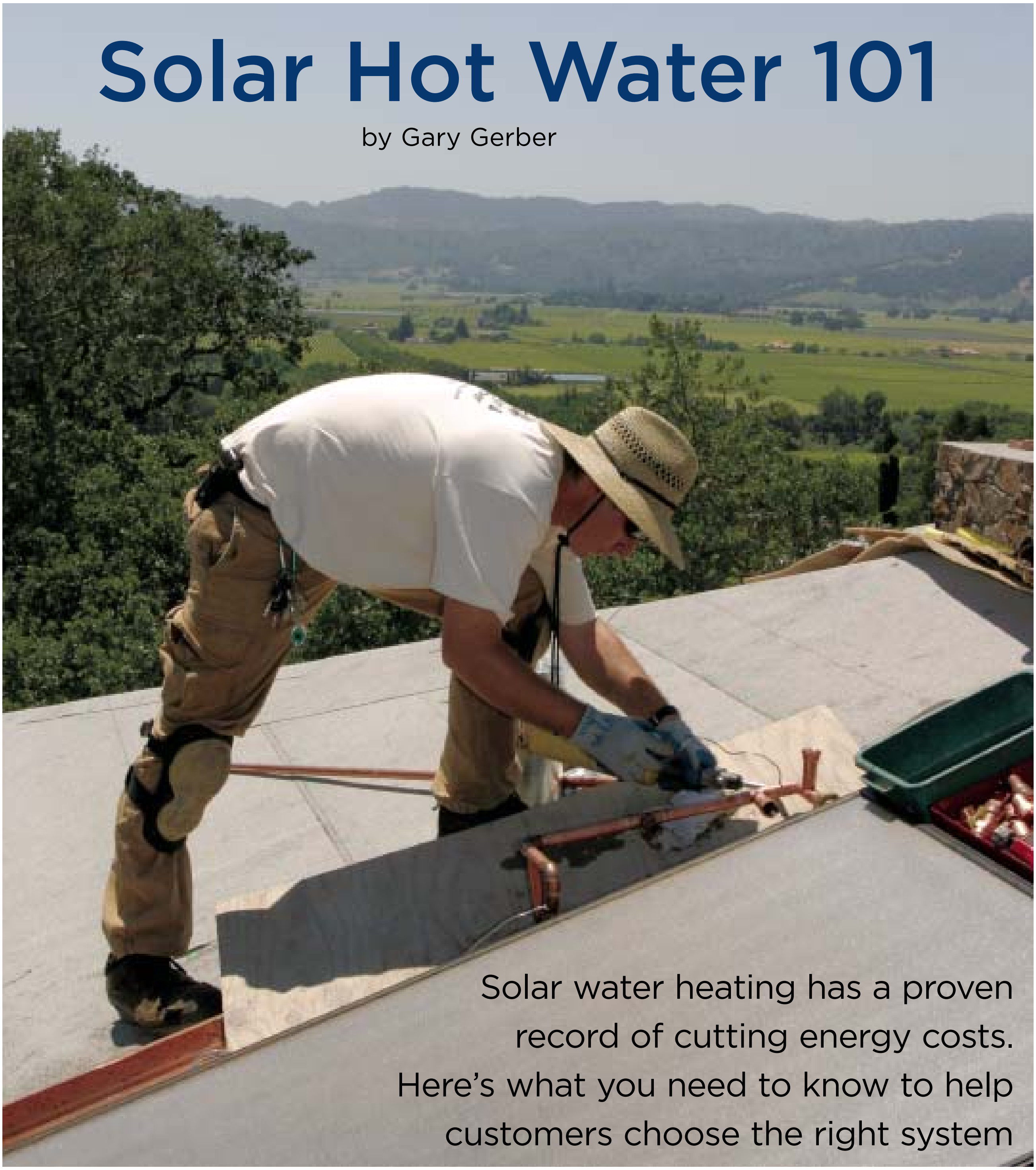
Solar Hot Water 101

by Gary Gerber



Solar water heating has a proven record of cutting energy costs. Here's what you need to know to help customers choose the right system

My company has been designing and installing alternative energy systems since 1975; to date, we've installed more than 1,000 solar water heating systems. Lately, as energy prices rise at an ever-accelerating rate, we've seen renewed interest in solar hot water.

