Chapter Seven
Components of Solar Water Heating Systems

Solar collectors, storage tanks, and anti-scald valves are components common to most solar domestic hot water systems. A variety of other components are required depending upon the specific system used. These include heat exchangers, expansion tanks, circulator pumps, differential controllers and sensors, and small solar electric panels. These components will be discussed in the pages that follow. Other components specific to individual systems will be discussed in Chapter Eight.

Solar Collectors

A solar collector can be as simple as a straight or spiral plastic pipe, placed on the ground and used to pre-heat water for a standard water heater. While this set-up works, it has its limitations. The pipe will cool off quickly at night and exposure to sunlight will degrade the plastic pipe in fairly short order. In Kentucky, the pipe would need to be drained in the winter to prevent it from freezing.

The amount of heat produced by solar collectors varies according to the specific collector model, the area of collector, and the local climate and site conditions. The Florida Solar Energy Center and SRCC certification systems rate collectors according to their efficiency and the amount of heat they provide per square foot of collector. This data is used for calculating the area of solar collectors needed for any given application, which also depends on the amount of hot water storage needed. The final section of this chapter describes how to estimate collector area and hot water storage capacity based on daily hot water demand.

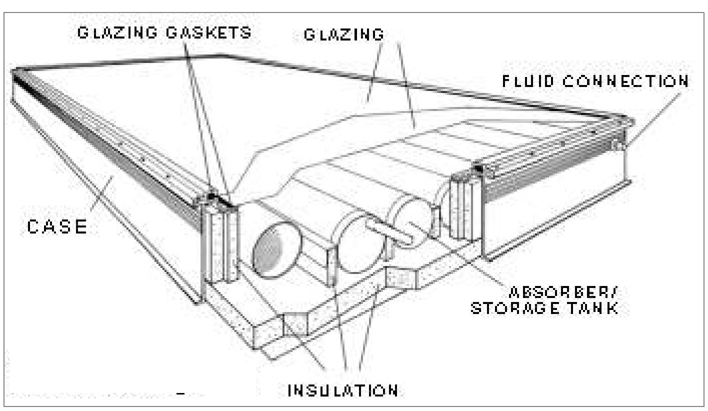

Figure 7.1: Cut-away of an integral collector storage (ICS) unit, *Back Woods Home Magazine, www.backwoodshome.com*[1]

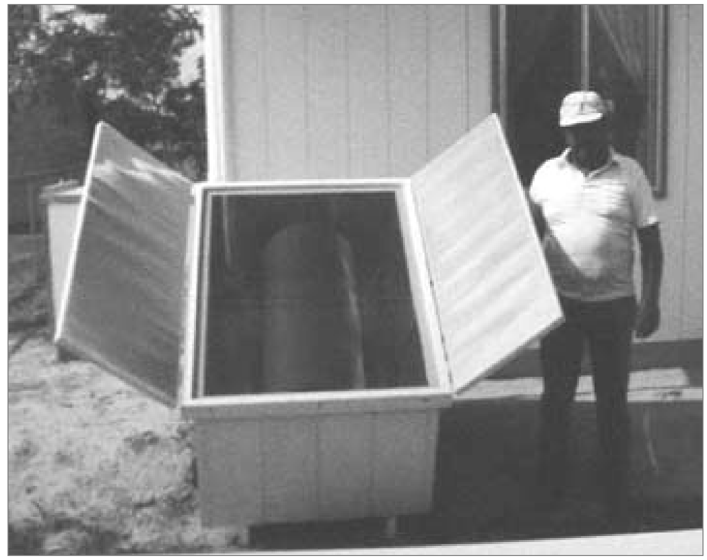

Figure 7.2: This batch solar water heater in South Texas provides year-round hot water, *David Omick*

Batch or ICS Collectors

In batch type solar water heaters (also known as integral collector storage (ICS) systems), the storage tank is built into the collector. The first commercial solar water heater, the "Climax" invented back in 1891, was of this type, as are the common solar shower bags used for camping. The solar water heater shown in Figure 7.2 is also a batch heater. It uses a recycled water heater tank inside of a glazed box. While batch collectors have the virtue of simplicity, they have no freeze protection and therefore are not suitable for year-round use in Kentucky, unless the water heater is built into a conditioned space. (See Chapter Eight for more information).

