UNIVERSITY OF HAWAI‘I SYSTEM

FEASIBILITY STUDY REPORT

REPORT TO THE 2007 LEGISLATURE

FEASIBILITY STUDY OF GREEN ROOF TECHNOLOGIES IN URBAN DISTRICTS IN HAWAII

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Feasibility of Green Roofs in Hawai'i:

A Source of Private and Public Benefits

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EXECUTIVE SUMMARY

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

In response to concern about increasing urbanization, the Hawai`i State Legislature passed Senate Resolution LRB 06-2901 (SR-86) (see Appendix 1), which calls for the University of Hawai`i at Manoa, College of tropical Agriculture and Human Resources to "to gauge the feasibility of rooftop landscaping and agriculture in urban districts subcategories, such as commercial, hotel, multi-family, industrial, or mixed use with a commercial component." This report addresses the Resolution by providing some basic facts about green roofs, and presenting the quantitative and qualitative information about various benefits and costs of green roofs in order to gauge feasibility. Policies instruments are then investigated in order to determine what decision-makers should consider in order to make the installation of green roofs more attractive to residents and businesses. Then, the potential for green roofs in downtown Honolulu, Waikiki and Kaka`ako are examined, followed by the results of an opinion poll for residents and visitors about green roofs. Finally, some overall conclusions and recommendations are offered in order to assist policymakers in looking toward the future of green roofs in Hawai`i.

The term green roof is generally used to describe a built surface containing a substantial portion that sustains a permanent vegetative layer (Environmental Affairs and Los Angeles, 2006). Green roof is used in a broad context 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 contains the same basic elements of a vegetative layer, a growing medium like soil, fiber cloth, a layer for drainage, water storage and aeration, a root barrier and a waterproof membrane (Moyer 2005).

Green roofs provide two types of benefits that have been widely documented. Private or direct benefits are those that accrue solely to the owner. These types of benefits generally include reduced energy consumption and increased roof life, but projects may increase building value, decrease building management costs, prevent fires, and boast customer and employee satisfaction. The public or indirect benefits of green roofs are much more extensive. They include improved rain water management, reduction in urban heat, improved air quality, increase in green space, increase in local food supply, increased wildlife habitat and native plants communities, noise abatement, and reduction in radiation from telecommunication towers. While the public benefits from green roofs are many, they are difficult to quantify because their monetary value is hard to assess.

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 costs between the two different roofing systems. However, the exact cost of a green roof will depend on a variety of factors.

The high initial cost of green roofs relative to conventional construction discourages their installation, while at the same time, many of the benefits of green roofs accrue to the public. While the private benefits are expected to be large enough to pay back the initial investment over the life of the building (http://www.lid-stormwater.net/greenroofs/greenroofs_cost.htm), most property owners have a high opportunity cost of waiting, which makes them more reluctant to invest in green roofs. At the same time, the benefits cannot be determined with certainty and this risk makes owners reluctant to invest.

The benefit-cost disparity creates a challenge as public decision-makers attempt to encourage the use of green roof. A variety of 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 adopt policies that ultimately make cities more sustainable (Chellsen, 2006). The regulatory approach appears to be much more effective than the 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 that the regulations should not mandate green roofs as the solution, but 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 secondly without proper buy-in from the public, resentment occurs (Chellsen, 2006).

The three tools that will likely be the most useful in implementing green roofs in the US are: 1) mitigation regulations designed to address increased urbanization; 2) storm water fees based on impermeable surfaces; and 3) decentralization of storm water management (Keeley, 2004). This provides a starting point for policy makers in Hawai`i. Clearly the private and public benefits of green roofs are greater than the costs and, based on this, countries around the world have aggressively encouraged green roof construction. However, private property owners may not perceive that the private benefits are greater than the private costs, which creates challenges for policymakers. Therefore, various legislative instruments were used to adjust the benefit and costs structure in order to assure that private owners perceive that the benefits outweigh the costs. At the same time, as green roofs become more commonplace, economies of scale occur and private costs decline over time.

Three highly developed areas, Waikiki, Downtown and Kaka`ako, on the island of O`ahu were selected for study in this report. The rooftops in these areas contain a total square footage of 10,216,310 that is 48 feet tall or less as acquired. This footage is considered to be the most attractive area in which to install green roofs because the private benefits from a reduction in the cost of cooling will accrue to owners of these properties. The buildings between 48 and 144 feet high 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 of roof area 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 enact to encourage the installation of green roofs in existing buildings. The study area has a large amount of impervious surface and a relatively small amount of vegetation, especially Kaka`ako. Illustrations showing 25, 50 and 75 percent green roof coverage demonstrate the visual impact of green roofs in the area.

Residents and visitors were surveyed to determine their attitudes toward green roofs and 36 percent had heard of green roofs and 61 percent had not. Of those who had heard of green roofs, only nine percent were very familiar with them, while 23 percent were somewhat familiar with them.

As far as having the local or State government promote green roofs, a 77 percent of the respondents were very much in favor or somewhat in favor. Forty-eight percent of respondents were very much in favor or somewhat in favor of the local or State government mandating green roofs, while 36 percent were neutral and 16 percent were somewhat or very much opposed.

Survey results show that 81 percent of the respondents indicated that improvements in air quality from green roofs would be very important to them. Likewise, 79 percent of the respondents believe that improved water quality was a very important benefit from green roofs, as well as 77 percent responded 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. Educational outreach is also of interest to survey respondents as reflected by a 79 percent agreement that it is very to somewhat important.

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 there 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 State Legislature wants more information about what policies are most effective. The University of Hawai`i can provide outreach education and could construct demonstration sites in order to collect the needed data. Landscape designers/architects, nursery operations, and landscape contractors are excited about this new market, which includes all existing and future roofs in the State.

Green roof technologies can help provide a more sustainable Hawai`i. Resources devoted to developing such technologies today will ensure a greener tomorrow for Hawai`i.

INTRODUCTION

As urbanization and density increases in Hawai`i, the views of open spaces and green landscapes are vanishing. Conventional rooftops are barren, harsh places that must weather rain, wind and sun. Therefore, they reflect light, absorb heat and act as waterproof surfaces, directing all the rain into roof drains. The air conditioning units, building ventilation and other utility features detract further from the view. Modern urban landscapes include acres of rooftops that for the most part lie desolate and forgotten. At ground level the buildings that dominate these landscapes are alive and vibrant with shopping, commuting, planting and people, but at the roof level they are lifeless. (Thompson & Sorvig, 2000)

In order to make the barren rooftops that exist in the State more green, the Hawai`i State Legislature passed Senate Resolution LRB 06-2901 (see Appendix 1.), which calls for the University of Hawai`i at Manoa, College of tropical Agriculture and Human Resources to "to gauge the feasibility of rooftop landscaping and agriculture in urban districts subcategories, such as commercial, hotel, multi-family, industrial, or mixed use with a commercial component." This report addresses the Resolution by providing some basic facts about green roofs, and presenting the quantitative and qualitative information about various benefits and costs of green roofs in order to gauge feasibility. Various policies are then investigated in order to determine what decision-makers should consider in order to make the installation of green roofs more attractive to residents and businesses. Then, specific benefits and costs of green roofs for downtown Honolulu, Waikiki and Kaka`ako are examined, followed by the results of an opinion poll for residents and visitors about green roofs. Finally, some overall conclusions and recommendations are offered in order to assist policymakers in looking toward the future of green roofs in Hawai`i.

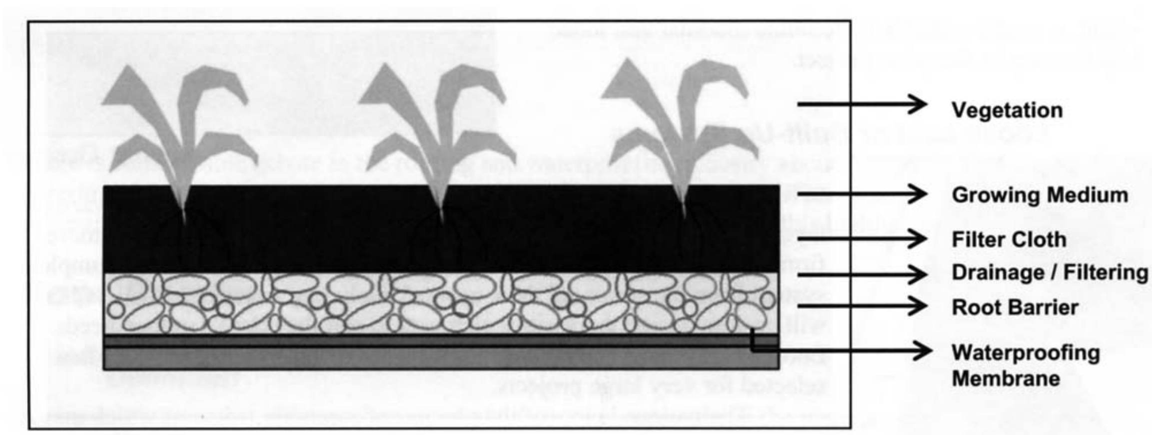
Green Roof Background and Definitions

The term green roof is generally used to describe a built surface containing a substantial portion that sustains a permanent vegetative layer (Environmental Affairs and Los Angeles 2006). 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 contains the same basic elements of a vegetative layer, a growing medium like soil, fiber cloth, a layer for drainage, water storage and aeration, a root barrier and a waterproof membrane in Figure One (Moyer 2005).

As globalization brings about more development and a decrease in green landscapes, the interest in green roofs is growing. The concept of green roofs has been around the idea since the hanging gardens of Babylon and therefore, is not a new technology. In the 1800's, green roofs were promoted by leading modernist architects Le Corbusier, Roberto Burle Marx and Frank Lloyd Wright. The 1868 World Exhibition in Paris included a planted "nature roof" on concrete, the first of a series of high-end experimental projects. Wright designed a restaurant roof garden in Chicago, IL, in 1914, and the roof garden on the Rockerfeller Center in New York, built in the 1930's, which is still in existence (Dunnett *et al.* 2004, Grant *et al.* 2003). In the 1980's, Germany started

Figure One. Overview of Green Roof Functions and 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



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

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 and recyclable materials, and intensive use applications similar to terrestrial spaces. "the green roof used to be in competition with other ecologically oriented forms of use such rain water use or solar power facilities. Today, a combination of different forms of use is preferred to even mix synergy effects."; "The excess water is guided into cisterns and used for the irrigation of the roof gardens and for flushing toilets"(Appl and Ansel 2004).

As Figure Two indicates, the two main types of green roofs are extensive and intensive (Grant *et al.* 2003). Both types furnish similar benefits to the building and surrounding area, but differ in their design, primarily in the depth of the growing media, and level of accessibility, although other differences are described in Figure 2. Semi-intensive roofs also exist which are typically between the two depths of growing media.