A simple solar hot-water system can be installed for as little as $4,000, while a larger and more complicated freeze-protected system can cost as much as $10,000. Thanks to the recently signed energy bill, the customer's cost is about to fall; the bill grants a 30 percent federal tax credit to property owners who install solar energy systems in 2006 and 2007

Figure 1. Flat-plate collectors range in size from 3 by 6 feet to 4 by 12 feet and are light enough to be carried by hand (above). Because the tubing inside is of small diameter, even a large collector might contain only a gallon or two of fluid.

(see "Incentives Sweeten Energy Bill for Builders and Homeowners," *In the News,* in this issue). Homeowners can claim a credit of up to $2,000; for business owners, there is no cap on the credit.

In areas where natural-gas water heaters are the norm, the payback period for a residential solar water heating system will be 9 to 12 years if the value of the credit is included. Because a well-designed system will last 20 to 30 years, it should pay for itself two to three times over. If the system saves $250 worth of natural gas the first year and gas prices escalate 5 percent per year, then it will save almost $17,000 over 30 years. If the homeowner is currently using an electric water heater, the savings may top $40,000.

On the environmental side, heating water with the sun will typically reduce a home's greenhouse gas emissions by 18 tons over the life of the system. With an extra 60 to 120 gallons of hot water at their disposal, homeowners can take long, guilt-free showers. We often equip our solar hot-water systems with valves that allow the customer to completely shut off the backup heater and use only solar-heated water in the summer.

Solar Water Heating Basics

All solar water heating systems contain collection, storage, and transfer components; some systems combine all three into a single element. Most systems are designed to preheat water that goes to a backup heater — typically a conventional gas or electric water heater. A tankless heater will also work as a backup, as long as it is designed to accept hot-water input (not all of them are).

Although there are some systems in which the preheated water flows directly to the backup, it's more common for the preheated water to be stored in a separate storage tank upstream from the backup. In hot, sunny weather, the backup is rarely if ever needed, but during cloudy periods it may have to provide virtually all the domestic hot water.

Collection. The most visible part of any solar hot-water system is the collector. There are three main types of collectors, but all basically consist of a black collecting surface that transfers heat to a fluid. The collecting surface is typically enclosed in an insulated aluminum box with clear glazing to trap the heat.

A flat-plate collector — which is about 3 inches thick — contains a grid of copper tubing attached to an aluminum or copper plate (see Figure 1). Both components have a black surface coating; when sunlight hits the plate, heat is conducted to the fluid inside the tubing. Sensors measure the temperature in the collector, and when it's hotter than the fluid in the system's storage tank, an electronic controller activates a pump to move the heated fluid to the tank. The uninstalled cost of a 4-by-8-foot flat-plate collector is approximately $750.

An evacuated tube collector is similar to a flat-plate collector except that the heat-absorbing tubes are housed in a series of evacuated glass cylinders. The vacuum insulates against heat loss in the same way that a thermos bottle does. Evacuated tube collectors are extremely efficient, but cost about twice as much as conventional flat-plate collectors.

In an integral collector storage —

Figure 2. Integral collector storage — or ICS — units contain 4-inch-diameter pipes in which water is heated and stored (far left). Because of their weight, they are typically craned into place (left). Potable water enters through a pipe at the lower end, is heated by the sun, and exits through the upper end (above) when a hot-water tap is turned on.

or ICS — unit, water is heated and stored in a series of interconnecting tubes in a roof-mounted box. Sometimes called batch heaters, ICS systems are simple and inexpensive because they require no pumps or controls. However, since they store water in an exposed location, they are subject to high heat loss and freezing (Figure 2). A 42-gallon ICS unit costs about $2,100 uninstalled.

Storage. Solar energy is available only for the six to 10 hours that the sun is out, so heated water must be stored for later use. While ICS systems store hot water right in the collector, most other systems keep it in a separate storage tank located upstream from the backup heater. Because the tank has to hold an entire day's worth of hot water, it is

Figure 3. An installer plumbs an 80-gallon storage tank for a pumped system (left). The tank has taps for supply and return lines to and from the collector, plus a cold-water supply inlet and a hot-water outlet to the home (below).

larger than a conventional heater.

There are some systems that send solar-heated water directly to the backup, but I'm not a fan of doing this with a conventional backup heater. Because it's too small to hold an entire day's worth of water, this kind of heater will short-cycle and heat the water before the sun has a chance to do its job.

In pumped systems, storage takes place in a pressurized steel tank that resembles an electric hot-water heater. Usually located near the backup heater, this storage tank connects to the collectors with copper pipes (Figure 3, previous page).

