction, the private and public benefits are greater than the costs in those locations. However, private prop-

Table 9. Importance of green roof benefits to survey respondents (in percentages).

Benefit	*Very important*	*Somewhat important*	*Slightly important*	*Not important*	*No opinion*
Improve air quality	81	13	1		3
Improve water quality	79	14	2		3
Reduce energy consumption	77	15	3		3
Provide outdoor recreation	47	30	12	5	3
Produce fresh vegetables	63	23	6	3	3

Table 10. Importance of demonstration site features to respondents (in percentages)

Factor	*Very important*	*Somewhat important*	*Slightly important*	*Not important*	*No opinion*
In Waikiki	33	17	10	19	10
Five minutes from home (or hotel)	27	19	11	19	9
Thirty minutes from home (or hotel)	23	19	18	19	10
Variety of types and plants	47	25	14	2	5
Educational program or tour	61	18	6	3	4

erty owners may not perceive that the private benefits are greater than the private costs, which creates challenges for policymakers. Owners often perceive that their cost of waiting is so high that any investment taking longer than three or four years to pay back is not sound. At the same time, many people in Hawai'i rent, which means that the savings from reduced energy consumption do not accrue to the owner. Various legislative instruments have been used to adjust the benefit and cost structure to ensure that private owners perceive that benefits outweigh costs. At the same time, as green roofs become more commonplace, economies of scale occur, and private costs decline over time.

Widespread acceptance of green roofs is hindered by lack of awareness, higher installation costs, insufficient information detailing their benefits, limited knowledge about how to build them, and lack of government policies that encourage them. These barriers have been overcome in other countries, and the strategies that were successful elsewhere can work in Hawai'i. Three urban areas in Honolulu have a significant percentage of impervious rooftops that could become green roofs. Residents and visitors support the idea of green roofs in the state. The Legislature wants more information about which policies are most effective. The University of Hawai'i can provide outreach education and could construct demonstration sites to collect the needed data. Landscape designers and architects, nursery operations, and landscape contractors are excited about this new market, which includes all existing and future roofs in the country.

Green roof technologies can help create a more sustainable Hawai'i. The opportunity to see integrated rooftop food production systems, green walls and facades, attractive cisterns that eliminate the need for irrigation with municipal water, and other environmentally sensitive approaches is at hand. Resources devoted to developing such technologies today will ensure a greener tomorrow for Hawai'i.

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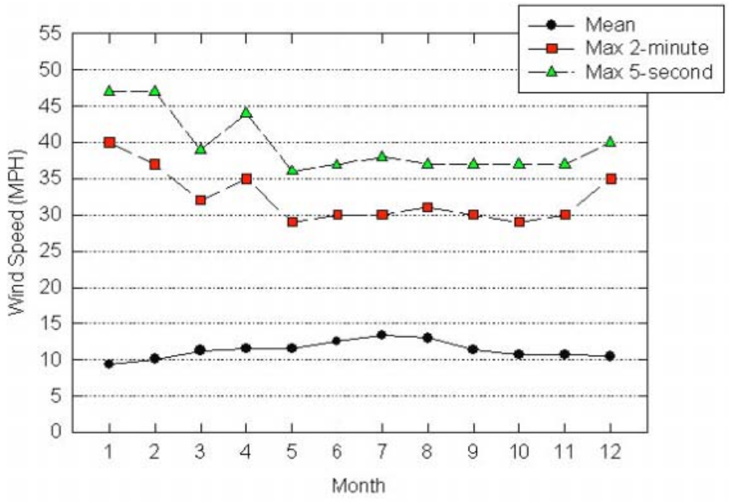
Appendix. Honolulu International Airport climatic wind (gust) record.



Appendix. Hawai‘i Green Roof Feasibility Questionnaire

The survey was given to two groups: residents and visitors.

1. Have you ever heard of green roofs?
Yes, No *If no, refer to picture and then go to question #4*

2. If yes, how familiar are you of green roofs?
Very familiar
Somewhat familiar
Slightly familiar
Not familiar
No opinion

3. By which means did you hear about green roofs?
Website
Demonstration site
Newsletter
Book
Magazine
Television
Word of mouth/friend
Other means
N/A

(Answer options, 4 and 5: Very much opposed, Somewhat opposed, Neutral, Somewhat in favor, Very much in favor)

4. How do you feel about local or state government promoting green roofs?

5. How do you feel about local or state government mandating green roofs?

(Answer options, 6 and 7: Very important, Somewhat important, Slightly important, Not important, No opinion)

6. If green roofs could provide the following benefits, please indicate how important each one is to you…
- Improve air quality
- Improve water quality
- Reduce energy consumption
- Provide outdoor recreation
- Produce fresh vegetables

7. If a demonstration site were to be built, how important are the following factors in your decision to visit?
- Located in Waikiki
- Within a 5 minute drive from your hotel
- Within a 30 minute drive from your hotel
- Has a variety of types and styles of plants
- Has an education program or tour

8. Would you be interested in learning more information and possibly installing a green roof?
(Answer options: Yes, No)
- At home
- At place of work

Mahalo for your kokua