PDHonline Course E295 (4 PDH)

Solar Water Heating Systems

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Table of Contents

Introduction

The world is increasing interested in reducing global warming because of the belief that it may be a real threat and we must find ways to reduce carbon emissions to protect the environment. As a result, there is a heightened interest in renewable energy production that can reduce the future demand for coal and natural gas fired power plants. Renewable power production technologies such as wind farms, photovoltaics, geothermal, hydroelectric, and biomass systems are all receiving a lot of attention. Another, less costly alternative, is solar thermal water heating systems.

The term "solar power" can be used to denote either solar thermal systems or photovoltaic systems. Photovoltaic systems generate electricity by using the interaction of sunlight with a semi-conducting material, which frees electrons in the material to create an electric current. In contrast, solar thermal systems use the heat generated by sunlight to heat air or water.

Solar thermal systems have been around since the 1920's with limited distribution. However, in the 1970's, Israel passed a law requiring the installation of solar water heaters in all new homes and Israel is now the world leader in the use of solar energy. Solar hot water systems are now popular in China where approximately 30 million Chinese households have solar water heating systems. And since 2005, Spain has required the installation of solar hot water systems in all new buildings. During this time, there was some resurgence of interest in solar heating in the United States. Technical innovation has improved performance, life expectancy and ease of use of these systems.

One of the most cost-effective ways to include renewable technologies into a building is by incorporating solar hot water. A typical residential solar water-heating system reduces the need for conventional water heating by about two-thirds. It minimizes the expense of electricity or fossil fuel to heat the water and reduces the associated environmental impacts.

Most solar water-heating systems have two main parts: a solar collector and a storage tank. There other components such as temperature sensors, check valves, and controllers that makes up the balance of the system equipment.

Solar water heaters use the sun to heat either water or a heat-transfer fluid in the collector. Heated water is then held in the storage tank ready for use, with a conventional system providing additional heating as necessary. The tank can be a modified standard water heater, but it is usually larger and very well insulated. Solar water heating systems can be either active or passive, but the most common are active systems.

Active solar water heaters rely on electric pumps, and controllers to circulate water, or other heat-transfer fluids through the collectors. Active systems are categorized as either direct-circulation or indirect-circulation systems. Direct-circulation systems use pumps to circulate pressurized potable water directly through the collectors. Indirect-circulation systems pump heat-transfer fluids through collectors. Heat exchangers transfer the heat from the fluid to the potable water.

Passive solar water heaters rely on gravity and the tendency for water to naturally circulate as it is heated. Because they contain no electrical components, passive systems are generally more reliable, easier to maintain, and possibly have a longer work life than active systems. The two most popular types of passive systems are integral-collector storage systems and thermosyphon systems. Integral-collector storage systems consist of one or more storage tanks placed in an insulated box with a glazed side facing the sun. These solar collectors are suited for areas where temperatures rarely go below freezing. Thermosyphon systems rely on the natural convection of warm water rising to circulate water through the collectors and to the tank (located above the collector).

Solar collectors are the key component of active solar-heating systems. Solar collectors gather the sun's energy, transform its radiation into heat, and then transfer that heat to water, solar fluid, or air. The most common types of solar collectors are flat-plate collectors, evacuated-tube collectors, and integral collector-storage systems. Flat-plate collectors are the most common solar collector for solar water-heating systems in homes and solar space heating. A typical flat plate collector is an insulated metal box with a glass cover and a dark-colored absorber plate.

Evacuated-tube collectors can achieve extremely high temperatures, making them more appropriate for cooling applications and commercial and industrial application. However, evacuated-tube collectors are more expensive than flat-plate collectors, with unit area costs about twice that of flat-plate collectors. Integral collector-storage systems, also known as ICS or "batch" systems, are made of one or more black tanks or tubes in an insulated glazed box. Cold water first passes through the solar collector, which preheats the water, and then continues to the conventional backup water heater.

In this course, we will review the basics of solar radiation, explore system types as well as collector types, and review the methodology to properly size a solar water heating system.

II. Solar Radiation

Solar radiation is radiant energy emitted by the sun, particularly electromagnetic energy. About one-half of the solar radiation is in the form of visible light with the remainder being infrared and a little ultraviolet radiation.

Sunlight reaches every spot on the Earth's surface at least sometime during the year. The amount of solar radiation that reaches any given location is dependent on several factors including the geographic location, time of day, season, local landscape, and area weather.

Because the Earth is round, the sun strikes the surface at different angles ranging from 0º (just above the horizon) to 90º (directly overhead). When the sun's rays are vertical, the Earth's surface gets all the energy possible. The more slanted the sun's rays are, the longer they travel through the atmosphere, becoming more scattered and diffuse.

The 23.5º tilt in the Earth's axis of rotation is a significant factor in determining the amount of sunlight striking the Earth at a particular location. Tilting results in longer days in the northern hemisphere from the spring equinox to the fall equinox. Days and nights are both exactly 12 hours long on the equinoxes, which occur each year on or around March 23rd and September 22nd.

The United States, which lies in the middle latitudes, receives more solar energy in the summer because the days are longer and the sun is nearly overhead. The sun's rays are far more slanted during the shorter days of the winter months. Cities like Denver, Colorado, receive nearly three times more solar energy in June than they do in December.

The rotation of the Earth is responsible for hourly variations in sunlight. In the early morning and late afternoon, the sun is low in the sky. Its rays travel further through the atmosphere than at noon when the sun is at its highest point. On a clear day, the greatest amount of solar energy reaches a solar collector around solar noon.

The solar power industry defines two standard terrestrial solar spectral irradiance distributions. They are: the direct normal spectral irradiance and the standard total global spectral irradiance. The direct normal spectrum, which is also known as direct beam solar radiation, is a component of the total spectrum. The solar radiation that reaches the Earth's surface without being diffused is called *direct beam solar radiation*. As sunlight passes through the atmosphere, some of it is absorbed, scattered, and reflected. This scattering is caused by air molecules, water vapor, clouds, dust, pollutants, forest fires, and volcanoes. This is called *diffuse solar radiation*. Even on a clear day the direct beam solar radiation may be reduced by 10% due to normal atmospheric conditions and on especially cloudy days there may not be any direct beam solar radiation. The sum of the diffuse and direct solar radiation is called global solar radiation.

The *solar constant* is the amount of incoming solar electromagnetic radiation per unit area measured on the outer surface of the earth's atmosphere in a plane perpendicular to the rays and is 1,366 watts per square meter. The average incoming radiation is known as solar insolation and is one-fourth the solar constant, or 342 watts/m^2.

Insolation is the amount of solar energy received on the surface of the earth over a period of time and is measured in kilowatt-hours per square meter (kWh/m^2). *Irradiance* is the amount of solar power received on the surface of the earth at a given time and is measured in kilowatts per square meter (kW/m^2).

Insolation is greatest when the surface is normal (i.e. at a 90 degree angle) to the Sun. As the angle increases beyond a direction normal to the surface and the sunlight, the insolation is reduced in proportion to the cosine of the angle.

Table 1 on the right shows the average annual solar radiation for several cities in the United States. From the table, we see that Atlanta, GA can expect 5.1 kWh/m^2/day of solar radiation. In comparison, Anchorage, AK only receives 3.0 kWH/m^2/day.

Table 1
Solar Radiation

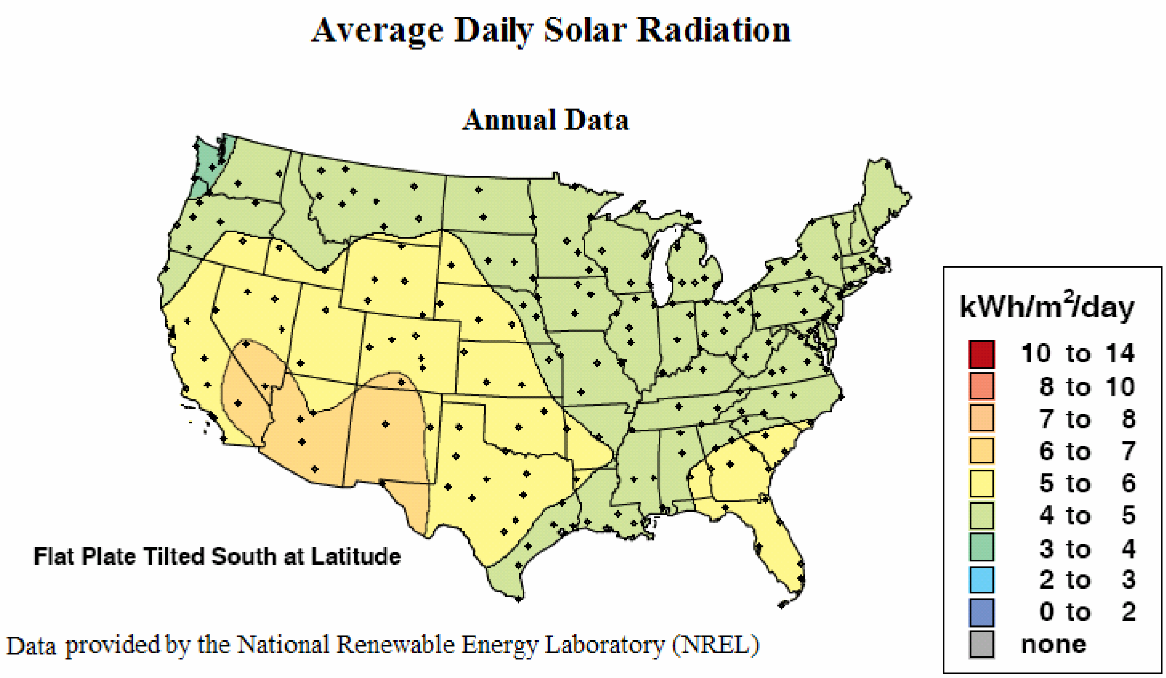
Location	**kWh/m^2/day**
Atlanta, GA	5.1
Miami, Fl	5.2
Omaha, NE	4.9
Concord, NH	4.6
Seattle, WA	3.7
Anchorage, AK	3.0
Chicago, IL	4.4
Lexington, KY	4.5
Hartford, CT	4.4
Albuquerque, NM	6.4

Table 2 is the same data as shown in Table 1, but expanded to show twelve months of data. This table also accounts for different orientations of the solar collector. For instance, in Table 1 we see that the average annual solar radiation is 5.1 kWh/ m^2/day for Atlanta, Ga. Looking at Table 2, we see that the solar radiation for Atlanta, Georgia, varies from 3.7 – 5.8 kWH/m^2/day at the latitude of Atlanta, Ga. Tilting the solar collector either up or down can have a slight impact on the total solar radiation.