Figure Two. Characteristics and Advantages of Extensive and Intensive Green Roofs

MAJOR GREEN ROOF TYPES

Characteristics of Extensive and Intensive Green Roofs			
CHARACTERISTIC	EXTENSIVE	SEMI-INTENSIVE	INTENSIVE
DEPTH OF MATERIAL	6" or less	Above and below 6"	More than 6"
ACCESSIBILITY	Often inaccessible	May be partially accessible	Usually accessible
FULLY SATURATED WEIGHT	Low 10-35 lb / ft^2 (48.8 - 170.9 kg / m^2)	Varies 35-50 lb / ft^2 (170.9 – 244.1 kg / m^2)	High 50-300 lb / ft^2 (244.1 – 1,464.7 kg / m^2)
PLANT DIVERSITY	Low	Greater	Greatest
COST	Low	Varies	Highest
MAINTENANCE	Minimal	Varies	Highest

GENERAL ADVANTAGES OF DIFFERENT GREEN ROOF TYPES		
EXTENSIVE	SEMI-INTENSIVE	INTENSIVE
Lightweight	Combines best features of extensive and intensive	Greater diversity of plants
Suitable for large areas	Utilizes areas with greater loading capacity	Best insulation properties and stormwater management
Low maintenance costs and no irrigation required	Greater coverage at less cost than intensive	Greater range of design
Suitable for retrofit projects	Average maintenance	Often accessible
Lower capital costs	Greater plant diversity than extensive	Greater variety of human uses
Easier to replace	Greater opportunities for aesthetic design than extensive	Greater biodiversity potential

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

Intensive roofs, as shown in Figure Three, are designed to provide the same recreation, relaxation and food production services as a garden on the ground. They may be considered to be roof gardens. They typically require regular maintenance and irrigation. The need for accessibility and the soil depth of up to 12 inches or 30 cm requires that the underlying roof be structurally capable of bearing considerable weight. An intensive planting generally adds between 80 to 150 lbs/square foot, or 391 to 732 Kg/square meters to roof weight (Environmental Affairs and Los Angeles 2006).

Extensive green roofs, also shown in Figure Three, are relatively self-sustaining after the establishment of the vegetative layer and are often constructed for their environmental and energy benefits. Access occurs only for maintenance, and little to none supplemental irrigation occurs 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 an extensive roof system makes them light enough for existing buildings with little or no additional structural support. The hearty vegetation survives in only a few inches of specialized soil substitutes, with very little organic matter. This growing medium, as it is called, is often very specifically designed, to fit the selected plants and the specific 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 its 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 expanded the ways in which vegetation can be integrated into the built spaces. Green walls/facades, roofs planted with sod or simple intensive green roofs, and hydroponic food production systems (Grant, Engleback et al. 2003; Wilson 2002) are related approaches to bringing 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, like 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 two types of benefits that have been widely documented. Private or direct benefits are those that accrue solely to the owner. These types of benefits generally include reduced energy consumption and increased roof life, but projects may increase building value, decrease building management costs, prevent fires, and boast customer and employee satisfaction. The public or indirect benefits of green roofs are much more extensive. They include improved rain water management, reduction in urban heat, improved air quality, increase in green space, in crease in local food supply, increased wildlife habitat and native plants communities, noise abatement, and reduction in radiation from telecommunication towers. 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 water 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. 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, since the water quality in a stream or ocean is not a good or service sold in a market, no market price exists. Various non-market valuation techniques exist; however, extensive research would be required to quantify each public benefit before totaling the public and private benefits. Therefore, the public benefits of green roofs are qualified in this report, but are not quantified.

Figure Three.
Examples of Green Roofs

Photo courtesy of http://www.hrt.msu.edu/greenroof/
Ford assembly plant, Michigan

Photo courtesy of http://www.hrt.msu.edu/greenroof/

Photo courtesy of http://www.hrt.msu.edu/greenroof/

Photo courtesy of http://www.hrt.msu.edu/greenroof/
Chicago City Hall. (Roofscapes, Inc.).

Photo courtesy of http://www.hrt.msu.edu/greenroof/

Photo courtesy http://www.hrt.msu.edu/greenroof/
(Behrens Systementwick)

Photo courtesy of http://www.hrt.msu.edu/greenroof/

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
  - 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 specific design and the property owner's objective. Designs that are integrated overall with the building are likely to achieve maximum benefits.

A study conducted by Ryerson University looking at the Environmental benefits and costs of green roof technology for the City of Toronto, Canada reveals some interesting aspects of using green roof for a variety of environmental and economic. The following blocks summarize some of the reports findings.

Indirect energy savings from green roof implementation
(Impact of reduction in urban heat island effect in Toronto)

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

Savings category	Amount of saving per sq. m. of green roof area
Direct energy savings	2.37 kWh/ sq. m./year
Demand load reduction from direct energy reduction	0.00267kW/ sq. m. peak

The economic benefits from the reduction in the urban heat island effect are calculated in the same manner as the building energy benefits. Based on the annual energy savings of 2.37 kWh per sq. m., the city-wide implementation of green roofs would result in a savings of $12 million.

The demand reduction based on peak demand reduction of 0.00267 kW per sq. m. for citywide green roof implementation would be 133 MW[8]. Based on the cost of bringing in new generation capacity at $0.6 million per MW (based on a cost of bringing in 2,500 MW of new power plant estimated at $1.5 billion) the cost avoided from reduction in peak demand would be $79.8 million.

Finally the carbon dioxide mitigation from reduction in fossil fuel use at power generating stations would be 32,200 metric tone per year. Assuming the cost of carbon permits to be $10 per metric tone, the cost savings from carbon dioxide mitigation would be $322,000 per year.

[8] The peak demand savings of approximately 248 MW (direct and urban heat island) resulting from 100% green roofs coverage may be considered high given the total peak demand attributed to cooling in Toronto of approximately 2.5 GW peak (as provided by Toronto Hydro during personal communications). Please refer to Section 5.4 regarding uncertainty in predicted values and sensitivity analysis

Direct Energy savings from green roof implementation

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

Savings category	Amount of saving per sq. m. of green roof area
Direct energy savings	4.15 kWh/ sq. m./year
Demand Load reduction from direct energy reduction	0.0023kW/ sq. m. peak

Before the economic benefits from building energy savings can be determined it is necessary to establish the cost of energy. We have calculated the cost of electricity, which is predominantly used to run equipment that cools buildings, to be $0.1017 per kWh. Based on annual energy savings of 4.15 kWh per sq. m., the city-wide implementation of green roofs would result in savings of $21 million per year.

The demand reduction, based on peak demand reduction of 0.0023 kW per sq. m. for citywide green roof implementation would be 114.6 MW[8]. Based on the cost of bringing in new generation capacity at $0.6 million per MW (based on a cost of bringing in 2,500 MW of new power plant estimated at $1.5 billion), the cost avoided from reduction in peak demand would be $68.7 million.

The carbon dioxide mitigation from reduction in fossil fuel use at power generating stations would be 56,300 metric tones per year. Assuming the cost of carbon permits to be $10 per metric ton, the cost savings from carbon dioxide mitigation would be $563,000 per year.

Summary of municipal level environmental benefits of green roof implementation in the City of Toronto (Assuming green roof coverage of approximately 5,000 hectares

Category of benefit	Initial cost saving	Annual cost saving
Stormwater		
Alternate best management practice cost avoidance	$79,000,000	
Pollutant control cost avoidance	$14,000,000	
Erosion control cost avoidance	$25,000,000	
Combined Sewer Overflow (CSO)		
Storage cost avoidance	$46,600,000	
Reduced beach closures		$750,000
Air Quality		
Impacts of reduction in CO, NO_2, O_3, PM_{10}, SO_2		$2,500,000
Building Energy		
Savings in annual energy use		$21,000,000
Cost avoidance due to peak demand reduction	$68,700,000	
Savings from CO_2 reduction		$563,000
Urban Heat Island		
Savings in annual energy use		$12,000,000
Cost avoidance due to 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

PRIVATE OR DIRECT BENEFITS

Energy conservation

A green roof adds layers of insulation, which reduces the amount of energy needed to cool the building. Research suggest that the energy savings can be maximized by targeting medium to low density areas in which the roof area compared to the building's square footage of internal space is greater. (Alcazar, Bass, 2006). This means that a high-rise building likely will not benefit as much a low-rise building because the cooling effect of the green roof does not extend past about six stories. Therefore, one-story establishments such as Costco, K-mart, and Home Depot are considered to be good candidates for green roofs.

The actual reduction that can be expected in energy consumption due to the installation of a green roof varies, depending on the climate and the cost of energy. Reduction in energy consumption for cooling were found to be 6.2 percent in Madrid, Spain (Alcazar, Bass, 2006), while the energy savings for a 12,000 square foot grocery store in Pittsburgh were $10 a year in natural gas or $657/yr in electric for an extensive roof and $20/yr in natural gas or $1314/yr in electric for an intensive roof (Kosareo, Ries, 2006). Little work on green roofs has been done in tropical regions.

Hawai`i energy costs are among the highest in the US. (USDE 2006) and this differential is expected to increase as oil prices climb higher. Ninety-three percent of the total energy used in Hawai`i comes from imported oil, while 32 percent of HI's oil imports are used to produce energy (HECO 2006). While the energy savings from green roofs cannot be estimated precisely due to a lack of data, the direct benefit will clearer be larger for property owners in Hawai`i, as compared to elsewhere in the U.S.

Increase in roof life

The green roof system adds component layers in addition to the vegetative layer, which adds a higher degree of protection from solar and other factors: UV rays, wind extremes, and temperature fluctuations (Taube, 2003). Therefore, a green roof system protects a roof's structural elements from these environmental factors which lends to a longer roof life as opposed to conventional roofing technology. A conservative estimate for a conventional roof is a life expectancy of twenty years. For a green roof system, a conservative estimate is 40 plus years (Brad Rowe, Ph.D., personal communication December, 14, 2006).

Other benefits

Other private benefits that are often mentioned include fire retardation, increased building value, decreases building management costs and increased customer and employee satisfaction. However, little has been done to quantify these benefits (Green Roofs Infastructure: Design and Installation 201, Participant's Manuel green Roofs for Healthy Cities, (www.greenroofs.org.).

PUBLIC OR INDIRECT BENEFITS

Improved Rain Water Management

Around 75 percent of a city's rain water is directly lost to surface runoff with roofs representing approximately 40 to 50 percent of the impermeable surfaces these urban areas (Sholz-Barth 2001 in Snodgrass 2005). Green roof systems absorb part of the water, using it as irrigation for the plants, although a small amount overflows into the storm drain system once the soil or soil replacement is saturated. Heavy rains tax existing storm water systems and may cause overflow or stress pipes. When storm systems are receiving smaller volumes, they will operate longer with reduced stress, which translates into fewer dollars that go into repairs and emergencies. Costs are also reduced as smaller bore pipes are used in drainage systems (Kohler et al. 2002).

Green roofs also have the ability to prevent pollutants from contaminating runoff by lengthening the time it takes for the water to reach the storm system and in the process, filtering out the pollutants. The storm water from rooftops is a significant factor in adding pollutants, such as oil, heavy metals, animal waste, pesticides, and other particulates, to downstream bodies of water. A recent study in North Carolina concluded that between 10 to 30 percent of the nitrogen and phosphorous added to downstream streams and lakes could be traced back to rooftop storm water. These chemicals are considered to be pollutants and have a destructive impact on aquatic habitats. Chellsen, 2006).

