Going Zero

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"Submitted towards the fulfillment of the requirements for the Doctor of Architecture degree."

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"We certify that we have read this Doctorate Project and that, in our opinion, it is satisfactory in scope and quality in partial fulfillment for the degree of Doctor of Architecture in the School of Architecture, University of Hawai'i at Manoa."

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Acknowledgement

Thank you to my family and friends who have supported me throughout my educational career. Without you, I could not have accomplished what I started.

Table of Contents

Abstract

Correctly guessing the future costs for energy is like winning the lottery. No one really knows how high prices may rise, but once it is revealed, future energy costs could be life changing. Now, imagine owning a home where it does not matter how outrageously high energy prices become. Remodeling or designing a home to achieve net-zero energy will lessen the burden of fluctuating energy prices. Today it is easy to create a comfortable home that is not 100% dependent on an electric company but making the commitment towards change may be the most difficult aspect of the whole process.

This Doctorate Project will explore the procedures for creating a net-zero energy home (ZEH), including an overview of the issues that were encountered as the research unfolded.

Background

The Beginnings of a Doctorate Project

As architecture students, we are taught different techniques for lowering energy consumption; however, there is not enough time in a semester to go into depth about diverse possibilities of designing a net-zero energy building.

The concept for this research arose from a debate between my parents and I over the relative qualities and cost-efficiency of installing a photovoltaic (PV) system to lower the energy bill of our household. I had been enlightening my parents about the opportunity of lowering their energy bill by producing their own electricity. My mom thought it was a great idea and she was ready to remodel the roof as well as install a photovoltaic system. My dad on the other hand was more conservative. He wanted to know all the little details, such as how much it was going to cost, when the system will pay for itself, and which company is the best one to go with. In the end, they decided not to do anything because the initial cost would be too much and they did not know where to start. Unfortunately, due to my lack of knowledge, I was not able to help in this situation. This incident made me realize how many gaps exist between what was taught in school and what I need to know as an architect. I knew of different possibilities, but I did not know how to choose a reliable contractor or who the different manufacturers were.

My research began by trying to create a home that ran 100% on a photovoltaic system, but while researching photovoltaic systems, I realized that installing enough arrays to supply a home of four people would not be economical. It would be more efficient to use a mixture of energy systems and other factors to reduce the electricity bill and create a net-zero energy home.

Net-Zero Energy

Net-zero energy refers to a building that consumes the amount of energy it produces and requires no additional power supply from the electric company. The building is made self-sufficient by reducing the amount of energy consumed through various efficiency measures and supplying the required amount of energy through a system that generates power on the building's site.

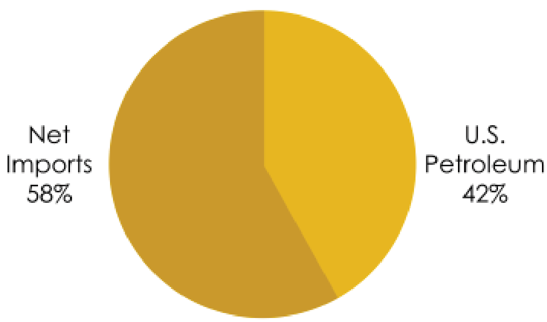
United States Consumption

In recent years, the general public has become more aware of the amount of petroleum we use, largely as a result of media presentations and activist educators. In 2007, the United States consumed 20.7 million barrels per day of petroleum[1], making us the largest consumer in the world. According to the Energy Information Administration website (which provides official energy statistics

1 http://tonto.eia.doe.gov/energy_in_brief/foreign_oil_dependence.cfm

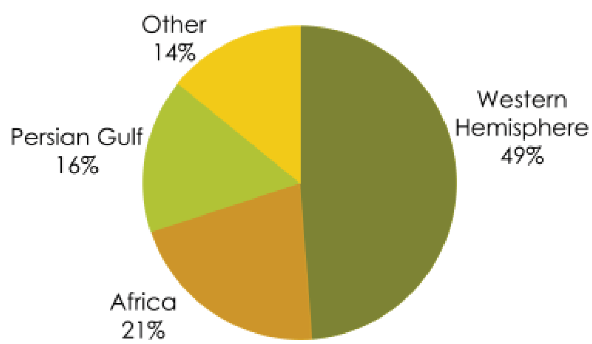
from the U.S. Government), the United States produces only 10% but consumes 24% of the world's petroleum. Therefore importing petroleum is a necessity. Below are some graphs from the Energy Information Administration website, illustrating a breakdown of our petroleum usage:

Net Imports and Domestic Petroleum as Shares of U.S. Demand (2007)

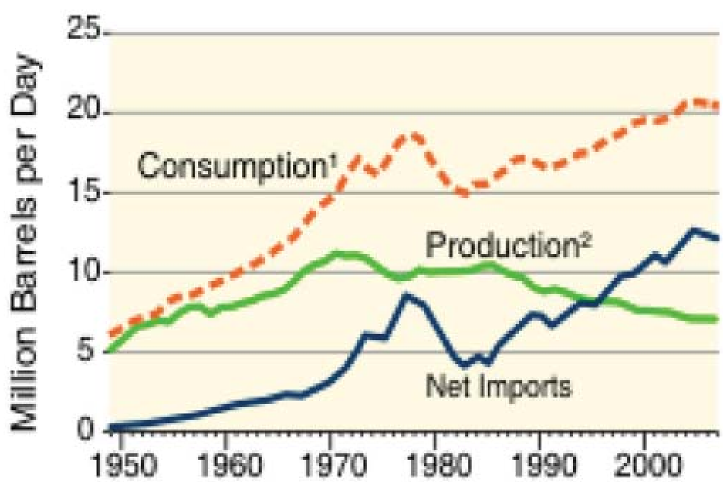


Source: Energy Information Administration

Sources of U.S. Petroleum Imports (2007)



Source: Energy Information Administration



[1] Petroleum products supplied is used as an approximation for consumption.
[2] Crude oil and natural gas plant liquids production.
Source: Energy Information Administration, *Annual Energy Review 2007*–Table 5.1. (June 2008)

The graphs show that the United States consumes more crude oil than we currently produce. As prices fluctuate, anyone who pays for electricity dreads watching the costs of crude oil reflected in their monthly bill. But while people may worry about individual effects like utility costs, everyone should be more aware of the bigger picture.

Effects in Hawai'i

Located in the middle of the Pacific Ocean, Hawai'i has some of the nation's highest energy costs due to its isolated location thousands of miles away from the rest of the United States. It is not feasible to borrow energy from a neighboring state when local electric generators go offline or the State needs a little more energy to supply the residents for the short term. Therefore, we need to be self-sufficient in our energy production instead of relying on another state for help. For that reason all of the oil needed for producing energy in the islands has to be imported. According to the Hawai'i government, 'Hawai'i is the most oil-dependent of the 50 states, (relying) on imported petroleum for about 90% of its primary energy[2].'

Governor Linda Lingle recognized this dependency on oil as both unwise and unnecessary and set a goal of producing 70% of Hawai'i's energy consumption from local renewable energy sources.[3] As a start, the Hawai'i State Legislature recently passed a bill that requires all new and newly-remodeled homes to have solar hot water heaters. "On June 26, 2008, Governor Linda Lingle signed into law a bill, which became Act 204, to increase the use of solar power, one of Hawai'i's most abundant renewable energy sources, to reduce our dependence on imported oil. The measure, SB644 SD3 CD1, prohibits the issuing of building permits for single-

2 http://hawaii.gov/dbedt/info/energy/
3 http://www.ecs.org/html/offsite.asp?document=http://hawaii.gov/gov/

family homes that do not have solar hot water heaters starting January 1, 2010."[4]

Due to the majority of days with high insolation as well as wind patterns and ocean currents, Hawai'i is considered to be an ideal state for producing energy from natural resources. With such abundant renewable resources, Hawai'i should be a leading example for sustainable energy instead of relying on imported resources to support our islands. If everyone in Hawai'i did their part to help reduce the demand for energy from the electric company, we could see a big difference in years to come.

<u>Summary</u>

The above comments identify some of the reasons why we should consider net-zero energy homes, especially in Hawai'i. With this in mind, the following research project could apply to anyone who is interested in remodeling their home to create a net-zero energy dwelling. To limit the scope of the research, I will concentrate on people in the median tax bracket of 25% (single: $31,850 to $77,100 or married filing jointly: $63,700 to $128,500[5]).

The following content is simplified into three categories: conservation, systems that generate power from the sun (photovoltaic systems, solar water heaters and solar attic fans), and design. Achieving a net-zero energy home is a very feasible undertaking that will have a big impact on energy cost savings on a personal level but have a bigger effect on the future for all residents in Hawai'i.

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4 http://hawaii.gov/gov/news/releases/2008/governor-lingle-signs-bill-to-increase-solar

5 http://www.irs.gov/formspubs/article/0,,id=164272,00.html

Doctorate Project Statement

The price of electricity in Hawai'i has always been among the highest in the nation and continues to climb each year. "Hawai'i's statewide average electricity costs are almost three times the national average because of local utilities' reliance on oil to generate most of their electricity."[6] Located remotely in the Pacific Ocean, Hawai'i is the most isolated state and must import all the oil that is needed for producing Hawai'i's electricity and gas. With the future of the global economy heading towards higher oil prices, the cost of Hawai'i's electricity likewise will rise. For this reason, it is likely that more people will seek alternatives to lower their electric bill.

This project will address different techniques for creating a net-zero energy home using solar renewable energy systems and ways to conserve energy. Hawai'i is

6 http://www.honoluluadvertiser.com/apps/pbcs.dll/article?AID=/20080815/NEWS01/808150361/-1/RSS02

an ideal locale in which to take advantage of the sun for energy due to the number of days with high insolation. Many residents realize this fact and are interested in different options for solar energy systems, but they do not know where to start or who to turn to.

By doing this research, I hope to share my educational findings with those interested in net-zero energy by opening the doors to an innovated side of architecture. For easy-to-understand facts and retrofitting techniques, the 'Easy Steps Towards Zero' section (page 40) gets straight to the point about what needs to be done to achieve net-zero energy.

To better understand net-zero energy, the goals for this project are to:

- Develop a handbook geared towards a moderate income family that wants to work towards creating a net-zero home, including discussions of:
    - Ways to lower energy consumption
    - Solar Energy Efficient Systems
- Understand and define the value of a "net-zero energy" home for the future
- Gain experience in preliminary/schematic design by remodeling an existing home as a test case to achieve a net-zero energy home
- Investigate and collect information from people who utilize solar renewable energy resources

Some methods this Doctorate Project will use:

- Read books, recent articles, newspaper articles, internet websites
- Interview experts or people who have experience with PV systems
- Conduct Case Studies: community homes using PV systems, net-zero home
- Analyze what has been done in the past

- Research products available in the Hawaii market
- Present information to Doctorate Committee members and other experts in the field, gather feedback to further develop and improve ideas

Chapter 1

Steps Towards Zero

The following steps are broken down by expenses, starting with less expensive adjustments, conservation and ending with items of greater cost. Baby steps is the key to successfully making a change in the energy lifestyle we are used to.

Step 1: Realize something needs to be done and strive towards making a change

Step 2: Evaluate and Reduce

- Turn off lights when not in use
- Turn off computers at night before bed
- Take shorter showers
- Less peeking in frigerator
- Use natural ventilation

Step 3: Determine main loss of energy in home

- Old appliances
- Heating water
- Computers
- Occupant usage

Step 4: Smaller changes

- Change incandescent bulbs to CFL bulbs
- Install ceiling fans
- Plug electronic devices into a surge protector
- Use shading devices – awnings, plants, etc.

Step 5: Larger changes – installations prior to photovoltaic system

- Install gas line/gas tank
    - Stove, Dryer, Water Heater
- Change old appliances to Energy Star approved appliances
- Upgrade electronic devices to more efficient ones
- Insulate the house
- Install radiant barrier
- Install solar attic fan
- Install solar water heater
- Install solar light tubes

Step 6: Photovoltaic system

- Find a company

- Calculate kW needed
- Install

Step 7: Evaluate the difference in the energy bill or lower energy costs

**These steps will be expanded in Chapter 6*

Chapter 2

Energy Reduction

The key step to achieving a net-zero energy home is to reduce consumption. Many people do not realize how much energy is wasted everyday by leaving the lights on when a room is not occupied or by keeping the refrigerator door open while thinking about what to eat.

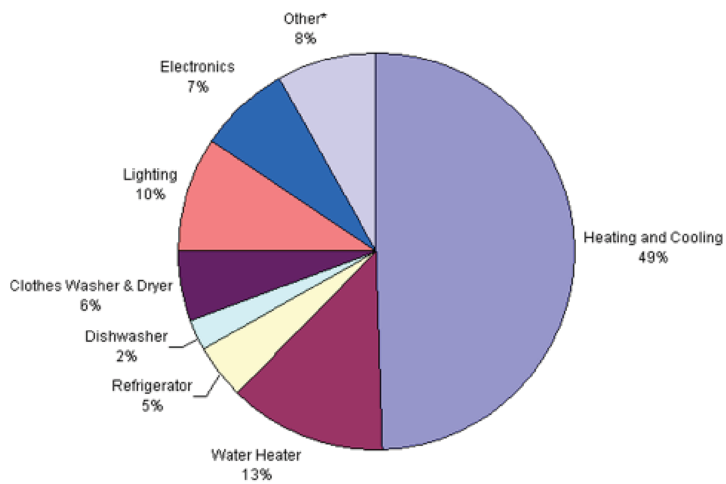
The first step anyone should take before spending money on new appliances or installing a renewable system is to become aware of how much energy is currently being wasted from bad habits like:

- Leaving lights on in unoccupied rooms
- Taking longer showers than necessary
- Leaving computers on when not in use
- Turning on extra lights when not needed
- Leaving the refrigerator/freezer door open for long periods of time

  - o While chopping food
  - o Trying to figure out what to eat
- Leaving the television on when not being watched
- Not unplugging phone chargers when not in use

Once the homeowners/occupants recognize and attempt to reduce the amount of wasted energy, making changes towards becoming net-zero will be easier and more effective.

The chart below shows the average annual energy bill in 2001 of a typical single family in the United States, which is approximately $2,000 according to Energy Star's national data compilation.[7]



Source: Residential Energy Consumption Survey, 2001
Average price of electricity is 10.6 cents per kilo-watt hour. Average price of natural gas is $12.42 per million Btu.

** "Other" represents an array of household products, including stoves, ovens, microwaves, and small appliances like coffee makers and dehumidifiers.*

7 http://www.energystar.gov/index.cfm?c=products.pr_pie

Are there more energy efficient appliances than the ones that are currently being used in the home? Are there ways to reduce the energy consumption in the home without adding a solar energy system? For example, eliminating the seldom-used old refrigerator in the garage or changing all the incandescent light bulbs to CFL bulbs are possible options. Just by changing the bulbs, you could reduce your energy consumption and save about 25% of yearly costs[8] on your electricity bill. According to Kevin Whitton[9], author of 'Green Hawaii', energy consumption in a home is like a bucket full of water except instead of water, it is full of energy. A bucket with holes cannot maintain the water because there are leaks. The holes need to be fixed in order for the bucket to hold the intended amount. A home is similar to that bucket of water. Having a second refrigerator in the hot garage or leaving lights on when not in use consumes more energy than necessary.

8 http://www.heco.com/portal/site/heco/menuitem.508576f78baa14340b4c0610c510b1ca/?vgnextoid=017a537387917110VgnVCM1000005c011bacRCRD&cpsextcurrchannel=1

9 Whitton, Kevin J. Green Hawai'i : A Guide to a Sustainable and Energy Efficient Home. Grand Rapids: Mutual LLC, 2008. (page 5)

Chapter 3

Solar Options to Think About

As energy prices fluctuate, many homeowners tend to look for available options to lower their energy consumption. Most people assume that the only way to lower their energy bill is to replace all their incandescent bulbs with compact fluorescent light bulbs (CFL) or to purchase *energy star* appliances. Although that is a good way to start, there are other alternatives that utilize natural, renewable resources, like the sun to produce a source for energy. However, these options take more consideration and money than changing light bulbs.

Some of the biggest concerns about attaining ZEH are the upfront cost of energy systems and finding the right company. The following sections provide a quick reference on what to look for and where to start by focusing on three solar energy systems: photovoltaic systems, solar water heaters and solar attic vents. Although there are different types of renewable systems (solar thermal, wind turbine, etc.)

these three were chosen because they require low maintenance and are available in Hawaii. Anyone can achieve a net-zero energy home and not rely 100% on the electric company.

3.1 Photovoltaic

History

The concept of photovoltaic cells has been around for many decades, starting in 1839 when a French experimental physicist, Alexandre Edmund Becquerel discovered the photovoltaic effect while experimenting with an electrolytic cell made up of two metal electrodes. Over the next century, many theorists and scientists have improved the quality as well as the capabilities of photovoltaic cells (See appendix 1).

How It's Made

A photovoltaic system (photo=light; voltaic=electricity) is composed of many different parts. Listed below are a few of the components:

- Photovoltaic panels – produce electricity
- Inverter – converts DC current to AC current for house use
- Batteries (optional) – stores energy
- Generator (optional) – utilizes the energy from the photovoltaic panels to create electricity during a power outage
- Monitoring system – calculates the output of electricity being produced
- Mounting system – secures the photovoltaic panels to roof structure
- Wiring – transports electricity to the main power panel

The most common form of photovoltaic panels contains cells that start out from high purity silicon, which is a good semiconductor for creating electricity. When the sunlight strikes the solar cell, the electrons knock loose from the atoms. The loose electrons are then collected as DC (direct current) power and an inverter converts that into AC (alternating current) power.

