Use Your Roof

A Guidebook of Resources and Considerations for Rainwater Catchment, Roof Gardens and Solar Power

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With excerpts from Tapping the Potential of Urban Rooftops

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Bay Localize is an Oakland based organization that catalyzes a shift from a globalized, fossil-fuel based economy to a localized green economy that strengthens all Bay Area communities. Bay Localize is a nonprofit project of the Earth Island Institute.

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Disclaimer

Use Your Roof *Guidebook* is intended to be a first step in researching the direction of your project, and is not a substitute for professional site-specific construction advice. We encourage you to consult with building professionals as needed in planning and implementing your specific project. Bay Localize cannot be held liable for damages resulting from design, installation, or maintenance of any element described in this *Guidebook*.

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PREFACE

The Rooftop Resources Project began with the question, how can rooftops be used to grow and harvest food? Any high vantage in the Bay Area will reveal a sea of unused, wasted rooftops throughout the city that can easily provoke the same question for the onlooker. With a constrained amount of open space in dense urban zones, rooftops are naturally looked to as potential spaces to fulfill this need. The determining factors are the capacity of existing buildings to hold the weight of gardens and the policy and design requirements for this form of roof gardening. Ultimately, if existing buildings have a limited threshold to carry edible gardens, how else can rooftops be utilized to foster urban ecological sustainability? In response to these questions, Bay Localize initiated a feasibility and benefits study and advocacy project for edible roof gardens, living roofs, rainwater catchment and solar power.

Bay Localize spent the first two years of the project working with task forces, consultants and volunteers to conduct a literature review, complete a neighborhood assessment and support various pilot projects and research. In this work, we've identified innovative design schemes, best practices and productivity levels of rooftop technologies and how to appropriately fit rooftop systems to a general set of building typologies. The results of this analysis show us that with a careful site assessment and implementation, as well as an appropriate design, rooftop technologies are viable for existing and new buildings and can be highly productive, contributing a significant volume of food, water and energy. In the past few years, awareness and interest for these technologies has grown and model projects have emerged along the skyline, showing exciting possibilities for other roofs to replicate. Bay Localize has gleaned the best practices from this growing field and synthesized our research and analysis to share with you in this *Guidebook*. We hope that the resources and information contained in the *Use Your Roof Guidebook* help you begin evaluating and deploying rooftop systems that provide you and your community food, water, and energy.

For the Earth and our communities,

Bay Localize

INTRODUCTION

Utilizing Rooftops in the City

Transforming Empty Spaces to Hubs of Regenerative Resources

Growing food, capturing water and generating solar power on rooftops is an empowering method of bringing greater ecological balance and local resilience to dense cities. These rooftop technologies are a sure mark of humanity's evolution towards a more sustainable and innovative future. While these systems are considered cutting edge technologies, they actually harken back to the traditions of our ancestors. Today's inhabitants of contemporary living roof buildings are finding the same benefit of insulation from heat and cold as did northern European Vikings and monks in the 6th century. Water harvesting systems have been recorded as far back as 4,000 years in the Negev Desert of Israel[1], and remain a common practice in many regions throughout the world. With what some see as a full circle, these traditions are seeing a revival: old technologies are being redesigned and improved, building a base to revitalize our economy through localization. Recovering and decontaminating water, cultivating organic food, filtering and cooling down air as well as bolstering electricity grids with clean energy are all ways to make our built environment more sustainable. Generating rooftop resources is a bridge to a more stable, healthy economy and locally resilient communities.

1 Will Critchley and Klaus Siegert. *Water Harvesting*, Food and Agriculture Organization of the United Nations. Rome, 1991

Rooftop Resources, Petroleum Depletion and Climate Change

The production and availability of food, water, and energy resources is a subject overlooked by most people. Water can be acquired with a shove of the faucet handle. One needn't do more than flick a switch on the wall for electricity. Vast quantities of food at grocery stores and restaurants can typically lie within one to five miles of the average person's residence.

These are the benefits of cheap energy and industrial, centralized resource production. While these resources have been affordable and available in unlimited supplies for the past forty years or so, the effects of global warming and petroleum depletion are beginning to restrict the production of these resources. The implications of global warming and petroleum depletion, also known as Peak Oil, run deep through both the economy and the environment. Ultimately, these intertwined global issues pose serious challenges that will require society to adjust and adapt.

Scientists predict climate change's most prominent effects to be erratic and extreme storm systems as well as acute droughts. Phenomena such as the 2005 Hurricane Katrina that hit Louisiana and Mississippi, the 2007 tornado that wiped out Greensburg, Kentucky, droughts plaguing California, Africa, and Australia, as well as melting glaciers and rising sea levels are all patterns that are expected to escalate. Cities throughout the country are gearing up to prepare for further heat waves like that of the July 2006 heat wave in California that resulted in 75 casualties. Increased temperatures will likely make the Central Valley's agricultural lands even more dependent on water diversions from the Bay Delta. Further compounding these issues, the consequences of temperature fluctuations, wildfires, erratic storms, and rising sea levels could place severe economic strain on many regions.

Sometimes referred to as the cousin of Climate Change, Peak Oil is a phenomenon posing a threat to industry and the economy. Peak Oil refers to the point at which half of the Earth's oil reserves have been used, resulting in energy scarcity and rising prices. The remaining petroleum is of lower quality and lies deeper in the earth's surface, thus making extraction and refinement more difficult and expensive. In 1956 geologist M. King Hubbert came up with the principle of peak oil, and predicted, accurately, that the United States would hit Peak Oil in the 1970s. There are multiple theories of when the global peak will hit, though many claim we are currently at the beginning of a global oil peak. Global oil production is experiencing reduced output, as the discovery of new oilfields has been on a steady decline since 1964.

It is fair to say that fossil fuel dependency constitutes a systemic problem of a kind and scale that no society has ever had to address before. The human community's central task for the coming decades must be the undoing of its dependence on oil, coal, and natural gas in order to deal with the twin crises of resource depletion and climate change.

Localization is a key strategy for adapting to these conditions. Through utilizing the assets and resources closest to our bioregions to innovate and build systems together, communities can create oil independence. Utilizing rooftop space where possible to harvest resources is part of the development of local resilience. The effects of such development not only benefit the environment, food, water and energy security, but it serves to stimulate a healthier local, green economy.

Why the Guidebook?

A tool to encourage the spreading of decentralized vital resources

Bay Localize presents this *Guidebook* of resources, prototypes and other information to help you research what rooftop systems may be applicable to your site as well as the process involved in designing and installing the systems, whether you choose to do it yourself or contract a professional. Reading this *Guidebook* is intended to be a first step in researching the direction of your project, and is not a substitute for professional site-specific construction advice. We encourage you to consult with building professionals as needed in planning and implementing your specific project.[2]

The *Guidebook* is divided into four chapters that cover the key steps for researching a rooftop project. It includes a basic definition and description of roof gardens, rainwater catchment and solar power, factors for consideration and how to assess your building for a given rooftop system, best practices, and a comprehensive list of resources and information to inform the implementation process. Depending on your goals and your experience, you may be more interested in the first chapters than by the technical information or vice versa.

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2 Bay Localize cannot be held liable for damages resulting from design, installation, or maintenance of any element described in this *Guidebook*.

PART 1

What are Rooftop Resources and How Do they Work?

Let's start with living roofs. As the name implies, a living roof is a layer of vegetation that serves as an extension of a building's roof. Also known as a green roof, rooftop garden or eco-roof, living roofs generally include a protective waterproofing layer, a root barrier, the growing medium, and an irrigation and drainage system. Living roofs were common thousands of years ago in Babylon, Iceland, and northern Europe. Our early ancestors used local resources and materials for building, and in using sod and vegetation as roofing materials, received the benefits of insulation from both heat and cold. Early settlers in America used sod roofs for their buildings, though this practice waned during the industrial revolution with the advent of petroleum based products.

Green roofs were revived in the 1970s in Europe, producing environmental and energy efficiency benefits. This prompted the American building sector to experiment with living roofs; and in the late 20th century, living roofs began popping up in new construction here and there. Nevertheless living roofs remain a rare building feature, though the technology is rapidly advancing in many cities in the United States. As it is a still a new form of green building, each built system is a valuable model from which others can learn. This section of the *Guidebook* will cover the different types and components of living roofs, and the proven social and environmental benefits these systems offer.

Extensive Living Roof

An extensive living roof's role is to provide the building with a layer of protection from the sun and thermal insulation from noise pollution and seasonal elements. The green roof also reduces the building's ecological footprint by retaining storm water that would otherwise add to the city's waste water management requirements. Extensive living roofs also provide aesthetic appeal that increases the property value of the building.