Table 2
Solar Radiation (kWh/m^2/day)
Atlanta, GA

Tilt	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Lat – 15	3.4	4.2	5.1	6.0	6.2	6.3	6.1	5.9	5.3	4.9	3.8	3.2	5.0
Latitude	3.8	4.6	5.3	5.8	5.8	5.8	5.7	5.7	5.4	5.2	4.2	3.7	5.1
Lat +15	4.1	4.7	5.1	5.4	5.2	5.1	5.0	5.2	5.1	5.3	4.5	3.9	4.9

Figure 1 is a graphical representation of the average annual solar radiation in the continental United States for a flat plate collector titled South at an angle equal to the latitude of the location. As you can see from the map, the Southwest has the highest solar radiation and the Pacific Northwest has the lowest solar radiation in the continental United States.


Average Daily Solar Radiation

Annual Data

Data provided by the National Renewable Energy Laboratory (NREL)

Figure 1

II. Solar Water Heaters Components

In this section we will look at the various types of solar water heating systems, collector types, and the balance of the equipment needed for a complete system.

Types of Solar Thermal Systems

Solar water heaters use the sun to heat either water or a heat-transfer fluid in the collector. Heated water is then held in the storage tank ready for use, with a conventional system providing additional heating as necessary. Solar water heating systems can be either active or passive, but the most common are active systems.

Active circulation systems require electric power to activate pumps and/or controls and *passive circulation systems* rely on natural convection rather than electric power to circulate the water. In addition to active versus passive, the systems are also classified as either direct or indirect heating. A direct heating, or open loop system, heats potable water directly in the collector and circulates it through the end use storage tank. An indirect heating, or closed loop system, heats a fluid such as propylene glycol in the collector and transfers this heat to potable water via a heat exchanger.

Active solar water heaters

Active solar water heaters rely on electric pumps, and controllers to circulate water, or other heat-transfer fluids through the collectors. There are the two types of active solar water-heating systems: Direct-circulation systems and indirect-circulation systems.

Direct-circulation systems use pumps to circulate pressurized potable water directly through the collectors. These systems are appropriate in areas that do not freeze for long periods and do not have hard or acidic water. These systems are not approved by the Solar Rating & Certification Corporation (SRCC) if they use recirculation freeze protection (circulating warm tank water during freeze conditions) because of the additional electrical power required for the protection to be effective.

Figure 2 shown below is an active direct-circulation system. It has a photovoltaic cell to power the pump and is a single tank system.

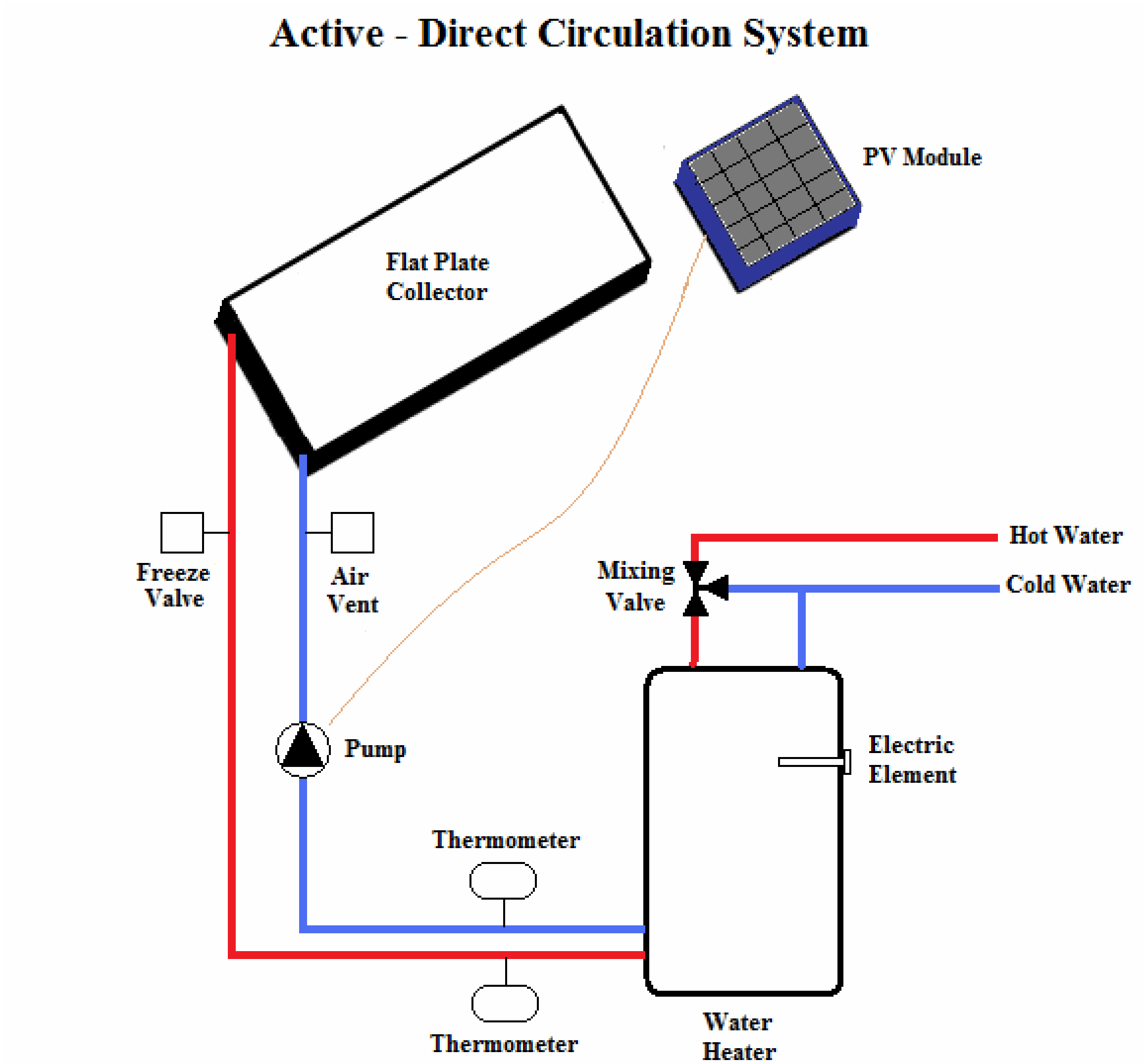


Figure 2

Indirect-circulation systems pump heat-transfer fluids through collectors. Heat exchangers transfer the heat from the fluid to the potable water. Some indirect systems have "overheat protection," which is a means to protect the collector and the glycol fluid from becoming super-heated when the load is low and the intensity of incoming solar radiation is high. The two most common indirect systems are antifreeze and drain-back systems.

With *antifreeze systems*, the heat transfer fluid is usually a glycol-water mixture with the glycol concentration depending on the expected minimum temperature. The glycol is usually food-grade propylene glycol because it is non-toxic.

With a *drainback system*, a type of indirect system, pumps circulate water through the collectors. The water in the collector loop drains into a reservoir tank when the pumps stop. This makes drainback systems a good choice in colder climates. Drainback systems must be carefully installed to assure that the piping always slopes downward, so that the water will completely drain from the piping. This can be difficult to achieve in some circumstances.

Figure 3 shows an active indirect-circulation system. Like the previous illustration, this system also has a PV cell to drive the pump. However, in this system, the fluid in the solar collector does not mix with the potable water. Instead it is used to heat the electric water heater tank via a coil of tubing wrapped around the exterior of the tank.

Active - Indirect Circulation System

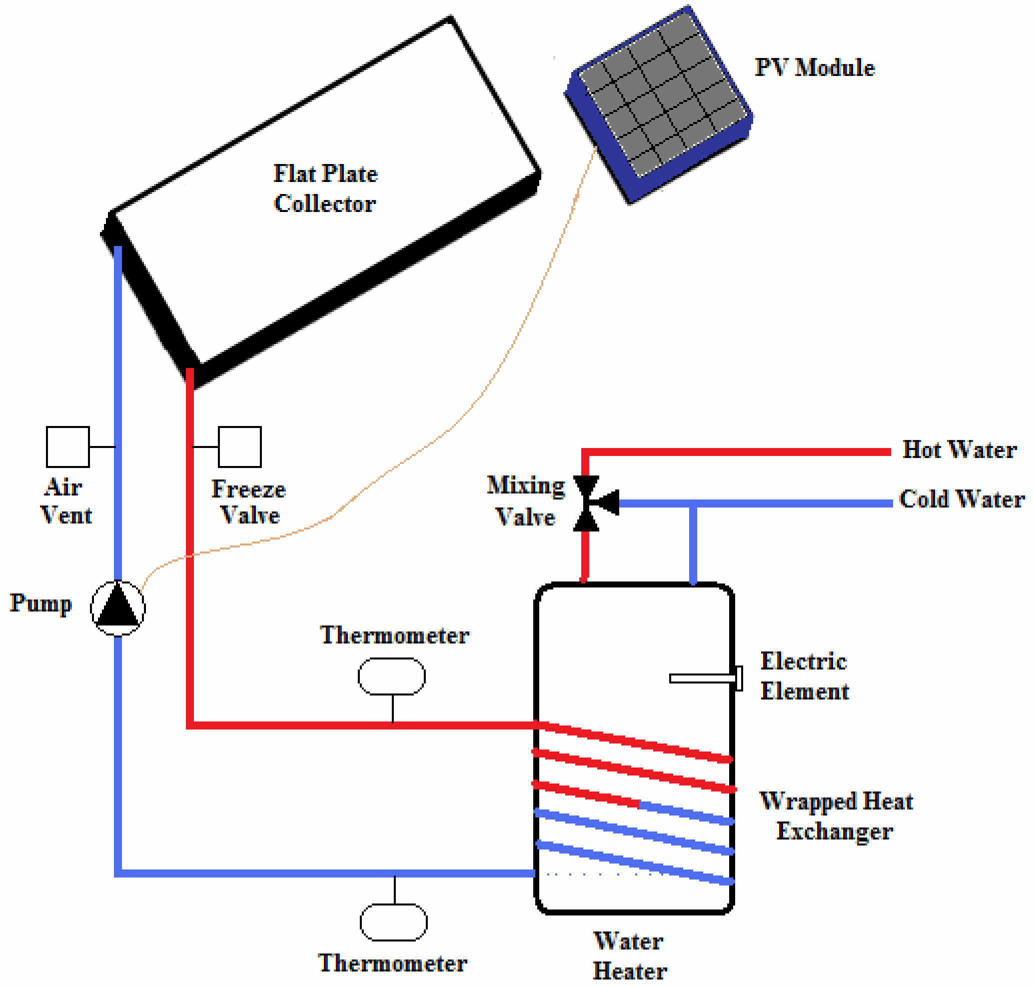


Figure 3

Active systems may be considered either zero carbon or low carbon systems depending on how the solar water heating system is pumped and controlled. Low carbon systems principally use electricity to circulate the fluid through the collector. The use of electricity typically reduces the carbon savings of a system by 10% to 20%. Conventional low carbon system designs use a utility powered circulation pump whenever the hot water tank is positioned below the solar panels.