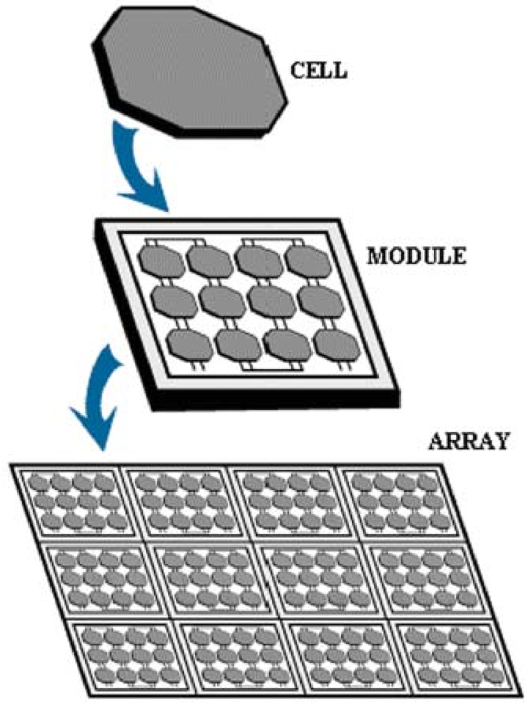


Figure 1: Photovoltaic Panel Diagram
http://science.nasa.gov/headines/y2002/solar-cells.htm

A number of interconnected solar cells create a module. Multiple modules then form an array, which is the basis for producing electricity in a photovoltaic system.

Today, photovoltaic systems are readily available to anyone who wants to have them installed.

<u>Considerations</u>

One of the main issues that needs to be considered prior to installing a photovoltaic system is the economical value of producing your own electricity because it is one of the costliest solar energy systems available on the market. Before thinking about the PV system, it would be a good idea to evaluate the energy consumption of the household to determine if there may be other ways to reduce the energy load.

It is important to first find areas in the home where you could conserve electricity prior to installing a photovoltaic system. This will minimize the amount of panels needed, thus saving money on the upfront costs.

There are many options when it comes to photovoltaic systems but the three main types of panels are: Monocrystalline, Multicrystalline and Amorphous (Thin-film).

- Monocrystalline Silicon Panels – most expensive, most efficiency
- Multicrystalline Silicon Panels – less expensive, less efficient
- Amorphous or Thin-film Panels – least expensive, least efficient

Type	Typical Module Efficiency [%]	Maximum Recorded Module Efficiency [%]	Maximum Recorded Laboratory Efficiency [%]
Monocrystalline Silicon	12 - 15	22, 7	24, 7
Multicrystalline Silicon	11 - 14	15, 3	19, 8
Amorphous Silicon	5 - 7	—	12, 7

Figure 2: Efficiency Diagram
http://www.iea-pvps.org/pv/materials.htm

The chart above illustrates the efficiency percentage of each type of panel. Monocrystalline Silicon, has the highest efficiency but is the most expensive out of the three. Multicrystalline Silicon is cheaper but not as efficient. Amorphous panels are the cheapest out of the three, but more surface area is needed to produce the same amount of electricity as the other two panels. It is easier to install amorphous panels if the roof is being reshingled or modified. Some people prefer it for aesthetic purposes because it looks similar to corrugated roofing.

The following page illustrates each type of silicon in the panel form.

Figure 3: Monocrystalline Panel
http://www.fuelthefuture.net/solarpv/Two-Layer-Glasses-Monocrystalline-Silicon-Solar-Panel.jpg

Figure 4: Multicrystalline
http://www.hebechina.com/Photovoltaic-Solar-Modules/

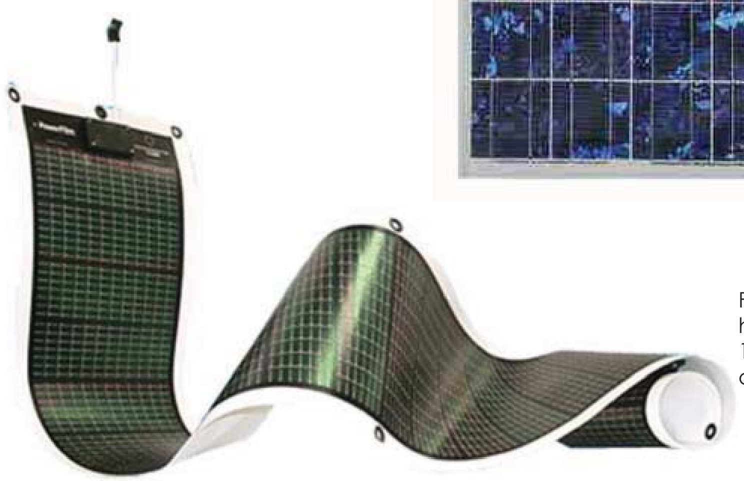


Figure 5: Amorphous (Thin-film)
http://www.spheralsolar.com/r15-120020watt12voltrollablesolarcharger.aspx

In addition to choosing the right photovoltaic panel, there are other situations that need to be considered. For example, will the system be on-grid, off-grid, with battery back up or without, with a generator or an automatic transfer switch?

- On-grid system – when extra electricity is needed, it is pulled from the electric company. During sunny days, the site produced electricity can be sold to the electric company.
- Off-grid system – self-sufficient, not connected to the electric company.
- Battery back-up – stores extra energy for emergencies such as power-outages.
- Back-up generator with automatic transfer switch – kicks in when there is a power outage; the switch allows all energy to stay on property

Most homeowners prefer to stay on-grid because the consumption of energy will fluctuate if there are guests or over the course of a few years, aging appliances, which need to be replaced. The main factor to consider is whether battery back-up will be useful or not. Listed below are a few options that are available:

Option 1: On-grid with no battery – sell all the energy produced to the electric company and use 100% from the grid 24 hours a day. At the end of the billing cycle, the electric company will determine how much energy was produced in comparison to how much was consumed. The difference will be a charge or a credit towards the monthly bill. At the end of the year, if there is a surplus, the owner will receive a credit towards the connection fee. The downfall though is that if there is a power outage, there will be no electricity to the home.

Option 2: On-grid with battery – use the energy produced during the day for appliances and charging the batteries, while the extra, unused energy is fed into the grid. Throughout the night the homeowner will use energy from the grid. At the end of the billing cycle, the electric company will determine how much energy was produced in comparison to how much was consumed. The difference will be a charge or a credit towards the monthly bill. At the end of the year, if there is a surplus, the owner will receive a credit towards the connection fee. Backup batteries fill in when the grid power goes down, and they may also be used as a supplemental source of power during peak demand periods for load shedding.

Option 3: On-grid with generator and automatic transfer switch – this is the most efficient way to run a photovoltaic system because the generator has less maintenance costs than a battery back-up system. In the event of a power outage, the automatic transfer switch will cut the power to the grid and use it to start the generator to power the home. This way, the home will still have power unlike the on-grid option with no battery or generator.

Option 4: Off-grid with battery – this is the only option for the homeowner who wants to stay off the grid or in rural areas where there is no connection to the electric company. The energy consumed during the day will come straight from the energy produced on-site. At night, all the energy consumed will come from the batteries that recharged during the day.

<u>Process For Installation</u>

Once an option is chosen and it is determined that all the energy leakage in the home is minimal, a photovoltaic system will be easier to size. Before contacting a company, research should be done for different products in the market. It is helpful to compile a list of issues regarding specific needs. Comparing different brands before choosing an installer is useful.

A company that is recognized by the electric company as a certified installer should be chosen. This way, the government will honor rebates for that installation. Some of the issues homeowners may face after installing a system with a contractor (not recognized by HECO) is that they are automatically disqualified for the rebate or the government may require more time for further investigation to validate the contractor.

After the right company is found, a representative will visit the site to determine the optimal placement of the photovoltaic panels and design a system that works for the roof. A contract will then be signed between the homeowner and the company. Depending where the system will be placed, extra reinforcement for the structure may need to be added. A structural engineer may be needed to calculate the load. If more structuring is needed, a permit will need to be obtained prior to installing the panels. Once the permit is approved, the company will layout and install the panels, install the inverter, and tie it into the load side of the metering. The permitting process can take up to 1 month. The actual installation of the system will take 1 – 2 days depending on the size of the system. Results will immediately be seen once the system is turned on. The last step for the installation is applying for Net Metering status with HECO. The electric company needs to know which home is producing electricity in the event one of their workers needs to work on a utility pole in the area. If all the currents are not turned off in the neighborhood, a worker could be seriously injured.

The diagram below illustrates how an on-grid photovoltaic system works.
(i.e. sun – solar panels – inverter – main panel – meter – grid)

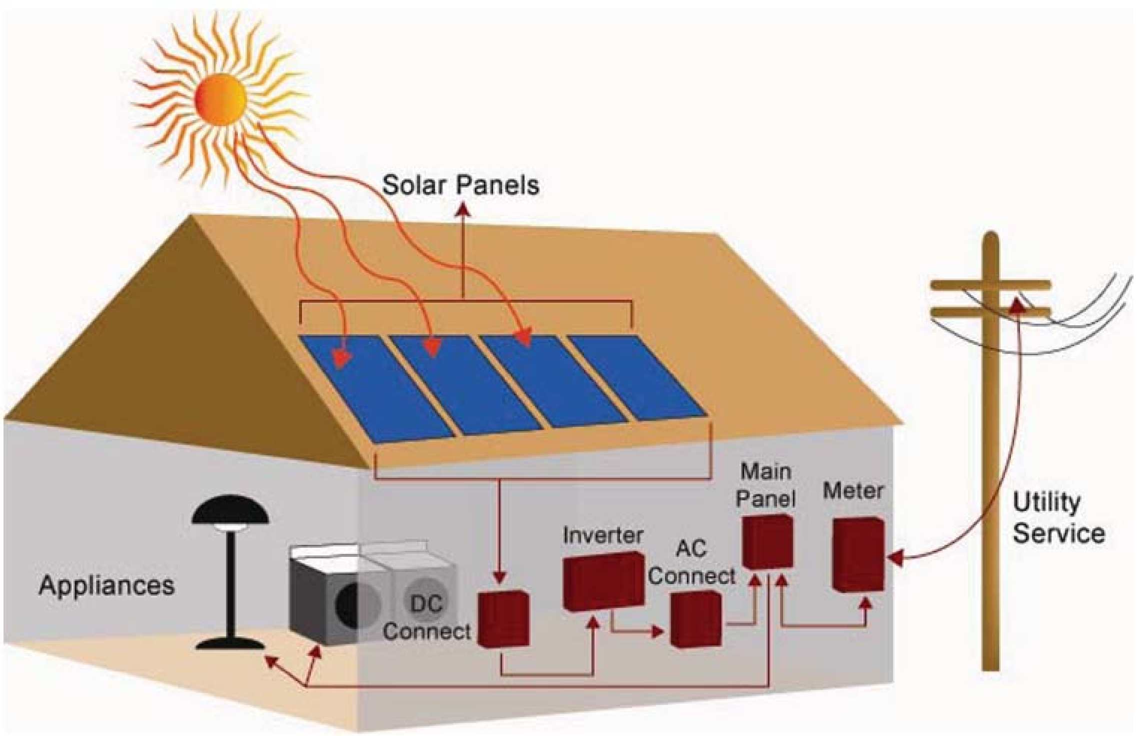


Figure 6: Photovoltaic System Diagram
http://www.hokuscientific.com/pdf/HowSolarWorks.pdf

Choosing The Right Company

In Hawaii there are many companies to choose from, however, which one is the best? Issues that would be good to consider are:

1. What are the brands they carry?
2. How long have they been in business?
3. What are their warranties?

4. How much will everything cost?
5. Are they certified with HECo?

In addition to the list above, the best question would be to ask other people who have dealt with a photovoltaic company and get their thoughts on the experience. It is overwhelming looking through the long list of approved companies on HECo's website as well as trying to determine if there are other reputable companies that may not be on the list because the site has not been recently updated.

The route taken for this research was to ask a reputable engineering firm who deals with LEED, Leadership in Energy and Environmental Design[10], technologies. The three local companies suggested by Lincoln Scott (an engineering firm leading in LEED) are: Hoku Scientific, Suntech Hawaii and PhotonWorks LLC.

Hoku Scientific was founded in 2001 and is a combination of three sections, Hoku Materials, Hoku Solar, and Hoku Fuel Cells. According to their website, "Hoku Solar is committed to maximizing renewable energy technologies in the State of Hawaii". [11] They offer photovoltaic installation, system design, engineering, and post-sale services.

Suntech Hawaii is a locally owned company, which was founded in 2004 and has since then installed numerous systems. Some of their biggest projects completed to date include the United States Army Schofield Barracks and the United States Coast Guard at Aliumanu Military Reservation.[12]

10 http://www.usgbc.org
11 http://www.hokuscientific.com
12 http://www.suntechhawaii.com

PhotonWorks LLC has over 25 years of experience and specializes in design, integration, and manufacturing. According to the company's website, their ability to custom manufacture, engineer, and design their own modules is what sets them apart from other competitors.[13]

Out of the three companies that were recommended and contacted, only two responded. Both were very eager and willing to provide helpful information for this research.

Customizing

Installing photovoltaic systems on the roof of a structure no longer has to look like a separate add-on. One of the new technologies is tile slate PV panels in different colors. This technology allows the color of the solar panels to match the color of the roof tile, however the efficiency of the photovoltaic is less than all of the original methods.

Getting The Most For Your Money

There are rebates available from the state and federal government The best way to get the most for your money is to install the photovoltaic system in phases since each year, only a certain amount of the total cost will qualify for a rebate. If the installation process is broken up into phases over the course of a few years, you could get the maximum credit allowed. The following tables on the next page illustrate the possibilities.

13 http://www.photonworks.com

Tax Incentives for Hawaii Residential PV Systems

installed cost of system	**$15,000**	**$30,000**	**$45,000**	**$60,000**	**$75,000**
35% State tax credit	$2,000	$2,000	$2,000	$2,000	$2,000
30% Federal tax credit	$5,000	$5,000	$5,000	$5,000	$5,000
total cost after incentives	**$8,000**	**$23,000**	**$38,000**	**$53,000**	**$68,000**

Figure 7: Tax Incentives
http://www.photonworks.com/manufacturing.php

Multi-Stage Installation Optimizes Tax Incentives

total cost **$45,000**	1 year	2 year	3 year	total
cost	$15,000	$15,000	$15,000	$15,000
35% State tax credit	$5,000	$5,000	$5,000	$5,000
30% Federal tax credit	$2,000	$2,000	$2,000	$2,000
total cost after in-centives	**$8,000**	**$8,000**	**$8,000**	**$24,000**

Disclaimer: This example is for illustrative purposes only and should NOT be considered tax advice. Consult with your tax advisor, IRS, or state tax office to determine how these credits should be calculated for your own individual situation.

Figure 8: Tax Incentives
http://www.photonworks.com/manufacturing.php

3.2 Solar Water Heater

History

The invention of solar water heaters dates back to 1767 when Horace de Saussure observed that he could heat water in a special box (named the 'hot box') to 16 degrees F above boiling when exposed to the sun. Saussure realized he created something that had important practical applications. This 'hot box' became the prototype for solar water heaters, however, it was not until 1800, that solar water tanks were invented. Many farmers would paint their water tanks black to absorb the heat from the sun. Unfortunately, the tanks took almost the whole day to heat up and once the sun went down, the temperature of the water also dropped rapidly. Since then, there have been many improvements to heat water and maintain its temperature by using better insulated tanks. (See Appendix 2 for more information)

How It's Made

Solar water heaters are made up of four components: collector, storage tank, distribution network, and controls. Unlike photovoltaic systems, there are two types of solar water heating systems: active, which have circulating pumps and controls, and passive, which do not.[14] In addition to the two types of solar water heaters, there are also demand (tankless or instantaneous) water heaters that do not require solar energy. The type of water heater system the homeowner chooses will determine how many different parts the system consists of.

Collectors[15]

There are three types of collectors that are used for residential solar water heaters:

14 http://apps1.eere.energy.gov/consumer/your_home/water_heating/index.cfm/mytopic=12850

15 http://apps1.eere.energy.gov/consumer/your_home/water_heating/index.cfm/mytopic=12850 and Diane M. Masuo, Buying a solar water heater system (Honolulu: Hawaii Institute of Tropical Agriculture and Human Resources, College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, 1982)

evacuated-tube solar collector, integral collector-storage systems, and flat-plate collector.

- Evacuated-tube solar collectors are most commonly used for U.S. commercial applications. Transparent glass tubes are situated in parallel rows. Each tube consists of two layers of glass (outer layer) and a metal absorber attached to a fin. The fin has a coating that allows the solar energy to be absorbed and at the same time radiative heat loss inhibits.
- Integral collector-storage systems, also known as ICS or batch system, work best in mid-freeze climates because pipes freeze in severely cold climates. The solar collector preheats the cold water as it passes through to the conventional backup water heater.
- Flat-plate collectors are the most frequently used out of the three, especially in Hawaii. This device usually consists of an insulated, weatherproof box with a dark absorber plate that is covered by one or more transparent cover.

Active

Active solar water heaters have two types of circulation systems, direct and indirect. Direct circulation moves household water through collectors into the home. On the other hand, indirect circulation sends non-freezing, heat-transfer fluid through collectors and a heat exchanger before it circulates into the home.

Passive

Passive solar water heaters have two types of systems, integral collector-storage passive system and thermosyphon system. In integral collector-storage passive system, cold water flows progressively through the collector where it is heated by the sun. In thermosyphon system, water flows through the system when warmer water rises as cooler water sinks.

Demand (tankless or instantaneous)

Demand water systems are another alternative to the solar water heater systems, however there are a few pros and cons. A demand water system is powered either by electricity or gas. Research has shown that installing an electrical demand water system is not efficient. Anytime electricity is used to produce heat the efficiency drops dramatically, therefore it is more efficient to use gas. Gas demand water systems have a higher rate of water flow than electrical but the downfall is that it is more difficult and more costly to install a demand water system into an existing house.