This type of roof garden is defined by a few key factors: the soil depth, scope of plants and the objective of the design. Extensive living roofs are the most shallow and light type of living roofs, and are designed to improve the building's performance rather than as spaces for human recreation or food production. The pitch of extensive green roofs can be as steep as 45 degrees, the soil depth ranges from two to five inches, and the plants foliage can range from 2 to 6 inches. When it is fully saturated or irrigated, the growing medium and vegetation weights range from 10 to 50 pounds per square foot. An extensive green roof is designed to require minimal maintenance. Plants include sedums and other succulents, flowering herbs, and certain grasses and mosses.

Intensive Living Roof

While extensive living roofs act as a roof cover and can add value to the building, intensive green roofs provide the same benefits and more. These deeper, heavier systems provide space for people and hold a greater variety of vegetation and habitat. Intensive living roofs are like a park on the roof. They are generally flat surfaces and can include trees, ponds, planter boxes, greenhouses, compost bins, etc. The growing media starts from about eight to twelve inches and can range up to 15 feet or more, depending on the loading capacity of the roof and the architectural and vegetation features. When fully irrigated, the weight of this living roof type can range from about 80 to 120 pounds per square foot and up. Due to a greater complexity and scale, these systems require have greater maintenance requirements.

Rainwater Catchment

Rainwater collection has been practiced for centuries as a way of gathering a scarce and essential resource – water. Harvesting water from the roof is a simple and elegant solution, powered by gravity. Since drainage is a standard component for most roofs, much of the infrastructure needed to harvest rainwater is already in place on existing buildings. Rainwater catchment systems simply involve using the roof as the catchment surface, placing a drainage filter on the gutters, using the downspout as the conveyance system, and installing a cistern for storage. The cistern can range in size from a 50-gallon drum to a tank of several thousand gallons. These storage vessels are typically located on the ground, but can be placed on the roof, elevated and mounted on the building's wall, or buried underground for storage. The harvested rainwater can be used for irrigation, drinking water or graywater, though this *Guidebook* focuses on using rainwater catchment for irrigation.

Solar Electric Power

Photovoltaic systems (solar panels) convert sunlight into electricity. Photovoltaic (PV) cells are made primarily of silicon, the second most abundant element in the earth's crust.

When sunlight hits the PV cells, direct current (DC) flows through the inverter, which converts it to alternating current (AC). The AC power then flows directly into the building to meet the current demand; any remaining power flows into backup batteries if the system has them or to the utility grid. In some areas with net metering programs, electricity flowing into the grid will make the meter turn backwards and earn the system owner credit toward the utility bill. Under a feed-in-tariff system the owner may be paid for electricity flowing into the grid by the utility.

There are three types of PV modules: single crystal, "multi" or "poly" crystalline, and amorphous silicon. All are rated to last at least twenty-five years. Some experts estimate that forty years is a reasonable expectation. The longevity rating of a module refers to the number of years before the unit starts producing only 80 percent of its original power rating. Single-crystal modules are currently the most efficient type available, as they produce the most power per square foot of module.

Solar Thermal Power

Solar thermal heating harnesses the power of the sun to provide solar powered heating for a building's kitchen and bathroom plumbing as well as outdoor pools and tubs. A solar thermal system consists of a solar collector, a pump station, a solar controller and a hot water storage tank. The solar collector on the roof collects the sun's energy and transfers the heat to the storage tank with the tank's internal heat exchanger. The storage tank allows the hot water to be stored until it is used. The storage tank also acts as a pre-heat tank for the existing hot water tank. The most common collector used in solar hot water systems is the flat-plate collector. A typical flat-plate collector is an insulated metal box with a glass or plastic cover and a dark-colored absorber plate. These collectors heat liquid or air at temperatures up to 180°F.

A solar heating system saves energy, reduces utility costs, and produces clean energy in the form of heated water. A typical residential solar water-heating system reduces the need for conventional water heating by around two-thirds. It minimizes the expense of electricity or fossil fuel to heat the water and reduces the associated environmental impacts.

While solar thermal is a high performance technology and is just as applicable and valuable to rooftops as solar photovoltaic systems, the Rooftop Resources Project and the *Use Your Roof Guidebook* focuses on solar PV technology. Solar thermal is a key component of local, clean energy that is definitely worth considering. We encourage you to explore the option of

solar thermal for your building. More information on policy incentives and current development of this technology can be found through one of the Bay Localize projects, the Local Clean Energy Campaign, at www.baylocalize.org/programs/local-clean-energy. Other rich sources of information can be found on the Northern California Solar Energy Association website: www.norcalsolar.org or through the California Solar Center, www.californiasolarcenter.org.

PART 2 Factors to Consider

How Rooftop Systems Can Be Fitted to Your Building

While every roof is a potential resource, every building is a unique container to hold a suitable rooftop technology. If you're reading this, you're probably already interested in a roof garden, rainwater catchment, or solar power. Or maybe you want a combination of these systems for your building. There are many design possibilities, and many approaches to implementation. Each of these rooftop technologies is a significant investment, and will benefit you in the years to come.

Ultimately, choosing the best system depends on the characteristics of your building, your objective, and your budget. This section of the *Guidebook* is not a how-to guide for do-it-yourself rooftop resource systems. It is meant to help you narrow down what might be possible on your roof so you can focus the next steps of your research. It will provide an overview of the architectural requirements for roof gardens, solar electric systems and rainwater catchment as well as a description of conceptual rooftop system prototypes. We encourage you to seek professional structural assessments specific to your site as needed.

What's your Building Type? Structural Considerations

Rooftop gardens, solar energy and rainwater catchment can work on multiple building types. Any given building type presents multiple factors that the rooftop design must accommodate. The main characteristics that will impact the rooftop design are roof loading capacity, positioning of the house, and the open space within the building's property. Roof gardens have a structural impact, whereas solar electric systems require access to sunlight which is determined by the positioning of the house and the tilt of the roof. For rainwater catchment, the property must be able to accommodate a storage container.

Bay Localize conducted a Neighborhood Assessment with the urban planning firm Design Community and Environment and the engineering Firm Holmes Culley to address these structural considerations (see http:// www.baylocalize.org/?q=node/48). The Assessment analyzed the structural capacity of ten common building types to carry various conceptual rooftop prototypes. The assessment explored the costs, benefits, best practices, feasibility, and productivity of edible roof gardens, living roofs, rainwater catchment and solar power. The table below shows a listing of the building types and characteristics from the Assessment.

TABLE 2 BUILDING TYPOLOGY-TYPICAL CHARACTERISTICS

Building Type	**Land Use**	**14 Occupied Stories**	**Construction Material**	**Construction Era**	**Size/Scale**	**Additional Loading Capacity* (psf)**
House	Residential	1-2	Wood-framed	Any	Up to 4 units	20
Apartment Building	Residential	1-4	Wood-framed	After 1950	4 to 10 units	15
Apartment Tower	Residential	5+	Concrete or Steel	After 1980	More than 10 units	5-7
Mixed Use	Retail/Residential	2-5	Wood framed	Any	Varies	Varies (8-12)
Shops	Commercial	1	Wood-framed	After 1970	Varies	17
Warehouse	Varies	1	Masonry or Concrete block walls, riveted steel or large-timber columns	Prior to 1960	Large, open floor plan	5
Big-Box	Retail, Industrial	1	Concrete block or tilt-up concrete walls, interior steel posts	After 1960	Large, open floor plan	5
Repair shop	Commercial	1	Concrete block	Any	Smaller, open floor plan, open storefront	7
Office Building	Office	2+	Varies	After 1960	Varies	17
Community Building	School, hospital, church, auditorium, library, theater, police, fire, post office, etc.	1+	Varies	Varies	Varies	Varies (5-17)

* A removal of pea-gravel/rock ballast (secured on the roofs of any of these buildings) can increase the "dead-load" capacity by an average of 4-5 psf for every inch of ballast removed.

Building Requirements for Roof Garden Systems

Table two presents building characteristics for ten common building types in the San Francisco Bay Area.

Assessing Buildings for Structural Capacity

The analysis from the Neighborhood Assessment was based on *Standards of Practice* in the structural engineering profession. The last item on table estimates the additional loading capacity for each building. "Additional" signifies the capacity the building has for loading beyond its "dead load" allowance. Dead load refers to the weight of roof-mounted equipment that is permanently placed on the roof such as HVAC (Heating, Ventilation, Air Conditioning) material, whereas live load refers to the weight of temporary/moveable items on the roof such as rain water in ponds, snow, furniture, and people. Although living roofs can be considered a permanent fixture on the roof, it is a living system that can shift in weight like snow; as it is not a component of the roof inherent to the building any green roof is likely to be classified as a "live load" by the building department. The structural analysis from the Neighborhood Assessment shows us that beyond the dead load capacity for which buildings are designed, the threshold for additional live load weights will range between 15-20 pounds per square foot. Keep in mind that this study is based on a generalization and many buildings can be an exception to this standard. Your building may be designed for a load greater than this average. The first step to initiating a green roof project is to consult a structural engineer about your building's load capacity or evaluate your building plans.

