Ultra Low Cost Solar Water Heater

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Concept Generation and Selection

Document

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1. Introduction

In the U.S. a high startup cost combined with a lack of knowledge about solar water heaters has contributed to low usage. Solar water heaters are a viable way of reducing energy consumption as well as reducing a household's carbon footprint. Solar energy is abundant and free which makes it the best option for a low cost energy source. Many factors must be considered when looking to reduce cost and improve or maintain efficiency of solar water heaters.

The U.S. Environmental Protection Agency (EPA) wants to change how solar water heaters are perceived which drove them to fund the project through the P3 – People, Prosperity, and the Planet Award Program. This program gives students the opportunity to research, develop, and design solutions to real world problems involving the sustainability of society as a whole. This program was developed in order to meet the technical needs of society in relation to a sustainable future. The following document contains key technologies and concepts that will be explored and tested in the following weeks.

2. Problem Definition

Current solar water heaters are too expensive and it takes a long period of use to make them financially sensible, therefore current solar water heater designs are financially impractical over a short period of use.

The solution to this problem is to design a low cost solar water heater that is efficient enough to produce a quick financial return.

3. Concepts for Consideration

The main specification evaluated in this section while determining possible solutions was absorption per cost per area. Designs that did not show promise of optimal absorption per cost per area were discarded.

Collector Systems

Involute Curve Solar Collector

An involute curve solar water heater consists of a system of one or more stationary parabolic or involute collectors focused on a cylindrical absorber as shown in Figure 1. The involute curve allows for nearly all the radiation energy from the sun to be directed to the absorber and subsequently absorbed and transferred to the fluid. Through the geometry of the involute curve the solar rays will bounce off the reflectors any number of times always being directed to the absorber. What makes this collector unique is the placement of the absorber. A hot air trap is created by placing insulation above the absorber so the heat cannot escape easily. By retaining more heat in proximity to the absorber the fluid stays at a higher temperature. A study done by Smyth in 1989 showed that involute solar water heaters retained 60% of the collected solar energy for a 16 hour non-solar period.

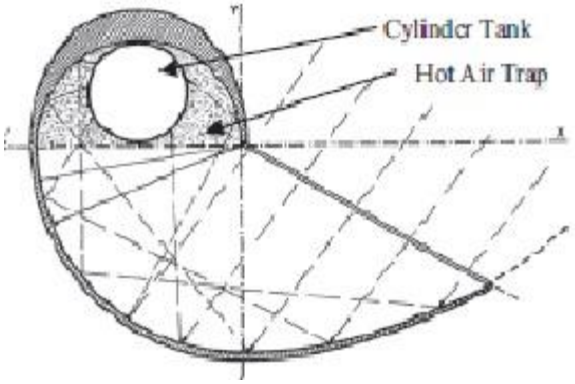

Figure 1: Involute Curve Collector

Variations of this design include: a system of multiple absorber tubes housed in parabolic crescents, double parabolic curves with an absorber placed in the center, and two absorbers stored in an involute curve. Figures 2, 3, and 4 below show diagrams of the various designs.

