NC STATE UNIVERSITY

RESIDENTIAL SOLAR HOT WATER SYSTEMS

North Carolina Solar Center

Introduction

Solar hot water heaters in various forms have existed for hundreds of years, supplying generations with free heat from the sun. During the 1980's poorly designed federal tax credits allowed short-lived companies to manufacture and install low quality systems. This history should not influence one's feelings towards today's solar hot water systems. The era of poor quality solar hot water systems is long gone; **today's solar hot water systems are high quality, reliable products.**

Solar hot water heaters can provide households with a large proportion of their hot water needs (50% to 80%+), as well as space heating needs, while reducing home energy costs. A back-up heating system for water will be necessary during times when solar radiation is insufficient to meet hot water demands. This back-up can come from an electric or gas tank or tankless water heater. See the descriptions of system components and types for more details. Two of the primary benefits of installing a solar hot water system are:

- Reduce a household's carbon use by up to 2 tons per year
- Save hundreds of dollars per year in energy costs

Figure 1. Homes in a neighborhood with Active Solar Water Heating Systems.

Energy and Cost Savings

The amount of energy, carbon, and cost savings a solar hot water system will provide depends on several factors, including how much hot water the household uses, the back-up fuel, system size and type, and the collector location. There are several ways to estimate the savings from a solar domestic hot water system before it is purchased or installed. The simplest option is to work with a professional installer and have him or her determine the expected savings. To estimate system savings, use the simple online estimator at www.findsolar.com or for a more detailed estimation, download the free RETScreen solar hot water program from Natural Resources Canada (www.retscreen.net).

A typical family of four in the southeast can use the following estimated energy and cost savings as a guide for potential savings:

System Overview	Annual Energy Savings	Annual CO_2 Savings	Annual Energy Cost Savings	Total Annual Energy Costs
1 Panel, electric backup	2.2 MWh	1.2 tons	$200	$200
2 Panel, electric backup	3.4 MWh	1.8 tons	$300	$100
2 Panel, gas tank backup (EF 0.65)	3.4 MWh	1.0 tons	$315	$115
2 Panel, gas tankless (EF 0.90)	3.4 MWh	0.7 tons	$200	$75

Calculated with RETScreen using average 2005 electricity rates (8.5¢/kWh) and average 2006 NG prices ($1.79 therm) for Southeast states , all from the Energy Information Administration, www.eia.org

Often the energy savings of a solar hot water system are presented in terms of direct payback (the number of years needed for the annual energy savings to equal the purchase price), however this is often not the most accurate representation of the benefits and costs of domestic solar hot water. If the solar system is purchased with a new home the cost of the system can be included in the home's mortgage, which in most cases provides an immediate positive monthly cash flow. This means that the monthly energy savings provided by the solar system is larger than the increase in mortgage payments due to the addition of the solar system.

Direct payback calculations do not recognize an increase in the value of a home due to the new solar hot water system and the reduction in energy bills it provides. A quality, properly maintained system should last 20 years or more, providing years of hot water heated for free by the sun.

Costs of a Solar Hot Water System

The cost of a typical (2 panel) turnkey solar hot water system in the southeast from a professional installer is currently around $5,000 to $6,500 before tax credits. It is possible for an individual to purchase and install a system for a lower cost, but this is not recommended unless you are a licensed plumbing contractor. The initial cost of a system can be significantly reduced by utility and/or governmental incentives. To find out the current federal and state incentives available, go to www.dsireusa.org.

Conservation First!

Reductions in hot water energy use need not only come from a solar hot water system; it is possible to significantly reduce your hot water energy demand with conservation practices. A few simple measures can markedly reduce consumption. Begin by installing low-flow showerheads or flow restrictors in showerheads and faucets. Next, check the thermostat setting on the hot water tank. Many thermostats are set at 140° F. It is possible to set the thermostat at 120°F and still have adequate hot water, particularly if the home has a newer dishwasher or does not use a dishwasher. (Dishwashers without automatic water heating features require that the water be heated to 140°F). If you are replacing your dishwasher or clothes washer, buy an Energy Star model. Install 'check valves' or 'heat traps' in both the hot and cold potable lines to avoid extra heat loss caused by hot water rising in these pipes. Avoid installing cold and hot water pipes in exterior walls due to condensation issues. Finally, insulate all hot water pipes, especially if they pass through unheated areas and consider installing a water heater insulating blanket.

For more information on conserving hot water, read the Energy Efficiency and Renewable Energy Network's (EREN) fact sheet ***Energy Efficient Water Heating***.
www.eere.energy.gov

Proper Collector Location

Is My House Suitable for Solar Hot Water?