ICS and thermosiphon systems are pumpless. Water moves through the ICS unit but does not circulate within it. Within thermosiphon systems, which rely on the principle that hot water rises, water circulates between the collector and a tank above.

Transfer. Solar hot-water systems can be categorized according to their method of heat transfer and freeze protection. In open-loop — or direct — systems, potable water flows through the collector and is heated there. In closed-loop — or indirect — systems, the liquid in the collector is isolated from the potable water and transfers heat to it with a heat exchanger next to or inside the storage tank.

Closed-loop systems provide the best freeze protection because the liquid in the collector is chemically or mechanically protected from freezing. Open-loop systems, on the other hand, are subject to freezing because the collector contains potable water. While it's possible to provide some freeze-protection to open-loop systems, I don't recommend installing them in climate zones where there are hard freezes more than once every five years.

On the following pages, I'll describe the most common system designs, ranging from simpler passive systems to more complex active systems.

Integral Collector Storage (ICS) System

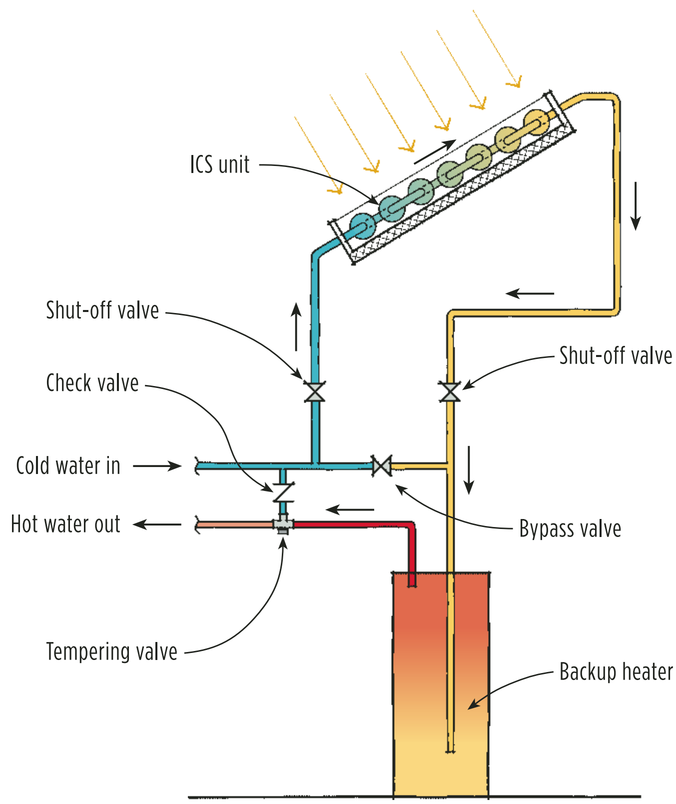


Figure 4. Since ICS heaters both heat and store water in the rooftop collector, they can be quite heavy, requiring reinforced roof framing. They are not well-suited for cold climates.

Integral Collector Storage

In an ICS system, potable cold water is piped into a roof-mounted unit and preheated by the sun on its way to the backup heater. Water moves through this system only when a hot-water tap is opened (Figure 4). An ICS system is simple and relatively inexpensive, but a lot of heat can be lost through the glass, so the backup has to run if the client wants hot water first thing in the morning.

Early manufacturers of ICS systems simply placed a single bulk storage tank within a glass-covered insulated enclosure aimed at the sun. Newer designs typically consist of an interconnected series of 4-inch-diameter copper tubes in an 8-inch-deep insulated box with glazing on top.

With a capacity ranging from 20 to 50 gallons, these collectors can be quite heavy. They are also subject to freezing, because the water is stored on the roof.