Newer zero carbon solar water heating systems' pumps are powered by photovoltaic cells. These typically use a 5-20W PV panel which faces in the same direction as the main solar heating panel and a small, low power diaphragm pump or centrifugal pump to circulate the water.

Passive solar water heaters

Passive solar water heaters rely on gravity and the tendency for water to naturally circulate as it is heated. Because they contain no electrical components, passive systems are generally more reliable, easier to maintain, and possibly have a longer work life than active systems. However, at night the remaining water can freeze and damage the panels, and the storage tank is exposed to the outdoor temperatures that will cause excessive heat losses on cold days. Passive systems are less costly and more efficient than active systems. Some systems can work for up to 25 years with minimum maintenance.

The two most popular types of passive systems are integral-collector storage systems and thermosyphon systems.

Integral-collector storage systems consist of one or more storage tanks placed in an insulated box with a glazed side facing the sun. These solar collectors are suited for areas where temperatures rarely go below freezing. They are also effective in households with significant daytime and evening hot-water needs; but they do not work well in households with predominantly morning draws because they lose most of the collected energy overnight. These systems are called *batch systems* because the tank acts as both storage and solar collector. Batch heaters are basically thin rectilinear tanks with glass in front of it generally in or on house wall or roof. They are seldom pressurized and usually depend on gravity flow to deliver their water. They are simple, efficient and less costly than intense plate and tube collectors but only suitable in moderate climates with good sunshine.

Figure 4 shows a passive direct-circulation system. This system does not have a pump to lift water to the collector.

Passive - Direct Circulation System

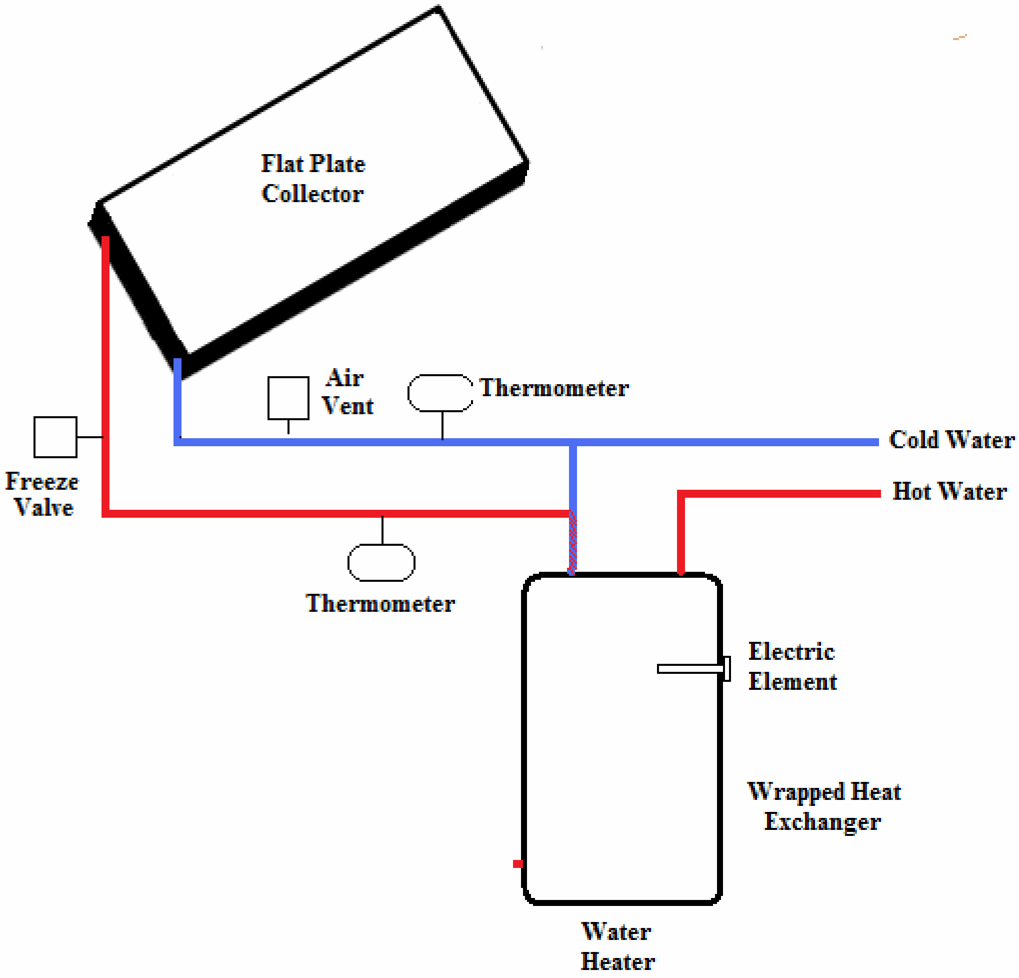
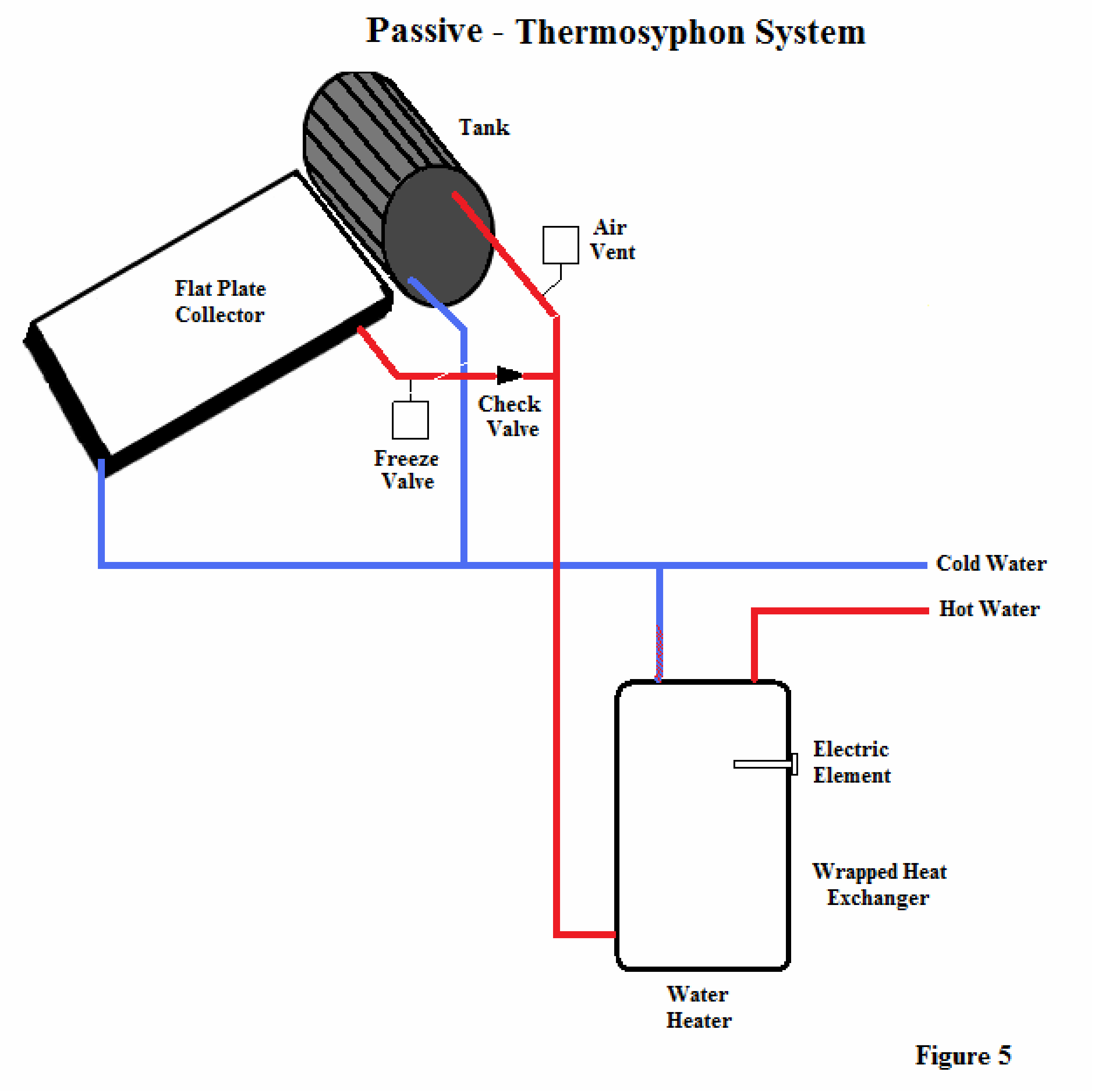


Figure 4

Thermosyphon systems are an economical and reliable choice, especially in new homes. These systems rely on the natural convection of warm water rising to circulate water through the collectors and to the tank (located above the collector). As water in the solar collector heats, it becomes lighter and rises naturally into the tank above. Meanwhile, the cooler water flows down the pipes to the bottom of the collector, enhancing the circulation. Some manufacturers place the storage tank in the house's attic, concealing it from view. Indirect thermosyphons (that use a glycol fluid in the collector loop) can be installed in freeze-prone climates if the piping in the unconditioned space is adequately protected. Figure 5 is an illustration of a thermosyphon system.



Collectors

Solar collectors are the key component of solar-heating systems. Solar collectors gather the sun's energy, transform its radiation into heat and then transfer that heat to water, solar fluid, or air. The efficiency of the system is directly related to heat losses from the collector surface. Heat losses are predominantly governed by the thermal gradient between the temperature of the collector surface and the ambient temperature. Efficiency decreases when either the ambient temperature falls or as the collector temperature increases. This decrease in efficiency can be mitigated by increasing the insulation of the unit by sealing the unit in glass such as with flat collectors or providing a vacuum seal as found in evacuated tube collector.

Solar thermal collectors (and the systems themselves) are defined by their operating temperature. Systems are described as low-temperature, mid-temperature, and high-temperature systems.