Flat Plate Collectors

The most common type of collectors used in areas that freeze in the winter are known as flat plate collectors (see Figure 7.3). These usually consist of an absorber plate made from copper pipe, thermally or mechanically attached to a tin or copper sheet blackened with paint or through an electrochemical process. Large copper pipe (3/4 to 1 ½ -inch diameter) header tubes run across the top and bottom of the absorber plate. Smaller copper pipes (½ inch diameter) run between the header tubes every three to six inches. The heating fluid (water or antifreeze) enters the collector at the bottom header pipe, which supplies

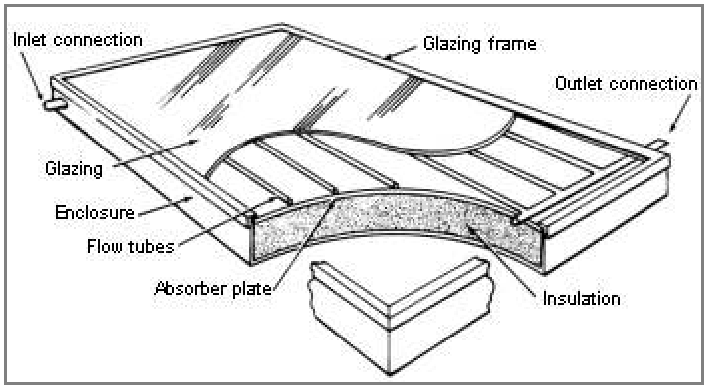

Figure 7.3: Cut-away view of a flat plate solar collector
Backwoods Home Magazine, www.backwoodshome.com[2]

the smaller vertical pipes. The fluid is heated as it flows to the top header pipe. The heated fluid then exits the collector out of the top header pipe. The absorber plate is placed in an insulated box shaped like a large shallow pan, with glass or plastic glazing placed over the exposed side of the box (facing the sun). The glazing allows the box and absorber plate to warm like a greenhouse, while slowing the rate of heat loss back to the sky. Collector sizes vary, ranging from 3 feet by 7 feet to 4 feet by 10 feet, with a depth of four to six inches. Manufactured collectors have boxes that are usually made from stainless steel or aluminum, while most homebuilt units are made from plywood. New flat plate collectors can operate for over 50 years, and they typically carry a ten-year warranty.

Homebuilt flat plate collectors can be durable when properly glued, screwed and sealed against weather. There are many plans available for making your own flat plate collectors. One, found in *The Homeowner's Handbook of Solar Water Heating Systems*[3], utilizes ready-made absorber plates around which a box is built. Absorber plates can be purchased at less than half the cost of complete manufactured collectors. One vendor's wholesale price for absorber plates ranges from $150 to $250, while their complete collectors wholesale for $400 to $600.[4] Many inexpensive used collectors are available that still have 20 or more years of useful life remaining. The experience of building one's own collector may help one appreciate how inexpensive used collectors really are.

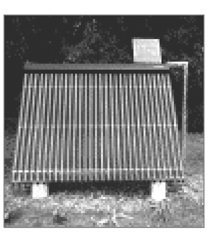
Figure 7.4: Evacuated tube collector, Thermomax. Inc.

Evacuated Tube Collectors

Evacuated tube collectors are more efficient than flat plate collectors and can heat water to temperatures between 170°F and 350°F. This feature makes them attractive for industrial applications, but they can also be used for domestic water heating when higher performance is desired in cloudy and cooler weather. They consist of rows of parallel transparent glass tubes, each containing an absorber plate covered with a selective coating to enhance heat absorption. A vacuum inside the tube minimizes heat loss, helping the collectors to achieve high temperatures. The absorber plate in each evacuated tube heats a fluid which transmits this energy to the water supply via a heat exchanger.


Figure 7.5: Evacuated tube collector doubles as an awning.
Thermomax, Inc.

Evacuated tube collectors are more fragile and more expensive than flat plate collectors and are typically only recommended when water temperatures from 180°F to 211°F are required. If temperatures above 212°F are needed, concentrating solar collectors are recommended. Flat plate collectors are usually the best choice for heating water from 120°F to 140°F, which is the temperature range for normal domestic hot water needs.[5] However, evacuated tube collectors can be a good option for use with solar space heating systems, since they can generate more heat during winter's cloudy weather.