Figure 2: Parabolic Crescent Collector

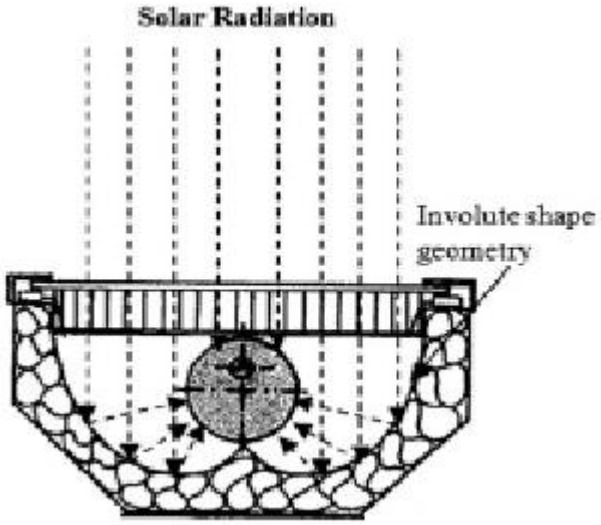

Figure 3: Tank Centered Between Two Involute Curves

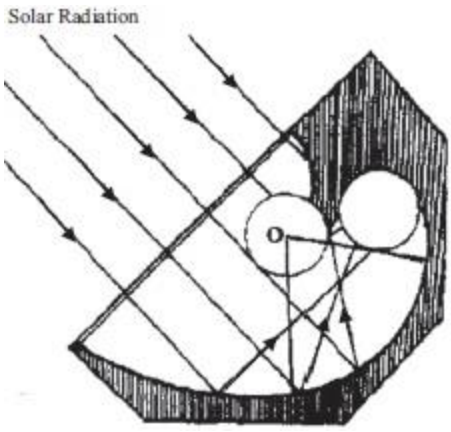

Figure 4: Involute Curve Collector with Two Tanks

The involute solar water collector paired with a passive circulation system provides a very high absorption per cost per area ratio. The biggest benefit of passive circulation is the high ratio of absorption per cost.

Flat Plate Solar Water Heating System Utilizing Passive Circulation

The solar radiation is absorbed by Flat Plate Collectors which consist of an insulated outer metallic box covered on the top with glass sheet as shown in Figure 5. Inside there are blackened metallic absorber sheets with built in channels or riser tubes to carry water. The absorber absorbs the solar radiation and transfers the heat to the flowing water. The water passing through the collector is then delivered to an insulated storage tank. The insulated box provides structure and reduces heat loss from the back or sides of the collector. The absorber plate surface is painted or coated to maximize radiant energy absorption. Absorber plates are usually made of high-thermal-conductivity metals. Choice of materials and design aspects can greatly affect not only the solar thermal performance but most importantly the overall cost of the system. High-temperature rigid-foam insulation, low-iron tempered glass, and aluminum frames are the most common materials.

The main advantage of flat plate solar collectors over other designs is their price. Even though recent trends in collector's technology closed part of the gap, flat-plate solar collectors are still a cheaper solution. However, freezing conditions may limit the efficiency of a flat plate collector because flat plate collectors are subject to a high heat loss factor. Because of this it is mostly used in warm and mild climates.

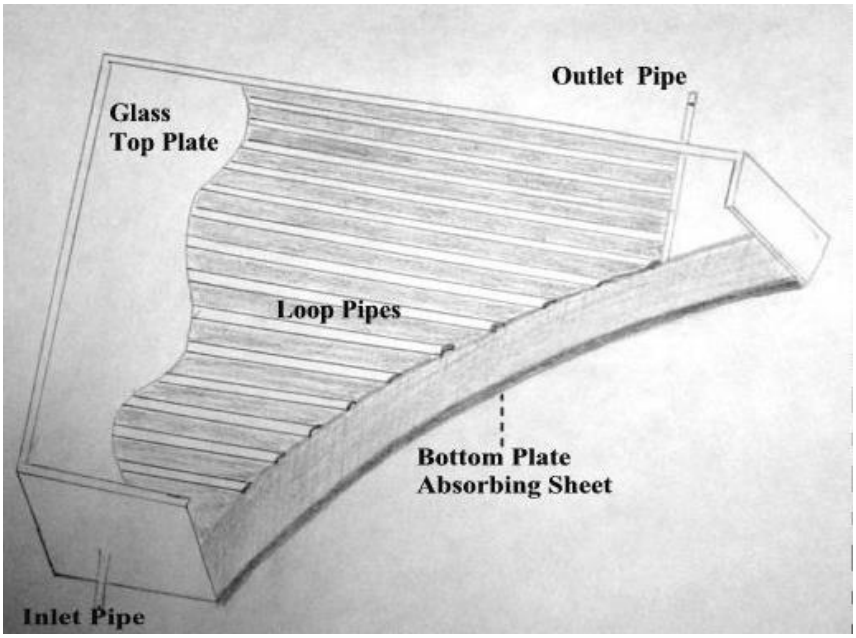

Figure 5: Flat plate collector

Breadbox Solar Water Heater Utilizing Active Circulation

The bread box solar water heater design utilizes a large frontal area of capture so that a large amount of solar radiation can be absorbed and stored. The basic concept is that a stripped black tank is mounted inside some kind of box and tilted towards the sun. A piece of dual pane glass is placed on top of the box so that the solar radiation can move into the box with the tank, but it cannot escape. The goal is to trap as much heat inside the box as possible without letting any of that heat out. This trapped heat moves through the tank and into the tank where the water is stored. Angled light reflectors will be connected to three of the four sides to direct as much light as possible into the area where the tank of water sits.