Considerations

The hardest choice to make as a homeowner is which system to go with, solar water heater or demand system. For most homes in Hawai'i, heating water is the biggest consumption of electricity in a home besides air conditioning. It accounts for about 1/3 of the total monthly cost of the utility bill.[16]

Option 1: Solar water heater utilizes the natural energy of the sun to heat water for the household. In Hawaii, this is the most efficient and most effective way to heat water. Sometimes two tanks are used because it is a better way to store hot water. One tank is hooked up to the cold water supply and the second tank stores the heated water from the solar panels.

Option 2: Demand system provides an endless supply of hot water when needed. Sometimes this may work better than a solar water heater

16 http://hawaii.gov/dbedt/info/energy/efficiency/solar-wh-pv.pdf

but, it depends on the occupancy of the household. Three things that may need to be considered prior to installation are:

1. The temperature of the cold water entering the house
2. The flow rate of hot water you'll most commonly need
3. The temperature of the hot water you want to use.[17]

Option 3: Utilize both types of systems to heat water. The solar heater will heat the water, but on cloudy days or if there are guests in the home and extra hot water is needed, the demand system will provide the difference.

Process For Installation

The first step towards installing a water heater is finding a company that is certified by the electric company and has years of experience.

After the right company is found, they will visit the home and size a system for the amount of people in the household. In the process of choosing the suitable solar water heater, they will also look for the optimal roof area to place the solar panels. Once that is completed, they will need to find a space for the water tank to be stored, which is usually in a washroom, garage or under the house (if on post and pier). When everything is finalized, it would take about a day to bolt the solar panels to the roof and have everything installed.

If a demand water system is being installed, the company will have to look for an area to place the heating unit. Once the unit is placed, the home will have hot water on demand.

17 http://www.motherearthnews.com/Green-Homes/On-Demand-Water-Heater.aspx

Sometimes it is more efficient to install a demand water system depending on the amount of space available and how much hot water will be needed. If most of the appliances being installed are gas, and there are not many people in the household, it may be more efficient to install a gas demand water system. Demand water systems only produce hot water when it is needed so if the smallest water tank is too much, then a demand system would work much better.

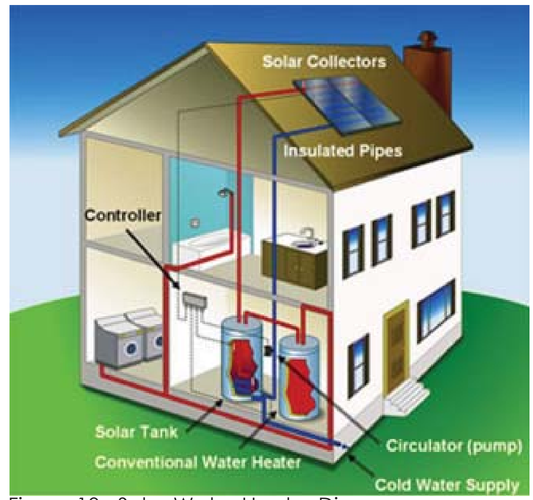


Figure 10: Solar Water Heater Diagram
https://members.priceenergy.com/SolarEnergy-CalculatorAction.do?actionType=solarWorking&uniqueAccountID=null

The diagram to the right illustrates how solar hot water system works.
(i.e. cold water – sun heats the water with solar panels – hot water is stored in the tank for use

<u>Choosing The Right Company</u>

There are many companies that the electric company recommends, however, some may not carry the brand you are looking for or may not be available to install the system right away.

Some issues that should be considered are:

1. What are the brands they carry?
2. How long have they been in business?
3. What are their warranties?
4. How much will everything cost?
5. Are they certified with HECo?

Similar to locating a reputable company for installing a photovoltaic system, the best information anyone can find is by asking people who have installed solar water heaters or demand systems and why they chose those companies. If the homeowner has had the system for a few years, they will also be able to tell you if they have had any problems and how it was resolved.

Gut instinct can indicate trust in a company and make it easier to speak with the representatives openly. You do not want to be unhappy with the chosen company and have to live with that regret every time the solar water heater or demand system needs to be repaired or checked. No one wants to be in that situation, especially if there are problems with the installation and the solar company has to come back to fix the problem.

Getting The Most For Your Money

Installing a solar water heater is the best way to save some money. According to Hawaii State Government, "... solar water heating is cost effective at any location in the Hawaiian Islands."[18] As stated in the Doctorate Project Statement, this is one reason why Governor Linda Lingle signed a law that requires all new homes to install solar water heaters.

The table on the following page illustrates how much it would cost to have a solar water heater installed and all the rebates available.

18 http://hawaii.gov/dbedt/info/energy/renewable/shw-2008.pdf

Rebates & Tax Incentatives for Hawai'i Residential Solar Hot Water Systems

installed cost of system	**$5,500**	**$6,500**	**$7,500**	**$8,500**	**$9,500**
HECO rebate	$1,000	$1,000	$1,000	$1,000	$1,000
cost after rebate (tax credits basis of system)	**$4,500**	**$5,500**	**$6,500**	**$7,500**	**$8,500**
35% State tax credit	$1,575	$1,925	$2,250	$2,250	$2,250
30% Federal tax credit	$1,350	$1,650	$1,950	$2,000	$2,000
total cost after incentatives	**$1,575**	**$1,925**	**$2,300**	**$3,250**	**$4,250**

Figure 9: Solar Water Heater Tax Incentives
http://www.suntechhawaii.com/residential/solar-options/solar-water-heating/index.html

Note: The tax credit basis of the system is calculated by subtracting the rebate amount from the installed cost.

Disclaimer: This example is for illustrative purposes only and should NOT be considered tax advice. Consult with your tax advisor, IRS, or state tax office to determine how these credits should be calculated for your own individual situation.

3.3 Solar Attic Fans

How It's Made

Solar attic fans are comprised of a few parts. In general, most solar attic fans consist of a 10 – 20 watt solar panel, a motor, fan, flashing, and exhaust screen. Some solar attic fans have the solar panel attached to the top of the system with brackets instead of being integrated into the system. The bracket system allows the solar panels to be adjusted to the optimal usage of the sun or to be placed in a different location from the fan. The solar panels create energy to turn the fan and exhaust the attic. When the sun is very bright, the fan will work harder, if there is less sun, then the fan will not exhaust as much air. There are two main types of attic fans: one where the solar panels are integrated into the unit and the other where the solar panels are bracketed to the unit.

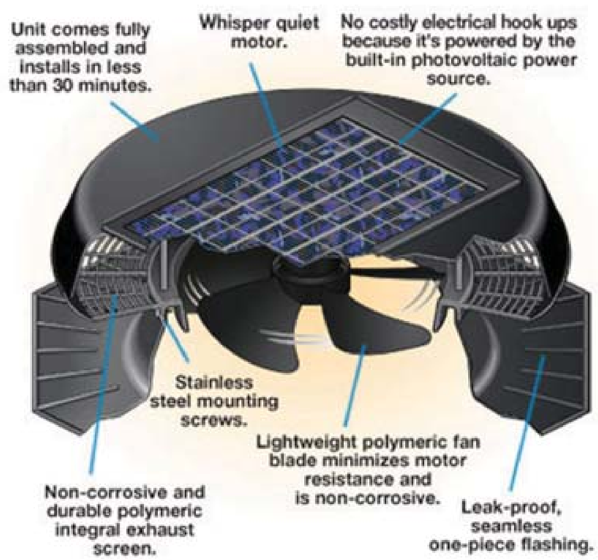


Figure 11: Solar Attic Fan
www.solatube.com/homeowner/solarstar.php

Figure 12: Solar Attic Fan
http://www.greenhome.com/products/appliances/heating_and_air_conditioning/115173/

Considerations

Installing a solar attic fan can help reduce the heat entering the living space of the home. By reducing the heat, appliances will work more efficiently and the ambient temperature will be more comfortable. In addition to reducing heat, solar attic fans also help reduce the moisture levels in the attic space.

Option 1: The solar attic fan with the solar panels integrated is an easy one-piece unit to install.

Option 2: The solar attic fan with brackets holds the solar panel to the unit and allows the flexibility to place the solar panel on a different area of the roof and still serve the same function from a more efficient area.

Choosing The Right Company

Most companies that install photovoltaic systems or solar water heaters also carry solar attic fans. Check with the company prior to installation in case they may give a better deal for installing more than one product with them. If not, find out which companies carry the different types and determine the one that will work best for your situation.

It may be cheaper to purchase the unit and install it yourself rather than going through a company. Videos are available on-line that show the process of installing the solar attic fan.

Process For Installation

Once it is decided how many attic fans are needed, the installation process is very easy. First step is to pound a nail 20" from the main beam and in the center of the rafters, through the roof from the interior attic space so that when you go on the roof, it will be easy to locate the center point of where the attic fan needs to go. From that center point, draw a radius of the diameter of the attic fan. Then cut the shingles out and mark a 7" radius circle from the center. Once the circle is marked, cut it out with a saw. Pull back the surrounding shingles to place the solar attic fan. Put a strip of caulking around the cut out circle and place the attic fan over it. Screw the fan to the roof and start placing the shingles back in place. Place a little caulking around the edges of the shingles closest to the fan. Once everything is done, the solar attic fan will help to ventilate the attic space and assist the rest of the house to stay cooler.

Getting The Most For Your Money

Shop around when looking for an attic fan. There are many different options and if you are a hands on type of person, this would be a good, easy project to work on.

Chapter 4

Other Suggestions

Installing solar systems is not the only method to reduce the energy bill. Some other options include changing the incandescent bulbs to Compact Fluorescent Light (CFL) bulbs or using natural ventilation instead of air conditioning. There are many ways to reduce the energy consumption prior to installing the bigger, more expensive systems.

Tubular Skylights: help bring natural light into a darkened area within the house. By doing this, it will reduce the need for lights to be on during the day. Unlike conventional skylights, tubular skylights distribute the sunlight evenly throughout the space. There are some options where the skylight serves as a regular light also. CFL bulbs could be placed within the tube for use at night.

Surge Protectors: help to completely shut down electronic devices like televisions, dvd players, computers, etc. with one simple switch. Even though electronics may be turned off, being plugged into the wall will still draw energy.

Ceiling Fans: a great way to push air around the room with or without the use of air conditioning. Ceiling fans help force the cooler air up or down depending on the time of year and the temperature that is desired within the room. During the winter if you want warmer air, reverse the motor and operate the fan in a clockwise direction. This will cause an updraft and circulate the warmer air down. In the summer, operate the fan in a counter-clockwise direction. This will blow the air down onto the person. Most ceiling fans have a switch that allows the direction of the fan to go into reverse.

Energy Star Appliances: the United States government realized there needed to be an easy way to shop for appliances so that consumers know what they are purchasing. In order to rate each product, they have tags that show the amount of wattage used and the yearly expense cost prediction. For the island of Oahu, the electric company recognizes this valuable factor and offers a rebate for the purchase of a new appliance.

Compact Fluorescent Lights:[19] more efficient than regular incandescent light bulbs by saving money and energy. Incandescent bulbs create heat when in use which wastes a lot of energy. CFL bulbs last up to ten times longer than an incandescent bulb and use about 2/3 less energy. Unfortunately, most CFL bulbs are not recommended for use in vibrating environments, such as ceiling fans because electronics in the CFL could fail. The only CFL

19 http://www.gelighting.com/na/home_lighting/ask_us/faq_compact.htm#difference

bulb that is designed to take the vibration of a ceiling fan is CFL bulb FLE11. Below is a small wattage conversion for switching out the incandescent light bulbs to CFL bulbs. (See Appendix 3 for more information)

Standard Bulb	CFL Bulb
60w	13w - 15w
75w	20w
100w	26w - 29w
150w	38w - 42w

Light color paint for walls: light colors for walls will help to reduce radiant heat from coming into the home during the day by reflecting most of the radiation from entering the home. With the reduction of heat, the house will be cooler and more comfortable, about 3 degrees cooler.

TechShield Insulation: a radiant barrier on the roof or walls can reduce about 97%[20] of the radiant heat from entering the home. By reducing the radiant heat, the home will be cooler which will also help some appliances from working harder. When the home is too hot, appliances such as the refrigerator and air conditioner have to work harder to keep things cooler.

Natural Venitlation: use natural venitlation before turning on air conditioning units. This will help to reduce the energy bill. Planting vegetation around the yard without blocking the wind flow will also help to reduce heat from entering the home. Plants have a natural way of cooling the air around them.

20 http://www.lpcorp.com/radiantbarrier/radiantbarrier.aspx

Energy Star Computer: many people today own a computer to stay connected to the rest of the world, however, most computers take up a lot of extra energy. There are new technologies that allow computers to consume very little energy when they are in sleep mode. Similar to the appliances in a home, Energy Star also lists qualified computers that meet low energy standards. To find out if your computer is energy efficient, you can visit: http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=CO.

Chapter 5

ZEH Retrofit

It is easy to start from the beginning and create a net-zero energy home, but it is a different story to modify an existing home because of hidden complications. For the design part of this project, I will be looking at the changes done in the past, monitor the energy consumption, address ways to passively cool the basement and recommend systems. An existing home located in Kaimuki on the island of Oahu was chosen whose owners are looking at ways to lower their utility bill. In an effort to lower their energy costs, listed below are a few changes they have made:

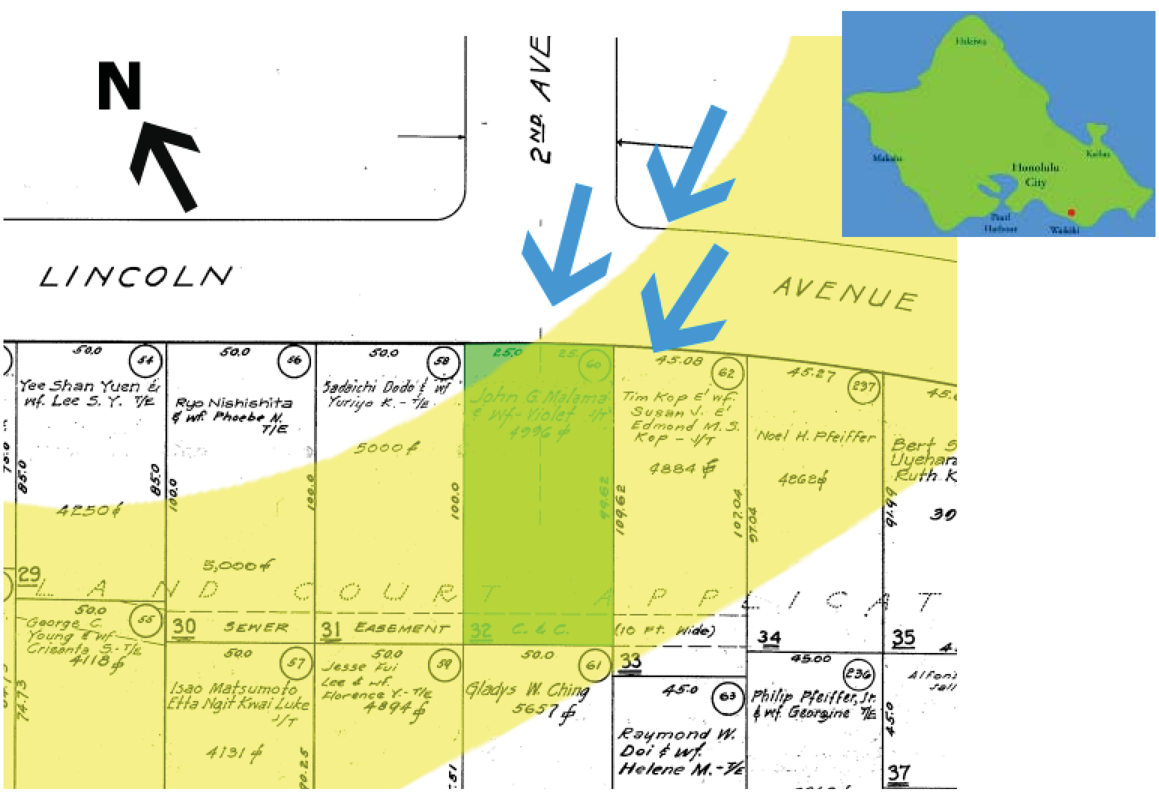
1. Changed all the incandescent light bulbs to CFL's
2. Installed a gas line
3. Purchased energy efficient and gas appliances:
   a. Stove
   b. Demand water system
   c. Dryer

5. Reconstructed roof and installed:
    a. TechShield barrier
    b. Ridge vent

Although they have begun the process of lowering the energy bill, there are other factors that need to be addressed to reach net-zero energy. In addition to aiming towards net-zero, the following items could passively cool the home to reduce any need for air conditioning:

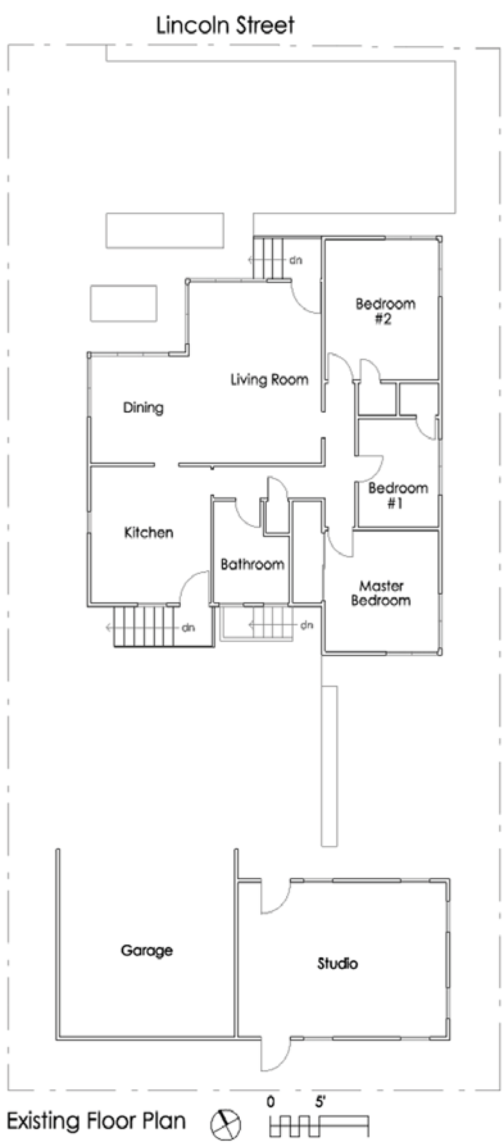
1. Enclose path from kitchen to basement to create solar chimney effect
2. Reclaim natural ventilation in basement (current use of air conditioning is inefficient.)