Other Structural Considerations

If your building has a "soft story" level, it is likely too weak to support additional weight on the roof. A soft story (usually the first story) has significantly less earthquake resistance than adjacent stories, for example, a building with an open front. Buildings with a bottom level of stilts, a high concentration of garage doors or an open glass front can be signs of a soft story, particularly if this occurs on multiple sides of the building. In an earthquake, the soft story will "sway" or "lean" much more prominently than the stiffer stories, and earthquake damage will be concentrated on that story.

Seismicity

Many conventional buildings of wood or concrete construction have inherent earthquake resistance above and beyond the minimum strength required to safely resist an earthquake.
Buildings with greater volumes of mass and self weight have greater durability to sustain a roof load. For example, buildings with greater mass in their walls constitute a stronger, heavier building. Typically, additional load that is less than 5 percent of the total building mass does not significantly affect the earthquake safety of that building. Many buildings weigh 50 pounds per square foot for each level above grade. Thus, if 10 pounds per square foot is added to the roof, the total weight is increased by 20% for a one-story building and 5% for a four-story building. Therefore, the seismic resistance of one- and two-story specialty buildings (those which are not conventional wood construction) should especially be assessed by a qualified professional.

For buildings that require alterations to accommodate roof gardens, the California Building Code does permit minor alterations. This is possible even if changes increase structural loading on existing elements, as long as those elements are not stressed beyond their capacity. The code triggers seismic strengthening in limited cases, including Change of Use (Occupancy), Substantial Change (remodeling more than 2/3 of the building at once), and Structural Alterations (such as additions). In general, strengthening will only be required in these cases.

Regulatory and Policy Requirements for Roof Garden Systems

Rooftop garden systems designed for public access are subject to state Building Code and city building, zoning, and fire code requirements. Guidelines for these requirements are city-specific and can be found in your city's building department. City staff can be helpful in guiding you through these requirements.

The California Building Code is contained in Title 24, Part 2 of the California Code of Regulations. The Code regulates the construction and function of buildings to ensure fire and life safety as well as adequate structural design. Pertinent sections of the code include Chapter 5, Section 509 (Guardrails), Chapter 10 (Means of Egress), Chapter 13, Section 1301 (Solar Energy Collectors), Chapter 15 (Roofing and Roof Structures), and Chapter 16 (Structural Design Requirements). The following considerations will affect the extent to which usable rooftop spaces can be created.

Occupancy Load and Means of Egress

Since construction of an accessible space on a rooftop alters the use of the roof, the municipal Building Department reviews the plans for improvement to ensure that Building Code requirements are met. Code requirements will vary depending on how the occupancy of the roof space is defined and on the maximum number of occupants allowed to use the space, which is the "occupant load."

The most relevant example is with regard to means of egress.[3] Accessible roof spaces that accommodate many occupants will be required to provide more than one exit, while spaces intended for ten or fewer occupants are adequately served by one exit. This is a critical variable for rooftop gardening since very few buildings have two exits from the roof. Therefore, for rooftop gardening to be possible, the Building Department must ensure safety by either calling for two exits or determining that the rooftop garden's occupancy load will be ten or less, making one exit sufficient.

The Building Department is responsible for assigning an occupancy load to the rooftop space, in accordance with the following direction from Chapter 10, Section 1003 of the California Building Code:

Areas with fixed seats

Occupant load for areas with fixed seats is determined by assigning one occupant per seat provided in the area. For example, an area with 12 seats has an occupant load of 12.

Areas without fixed seats

Here the occupant load is determined by dividing the occupied square footage by an "occupant load factor" in Table 10-A of the California Building Code. For uses not included in the table, such as gardening, a factor for a similar type of use will be used. Speculatively, a case could be made that gardening has similar intensity of use to manufacturing or a commercial kitchen, where a limited number of people are involved in a productive activity over a large area. If these factors are used, as much as 2,000 square feet can be occupied for gardening without exceeding the maximum desirable occupant load of 10.

3 Means of egress are Code-compliant exits. Any occupiable space, such as a rooftop garden, must have at least one Code-compliant means of egress.

Because rooftop gardening is a relatively rare phenomenon within the Bay Area region, no interpretation of the Code with regards to occupancy has been established. It is possible that Code officials will be wary of rooftop uses more intensive than gardening and will consider the space a gathering place, thereby requiring an additional exit. The outcome will depend on the municipality and on assurances that can be made to limit the number of occupants.

Guardrails

Chapter 5 of the Building Code requires a guardrail around habitable space in order to protect people from falling off the roof. Many buildings have fixed parapets lining the perimeter of the roof area and extending as high as a few feet. Others have no perimeter barrier at all. In any case, a code-compliance barrier that extends 42 inches in height is required.

Accessibility

Local, state, and federal governments address accessibility for the mobility-impaired through several codes and laws. At the federal level, the Americans with Disabilities Act (ADA) requires that equal access be provided for the mobility-impaired when alterations to public spaces are made. Chapter 11 of the California Building Code also sets forth stipulations for accessibility, which are enforced by municipal Building Departments. Both the ADA and Chapter 11 must be satisfied, and every effort should be made to provide universal accessibility to rooftop gardens when feasible.

Americans with Disabilities Act Compliance

ADA requirements for building alterations do not apply to buildings that are used for strictly residential purposes; only buildings considered "public accommodations"—such as restaurants, hotels, theaters, doctors' offices, pharmacies, retail stores, museums, libraries, parks, private schools, and day care centers—are subject to ADA rules. Some rooftop garden retrofits that are accessible to the public would fall under ADA and would need to include accessibility features to the roof, in the form of either elevators or ramps. It is likely that these features would prove prohibitively expensive to install and could create a major disincentive for creating accessible rooftop spaces on existing buildings.

ADA requirements apply only to public accommodations and do not address residential environments. Even for public accommodations, elevators would not be required in many cases. According to the Department of Justice, elevators are generally not required in facilities under three stories or with fewer than 3,000 square feet per floor, unless the building is a shopping center or mall; the professional office of a health care provider; a terminal, depot, or other public transit station; or an airport passenger terminal.[4] In addition, accessibility requirements may be waived as an undue hardship if accessibility features cost more than 20 percent of the total alteration cost, which would often apply in the case of rooftop gardens.

California Building Code, Chapter 11

Accessibility requirements in the State Code are similar to ADA requirements, but also include residential uses in their scope. Like the ADA, the Code allows for exemptions based on "unreasonable hardship," which waives accessibility requirements when the cost of accessibility features exceeds 20 percent of the total alteration cost, and the total alteration cost is less than $120,000 (both of which are generally true for rooftop gardens). Installation of a new elevator in an existing building in order to access a new garden on the roof may be acknowledged as unreasonable hardship, particularly if the structure is not a major commercial or institutional building.

Again, every effort should be made to provide universal accessibility to rooftop gardens. The Americans with Disabilities Act and California Building Code require that these improvements be made whenever feasible, but may provide flexibility when the costs of accessibility improvements are unreasonably high, as with elevator installation in existing residential structures and other small buildings.

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4 US Department of Justice, "Americans with Disabilities Act Questions and Answers," http://www.usdoj.gov/crt/ada/qandaeng.htm.

Building Requirements for Solar

In order to generate significant solar electric output, pitched roofs must have an acceptable tilt and orientation. Ideally the roof should have a sufficient south facing roof area to place a PV array; southeastern and southwestern orientations are also acceptable. The average solar panel is one square meter in size; an average system of two kilowatts will need between 200 to 400 square feet of unobstructed area. In applying PV arrays on pitched roofs, the best orientation is either southeast (135 degrees) or southwest (225 degrees).

Flat roofs are suitable for PV panels as long as they accommodate sufficient space for southern orientation. Currently, public financial incentives are directed toward electricity production during times of peak demand, which favors southwestern-facing installations. The location should be mostly unshaded by trees or adjacent buildings and panels should be set back from roof obstructions that cast shadows, such as chimneys, enclosed stairway landings or mechanical equipment. Roofs fitted with photovoltaics must be able to support the weight of a typical multicrystalline PV panel and mounting hardware, which is approximately five pounds per square foot.

