Solar Hot Water for Cold Climates

Closed Loop Antifreeze System Components

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If you want a solar hot water system for your home and you live where it freezes, this article is for you. If you're installing your own system, it will help you get the right parts for a system that works. If you're planning to hire a professional, it will help you know what you're getting.

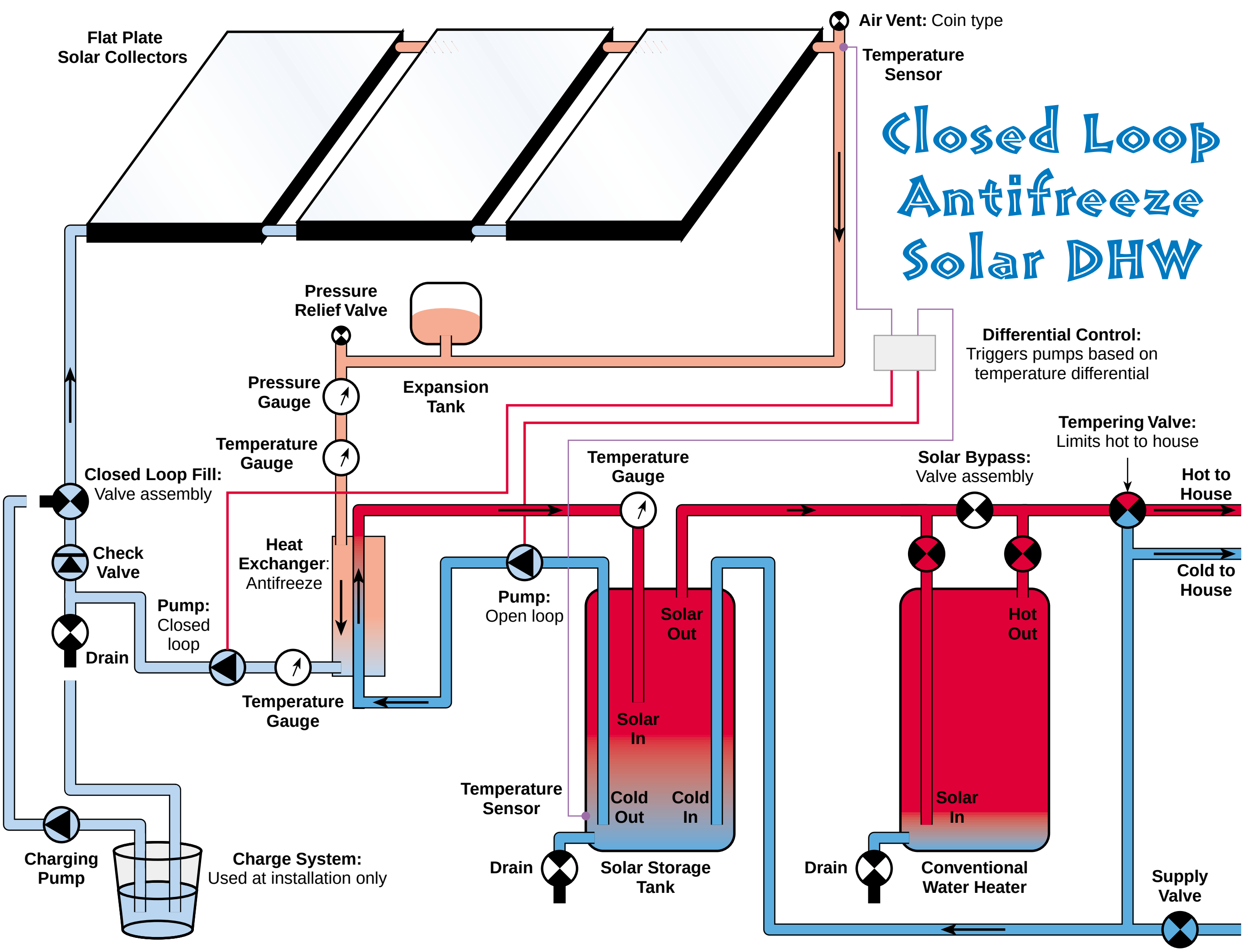
Solar Hot Water: A Primer (HP84) covered the fundamentals of solar hot water heating systems, including collectors, different types of systems, and rules of thumb for sizing. In this article, I focus on one system that is commonly used for solar hot water in freezing climates. You will learn the principles and parts that make up the "closed loop antifreeze" type solar water heating systems.