Thermosiphon System

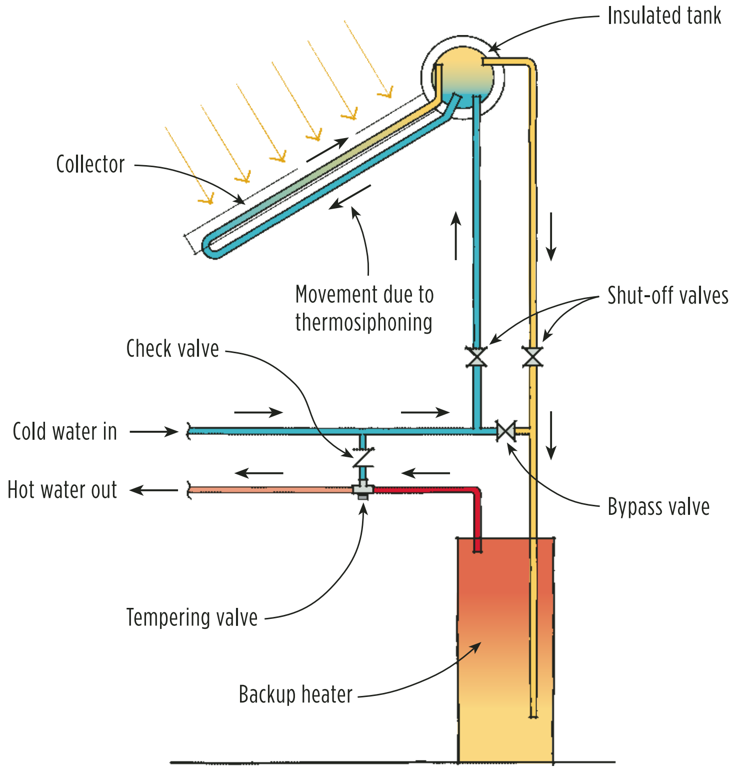


Figure 5. Thermosiphon units rely on convection to move hot water from the collector to the storage tank, which is mounted right above the collector. As hot water rises into the storage tank, cool replacement water enters at the bottom of the collector.

Figure 6. The author's crew always installs a freeze drip valve on the outlet side of the collectors on open-loop systems. If the temperature drops below 35°F, the valve drains enough water from the collectors to bring warm replacement water up from the house.

Thermosiphon Systems

Like an ICS system, a thermosiphon system has no pump, but it's more efficient because it separates heating and storage functions. When sunlight hits the collector, the liquid inside heats up and becomes buoyant, then flows up to the storage tank, which is located above the collector. It's replaced by cooler liquid that flows down from a separate line on the bottom of the storage tank (Figure 5). While a pump would certainly speed up the recirculation process, the convective flow is more than adequate

Figure 7. Because it's located in a warm climate, this thermosiphon unit contains potable water. Closed-loop thermosiphon systems containing glycol are also available for areas where freezing temperatures are common.

to move the entire contents of the tank through the collector several times per day in sunny weather.

Thermosiphon systems are available in both open-loop and closed-loop configurations. In the open-loop version, the collector contains potable water, whereas the closed-loop version contains a glycol mix that flows to a heat exchanger surrounding the tank.

Two mechanisms provide freeze protection in an open-loop thermosiphon system. Water gets lighter just before it turns to ice, creating a "reverse thermosiphon" that pulls warm water down from the tank. I don't rely on this phenomenon alone, however; we also install a freeze drip valve, which opens when the collector temperature reaches 35°F (Figure 6, previous page). This bleeds water from the collector and brings warm replacement water from the tank. Normally, the freeze valve won't open unless the primary protection fails.

Since they don't involve any pumps or controllers, thermosiphon systems are simple and extremely reliable. But, because the tank is outside, they have low flow rates and high storage losses, making them less efficient than pumped systems. Also, the tank in these systems is typically mounted on the roof, which means there are aesthetic and structural issues to deal with, too (Figure 7, previous page).