Building and Property Requirements for Rainwater Catchment

Drainage is a standard component on most buildings, comprised of a roof gutter system and downspouts. This is the basic infrastructure needed to harvest rainwater. Of course the catchment design also depends on the water needs. As long as your building has adequate rain gutters and downspouts, your system is half way built. While some flat or low-slope roofs have external drainage systems as described above, others do not have drainage or use internal downspouts that drain directly to the storm sewer or to a ground-level discharge spout. In these cases, capturing rainwater is a more expensive proposition as the drainage system needs to be modified with external conveyance equipment.

After catching and filtering the rainwater, it must be stored for later use. Storage is the limiting factor in rainwater catchment systems, since in urban areas space is often limited for installation of cisterns. Below-ground cisterns have been used for individual buildings or community systems, particularly when they can be planned into new construction, but the expense of excavation and pumping water back up into the distribution system can be costly. When designing a rainwater catchment system, the first question is, "what purpose will the water serve and how much is needed?"

Rainwater catchment can be as simple as placing a barrel under the downspout for an irrigation system, or it can be an elaborate system such as a multiple thousand gallon cistern that feeds the building's plumbing system. This *Guidebook* focuses on harvesting rainwater for landscape irrigation purposes. This leaves the more complex design specifications such as appropriate roofing material, filtration and pipe fitting to plumbers, engineers and other professionals. Even within this simple scope, the design objective question still applies: what is the volume of your watering needs? Given that 100 square feet of surface can capture 60 gallons of water per inch of precipitation, the efficacy of rainwater catchment depends more on the size of the storage vessel than the dimension of the roof surface. Implementation of rainwater catchment depends on whether the building's property can house the appropriate-sized system. The dimensions of cisterns range from the 40"(h) x 30"(w) 50 gallon drum to the 6' (h) x 6' (w) 1,000 gallon tank and other larger systems that vary in dimensions. The next section includes further explanation of rainwater catchment designs as well as the other rooftop technologies.

Part 3 Resources and Considerations for the Optimum System

Roof Garden Systems

Of all the roof garden systems, extensive green roofs are the most simple and lightweight at an average of 12 pounds per square foot (psf). Unfortunately, an extensive green roof will not grow vegetables, but they do provide habitat, help maintain the temperature of the building, absorb water for slower release after a rainfall, and help reduce the urban heat island effect. Many roofs can handle their weight.

Roofs that have enough soil to grow herbs or vegetables (known as "intensive green roofs") need the durability to hold roughly 50 psf and upwards; hence, few existing roofs can hold them. The higher end of this range is actually similar to what is structurally required to park cars on a roof.

An intensive green roof is one in which the substrate (soil) depth is 6 inches or more and an extensive green roof is one in which the substrate depth is less than 6 inches. Intensive gardens, because of their greater substrate depth – and, hence, their greater weight – are not usually installed over large roof areas. If it helps to remember the name, think of them as intense little areas of gardening. Extensive gardens are much lighter due to their smaller substrate depths. However, the range of plants that can be grown is also less.

Another interesting green roof possibility, because it is moderate in weight at 16 psf and very productive in terms of vegetable yields, is a hydroponic garden. Greenhouses are another way of greatly enhancing productivity in a limited space.

If you are constructing a new building, then the typical weights above are useful to know. A voluntary standards-making body, ASTM International, has a standardized procedure for predicting the loads of green roofs called "ASTM E2397-05 Determination of Dead Loads and Live Loads associated with Green Roof Systems." Green Roofs for Healthy Cities has estimates as well.

Note: Before any specific rooftop resource is developed, professional consultation should be obtained to determine precise design loads and roof loading capacity.

Examples of Weights
Intensive Green Roof for Vegetables: 108 psf (18" organic/mineral substrate)
Intensive Green Roof for Herbs: 51 psf (8" organic/mineral substrate)
Extensive Green Roof: 12 psf (2" organic/mineral substrate)
Hydroponic Rooftop Garden: 16 psf (4" inert substrate - Perlite)

Note: These examples are conceptual prototypes and generalized building typologies drawn from the Bay Localize Neighborhood Assessment[5] *and cannot be assumed to be applicable to a specific building.*

When deciding how to get the most from rooftop resources on a new building, contact a structural engineer to determine whether there is sufficient load-bearing capacity for the system you are interested in. In the next section, we look at some of the safety codes that are required.

Prototypes from the Neighborhood Assessment Report

This section describes four rooftop resource prototypes developed from the Bay Localize Neighborhood Assessment Report. It includes system weight and productivity, covering each of the rooftop resource strategies in the Neighborhood Assessment.

The goal of assessing rooftop capacity on existing buildings in their current condition, rather than focusing just on new construction or on structurally reinforced buildings, figured in the creation of these prototypes. The table below describes the components, cost ranges, and yields of the prototypes.

The prototypes are necessarily generalized to allow for variations in roof size and type, roof slope, building type, wind variables, client budget, and other conditions. They should be taken as examples of possible configurations and should not be relied upon for specifications for any site. Before any specific rooftop resource is developed, professional consultation should be obtained to determine precise design loads and roof loading capacity.

5 Brian Holland, Sarah Sutton, Kate Stillwell, Ingrid Severson, Kirsten Schwind. 2007. *Tapping the Potential of Urban Rooftops.*

Prototype Characteristics

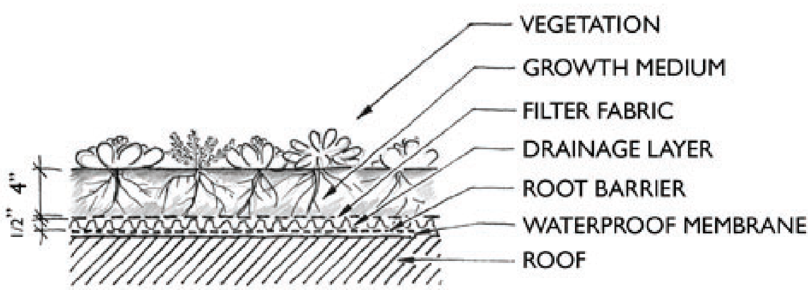
Prototype	Major Components	Maximum Weight	Annual Productive Yield
Extensive Green Roof	½" Drainage Mat 4" Mineral Substrate Sedums	22 psf	drainage and energy benefits
Intensive Green Roof—Vegetables	2¼" Drainage Board 18" Organic/Mineral Substrate Variety of Vegetable Crops	108 psf	1.86 psf vegetables
Intensive Green Roof—Herbs	1 ¼" Drainage Board 8" Organic/Mineral Substrate Herbaceous Plants	51 psf	perennial yield
Hydroponic Rooftop Garden	Growing Container Reservoir Container 4" Inert Substrate Variety of Vegetable Crops	16 psf	4 psf vegetables

These four prototypes and most of the documentation below come from Chapter 3 of the Rooftop Resources Feasibility Survey created for Bay Localize by Design Community & Environment. For costs and benefits of each of the prototypes, see Chapter 3 of the Bay Localize report, *Tapping the Potential of Urban Rooftops.*[6]

6 Brian Holland, Sarah Sutton, Kate Stillwell, Ingrid Severson, Kirsten Schwind. 2007. *Tapping the Potential of Urban Rooftops. http://www.baylocalize.org/?q=node/48*

Prototype 1: Extensive Green Roof

The first prototype is a typical configuration of extensive green roofs for arid climates, in which low-growing, drought-tolerant ground cover is planted in 4 to 6 inches of growing substrate and placed on an assembly of filter fabric, a drainage layer, root barrier, and a waterproof roof membrane. This assembly can be installed directly on the roof or placed in trays that are installed as a modular system



Assembly

Plants are established in four inches of substrate, considered a minimum depth for plants to endure dry Bay Area summers. In this case, a blend with high mineral content and low organic content should be developed to provide moisture and air retention while minimizing the load imposed upon the roof. While the exact blend depends highly on the site, one very appropriate medium is pumice, which is one of the lightest mineral materials mined within 500 miles of the Bay Area. Expanded shale is another very lightweight mineral that exists in California; however, it is currently shipped in from Colorado and other Western states, resulting in higher transportation costs and environmental impacts. Lava and scoria are available from the Clearlake, California area, but they are heavier than pumice and expanded shale. Whichever mineral medium is selected, it should be combined with a minimal amount of organic material, such as locally available compost.

Beneath the substrate, a ½ inch thick recycled polyethylene drainage mat should aerate and drain the media, and an attached filter fabric will prevent it from clogging the drainage layer. Finally, a root barrier and waterproof membrane will protect the roof deck from the living layer above.