Low-temperature systems are usually unglazed and operate at up to 18°F above ambient temperature. Low-temperature collectors are extruded from polypropylene or other polymers. Flow passages for the water are molded directly into the absorber plate. These systems are commonly used for swimming pool applications. This type is very efficient at collecting solar energy at low temperatures above ambient, but becomes very inefficient at medium and high temperatures above ambient.

Mid-temperature systems produce water between 18°F and 129°F above ambient. Mid-temperature collectors are usually flat plates insulated by a glass cover and fiberglass or other insulation. Reflection and absorption of sunlight in the cover glass reduces the efficiency at low temperature differences, but the glass is required to retain heat at higher temperatures. A copper absorber plate with copper tubes welded to the fins is used. In order to reduce radiant losses from the collector, the absorber plate is often treated with a black surface. Flat-plate collectors are mid-temperature collectors and are well suited for residential water heating systems.

High-temperature systems utilize evacuated tubes around the receiver tube to provide high levels of insulation and often use focusing curved mirrors to concentrate sunlight. Due to the tracking mechanism required to keep the focusing mirrors facing the sun, high-temperature systems are usually very large and mounted on the ground adjacent to a facility.

Table 3 shows the different categories of collectors and their application. A category A system is applicable for heating swimming pools. Category C is used for hot water heating systems.

Table 3
Collector Categories

Category	Temperature	Application
A	-9F	Solar assisted heat pumps Swimming pools
B	9F	Solar assisted heat pumps Swimming pools Space heating – air systems
C	36F	Hot water systems Space heating – air systems
D	90F	Hot water systems Space heating – liquid systems Air-conditioning systems
E	144F	Space heating – liquid systems Air-conditioning systems Industrial process heat

The temperature rating shown in Table 3 is known as the T_i-T_a temperature. T_i is the temperature of the water or fluid in the collector and T_a is the ambient temperature at the collector. The higher the number the more efficiently the collector can convert the solar energy into hot water.

Solar system manufacturers use the American Water Works Association (AWWA) fluid classification system to define the types of fluids used in their systems. The classification system indicates the potential for a fluid to contaminate a water supply during a heat exchanger failure. There are three categories of fluids for heat exchangers. They are,

Fluid Class	**Heat Transfer Fluid**
I	Potable fluid such as water
II	Non-toxic fluid such as Propylene Glycol
III	Toxic fluid such as Ethanol

There are four primary types of solar collectors:

- Formed plastic collector
- Flat-plate collectors
- Evacuated-tube collectors
- Integral collector-storage systems

Formed plastic collector

Formed plastic collectors use plastics such as polypropylene, EPDM or PET and consist of tubes or formed panels through which water is circulated and heated. These low-cost systems are used as swimming pools water heaters. They are not suitable for year-round uses like providing hot water for home use, primarily due to the lack of insulation which reduces its effectiveness greatly when the ambient air temperature is lower than the temperature of the fluid being heated.

Flat-plate collectors

Flat-plate collectors are the most common solar collector for solar water-heating systems in homes and solar space heating. A typical flat-plate collector is an insulated metal box with a glass or plastic cover (called the glazing) and a dark-colored absorber plate. These collectors heat liquid or air at temperatures less than 180°F.

In a flat-plate collector, fluid is circulated through the tubing to remove the heat from the absorber and to transport it to an insulated water tank, sometimes directly or otherwise to a heat exchanger or to some other device for using the heated fluid. Some fabricants have a completely flooded absorber consisting of two sheets of metal stamped to produce a circulation zone. Because the heat exchange area is greater they may be marginally more efficient than traditional absorbers.

As an alternative to metal collectors, new polymer flat plate collectors are now being produced. These may be wholly polymer, or they may be metal plates behind which are freeze-tolerant water channels made of silicone rubber instead of metal. Polymers, being flexible and therefore freeze-tolerant, are able to contain plain water instead of antifreeze, so that in some cases they are able to plumb directly into existing water tanks instead of needing the tank to be replaced with one using heat exchangers. By dispensing with a heat exchanger in these flat plate panel, temperatures need not be quite so high for the circulation system to be switched on, so such direct circulation panels, whether polymer or otherwise, can be somewhat more efficient, particularly at low light levels. Figure 6 shows a typical flat plate collector design.

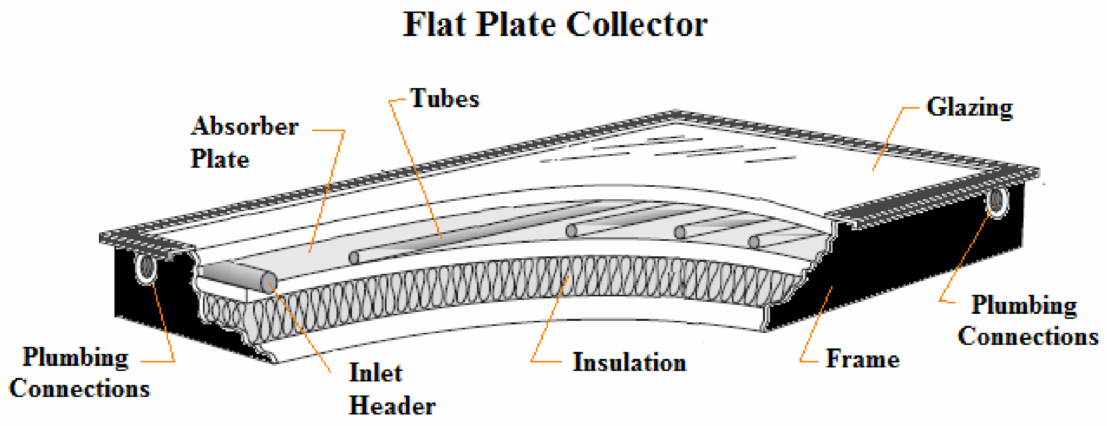


Figure 6

Flat-plate collectors are the first choice for residential water heating. Liquid flat-plate collectors heat liquid as it flows through tubes in or adjacent to the absorber plate. The simplest liquid systems use potable household water, which is heated as it passes directly through the collector and then flows to the house.

A special type of flat-plate collectors is the *air flat-plate collector*. This type uses unglazed solar collectors and is most often used for swimming pool heating and solar space heating. The absorber plates in air collectors can be metal sheets, layers of screen, or non-metallic materials. The air flows past the absorber by using natural convection or a fan. Because air conducts heat much less readily than liquid does, less heat is transferred from an air collector's absorber than from a liquid collector's absorber, and air collectors are typically less efficient than liquid collectors.

Flat plate collectors have a life expectancy of over 25 years.

Evacuated-tube collectors

Evacuated-tube collectors can achieve extremely high temperatures (170°F to 350°F), making them more appropriate for cooling applications and commercial and industrial application. However, evacuated-tube collectors are more expensive than flat-plate collectors, with unit area costs about twice that of flat-plate collectors. Figure 7 shows a typical evacuated-tube collector.

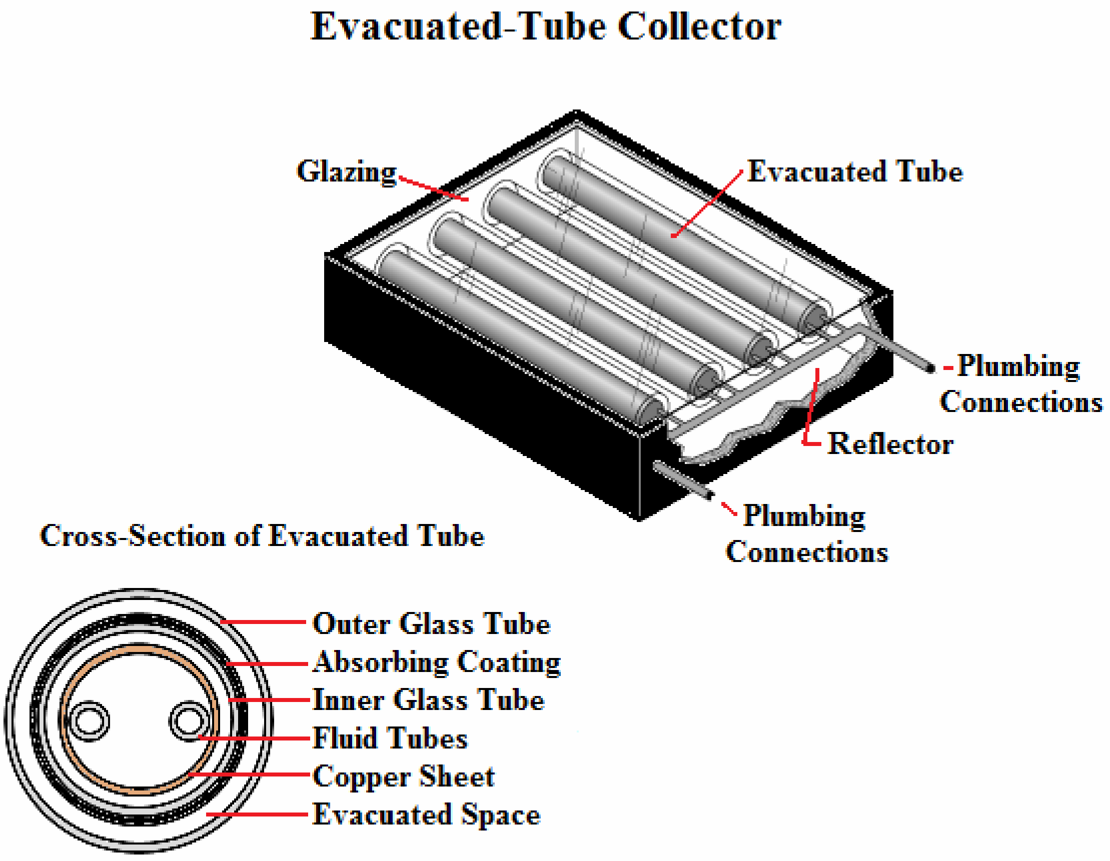


Figure 7

Evacuated-tube collectors are efficient at high temperatures. The collectors are usually made of parallel rows of transparent glass tubes. Each tube contains a glass outer tube and metal absorber tube attached to a fin. The fin is covered with a coating that absorbs solar energy well, but which inhibits heat loss. Air is removed, or evacuated, from the space between the two glass tubes to form a vacuum, which eliminates conductive and convective heat loss.

A new evacuated-tube design, called the “dewar” is a design that features a vacuum contained between two concentric glass tubes, with the absorber selective coating on the inside tube. Water is typically allowed to thermosyphon down and back out the inner cavity to transfer the heat to the storage tank. There are no glass-to-metal seals. This type of evacuated tube has the potential to become cost-competitive with flat plates.