Open-Loop Recirculation System

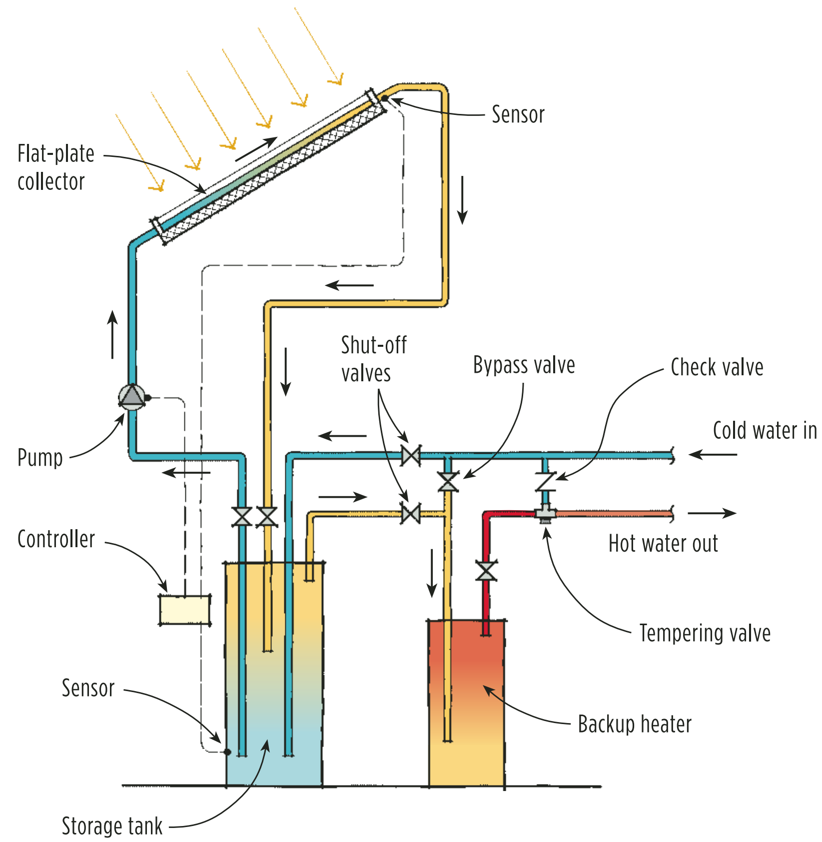


Figure 8. In an open-loop recirculating system, a sensor-activated pump moves water between the collector and the storage tank whenever the collector's temperature is warmer than the tank's. When the temperature drops, the sensor activates the pump to bring warm water from the tank back into the collector to protect against freezing.

Open-Loop Recirculation

In an open-loop recirculation system, pressurized potable water is actively pumped between the collectors mounted on the roof and a storage tank installed inside the house (Figure 8). Heat sensors wired to an electronic controller activate the electric recirculating pump — typically whenever the collectors are 5°F warmer than the tank. This "differential" control causes the pump to run continuously as long as the sun is out (Figure 9, next page).

If the weather gets cold enough, the collector could freeze and burst, so when the controller senses an imminent freeze the pump comes on and brings warm water up from the indoor tank. It shuts off once the collectors reach 40°F. While this is a simple method of freeze protection, it's not particularly energy-efficient, and there are several ways it might fail: Power may go out, the pump can stop working, or a sensor or controller might malfunction. So, again, we always install a freeze drip valve just in case.

Although more expensive than such passive systems as thermosiphon and ICS, open-loop recirculation costs less than other types of pumped systems.

Closed-Loop Antifreeze System

A closed-loop antifreeze system is designed for areas with moderate to frequent freezing. These systems resemble pumped open-loop systems, except they have additional components like a

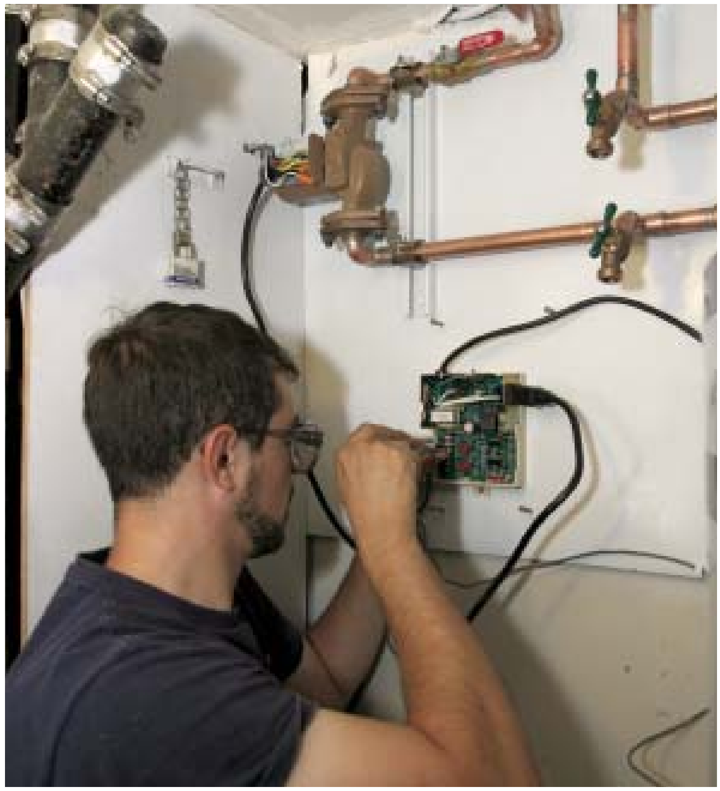


Figure 9. An the installer inserts a heat sensor into a flat-plate collector (above left); this sensor and another one on the storage tank connect to an electronic controller (left) that activates the pump (top center in photo above) whenever the collector is 5°F hotter than the tank.

heat exchanger, two independent sets of pipes, and sometimes a second circulating pump. One pump circulates antifreeze between the collectors and a heat exchanger, while the other circulates potable water between the heat exchanger and the storage tank (Figure 10, next page).