Research comparing traditional methods for reducing storm water runoff with an extensive and intensive green roof found that the control or traditional method generated a 33 percent reduction, while an extensive and intensive green roof generated a 60 and 85 percent reduction, respectively (Kosareo, Ries, 2006). In further comparisons of the runoff from green roofs to conventional roofs, research concluded that extensive and intensive green roofs, respectively, can reduce lead levels 9.3 and 5.3 times, zinc levels 2.5 and 1,2 times and cadmium levels 5 and 2.8 times lower than those for conventional roofs (Kosareo, Ries, 2006). As plants in the green roof develop, the amount of P (phosphorous) that they retain from the rainwater increased from around 26 percent the first year, 61 percent the second year, and 80 percent in fourth year (Kohler *et al.* 2002).

Quantifying the total monetary value to the public from a reduction in storm water runoff has not been done directly. However, many municipalities are moving towards assessing storm water fees based on a property's total impervious surface. This fee would provide public funds to mitigate storm water runoff and the damage caused the resulting pollution. By installing a green roof to mitigate runoff, property owners would realize a direct benefit as a reduction in the impervious surface fee. (Clark, Adriaens, & Talbot, 2003).

O`ahu does not have a combined sewer and rain water management system (Honolulu ENV 2006), which causes frequent sewer overflows in New York and many other municipalities (Hoffman 2006). However, heavy rains were cited as one of the possible causes for the rupture of a wastewater pipe along the Ala Wai Canal that resulted in 48,000 tons of sewage being dumped into the canal (HSIWTS 2006).

Runoff is a concern for coastal waters, beaches, coral reefs and marine life, particularly given the State's small island ecosystems. All of the water that falls on O`ahu rooftops soon makes its way very quickly to the ocean. The silt and sediment it carries damages the reefs and lowers the water quality that is so critical to the habitat of many of our marine species. Runoff rich in nutrients and sediment can smother reefs, encourage algal growth that competes with corals, and decrease fish populations. (Yuen 2005) O`ahu has 11 water bodies that have been reported as having water quality problems. These include: Ala Wai Canal, Honolulu Harbor, Kahana Bay, Kaneohe Bay, Kapaa Stream, Kawa Stream, Keehi Lagoon, Kewalo Basin, Pearl Harbor, Waialua-kaiaka Bays, and Waimanalo Stream (http://www.scorecard.org/env-releases/water/cwa-county.tcl?fips_county_code=15003#ranking). Clearly, runoff from urban areas has already affected the water quality in O`ahu's coastal zones. At the same time, runoff can also threaten humans. Since water quality measurements taken at the State's beaches have been improved, the number of Hawai`i beach closures that occurred due to high levels of contamination increased by 91 percent (ENS 2006).

Currently property owners in Hawai`i are not charged direct fees charged based on a property's impervious surfaces or on the actual storm water volumes leaving a site. Therefore, any reduction in these volumes from green roofs, while alleviating some stress on the existing municipal drainage framework and preventing pollution in the State's highly valued beaches and reefs, would generate a financial return to the property owner. However, property owners would glean positive non-market values associated with their contribution toward moving Hawai`i into a more sustainable future.

Reduction in Urban Heat Island Effect and Improved Air Quality

Evapotranspiration and photosynthesis from green plants can help lower temperatures and increase air quality by absorbing CO_2 and releasing oxygen. Research indicates that a 155 m2 of 'plant surface area' can produce enough oxygen for one person for 24 hours (Kuhn, 1996)." In addition to increasing the oxygen supply, green roofs filter pollutants, bind dust particles, and reducing glare (Chellsen, 2006). Since green roofs introduce plants into areas that are expected to have substantial amounts of NOx, green roofs have been shown to help mitigate smog (Chellsen, 2006).

Since improved air quality is a public benefit, determining its value is difficult. However, some research has been done in this area, which values the NOx reduction for a square foot of green roof per year at $0.02-$0.70 (Clark, Adriaens, Talbot, 2003). In some municipalities, the inclusion of NOx and other air pollutants in a tax, with rebates based on property owners measures to reduce air pollution caused by improvements on their property is another alternative tax and incentive. (Clark, Adriaens, Talbot, 2003). O`ahu does appear to face challenges with its air quality. Emissions of carbon monoxide, nitrogen oxide, PM-2.5, PM-10, sulphur dioxide and volatile organic compounds place O`ahu in the 90 to 100 percentile for dirtiest counties in the U.S. (http://www.scorecard.org/envreleases/cap/county.tcl?fips_county_code=15003#air_rank ings). The air quality index places O`ahu in the 80 to 90 percentile for worst countries in the U.S. Thus, it appears that the public would benefit from an increase in air quality that would be expected to accrue from the installation of green roofs.

Increase in green space

People prefer the view of a green field of green to a sea of pavement and hard surfaces. Rooftops present a large untapped resource for urban greening, as they constitute most of the unused space in cities and towns. For example, the combined roof area of Greater London is 28 times the size of Richmond Park (Grant *et al.* 2003). The replacement of conventional rooftops with green roofs would provide a significant visual improvement for residents and visitors. As green roofs become more prevalent, these spaces will start to visually link and become a larger pattern of connected greenways and increase their positive impact.

The value of public views is not been widely documented. It is possible for private property owners to benefit from views of green space and this benefit is the most widely documented. Vancouver's Fairmount hotel, which has a 2,098 square foot roof garden, is able to charge a higher rate for adjacent rooms (Dunnett and Kingsbury 2004). In Hawai`i green space is an important source of benefit for the visitor industry. Based on a survey of 64 visitors to Hawai`i, Foy *et al.* (2002) determined that roughly one third of surveyed visitors would be willing to pay more for a hotel room from which the view of adjacent buildings is obscured by landscaping features. Study results indicated that, for each percent of the view that includes greenery, hotels could garner an additional $0.36 on the daily room rate from guests who are willing to pay for a view (Foy *et al.* 2002).

Increase in the local food supply

Food produced by rural growers travels an average of 1,500 miles to reach its North American consumers, losing nutritional value and requiring significant energy expenditures (Smith, 1998; Wilson, 2002). Green roofs can contribute to the availability of locally grown food. The literature has extensive examples that demonstrate the degree to which green roofs increase the local food supply.

In Toronto, Canada, restaurant buyers value the fact that they can receive produce from rooftop grower Annex Organics the day it is picked. Using a semi-hydroponic system, in which soil planters sit inside troughs of water, the company produced 550 lbs of tomatoes in its first year, and anticipated twice that amount in the second year. The rooftop enterprise is supported by the municipal agency Foodshare Metro (Smith, 1998). In Brisbane, Australia, surveys of potential buyers suggest that organic produce sold on the day of harvest could garner 10 percent higher prices from many potential consumers, and minimize the cost of transporting produce to market (Wilson, 2002). In Vancouver, the Fairmont Hotel's 2,098 square foot roof garden, with a soil depth of 18 inches, supplies all of the culinary herbs used in the hotel, at an annual cost saving of 25,000-30,000 Canadian dollars (Dunnett and Kingsbury 2004).

The potential exists for making green roofs an interactive agricultural tourist attraction, both to vacationers, and to professionals seeking exposure to rooftop technologies

(Wilson, 2005). Hotel guests can view or pick produce grown on the roof and eat it in the hotel restaurant. An organization in New York City hosts cooking classes which showcase produce grown on the organization's roof (Dunnett and Kingsbury 2004). Other commercial opportunities include leasing of accessible rooftop space for crop cultivation (Dunnett and Kingsbury 2004).

Bringing food production closer to consumers is also facilitates the systemic linkages that will result in waste being converted to into resources. A pilot project of the Southside Chamber of Commerce in Brisbane, Australia, slated to begin this year, will integrate hydroponic and containerized-soil agriculture with aquaculture and food waste recycling on the roof of a local supermarket. This innovative urban microfarm model brings together many of the benefits of agriculture on green roofs, including localized food production, waste recycling, job creation and the environmental services provided by a green roof. Local restaurants, clubs and hospitals will contribute their food waste to the rooftop worm composting operation, where it is turned into quality soil and liquid fertilizer for the rooftop plantings. Extra worm castings may be sold to garden stores as a valuable soil amendment. The worms are processed and fed to fish and crustaceans in the aquaculture operation. Liquid worm casting and fish effluent fertilize the plants grown hydroponically, allowing the growers to fetch higher prices with an organic certification. The food waste is thus diverted from a landfill, where it would produce methane, a powerful greenhouse gas that contributes to global warming. In Brisbane, where periurban farms are under constant threat from urban expansion, this model utilizes rooftop space that does not currently compete with anything. A 1999 feasibility study by Integrated Skills Consulting Pty Ltd. for the approximately 2000 square foot project projected a total startup cost of 114,840.54 USD. They expect the enterprise to generate a net profit after 17 months of operation, with a subsequent 20 percent return on investment. The necessary equipment is either commercially available, or can be constructed with proven and available elements.

Increase in wildlife habitat and native plant communities

Green roofs supply open green space that can create wildlife habitat for birds and insects. These areas could be used for specially selected native species that grow in rocky, cliff locations that survive hot, windy conditions naturally and may increase their likelihood of survival because they don't have to compete with invasive or dominant introduced plant species. (Green Roofs Design 101, Participant's Manuel, Green Roofs for Healthy Cities, www.greenroofs.org.)

Noise and radiation abatement

The literature documents that green roofs provide noise abatement, and a reduction in radiation from telecommunication towers (Chellsen, 2006; Taube, 2003). Noise from construction has been shown to have significant psychological effects on people in urban areas, and is increasing increase as cities continue to grow (NRIAQ 2006).

COSTS

The overall out-of-pocket investment in 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 costs between the two different roofing systems. However, the exact cost of a green roof will depend on a variety of factors. These factors are also discussed here.

Installation costs

Extensive roof systems cost less than either semi-intensive or extensive gardens, although intensive systems offer a greater return on investment (ROI) due to the increased energy savings, primarily cooling, and improved water and air management. The cost of an extensive system is $10 to $20 per square foot (Earth Pledge, 2005). The cost of intensive systems varies, with one source indicating a modular unit would cost as little as $13 per square foot. However, intensive systems will be higher than those for extensive systems because of the increased structural support needed in order to support the additional weight. Costs can vary substantially, particularly for intensive systems, based on the design, as indicated in Figure Four and Five. One reference indicated that the cost of a semi-intensive green roof was $45.50 in 2001 (Earth Pledge, 2005)

Costs will likely go down as the standardization and certification of green roofing 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 US costs. The benefit 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 separated 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). This type of standardization and design guidelines in the United States will certainly improve the chances of green roofs being implemented.

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 is 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 the volcanic rock, "Grodan", has been used in Denmark as growing media on green roofs for more than 20 years (Thompson & Sorvig, 2000). Hawai`i may have an opportunity to develop green roof materials 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.