Evacuated tube collectors are made of a series of modular tubes, mounted in parallel, whose number can be added to or reduced as hot water delivery needs change. In contrast to a flat plate collector, in an evacuated tube collector there are rows of parallel transparent glass tubes, each of which contains an absorber tube. The tubes may be covered with a special light-modulating coating. In an evacuated tube collector, sunlight passing through an outer glass tube heats the absorber tube contained within it.

The absorber can either consist of copper or specially-coated glass tubing. The copper evacuated tubes are typically sealed at the manifold end, and the absorber is actually sealed in the vacuum, thus the fact that the absorber and heat pipe are dissimilar metals creates no corrosion problems. Some systems use foam insulation in the manifold.

Lower quality evacuated tube systems use a glass coated absorber. Due to the extreme temperature difference of the glass under stagnation temperatures, the glass sometimes shatters. The glass is a lower quality and the aluminum absorber and copper heat pipe are slid down inside the open top end of the tube. Moisture entering the manifold around the sheet metal casing is eventually absorbed by the fiberglass insulation and then finds its way down into the tubes. This leads to corrosion at the absorber/heat pipe interface area, also freeze ruptures of the tube itself if the tube fills sufficiently with water.

Two types of tube collectors are distinguished by their heat transfer method: the simplest pumps a heat transfer fluid through a U-shaped copper tube placed in each of the glass collector tubes. The second type uses a sealed heat pipe that contains a liquid that vaporizes as it is heated. The vapor rises to a heat-transfer bulb that is positioned outside the collector tube in a pipe through which a second heat transfer liquid is pumped. For both types, the heated liquid then circulates through a heat exchanger and gives off its heat to water that is stored in a storage tank.

Evacuated tube collectors heat to higher temperatures, with some models providing considerably more solar yield per square foot than flat panels. However, they are more expensive and fragile than flat panels. Evacuated heat tubes perform better than flat plate collectors in cold climates because they only rely on the light they receive and not the outside temperature. The high stagnation temperatures can cause antifreeze to break down, so careful consideration must be used if selecting this type of system in temperate climates. Tubes come in different levels of quality so the different kinds have to be examined as well. High quality units can efficiently absorb diffuse solar radiation present in cloudy conditions and are unaffected by wind. They also have the same performance in similar light conditions summer and winter.

For a given absorber area, evacuated tubes can maintain their efficiency over a wide range of ambient temperatures and heating requirements. In extremely hot climates, flat-plate collectors will generally be a more cost-effective solution than evacuated tubes. They are well suited to extremely cold ambient temperatures and work well in situations of consistently low-light.

Properly designed evacuated tubes have a life expectancy of over 25 years which greatly adds to their value.

Integral collector-storage systems

Integral collector-storage systems, also known as ICS or "batch" systems, are made of one or more black tanks or tubes in an insulated glazed box. Cold water first passes through the solar collector, which preheats the water, and then continues to the conventional backup water heater. ICS systems are simple, reliable solar water heaters. However, they should be installed only in climates with mild freezing because the collector itself or the outdoor pipes could freeze in severely cold weather. Some recent work indicates that the problem with freezing pipes can be overcome in some cases by using freeze-tolerant piping in conjunction with a freeze-protection method.

Balance of System Equipment

In addition to the collector, there are several other components that are necessary for a solar thermal water heating system. The components vary by the type of system employed. These additional components are sometimes referred to as the "balance of system" components. The balance of system equipment may include a system controller, a back-up water heater, an expansion tank, a heat exchanger, isolation valve, and a tempering valve.

Heat Exchanger

Indirect solar water heater systems must have a heat exchanger to transfer the heat from one fluid to another without the two mixing. Heat exchangers, such as the one shown on the right, are inside the water heater tank. Some heat exchangers are simply a coil of pipe resting in the bottom of the tank, or wrapped around the outside beneath the insulation and cover. As the heated fluid from the solar collector travels through the coil, the heat is passed from the hotter fluid to the cooler potable water.

Another type of heater exchanger is an external heat exchanger. These are usually a pipe within a pipe. The solar fluid and potable water flow counter to one another, and heat is transferred within the heat exchanger pipe.

Expansion Tank

Closed-loop systems require an expansion tank. An expansion tank has a chamber in which air is locked inside a bladder or diaphragm. When pipes are filled with heat-transfer fluid (water and glycol) and the operating pressure of the system is set, the fluid will occupy a given volume based on the temperature. As the fluid is heated by the sun, it expands.

The expansion tank allows the fluid to safely expand by compressing the air in the chamber. The size of the expansion tank needed depends on the total volume of fluid, which is determined by the number and size of collectors, and the length and diameter of the pipes in the solar loop. With the proper expansion tank in place, the fluid can go from 0 to 200°F with the pressure in the solar loop remaining the same.

Controller

In active systems that use circulating pumps, whenever the collector is hotter than the storage tank, the pump should be on circulating fluid through the system. When the tank is hotter than the collector, the pump should be off. This function is normally performed by a special controller called a *differential thermostat* control system. The differential thermostat controller compares heat sensor readings from the storage tank and collectors and switches the pump accordingly.

Differential thermostat controllers provide for the automatic, safe, and reliable operation of domestic solar water heating systems. The control output is wired to a pump that circulates the heat transfer fluid between the solar thermal collectors and the storage tank during the course of the day. The controllers are typically microprocessor-based controllers that utilize resistance type sensors to monitor collector and tank temperatures with digital accuracy.

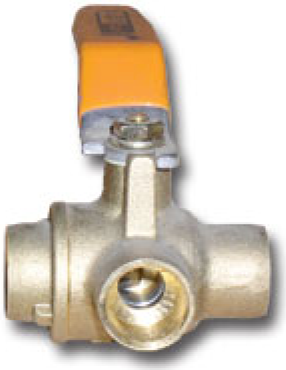
Many models include an LCD display to give the homeowner a variety of real time information including system temperatures at up to three separate locations.

In addition to the primary function of turning the circulating pump on and off during the day, the controllers can provide important diagnostic and safety functions. For example, the LCD may indicate fault conditions such as sensor shorts or pump failure.

Many controllers offer adjustable on/off differential (8 - 20° F) and high limit (32° F - 205° F) switches, an evacuated tube collector function, vacation overheat protection to minimize collector stagnation, and a freeze-recirculation option.

With a PV-powered pump, a solar-electric panel is connected directly to the pump and a controller is not really necessary because when the sun comes out, the pump comes on. The brighter the sun, the faster it pumps. Controls are not needed in batch heater systems, where energy is moved by simple water pressure, or in thermosyphon systems, where energy is moved naturally by heat rising.

Isolation Valve



An isolation valve is used to isolate the solar tank in case of a problem, while still allowing the backup water heater to remain in service. The isolation valve is a manual valve or valves placed in both the incoming and outgoing potable water lines to the solar tank. Manually turning the valve or valves will place the solar tank "on line" or "off line." It works by directing the flow either through or past the solar tank. These valves can also be plumbed to bypass the backup gas or electric water heater, allowing them to be turned off (eliminating standby heat loss) during the seasons when the solar hot water system can supply 100 percent of the household´s hot water.

Backup Water Heater

The backup water heater ensures that hot water is available whether the sun shines or not. On a sunny, hot day, if the sun has preheated the water to 140°F or more, the backup water heater uses no energy at all because the solar preheat temperature is greater than the typical 120°F thermostat setting. On a day when the solar preheat is 90°F, the backup heater boosts the temperature the remaining 30°F. Since incoming cold-water temperatures are at ground temperature of around 60°F, 90°F represents 50 percent of the energy needed to bring the water from 60°F to 120°F.

Tempering Valve

Providing a tempering valve and bypass capability is very important to assure consistent temperature water is delivered to the end user. Bypass piping and valves allow the conventional system to provide hot water if the solar heating system is down for any reason.

On a sunny day, the water in a solar collector can reach scalding temperatures. A tempering, or *mixing*, valve mixes cold incoming water with the solar heated water to insure a consistent output water temperature. The tempering valve goes at the very end of the chain, right after the backup water and before being delivered to the end user. If the water coming out of the backup heater is too hot, the tempering valve opens to mix cold water back in and prevent scalding. The temperature of the hot water can be set by the user on most valves. For instance, a popular valve allows a temperature setting between 120°F and 160°F.

II. Solar Water Heater Design

The design of a solar water heating system can be broken down into the following seven steps.

1. Determine daily hot water demand for the application.
2. Determine BTU/day required.
3. Determine the orientation and tilt of the system.
4. Find the solar insolation for the given location and tilt.
5. Determine the percent of the daily hot water required from the solar system.
6. Calculate the solar panel size required.
7. Select an appropriate solar panel.

Let's follow a design through each of these seven steps.

Step 1. Determine daily hot water demand for the application

Before sizing a solar water heating system, we need to know how much hot water will be required for a given application. Once we have this information, the system can be sized accordingly. There are many rules of thumb to calculate hot water needs. However, the following is empirical approach to determining residential hot water demand that was developed by the Electric Power Research Institute (EPRI) several years ago.

This formula considers the number of people in the home, their ages, and time of occupancy. In addition, the tank size, water temperatures, use of a dish washer, and a clothes washer are also considered. For simplicity, the formula is broken down into four components. The first component is based on people in the home. The formula is,

$$HW_P = -1.78 + P_T * 0.9744 + P_5 * 6.3933 + P_{13} * 10.5178 + P_A * 15.3052 + P_H * 10.2191$$

Where,
HW_P = Hot water use due to human activity, gallons/day.
P_T = Total number of people in the home.
P_5 = Number of people in the home aged 5 and under.
P_{13} = Number of people in the home between the ages of 6 and 13.
P_A = Number of people in the home aged 14 and above.
P_H = 1 if someone is at home during the day, else the value is 0.

For example, consider a case that includes a family of four with one 3-year old child, a 7-year old, and the mother stays home during the day. The hot water use based on occupancy is,

$$HW_P = -1.78 + 4 * 0.9744 + 1 * 6.3933 + 1 * 10.5178 + 2 * 15.3052 + 1 * 10.2191$$

HW_P = 59.9 gallons/day

Next, we need to consider the impact of the water heater temperature settings and tank size on the hot water demand.

$$\mathbf{HW_T} = -T_{Set} * 0.1277 - T_{In} * 0.1794 + T_{Amb} * 0.5155 + Tank_{Size} * 0.1437$$

Where,
HW_T = Impact of water heater parameters on hot water demand, gallons/day.
T_{Set} = Water heater temperature set point, degrees, F.
T_{In} = Incoming water temperature, degrees, F.
T_{Amb} = Ambient temperature, at the water heater location, degrees, F.
$Tank_{Size}$ = Size of water heater tank, gallons.