A typical heat exchanger consists of a pair of concentric copper pipes; liquid from the collectors flows through one pipe and potable water flows through the other. The liquids don't mix, but heat transfers easily though the conductive wall of the inner pipe. It's also possible to exchange heat by running heated fluid through a coil inside the storage tank or backup heater, but an external heat exchanger is usually less expensive and easier to repair.

Because the liquid in the collectors contains a mixture of propylene glycol and water, it won't freeze. Unlike the ethylene glycol used in automobile radiators, this antifreeze is a nontoxic food-grade additive, so if a leak in the heat exchanger did occur, the worst that would happen to the homeowner is that the water might taste sweet. Good-quality antifreeze in a well-designed system should last at least 10 years. But because antifreeze can degrade and become acidic enough to damage the system, it should be periodically replaced.

This type of system is virtually immune to freezing, but the heat exchanger, additional pump, and antifreeze increase the cost of the system.

Drain-Back System

A drain-back system is a closed-loop system that relies on a pump to lift distilled water from a nonpressurized indoor reservoir and move it through the collector. When the outdoor temperature is high enough and the collector is warmer than the reservoir, the pump comes on and circulates water between the reservoir and collector. When the pump is off, gravity causes the water to drain out of the collectors and into the reservoir below. The controller won't activate the pump when the outdoor temperature is close to freezing; this keeps water out of the collector, which protects the system (Figure 11, next page).

Solar-heated water is stored in the reservoir and transferred to the potable water with an internal or external heat exchanger. In some designs, a second pump moves water between the heat exchanger and the storage tank. In others, the reservoir is the tank, so there's no need for a second pump.

Drain-back systems provide trouble-free, reliable freeze protection because the closed side of the loop contains distilled water, which, unlike glycol, doesn't require periodic replacement. On the other hand, drain-back systems require greater pump power to lift fluid to the collectors.

Closed-Loop Antifreeze System

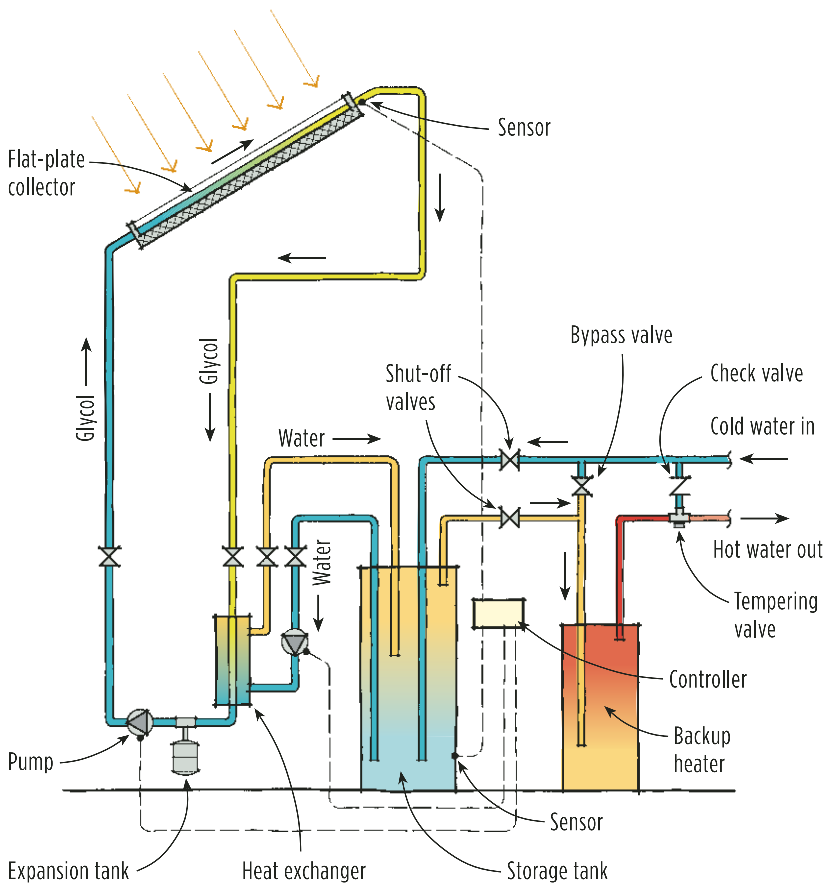


Figure 10. Designed for cold climates, closed-loop antifreeze systems use glycol to protect the collector. This requires a heat exchanger to transfer heat to the potable water, and a second pump to circulate domestic water between the heat exchanger and storage tank.