Storage Tanks

Solar-heated hot water is typically stored in standard 60, 80, or 120-gallon hot water tanks. Even for systems designed for residential space heating, it is unnecessary to get a custom- made storage tank unless more than 480 gallons of storage is needed. In some situations a home's existing hot water tank can be used to store solar-heated water. An existing water tank may be suitable if it is the proper size, relatively new, and among the most-efficient models. Otherwise, a new water storage tank is probably recommended. Even if an existing tank is used, an additional hot water storage tank may be included in a solar water heating system.

Standard 60 to 120-gallon hot water tanks with integral (built-in) heat exchangers are available and can be preferable for systems requiring a heat exchanger. A heat exchanger is a device that transfers heat from one fluid to another- in this case from the solar heated fluid to the domestic hot water in the tank. Some integral heat exchangers are removable, while others are not. External heat exchangers are commonly used with conventional hot water tanks that do not have integral heat exchangers.

The choice between these three types of heat exchangers is often based on the expected lifetime of the tank. Hot water tanks can last just a few years or as many as thirty years, depending on water quality and maintenance practices. Ask a local plumber or salesman at a wholesale plumbing warehouse what the expected lifetime is in your area for standard glass-lined electric and gas water heaters. If tanks don't last long in your

Figure 7.6: A conventional electric water heater tank uses an external heat exchanger in the solar water heating system at the ASPI office in Mt. Vernon, Kentucky, *Andy McDonald*

area, you may opt for an external heat exchanger that can continue to function long after the water tank has been replaced. Tom Lane, a long-time solar installer in Florida, recommends using either an external or removable heat exchanger if the expected tank life is less than 10 to 12 years.[6] If average tank life expectancy exceeds 15 years, choose an integral heat exchanger (either removable or non-removable.)

Hard water may also affect choice of tank. As water is heated, its capacity to scale the insides of pipes, and especially heat exchangers, increases. In Kentucky, where rocks and minerals such as limestone, gypsum, fluorspar, magnesium, and pyrite are common, well water is often high in calcium content, and therefore considered "hard". If you find that your water leaves a hard film on surfaces or if you find it hard for soap to lather, you probably have hard water. In this case we recommend against using direct active systems (in which the heated water is pumped through the system) and advise care in choosing a heat exchanger for an indirect system (see Chapter Eight for more information on system types). A good tank choice for areas with hard water would be the Rheem/Rudd tank with wrap-around heat exchanger. This heat exchanger is the only type available that does not come in contact with the water. It consists of copper pipe wrapped around and in contact with the outside of the storage tank, but underneath the tank's insulation.[7]

Solar hot water tanks, unless already manufactured with R-17 or greater insulation, should be wrapped to achieve a minimum of R-17 insulation. If the tank is placed on a concrete slab, it should rest on a pad of two-inch rigid polystyrene insulation or wood strips to keep the tank off the floor. If insulation is added to the tank and it is stored in a conditioned space, place a plastic water heater drip pan under the tank to catch any condensation that might form.

Heat Exchangers

In an indirect solar water heating system, the fluid used to collect heat (propylene glycol or distilled water) is separate from the fluid that distributes it (e. g. household water). In virtually all systems of this kind a liquid-to-liquid heat exchanger is needed, to transfer the heat gathered in the solar collector to the household water. The radiator in a car is an example of a liquid-to-air heat exchanger, in which the heat from the engine is transferred to the air in order to cool the engine. Direct solar water heating systems (such as the batch, thermosiphon, and open loop active systems) do not incorporate heat exchangers because the household water is heated directly in the solar collector. Each of these solar water heating systems will be discussed in detail in Chapter Eight.