The main advantage of this design is its simplicity and the ability to store and heat water at the same time. The bread box design is something that almost anyone can build and utilize with simple knowledge and materials. This simplicity allows for a low initial cost of building but it may not be as efficient as some of the other proposed designs. The other advantage is the ability to heat and circulate water in the same vessel. There is no need for a storage tank to keep the water warm. This helps the user because he or she can just take from the hot water supply as needed. This advantage greatly reduces overall cost compared to the other proposed systems. If the cost of materials can be severely minimized and the efficiency can get to a moderate level, than the bread box design shows the most promise for a final concept.

The bread box design must utilize an active system of circulation. Although the active system is less cost effective, this concept can use the pressure provided by the city to pump the cold water to the home. This lowers cost because the user doesn't have use an outside pump to move the water through the system. The water is going to move as fast as the pressure the city provides moves it. This allows for the cold water to be heated up longer because it is going to sit in the tank a little longer than if you pump the water in and out of the tank. Below is a simple graphic of the structure of a bread box designed solar water heater.

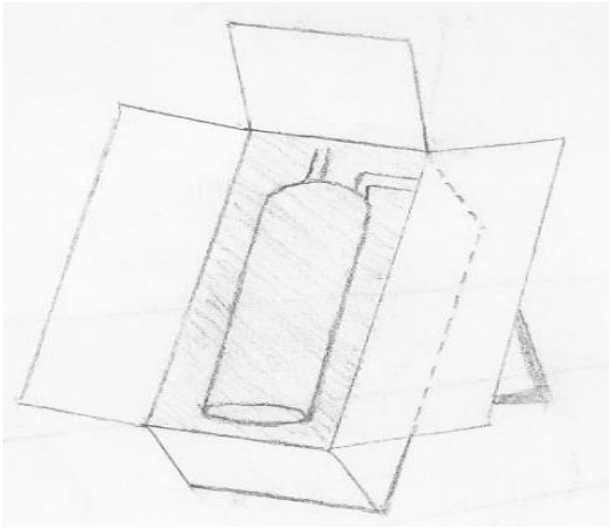

Figure 6: Bread Box Solar Water Heater

4. Implementation and Circulation

Our SWH will be integrated through the cold water inlet to an existing water heater. There will be a simple valve system shown in Figure 1 which will allow the homeowner or tenant to shut off water flow to the SWH and use the existing water directly from the source. It will require two T joints to be installed directly above the cold water inlet to the existing water heater. The pre-heated water from the solar water heater will return back to the original inlet allowing the existing water heater to function as originally intended.

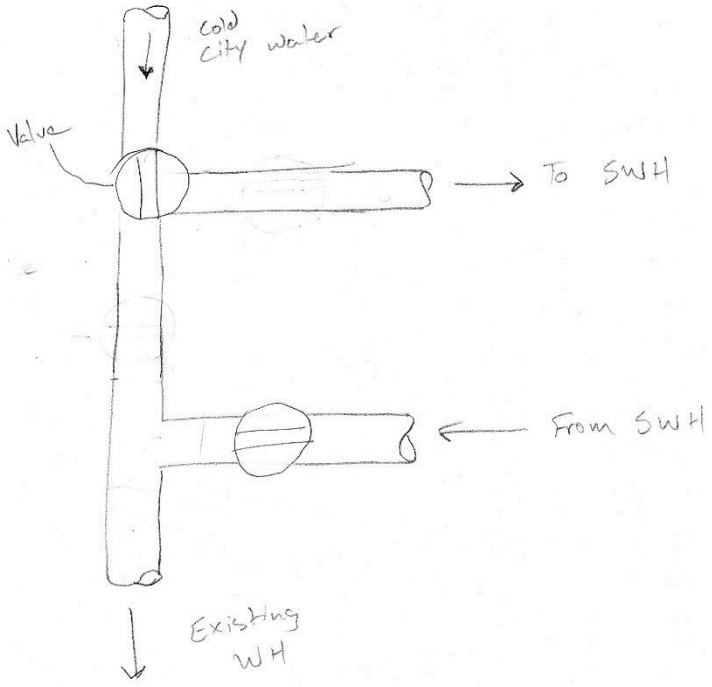

Figure 1: Integration schematic

Active Circulation System

In the active system concept, water is drawn from the original source and fed into a secondary storage tank. From there, a pump draws the water out of the tank and feeds it to the collector at an efficient rate. The water is heated in the collector and flows back into the tank. This process gradually raises the average temperature of the tank. When the existing water heater draws water, it is taken from this tank. It is important to note that a pressure release valve must be placed in the secondary storage tank to avoid a dangerous buildup of gasses.