Designing the System

Because there are bound to be periods when the sun doesn't shine for several days in a row, there's no point in trying to design a solar hot-water heating system that provides 100 percent of the total yearly hot-water demand. We typically aim for 60 percent to 80 percent capacity, with the backup heater providing the rest.

As a rule of thumb, we assume that each person in a household uses 20 gallons of hot water per day, so a family of four would need an 80-gallon storage tank. In our mild San Francisco Bay–area climate, 1 square foot of collector will produce about 1.5 gallons of hot water per day, so a system with an 80-gallon tank requires 53 square feet of collector. Since collectors aren't available in that size, we would install two 4-by-8-foot collectors (Figure 12, next page).

The relationship between collector and tank varies by climate. In the Sun Belt, the rule of thumb is 1 square foot of collector per 2 gallons of tank capacity (daily use). In the Southeast and Mountain states, this ratio is 1-to-1.5, in the Midwest and Atlantic states it's 1-to-1, and in the Northeast and Northwest it's 1-to-.75

Orientation. It's generally best to face the collectors due south, though in some cases it's wise to account for local weather patterns. For example, in the San Francisco Bay area there are a lot of overcast mornings, so we prefer to orient collectors slightly more to the west.

For optimal annual collection, collectors should not face straight up, but should be tilted above horizontal to an angle 5 to 10 degrees higher than the lati-

Drain-Back System

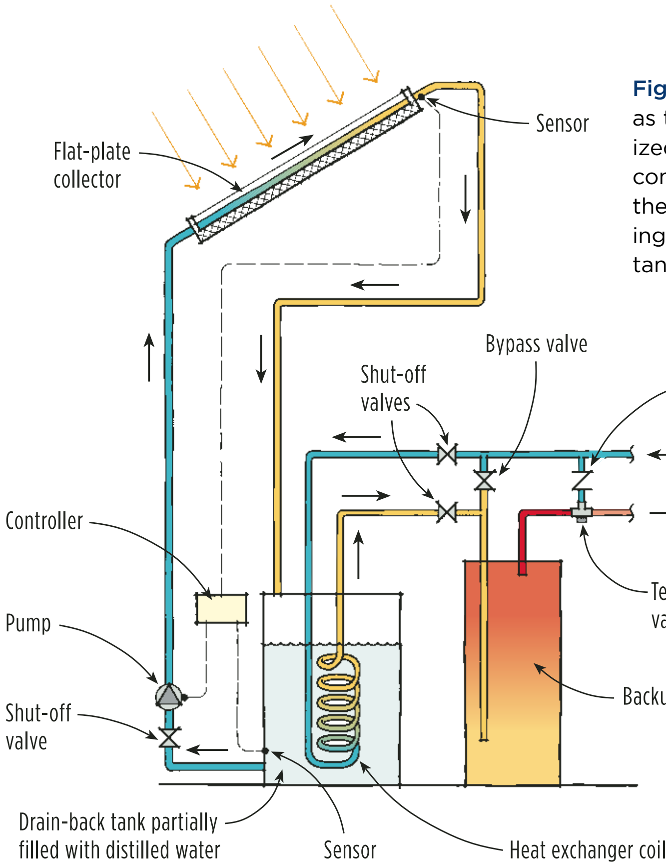


Figure 11. A drain-back system uses distilled water as the collector fluid, pumped from a nonpressurized indoor holding tank. The circulator pump runs continuously while heating conditions are good, then shuts off when the temperature drops, allowing the water in the collector to drain back to the tank, thereby preventing freeze damage.

tude at which they are located. Our latitude is 38 degrees, so ideally the collectors would be tilted 43 to 48 degrees. The steeper angle makes for better wintertime solar collection, when the sun is lower in the sky. In cases where aesthetic concerns trump efficiency, we'll install the collectors at the same pitch as the roof.