A solar energy system needs to be located where plenty of sunshine strikes its collection surface. Typically, the collectors are installed on the roof, but it is also possible to mount them on a pole or frame at ground level. Either way, the collectors must face an acceptable direction and must be reasonably free of shade. Below are some basic guidelines on properly locating a solar system. The NC Solar Center (**www.ncsc.ncsu.edu**) has a fact sheet on the siting of solar collectors that provides more details. It is often worth hiring a professional solar designer or installer to complete a thorough assessment of the viability of a site for solar hot water.

Although solar collectors perform best if they are oriented toward true South, facing collectors 45° East or West of true South to accommodate roof orientation, aesthetics, and other local factors will reduce their energy output by less than 5%. Facing the collectors 90° off of South, toward due East or West, will reduce their annual energy output by only 10% to 20%. Therefore, acceptable roof orientations for solar hot water systems in the southeastern US include E, SE, S, SW, and W.

In addition to collector orientation, the horizontal tilt of the collectors will also affect their performance. The optimum tilt angle for annual performance is an angle equal to the local latitude (30° at the southern tip of FL and 39° at the northern tip of VA). However, for simplicity and aesthetics it is best to mount collectors parallel to the roof. The exact tilt of a collector is not crucial; a 15° variation to suit a roof's pitch makes a very small difference in the output of the solar hot water system.

Once one or more potential locations with an appropriate orientation and tilt have been selected it must be determined if or when those locations are shaded. Shading may be caused by other sections of roof, chimneys, other buildings, and nearby trees. To determine when a location will be shaded one must consider the sun's motion throughout each day and throughout the year. This means that even if the location is unshaded in May it may be in full shade in January.

Many solar professionals use a tool called a Solar Pathfinder (**www.solarpathfinder.com**) to determine the annual shading profile of a potential collector location. Another option, which does not require any special equipment, is a sun chart for the home's latitude which is available for free from **http:\\solardat.uoregon.edu\SunChartProgram.html**. A sun chart maps out the position of the sun throughout the year, allowing you to determine if and when the potential location is shaded. Some shading, particularly before 9AM and after 3PM, is usually acceptable. If you are unsure it is best to consult with a solar professional.

System Sizing

Cost effective solar hot water systems should be sized to provide 50% to 80% of household domestic hot water needs. A system large enough to provide 100% of a home's hot water must have enough collectors and enough hot water storage to carry the household through several cloudy winter days in a row. A system large enough to do this is much bigger than is needed during the other 360 days of the year, thus reducing its cost effectiveness. The proper system size depends on the hot water consumption of that family, but rules of thumb can help give an idea of system size.

In general, a system will need about 10 to 18 ft^2 of collector area per person in a household and around 1.5 to 2.0 gallons of storage per square foot of collector area. For a family of four, these guidelines translate into 40 to 72 ft^2 of collector area and 60 to 140 gallons of storage. Collector dimensions are roughly 4' X 8' or 32 square feet, therefore, a system for a family of four generally will have 1 to 3 collectors.

Basic Components

Although the design of systems can significantly differ, certain components are common to all systems, namely collectors and storage tanks.

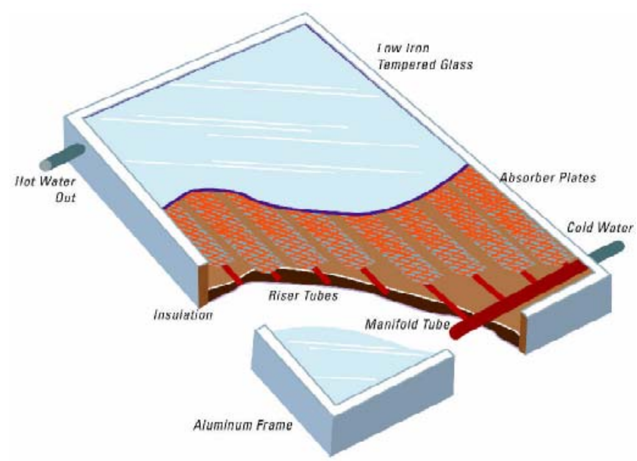

Figure 2. Flat-Plate Solar Collector

Collectors

A diagram of the most common collector type used in domestic water heating in the United States, a ***flat plate collector***, is shown in Figure 2. The panel is an insulated weatherproof metal box containing a dark solar absorber plate under one or more transparent covers, which are usually glass. The dark absorber soaks up heat from sunlight that passes through the cover and then gives the heat up to a heat transfer fluid (water or antifreeze) flowing through metal tubes under the absorber plates.