Maintenance cost

The maintenance cost of a conventional roof that is assumed to be replaced every 20 years costs $0.01per square roof per year, while a green roof costs $0.10 per square foot per year to maintain for the first five years and then drops to $0.05 per square foot as the green roof matures In year six (Clark, Adriaens, Talbot, 2003).

Figure Four. Cost Ranges and Factors for Green Roofs

COST RANGES AND FACTORS*		
ELEMENT	**PRICE RANGE $USD**	**COST FACTORS**
DESIGN	4-8% of project cost	Size and complexity of project
PROJECT ADMIN. / SITE REVIEW	6-12% of project cost	Size and complexity of project and number of professions involved
INITIAL STRUCTURAL EVALUATION	$0-$1000	New versus existing building, Quality of documentation.
(RE) ROOFING WITH HIGH-QUALITY MEMBRANES	$0-12 / ft^2	Depends on components, size, accessibility and the number of roof penetrations.
DRAINAGE	$1-$5.50 / ft^2	Type of drainage layer, size of project
FILTER CLOTH	$0 -$0.50 / ft^2	
GROWING MEDIUM	*Extensive* $2 - $12 / ft^3	Volume / type of growing medium, shipping distances and how transported to roof (crane, blower truck, manual etc.)
	Intensive $2 - $20 / ft^3	
VEGETATION	*Extensive* $0.20 - $5.00 / ft^2	Type and size of plants, time of year, seeds, cuttings, plugs, mats, pots, shrubs, trees – may require containers and / or anchorage
	Intensive $1.25 - $10 / ft^2	
INSTALLATION	*Extensive* $2.40 - $6.40 / ft^2	Size of project, sophistication of design, type of planting approach, nature of access to roof, etc.
	Intensive $6.40 – $14.40 / ft^2 (100 to 200 % of material costs)	

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

Figure Five. Cost Ranges and Factors for Green Roofs

COST RANGES AND FACTORS*		
ELEMENT	**PRICE RANGE $USD**	**COST FACTORS**
MODULAR GREEN ROOF SYSTEM (includes vegetation, planting, growing medium & root repellant layer)	*Extensive* $10+ / ft^2	Sophistication of design, shipping, installation, plant species and density
	Intensive $13+ / ft^2	
STRUCTURAL REINFORCEMENT OF EXISTING ROOF	(costs are highly dependent on existing structure)	May not be necessary. Consult a structural engineer to determine the load carrying capacity of any roof
CURBING / BORDERS	$0 - $20 per linear foot	May not be necessary. Type (pre-cast concrete, aluminum edging, wood, gravel, timber borders, modular systems, recycled products etc.) & length
WALKWAYS	$0 - $10.20 / ft^2	May not be necessary. Type (pre-cast concrete unit pavers, natural stone, wood decking, recycled products etc) & length
RAILINGS	$0 - $65.45 per linear foot	May not be necessary. Material (aluminum, brass, wrought iron, welded steel, etc.). Thickness of railing. Number of rails. Roof deck penetration.
MAINTENANCE	*Extensive* $0.25 - $4.10 / ft^2 for the first two years	Size of roof, types of plants, nature of access.
	Intensive $1.00 - $4.10 / ft^2	
IRRIGATION SYSTEM	$0 - $5.00 per linear foot	May not be necessary. Type of irrigation system used and size of project.

*Costs may vary significantly due to regional differences
**Based on 2005 National Construction Estimator

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POLICY DIRECTIVES TO ENCOURAGE GREEN ROOF INSTALLATION

The high initial cost of green roofs relative to conventional construction discourages their installation, while at the same time, many of the benefits of green roofs accrue to the public. While the private benefits are expected to large enough to pay back the initial investment over the life of the building (http://www.lid-stormwater.net/greenroofs/greenroofs_cost.htm), most property owners have a high opportunity cost of waiting, which makes them more reluctant to invest in green roofs. At the same time, the benefits are cannot be determined with certainty and this risk makes owner reluctant to invest.

The benefit-cost disparity creates a challenge as public decision-makers attempt to encourage the use of green roof. A variety of policy instruments aimed at increasing the use of green roofs have been used around the world. Table One lists various policies that are used worldwide to encourage green roof installation.

In a study that looked at many different types of green roof policies, researchers concluded that policy makers should not mandate a particular solution, but instead adopt policies that ultimately make cities more sustainable (Chellsen, 2006). The regulatory approach appears to be much more effective than the incentives, although incentives that mitigate the cost of installing a green roof are generally effective. Six policies designed

Table One. Types of policies that encourage green roof installation

Economic Incentives	**Regulatory or Process Benefits**
Reduction in permitting fees	Density Bonus Allowance
Grants	Green Space Waivers or Variances
Tax incentives	Expedited Permitting Process
Low interest loans	
Storm water Credits	

to encourage the adoption of green roofs in Portland, Chicago, and Minneapolis were examined and the incentive based approaches accounted for the fewest number of green roofs, while flexible and inflexible regulations yielded roughly the same number. 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 that the regulations should not mandate green roofs as the solution, but 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 secondly without proper buy-in from the public, resentment occurs (Chellsen, 2006).

Green roof policies in other cities

Germany is likely the world's leader in green roofs. Federal environmental laws require mitigation or compensation for the destruction of natural open space caused by development. Because of high urban density to real estate values, Germany provides indirect and direct subsidies and ordinances for the installation of green roofs. In 1996 a survey done by *Zentralverband Gartenbau e.V.* (ZVG), the Gardening Central Association, revealed that approximately 50 percent, or over 80 cities in Germany offered incentives to building owners utilizing green roofs. In Stuttgart, Germany green roofs are required in developing housing areas to offset the human impact on the natural environment, which has resulted in more than 100,000 sm of public rooftop and 50,000 sm of private roofs have been greened since 1986 (Appl, 2006).

According to Green Roofs for Healthy Cities, 80 percent of the green roofs are extensive. A tax is used to cover the cost of rainwater management and a 100 percent utility surcharge is levied against owners of impervious roof covers (Dr. Michael Krebs, 1999). German cities allow a reduction between 50 percent and 80 percent of the utility fee for using a green roof. Over a 36-year period, the reduction in the usage fee alone can

compensate the building owner for as much as 50 percent of the additional capital cost (ZVG, 1996).
An indirect subsidy allows developers to use green roofs as mitigation for the provision of open space, which is an attractive alternative in areas with high real estate prices. Depending on the plant material, local land development ordinances allow green roofs to compensate for lost open space using a ratio of .50 to .70. Other alternatives for mitigation include the restoration of existing impervious surfaces to create open space or improving the biodiversity of existing open space (Charlie Miller publication, 1998; Greenroofs.com 2006).

In Japan, as of 1 April 2000, new public and private commercial developments with roof areas over 250 meters and 1,000 meters respectively, are expected to green a minimum of 20 percent of any flat roof area. In Singapore, the National Parks Board promotes the use of green roof technology on built structures. The large number of high-rise building in Singapore that have roofs that are not meant to be publicly accessible makes them an ideal location for extensive green roofs. Green roofs that originated in temperate countries are now being tested for large-scale use in Singapore. A Pilot Green Roof Research Project in Singapore conducted by researchers, and is one of the first testing to be done in tropical environments (Yok and Sia, 2005).

Chicago first led by implementing green roofs on the city owned buildings, then providing incentives, but when there was little change, the city adopted the "Building Green/Green Roof Policy". Since 2002 when it was enacted, 150 green roofs have been constructed, which cover more than two million square feet. To illustrate how an incentive program stacks up against the regulation, only 10 of the 150 green roofs implemented applied for the density bonus (Chellsen, 2006). The Energy Conservation Ordinance of 2002 requires all new and refurbished roofs to install green roofs or reflective coatings; enacted in 2002). Chicago also has a Density Bonus enacted in 2004 that gives a credit based on square feet of green roof. The City announced a pilot program in June of 2006 to match up to $100,000 for downtown buildings to retrofit their roofs with green roofs (Buscemi, 2006).

Minneapolis implemented their "Storm Water Ordinance" in 1999 with the goals of reducing pollutants and nutrients and reducing the volumes of water conveyed. Since the regulation approached storm water in a more general sense, only seven green roofs have been installed, but over 200 projects have been implemented that include best management practices (BMP's) such as rain gardens, infiltration areas, and pervious pavements (Chellsen, 2006). Minneapolis also enacted a Storm Water Fee Credit gives incentives to implement best management practices in 2005.

Portland, Oregon has a Density Initiative that credits square feet of green roof towards their density regulations enacted in 2001. Portland also has a "Storm Water Management" ordinance enacted in 2003 that requires reduced runoff, reduced storm water peak flows and volumes and increase groundwater recharge. Portland also has a green roof development bonus and the "Central City Fundamental Design Guidelines" have been revised to include green roofs. Portland has an existing infrastructure of technical assistance programs and policies that are credited with much of the successful implementations of green roofs (Johnson, 2004). A program to educate developers about the benefits and technical construction of green roofs is also in place.

In New York a “Green Roofs Policy Task Force” was created by a non-profit group called Earth Pledge to evaluate, strategize and recommend solutions that are most appropriate for New York. The theory is that without strong government support on building incentives, regulations on storm water and energy conservation, tax credits, direct grants, and provisions for green roofs in local codes and zoning ordinances that green roofs will not be prolific in American cities.

Germany can thank 30 years of green roofs to many factors including citizen action, scientific research, and public policy that promotes or requires implementation. (Keeley, 2004). In 2001 an estimated 14 percent of the whole countries new flat roofs were green roofs. Over 1300 businesses provide green roof services. Green roof incentives, including subsidies, tax and fee reductions and regulations, have been used since the 1980’s. Initially when the price of this new technology was relatively high, these subsidies helped defray construction costs. Currently many of those programs have been downsized or eliminated, due to financial shortfalls, luckily the cost of construction has dropped considerably since the technology has become more common (Keeley, 2004).

The three tools that will likely be the most useful in implementing green roofs in the US are: 1) mitigation regulations designed to address increased urbanization; 2) storm water fees based on impermeable surfaces; and 3) decentralizing storm water techniques (Keeley, 2004). This provides a starting point for policy makers in Hawai`i. Clearly the private and public benefits of green roofs are greater than the costs and, based on this, countries around the world have aggressively encouraged green roof construction. However, private property owners may not perceive that the private benefits are greater than the private costs, which creates challenges for policymakers. Therefore, various legislative instruments were used to adjust the benefit and costs structure in order to assure that private owners perceive that the benefits outweigh the costs. At the same time, as green roofs become more commonplace, economies of scale occur and private costs will decline over time.

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 of the needed structural reinforcement. This assessment would depend on a case by case basis to determine structural load capacities for an intensive green roof system. The associated costs of structural reinforcement may be prohibitive in most situations. Therefore, extensive roofs, which are estimated to cost $20 per sq foot in Hawai`i would be a more cost effective option in most situations. Since 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 feasible for Hawai`i for private landowners. 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 costs structure in order to assure that private owners perceive that the benefits outweigh the costs.

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 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 side and by multi-family buildings on the Mauka side, along Alawai Canal. The Downtown and Kaka`ako areas were selected because the areas represent state's commercial and industrial areas, respectively.