Luckily, they are open to other suggestions and are willing to be my experimental subjects in a process to remodel an existing home to achieve net-zero energy. The diagrams below show the location of the site, sun path over the site and wind direction.

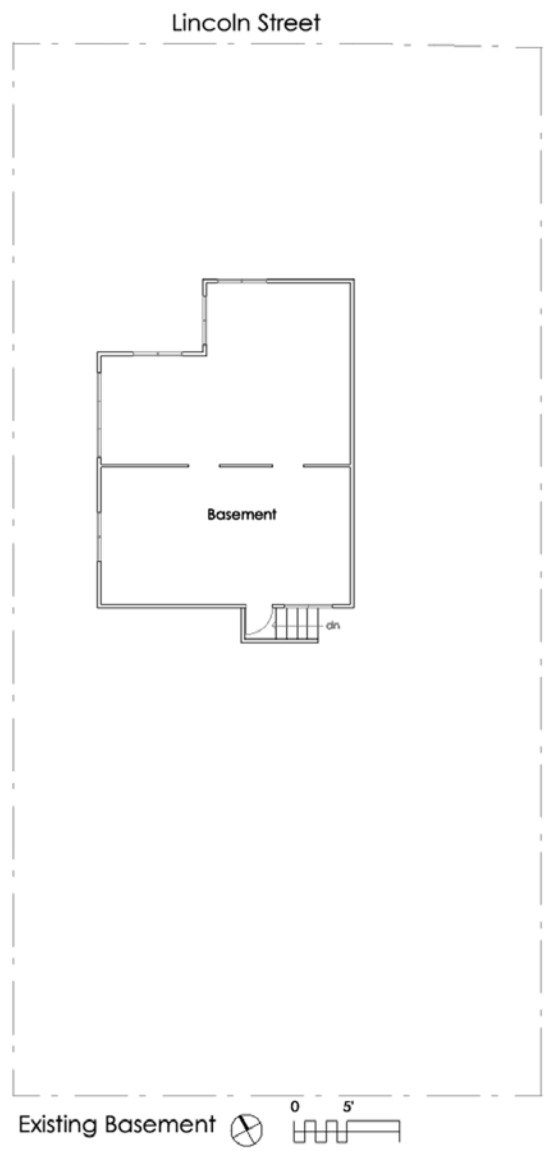


The site currently has two dwellings. The main house, which is approximately 1,852 sq.ft. and a cottage about 332 sq.ft. The utility bills are combined between both homes (four people), which makes quantifying electrical usage difficult.

One aspect of the site important for the ZEH goal is the roof orientation on the main house and the cottage are facing almost due south, a perfect location for the installation of a photovoltaic system with little shading from tall trees.



Existing Floor Plan



Existing Basement

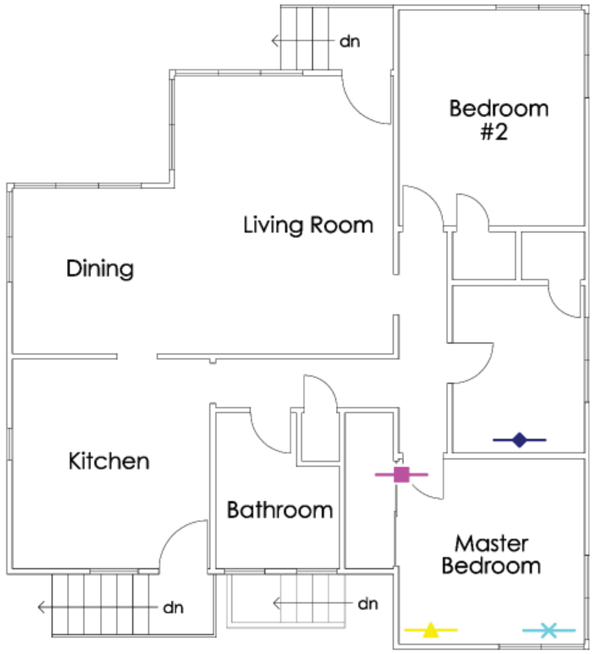
5.1 Evaluation

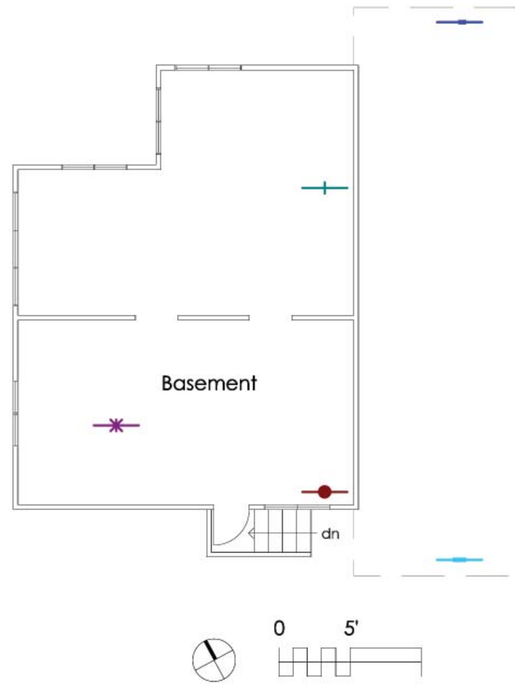
Like many existing, older homes, there are circumstances that need to be addressed prior to making changes to create a net-zero energy home. For example, the owners of the home concerned with airborne dust, closed a major part of the cross ventilation in the basement which caused the space to become stuffy. They realized the outcome from this enclosure, but felt it was a better situation rather than dealing with a layer of dirt on the furniture everyday. In an effort to resolve the stuffy condition, an air conditioning unit was installed. However, in order to feel its cooling effects throughout the basement, fans are required to blow the air around. If net-zero is to be achieved in this household, utilizing an air-conditioning unit should be out of the question, especially since the owners claimed the basement used to be the coolest, most comfortable spot in the house. Now, it is warmer than the upstairs space even though most of the walls are underground and are radiantly cooled by the earth.

To justify the temperature differences from the upstairs to the basement scientifically, thermometers were located in various places throughout the south side of the home and under the house on the north side for about two weeks. The following graphs and charts illustrates where temperatures were taken at the same time on different days and shows the readings that were obtained.

Temperature Reading at 4:00PM

	Office	Bedroom (Entrance)	Bedroom (SW Wall)	Bedroom (SE Wall)	Basement (Mid Space)	Basement (S. Wall)	Basement (E. Wall)	Under House (N. Bdrm)	Under House (S. Bdrm)
4-Apr	77.749	77.749	78.800	78.274	78.449	77.923	76.528	75.659	77.400
5-Apr	78.449	78.624	80.735	79.678	78.274	78.800	76.703	75.832	79.502
6-Apr	79.502	78.975	81.797	80.382	78.274	78.800	76.703	76.354	81.090
7-Apr	78.624	78.800	81.266	79.853	77.400	78.975	76.703	76.181	80.735
8-Apr	77.050	76.876	77.923	77.574	76.354	77.400	76.006	74.964	77.050
9-Apr	73.753	74.791	74.791	74.271	75.484	75.832	75.139	72.718	73.234
10-Apr	76.876	76.528	76.181	75.659	75.832	76.876	75.659	73.753	73.062
11-Apr	81.090	79.678	82.508	81.442	79.151	79.853	77.225	77.574	83.221
12-Apr	82.508	81.797	85.014	83.043	80.735	80.911	78.800	78.800	83.757

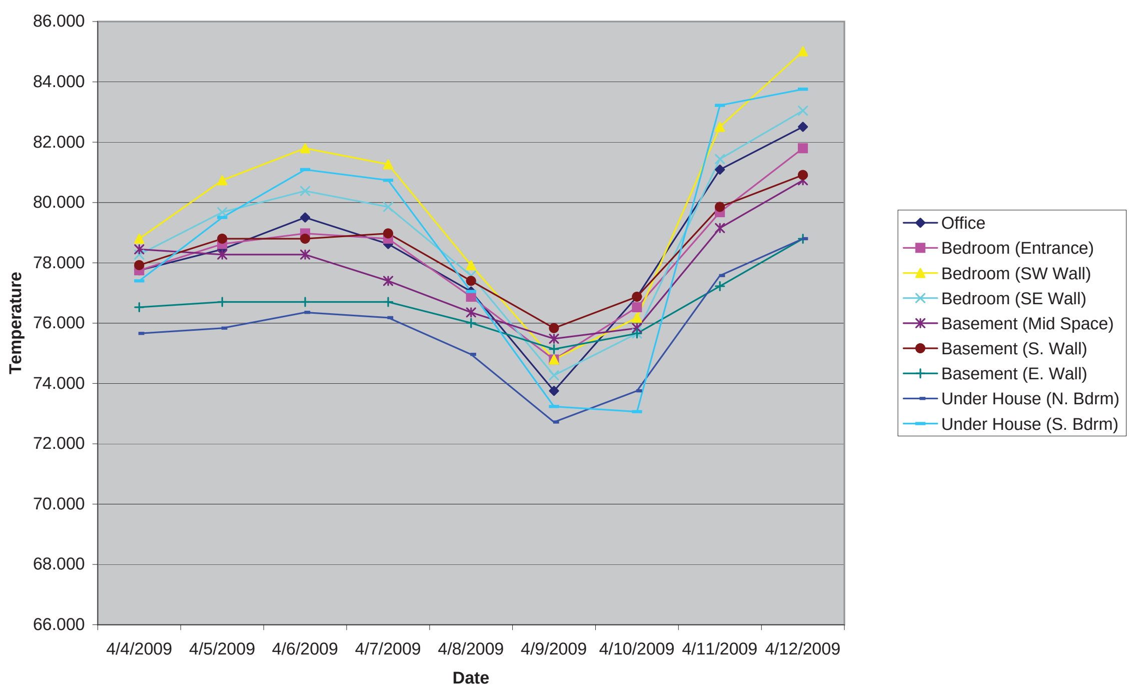




Upstairs Placement

Basement Placement

Temperature Reading at 4:00PM



In addition to the temperature readings, electricity consumption (kWh) readings were also taken on most electrical devices and appliances. The following chart contains a list with most of the items used in the main house.

Appliances on 24 hours a day	Date	Start Time	Total Time Tested	kWh Used		Hourly Rate		Cost Per Day
*Refridgerator			hrs. min.	1.69 /day	x	$0.277	=	$0.47 /day
Refridgerator-Garage	1-Feb-09	4:54 PM	23 hrs. 40 min.	1.38 /day	x	$0.277	=	$0.38 /day
Fan in Bedroom	4-Feb-09	5:45 PM	20 hrs. 50 min.	0.77 /day	x	$0.277	=	$0.21 /day

Appliances Commonly Used	Date	Start Time	Total Time Tested	kWh Used		Hourly Rate		Cost Per Day
Oven			hrs. min.	/day	x	$0.277	=	$0.00 /day
*Dishwasher			hrs. min.	0.92 /day	x	$0.277	=	$0.25 /day
*Washer/Dryer			hrs. min.	0.47 /day	x	$0.277	=	$0.13 /day
Toaster	19-Feb-09	7:00 PM	110 hrs. 12 min.	0.24 /day	x	$0.277	=	$0.07 /day
Microwave	2-Feb-09	3:14 PM	20 hrs. 30 min.	0.17 /day	x	$0.277	=	$0.05 /day
Lamps								
Living Room								
1. Wavy	21-Jan-09	7:45 PM	24 hrs. 18 min.	0.06 /day	x	$0.277	=	$0.02 /day
2. Short Black	22-Jan-09	8:31 PM	17 hrs. 31 min.	0.17 /day	x	$0.277	=	$0.05 /day
Computer								
1. Black Tower	24-Jan-09	3:36 PM	22 hrs. 34 min.	1.41 /day	x	$0.277	=	$0.39 /day
2. Apple Tower	25-Jan-09	1:48 PM	55 hrs. 34 min.	2.72 /day	x	$0.277	=	$0.75 /day
3. Apple Monitor	27-Jan-09	10:14 PM	50 hrs. 49 min.	1.02 /day	x	$0.277	=	$0.28 /day
4. Alex's Work Area	29-Jan-09	1:00 AM	66 hrs. 54 min.	2.22 /day	x	$0.277	=	$0.62 /day
Coffee Maker	3-Feb-09	4:30 PM	25 hrs. 10 min.	0.16 /day	x	$0.277	=	$0.04 /day
Total Usage				13.4 /day	x	$0.277	=	$3.72 /day
							x	31 days
								$115.32 /month

*Based on EnergyStar.com product rating according to model number

5.2 Passive Cooling Strategies

In order to passively cool the basement to eliminate the usage of the air-conditioning, four strategies were considered. Although each option explores an assortment of techniques, different options could be combined to incorporate more than one opportunity to passively cool the basement.

5.3 Strategies for System Placement

Three companies were contacted for price quotes on Photovoltaic systems and Solar Water Heaters, however, only two of them install solar hot water heaters. The process taken was through HECO's website and asking environmental engineer consultants.

The table below is a brief summary of the outcome of price quotes. A more detailed evaluation is elaborated on the following pages.

Company	**Photovoltaic System** (Total Net Cost)	**Solar Hot Water System** (Total Net Cost)
Alternate Energy Inc.	$9,323	$2,123
Sunetric	$14,543	$3,798
Hoku Solar	$18,471	—

Alternate Energy Inc. | 549 KOKEA STREET, SUITE C5 | HONOLULU, HI 96817 | 808.842.5853

founded: 1998

PV brand: Sanyo
module efficiency: 17.2%
power output: 200 Watts
system size: 2.8 kW
daily energy production: N/A

warranty: 10 yr factory, 20 yr module

experience: Residential Homes

total cost of system: $26,638

35% state tax credit: $9,323

30% federal tax credit: $7,991

net cost: **$9,323**

investment return: **7 years**

solar hot water: Corona
capacity: 2-40gallons
efficiency: 78.7 - 81

warranty: 5 yr full warranty

experience: Residential Homes

total cost of system: $6,067

35% state tax credit: $2,123

30% federal tax credit: $1,820

net cost: **$2,123**

investment return: **5 years**

**Offered a discount of $2,705 off the total cost if installed both options at the same time.*

Sunetric | PO BOX 1462 | KAILUA, HI 96734 | 808.262.6600

founded: 2004

PV brand: SunPower 225 Black
module efficiency: 18.1%
power output: 225 Watts
system size: 5 kW
daily energy production: 19 kWh

warranty: 5 yr full, 10 yr inverters,
25 yr module, 2 check-ups

experience: Residential Homes
Army at Schofield Barracks
Aliumanu Military Reservation

total cost of system: $41,550

35% state tax credit: $14,543

30% federal tax credit: $12,465

net cost: **$14,543**

investment return: **11 years**

solar hot water: SunEarth
capacity: 2-40gallons
efficiency: 78.7 - 81

warranty:

experience: Residential Homes

total cost of system: $7,675

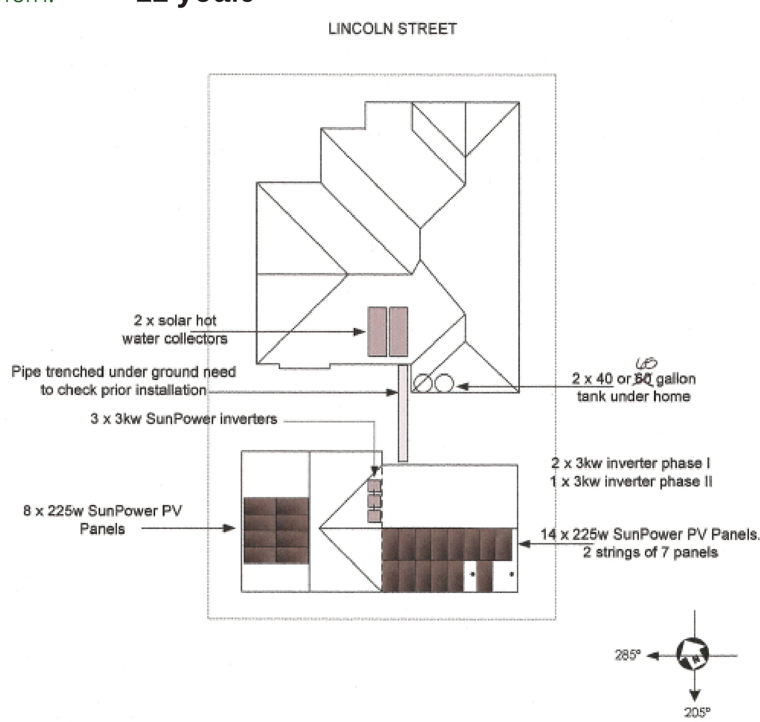
35% state tax credit: $2,303

30% federal tax credit: $2,250

30% federal tax on state credit: $675

net cost: **$3,798**

investment return: **7 years**



Hoku Solar Inc. | 1288 ALA MOANA BLVD., SUITE 220 | HONOLULU, HI 96814 | 808.682.7800

founded: 2001

PV brand: SunTech
module efficiency: 14.1%
power output: 175 Watts
system size: 4.9 kW
daily energy production: 20.4 kWh

warranty: 15 yr inverters, 25 yr module

experience: Kahului Airport
Lihue Airport
Hilo Airport
Kona Airport

total cost of system: $33,530

35% state tax credit: $5,000

30% federal tax credit: $10,059

net cost: **$18,471**

investment return: **13 years**

**There is a state tax credit cap if 35% exceeds $5,000.00. Some companies found a loop hole that allows a larger tax credit however, it would be best to consult with a tax advisor before making any purchasing decisions.*

5.4 Retrofit Conclusion

Retrofitting an existing residence to become a net-zero energy home is an important component of this research because it relates to the majority of homeowners who have existing homes but cannot afford major renovations. The preceding analysis and proposed retrofit reveals the complications of a pre-existing condition.