Flat plate collectors are not the only collector option. ***Evacuated tube collectors*** (figure 3) are the most common type of collector internationally and are another option to US consumers. This type of collector consists of a bank of glass vacuum tubes each containing a black absorbing surface. Evacuated tubes have the ability to operate efficiently at much higher temperatures than flat plate collectors. However, in typical domestic hot water systems, particularly in warmer regions of the country, flat plate collectors meet or exceed the annual efficiency of evacuated tube collectors.

Figure 3. Evacuated Tube Collector

A third option for collectors is a ***compound parabolic concentrator (CPC)*** collector. This type of collector incorporates small curved reflectors to concentrate solar energy onto a smaller absorber surface. Like evacuated tubes, they have the advantage of operating efficiently at high temperatures and in very cold weather. CPC collectors consist of an insulated metal box and clear cover, giving them the same appearance as flat plate collectors.

Storage Tank

Solar heated water may be stored in a tank that also houses an electric backup heating element (a "one-tank" system), or it may be stored in a separate tank that feeds into the tank of a conventional gas or electric water heater (a "two-tank" system). The back-up heat source can also be a tankless gas or electric water heater. Some systems require a heat exchanger to deliver the collected solar heat to the water in the hot water tank. This heat exchanger can either be integrated into the tank, commonly referred to as a solar tank, or be an external unit mounted on or near the water heater. Regardless of the type of storage tank, solar energy only preheats the household water during much of the year. At night and on cloudy days, the conventional backup heater is needed to boost the water temperature to the desired temperature. In many systems, the full hot water load can be met by the solar system alone during most of the summer. The solar storage tank is usually large enough to hold at least a day's supply of hot water.

Common Types of Systems

Systems are classified as either passive or active and as either direct or indirect. Passive systems rely on natural convection to circulate the water through the collectors. Integral Collector Storage (ICS) and thermosiphon systems are passive systems. Active systems use electrically driven pumps to control the circulation of the heat absorbing liquid. This allows greater flexibility than their passive counterparts since the hot water storage tank does not have to be above or near the collectors. ***Active systems are designed to operate year round without any danger of freezing.*** Types of active systems are ***pressurized glycol*** and ***drainback***

All solar water heating systems can be characterized as either direct or indirect, depending on whether household water is heated directly in the collector or via a heat exchanger. For direct systems, the fluid heated in the collectors is potable water, which flows directly to the faucet or washing machine. Direct systems, whether pumped or thermosiphoning, cannot be used in areas with hard or acidic water. Scale deposits would quickly clog the inside of the absorber tubing, and corrosion would impair the entire system. They also offer little protection against freezing and are therefore typically limited to very warm climates, including much of Florida.

Indirect or closed loop systems (Figure 4) use a heat transfer fluid of treated water or a non-freezing liquid such as an anti-freeze solution. The heat it collects from the absorber plate is transferred to the potable water through a heat exchanger. Examples include a coil either inside or wrapped around the storage tank or an external counter flow unit. The indirect systems types are indirect thermosiphon, drainback, and pressurized glycol.

Protection against freezing is essential for maintaining all solar domestic hot water systems, especially in regions where the temperature frequently drops below 32°F. Freezing can occur at night even at temperatures above 32°F because the collectors radiate heat out to the cold dark sky. ***The need for freeze protection may dominate the choice of what type of system you install. Passive systems are generally the most susceptible to freezing.***

Passive Systems

Integral Collector Storage (ICS)

In an integral collector system, the collector and storage tank are combined. The ICS consists of several metal tubes at least 4" in diameter with a selective absorber finish. The outlet at the top of one tube is connected to the bottom of the inlet of the next tube to create a serpentine route for the incoming city water. The solar heated water is drawn directly into an auxiliary heater inside the house as needed. These systems are less expensive and simple, but there is more heat loss at night. **For the regions of the southeast that experience temperatures below 10°F an ICS system does not offer adequate freeze protection**.

Thermosiphon Water Heaters

Thermosiphon systems consist of a solar collector panel to absorb solar heat and a separate storage tank, either attached to the top of the collector or placed inside the house. The collector must be mounted at least a foot below the storage tank to permit thermosiphoning, which is the upward movement of heated water by natural convection. When the fluid in the collector is heated, it becomes less dense and rises to the top of the collector and into either a heat exchanger or the storage tank.

In a thermosiphon system, fluid remains in the collector when convection stops (during sunless periods). Direct thermosiphon collectors generally cannot tolerate freezing conditions. If the water freezes, it can expand with enough force to burst the pipes or tanks. On the other hand, indirect thermosiphon collectors are rated by the ***Solar Rating and Certification Corporation (SRCC) (www.solar-rating.com)*** to be freeze protected to 19°F.