A Geographic Information System (GIS) layer of building footprints and heights was obtained from the City & County of Honolulu's Department of Planning and Permitting (http://gis.hicentral.com/). The building footprint and height were retrieved from stereo aerial photos acquired by Air Survey Hawai`i on January 7, 2004 (Pennington et al. 2004). The GIS layer for the 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 six 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 than144 feet. These heights correspond to the approximate height of six stories and 12 stories buildings, respectively. Buildings less than 48 feet are likely to reap a large 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, however, no information is currently available that addresses the maximum wind that an extensive green roof can withstand. Monthly mean wind speeds for a maximum of two minutes and a maximum of five second gusts from 1998 thru 2006 that were recorded at the Honolulu International Airport was obtained from National Oceanic and Atmospheric Administration National Climate Data Center (see Appendix). Since wind gusts equal to 50 mph were recorded, any building taller than 144 ft were excluded from the study area because the wind above this height is assumed to be too strong. Since 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.

The square footage that is available to become a green roof for buildings is found in Table Two.

Table Two. The Square Footage for Various Types of Space less than 48 feet tall and between 48 and 144 feet in each Study Area

	Square footage less than 48 feet	Square footage between 48 and 144 feet
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

As Table Two indicates, the study area contained a total square footage of 10,216,310 that is 48 feet tall or less. This footage is considered to be the most attractive area in which to install green roofs because the private benefits from a reduction in the cost of cooling will accrue to owners of this property. The buildings between 48 and 144 feet high 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 enact to encourage the installation of green roofs in existing buildings.

To illustrate the visual impact of installing green roofs in Honolulu, green roof installations of 25, 50 and 75 percent were simulated in each study area. As shown in Figures Six, Seven and Eight, 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.

Figure Six. Existing – Waikiki

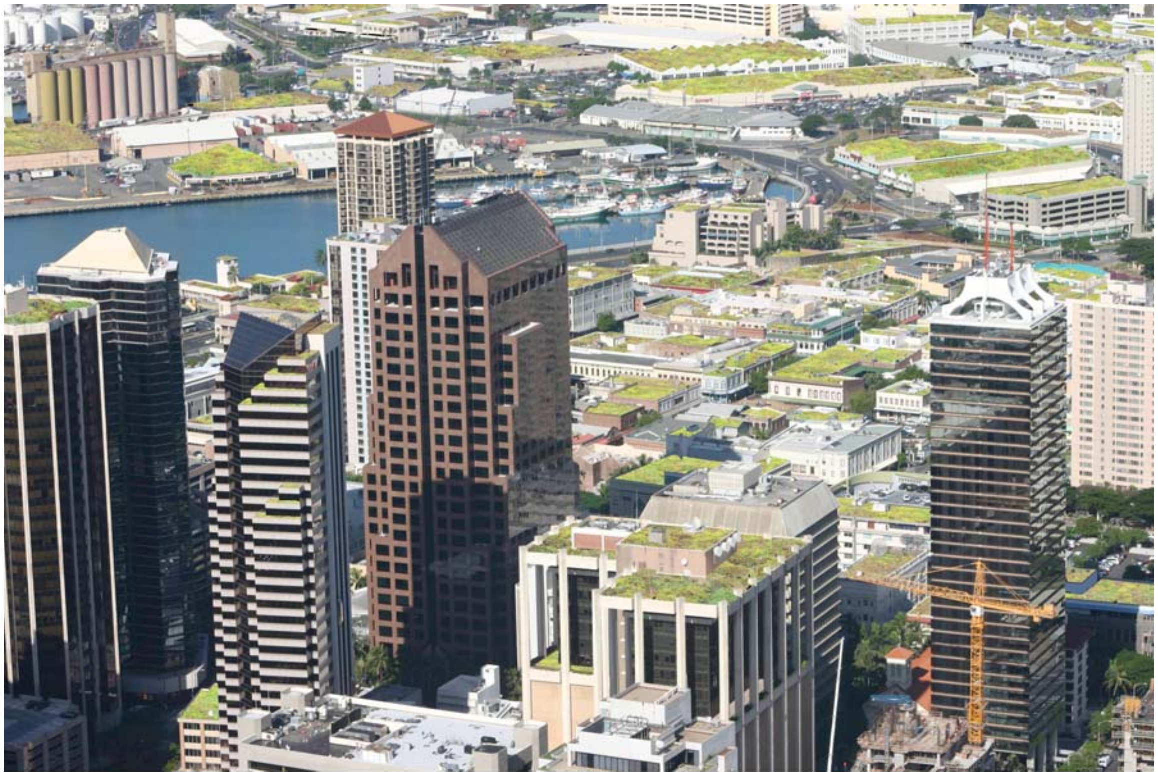
Visual Impact 25 percent coverage – Waikiki

Visual Impact 50 percent coverage – Waikiki

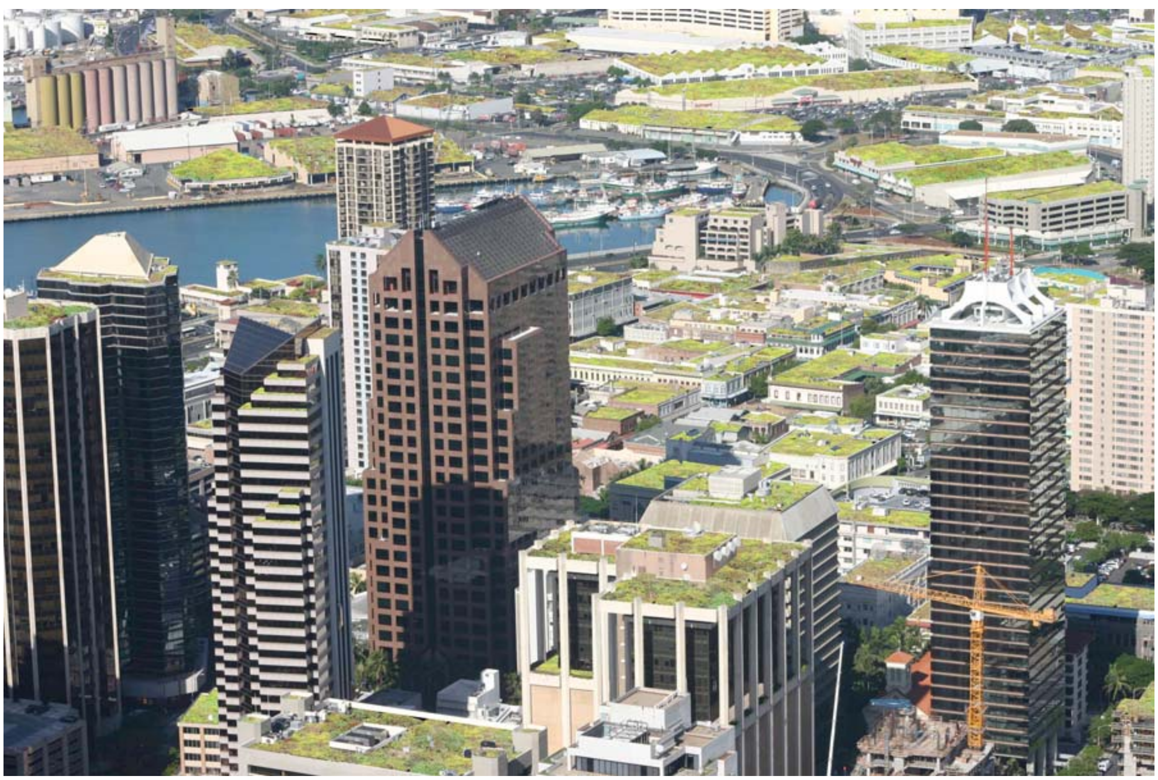
Visual Impact 75 percent coverage - Waikiki


Figure 7. Existing – Downtown


Visual Impact 25 percent coverage – Downtown



Visual Impact 50 percent - Downtown



Visual Impact 75 percent – Downtown

Figure Eight. Existing Kaka`ako

Visual Impact 25 percent coverage - Kaka`ako

Visual Impact 50 percent coverage - Kaka`ako

Visual Impact 75% coverage - Kaka`ako

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

For each area, three sets of 100 random points from Orthorectified, digital EarthData imagery pf each location were selected for a total of 300 points for each area (see Appendix Six). 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 (AMT), resulting in a photo scale of 1:19,200 with a one foot spatial resolution (EarthData International 2005). The cover surface of vegetation, rooftop, or any impervious surface 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 Three.

Table Three. Percent of Surface Cover in Each Study 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

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 in Ala Wai Canal, Honolulu Harbor, Keehi Lagoon, and Kewalo Basin (http://www.scorecard.org/env-releases/water/cwa-county.tcl?fips_county_code=15003#ranking). The conversion of the rooftops in each study area to green roof is expected to have an impact on the 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 fame 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 be find the idea attractive. This provides policymakers a general overview of public opinion.

Residents were surveyed at Kahala Mall on November 26 and visitors were surveyed in Waikiki on December 1. One hundred and eighteen people were surveyed, 53 percent of which were residents and 47 percent were visitors. Of those surveyed, 36 percent 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 nine percent were very familiar with them and 23 percent were somewhat some what 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 Four 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 air quality from green roofs would be very important to them. Likewise, respondents indicated that 79 percent believe that improved water quality was a very important benefit from green roofs, as well as 77 percent responding 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 respondents felt was relatively less important, compared to the others listed in Table Four. Clearly the public benefits of green roofs are known and valued by residents and visitors.

Table Four. Importance of Green Roof Benefits to 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

Demonstration sites are commonly used as a means of providing green roofs education and a means of conducting on-site research. Hawai`i has no demonstration sites and the State faces a significant challenge given in the lack of research in tropical green roofs. In response to a query about the important features of a demonstration site in Table Five, 79 percent respondents indicated that an educational program or tour was very important or

Table Five. 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

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 roof 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 seriously affect the people, the economy, and the environment. Clearly the private and public benefits of green roofs are greater than the costs and, based on this, countries around the world have aggressively encouraged green roof construction. However, private property owners may not perceive that the private benefits are greater than the private costs, which creates challenges for policymakers. Therefore, various legislative instruments were used to adjust the benefit and costs structure in order to assure that private owners perceive that the benefits outweigh the costs. At the same time, as green roofs become more commonplace, economies of scale occur and private costs decline over time.

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.

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 there 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 State Legislature wants more information about what policies are most effective. The University of Hawai`i can provide outreach education and could construct demonstration sites in order to collect the needed data. Landscape designers/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 provide a more sustainable Hawai`i. The opportunity to see integrated rooftop food production systems, green walls/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 One

THE SENATE
TWENTY-THIRD LEGISLATURE, 2006
STATE OF HAWAI`I

MAR 1 5 2006

SENATE RESOLUTION

REQUESTING THE COLLEGE OF TROPICAL AGRICULTURE AND HUMAN RESOURCES OF THE UNIVERSITY OF HAWAI`I AT MANOA TO STUDY THE FEASIBILITY OF MANDATED OR INCENTIVE BASED VOLUNTARY ROOFTOP LANDSCAPING AND AGRICULTURE IN URBAN DISTRICTS.