A popular alternative to the type of assembly described above (which is built-up directly on the roof) is the modular approach, in which the above components are assembled in container trays and installed on the roof. Modular systems present a number of benefits. Perhaps the most notable of these is the flexibility with respect to installation and removal. These modular systems can often be installed without re-roofing, while the soil membrane system may require replacement or major repair to the roof membrane. Building owners may also be more open to experimenting with a green roof installation knowing that the trays can be easily removed if desired.

Whether the soil membrane approach or the modular system is chosen for a particular roof, the described components of the extensive green roof assembly are almost identical in other respects.

Plants

The Extensive Green Roof prototype is planted with of a mix of regionally appropriate sedums, such as *Sedum album*, *Sedum spathuifolium*, *Sedum spurium*, and *Sedum sexangulare*. The specific species chosen for a particular rooftop context depends on many factors, including:

- Initial budget and maintenance budget
- Physical conditions, such as shading and wind
- Roof slope
- Retrofit schedule and seasonal variables

Planting methods can vary, from direct seeding in the growing medium during installation to application of pre-planted container trays or vegetated mats. Generally, materials for vegetated mats and modular tray systems are more expensive but labor costs are reduced, while seeding or transplanting plugs directly is more labor-intensive but reduces materials costs.

Consider moss and native wildflowers as two plants with very lightweight needs and valuable habitat especially for native bees.

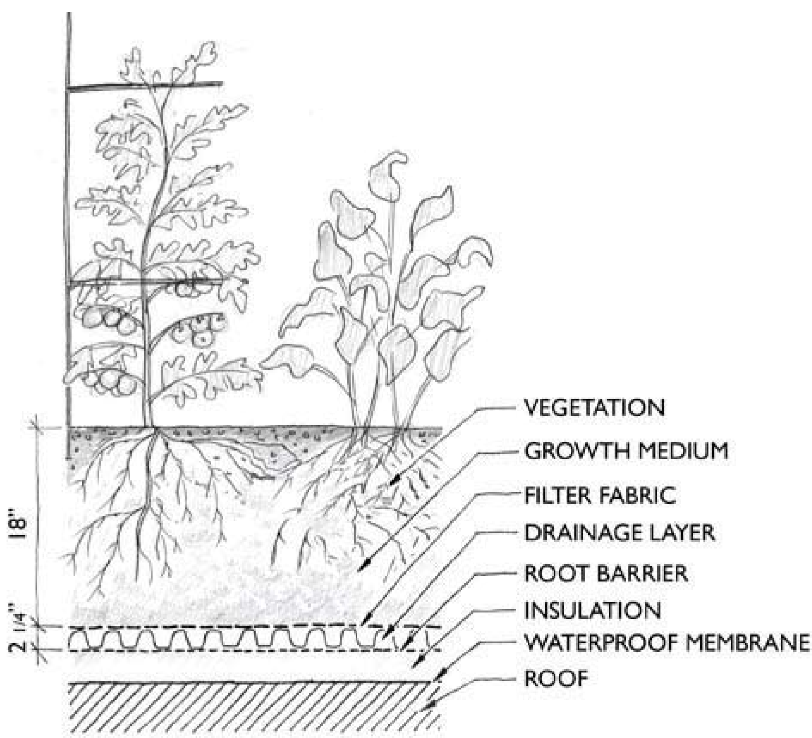
Maintenance Requirements

Extensive green roofs are generally a low-maintenance system, although during the first year after installation plants need to be irrigated as they establish themselves. Planting hardy, drought-resistant, regionally-appropriate varieties such as those specified in this prototype will limit irrigation needs over the long-term since these plants are accustomed to the arid conditions of Bay Area summers. However, minimizing substrate depths to the level entailed in this prototype would likely require that some irrigation occur on a regular basis, depending on the conditions of the site. The extensive green roof needs to be inspected only a few times a year to ensure that all components, including the membrane, are functioning as intended.

Extensive green roofs can reduce roof maintenance demands and as much as double the life of the roof membrane by protecting it from extreme temperature changes, ultraviolent radiation, and accidental damage.

Prototype 2: Intensive Green Roof – Vegetables

The Intensive Green Roof-Vegetable Garden prototype is designed to provide the environmental and aesthetic benefits of the extensive prototype as well as food production and open space that can be occupied. This prototype has 18 inches of growing medium, the minimum depth to support a large variety of vegetables. The assembly for this prototype is similar to that of the extensive prototype, consisting of a waterproof membrane, root barrier, drainage layer, filter fabric, substrate layer, and plants.



In this case, however, the vegetated roof is not intended to cover the entire roof area. Instead, paths are created by closing in growing areas with retaining walls, constructed of lightweight materials such as wood or recycled plastic. A protective surface would be installed to protect the roof from foot traffic damage. This arrangement effectively creates accessible spaces similar to ground-level container gardens. While a multitude of different arrangements are possible, depending on the fixed obstructions on the roof, this prototype generally provides an average growing area of 60 percent of total roof area. This takes into account the typical space unavailable due to fixed obstructions as well as space needed for paths and equipment storage.

Assembly

Conventional topsoil and potting soil are too heavy for most rooftop environments, particularly existing buildings. The medium used in this prototype would include approximately equal parts organic material, such as compost or bark humus, and mineral material such as pumice or scoria. The drainage layer in this prototype is a 2¼ inch thick recycled polystyrene drainage board. The drainage layer of the system is generally comprised of lava or similar mineral material for structure. Other components are similar to the extensive green roof prototype.

Plants

This prototype is designed to provide year-round vegetables that would thrive in the Bay Area. Selection of vegetables depends on several criteria that include:

- Regional suitability
- Growing medium depth requirements
- Plant weight at maturity (structural consideration)
- Height at maturity (wind loading considerations)
- Full sun tolerance
- Normal to low water needs
- Growing season

Based on this criteria, plants can be rotated to grow on a year-round basis. Cool-season crops in the prototype are spinach, mustard, carrots, and beets. Tomatoes, cucumbers, and winter squash are included as warm-season crops, along with leaf lettuce, which in many cases can be grown year round. Variations on this arrangement should provide an opportunity to grow cool-season crops twice yearly, planted in the early Spring and Fall, while planting warm-season crops in late Spring.

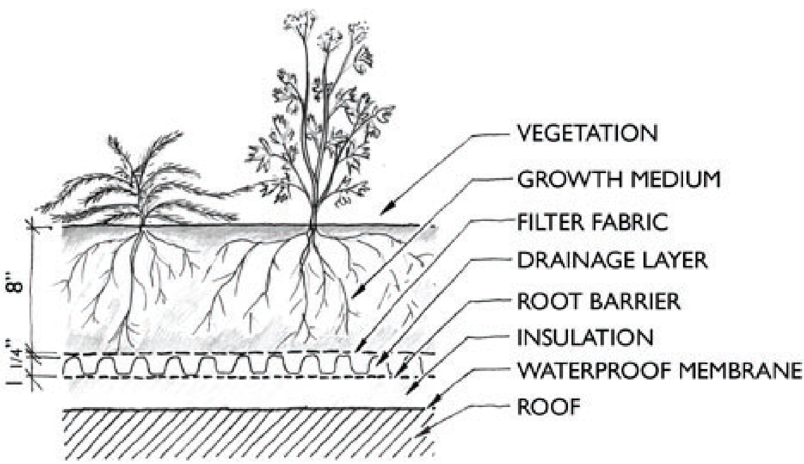
Maintenance Requirements

The prototype would require substantial maintenance, much of which is associated with normal vegetable gardening activities. Maintenance demands would include regular irrigation, weeding, fertilizing, and pest control. Water needs could be increased relative to ground-level gardening due to higher rates of heat- and wind-induced evaporation. Depending on budget, irrigation could take place through hand-watering or sub-surface drip irrigation, the latter of which would reduce water usage and labor requirements. In addition to regular maintenance of the growing area, inspection and repair of the roof membrane would be required on an occasional basis. In a worst case scenario, roofs can leak from drainage backups or root puncture or if the correct waterproofing membrane system, root barrier, and/or drainage layer are not selected. Areas where occasional inspection for leaks is advisable include abutting vertical walls, roof vent pipes, outlets, air conditioning units, perimeter areas, etc.[7] Most roofing companies, including those that install green roofs, will provide a warranty for the waterproofing integrity of the roof membrane(s) they have installed, including green roof membranes.

7 Exploring the Ecology of Organic Green Roof Architecture, Green Roofs Web Site, (http://www.greenroofs.com/), Velazquez

Prototype 3: Intensive Green Roof - Herbs

The concept of this prototype is largely similar to the Vegetable Garden prototype, except that herbs are grown rather than vegetables. The main plant themes are rosemary, thyme, and cilantro. The growing medium remains the same – a lightweight, soil-free mix of approximately equal parts organic and mineral material -- but substrate depth is reduced to 8 inches, a minimum for many herbs that would be suitable for a rooftop environment. The drainage layer is also similar to the Vegetable Garden prototype, but its thickness is reduced to 1¼ inches.