In this situation, the homeowners made some modifications to their home that improved the value of the house, but also reduced the comfort level in some areas. As stated previously, one of the major factors that was altered was the enclosure of the basement which took away the natural ventilation. The air conditioning does not help the comfort level but this analysis showed the owners its impact on the electric bill. In addition, after dissecting the energy bills, having an air-conditioning unit was not the only culprit in their energy costs.

Before trying to size a photovoltaic system, I began my analysis by observing the homeowners to see if there were other ways to reduce the energy bills by making small changes. That is when I realized that they could easily cut their energy costs correcting bad habits. For about a month, I would point out ways to reduce usage by turning off lights when not in the room, using only the amount of light needed for a task, or closing the refrigerator door while chopping vegetables.

I began taking kWh readings of the appliances and electronic devices around their house to justify where some of the energy was going. Maybe there were devices that did not need to be on all the time or could be switched for something more efficient. It was really interesting to see the different readings especially when something the owners thought was efficient was not.

To turn this existing home into a net-zero energy home, different factors were taken into consideration. The biggest, top priority in this study was to change the wasteful habits of the homeowners. They were trying to make a difference in other ways, but forgot to look at themselves. As stated previously, they changed all their incandescent bulbs to CFL's, reroofed their home with techshield along with ridge vents, and installed a gas line for their stove, water heater, and dryer. Now they are considering the different options to passively cool the basement and look forward to becoming net-zero energy homeowners.

From the month prior to the start of the analysis (December) to two months later (February), they were able to reduce the energy consumption by almost 24% (see Appendix 8 for more calculations). Three months later, they are still trying to change their habits (which will take some time), but seeing a difference in their utility bills is very motivating for them. When this project began, they thought nothing else could be done to reduce their energy bill without installing a photovoltaic system. Now, they realize there are a few other things that need to be taken care of but once everything is done, they feel it would be worth it.

Eventually homes need to be remodeled, so why not strive towards a net-zero energy home. Even if the money for a photovoltaic system is not available, there are other ways to reduce the utility costs so that when the money is available, all that is left to do is install the PV system.

Chapter 6

Steps Expanded

The following steps have been expanded from Chapter 1 based on the ZEH retrofit design experience.

Step 1: 'Realize something needs to be done and strive towards making a change'

Many people do not realize how much energy they waste every month from bad habits. Recognizing there needs to be a change is the first step because without acknowledging there is a problem, nothing will happen.

The homeowners realized there needed to be a change and (as stated previously in Chapter 5,) attempted by:

- purchasing energy efficient appliances
- reroofing the home
    - installed TechShield
    - ridge vents
- hooking up to a gas line
    - stove
    - demand water heater
    - dryer
- swapping all the incandescent bulbs to compact fluorescent light bulbs (CFL).

Step 2: 'Evaluate and Reduce'

Utilizing less energy will help to minimize the size and cost of a solar powered systems. There are many ways to reduce the energy consumption of a household without spending anything.

After analyzing the owner's energy bills (electric, water, gas), I noticed that part of the problem was the owners bad habits. Therefore, I observed some of the owner's habits for about a week then suggested ways of attempting to lower their energy costs as well as making them aware of their bad habits.

Step 3: 'Determine main loss of energy in home'

Old appliances, old computers and air conditioning are inefficient examples of what use unnecessary energy. As technology improves, appliances energy efficiency also improves, but as they age, they become less efficient. There are kilowatt per hour (kWh) readers that will help determine the energy draw.

To pinpoint which items were drawing the most energy, I purchased a 'Kill-A-Watt EZ' ($20-$30) meter to analyze a more accurate reading of each object. The results showed the owners which electronic device should be updated or used sparingly.

Step 4: 'Smaller changes'

Sometimes it is the little things that make a big difference. For example, although you turn off the television and dvd player once you are done watching, it is still drawing energy, waiting for you to push the power button. Placing electronic devices onto a surge protector and turning off everything with one button makes a huge difference. Lights are also a big factor when it comes to saving energy. One incandescent bulb may use 60 kWh where as a CFL may use 13 kWh, and that is the difference for only one bulb. Imagine the difference changing every bulb in the house could make.

Fortunately, the owners knew about changing the bulbs to CFL's so by the time I came into the picture, they were already making a difference in their electric bill. As far as installing ceiling fans, the basement height is too low to install any and the main living space constantly has cross ventilation which keeps that area at a comfortable temperature. Many of their electronic devices are on surge protectors, however, a change in procedures for shutting things off (pushing the off button on the surge protector) is different from what they are used to and keep forgetting.

Step 5: 'Larger changes – installations prior to photovoltaic system'

Before installing a photovoltaic system (which has great cost), it is best to reduce the energy consumption to the maximum amount. Putting a gas tank or hooking up to the gas line is more efficient than using electricity to heat water, cook or dry clothes. A Solar Water Heater is the most efficient way to heat water and changing the old inefficient appliances to EnergyStar approved ones will also make a difference in energy usage. Some other changes that were suggested like installing a radiant barrier and solar attic fans will also help to cool down the home and reduce the need for air conditioning.

The owners had attempted to make a few big changes like reroofing the home (which made the main living space temperature comfortable), purchasing EnergyStar rated appliances, and hooking up to the gas line. After learning about the qualities of solar water heaters, they are looking forward to installing one that works for them.

Step 6: ‘Photovoltaic system’

This is the last phase before achieving a net-zero energy home and the costliest. That is why it is best to try and lower the energy costs prior to sizing the photovoltaic system. Once everything is complete, the only cost for electricity that will appear on the monthly electric bill may be a hook-up fee (approximately $25.00).

The site that was chosen is in an optimal location to obtain the maximum use of solar rays. Due to the high initial costs, it is a big step for the owners, but after receiving a few quotes, they are seeing an innovated future.

Step 7: ‘Notice the difference in the energy bill or lack of energy costs’

This step is self-explanatory. Who would not want an electric bill that is $25 a month.

Chapter 7

Reflection

More people are looking towards different ways to reduce their energy costs whether it is changing to CFL's or turning off the lights when not in the room. Striving for a net-zero energy home is a great way to help the environment. At the beginning of this research, I was not too sure where to begin or who to ask for help. I read articles and books, but none of them explained the process that needs to be taken, the complications that were involved or where to turn if I needed help. I had a lot of questions that needed to be answered and I was curious whether it would be worth someone's time and effort to consider net-zero energy.

To answer some of my questions, I decided to do two case studies that were striving towards or achieved net-zero energy. Through internet research and interviews, I got a few answers, but most people will not want to take the time out of their busy schedules to do case studies or research everything to truly understand what needs to be done.

I began calling and e-mailing various people who I thought would be valuable towards answering my questions. Conversing with people made the issues clearer than just reading books and visiting websites. When I first started, the information from reading articles was confusing. If I were a person not in school and wanted to reduce my energy bill, I would probably go on the internet and do all my research there. I would not have enough time during business hours to make phone calls to people who could answer my questions.

That is where the whole premise of this investigation began to provide a document to enlighten the curious and the discouraged to consider net-zero energy for their homes. This research was done to help others to easily find the information they are craving and answer questions they may have. Hopefully I have achieved my goals by providing an easy to understand, straight to the point research paper that encourages readers to reevaluate their energy consumption.

Appendix 1

History[21] of Photovoltaic

1839:

Nineteen-year-old Alexandre Edmund Becquerel, a French experimental physicist, discovered the photovoltaic effect while experimenting with an electrolytic cell made up of two metal electrodes.

1873:

Willoughby Smith discovered the photoconductivity of selenium.

1876:

William G. Adams and his student, R. E. Day observed the photovoltaic effect by illuminating a junction between selenium and platinum.

21 http://inventors.about.com/od/timelines/a/Photovoltaics.htm, http://www.pvresources.com/en/history.php and http://www1.eere.energy.gov/solar/solar_timeline.html

1877:

First selenium solar cell construction.

1883:

Charles Fritts, an American inventor, described the first solar cells made from selenium wafers.

1887:

Heinrich Hertz discovered that ultraviolet light altered the lowest voltage capable of causing a spark to jump between two metal electrodes.

1904:

Albert Einstein published his theoretical work on the photovoltaic effect.

1914:

The existence of a barrier layer in PV devices was reported.

1916:

Millikan provided experimental proof of the photoelectric effect.

1918:

Polish scientist Czochralski developed a way to grow single-crystal silicon.

1921:

Albert Einstein received the Nobel Prize for his theories explaining the photoelectric effect.

1941:

First silicon monocrystalline solar cell was constructed.

1951:

The first germanium solar cells have been made.

1953:

Dr. Dan Trivich of Wayne State University has made some theoretical calculation on solar cell efficiency with different materials and on solar spectrum wavelengths.

1954:

The PV effect in Cd was reported; primary work was performed by Rappaport, Loferski and Jenny at RCA. Bell Labs researchers Pearson, Chapin, and Fuller reported their discovery of 4.5% efficient silicon solar cells; this was raised to 6% only a few months later (by a work team including Mort Prince). Chapin, Fuller, Pearson (AT&T) submitted their results to the Journal of Applied Physics. AT&T demonstrated solar cells in Murray Hill, New Jersey, then at the National Academy of Science Meeting in Washington, DC.

1955:

Western Electric began to sell commercial licenses for silicon PV technologies; early successful products included PV-powered dollar bill changers and devices that decoded computer punch cards and tape. Bell System's demonstration of the type P rural carrier system began in Americus, Georgia. Hoffman Electronics's Semiconductor Division announced a commercial PV product at 2% efficiency; priced at $25/cell and at 14 mW each, the cost of energy was $1500/W.

1956:

Bell System's demonstration of the type P rural carrier system was terminated after five months.

1957:

Hoffman Electronics achieved 8% efficient cells. "Solar Energy Converting Apparatus," patent #2,780,765, was issued to Chapin, Fuller, and Pearson, AT&T.

1958:

Hoffman Electronics achieved 9% efficient PV cells. Vanguard I, the first PV-powered satellite, was launched in cooperation with the U.S. Signal Corp. The satellite power system operated for 8 years.

1959:

Hoffman Electronics achieved 10% efficient, commercially available PV cells and demonstrated the use of a grid contact to significantly reduce series resistance. Explorer-6 was launched with a PV array of 9600 cells, each only 1 cm x 2 cm.

1960:

Hoffman Electronics achieved 14% efficient PV cells.

1961:

The UN conference on Solar Energy in the Developing World was held. The precursor to the PV Specialists Conference, the Meeting of the Solar Working Group (SWG) of the Interservice Group for Flight Vehicle Power, was held in Philadelphia, Pennsylvania. The first PV Specialists Conference was held in Washington, DC.

1963:

Sharp Corporation developed the first usable photovoltaic module from silicon solar cells. Japan installed a 242-W PV array on a lighthouse, the world's largest array at that time.

1964:

The Americans applied a 470 W photovoltaic field in the Nimbus space project.

1965:

The Japanese scientific programme for Japanese satellite launch commenced. Peter Glaser, A.D. Little, conceived the idea of a satellite solar power station. Tyco Labs developed the edge-defined, film-fed growth (EFG) process, first to grow crystal sapphire ribbons and then silicon.

1966:

The Orbiting Astronomical Observatory was launched with a 1-kW PV array.

1968:

The OVI-13 satellite was launched with two CdS panels.

1969:

Roger Little established Spire Corporation, which became an important producer of solar cells production equipment.

1972:

Solar Power Corporation was established and began business in 1973. The French implemented a CdS photovoltaic system enabling educational TV programme broadcast in the province of Niger.

1973:

Solarex Corporation was established. At the Delaware University a photovoltaic-thermal hybrid system Solar one, one of the first photovoltaic systems for domestic application was developed. A silicon solar cell of US$ 30 per W was produced.

1974:

The Japanese Sunshine project commenced. Tyco Labs grew the first EFG, 1-inch-wide ribbon by an endless-belt process.

1975:

Solec International and Solar Technology International were established. The American government encouraged JPL Laboratories research in the field of photovoltaic systems for application on Earth the same year. Exxon opened Solar Power Corporation. JPL instituted the Block I procurement by the U.S. government.

1976:

Under NASA protection LeRC commenced photovoltaic system installations for application on Earth, which continued until 1985 and later from 1992 until 1995. The systems were meant for refrigerator telecommunication equipment, medical equipment, lighting and water pumping power supply as well as for other applications. NASA LeRC introduced several demonstration projects. The first amorphous silicon solar cell was developed by RCA Laboratories the same year Solec International was established (1975).

1977:

The world production of photovoltaic modules exceeded 500 kW. Solar Energy Research Institute located in Golden, Colorado launched its operation, later to become the National Renewable Energy Laboratory (NREL). Total PV manufacturing production exceeded 500 kW.

1979:

Solenergy was founded. ARCO Solar of Camarillo, California, built the biggest solar cells and photovoltaic systems production plant premises at the time. In Mt. Laguna, California, a trial 60 kW hybrid diesel-photovoltaic system was built for radar station power supply. NASA's Lewis Research Center (LeRC) completed a 3.5-kW system on the Papago Indian Reservation in Schuchuli, Arizona; this was the world's first village PV system. It was used for water pumping and power supply of 15 households. NASA's LeRC completed an 1.8-kW array for AID, in Tangaye, Upper Volta, and later increased power output to 3.6 kW.

1980:

ARCO Solar was the first to produce photovoltaic modules with peak pwer of over 1 MW per year. A trial photovoltaic system installation was made in the center of the volcano observatory in Hawaii. The first William R. Cherry Award was given to Paul Rappaport, SERI's founding director. New Mexico State University, Las Cruces, was selected to establish and operate the Southwest Residential Experimental Station (SW RES). A 105.6-kW system was dedicated at Natural Bridges National Monument in Utah; the system used Motorola, ARCO Solar, and Spectrolab PV modules.

1981:

A 90.4-kW PV system was dedicated at Lovington Square Shopping Center (New Mexico) using Solar Power Corp. modules. A 97.6-kW PV system was dedicated at Beverly High School in Beverly, Massachusetts, using Solar Power Corp. modules. An 8-kW PV-powered (Mobil Solar), reverse-osmosis desalination facility was dedicated in Jeddah, Saudi Arabia. Solar Challenger, the first plane ever powered by solar energy took off.

1982:

Worldwide PV production exceeded 9.3 MW. Solarex dedicated its 'PV Breeder' production facility in Frederick, Maryland, with its roof-integrated 200-kW array. ARCO Solar's Hisperia, California, 1-MW PV plant went on line with modules on 108 dual-axis trackers. Volkswagen began testing photovoltaic systems placed on vehicle roofs with 160 W peak power for vehicle start up.

1983:

The JPL Block V procurement was begun. Solar Power Corporation completed the design and installation of four stand-alone PV village power systems in Hammam Biadha, Tunesia (a 29-kW village power system, a 1.5-kW residential system, and two 1.5-kW irrigation/pumping systems). Solar Design Associates completed the stand-alone, 4-kW (Mobil Solar), Hudson River Valley home. Worldwide PV production exceeded 21.3 MW, and sales exceeded $250 million. Solar Trek vehicle with photovoltaic system of 1 kW drove 4,000 km in twenty days of Australia Race. The maximum speed was 72 km/h, and the average speed was 24 km/h.

1984:

The IEEE Morris N. Liebmann Award was presented to Drs. David Carlson and

Christopher Wronski at the 17th Photovoltaic Specialists Conference, “for crucial contributions to the use of amorphous silicon in low-cost, high-performance photovoltaic solar cells.” A 1 MW photovoltaic power plant began to operate in Sacramento, California. ARCO Solar introduced the first amorphous modules. NASA LeRC placed 17 photovoltaic systems to satisfy the demands of the local schools, lighting, medical equipment and water pumping in Gabon.

<u>1985:</u>

Researches of University of New South Wales in Australia have constructed a solar cell with more than 20% efficiency.

<u>1986:</u>

ARCO Solar introduced a G-4000, the first commercial thin film photovoltaic module.

<u>1991:</u>

The Solar Energy Research Institute was redesignated as the U.S. Department of Energy’s National Renewable Energy Laboratory by President George Bush.

<u>1992:</u>

A photovoltaic system of 0.5 kW was placed in Antarctica for the laboratory, lighting, personal computers and microwave ovens needs. A silicon solar cell with 20% efficiency was patented.

<u>1993:</u>

The National Renewable Energy Laboratory’s Solar Energy Research Facility (SERF), opened in Golden, Colorado.

1994:

DOE built several trial systems for the need of agriculture, hospitals, lighting, water pumping and so on in Brazil. The National Renewable Energy Laboratory develops a solar cell made of gallium indium phosphide and gallium arsenide; it's the first one of its kind to exceed 30% conversion efficiency.

1995:

The first international fond for promotion of photovoltaic system commercialization was established, which supported projects in India. The World Bank and the Indian Renewable Energy Sources Agency sponsored projects in co-operation with Siemens Solar.

1996:

The U.S. Department of Energy announces the National Center for Photovoltaics, headquartered in Golden, Colorado. The world's most advanced solar-powered airplane, the Icare, flies over Germany. Its wings and tail surfaces are covered by 3,000 super-efficient solar cells, for a total area of 21 square meters.

1998:

On August 6, a remote-controlled, solar-powered aircraft, "Pathfinder," sets an altitude record of 80,000 feet on its 39th consecutive flight in Monrovia, California — higher than any prop-driven aircraft to date.

1999:

Solar Cells, Inc. (SCI), True North Partners, and LLC of Phoenix, Arizona merged to First Solar, LLC. Construction is completed on 4 Times Square in New York, the tallest skyscraper built in the city in the 1990s. It has more energy-efficient features than any other commercial skyscraper and includes building-integrated photovoltaic (BIPV) panels on the 37th through the 43rd floors on the south- and west-facing facades to produce part of the building's power.