WHEREAS, in certain areas of the State, the amount of usable agricultural zoned lands is vanishing due to increased urban sprawl; and

WHEREAS, examples of rooftop landscaping already exist in Honolulu, including the Hawai`i State Capitol Building and the Kalanimoku Building, where the roof over a large area of the parking garage is covered with fields of open grass, flowers, and shrubs; and

WHEREAS, scientific testing in several countries has shown that rooftop landscaping helps to reduce the amount of pollutants and dust particles in the air and water; and

WHEREAS, vegetation on city rooftops helps to reduce what is known as the heat island effect by blocking the sun's rays and conserving energy by keeping buildings cooler, thereby reducing the necessity of cooling systems and providing sound insulation; and

WHEREAS, the definition of "urban heat island" is a metropolitan area that is considerably warmer than the surrounding areas, due in part to the lack of vegetation and standing water and the thermal properties of building materials, such as concrete and asphalt; and

WHEREAS, because flora acts as a natural heat absorber and insulator, roof top landscaping can help to reduce electricity consumption; and

WHEREAS, in *a* study conducted by the Los Angeles-based Heat Island Group, it was found that rooftop cooling efforts could lead to an annual energy savings of $16,000,000; and

WHEREAS, the economy of the State of Hawai`i is largely dependent on the visitor industry, the main attraction being the natural beauty of our island state, which should be evident in urban areas, as well as forests, parks, and conservation areas; and

WHEREAS, extensive positive examples of rooftop landscaping and agriculture can be found throughout Germany, Japan, Singapore, Australia, Canada, Switzerland, and China and experimental projects are underway in Portland, Oregon; Chicago, Illinois; and New York City, New York; and

WHEREAS, the Changi Hospital in Singapore converted *a* bare concrete roof that diverted sunlight into nearby wards, causing unwanted glare and heating, into a highly productive hydroponic farm of cherry tomatoes and herbs used to provide fresh healthy meals to patients; and

WHEREAS, a survey done by Ngee Ann Polytechnic students found that approximately five hundred twenty-three acres of apartment and commercial rooftops in four suburbs of Singapore use hydroponics to grow fresh vegetables and thus noted that, managed properly, five hundred twenty-three acres could produce up to thirty-nine thousand tons of vegetables a year at a value of around $24,500,000; and

WHEREAS, the current law in Germany gives owners of newly constructed buildings the following three options regarding rooftop landscaping of which the first is the most economical:

(1) Carry out green rooftop landscaping on the newly constructed building;

(2) Carry out green landscaping in a different location from the newly constructed building but with an area equivalent to the rooftop area; or

(3) Pay a fine; and

WHEREAS, the current law in Tokyo mandates that any newly constructed building with a ground area exceeding one thousand square meters must use at least twenty per cent of the area for green rooftop landscaping; now, therefore, BE IT RESOLVED by the Senate of the Twenty-third Legislature of the State of Hawai`i, Regular Session of 2006, that the College of Tropical Agriculture and Human Resources of the University of Hawai`i at Manoa is requested to study the feasibility of mandated or incentive based voluntary rooftop landscaping and agriculture in urban districts; and

BE IT FURTHER RESOLVED that while the College of Tropical Agriculture and Human Resources is taking the lead, this study should be a collaborative effort between the Department of Agriculture, the planning departments of the four counties, the Hawai`i Farm Bureau, the Landscape Industry Council of Hawai`i, the American Planning Association, Hawai`i Chapter, the Urban Land Institute, and the University of Hawai`i School of Architecture; and

BE IT FURTHER RESOLVED that the College of Tropical Agriculture and Human Resources is requested to study buildings in urban districts in subcategories, such as commercial, hotel, multi-family, industrial, or mixed use with a commercial component, so that the findings can be used to gauge the feasibility of rooftop landscaping and agriculture in each specific area; and

BE IT FURTHER RESOLVED that the College of Tropical Agriculture and Human Resources is requested to submit its report to the Legislature not later than twenty days prior to the convening of the Regular Session of 2007; and

BE IT FURTHER RESOLVED that certified copies of this Resolution be transmitted to the Dean of the University of Hawai`i College of Tropical Agriculture and Human Resources, the Chairperson of the Board of Agriculture, the Dean of the University of Hawai`i School of Architecture, the head of the planning office of each county, the Hawai`i Farm Bureau, the Landscape Industry Council of Hawai`i, the American Planning Association, Hawai`i Chapter, and the Urban Land Institute.

OFFERED BY :

SR LRB 06-2901.doc

Appendix Two. **Request for participation from Potential Cooperators**

Aloha (Insert Name),

The Hawai`i State Legislature has requested that the College of Tropical Agriculture and Human Resources of the University of Hawai`i at Manoa study the feasibility of rooftop landscaping and agriculture in urban districts. The requested informational report deadline is December 29, 2006.

The Legislature has asked that a collaborative effort between the College of Tropical Agriculture and Human Resources and various campus departments and governmental agencies occur. Your organization has been recognized as one of the possible participants for this study. The main focus will be to gather information in the following areas.

- Building energy savings
- Storm water reduction
- Air pollution reduction
- Reduction of heat island
- Roof life extension
- Building roof structure requirements to support extensive and intensive Green Roofs.

We look forward to receiving relevant information from you, based on your area of expertise. If you have any questions, please feel free to e mail me at: kaufmana@Hawai`i.edu

Sincerely,

Andy Kaufman, ASLA, MLA, Ph.D.
Assist. Prof../Landscape Specialist
Dept.Tropical Plant and Soil Sciences
College of Tropical Ag & Human Resources
University of Hawai`i at Manoa
3190 Maile Way, Room #102
Honolulu, HI 96822-2279, USA

Sent to :

Hawai`i Department of Agriculture
Sandra Lee Kunimoto, Chairperson
Hawai`i Department of Agriculture
Office of the Chairperson
1428 South King Street
Honolulu, HI 96814-2512

Planning departments of the four counties:

-Hawai`i County comprises Hawai`i.
-Honolulu County, the City and County of Honolulu,
-Kauai County comprises Kauai and Niihau.
-Maui County comprises Kahoolawe, Lanai, Maui, and Molokai

Chris Yuen, Planning Department Head
Aupuni Center, 101 Pauahi Street, Suite 3,
Hilo, HI 96720

Ean Costa, Planning Director
County of Kaua'i Main Office
4444 Rice Street,
Lihue, Hawai`i, 96766

Maui Planning Department
250 South High Street Ste. 200
Wailuku, HI 96793-2155

Henry Eng, FAICP, Director
Department of Permitting & Planning
City and County of Honolulu
650 So. King St
Honolulu, HI 96813

- Hawai`i Farm Bureau,

Dean Okimoto, President
Hawai`i Farm Bureau
2343 Rose Street
Honolulu, Hawai`i, 96819

- Landscape Industry Council of Hawai`i,

Boyd Ready, President
Landscape Industry Council of Hawai`i
P.O. Box 22938 - Honolulu, HI 96823-2938

American Planning Association, Hawai`i Chapter
Gene Yong, AICP
Hawai`i Chapter of the American Planning Association
P.O. Box 557
Honolulu, Hawai`i 96809

Urban Land Institute
David A. Miller, Chair, Urban Land Institute Hawai`i
1001 Bishop St. Suite 300
Honolulu HI 96813

University of Hawai`i School of Architecture
Dean Raymond Yeh, FAIA
School of Architecture
University of Hawai`i
2410 Campus Road
Honolulu, HI 96822

LINDA LINGLE
Governor

SANDRA LEE KUNIMOTO
Chairperson, Board of Agriculture

DUANE K. OKAMOTO
Deputy to the Chairperson

State of Hawaii
DEPARTMENT OF AGRICULTURE
1428 South King Street
Honolulu, Hawaii 96814-2512
Phone: (808) 973-9600 Fax: (808) 973-9613

November 30, 2006

Mr. Andy Kaufman, ASLA, MLA, Ph.D.
Department of Tropical Plant and Soil Sciences
UH-College of Tropical Ag & Human Resources
3190 Maile Way, Room #102
Honolulu, HI 96822

Dear Mr. Kaufman:

Thank you for your letter seeking information in the areas of:

- Building energy savings
- Storm water reduction
- Air pollution reduction
- Reduction of heat island
- Roof life extension
- Building room structure requirements to support extensive and intensive Green roofs.

I understand this information will be used in a study of the feasibility of rooftop landscaping and agriculture in urban districts.

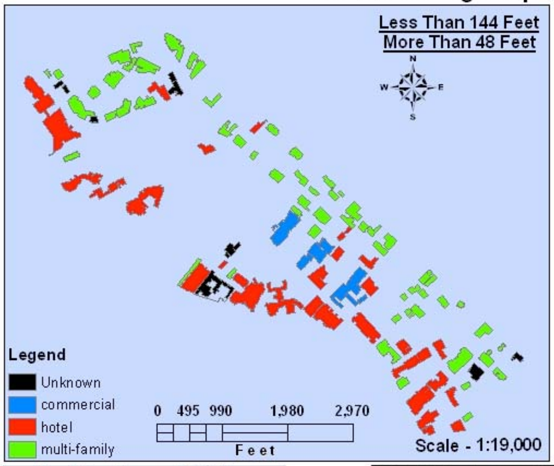
I have queried the divisions within the Department of Agriculture that might have the information you are seeking and find that we do not possess the specific information and expertise you are seeking. However, the department is a participant in the State's Energy Efficiency initiative, led by Carilyn Shon in DBEDT's Strategic Industries division, and a major focus of the initiative is to institute the LEED Silver Standard in the construction and renovation of State buildings. I believe that you can gain a lot of valuable information about building energy savings by contacting Ms. Shon at 587-3810 or by email at cshon@dbedt.hawaii.gov.

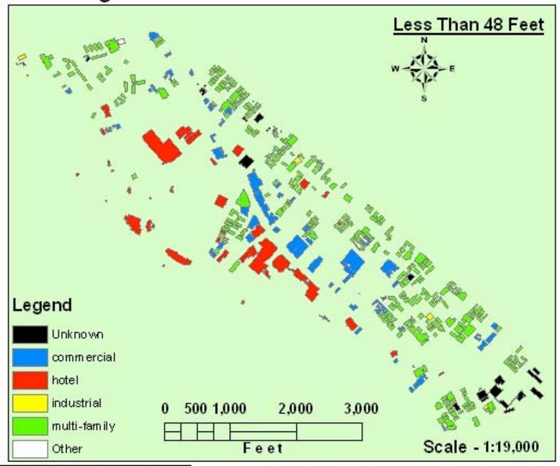
While we are not in a position to contribute to this architectural-engineering information request, we would be happy to assist in any agriculture-related aspects of the study.