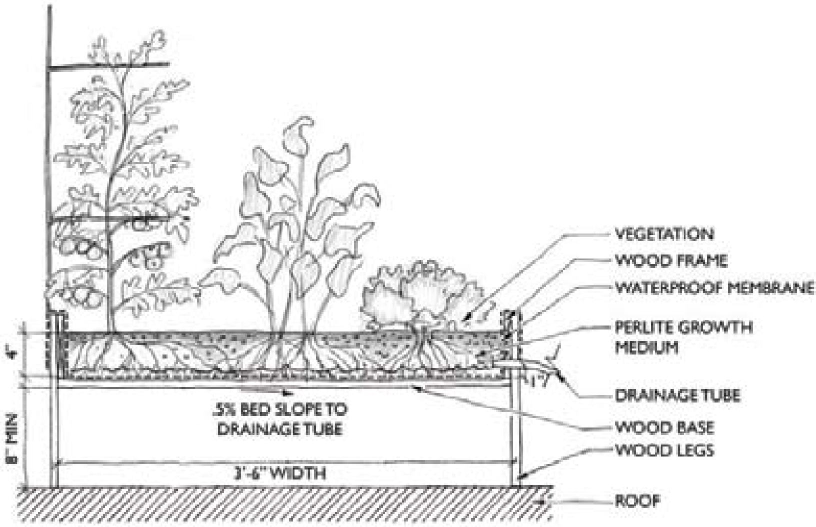


Maintenance Requirements

Maintenance needs would be significant and would include regular irrigation, pruning, weeding, fertilizing, and pest control. Irrigation needs would be less than the Vegetable Garden prototype, but a sub-surface drip irrigation system would still be desirable. As with all green roofs, regular inspection of the roof membrane would be required and occasional repair of the membrane could prove necessary.

Prototype 4: Hydroponic Vegetable Garden

Hydroponics is a horticultural method that supplies plant roots with liquid nutrients, eliminating the need for organic material that provides nutrients under conventional methods. Plants are provided with nutrient solution and are either grown in an inert mineral substrate or are suspended above the solution without substrate. The hydroponic model substantially reduces the weight of vegetable cropping systems by eliminating the growing medium.

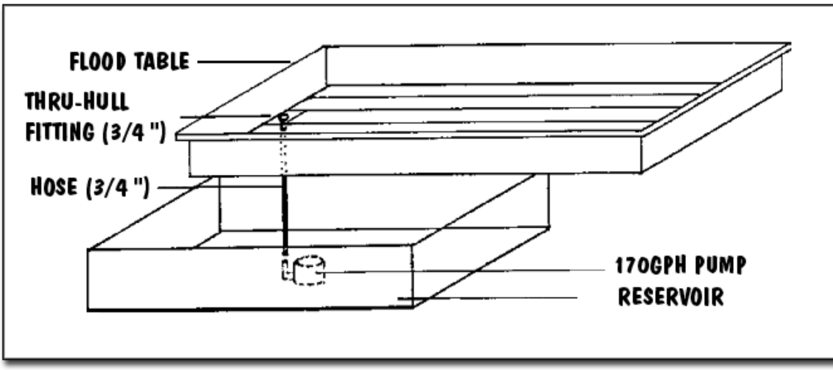


The Hydroponic Rooftop Vegetable Garden prototype utilizes a low-tech, low-cost method that minimizes weight while maximizing vegetable productivity, variously called Simplified Hydroponics or Popular Hydroponic Gardens (PHG). The design is based on concepts developed and implemented around the world by the UN Food and Agriculture Organization (FAO), the UN Development Program (UNDP), and the Institute for Simplified Hydroponics.

Assembly

No fewer than six different techniques can be used to operate the system, some of which involve such equipment as water pumps, air pumps, computerized monitors, timers, and lighting.

In this prototype, containers are filled with lightweight mineral substrate to a depth of 4 inches. Perlite is used as a base, and combined with inert organic material such as rice hulls, peanut hulls, grain chaff or coconut coir. The addition of these organic materials provides a more balanced substrate, thus fostering a healthier medium for the plants. This growing medium is ideal for its extremely low weight, but it should be noted that other lightweight bases could be used, such as pumice. Vermiculite is not recommended as it is strongly associated with cancer. Appropriate plants include cooking and salad greens, most summer and winter vegetables, and herbs. Root vegetables can be grown hydroponically but require greater substrate depths than specified in the prototype. Planting methods may vary among vegetable types, but generally seedlings are transplanted into the substrate, where they have regular access to the nutrient solution.



The prototype utilizes the "flood and drain" method of hydroponics, in which the nutrient solution is circulated back and forth between the growing container and a reservoir container. The growing container is constructed with a drain approximately one inch above the base, allowing for some accumulation of solution in the bottom of the container but draining the remainder. If the growing container is elevated and placed at a minimal slope, drainage can be gravity-fed. Alternatively, a pump can be used to continually flood and drain the growing container, recirculating the nutrient solution.

Accounting for roof obstructions, pathways and storage areas, a maximum growing area of 60 percent of the total roof area is recommended.

Solar Photovoltaic Systems and Energy Efficiency

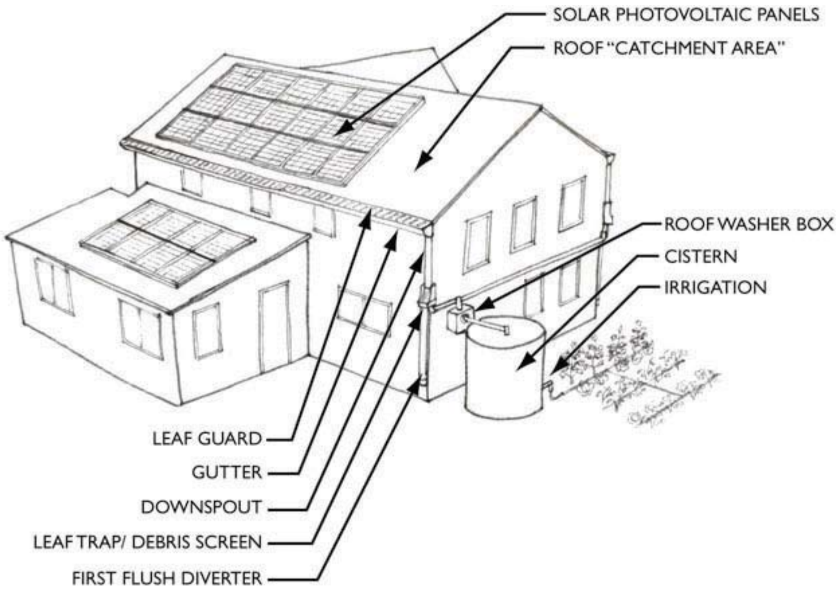
Adding solar energy to a building can be likened to adding a clean energy power-plant to the building. Producing energy is one thing, whereas how the energy is managed is another thing. The majority of buildings in the U.S. are not energy efficient. If the motivation of incorporating solar to a building is to save on energy bills by using your own supply, or for more environmental reasons, like reducing the usage of dirty, nonrenewable energy supplies, a solar electric system will only be worthwhile if the building is energy efficient. Many buildings require unnecessary heating and cooling and waste energy due to poor insulation, inefficient HVAC systems and air leakages. Building performance improvements should treat the building as a holistic system in which the building is evaluated for how well the ventilation, air filtration (treating air from outside), insulation, heating and cooling systems work. These components constitute the building envelope, or the outer layer of the building that separates the living space from the outdoor environment, both above and below grade.

Improving the building's energy performance is a key precursor to installing solar and having a clean, low cost, and energy smart building. As energy costs rise and public response to reducing greenhouse gases increases, more standards, processes and services for energy efficiency retrofitting have emerged. Some solar electric companies offer energy efficiency work as part of their services. If you are shopping around for solar power estimates, make sure to ask if the company includes energy retrofitting as part of their services. Many local and state governments support the transition to make buildings energy efficient.

The building improvement process usually involves assessing the building's envelope quality, for example the existing insulation levels of the various parts of the house, windows, and doors. This can usually be done with a professional energy auditing process. Structural problems may need to be assessed to assure there are no structural deficiencies. The building envelope assessment will inform the retrofitting design. The retrofit involves choosing the right products and determining the preparation and installation requirements for each product and finally the installation. If you decide to perform your own retrofit, there are many resources available. Your utility may have free products and services. Additionally, there may be local government agencies that offer free or low cost services. Finally there are many professional energy retrofitting services available that can provide a high quality retrofit and ultimately help you save costs in the long term. Please see the resources listed at the end of this *Guidebook* for further information.