Heat exchangers used in domestic solar water heating are made from copper or stainless steel. The efficiency of a heat exchanger is increased with:

- Highly conductive materials that readily transmit heat
- High surface-to-volume ratio
- High difference in temperatures between the two fluids
- Sufficient flow rate
- Sufficient heat capacity of the fluids (specific heat)

The Uniform Solar Energy Code (USEC) requires double-wall heat exchangers in solar water heating systems when a fluid that is not potable is used for the collector loop. This provides two walls of separation between the two fluids, with the space between the two walls vented to the outside of the exchanger. Thus, if one wall fails, there will be a visible leak in the system before any potential mixing of fluids can occur. Well-made double wall heat exchangers reduce system efficiency by less than five percent. A conductive paste is often used in the space between the two walls to increase efficiency.[8]

During the solar water heating boom of the 1970's, many systems were installed using toxic ethylene glycol solutions (traditional car anti-freeze) in the collector loop. The double-wall heat exchanger made it impossible for the toxic solution to mix with the potable domestic hot water supply. Today, virtually all indirect systems use non-toxic propylene glycol solutions. However, double wall heat exchangers are still almost universally required in case someone should mistakenly add car anti-freeze to a system. Single wall heat exchangers are more efficient and are used with radiant floor home heating systems, hot tubs, and other non-potable applications.

Heat exchangers that are incorporated into the storage tank are ideal since they eliminate the need for the water side of the heat exchanger to be pumped through the exchanger. Some external heat exchangers can be mounted on the side of the storage tank to allow natural thermosiphoning to circulate water from the storage tank through the exchanger. However, on sunny days these systems will only collect 80 percent as much energy as a tank with an internal heat exchanger, and only 65 percent as much energy as a double-pumped heat exchanger. Double-pumped systems pump fluid from the collector through one side of the heat exchanger, and household water through the other side. While these systems are more efficient, they cost more to install, require more components that could potentially fail, and require more energy to operate the second pump.

A tank with an internal heat exchanger may offer the best balance of cost, complexity, and efficiency. They are more expensive than external thermosiphon heat exchangers, however, and only a limited number of manufacturers offer these types of tanks. In some internal heat exchanger designs, the heat exchanger can be removed from the tank and replaced. In other models it is welded to the tank and cannot be removed. For areas with hard water, one choice exists that minimizes the potential scaling that can occur with both internal and external heat exchangers. This is the Rheem/Ruud wrap around (integral) heat exchanger, which consists of a copper pipe wrapped around and in contact with the outside of the storage tank, but underneath the tank's insulation. Unfortunately, this design is currently available only in an 80-gallon tank with an electric element backup.

Anti-Scald Valve

Solar hot water systems with flat plate collectors can get as hot as 190° F during periods when no hot water is being drawn from the system (especially when the collector is exposed to many consecutive sunny days). Anti-scald valves assure safe temperatures at plumbing fixtures by mixing cold water into the hot water as it heads from the storage tank to the fixture. Only passive batch-type systems are safe without anti-scald valves. Mixing and tempering valves should NOT be confused with anti-scald valves. The output temperature of mixing and tempering valves can vary with changes in water pressure, whereas anti-scald valves can set the output temperature. Honeywell Sparco and Amtrol Inc. manufacture anti-scald valves.

Anti-Freeze Recommendations

The propylene glycol used in the solar collector needs to be mixed in solution with distilled water (see below for more information). In Kentucky, with average record-low temperatures around -20°F, a solution of 40 to 50 percent propylene glycol is recommended. To find out the specific amount of propylene glycol to use, follow the glycol manufacturers' recommendations for fluid concentrations, based on the lowest temperatures the solar collectors will be exposed to. Local freeze records can be found on-line at www.NOAA.gov. WARNING: Make absolutely sure not to use standard anti-freeze, toxic ethylene glycol.

Notes on Heat Exchanger Fluids[9]