If the water heater setpoint is 125 degrees, the incoming water temperature is 58-degrees, the tank size is 50 gallons, and the ambient temperature is 60-degrees, then the hot water demand impact from the water heater parameters is,

$HW_T = -125 * 0.1277 - 58 * 0.1794 + 60 * 0.5155 + 50 * 0.1437$

HW_T = 11.8 gallons/day

The next parameter considers the impact of a residential dish washer. If a dishwasher is _not_ present in the home, then an amount of hot water is deducted based on the following formula,

$$\mathbf{HW_{DW}} = -\left(P_T * 0.692 + 1.335 * \sqrt{P_{T\square}}\right)$$

Where,
HW_{DW} = Hot water demand based on a dishwasher, gallons/day.
P_T = Number of people in the home.

In our example, where the home has four people, without a dishwasher the deduct is,

$HW_{DW} = -\left(4 * 0.692 + 1.335 * \sqrt{4\square}\,\square\right)$

HW_{DW} = -5.4 gallons/day

The final component is the hot water use of a residential clothes washer. Like the dishwasher, the hot water demand for a clothes washer is deducted if a clothes washer is _not_ present in the home.

$$\mathbf{HW_{CW}} = -\left(P_T * 1.1688 + 4.7737 * \sqrt{P_{T\square}}\right)$$

Where,
HW_{CW} = Hot water demand based on a clothes washer, gallons/day.

P_T = Number of people in the home.

In our example, where the home has four people, the dishwasher demand for hot water is,

$HW_{CW} = -\left(4 * 1.1688 + 4.7737 * \sqrt{4}\right)$

HW_{CW} = -14.2 gallons/day

Putting it all together, the total hot water demand for a residential application, where a dishwasher and clothes washer are not present, is the sum of the previous four components,

$$\mathbf{GPD = HW_P + HW_T + HW_{DW} + HW_{CW}}$$

Where,
GPD = Total hot water demand for a residential home, gallons/day.
HWp = Hot water use due to human activity, gallons/day.
HW_T = Impact of water heater parameters on hot water demand, gallons/day.
HW_{DW} = Hot water demand deduct based on a dishwasher, gallons/day.
HW_{CW} = Hot water demand deduct based on a clothes washer, gallons/day.

From our previous examples, except assuming that a clothes washer and dishwasher are present, the total hot water demand is,

GPD = 59.8 + 11.8

GPD = 71.6 gallons/day.

If a dishwasher and clothes washer were not present, we would have subtracted 5.4 and 14.2 gallons per day respectively from the total hot water demand resulting in a daily demand of 52 gallons.

For comparison, consider Table 4, which has a rule of thumb for determining the daily hot water demand of a residential house.

Table 4
Daily Hot Water Usage
(Rule of Thumb)

Occupancy	GPD
One person	10
Two people	20
Each add'l person	15

Using the rule-of-thumb factors from Table 4, a family of four can expect to use 50 GPD of hot water (20 + 15 + 15 = 50). The empirical calculation – which is the most accurate procedure – yielded 72 GPD versus 50 GPD for the rule-of-thumb calculation.

Step 2. Determine BTU/day required

Next, we need to consider the power required to provide the hot water demanded by the previous calculations. The following formula calculates the energy required to meet the expected hot water demand in a residential application. The formula provides the BTU's per day required.

$$Q_{in} = \frac{GPD * 8.3 * (T_{Set} - T_{In})}{RE} * \left[1 - \frac{UA * (T_{Set} - T_{Amb})}{P_{in}}\right] + \left(24 * UA * (T_{Set} - T_{Amb})\right)$$

Where,
Q_{in} = Hot water energy required, BTU/day.
GPD = Hot water demand, gallons/day.
T_{Set} = Hot water heater set point temperature, degrees, F.
T_{in} = Incoming water temperature, degrees, F.
RE = Recovery efficiency of the water heater (typically 0.86 for gas, and 0.98 for electric).
UA = Standby heat loss coefficient of the water heater.
P_{in} = Rated input power of the water heater, BTU/Hr
T_{Amb} = Ambient temperature at the water heater location, degrees, F.

The standby heat loss coefficient of the water heater can be found from the following formula,

$$UA = \frac{\left(\frac{1}{EF} - \frac{1}{RE}\right)}{67.5 * \left(\frac{24}{Q_{out}} - \frac{1}{(RE * P_{in})}\right)}$$

Where,
UA = Standby heat loss coefficient of the water heater.
RE = Recovery efficiency of the water heater (typically 0.86 for gas, and 0.98 for electric).
EF = Energy factor, (0.6 gas, 0.9 electric)
Q_{out} = Energy content of water drawn from water heater (assume 41093.7 BTU/day).
P_{in} = Rated input power of the water heater, BTU/Hr.

Let's work an example of the calculation of the hot water energy requirement for the residential application previously described. The parameters are,

GPD = 71.6 gallons/day.
T_{Set} = 125F.
T_{in} = 58F.
RE = 0.98.
P_{in} = 15,350 BTU/Hr
T_{Amb} = 60F.
EF = 0.9.

Q_{out} = 41,093.7 BTU/day.

First, we have to find the value for the standby heat loss coefficient of the water heater, UA.

$$UA = \frac{\left(\frac{1}{0.9} - \frac{1}{0.98}\right)}{67.5 * \left(\frac{24}{41{,}093.7} - \frac{1}{(0.98 * 15{,}350)}\right)}$$

UA = 2.60

Now that we have the standby heat loss coefficient, we can calculate Q_{in},

$$Q_{in} = \frac{71.6 * 8.3 * (125 - 58)}{0.98} * \left[1 - \frac{2.6 * (125 - 60)}{15{,}350}\right] + \left(24 * 2.6 * (125 - 60)\right)$$

Q_{in} = 44,407 BTU/day

In this example, 44,407 BTU/day is needed to supply the hot water demands of the hypothetical family of four. This energy value can be converted to electric units (kWh's) by using the conversion factors in Table 5.

Table 5 Hot Water Heating Annual Energy Consumption		
Fuel Type	**Conversion**	**Units**
Electricity	365 * Qin /3,412	kWh/yr
Natural Gas	365 * Qin / 100,000	Therm/yr
Propane	365 * Qin / 91,500	Gal/yr
Fuel Oil	365 * Qin / 140,000	Gal/yr

From Table 5, we see that the conversion from BTU/day to kWh/year is,

kWh = 365 * Qin /3,412

In our example, the electric usage is,

kWh = 365 * 44,407 / 3,412

kWh = 4,750 kWh/yr.

Using a national average cost of \$0.09 cents per kWh, it will cost this family \$427.50 per year for hot water or \$35.60 per month.

The following is a simplified calculation of the hot water energy requirement. This calculation is not as accurate as the previous formula, but is much easier to calculate and may be accurate enough for many applications.

$$\mathbf{Q}_{\text{in}} = GPD * 8.345 * (T_{Set} - T_{In}) * \frac{1}{(1 - Losses)}$$

Where,
Q_{in} = Hot water energy required, BTU/day.
GPD = Hot water demand, gallons/day.
T_{Set} = Hot water heater set point temperature, degrees, F.
T_{in} = Incoming water temperature, degrees, F.
Losses = Energy loss in the water heating system, percent.

This calculation makes numerous assumptions about standby losses, ambient temperature, etc, and rolls everything into one loss factor. The loss factor is traditionally approximated at 10%

Continuing with our previous example, the GPD is 71.6, set point temperature is 125F, and the input temperature is 58F. With losses at 10%, the hot water energy requirement is,

$$Q_{in} = 71.6 * 8.345 * (125 - 58) * \frac{1}{(1 - 0.10)}$$

Q_{in} = 44,481 BTU/day.

In this example, the simplified calculation is very close to the more rigorous calculation. However, at other set points and GPD, it can be off by several thousand BTU/day.

Step 3. Determine the orientation and tilt of the system

Two factors that will affect the efficiency of a solar hot water heater are the orientation of the solar panel and the tilt of the solar panel. Ideally, the panels should be facing directly south. Any variance from a southern exposure will reduce the efficiency of the system. Table 6 shows the impact of orientation by providing an *orientation factor* which is used to increase the size of the solar panels required for a given installation.

Table 6
Orientation Factor

Direction	Multiplier
South	1.00
Southeast	1.15
Southwest	1.15
East	1.40
West	1.40

From Table 6, we see that a westerly facing solar panel will require 40% more surface area than a southern facing panel.

Generally, it is best to have the solar panel tilted at an angle about equal to the geographic latitude of the location of the panel. The geographic location of Atlanta, Georgia is 33° 44' 56" North latitude, 84° 23' 17" West longitude, so, ideally, a solar panel should be tilted 33.5 degrees up from a horizontal position. A typically residential house has an 8/12 sloped roof, which coincidentally results in an angle of 33.7 degrees, so in many cases, the solar panel can be mounted flat on a residential roof. The angle of a roof can be found as,

$$\textbf{Angle} = Tan^{-1}\left(\frac{Rise}{Run}\right)$$

Where,
Angle = Angle of a roof, degrees.
Tan-1 = Trigonometric function.
Rise = Vertical rise of the roof, inches per foot.
Run = Horizontal distance of the vertical rise, generally 12 inches.

A roof with a 12” rise per 12” of horizontal distance will have an angle of,

$$\text{Angle} = Tan^{-1}\left(\frac{12}{12}\right)$$

Angle = 45 degrees.

Step 4. Find insolation for the given location and tilt

The next step is to determine the solar insolation for a given location and tilt. Table 2, on page 6, shows the average insolation for Atlanta, Georgia. Notice in Table 2, that the average solar radiation for Atlanta, Georgia is 5.1 kWh/m^2/day when the solar panel is tilted at an angle equal to the geographic latitude. If the panel is tilted up 15 degrees above the latitude (i.e. 48.5 degrees) the solar radiation is 4.9 kWh/m^2/day. Likewise, if the panel is tilted 15 degrees down from the latitude, the solar radiation is 5.0 kWh/m^2/day. If you look closely at Table 2, you will see that during the summer months more solar radiation reaching the solar panel if it is tilted below the latitude. In the winter months, the opposite is true; more radiation reaches the panel if it is tilted up above the latitude. This is important if the panel is being designed for a house that is only occupied part of the year, such as a summer cabin.