Once you have ensured your structure is energy efficient, consider the benefits of solar energy. Solar photovoltaic (PV) technology offers the opportunity to produce clean, renewable energy on a wide range of residential and non-residential rooftops. While the technology has existed for many years, recent advances are improving the efficiency of PV cells, which are the individual units that produce electricity. These cells are combined into modules that are available in single crystal, multi-crystalline, and amorphous silicon (thin-film) varieties, differing in their efficiency and cost.

The key factors in choosing a solar electric system for your building are determining the size of the system based on how much of your load you want to offset, your budget, and whether or not you want to purchase equipment and plan to install the system yourself or if you want a licensed local solar contractor or a licensed electrical contractor and roofer to install the system. Another option is to enter into a residential Power Purchase Agreement (PPA) with a company that installs and owns the system and sells the electricity back to the individual, generally resulting in a monthly savings on your energy bill. Since the systems is owned by a company it gets the full 30% investment tax credit, a more generous subsidy than those available to individual consumers. Entering into a residential Power Purchase Agreement greatly reduces up-front costs.



Hiring a professional designer/installer will guarantee the operation and warrantee of your system, and can save you the hassle of applying for your state rebate. Although hiring a professional can be a safer and easier route to implementing a solar system, many people have had success with the DIY (Do It Yourself) approach.

The first thing a solar electric design professional will do is perform a solar site analysis. A solar site analysis can be used to determine whether the roof or ground location has adequate sun access from 9am to 3pm in the winter and 9am to 4pm in the summer. Most licensed solar contractors have a tool for finding the best location. You can perform your own site analysis. It's possible to obtain a rough estimation of your solar availability simply by walking around your property and assessing your building's shading and access to the sun. Be sure your site has good exposure to an unobstructed and open sky. Remember that solar angles change considerably between summer and winter.

The following website from the State of California's Go Solar program lists several on-line calculators that can help you determine the potential solar output of your site:

http://www.gosolarcalifornia.ca.gov/solar101/calculators.html

If you want your solar electric system to completely offset your energy load, you can estimate your energy load, or consumption by averaging the kilowatt-hour totals on your utility bills from the past year. Alternatively, you can estimate the energy use of the lighting and appliances in your household. The table below provides a model for this tabulation. The table is also a good method for assessing the energy consumption of your electrical devices. Understanding the load generated by each device can help you determine how to cut back or replace the devices with more energy efficient models.

Make a list and record the wattage of each unit (appliance, stereo, computer, entertainment item, etc). Each unit and appliance has a nameplate on it that tells you how many watts it needs. You could also look up the units' model# on the web, look at a specification sheet, or ask an appliance dealer/manufacturer to get the wattage rating.

First make a table of your daily and weekly energy needs, by multiplying the unit's watts by the average number of hours per day you use it, and then by the average days per week that you use it. Note that some of the following appliances may run off a combination of electricity and natural gas. Tabulate electricity usage here. It may be enlightening to calculate your natural gas usage separately to assess how you can best conserve this resource as well.

Wh (Watt hours) / day = Watts multiplied by average hours/day use **Wh (Watt hours)/ week** = Wh(Watt hours)/day multiplied by average days/ wk use

Fill In Your Own Units and Watts (and electrical devices you use):

UNIT		Watts	Your Watts	Wh/ Day	Your wh/ Day	Wh/ Week	Your wh/ Week
Lighting							
Refrigerator							
Stove							
Dishwasher							
Other Kitchen Appliances							
Air Conditioners							
Heaters							
Hot Water Heater							
Television							
Stereo							
Power Tools							
Computers							
All Other Appliances							
Ceiling Fans							
Water Pumps							
Misc. Other							
Total							

Keep in mind that under the current California net metering laws, any additional energy produced from a grid tied system beyond what your building consumes will feed back to the grid. The excess energy you produce will then be credited to your account. However, if on average you produce more electricity than you use, under current net metering laws you will not be reimbursed for the excess energy you provide to the grid, creating an incentive to size your system conservatively. Under a feed-in tariff policy, excess energy provided to the grid could be eligible for monetary reimbursement.

A few words on the type of panel you may choose. Research and literature surveys conducted in the Rooftop Resources Project found single crystal and multicrystalline systems to be the most popular and cost-effective types of installations. Single crystal and multicrystalline cells are comparable in most ways, though the former is generally the more efficient and the latter generally the more affordable. Both are commonly installed in the Bay Area and both can be considered "high-efficiency" systems. Multicrystalline panels have a typical generating capacity of 1 kilowatt (kW) per 100 square feet. As multicrystalline systems are a more familiar and commonly used technology, the content in the *Guidebook* is based on this system.

As discussed in the previous section, energy efficiency improvements should be done before sizing and installing the system. Any PV system should be installed with an acceptable tilt and orientation to be effective.. For optimum effect, the array should face south, southeast, or southwest. Ideally the array should be tilted towards the sun, but even flat installations on a flat roof can qualify for financial incentives and produce nearly as much electricity as a system with the ideal tilt.

Rainwater Harvesting Systems

Catchment and Conveyance

The first step in rainwater harvesting and reuse is to capture the precipitation. Typically, pitched roofs are fitted with external gutters and downspouts to carry water off the roof and away from the exterior walls of the house. The prototype rainwater harvesting system entails installation of a cistern connected to the downspout, intercepting water that would otherwise reach the ground and run away from the foundation of the building.[8]

While some flat or low-slope roofs have external drainage systems like the one described, others do not have drainage or use internal downspouts that drain directly to the storm sewer or to a ground-level discharge spout. In these cases, capturing rainwater is a more expensive proposition, as the drainage system needs to be modified with external conveyance equipment.

8 Not all rain that falls on the roof will be drained, due to absorption and evaporation. A runoff coefficient of 0.85 is assumed for pitched roofs in this prototype, meaning that 85 percent of fallen precipitation will be conveyed into the rainwater harvesting system. The assumed runoff coefficient for flat roofs is 0.50, accounting for pooling conditions or gravel ballasted roofs.

Filtration

After collection and conveyance, several features should be incorporated to filter out roof debris and pollution before storage. A simple debris screen should be fitted to the gutter or downspout to catch leaves and other large particles. In addition, a first-flush diverter is commonly used to capture the first few gallons of rainwater during a storm, which is usually more laden with pollutants that have accumulated on the roof between rain events, such as dust and bird droppings. The first flush of storm water then drains separately from the rainwater harvesting system. There are a variety of first flush diverters commercially available.

The common models are automatic systems that do not rely on mechanical parts or mechanical intervention. The recommended capacity of the diverter varies by roof type, the likely presence of pollutants, and the expected duration between rain events, but a general rule of thumb is a minimum of one gallon of diversion capacity per 1,000 square feet of catchment area.[9]

Another filtration component to consider is a roof washer. Roof washers are usually installed to filter out smaller debris and organic materials. Roof washers commonly take the form of a container with one or two canister filters inside, installed directly before the cistern. The necessity of this component will depend on the type of irrigation system you are using this water for; drip irrigation systems are likely to become clogged without micro-filtration.

9 Texas Water Development Board, *Texas Manual on Rainwater Harvesting*, Third Edition, 2005.

Storage

After catching and filtering the rainwater, it must be stored for later use. Storage space for cisterns is often the limiting factor in this prototype. Below-ground cisterns have been used for individual buildings or community systems, particularly when are planned into new construction. Since the expense of excavation and pumping water back up into the distribution system can be cost-prohibitive for many residents and building owners, this prototype uses an above-ground cistern.

Cisterns vary in type and size. Plastic or steel cisterns are commonly available and are durable and movable. Reclaimed containers such as trash cans or steel or plastic drums can also be used. Cistern size is based on the size of the roof, rainfall patterns, the amount of space available for siting, and the proportion of rainwater versus municipal water use that is desired. While some lots could accommodate a 1,500-gallon cistern, others would be confined to a 500-gallon or even 110-gallon tank. The prototype has a storage capacity of 1,000 gallons.

Distribution

Water can be distributed to meet landscaping needs either through drip irrigation or watering by hand. Ideally, the cistern is located at the highest elevation on the lot, enabling gravity-fed irrigation. If drip irrigation is used, in some circumstances a pump would be needed to pressurize the system.

Mixtures of Prototypes

This final section identifies opportunities and constraints for implementing multiple rooftop resource strategies in the same roof space. While there are many unknown variables that influence these possibilities, research is beginning to look at what type of synergies may come about through interaction of these systems. This section considers a few of the most likely interactions.