2002-2003:

Several large power plants were built in Germany. Due to renewable energy law "EEG" many large systems up to 5 MWp were built in Germany in 2004.

2000:

First Solar begins production at the Perrysburg, Ohio, photovoltaic manufacturing plant, the world's largest at the time; estimates indicate that it can produce enough solar panels each year to generate 100 megawatts of power. At the International Space Station, astronauts begin installing solar panels on what will be the largest solar power array deployed in space. Each "wing" of the array consists of 32,800 solar cells. Industry Researchers develop a new inverter for solar electric systems that increases safety during power outages. Inverters convert the direct current (DC) electrical output of solar systems to alternating current (AC) — the standard for household wiring as well as for power lines to homes. Two new thin-film solar modules developed by BP Solarex break previous performance records. The company's 0.5-square-meter module has a 10.8% conversion efficiency — the highest in the world for similar thin-film modules. Its 0.9-square-meter module achieves 10.6% efficiency and a power output of 91.5 watts — the highest in the world for a thin-film module. The 12-kilowatt solar electric system of a Morrison, Colorado, family is the largest residential installation in the United States to be registered with the U.S. Department of Energy's Million Solar Roofs program. The system provides most of the electricity for the family of eight's 6,000-square-foot home.

2001:

Home Depot begins selling residential solar power systems in three stores in San Diego, California. A year later it expands sales to 61 stores nationwide. NASA's solar-powered aircraft Helios sets a new world altitude record for non-rocket-powered craft: 96,863 feet (more than 18 miles up). The National Space Development Agency of Japan, NASDA, announces plans to develop a satellite-based solar power system that beams energy back to Earth. A satellite with large solar panels would use laser technology to transmit solar power to an airship at an altitude of about 12 miles; the airship would then transmit power to Earth. TerraSun LLC develops a unique method of using holographic films to concentrate sunlight onto a solar cell. Fresnel lenses or mirrors are usually used to concentrate sunlight, but TerraSun claims that holographic optics are more selective, allowing light not needed for power production to pass through the transparent modules so they can be used as skylights. PowerLight Corporation connects the world's largest hybrid solar-wind power system to the grid in Hawaii. Its solar energy capacity — 175 kilowatts — is larger than its wind energy capacity — 50 kilowatts; this is somewhat unusual for hybrid power systems. British Petroleum and BP Solar announce the opening of a service station in Indianapolis that features a solar-electric canopy. The station is the first U.S. "BP Connect" store, a model that BP intends to use for new or revamped BP service stations. The canopy contains translucent photovoltaic modules made of thin films of silicon deposited on glass.

2002:

NASA conducts two successful tests of a solar-powered, remote-controlled aircraft called Pathfinder Plus. In July, researchers demonstrate the aircraft's use as a high-altitude platform for telecommunications technologies. In September, it's tested for use as an aerial imaging system for coffee growers. The Union Pacific Railroad installs 350 blue-signal rail yard lanterns, which incorporate energy-saving light-emitting diode (LED) technology and solar cells, at the large North Platt, Nebraska, rail yard. ATS Automation Tooling Systems Inc. in Canada begins commercializing spheral solar technology. Employing tiny silicon beads bonded between two sheets of aluminum foil, this solar-cell technology uses much less silicon than conventional multicrystalline silicon solar cells, thus potentially reducing costs. The technology was first championed in the early 1990s by Texas Instruments, but TI later discontinued work on it.

The largest solar power facility in the Northwest — the 38.7-kilowatt White Bluffs Solar Station — goes online in Richland, Washington.

PowerLight Corporation installs the largest rooftop solar power system in the United States — a 1.18-megawatt system at the Santa Rita Jail in Dublin, California.

Appendix 2

History[22] of Solar Water Heater

<u>1767:</u>

Horace de Saussure, a noted Swiss naturalist, is credited with building the world's first solar collector. He observed that when he built a box with insulation on the inside, had the top covered with glass, and had two smaller boxes placed inside, the bottom box heated up 16 degrees F above boiling when exposed to the sun. Its inventor realized that someday the hot box might have important practical applications, as "it is quite small, inexpensive and easy to make." Indeed, the hot box has become the prototype for the solar collectors that have provided sun-heated water to millions since 1892.

22 http://www.californiasolarcenter.org/history_solarthermal.html and http://www1.eere.energy.gov/solar/solar_time_1767-1800.html

1800:

To circumvent the problem of heating water, many handy farmers or prospectors or other outdoors men devised a much safer, easier, and cheaper way to heat water - placing into the sun a metal water tank painted black to absorb as much solar energy as possible. These were the first solar water heaters on record. The downside was that even on clear, hot days it usually took from morning to early afternoon for the water to get hot. And as soon as the sun went down, the tanks rapidly lost their heat because they had no protection from the night air.

1891:

The shortcomings of the bare tank solar water heaters came to the attention of Clarence Kemp, who sold, in Baltimore, Maryland, the latest home heating equipment. In 1891, Kemp patented a way to combine the old practice of exposing metal tanks to the sun with the scientific principle of the hot box, thereby increasing the tanks' capability to collect and retain solar heat. He called his new solar water heater the Climax - the world's first commercial solar water heater. Kemp originally marketed his invention to eastern gentlemen whose wives had gone off with their maids to summer at some resort, leaving their husbands to fend for themselves. The solar water heater, Kemp advertised, would simplify housekeeping duties for this class of men already burdened by their wives and domestic staffs absence and unaccustomed to such work as lighting the gas furnace or stove to heat water.

1896:

The Climax sold well in states with greater amounts of sunshine throughout the year. Sixteen hundred had gone up in homes throughout Southern California by 1900, including the one installed for Walter van Rossem's mother in Pasadena where three years earlier a third of the households in this California city heated their water with the sun.

1909:

William J. Bailey patented a solar water heater that revolutionized the business. He separated the solar water heater into two parts: a heating element exposed to the sun and an insulated storage unit tucked away in the house so families could have sun heated water day and night and early the next morning. The heating element consisted of pipes attached to a black-painted metal sheet placed in a glass-covered box. Because the water to be heated passed through narrow pipes rather than sat in a large tank, Bailey reduced the volume of water exposed to the sun at any single moment and therefore, the water heated up faster. Providing hotter water for longer periods put Bailey's solar hot water heater, called the Day and Night, at a great advantage over the competition. Soon the Climax went out of business.

1909-1918:

Bailey's company had sold more than 4,000 Day and Night Solar Hot Water Heaters.

1920-1940:

Because people had to rely on expensive imported coal or wood for fuel, many found solar a cheaper alternative. The huge discoveries of natural gas in the Los Angeles basin during the 1920s and 1930s killed the local solar water heater industry. Rather than lose money from the energy changes in the Southland, Bailey took the innovations he had made in solar and applied them to develop the thermostatically-controlled gas water. His Day and Night Gas Water Heater made him his second fortune. He also sold the patent rights of the Day and Night

Solar Water Heater to a Florida firm. A building boom in Florida during the 1920s had tripled, but just as in California before the great oil strikes, people had to pay a pretty penny to heat water. The high cost of energy combined with the tropical climate and the great growth in housing stock created a big business for those selling solar water heaters.

1941:

More than half the population heated its water with the sun! Declining electric rates after World War II, in tandem with an aggressive campaign by Florida Power and Light to increase electrical consumption by offering electric water heaters at bargain prices, brought Florida's once flourishing solar water heater industry to a screeching halt.

1960:

A Japanese company began marketing simple solar water heater consisting of a basin with its top covered by glass, more than 100,000 were in use. People living in the towns and cities bought either a plastic solar water heater that resembled an inflated air mattress with a clear plastic canopy or a more expensive but longer lasting model that resembled the old Climax Solar Water Heaters - cylindrically shaped metal water tanks placed in a glass-covered box. Close to 4,000,000 of these solar water heaters sat on roof tops by 1969. The advent of huge oil tankers in the 1960s allowed the Japanese access to new oil fields in the Middle East, supplying them with cheap, abundant fuel. As had happened in California and Florida, the solar water heater industry collapsed. But not for long.

1973:

The Oil Embargo and the subsequent dramatic increase in the price of petroleum revived the local solar water heater industry. Annual sales of greater than 100,000 units continued to hold steady from 1973 until the second oil shock of 1979. Sales then jumped to almost half a million that year and leaped to nearly a million the following year. By this time, the Japanese favored solar water heaters closely resembling the type introduced to California in 1909 by William J. Bailey with the heating and storage units separated. As the price of oil began to stabilize in 1985 and then drop sharply in subsequent years, so did the sales of solar water heaters; still the Japanese purchase around 250,000 each year. Today, more than 10,000,000 Japanese households heat their water with the sun.

Australia:

From the 1950s to the early 1970s, a few thousand Australians relied on the sun to heat their water. The numbers grew phenomenally as a consequence of two huge spikes in oil prices in 1973 and 1979. Interestingly, purchasing of solar water heaters during these heady years varied from state to state. While 40 to 50% of those living in Australia's Northern Territory heated their water with the sun, the percentage dropped to around 15% in Western Australia and sunk to below 5% in the more populated eastern states. The sharp difference had more to do with the cost of electricity than the amount of sun available. People in the Northern Territory and Western Australia bought electricity generated by imported and increasingly costly petroleum while those in the eastern states of New South Wales, Queensland and Victoria had their electricity produced by locally mined and very cheap coal. In the late 1980s, the Australian solar water heater market began to stagnate. Pipelines bringing newly discovered natural gas to previously fuel-short regions such as the Northern Territory and Western Australia has braked any growth in these once fertile markets for solar water heaters. Exports now account for more than 50% of the sales made by Solahart, Australia's leading manufacturer of solar water heaters.

Israel:

Unlike the United States and much of Europe, Israel, like Japan, found itself without sufficient fuel supplies in the early 1950s. The power situation became so bleak in the early days of the Jewish State that the government had to forbid heating water between 10 p.m. and 6 p.m. Despite mandatory domestic rationing of electricity, power shortages worsened, causing pumping stations to fail and threatening factory closures. A special committee impaneled by the government could only suggest the purchase of more centralized generators to overcome the problem. This conclusion raised the ire of Israeli engineer, Levi Yissar, who complained, “How about an already existing energy source which our country has plenty of - the sun. Surely we need to change from electrical energy to solar energy, at least to heat our water.” Yissar put his money where his mouth was, becoming Israel’s first manufacturer of solar water heaters. By 1967 about one in twenty households heated their water with the sun. But cheap oil coming from Iran in the late 1960s as well from oil fields captured during the Six Day War drastically reduced the price of electricity and the number of people purchasing solar water heaters.

Israeli success in the Yom Kippur War brought on the infamous oil boycott of 1973. The Israelis responded by mass purchasing of solar water heaters. By 1983, 60% of the population heated their water with the sun. When the price of oil dropped in the mid 1980s, the Israeli government did not want people backsliding in their energy habits as has happened in the rest of the world. It therefore required its inhabitants to heat their water with the sun. Today, more than 90% of Israeli households own solar water heaters.

Pools:

Solar swimming pool water heaters rank as the most successful yet least heralded commercial solar application. The use of solar energy for pool heating and the equipment and need of pool owners make a perfect match. The storage unit for the solar heated water already exists - the swimming pool. The pump needed to push water through the solar collector also must be bought irrespective of the technology used to heat the water. The pool owner merely has to purchase the solar collectors. Since those using the pool only want the temperature of the pool to reach no greater than 80 or so degrees F (27 degrees C), the solar collector does not require a costly glass cover or expensive metal sheeting and piping. In fact, in the 1970s, American Freeman Ford developed low-cost plastic to act as the solar collector. Exposed to the sun, water would pass through narrow ducts in the plastic and heat up sufficiently to warm the pool. Of course, the outdoor swimming season harmoniously coincides with the maximum output of the solar collectors. Even with other forms of energy selling very cheaply, the pool owner buying a solar unit starts to save money very quickly. In the United States alone, solar swimming pool heaters have produced the energy output equivalent to running ten nuclear power plants.

Appendix 3

CFL Lights[23]

Although Compact Fluorescent Light Bulbs (CFLs) are a great way to reduce energy consumption, they contain mercury in them, which could be harmful if one is broken. According to Energy Star, 'CFLs contain a very small amount of mercury sealed within the glass tubing – an average of 4 milligrams (approximately the tip of a ball point pen). By comparison, older thermometers contain about 500 milligrams of mercury – an amount equal to the mercury in 125 CFLs'. Most mercury emissions emitted into the air and water are caused from coal-fired electrical power. As a result, consuming contaminated fish is the main way people are exposed to mercury. The chart below indicates the different levels of mercury emissions produced regarding CFL and incandescent bulbs.

23 http://www.energystar.gov/ia/partners/promotions/change_light/downloads/Fact_Sheet_Mercury.pdf

Light Bulb Type	Watts	Hours of Use	kWh Use	National Average Mercury Emissions (mg/kWh)	Mercury from Electricity Use (mg)	Mercury from Landfilling (mg)	Total Mercury (mg)
CFL	13	8,000	104	0.012	1.2	0.6	1.8
Incandescent	60	8,000	480	0.012	5.8	0	5.8

As a result, CFL bulbs are more environmentally friendly when compared to the incandescent bulbs however there are some precautions that should be taken into consideration if a CFL bulb burns out or breaks:

What to do if a CFL bulb **burns out**:[24]

- Veolia Environmental Services has an agreement with the U.S. Postal Services to ship recycled CFL bulbs from Hawaii through the mail to the mainland-based recycling company
  - Kits are available online at www.prepaidrecycling.com or by calling 1-888-669-9725.
    - Each kit costs about $20 (which include shipping and recycling fees) and can hold about 6-8 bulbs or 10-12 mini/specialty CFL's

- Home Depot has a recycling center in each store
  - On Oahu, the drop off is near the lumber section
  - On Maui, it is near the customer service

- Other option is to put the bulb in two plastic bags and place outside in a

24 http://www.heco.com/portal/site/heco/menuitem.508576f78baa14340b4c0610c510b1ca/?vgnextoid=1bd36de01aaa8110VgnVCM1000005c011bacRCRD&cpsextcurrchannel=1

protected location for the next trash collection (if the state environmental agency allows)

- Bulbs that are broken will not qualify for recycling

What to do if a CFL bulb **breaks**:[25]

1. Air out the room prior to clean-up
   - o Shut off air conditioning system (if you have one)
   - o Open a window and leave the room for 15 minutes or more
   - o Evacuate the room, do not let anyone walk through the breakage area on their way out

2. Hard Surfaces
   - o Carefully scoop up glass fragments and powder using still paper or cardboard
   - o Place them in a glass jar with metal lid or in a sealed plastic bag
   - o Use sticky tape (duct tape) to pick up remaining small glass pieces and powder
   - o **Do not use a vacuum or broom to clean up the broken bulb on hard surfaces**

3. Carpet or Rug
   - o Carefully pick up glass fragments
   - o Place them in a glass jar with metal lid or in a sealed plastic bag
   - o Use sticky tape (duct tape) to pick up any remaining small glass fragments and powder

25 http://www.energystar.gov/ia/partners/promotions/change_light/downloads/Fact_Sheet_Mercury.pdf

- If vacuuming is needed after all visible materials are removed, vacuum the area where the bulb was broken.
- Remove the vacuum bag or empty the wipe the canister and put the bag or vacuum debris in a sealed plastic bag

4. Clothing, Bedding, etc.
   - If clothing or bedding materials come in direct contact with broken glass or mercury containing powder from inside the bulb that may stick to the fabric, the clothing or bedding should be thrown away.
   - **Do not wash such clothing or bedding (with powder substance) because mercury fragments in the clothing may contaminate the machine and/or pollute sewage.**
   - You can wash clothing or other materials that have been exposed to the mercury vapor from a broken CFL, such as the clothing you were wearing when you cleaned up the materials from the broken bulb.
   - If shoes come into direct contact with broken glass or mercury-containing powder from the bulb
     - wipe them off with damp paper towels or disposable wet wipes
     - place the towels or wipes in a glass jar or plastic bag for disposal

5. Disposal of Clean-up Materials
   - Immediately place all clean-up materials outdoors in a trash container or protected area for the next normal trash pickup
   - Wash hands after disposing of the jars or plastic bags containing

clean-up materials

- Check disposal requirements in specific area. Some states do not allow such trash disposal

6. Future Cleaning of Carpeting or Rug
   - The next several times you vacuum, shut off the central conditioning system and open a window before vacuuming
   - Keep the air conditioning system shut off and the window open for at least 15 minutes after vacuuming is completed

"EPA is continually reviewing its clean-up and disposal recommendations for CFL's to ensure that the Agency presents the most up-to-date information to consumers and businesses."[26]

26 http://www.energystar.gov/ia/partners/promotions/change_light/downloads/Fact_Sheet_Mercury.pdf


Figure 13: Schofield Barracks
http://dotearth.blogs.nytimes.com/2008/04/15/the-race-between-two-forms-of-sunlight/

Appendix 4

Case Study – Schofield Barracks

Owner: Army Hawaii Family Housing LLC

Developer: Actus Lend Lease

Years community in progress: 2005 - present

Design Objectives:

Create a sustainable community of homes that were efficient and aesthetic in application, but economically feasible in the long run. According to Actus Lend Lease, "Both the Lend Lease Corporation and the U.S. Army are committed to sustainable community practices, including the use of alternative energy technologies where it is possible to do so. In the case of the Army Hawaii Family Housing LLC partnership between the two entities, our inherent house and community designs combined economies of scale made employment of PV technology attractive from many fronts – particularly in offsetting our energy consumption footprint and protecting against rising energy consumption costs." Some considerations that were taken into account were the replicable nature of product chosen, product life cycle for all PV system components, replacement cost, cost benefit of capital investment vs. credit offset for energy production, and carbon footprint offset.

Design Outcome:

Actus Lend Lease created a community of homes which proves that an economically friendly home could be constructed on a individual scale or a whole subdivisions.