Sincerely,

Sandra Lee Kunimoto, Chairperson
Board of Agriculture

Waikiki Building Footprint with Height Restrictions





Total Roof Area of Buildings

Type	Square Feet	Number
Unknown	227883	8
Commercial	340776	4
Hotel	1743958	29
Industrial		
Multi-Family	1346848	56
Other		

Total Area	3659465
Total Buildings	97

Total Roof Area of Buildings

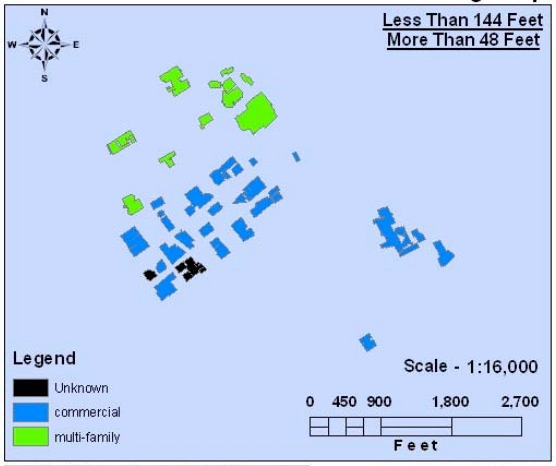
Type	Square Feet	Number
Unknown	187377	31
Commercial	589673	64
Hotel	701525	69
Industrial	24274	4
Multi-Family	1337847	344
Other	7680	2

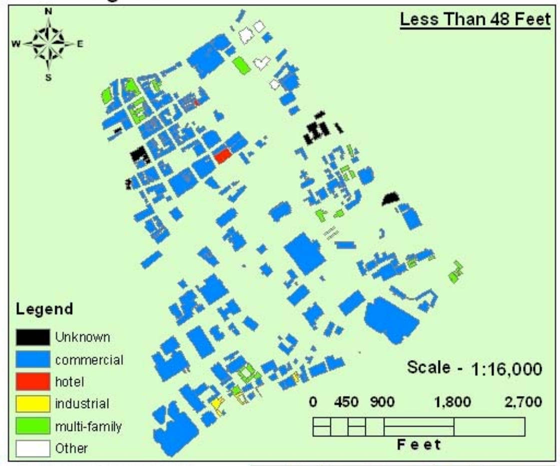
Total Area	2848376
Total Buildings	514

Map projects the same data as the WAIKIKI BUILDING FOOTPRINT CLASS LEDGEND except that this map displays only those buildings between the indicated height restrictions

Produced by: Geospatial Analysis and Remote Sensing Labratory
Data Source: City & County of Honolulu as of January 2004
Datum: Hawaii State Plane Zone 3
Date of Production: 2006 November 17

Downtown Building Footprint with Height Restrictions





Total Roof Area of Buildings

Type	Square Feet	Number
Unknown	70943	2
Commercial	831949	25
Hotel		
Industrial		
Multi-Family	438400	9
Other		

Total Area	1341292
Total Buildings	36

Map projects the same data as the DOWNTOWN BUILDING FOOTPRINT CLASS LEDGEND except that this map displays only those buildings between the indicated height restrictions

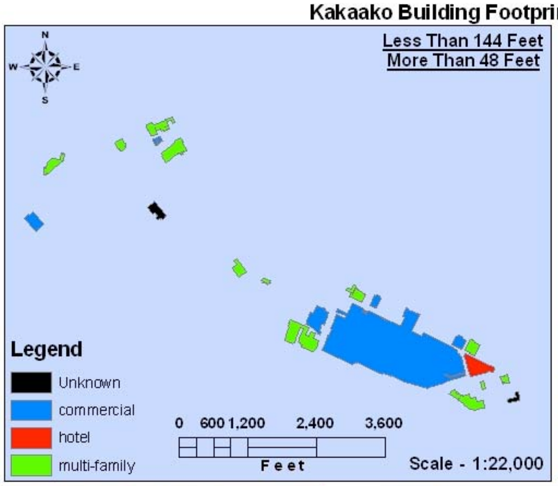
Total Roof Area of Buildings

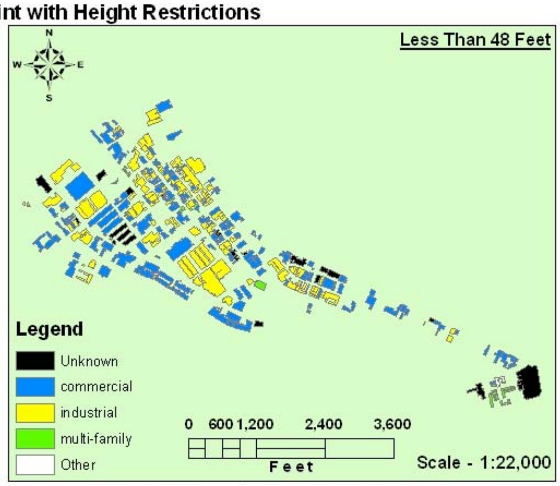
Type	Square Feet	Number
Unknown	124605	7
Commercial	3499437	234
Hotel	27163	2
Industrial	33269	7
Multi-Family	198189	23
Other	64631	4

Total Area	3947294
Total Buildings	277

Produced by: Geospatial Analysis and Remote Sensing Labratory
Data Source: City & County of Honolulu as of January 2004
Datum: Hawaii State Plane Zone 3
Date of Production: 2006 November 17

Kakaako Building Footprint with Height Restrictions





Total Roof Area of Buildings

Type	Square Feet	Number
Unknown	66504	2
Commercial	2322028	7
Hotel	107548	1
Industrial		
Multi-Family	649963	12
Other		

Total Area	3146043
Total Buildings	22

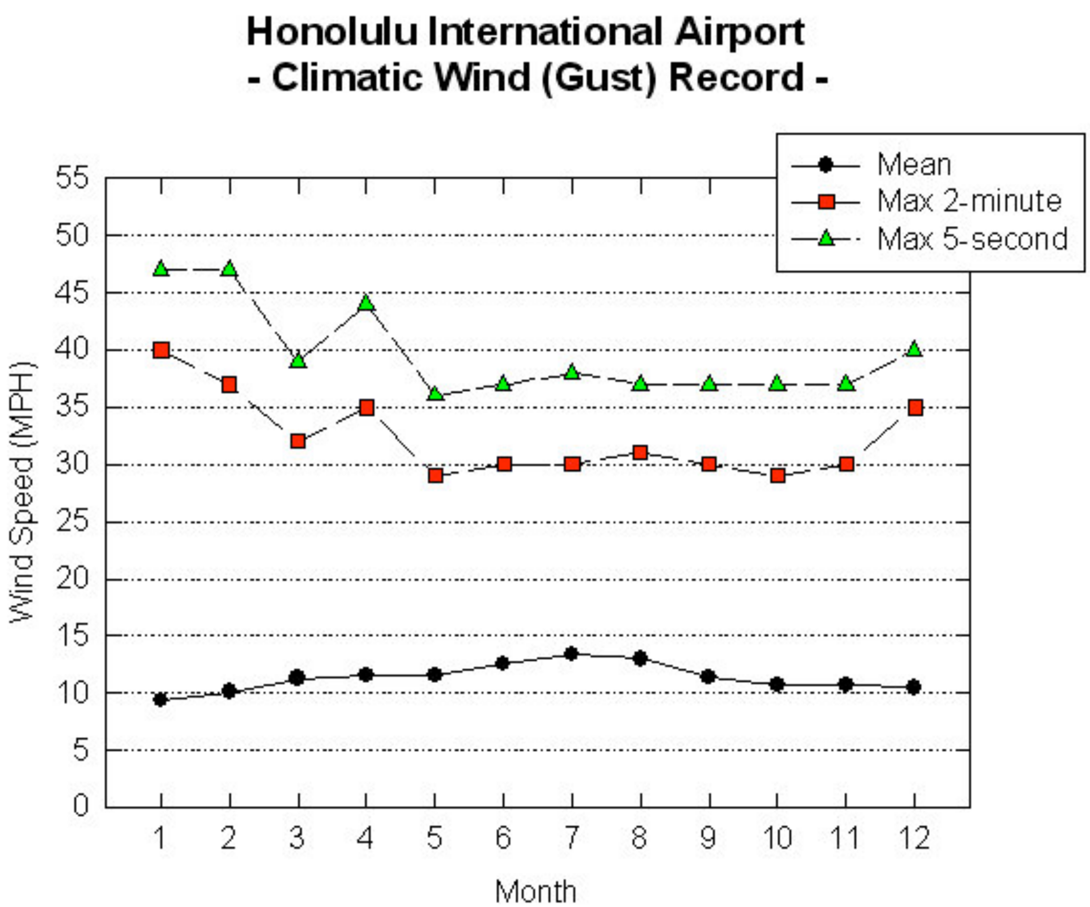
Total Roof Area of Buildings

Type	Square Feet	Number
Unknown	622686	36
Commercial	2023260	200
Hotel		
Industrial	1686694	126
Multi-Family	94979	25
Other	16804	2

Total Area	4444423
Total Buildings	389

Map projects the same data as the KAKAAKO BUILDING FOOTPRINT CLASS LEDGEND except that this map displays only those buildings between the indicated height restrictions

Produced by: Geospatial Analysis and Remote Sensing Labratory
Data Source: City & County of Honolulu as of January 2004
Datum: Hawaii State Plane Zone 3
Date of Production: 2006 November 17


Honolulu International Airport
- Climatic Wind (Gust) Record -
Mean
Max 2-minute
Max 5-second
Wind Speed (MPH)
55
50
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month

Building Footprint Class
Waikiki
Impervious surface areas estimates

Sample Set 1	
V	29
R	28
I	43

Sample Set 2	
V	27
R	41
I	32

Sample Set 3	
V	25
R	37
I	38

Sum	
V	81
R	106
I	113

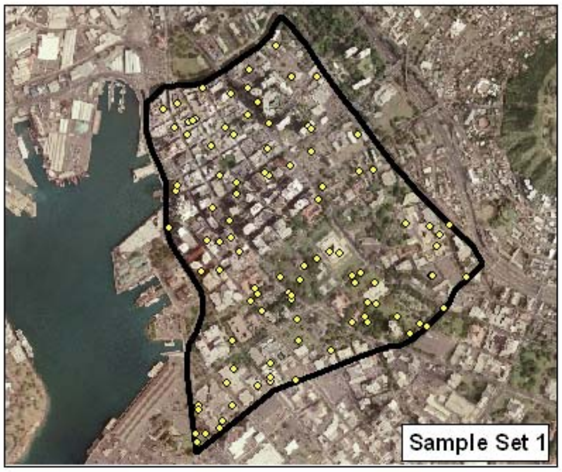
V = Vegitation
R = Roof Top
I = Impervious

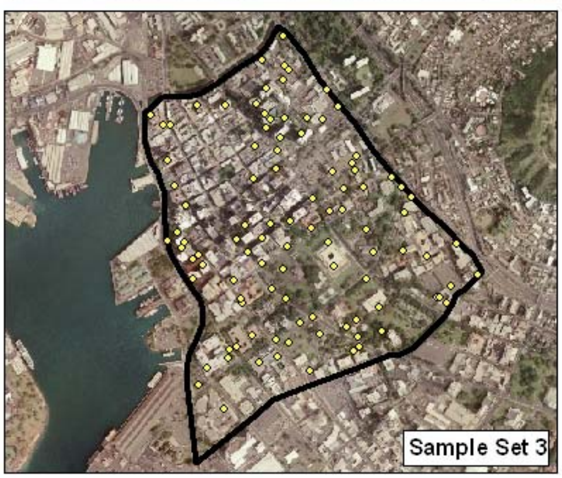
Roof Tops make up 48% of the impervious surface areas

Scale: 1:25,000

Each Sample Set is made up of 100 random points.
Each point was checked for the
type of surfuce underneath it.