Closed Loop Antifreeze Systems

"Closed loop" is a general term for any portion of a hydronic heating system that is filled with a fluid at the time of installation. These systems remain closed to renewed supplies of corrosive oxygen. Open loop systems handle new water on a frequent basis, and must resist the deteriorating effects of exposure to a recurring supply of oxygen.

A "closed loop antifreeze" system is nearly identical in design to a conventional hydronic heating system; it simply uses solar collectors in place of a boiler. A hydronic heating system is any system that uses a fluid such as water, antifreeze, or oil as the medium of heat transfer. A "boiler" is where the fluid is heated. A closed loop solar hot water system includes

A closed loop module groups the major components on one board. This homebrew model by the author has functioned without fail since 1982.

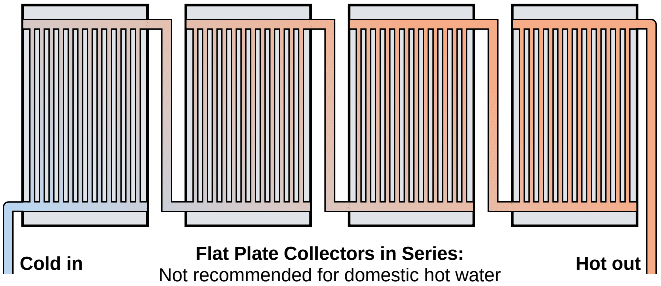


a closed loop and an open loop. The solar collectors are part of the closed loop. The open loop portion circulates the domestic water to be heated.

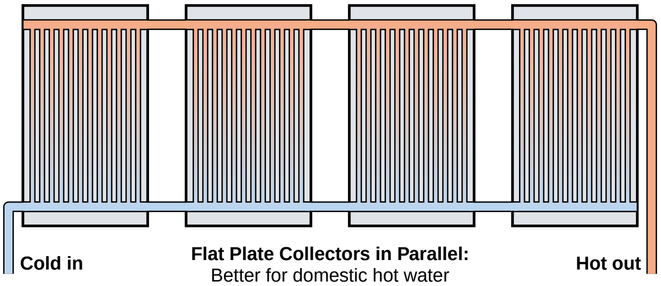
The major parts of a closed loop, antifreeze type system include solar collectors, circulating pumps, a differential control with sensors, heat exchangers, and storage tank. Lesser but essential parts include an expansion tank, pressure relief valve, check valve, drain/fill assembly, and pressure and temperature gauges.

Flat plate solar thermal panels are connected in parallel, and usually installed on a roof or mounted on a ground structure. The closed loop components can be pre-assembled into a "module" that can be fastened to the wall near the solar storage tank. Finally, the heat exchanger, solar storage tank, and collectors are connected to the closed loop module. Let's take a closer look at the function of each of these components.

Flat Plate Collector Interconnection



Flat Plate Collectors in Series: Not recommended for domestic hot water



Flat Plate Collectors in Parallel: Better for domestic hot water

Collectors

Flat plate collectors are most commonly used for low-temperature applications (up to 140°F; 60°C), such as residential domestic water heating and pool heating. Water passes through parallel copper tubes bonded to a flat copper sheet under glass, all enclosed in a weathertight insulated frame. For higher temperature applications (over 140°F), evacuated tube collectors are more efficient. The design of evacuated tube collectors reduces heat loss caused by convection, radiation, and conduction. (Flat plate and evacuated tube collectors were discussed in *HP84.*) To locate a supplier of solar collectors in your region, contact the American Solar Energy Society or the Solar Energy Industries Association or check your local yellow pages.

A flat plate (left) and an evacuated tube (right) solar collector.

Circulating Pumps

Centrifugal-type circulating pumps are most commonly used in solar hot water systems and hydronic heating applications. Centrifugal circulating pumps are appropriate for their low power consumption, low

Fluid Basics

Fluid Flow

Rule of Thumb: For optimum flow rate through flat plate collectors, provide about 0.015 gallon (0.057 l) per minute (gpm) for each square foot (0.09 m^2) of collector. That translates roughly into about 1/3 gallon (1.3 l) per minute for each 3 by 8 foot (2.2 m^2) collector, and 1/2 gallon (1.9 l) per minute for each 4 by 8 foot (2.97 m^2) collector.