1. The least expensive type of propylene glycol is sold at auto supply stores under the brand names "Prestone II Lotox" and "Sierra." These are sold as non-toxic automobile anti-freeze, but they work well in solar collectors. They should last for 10 years as long as the fluid does not suffer stagnation in the collectors (when the fluid does not flow at high collector temperatures due to a problem in the system. Stagnation leads to overheating, causing this type of anti-freeze to degrade, requiring replacement).
2. Many solar collector and system manufacturers recommend DOWFROST or DOWFROST HD "inhibited propylene-based heat transfer fluid (HTF)". An Engineering and Operating Guide on DOWFROST HD is available by calling 800-447-4369.
3. Camco manufacturing (800-334-2004 www.camco.com) makes an anti-freeze for solar systems called Premium BAN FROST 2000.
4. To prepare the proper propylene glycol solution, mix the glycol with distilled reverse osmosis or de-ionized water if the pH of the local water is below 7.5 and / or has excessive metals or chlorine content.
5. The pH of heat exchange fluid should be checked every two to three years. If the pH of the solution is less than 8 it was likely subjected to excessively high temperatures due to stagnation and should be replaced. The original problem allowing the stagnation to occur should also be resolved. If it was due to a power outage perhaps an uninterruptible power supply is in order. PH testers and pH litmus paper are available from Misco Products (1-800-358-1100). Do not use glycol solutions stronger than 50 percent. They will be too viscous for proper pump operation, especially solar-powered DC pumps.

Circulator Pumps

Active systems use one or more pumps to circulate heat transfer fluids between the collector and storage tank/heat exchanger, and/or to pump water from the tank through the heat exchanger. AC powered pumps are operated by standard household electricity. DC powered pumps use appropriately sized photovoltaic (PV) solar electric panels to operate. Regardless of the power source the most common pumps for solar hot water systems are the centrifugal type. These pumps have rotating blades that spin and discharge the fluid from the pump by means of centrifugal force.

Pumps should always be mounted on the supply side to the collector in an orientation that allows air to pass through freely. Thus, the intake and output are lined up vertically with the output facing up. Grundfos, Taco, and March manufacture AC pumps for solar hot water systems and March, Hartell, and El Sid manufacture DC pumps.

Direct systems should use stainless steel or brass pumps, since air commonly gets into the system, which can corrode cast iron pumps. Indirect systems commonly use cast iron pumps since they are not constantly exposed to oxygen in the system. See Chapter Eight for descriptions of direct and indirect systems.

Whole solar hot water system kits are available that often specify the pump(s) used. However, if you were to size the pump(s) yourself, you would need to calculate the total system head the pump needs to overcome at the flow rates necessary to transfer heat efficiently. Once this information is solved for, pump curves are available from manufacturers to determine the appropriate pump(s) needed. Explaining these calculations is beyond the scope of this Guide, yet they are critical when designing systems that use pump(s) powered with solar photovoltaics. If you are installing a system yourself, you may want to stick with pre-designed kits or defer pump sizing work to a professional installer. Otherwise, friction loss tables are available in plumbing reference books.

Differential Controllers and Sensors

Active systems that rely on AC powered pumps require a differential controller and sensors in order to know when the collectors are hot enough to warrant circulating the fluids, which transfers the heat from the collectors to the storage tank. The controller turns the pumps on and off based on the temperatures it senses on the output side of the collector and at the bottom of the storage tank. When the fluid in the collector is sufficiently hotter than the water in the tank, the pumps turn on, circulating the fluids and transferring heat from the collector to the water tank. When night falls and the temperature in the collector drops, the pumps turn off, preserving the heat within the water tank.

The collector sensor is clamped with a stainless steel clamp to the collector output pipe within two inches of the collector. If there is more than one collector the sensor is often clamped to the header between the collectors. The storage tank sensor is slipped under the insulation, in contact with the metal wall of the coldest storage tank in the system. The sensors change resistance as the temperature changes. The controller compares the resistance of the two sensors and turns on the pumps when a temperature differential threshold is met.

Small Photovoltaic (PV) Solar Electric Panels

Active systems that rely on DC powered pumps utilize a solar electric PV panel for power as well as for timing their operation. This occurs via the synchronous action sunlight has on the solar heat collector and the solar electric panel. As sunlight increases on the collector, the collector gets hotter and the PV panel generates more electricity, turning the pump faster and circulating more fluid. The PV panel should be placed in the same location and orientation as the solar heat collector.

It is important to match the PV module with the DC pump performance curve in order to assure that adequate flow (not too much and not too little) occurs in all circumstances- morning start up, overcast, afternoon waning, etc. PV module and DC pump matching is beyond the scope of this manual. Manufacturers have recently been reducing the variety of PV modules in this size range (5-30 watts) as larger PV systems are becoming commonplace. Meanwhile there has been an influx of different DC pumps available for solar hot water systems.