Advantages and Disadvantages

There are several advantages to using an active circulation system. First, an active system allows more freedom in implementation. This system makes the position of the collector irrelevant to the position of the secondary storage tank. Second, this system may yield much higher system efficiencies by allowing much more control of the flow rate of fluid through the collector. Third, this system can much more easily control when, and how much, water is drawn from the SWH.

There are also some disadvantages to this type of system, most importantly, being its cost. This type of system requires a possibly expensive secondary pump to be installed within the SWH system. Also, it is much more difficult to build and maintain, especially for the average homeowner.

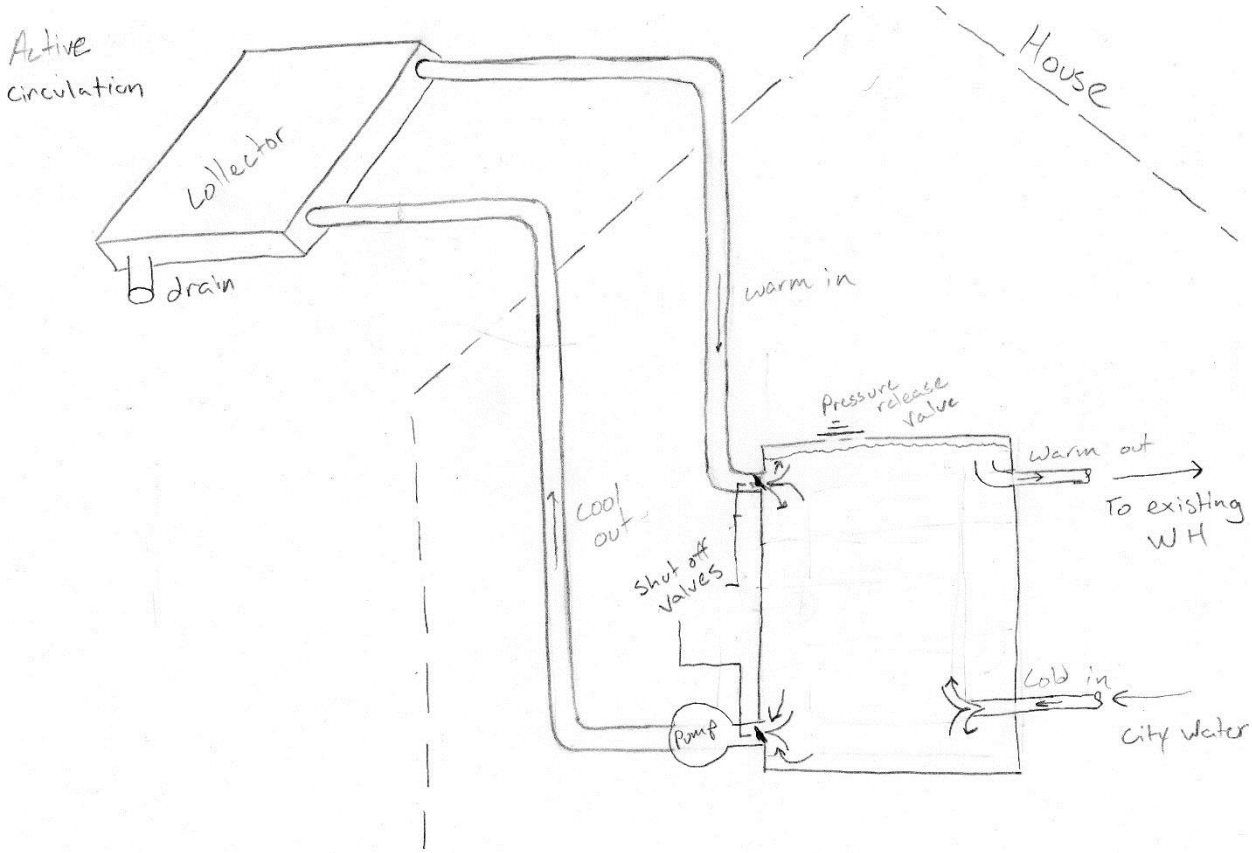

Figure 2: Active circulation system

Passive Circulation System

In the passive system concept, water is drawn from the original source and fed into a secondary storage tank. The entire system must be filled for flow to start. This system relies entirely on a thermosyphon to move water through the collector. The collector must be placed below the storage tank in order for the thermosyphon to work. When water is heated in the collector, the resulting pressure difference causes it to rise and flow into the storage tank. A one way valve is place near the collector to ensure the flow continues to circulate. This process gradually raises the average temperature of the tank. When the existing water heater draws water, it is taken from this tank. It is important to note that a pressure release valve must be placed in the secondary storage tank to avoid a dangerous buildup of gasses.