Indirect Active Systems

Drainback

To avoid freezing damage, the drainback system (Figure 4) empties its collector(s) of fluid when the temperature falls to near freezing. The only time water is in the collector loop is when the circulation pump is running. The loop between the holding tank and the collectors is not pressurized. Therefore, when the thermostat signals the pump to turn off, the water drains by force of gravity back into a holding tank, known as a drainback tank, where it is saved. It is very important that the panels themselves and all piping in the collector loop are adequately sloped to allow for proper drainage. No electric valves are used which might fail and there is no need for expansion tanks. Distilled water, often treated with an anti-corrosive, is used for the heat transfer fluid in the collector loop.

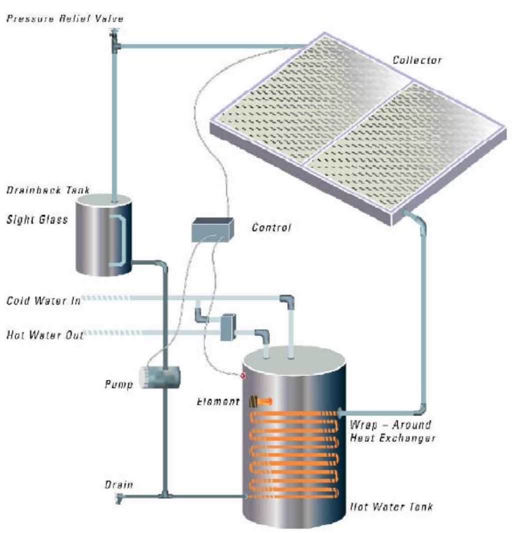

Figure 4. Drainback Solar Water Heating System

Pressurized Glycol

Another indirect active system is the pressurized glycol (antifreeze) system (Figure 5). The heat transfer fluid, either a glycol (usually propylene glycol) or other hydrocarbon, provides freeze protection. The glycol solution should be inspected every 1 to 2 years and replaced when it becomes too acidic. Follow the fluid manufacturers' guidelines for inspecting and refilling collectors. Because these systems are pressurized, fill and drain valves must be incorporated to add or change the collector fluid. In a pressurized glycol system, a PV module can be used to power the pump and create a system that continues to provide solar hot water during a power outage.

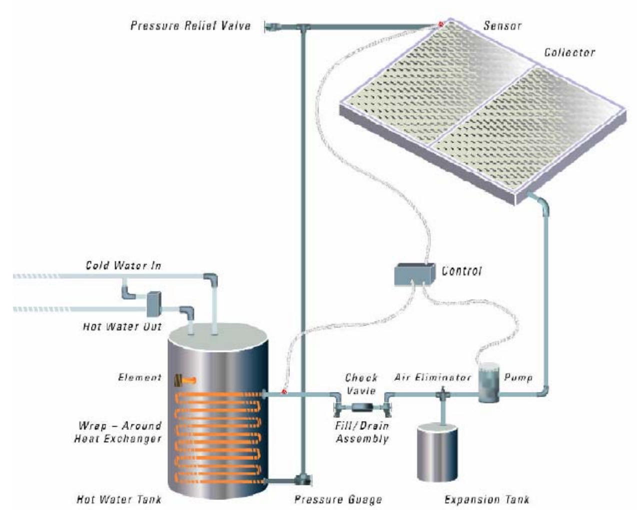

Figure 5. Pressurized Glycol Solar Water Heating System

Space Heating with Solar Hot Water

In addition to providing hot water for domestic use, solar hot water systems can also supply a portion of a home's space heating needs. The solar portions of a solar hot water space heating system are essentially the same as a solar system that is only supplying domestic hot water, except that the system has more panels and a larger storage tank. The collected hot water can be delivered to the house in a few different ways. Radiant floor heating systems are often used to circulate 100° to 150° water through plastic piping in the floor. Alternatively, a hot water coil can be added to the forced air HVAC system, heating the air flowing over the coil. If a home has a geothermal heat pump, the solar hot water can be used to heat the water returning from the geothermal ground loop.

Summary

Properly installed domestic solar hot water systems are efficient and reliable. System configurations can range from simple systems that rely on gravity for circulation to more complex systems that require pumps, controllers, and heat exchangers. Most areas of the southeast must use a drainback or glycol system in order to have adequate freeze protection. Warmer portions of the southeast are able to use other types of systems as well. Although they have a higher initial cost than a conventional water heater, solar hot water systems dramatically reduce fuel consumption and can have a direct payback of 5-10 years, while providing a positive cash flow and adding value to your house. It is recommended that all solar hot water systems be designed and installed by professionals. Visit **www.dsireusa.org** to learn about local, state and national incentives.

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