Design Features[27]:

1. Reflective paint coverings
2. Low E dual pane windows
3. Static attic ventilation designed to maximize air turns
4. Energy Star appliances
5. Extended eaves
6. Use of radiant barrier
7. Thicker than industry standard insulations
8. Solar domestic hot water system
9. Photovoltaic system (thin film laminate)
   - 6 mega-watt
10. An urban plan that preserved hundreds of significant trees and the existing natural environment
11. Development of a Pesticide Impacted Soils Program that established PI soil investigative procedures, which resulted in a 65 percent reduction in

27 http://www.armyhawaiifamilyhousing.com/about_us/ahfh.asp#q1

investigative costs

12. Recycling 90 percent of concrete and asphalt, establishment of a Home Destruction and Salvage Program and a Green Procurement Program
13. Home design and amenities that meet Gold Star standards
14. SYNERGY, a resident education program targeting resident behavior with the goal of reducing energy consumption
15. Curbside recycling in neighborhoods

Facts:

- Photovoltaic
  - Uni-Solar Triple Junction Thin Film Laminate
  - Laminated with an adhesive backing to a standing seam roofing system
  - All grid-tied
  - Problem: some inverters had to be replaced
  - 1/3 of 6 megawatt system currently installed, may take years to figure weather anomalies for accurate expected efficiency

Conclusion:

The Army is looking towards the future and preparing an energy efficient community to prove they believe in conserving the earth's resources. Maybe in the near future, other developers could also create homes that are energy efficient.


Figure 14: Before
ADI Architects


Figure 15: After
ADI Architects

Appendix 5

Case Study – Net-Zero Energy Home

Owner: Harrison (purchased in 2000)

Year built: 1954

Original Architect: Vladimir Ossipoff

Original Floor Area: 2,633 sq.ft.

Year remodeled: 2005

Redesign Architect: Paul Noborikawa

ADI Design Group, Inc.

Remodeled Floor area: 3,013 sq.ft.

Design Objectives:

Create a home that was more inviting and utilize the unusable patio area. Given the fact that the roof would have to be rebuilt due to rot and termite damage, the Harrison's decided to incorporate insulation, ventilation and better lighting into the main living space.

Specific Design Provisions:

1. Repair damaged roof rafters and eaves; replace roof
2. Enclose existing lanai
3. Integrate den, living room and family room addition to avoid "add-on" sense
4. Relocate laundry to carport
5. Convert existing laundry/furo into a new guest studio
6. Re-orient carport roof design to optimize solar incidence angle
7. Install solar thermal and photovoltaic energy systems
8. Replace electric stove and dryer with natural gas equivalents
9. Employ recycled materials where feasible
10. Avoid using scarce resources (i.e., tropical hardwoods)

Design Outcome:

The collaboration between the architect and owners created an open, well lit dining/living room which achieved the goal of avoiding an "add-on" sense. Although the big windows that followed the new roofline face east and west, the quality of living is comfortable. The Harrison's have also created a net-zero energy home which in turn has no electricity bill (except a monthly connection fee of $17). The features of creating a net-zero energy home is so subtle that upon entering the property, it looks like any typical home.

Design Features:

1. Tech-Shield boards to create an air space above the sub-roof
2. Ridge vents
3. 3 Solar fans
4. Landscape vegetation to passively cool circulated air

5. Task lighting
6. Exterior Lighting uses CFL devices, motion sensors
7. Gas units: stove and dryer
8. Energy efficient refrigerator, dishwasher, clothes washer and dryer
9. Solar thermal hot water system with timer
    a. 2 standard collectors
    b. 125-gallon tank
10. Photovoltaic system (32 mono crystalline panels)
    a. Capacity: 5kW (two 2.5 kW subunits)
    b. Battery charger and inverter for each subunit
    c. 24 kW-hr battery system (divided into two 48-volt banks)
    d. Net-metered

Comparison:

Before remodeling, the Harrison's electricity consumption was about 700 kW-hrs/month (23 kW-hrs/day). After the photovoltaic system was installed, the system produced 301 kW-hrs more than they could consume in that year.

Facts:

- Photovoltaic system
    - Elevated off the roof for better efficiency. (Photovoltaic cells work better if they do not get too hot.) The system is also bolted to the structure in case of a hurricane.
    - 3 problems since it was installed
        - One inverter fan kept going on and off instead of staying constant like the other fan. Since it was under warranty, the installers changed the circuit board.

- After 1 year, half of one array was producing less electricity than the others.
- A $5 circuit breaker had to be changed

- The Harrison's did not maximize their credit rebates because they wanted to install the whole photovoltaic system at one time instead of in phases.
- The month after the installation was completed, the Harrisons saw a difference in their electricity bill.
- The amount of energy produced was pretty close to the anticipated amount.
- Total cost: $50,000 ($6,000 for 8 batteries)

Conclusion:

Many people envision a dark, uncomfortable living space when someone says their house is energy efficient. The Harrison's have proved that a net-zero energy home can be welcoming and comfortable. In the end, the only thing Mr Harrison wish he had done was create a net-zero energy home sooner.

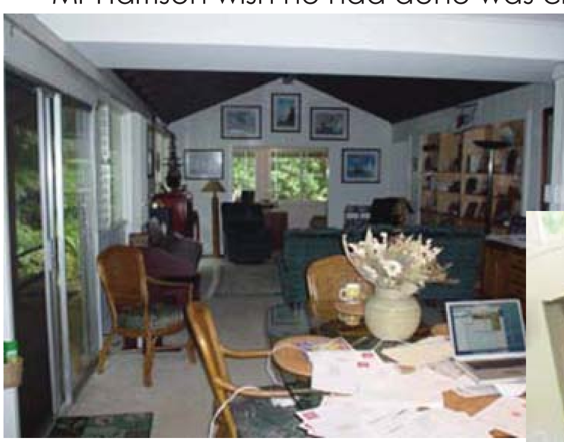


Figure 16: Before
ADI Architects

Figure 17: After
ADI Architects

Appendix 6

Handbook

Appendix 7

Calculations

The calculations on the following pages reflect the electric bills over the course of five years for the home researched. There are a few circumstances that needed to be considered when analyzing the data. Listed below are the fluctuations that played a major role in the energy consumption:

1. 2005, Oct. Gas Line Installed
2. 2007, Jan. One of the owners moved away for five months
3. 2007, Feb. The other owner's parents move in
4. 2008, Jan. One of the owners (same as before) moved away for six months
5. 2009, Jan. Start of house analysis

**Because of so many changes in a close proximity for the beginning of 2007, it is hard to determine an accurate ratio of energy consumption.*

1 Year Prior to Gas Installation (Nov. '05), 2 People

Year	Month	kwh
2004	Nov	987
	Dec	917
2005	Jan	1088
	Feb	905
	Mar	1054
	Apr	904
	May	926
	June	1065
	July	1063
	Aug	1081
	Sept	1070
	Oct	998
	Total	12,058 kwh / 12 months = **1004.83 kwh/mo**

1 Year After Gas Installation, 2 People

Year	Month	kwh
2005	Nov	666
	Dec	475
2006	Jan	643
	Feb	536
	Mar	587
	Apr	603
	May	623
	June	674
	July	663
	Aug	610
	Sept	566
	Oct	495
	Total	7,141 kwh / 12 months = **595.08 kwh/mo**

(1004.83 – 595.08) / 1004.83 = **40.8% decrease**

**By installing a gas line for the stove, water heater and dryer, they reduced their electric consumption by almost 41%.*

1 Year Prior to Parents Moving In (Feb. 15, 2007), 2 People

Year	Month	kwh	
2006	Feb	536	
	Mar	587	
	Apr	603	
	May	623	
	June	674	
	July	663	
	Aug	610	
	Sept	566	
	Oct	495	
	Nov	557	
	Dec	551	
2007	Jan	519	*Owner leaves for 5 months (3rd week)
	Total	6,984	kwh / 12 months = **582.00 kwh/mo**

1 Year After Parents Move In, 3-4 People

Year	Month	kwh	
2007	Feb	364	
	Mar	502	
	Apr	434	
	May	460	
	June	659	*Owner returns
	July	765	
	Aug	605	
	Sept	851	
	Oct	831	
	Nov	586	
	Dec	782	
2008	Jan	480	*Owner leaves for 6 months
	Total	7,319	kwh / 12 months = **609.92 kwh/mo**

(609.92 – 582.00) / 609.92 = **4.6% increase**

**Although the increase is very slight, it is hard to determine an accurate percentage due to one of the owner's moving.*

Owner Away (Spr. ’07 & ’08), 3 People

Year	Month	kwh	
2007	Jan	519	
	Feb	364	
	Mar	502	
	Apr	434	
	May	460	
	Total	2,279	kwh / 5 months = 455.80 kwh/mo
2008	Jan	480	
	Feb	445	
	Mar	388	
	Apr	445	
	May	433	
	June	447	
	Total	2,638	kwh / 6 months = 439.67 kwh/mo

455.80 + 439.67 = 895.47 kwh/mo / 2 = **447.74 kwh/mo (avg.)**

Owner At Home, 4 People

Year	Month	kwh	
2007	June	659	
	July	765	
	Aug	605	
	Sept	851	
	Oct	831	
	Nov	586	
	Dec	782	
	Total	5,079	kwh / 7 months = 725.57 kwh/mo

Owner At Home, 4 People (continuation)

Year	Month	kwh	
2008	July	673	
	Aug	758	
	Sept	788	
	Oct	944	
	Nov	694	
	Dec	676	
	Total	4,533	kwh / 6 months = 755.50 kwh/mo

725.57 + 755.50 = 1,481 kwh/mo / 2 = **740.54 kwh/mo (avg.)**

(740.54 – 447.74) / 740.54 = **39.5% increase**

**When the owner is at home, there is about a 40% increase in the electric bill.*

2 Months Before Start Of Project (Jan. '09)

Year	Month	kwh	
2008	Nov	694	
	Dec	676	
	Total	1,370	kwh / 2 months = 685 kwh/mo

2 Months After Start Of Project

Year	Month	kwh	
2009	Jan	668	
	Feb	516	
	Total	1,184	kwh / 2 months = 592 kwh/mo

(685 - 592) / 685 = **13.6% decrease**

**Two months after the start of the project, there is about a 14% decrease in the electric bill from the owners trying to change their bad habits.*

Appendix 8

Companies

Actus Lend Lease, Hawaii Regional
215 Duck Road, Building 950
Schofield Barrachs, HI 96857

808.687.8300

ADI Design Group Inc.
851 Pohukaina Street, Bldg C, Bay 3
Honolulu, HI 96813

808.593.8950

Alternate Energy Inc.
549 Kokea St, Suite C5
Honolulu, HI 96817

808.842.5853

Hoku Solar, Inc.
1288 Ala Moana Boulevard, Suite 220
Honolulu, HI 96814

808.682.7800

Inter-Island Solar Supply
761 Ahua Street
Honolulu, HI 96819

808.523.0711

Lincolne Scott Inc
1132 Bishop St, Suite 1850
Honolulu, HI 96813

808.536.1737

PhotonWorks LLC
1188 Bishop Street, Suite 2307
Honolulu, HI 96813

808.951.4100

Sunetric
PO Box 1462
Kailua, HI 96734

808.262.6600

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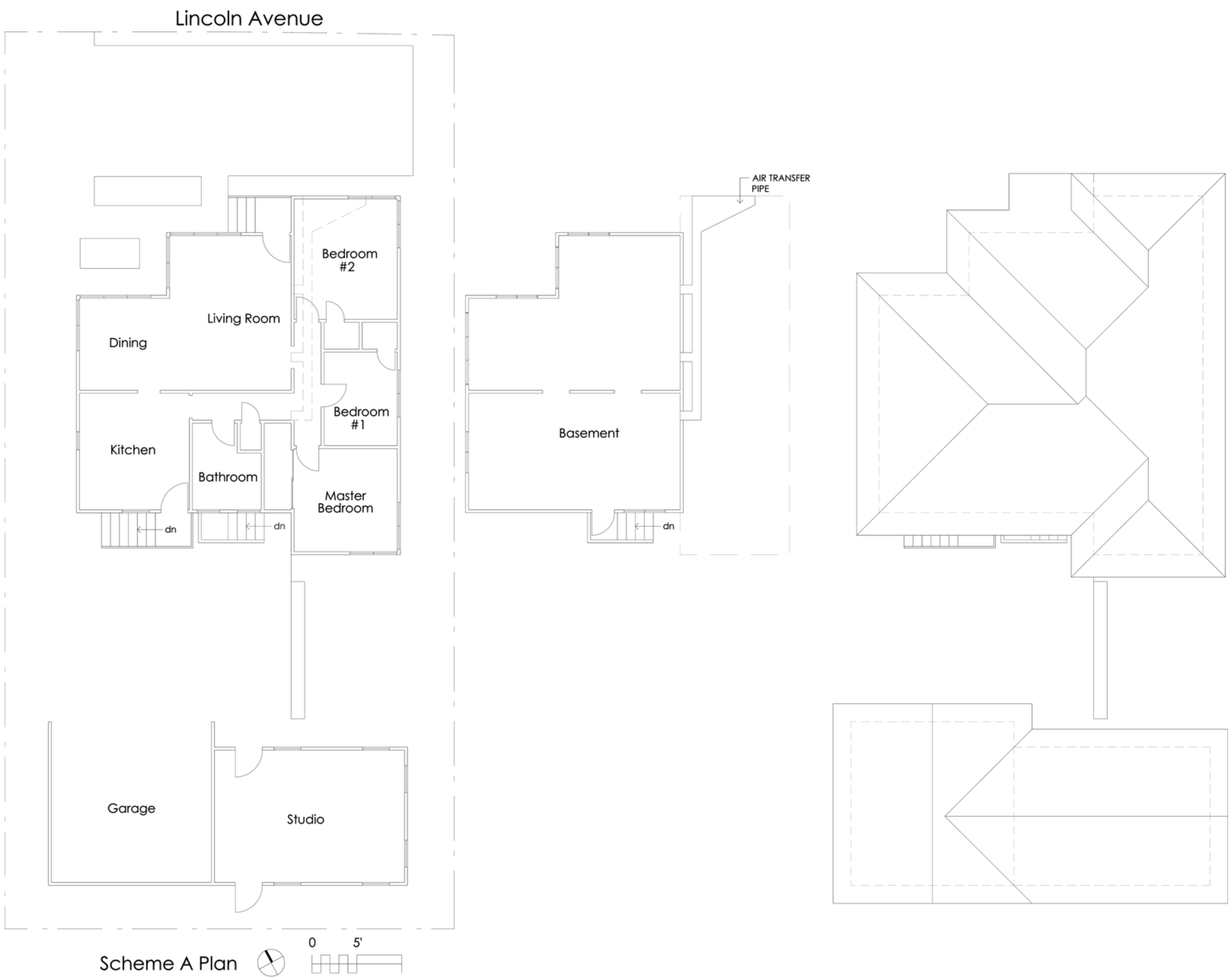
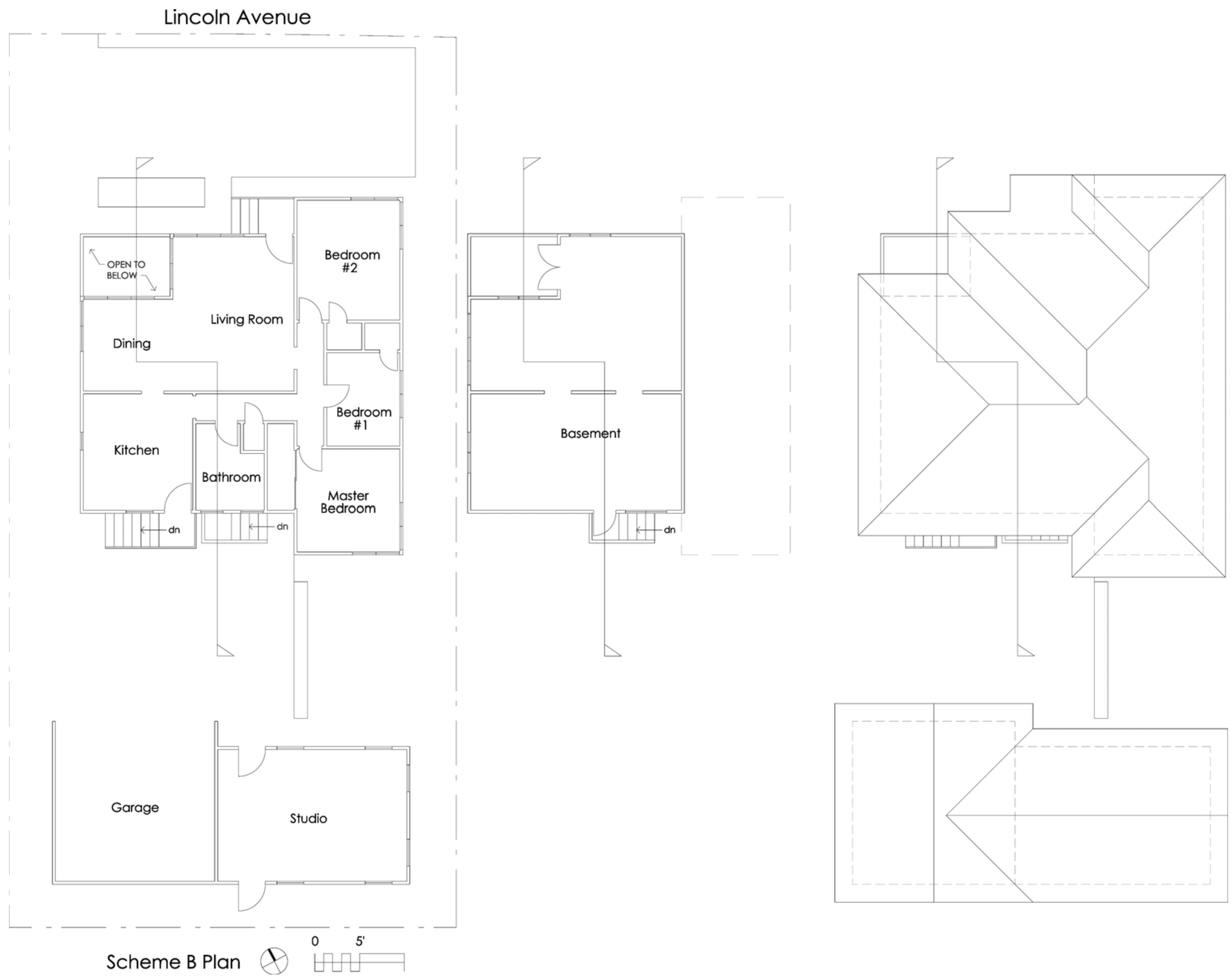


Scheme A Plan

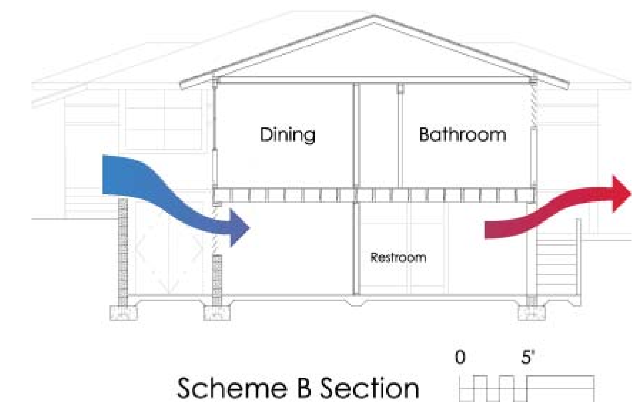
Scheme A North Elevation

This option explores the cheapest solution to passively cooling the basement by installing a pipe under the house to draw air into the space. In order to prevent dirt and rubbish from entering the home, a filter should be installed on the ends of the pipe.