Advantages and Disadvantages

A thermosyphon circulation system is much cheaper than an active system. This is because it does not require a secondary pump. However, the circulation is entirely dependent on solar energy. This means two things. First, without maximum solar radiation on the collector, possible on a cloudy day, the circulation is severely hindered. Second, this means that the efficiency of the SWH will be notably less than a SWH with an active system.

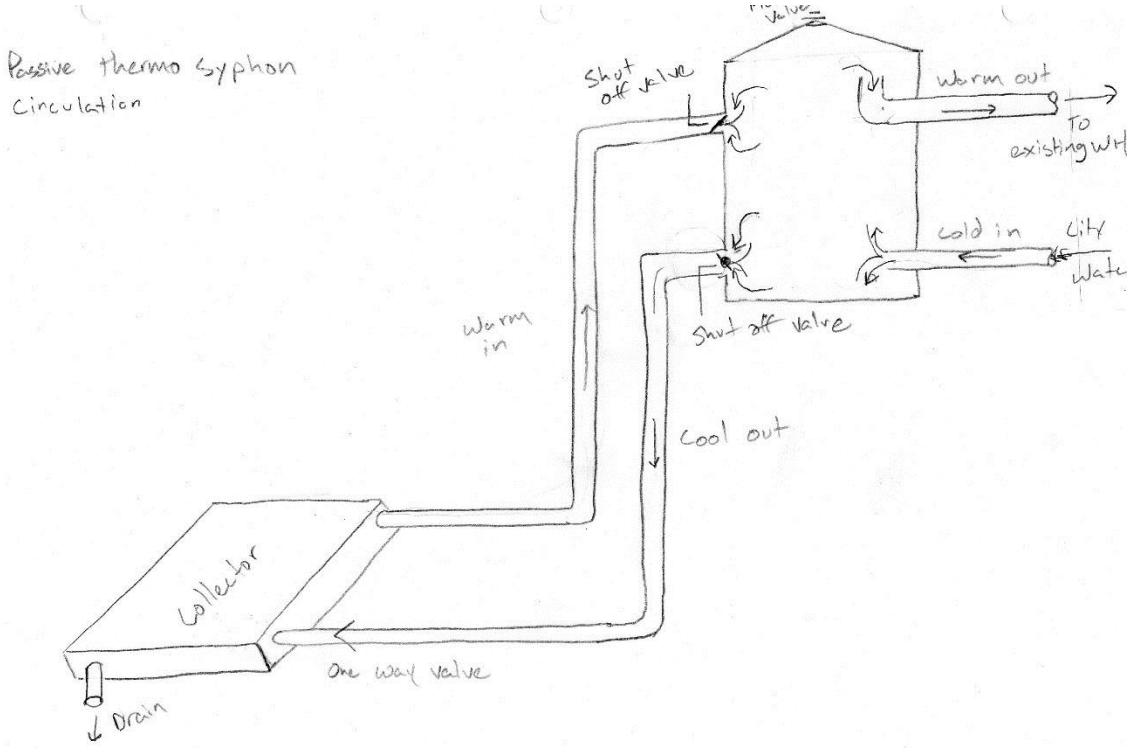

Figure 3: Passive circulation system

Bread Box Circulation System

The bread box collector system requires a unique, but simple, circulation system. The flow through this system is entirely dependent on the rate at which the existing water heater uses water. This is because the secondary storage tank in this SWH is also the collector. It is connected so that water flows freely through the collector at the same rate it is used in the existing water heater.

5. Conclusion

Because current solar water heaters are too expensive and it takes a long period of use to make them financially sensible, a need for an inexpensive and effective solar water heater is apparent. There are three collector designs that will be considered for the final design, two circulation designs that will be considered for the final design and one implementation design that will be considered for the final design.