Extensive Green Roof and Photovoltaics

This combination presents both positive and negative interactions, and existing research has not adequately tested its feasibility. Installation of solar panels above the green roof vegetation would create a good deal of shade and would keep precipitation from falling evenly over the vegetation. Nevertheless, some Sedum varieties have demonstrated shade tolerance, including Sedum ternatum and Sedum telephium. Shading would reduce evaporation as well, potentially allowing for reduction of substrate depths beyond what is otherwise feasible in the seasonally arid Bay Area climate, or the elimination of installed irrigation.

A research plot maintained by University of Applied Sciences Neubrandenburg and the Technical University of Berlin has had success not only in green roof plant growth under a photovoltaic installation, but also in demonstrating increased PV output in this scenario. Their research indicates that green roofs can improve the efficiency of photovoltaics mounted above them. Ambient temperatures on the test plot were reduced 16 degrees Celsius compared to an adjacent conventional roof, which improved the efficiency of the PV and resulted in an average 6 percent increase in energy yields. The combined load of the Extensive Green Roof prototype and the Solar Photovoltaic prototype would be approximately 17 psf.

Green Roofs and Rainwater Harvesting

Installation of these technologies in concert is technically feasible. Precipitation that is not taken up by the green roof vegetation is sometimes drained to downspouts as in the conventional scenario. However, the cost-effectiveness of this strategy is questionable due to the retention and absorption capabilities of the green roof. Runoff coefficients of green roofs can range from 0.50 to 0.80, draining as little as 20 percent of the precipitation into the water storage system.

Photovoltaics and Rainwater Harvesting

Photovoltaic systems do not intercept or impede the flow of water from the roof, so these prototypes can usually be implemented together. Because photovoltaic panels do not absorb any water, the runoff coefficient of a roof fitted with a solar installation may be improved relative to that of normal asphalt roofing material, resulting in a marginally higher catchment capacity. In addition, photovoltaic systems require periodic washing to remove dust and dirt buildup, and the wash water could be harvested under this scenario, if pollutants are not a concern.

Make it Happen!

The guidelines and information in the previous chapters of this *Guidebook* outline the first steps to planning your ideal rooftop system. Know that as you embark on your rooftop project, your system will stand as a beacon to the rest of the city, illuminating the path towards a more sustainable built environment. Bay Localize hopes to share your successes and lessons learned. Please help us disseminate information about your system and best practices by documenting your project with pictures and notes, and joining our Rooftop Systems Gallery. You can upload pictures and project specs at www.baylocalize.org/webgallery/. Thank you for being a pioneer in the field of appropriate technology!

PART 4 Appendix

Putting the Technology to Practice

Resources to Begin Implementation

These listings include references to retailers for materials, supplies, educational facilities and books etc. For a current list of vendors, please refer to the Bay Localize website at www.baylocalize.org/projects/rooftop/systems/resources

Living Roofs

American Society of Landscape Architects
Referrals for landscape architects
San Francisco, CA
www.asla.org, (415) 974-5430

American Soil and Stone
Retailer of horticultural soils, mulch, soil amendments
Richmond, CA
www.americansoil.com, (510) 833-7201

Bayview GreenWaste
Retailer of compost
San Francisco, CA
No website, (415) 822-7686

Berkeley Horticulture
Nursery & garden center
Berkeley, CA
www.berkeleyhort.com, (510) 526 4704

California Native Plant Society
Provides information about gardening with native plants
San Francisco, CA
www.cnps.org, (415) 731-7318

Caldwell's Lumber
Retailer of recycled lumber
San Francisco, CA
www.caldwelllumber.com, (415) 550-6777

City Slicker Farms
Garden training, education, food distribution and garden developer
Oakland, CA
www.cityslickerfarms.org, (510) 763-4241

Eco Timber
Retailer of ecological timber
Sold at various locations
www.ecotimber.com, (510)549-9300

Quasimodo Metal Works
Metals, custom design & manufactured garden beds
Berkeley, CA
www.quasimodo.net, (510) 841-4033

SF Garden for the Environment
Horticulture and garden training, workshops
San Francisco, CA
www.gardenfortheenvironment.org, (415) 731-5627

Spiral Garden
Nursery, food garden, community classroom
Berkeley, CA
www.spiralgardens.org, (510) 843-1307

Sustaining Ourselves Locally
Urban gardening workshops and training, community events and retailer or plant starts
Oakland, CA
www.oaklandsol.org, (510) 534-9987

The Reuse People
Distribution of recycled building materials
Oakland, CA
www.thereusepeople.org, (510) 383-1983

The Urban Farmer Store
Irrigation, gardening and other small scale farming supplies
Richmond, Mill Valley, CA
www.urbanfarmerstore.com, (415)380-3840, (510) 524-1604

Urban Ore
Retailer of recycled lumber
Berkeley, CA
www.urbanore.citysearch.com, (510) 559-4450

Books and Websites

Green Roofs: Ecological Design and Construction; Earth Pledge Foundation

Green Roof Plants; Edmund C. Snodgrass and Lucie L. Snodgrass

Planting Green Roofs and Living Walls; Nigel Dunnett and Noel Kingsbury

Roof Gardens: History, Design and Construction; Theodore Osmundson

Golden Gate Gardening: Year-Round Food Gardening in the San Francisco Bay

Area and Coastal California; Pam Peirce

U.S. Green Building Council/ Leadership in Environment and Energy Design
Directory of LEED Accredited Professionals by region and area of practice
http://www.usgbc.org/LEED/AP/ViewAll.aspx
www.greenroofs.com
www.greenroofs.net
www.skyvegetables.com
www.rooftopgardens.ca/
www.greenroofplants.com/green_roof_links.htm
www.usgbc.org
http://commons.bcit.ca/greenroof/

Rainwater Catchment

American Rainwater Catchment Systems Association

Educational networking group
Austin, TX
www.arcsa.org

Loomis Tank Centers

Retail and wholesale distributor of polyethylene ground water tanks
Arroyo Grande, CA
www.loomistank.com, (800) 549-5514

Oasis Design

Offers hardware and do-it-yourself guides for conceptualizing, designing and implementing sustainable water harvesting systems
Santa Barbara, CA
www.oasisdesign.net, (805) 456-2262

Pioneer Water Tanks USA

Tank distributor and wholesaler
Napa, CA
www.pwtusa.com, (707) 965-3600, email: pwtnc@sbcglobal.net

Books and Websites

Water Storage: Tanks, Cisterns, Aquifers and Ponds; Art Ludwig
Rainwater Catchment for the Mechanically Challenged; Suzy Banks with Richard Heimichen
Forgotten Rain: Rediscovering Rainwater Harvesting; and Design for Water: Rainwater Harvesting, Stormwater Catchment and Alternate Water Reuse; Heather Kinkaid Levario
Rainwater Harvesting for Drylands, vol. 3: Roof Catchment and Cistern Systems; Brad Lancaster

www.harvestingrainwater.com
www.harvesth2o.com
www.watertanks.com

Energy Efficiency Retrofitting

Energy Star

A joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy with a mission of helping the public save money and protect the environment through energy efficient products and practices.
www.energystar.gov, (888) STAR-YES

Pacific, Gas & Electric

Energy Efficiency Program
www.pge.com/myhome/saveenergymoney/, 1-800-743-5000

Books and Websites

Consumer Guide To Home Energy Savings; Alex Wilson, Jennifer Thorne, and John Morrill
http://www.energysavers.gov/
www.solutionsforremodeling.com

Solar Electric Design and Installation

Northern California Solar Energy Association

Non-profit educational organization with a mission of accelerating the use of solar energy technology through the exchange of information
Berkeley, CA
www.norcalsolar.org, (530) 852-0354

Solar Energy International

U.S. based non-profit organization whose mission is to help others use renewable energy and environmental building technologies through education
Carbondale, CO
www.solarenergy.org, (970) 963-8855

Pacific Energy Center (PG&E)

Commercial & municipal advice on energy efficient architecture and design
San Francisco, CA
www.pge.com/pec, (415) 896-1290

Websites and Books

www.californiasolarcenter.org
www.builditsolar.com

The Fuel Savers: A Kit of Solar Ideas for Your Home, Apartment, or Business; Bruce Anderson

The Homeowner's Guide to Renewable Energy: Achieving Energy Independence through Solar, Wind, Biomass and Hydropower; Dan Chiras

Real Goods Solar Living Sourcebook: The Complete Guide to Renewable Energy Technologies & Sustainable Living; John Schaeffer

Notes

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