Produced by: Geospatial Analysis and Remote Sensing Labratory
Data Source: USGS Earth Data Imagery
Datum: Hawaii State Plane Zone 3
Date of Production: 2006 December 7





Building Footprint Class
Downtown
Impervious surface areas estimates

Sample Set 1	
V	21
R	34
I	45

Sample Set 2	
V	13
R	43
I	44

Sample Set 3	
V	21
R	36
I	43

Sum	
V	55
R	113
I	132

V = Vegitation
R = Roof Top
I = Impervious

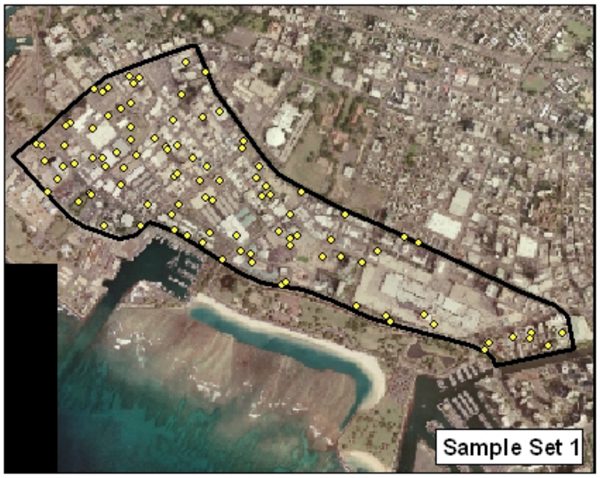
Roof Tops make up 46% of the impervious surface areas

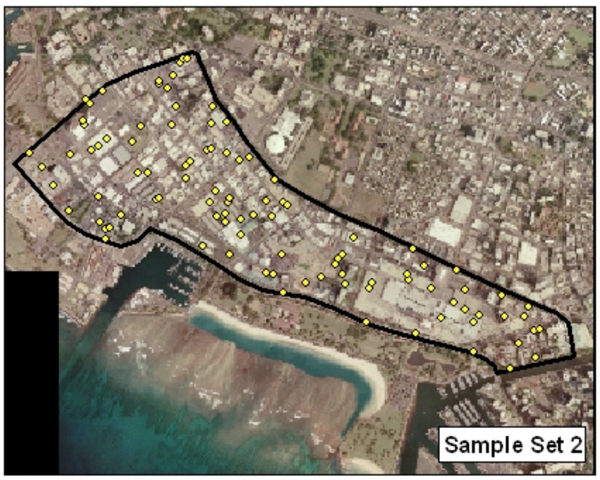
Scale: 1:23,000

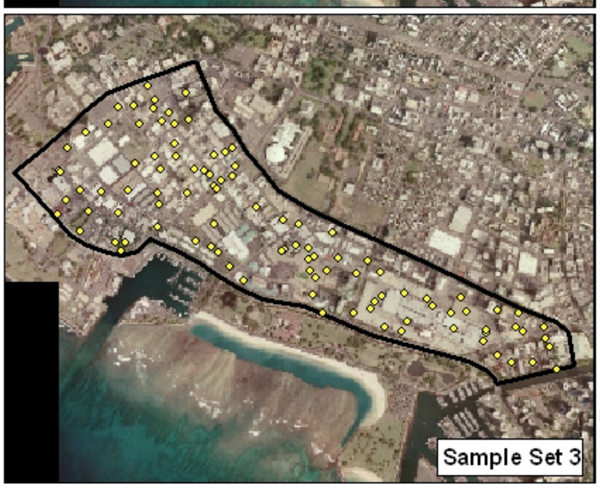
Each Sample Set is made up of 100 random points.
Each point was checked for the type of surfuce underneath it.

Produced by: Geospatial Analysis and Remote Sensing Labratory
Data Source: USGS Earth Data Imagery
Datum: Hawaii State Plane Zone 3
Date of Production: 2006 December 7

Building Footprint Class
Kakaako
Impervious surface areas estimates







	Sample Set 1	Sample Set 2	Sample Set 3	Sum
V	10	7	9	26
R	32	42	47	121
I	58	51	44	153

V = Vegitation
R = Roof Top
I = Impervious

Roof Tops make up 44% of the impervious surface areas

Scale: 1:28,000

Each Sample Set is made up of 100 random points.
Each point was checked for the
type of surface underneath it.

Produced by: Geospatial Analysis and Remote Sensing Labratory
Data Source: USGS Earth Data Imagery
Datum: Hawaii State Plane Zone 3
Date of Production: 2006 December 7

Appendix Seven. **Resident and Visitor Satisfaction Survey**

C/T/A/H/R
College of Tropical Agriculture and Human Resources
University of Hawai'i at Mānoa

Hawai`i Green Roof Feasibility Questionnaire

Visitor

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 ❒

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

very much opposed ❒
somewhat opposed ❒
neutral ❒
somewhat in favor ❒
very much in favor ❒

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

very much opposed ❒
somewhat opposed ❒
neutral ❒
somewhat in favor ❒
very much in favor ❒

6. If green roofs could provide the following benefits, please indicate how important each one is to you…

	very important	somewhat important	slightly important	not important	No opinion
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…

	very important	somewhat important	slightly important	not important	No opinion
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…

	Yes	No
at home	❒	❒
at place of work	❒	❒

Mahalo for your kokua

C/T/A/H/R
College of Tropical Agriculture and Human Resources
University of Hawai'i at Mānoa

Hawai`i Green Roof Feasibility Questionnaire
Local

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 ❒

4. How do you feel about local or State government promoting green roofs?
very much opposed ❒
somewhat opposed ❒
neutral ❒
somewhat in favor ❒
very much in favor ❒

5. How do you feel about local or State government mandating green roofs?
very much opposed ❒
somewhat opposed ❒
neutral ❒
somewhat in favor ❒
very much in favor ❒

6. If green roofs could provide the following benefits, please indicate how important each one is to you…

	very important	somewhat important	slightly important	not important	No opinion
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…

	very importan t	somewh at importa nt	slightly importa nt	not importa nt	No opini n
Located in Waikiki	❐	❐	❐	❐	❐
Located within a 5 minute drive from home	❐	❐	❐	❐	❐
Located within a 30 minute drive from home	❐	❐	❐	❐	❐
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…

	Yes	No
at home	❐	❐
at place of work	❐	❐

Mahalo for your kokua

Appendix Eight. Green Roof Bibliography

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Appendix Nine. **Plants for Testing in Hawai`i Green Roof Systems**

Index of Plants

Scientific Name	Family
Alternanthera ficoidea 'White Carpet'	Amaranthaceae
Aptenia cordifolia	Aizoaceae
Bryophyllum 'Crenatodaigremontianum'	Crassulaceae
Bryophyllum fedtschenkoi	Crassulaceae
Callisia repens	Commelinaceae
Carpobrutus edulis	Aizoaceae
Commelina diffusa	Commelinaceae
Cyanotis cristata	Commelinaceae
Delosperma cooperi	Aizoaceae
Furcraea foetida 'Mediopicta'	Agavaceae
Kalanchoe tomentosa	Crassulaceae
Liriope muscari	Convallariaceae
Murdannia nudiflora	Commelinaceae
Murdannia vaginata	Commelinaceae
Plectranthus verticillatus	Labiatae
Portulaca grandiflora	Portulacaceae
Portulaca oleracea	Portulacaceae
Portulaca pilosa	Portulacaceae
Rhipsalis mesembryanthemoides	Cactaceae
Sanseviera trifasciata 'Golden Hahnii'	Dracaenaceae
Sanseviera trifasciata 'Hahnii'	Dracaenaceae
Sanseviera trifasciata 'Laurentii'	Dracaenaceae
Sedum acre	Crassulaceae
Sedum mexicanum	Crassulaceae
Sedum nussbaumerianum	Crassulaceae
Sedum sarmentosum	Crassulaceae
Sedum sexangulare	Crassulaceae
Sesuvium portulacastum	Aizoaceae
Tradescantia pallida 'Purpurea'	Commelinaceae
Tulbaghia violacea	Alliaceae
Variegated sedum	Crassulaceae
Zephyranthes candida	Amaryllidaceae
Zephyranthes rosea	Amaryllidaceae

Recommendations by National Parks Board Singapore

Index of Plants 2

Sedum confusum
Sedum makonoi
Delosperma 'Abby White'
Delosperma aberdeenense
Delosperma congestum 'Gold Nugget'
Delosperma latifolia 'Ecklonis'
Delosperma nubigenum 'Basutoland'
Delosperma sutherlandi
Maleophora 'Tequila Sunrise
Sedum album 'Coral Carpet'
Sedum luteoviride
Sedum clavatum
Sedum linare variegatum
Talinum parvifolium
Talinum calycinum
Talinum rugosperum
Allium schoenoprasum
Delosperma floribundum 'Starbust'
Sedum moranense
Sedum praealtum ssp. praealtum

Recommendations by Ed Snodgrass

Index of Plants 3

Sporobolus virginicus- 'aki 'aki,
Sesuvium portulacastrum- 'akulikuli"
Myoporum sandwicense- Naio Papa
Kawululu Mau u aki aki
Recommendations by Hui ku Maoli ola

Index of Plants 4

Wilkstroemia uva ursi- akia
Scaevola sericea- beach naupaka
Scaevola coriacea- endangered native, better longevity than others
Naio papa
Plumbago
Bacopa- aiai
Ma`o
Bigna marina
Nehe
Dianella sandwichensis- ukiuki
Ulei
Carissa grandiflora- boxwood beauty, or something in same family
Russelia equisetiformis-
Crinum- spiderplant
Asparagus fern
Iceplant
Ruellia
Recommendations by Dennis Kim

Index of Plants 5

Jaquemontia ovalifolia-pa`uohi`iaka
Ipomoea imperati -hunakai
Ipomoea pes-caprae subsp. *brasiliensis*- pohuehue, beach morning glory
Vitex rotundifolia-po`hinahina
Sida fallax- ilima papa (flat/beach type)
Sesuvium portulacastrum- 'akulikuli
Bonamia menzesi
Shrubs, reeds and grasses:
Heterpogon contortus- pili grass
Sesbania tomentosa-`ohai
Carex wahuensis - makaloa
Dodonea-a`ali`i
Dianella sanwichense- ukiuki grass
Sporobolus virginicus- 'aki 'aki,
Peperomia blanda
Myoporum sandwichense.
Chamaesyce sp.
Plumbago zeylanica
Recommendations by Priscilla Millen