Temperature rise. When an actively pumped system has been properly sized, each exchange of water will increase the temperature in the storage tank 10°F. On an average day, there might be eight ex-

Figure 12. A pumped system typically contains more than one flat-plate collector (left). To allow for easy installation and repair, the author joins the collectors with unions (above).

Figure 13. When this system is up and running, the gauges (top) will show how much heat the water gains as it passes through the collectors. Because the water may become too hot to safely use, the author always installs a tempering valve to prevent scalding (above left). A pressure-relief valve (in the center of the photo above right) opens if the collector itself gets too hot; the cylindrical valve at the top automatically bleeds air from the system.

changes, creating a total temperature rise of 80°F; in hot, sunny weather it could be more. Our systems routinely reach 180°F in the summer, especially when water usage is low. This water would be too hot to use safely, so to prevent scalding we install a tempering valve downstream from the backup heater.

Excessive pressure can build up in the collectors if they get too hot, so as a matter of course we install a pressure-relief valve on the pipe where fluid exits the collector or group of collectors. A closed-loop system will have a pressure-relief valve on the roof and, if the loop contains glycol, an expansion tank in the building (Figure 13).

Installation

The lines to the roof are usually 3⁄4-inch copper. We don't use PEX because in California it's illegal to use it for potable water — plus the high temperatures found in the closed loop of a glycol sys-

Solar Orphans

In the early 1980s, hefty tax credits and high energy prices led to a boom in the installation of solar water heaters. A lot of people entered the business and installed all kinds of equipment, then went under after the tax credits expired and energy prices fell in 1986.

Whereas some of these systems were quite good, others were experimental, and with so many solar companies out of business, there were few qualified people around to maintain and repair them. As a result, many of the older systems failed and gave a black eye to a legitimate technology. Our company runs into these orphaned systems all the time; some are still going strong while others have been "broken" for many years.

Bad advice. When homeowners move into a house with a nonfunctioning system, they're almost always advised to tear it out. Unfortunately, most of the people giving this advice — plumbers, roofers, and GCs — don't know anything about solar water heating.

An experienced solar hot-water installer can tell you which systems should be torn out and which can be repaired. If the system was built with high-quality components and the collectors have never frozen, there's a reasonable chance it can be saved.

Inexpensive repairs. Our repair crews have revived any number of systems by making a few inexpensive repairs. Sometimes it's a matter of spending $450 (including labor) to replace a pump. A leaking storage tank can be replaced for just over $1,000, which may seem like a lot, but it's a small price to pay to repair a system that would cost $6,000 new.

The most common problem with a pumped system is a failed sensor or loose wire. These repairs may cost only $100, but most plumbers don't know how to make them.

Sometimes the problem is simply that the homeowner doesn't know how to turn on the system.

Old solar systems, like the one on this original wood roof, may no longer be operable but can often be put back into service for a reasonable cost.

tem could easily be too hot for it.

On new work, we run the lines up through the house. Because we work in a mild climate, on retrofits we usually run pipes down the exterior of the house. We insulate all the pipes that carry hot or recirculated liquid with 3/4-inch neoprene, which handles high temperatures better than plastic foam insulation does. Without UV protection, the sun will destroy this insulation in less than five years, so we jacket it with aluminum (Figure 14).

Another option is to protect the insulation with a painted coating, but a metal jacket looks better.

Structural issues. To install the collectors, we use the same mounting hardware we use to install the roof-mounted portions of a photovoltaic system (see "Installing Solar Electric Power," 3/05). The best approach is to install post mounts before the roofing material goes on, but it's also possible to retrofit various mounting brackets over the shingles.

Weight is rarely a concern with flat-plate collectors, the largest of which weigh less than 175 pounds even when full of water. But a full ICS unit might weigh 500 pounds, and the system might require more than one unit. In such a case, it's important to find out if the roof can carry the load.

Power needs. Most pumps will run on less than one amp of electricity, so inspectors often allow us to tie into an existing circuit or share a circuit with another load in new construction. A few inspectors require us to install a separate circuit. In some jurisdictions, it's legal to plug pumps and controllers into wall receptacles, which we do whenever possible to reduce wiring costs.

***Gary Gerber** is the owner of Sun Light & Power in Berkeley, Calif. He has been in the solar business since 1975.*

Figure 14. The author's crew insulates every pipe that contains hot or warm water. Here, an installer protects the neoprene insulation with an aluminum jacket.