In our example, we will use the average solar radiation at the latitude for Atlanta, Georgia, which is 5.1 kWh/m^2/day.

Insolation can be found for other locations using data from the National Renewable Energy Laboratory *(www.nrel.gov/rredc/).*

Step 5. Determine the percent of the daily hot water required from the solar system

For most applications it is impractical to expect the solar water heating system to supply all of the hot water needs of a residence. Typically, systems are designed to handle between 50 and 70% of the maximum hot water demand of a residence.

For our example, we will assume the system will be expected to meet 50% of the hot water demand. This percentage is called the *solar factor*.

Step 6. Calculate the solar panel size required

We are now ready to calculate the size of the solar panels required to meet our hot water demand. The following formula is used to size the panel and it takes into account the solar factor, hot water demand (in BTU/day), solar insolation, orientation of the panels, and system losses. The formula is,

$$\mathbf{Area_{Solar}} = \mathbf{SF} * \frac{BTU}{Insolation * 317} * \mathbf{OF} * [\![(1 + \mathbf{L}]\!]_{\mathbf{S}}\mathbf{F})$$

Where,
$\text{Area}_{\text{Solar}}$ = Square footage of solar panels required for the system, square feet.
SF = Solar factor, percentage of daily hot water needs met by the solar system, decimal value.
BTU = BTU/day required for water heating
Insolation = Solar radiation at the given location, kWh/m^2/day.
OF = Orientation factor, see Table 6.
L_SF = Loss factor, typically 25%, decimal value.

The loss factor is accounts for several loss items in the system including pipe losses, the efficiency of the collector absorber plate coating, efficiency of the heat transfer fluid, ambient temperature, and the internal temperature of the collector and the heat transfer fluid. Loss factors range from about 15% for systems with solar PV pumps to around 25% for electrically driven pumps.

Continuing with our example, we have the following parameters for a south facing solar water heating system,

SF = 50%.
Energy demanded = 44,407 BTU/day.
Insolation = 5.1 kWh/m^2/day.
OF = 1.0.
L_SF = 25%.

$$\text{Area}_{\text{Solar}} = 0.50 * \frac{44{,}407}{5.1 * 317} * 1.0 * (1 + 0.25)$$

$$\text{Area}_{\text{Solar}} = 17.2 \text{ ft}^2.$$

This system should require a solar panel of about 17.2 ft^2 to meet one-half the hot water demands of the residence.

For a comparison, look at Table 7, which shows a rule-of-thumb method of determining the size of a solar collector. This table has commonly used multipliers to determine the solar panel size based only on the gallons per day of hot water required and the area of the country. All other factors, such as losses and insolation are assumed.

From our example, the residence is requiring 71.6 GPD of hot water. For a system installed in Atlanta, Georgia, that is expected to meet 50% of the demand, the rule of thumb calculation from Table 7 says the solar panel should be,

Table 7
Collector Size
(Ft^2)
(Rule of Thumb)

Location	Multiplier x Daily Usage
Southeast	0.67
Northeast	1.33
Northwest	1.33
Midwest	1.00
Atlantic States	1.00
Sunbelt	0.50

$$\text{Area}_{\text{Solar}} = 0.50 * 71.6 * 0.67$$

$$\text{Area}_{\text{Solar}} = 24 \text{ ft}^2.$$

So the rule of thumb calculation yielded 24 square feet of solar panel and the more rigorous calculation yielded 17 square feet, which suggests that a panel size of around 20 square feet is probably adequate.

Step 7. Select an appropriate solar panel

The final step is to select a system type and manufacturer for the desired system. An excellent resource is the Solar Rating and Certification Corporation (SRCC). The SRCC is a third-party certification organization that administers national certification and rating programs for solar energy equipment. The SRCC is located in Cocoa, Florida. Their website address is www.solar-rating.org.

The SRCC has a program to certify solar collectors (OG-100), and entire solar systems (OG-300). All solar collectors that have been certified by the SRCC will bear the SRCC label, which assures the consumer that an independent third-party has verified the performance of the solar panel. It is in essence, a "Good Housekeeping Seal of Approval" for solar systems.

The following page has an excerpt from SRCC, OG-100, which shows a few solar collectors. Notice the fifth panel in the list is a model number AE-24 and is made by Alternate Energy Technologies. This panel has a rating of 24,000 BTU/day for a category C application. The panel size is 23.8 square feet. The next panel is also made by Alternate Energy Technologies, model number AE-24E and the panel rating is 21,000 BTU/day and is also 23.8 square feet. These ratings should be considered similar to the EPA MPG rating labels. They are good for comparisons, but do not necessarily reflect real world performance. The best use of these figures is to compare cost per BTU between systems. Assume that the AE-24 panel costs $500 and the AE-24E costs $450. Which is the better buy? Note: these costs are for example only and are not indicative of actual costs.

The AE-24 panel is $500/24, or $20.83 per kBTU/day.

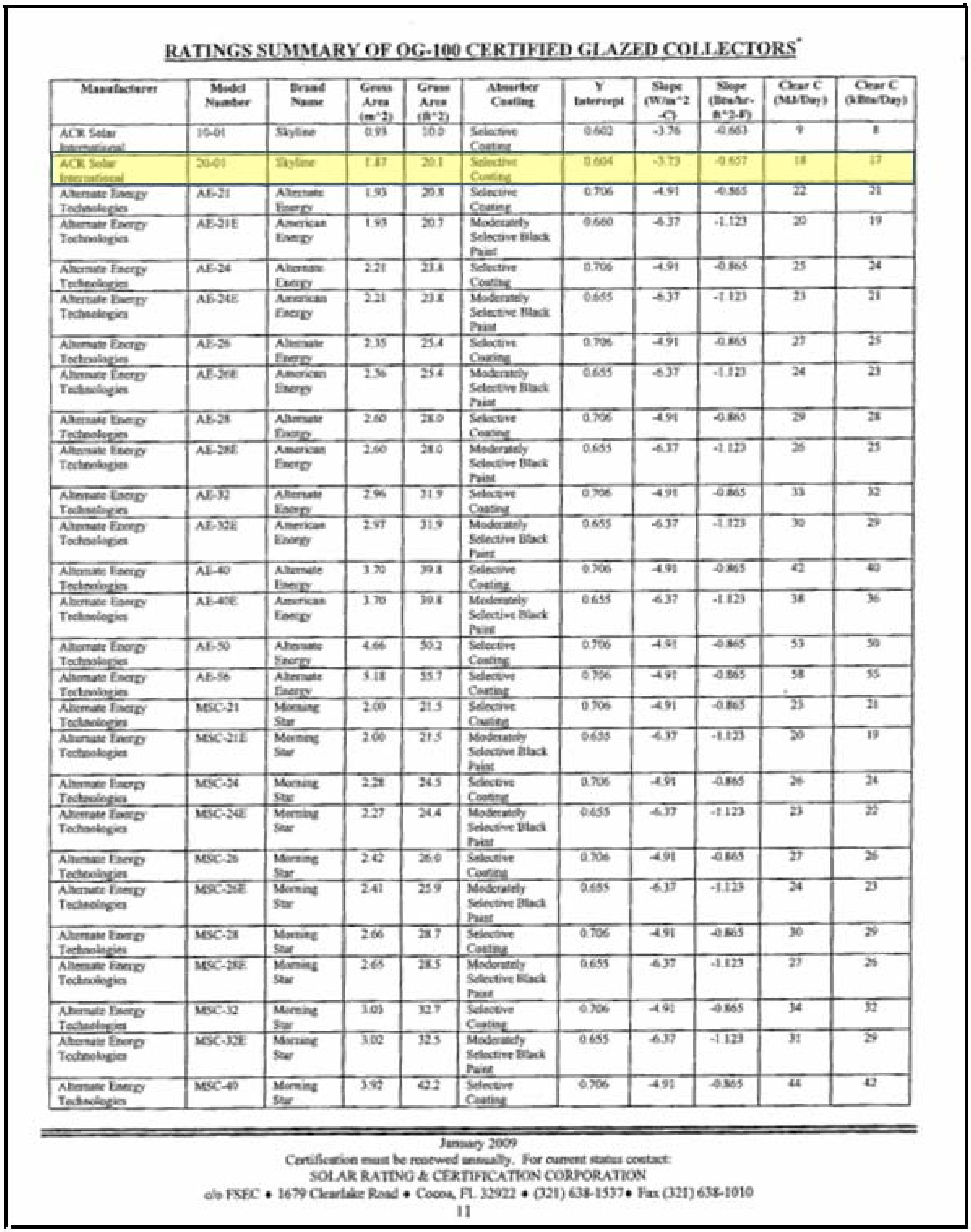
The AE-24E panel is $450/21, or $21.43 per kBTU/day.

Therefore, in this example, the AE-24 is a more economical choice.

Continuing with our example, let's assume that we want an active, direct circulation system. From the SRCC, OG-300 document we find a system made by ACR Solar International. The system is called the Skyline System 3. The parameters of the system are shown on page 35.

The Skyline System 3 uses a glazed flat-panel collector with a photovoltaic controller. It uses Class I fluid (potable water) and has an auxiliary electric water heating tank. From the drawing on page 35 you can see that the system has a mixing valve (M) for tempering the hot water and includes a freeze valve (FV) and an air vent (AV) at the collector.

The unit uses an ACR Solar International solar panel, model 20-01, which has 20.1 square feet of panel area. The panel specifics are included in the SRCC document OG-100, on page 34.