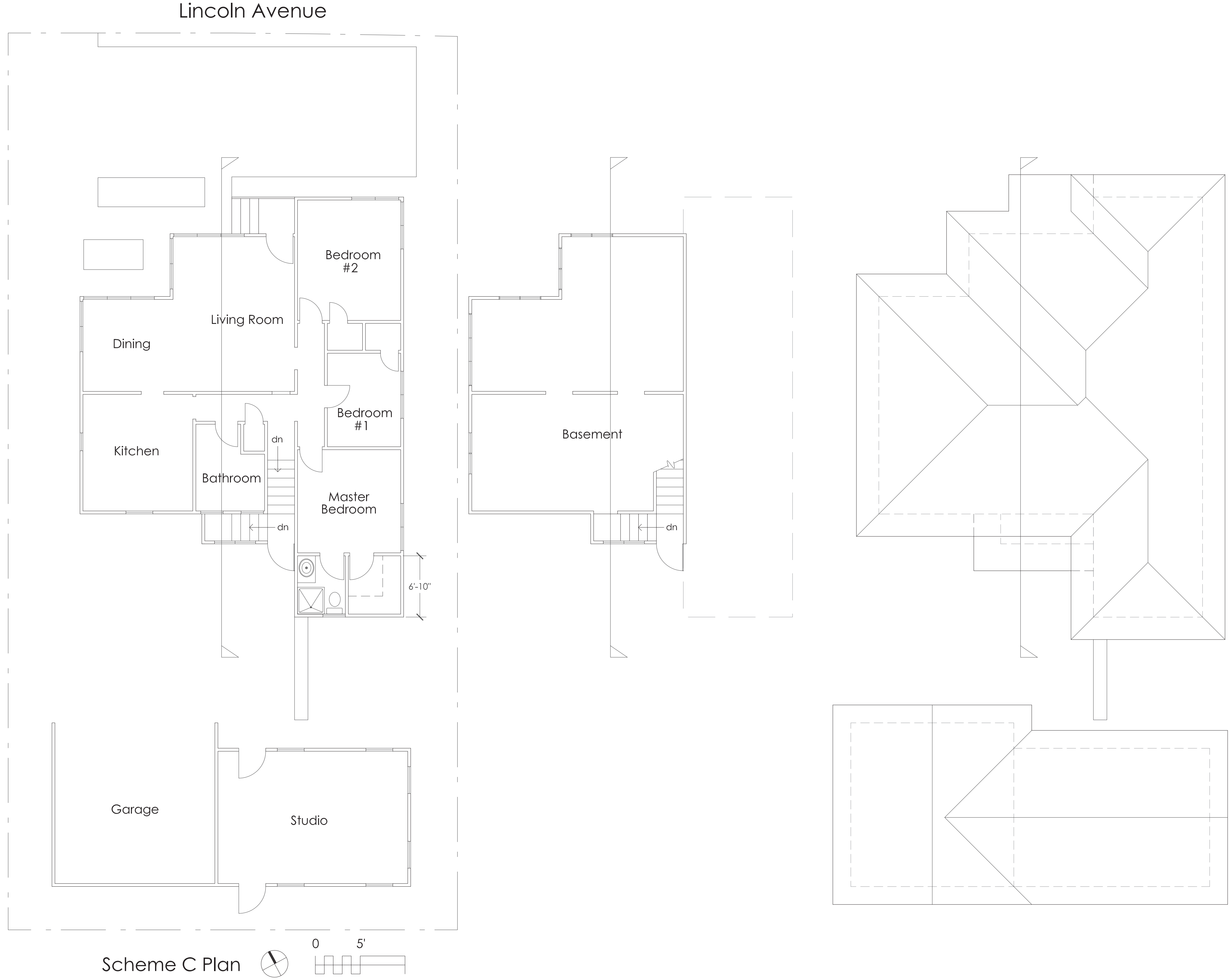
Scheme B Plan

Scheme B North Elevation



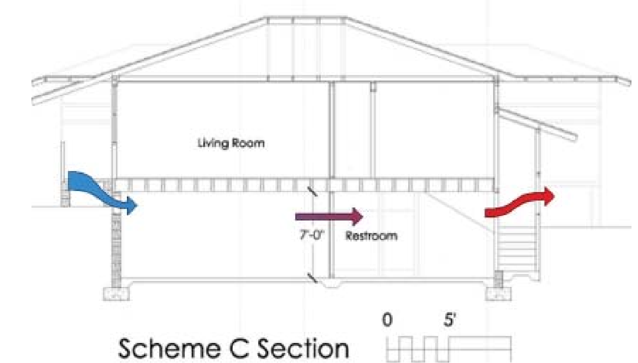
Scheme B Section

Scheme B may be one of the most expensive options due to the excavating in the front of the home. Although it may be the costliest, the option of having an exterior lanai to draw air into the basement and connect the interior to the exterior may be a good experience.



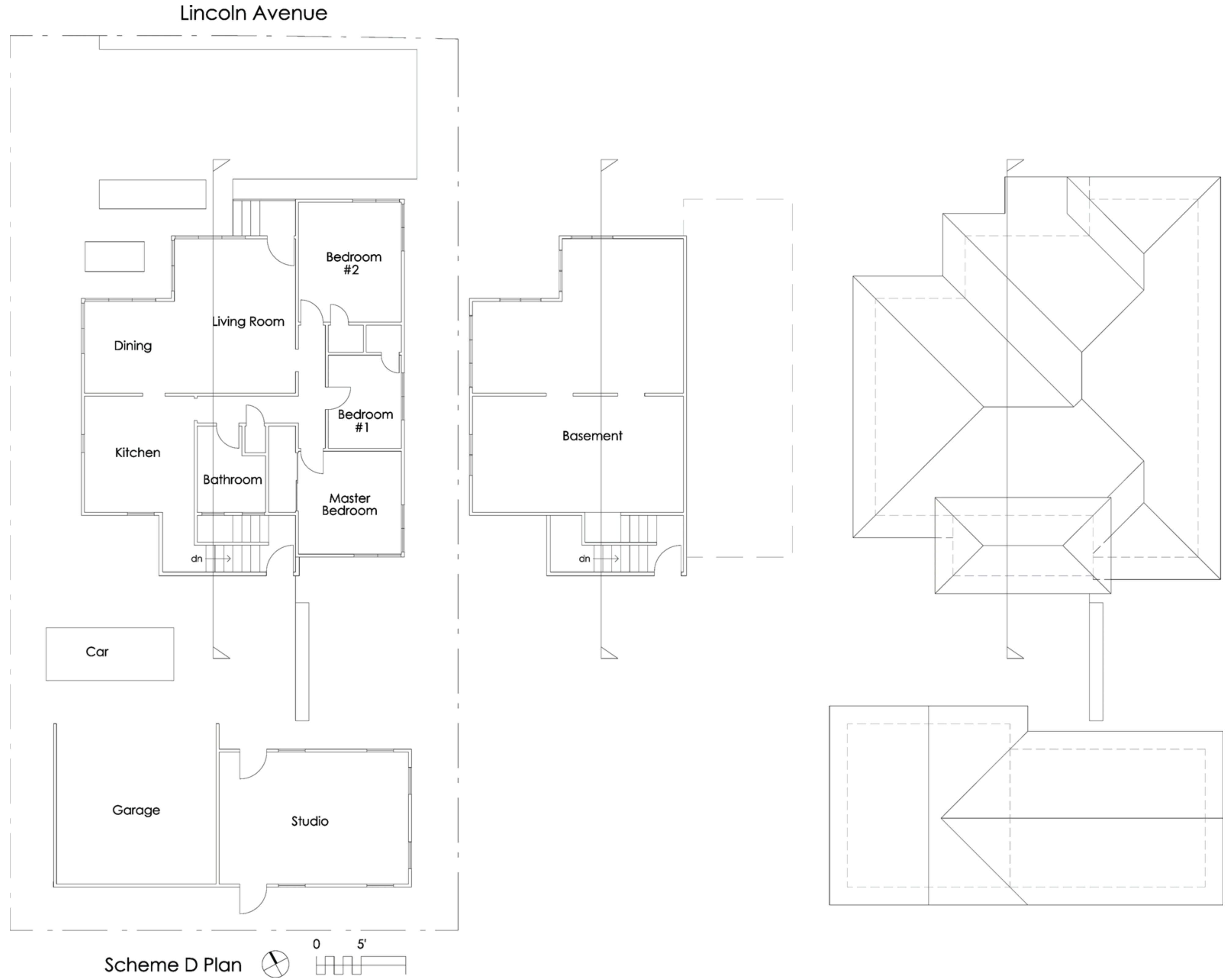
Scheme C Plan

Scheme C South Elevation



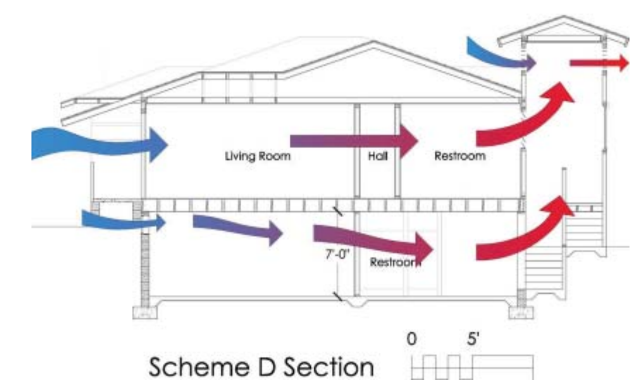
Scheme C Section

This scheme looks into the option of connecting the main floor to the basement by turning the existing master closet into part of the staircase. An addition to the master bedroom, which would add value to the home, could be added at a different phase. By connection the two floors, the hot air will be able to rise.



Scheme D Plan

Scheme D South Elevation



Scheme D Section

This last scheme takes a very different approach to passively cool the basement. The stairwell on the south side of the home will function similar to a chimney. As the air heats up in the stairwell, it will pull cooler air from the basement and push the hot air through the windows at the top.

**A model of the home with the thermal analysis of the home prior to constructing should be done to ensure the quality of passively cooling the basement.*

Easy Steps Towards Achieving a Net-Zero Energy Home:

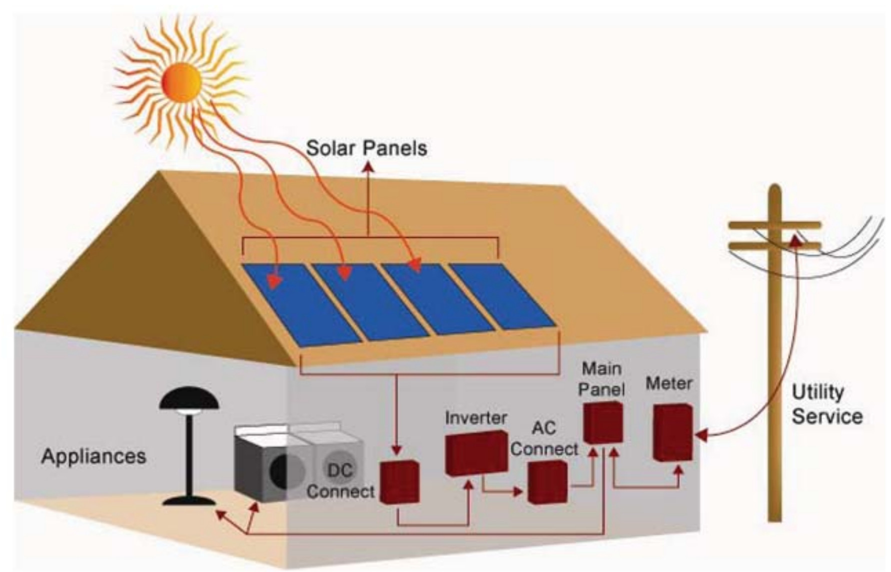
1. Realize something needs to be done and strive towards making a change
2. Evaluate and Reduce
    a. Turn off lights when not needed
    b. Keep refrigerator/freezer doors open at a minimum amount of time (i.e. less peeking)
    c. Unplug/completely shut off electronic devices when not in use
        i. Television
        ii. Computer
        iii. Cell phone charge
        iv. Etc.

    **plug everything into surge protectors and turn off everything with one button*

    d. Use natural ventilation instead of air-conditioning
    e. Shorter showers
3. Determine main loss of energy in home
    i. Old appliances
    ii. Heating water
    iii. Computers
    iv. Occupant usage

" Kilowatt meters help determine how much electricity each electronic device is using."

4. Smaller Changes
    a. Switch incandescent bulbs to Compact Fluorescent Lights (CFLs)
    b. Install ceiling fans
    c. Put electronic devices onto surge protectors
    d. Shading
        i. Awnings
        ii. Plants
        iii. Low-E glazing on windows to reduce heat gain
        iv. Etc.
5. Larger Changes
    a. Switch inefficient older appliances for EnergyStar[1] rated appliances
    b. Upgrade electronic devices to more efficient ones
        i. Computer
        ii. Television
        iii. Night lights
    c. Go gas, gas heating appliances are more efficient than electric, e.g.
        i. Stove
        ii. Dryer
        iii. Water Heater
    d. Install solar water heater
    e. Remodel roof
        i. Install TechShield and ridge vents to reduce heat gain
    f. Install solar attic fans
6. Sizing a photovoltaic system will be more accurate and cost efficient
    a. Find a company
    b. Calculate kWh needed
7. Notice the difference in the energy bill or lack of energy costs



"Photovoltaic System Diagram"[2]

[1] "ENERGY STAR is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy www.energystar.gov

[2] http://www.hokuscientific.com/pdf/HowSolarWorks.pdf

Going Zero

Easy Steps Towards Achieving A Net-Zero Energy Home

2009
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University of Hawai'i
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Types of CFL Bulbs[3]

Standard Spiral Bulbs

The most popular bulb available, the spiral CFL bulb's ice cream cone shape helps distribute light evenly in all directions and is best used in desk, floor and shade lamps, swing arm lamps, and wall lights and sconces that allow ample air flow. Spiral bulbs also are available in a mini size.

To properly install or remove a spiral CFL, grip the unit by its plastic base and not by the spiral glass tube. The base of a CFL is typically comprised of white plastic. You can then install the CFL bulb into the fixture by turning the base clockwise. To remove the CFL, turn the base counter clockwise. By holding the base, you minimize the risk for shattering the glass tube.

Specialty CFL

Most specialty bulbs are available in different sizes, so be sure to select bulbs that fit your fixtures and allow for ample air flow. Note that not all CFLs are designed to be used in damp or wet locations.

Specialty A-Type Shape CFL

For aesthetic reasons, choose A-in bulbs for light fixtures where the bulb will be exposed, such as ceiling fan light fixtures.

Specialty Globe Shape CFL

Globe-style bulbs work best for vanity mirrors, bathroom light fixtures and some ceiling fan light fixtures where you would like an attractive display of this type of bulb.

Specialty Shape Chandelier CFL

This bullet-shaped CFL bulb offers a stylish look for chandeliers, specialty decorative lamps and some ceiling fan light fixtures.

Reflector CFL

Downlight can fixtures are popular in many newly constructed homes, and reflector CFL bulbs offer the perfect fit for this type of Recessed lighting. Reflector bulbs also work in upright can fixtures, track lighting and accent lighting fixtures. Be sure to choose bulbs that fit properly and do not protrude from the fixture as this can cause glare.

3-way CFL (three levels of light)

Some 3-way bulbs closely resemble spiral bulbs and also are available in different shapes such as A-line and circleline. Use them in desk, floor and shade lamps, swing arm lamps, wall lights and sconces that allow ample air flow and that use a three way switch. Note that most 3-ways bulbs should not be used in enclosed fixtures, damp or wet locations.

Dimming CFL (spiral and reflector shapes)

CFLs with the dimmer feature are now available and you'll find them in spiral and reflector shapes with the word dimmable on the CFL bulb or packaging. Manufacturers continue to add new shapes each year, so check with your retailer for updates. Be sure to only use dimmable CFLs in fixtures that have the dimmer control feature.

Resources:

www.heco.com

www.gelighting.com/na/home_lighting/ask_us/faq_compact.htm#difference

www1.eere.energy.gov/solar/photovoltaics.html

www.energystar.gov

For more information, please refer to 'Going Zero' Doctorate Thesis

[3] www.heco.com