The involute solar collector uses an involute curve to capture sunlight and direct all of it one location. The location of where all the sunlight is directed will be where the working fluid pipe will be placed. This working fluid pipe has the capability of being insulated and therefore provides a viable solution to circumstances where sunlight is variable throughout the day.

The flat plate solar collector uses a direct absorption of sunlight to transfer heat to working fluid flowing through the collector. The working fluid will most likely flow through black pipes underneath a transparent insulator that is on top of the collector. The flat plate solar collector is a relatively simple design whose components can more than likely be obtained from a standard hardware store.

The bread box solar collector is very simple. It requires no circulation of the working fluid to another storage tank because of the utilization of direct absorption. One large tank that absorbs direct sunlight transfers heat to the water inside a large tank. The biggest disadvantage with this design is that the acquirement of a large enough tank is difficult and relatively expensive.

One implementation will be considered. Implementation to the existing home water heater will be done with a simple valve system that provides the operator with two options. The first option includes the solar water heater into the water heating process before the water goes into the home water heater. The second option excludes the solar water heater from the existing home water heater

for situations where the temperature outside will negatively impact the efficiency of the overall water heating system.

The active circulation system that will be considered in the final design uses a pump to make the working fluid flow at the most efficient rate to absorb the most heat transfer from sunlight. This circulation system is therefore more complex and requires more skill from the owner of the system because of maintenance and installation of the pump.

The passive circulation system that will be considered in the final design is much simpler than that of the active one because of the exclusion of a pump. The passive circulation system uses a thermosyphon to move the working fluid from a low pressure to a higher pressure, and because of this the collector placement must be below the external storage tank.

6. References

- Energy Protection Agency (EPA). (2013). *P3:People, Prosperity, and the Planet Student Design Competition for Sustainability* . Washington, DC: EPA. http://www.epa.gov/P3/. Accessed October 2013
- U.S. Department of Energy (DOE). (2012). *Building Energy Codes Program*. Washington, DC:
- U.S. Department of Energy. http://www.energycodes.gov/adoption/states/. Accessed October 2013.
- Raisul Islam, K. Sumathy and S. Ullah Khan, "Solar water heating systems and their market trends," *Renewable and Sustainable Energy Reviews*, vol. 17, pp. 1-25, 1, 2013.
- U.S. Department of Energy (DOE). (2005). *Residential Energy Consumption Survey 2005*. Washington, DC: Energy Information Administration. http://www.eia.doe.gov/emeu/recs/. Accessed October 2013.
- Energy Information Administration (EIA). (2005). *Office of Energy Markets and End Use, Forms EIA-457 A-G of the 2005 Residential Energy Consumption Survey*. Washington, DC: EIA.

- American Society of Heating and Air-Conditioning Engineers (ASHRAE). (1987). *Methods of Testing TO DETERMINE THE SOLAR PERFORMANCE OF SOLAR DOMESTIC WATER HEATING SYSTEMS*. Atlanta, GA: ASHREA Standard- 95.

- American Society of Heating and Air-Conditioning Engineers (ASHRAE). (1987). *Methods of Testing to Determine the Performance of Solar Collectors*. Atlanta, GA: ASHREA Standard-93.

- M. Raisul Islam, K. Sumathy, Samee Ullah Kahn. (2012). *Solar water heating systems and their market trends*. Atlanta, GA: Renewable and Sustainable Energy Reviews. http://www.elsevier.com/locate/rser/. Accessed October 2013.

- Database of State Incentives for Renewables and Efficiency (DSIRE). (2012). *Arizona Incentives/Policies for Renewables and Efficiency*. Raleigh, NC: North Carolina State University.
- http://www.dsireusa.org/incentives/index.cfm?re=0&ee=0&spv=0&st=0&srp=1&state=AZ/. Accessed October 2013.

- U.S. Department of Energy (DOE). (2012). *Building Codes and Regulations for Solar Water Heaters*. Washington, DC: U.S. Department of Energy. http://energy.gov/energysaver/articles/building-codes-and-regulations-solar-water-heating-systems/. Accessed October 2013.

- U.S. Department of Energy (DOE). (2012). *Building Energy Codes Program*. Washington, DC: U.S. Department of Energy. http://www.energycodes.gov/adoption/states/. Accessed October 2013.

- Energy Protection Agency (EPA). (2013). *P3:People, Prosperity, and the Planet Student Design Competition for Sustainability* . Washington, DC: EPA. http://www.epa.gov/P3/. Accessed October 2013