RATINGS SUMMARY OF OG-100 CERTIFIED GLAZED COLLECTORS*

Manufacturer	Model Number	Brand Name	Gross Area (m^2)	Gross Area (ft^2)	Absorber Coating	Y Intercept	Slope (W/m^2-C)	Slope (Btu/hr-ft^2-F)	Clear C (MJ/Day)	Clear C (kBtu/Day)
ACR Solar International	10-01	Skyline	0.93	10.0	Selective Coating	0.602	-3.76	-0.663	9	8
ACR Solar International	20-01	Skyline	1.87	20.1	Selective Coating	0.604	-3.73	-0.657	18	17
Alternate Energy Technologies	AE-21	Alternate Energy	1.93	20.8	Selective Coating	0.706	-4.91	-0.865	22	21
Alternate Energy Technologies	AE-21E	American Energy	1.93	20.7	Moderately Selective Black Paint	0.660	-6.37	-1.123	20	19
Alternate Energy Technologies	AE-24	Alternate Energy	2.21	23.8	Selective Coating	0.706	-4.91	-0.865	25	24
Alternate Energy Technologies	AE-24E	American Energy	2.21	23.8	Moderately Selective Black Paint	0.655	-6.37	-1.123	23	21
Alternate Energy Technologies	AE-26	Alternate Energy	2.35	25.4	Selective Coating	0.706	-4.91	-0.865	27	25
Alternate Energy Technologies	AE-26E	American Energy	2.36	25.4	Moderately Selective Black Paint	0.655	-6.37	-1.123	24	23
Alternate Energy Technologies	AE-28	Alternate Energy	2.60	28.0	Selective Coating	0.706	-4.91	-0.865	29	28
Alternate Energy Technologies	AE-28E	American Energy	2.60	28.0	Moderately Selective Black Paint	0.655	-6.37	-1.123	26	25
Alternate Energy Technologies	AE-32	Alternate Energy	2.96	31.9	Selective Coating	0.706	-4.91	-0.865	33	32
Alternate Energy Technologies	AE-32E	American Energy	2.97	31.9	Moderately Selective Black Paint	0.655	-6.37	-1.123	30	29
Alternate Energy Technologies	AE-40	Alternate Energy	3.70	39.8	Selective Coating	0.706	-4.91	-0.865	42	40
Alternate Energy Technologies	AE-40E	American Energy	3.70	39.8	Moderately Selective Black Paint	0.655	-6.37	-1.123	38	36
Alternate Energy Technologies	AE-50	Alternate Energy	4.66	50.2	Selective Coating	0.706	-4.91	-0.865	53	50
Alternate Energy Technologies	AE-56	Alternate Energy	5.18	55.7	Selective Coating	0.706	-4.91	-0.865	58	55
Alternate Energy Technologies	MSC-21	Morning Star	2.00	21.5	Selective Coating	0.706	-4.91	-0.865	23	21
Alternate Energy Technologies	MSC-21E	Morning Star	2.00	21.5	Moderately Selective Black Paint	0.655	-6.37	-1.123	20	19
Alternate Energy Technologies	MSC-24	Morning Star	2.28	24.5	Selective Coating	0.706	-4.91	-0.865	26	24
Alternate Energy Technologies	MSC-24E	Morning Star	2.27	24.4	Moderately Selective Black Paint	0.655	-6.37	-1.123	23	22
Alternate Energy Technologies	MSC-26	Morning Star	2.42	26.0	Selective Coating	0.706	-4.91	-0.865	27	26
Alternate Energy Technologies	MSC-26E	Morning Star	2.41	25.9	Moderately Selective Black Paint	0.655	-6.37	-1.123	24	23
Alternate Energy Technologies	MSC-28	Morning Star	2.66	28.7	Selective Coating	0.706	-4.91	-0.865	30	29
Alternate Energy Technologies	MSC-28E	Morning Star	2.65	28.5	Moderately Selective Black Paint	0.655	-6.37	-1.123	27	26
Alternate Energy Technologies	MSC-32	Morning Star	3.03	32.7	Selective Coating	0.706	-4.91	-0.865	34	32
Alternate Energy Technologies	MSC-32E	Morning Star	3.02	32.5	Moderately Selective Black Paint	0.655	-6.37	-1.123	31	29
Alternate Energy Technologies	MSC-40	Morning Star	3.92	42.2	Selective Coating	0.706	-4.91	-0.865	44	42

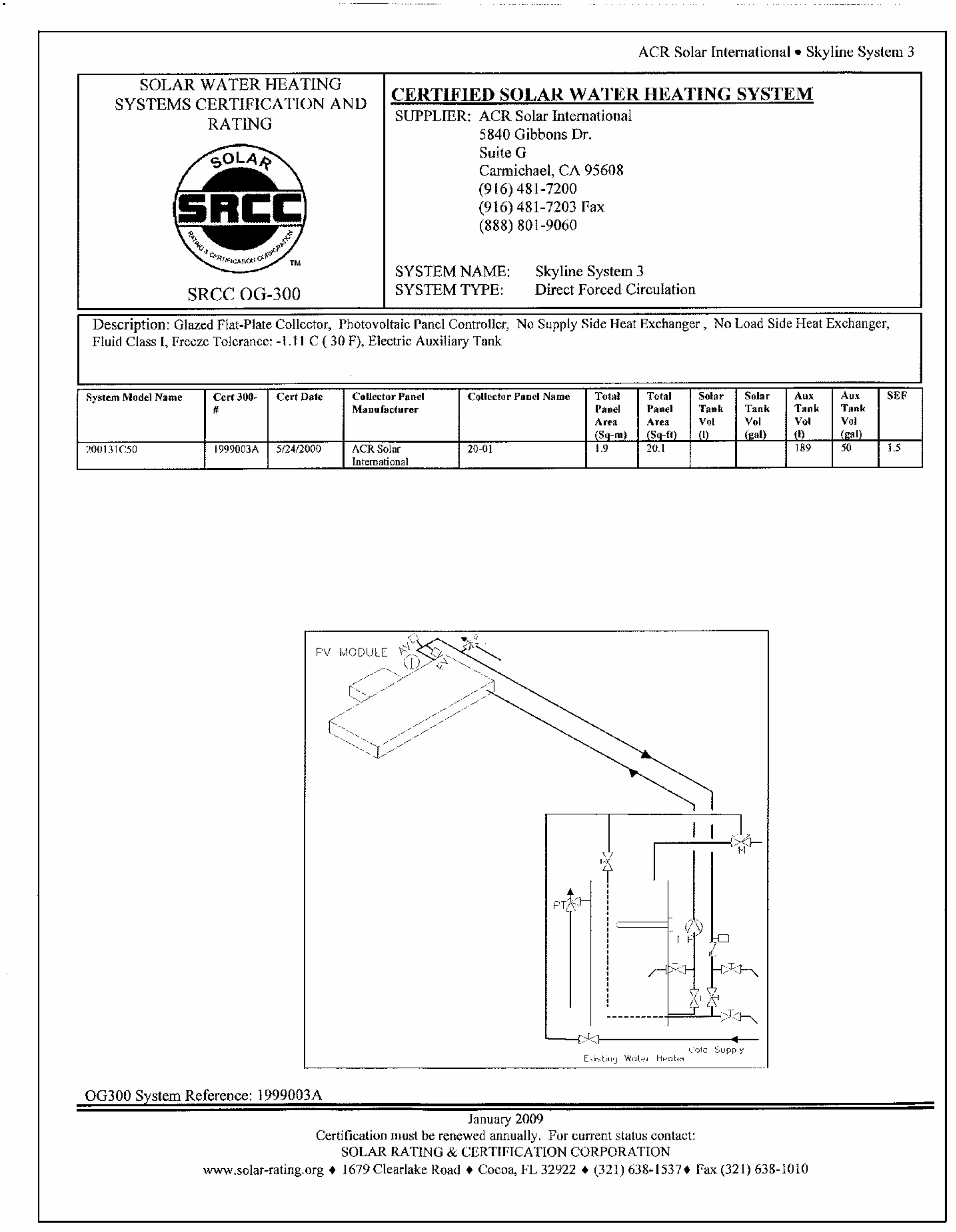
January 2009

Certification must be renewed annually. For current status contact:

SOLAR RATING & CERTIFICATION CORPORATION

c/o FSEC • 1679 Clearlake Road • Cocoa, FL 32922 • (321) 638-1537• Fax (321) 638-1010

11



ACR Solar International • Skyline System 3

SOLAR WATER HEATING
SYSTEMS CERTIFICATION AND
RATING

SRCC OG-300

CERTIFIED SOLAR WATER HEATING SYSTEM

SUPPLIER: ACR Solar International
5840 Gibbons Dr.
Suite G
Carmichael, CA 95608
(916) 481-7200
(916) 481-7203 Fax
(888) 801-9060

SYSTEM NAME: Skyline System 3
SYSTEM TYPE: Direct Forced Circulation

Description: Glazed Flat-Plate Collector, Photovoltaic Panel Controller, No Supply Side Heat Exchanger , No Load Side Heat Exchanger, Fluid Class I, Freeze Tolerance: -1.11 C (30 F), Electric Auxiliary Tank

System Model Name	Cert 300-#	Cert Date	Collector Panel Manufacturer	Collector Panel Name	Total Panel Area (Sq-m)	Total Panel Area (Sq-ft)	Solar Tank Vol (l)	Solar Tank Vol (gal)	Aux Tank Vol (l)	Aux Tank Vol (gal)	SEF
200131C50	1999003A	5/24/2000	ACR Solar International	20-01	1.9	20.1			189	50	1.5

OG300 System Reference: 1999003A

January 2009
Certification must be renewed annually. For current status contact:
SOLAR RATING & CERTIFICATION CORPORATION
www.solar-rating.org ♦ 1679 Clearlake Road ♦ Cocoa, FL 32922 ♦ (321) 638-1537♦ Fax (321) 638-1010

The OG-300 document lists a Solar Energy Factor for each model that is certified. The *Solar Energy Factor*, SEF, is a ratio of how much energy will be delivered by the solar heating system, compared to the electrical energy required to for auxiliary heating and the energy required to run other components of the system such as pumps, controllers, etc. Mathematically, the SEF is,

$$\mathbf{SEF} = \frac{Q_{DEL}}{Q_{AUX} + Q_{PAR}}$$

Where,
SEF = Solar Energy Factor
Q_{DEL} = Energy delivered by the solar system, BTU/day.
Q_{AUX} = Energy required by the auxiliary electric water heating tank, BTU/day.
Q_{PAR} = Energy required by the other equipment, such as pumps, etc, BTU/day.

Higher SEF ratios indicate that the solar system is supplying more of the water heating energy. Systems with PV-driven pumps have very little, if any, parasite energy consumption. A passive, direct connected solar water heating system without an auxiliary electric tank would have no auxiliary or parasitic energy consumption. In this case, the SRCC shows the SEF as 99.9, the highest value they assign.

This example has shown that basic steps in designing and sizing a solar water heating system. This process was shown for illustrative purposes only. Each situation is different and a professional solar installer should be consulted for an actual system design.

Summary

This course has reviewed the basics of solar hot water systems, including the components, calculations and sizing criteria for a residential system. Solar thermal systems are one of the more cost cost-effective renewable projects for a residential application. Still, it is not cheap. In 2009, solar hot water systems for residential applications cost between $5,000 and $8,000. With a solar factor of 50% these systems will save about $300 per year on water heating costs, so the payback is long. Federal tax credits and reduced construction costs may make the economics better in the future. However, for many people, the environmental benefits outweigh the economic evaluation and we are likely to see more roof top units in the future.

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