For further information on solar module and pump matching refer to *Solar Hot Water Systems, 1977 to Today: Lessons Learned.*[10] You can also ask the DC pump manufacturer what PV module is recommended with their pump given the collector area and the total system head your installation requires. You may want to defer these calculations to a professional installer.

Estimating Collector Size and Storage Tank Capacity for Residential Systems

For residential solar water heating systems that require freeze protection, flat plate solar collectors and separate hot water storage tanks would typically be recommended. The area of collector panels required depends on the amount of hot water storage needed. While numerous solar water heating systems and collector models are available, a general rule-of-thumb for Kentucky is that you need 1.0 square foot of collector for every 1.5 gallons of hot water storage.[11] While the actual collector area required will depend on

Table 7.1: Estimated Storage Tank Size and Solar Collector Area Based On Average Daily Hot Water Use		
Daily Hot Water Use	**Tank Size**	**Collector Area**
0-30 gallons	30 gallons	20 square feet
0- 40 gallons	40 gallons	27 square feet
41-60 gallons	60 gallons	40 square feet
61- 80 gallons	80 gallons*	54 square feet
81- 120 gallons	120 gallons	80 square feet
* If you use 61- 80 gallons per day, a 120 gallon tank may be more economical.		

Table 7.2: Flat Plate Collectors are sold in the following sizes	
Dimensions	**Area**
4 feet x10 feet	40 square feet
4 feet x8 feet	32 square feet
4 feet x7 feet	28 square feet
4 feet x 6.5 feet	26 square feet
3 feet x8 feet	24 square feet
3 feet x7 feet	21 square feet

several factors, including the specific collector model and the available sunlight where the collector will be mounted, this rule-of-thumb can give you a general idea of how large your solar collectors need to be.

The hot water storage tank should be large enough to hold the amount of hot water used in a typical day, so figure out how much hot water your family uses each day. Table 7.1 shows what size tank you'll need based on your hot water use. (The average American family uses 20 gallons of hot water per day per person for the first two people, and 15 gallons per day for each additional person. Thus, a typical family of four will need 70 gallons of hot water per day.)[12] Note that if you need more than 60 gallons per day, a 120-gallon tank may be more economical than an 80-gallon tank.

Once you know the size of the storage tank, divide that by 1.5 to estimate the area of the collector panels. Bear in mind that the collector area required is based on the size of the storage tank, not actual daily usage. This is because the collector will need to heat all the water in the storage tank whether it is used or not, and the storage tank should be at least slightly larger than household demand (because storage tanks are only made in limited sizes, i.e. 30-40-60-80-120 gallons). With this ballpark figure in mind, you can estimate the cost of equipment needed for your system. A solar equipment vendor or installer can then help you integrate the other variables that influence collector and tank size, enabling you to purchase the system that's appropriate for your circumstances.

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End Notes

1. M. Hackleman, "Seven Solar Water Heating System Designs," Back Woods Home Magazine, # 65. Article available on-line at www.backwoodshome.com/articles/hackleman65.html
2. Ibid.
3. B. Keisling, *The Homeowner's Handbook of Solar Water Heating Systems*, Rodale Press, Emmaus, PA, 1983, p.116.
4. Prices according to Alternative Energy Technologies, Jacksonville, Florida, www.aetsolar.com, September 2004.
5. Tom Lane, *Solar Hot Water Systems 1977 to Today, Lessons Learned*, 26th Edition, Energy Conservation Services of North Florida, Inc., Gainesville, FL, 2003, p. 69.
6. Ibid, p.8.
7. Rheem/Ruud 80 gallon heat exchange tanks are available nationwide. Rheem/Ruud Manufacturing Corporation, 5780 Peachtree-Dunwoody Road NE, Atlanta, Georgia 30342, Tel: 800-621-5622.
8. Chuck Marken, "Heat Exchangers for Solar Water Heating," Home Power Magazine #92, p. 69.
9. Tom Lane, pp.33 and 51.
10. Ibid, pp. 39-45.
11. Ken Olson, "Solar Hot Water: A Primer," 2001. Available on-line at www.azsolarcenter.com/technology/solarh2o.html
12. Tom Lane, p.97.

Figure 7.7: Solar water heater at Berea College.
Andy McDonald