This will result in a 15 to 20°F (8–11°C) rise in temperature from inlet to outlet of the collector. Higher flow rates are unnecessary and use more electricity, but are not detrimental to performance. Lower flow rates result in less thermal efficiency because the collector runs hotter and loses more heat to the ambient environment. If you are using evacuated tube collectors, you could safely double the flow rate per square foot of collector.

Pressure & Head

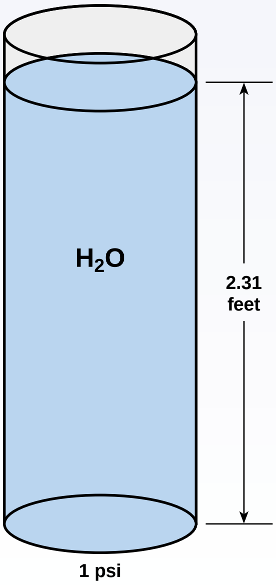
A column of water 2.31 feet (0.7 m) high exerts a pressure of one pound per square inch (psi). Therefore, 2.31 feet of head is equal to 1 psi. If you ever need to do the math to convert feet of head to psi, just divide feet of head by 2.31 or, conversely, you can multiply psi by 2.31 to arrive at feet of head.

head (in feet) ÷ 2.31 = psi

psi X 2.31 = head (in feet)

These equations are just two different ways of saying the very same thing—pressure. And the pressure is the force a pump must overcome.

The static head is equal to zero in a pressurized, closed loop system completely filled with fluid. Gravity is not a factor because the pressure is equal throughout the system. The amount of force (pressure) of the fluid above the discharge or outlet side of the pump is counterbalanced by the amount of force (pressure) of the fluid above the suction or inlet side of the pump; net static head is zero.



Circulating pumps in pressurized closed loop systems are low head circulating pumps, since they only need to overcome dynamic head, which is usually quite low. As a result, they have very low power requirements.

The Grundfos UP 15-42 F is a typical AC circulating pump for closed loop systems.

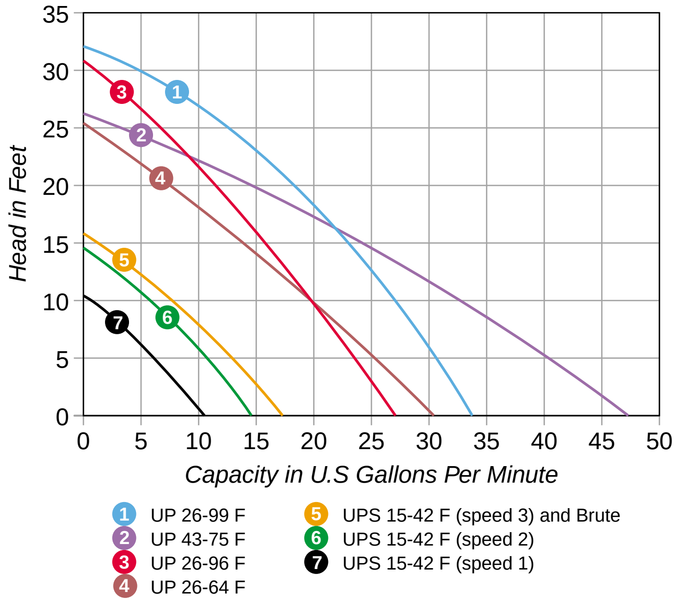
maintenance, and high reliability. They typically are made with cast iron, bronze, or stainless steel bodies.

For closed loop systems, (see *Rust Never Sleeps, HP84,* page 49), lower cost, cast iron circulating pumps are adequate. For the open loop part of the system, which circulates a replenishing supply of water, a bronze circulating pump is necessary. Stainless steel circulation pumps are used in pool systems and other applications where chemicals are present.

Once you know whether your circulating pump is to operate in a closed loop, open loop, or other particular environment, pump selection will be based on head and flow requirements. Head is the pressure the circulating pump must develop in order to create desired flow through the system. The overall pressure a pump must create is determined by the height the water must be lifted and the frictional resistance of the pipe.

Static head is pressure resulting from the vertical height and corresponding weight of the column of fluid in a system. The higher a pump must lift the fluid against gravity, the greater the static head it must develop. Dynamic head includes the frictional resistance of the fluid flowing through the pipe and fittings in the system. The pressure a pump must develop to overcome dynamic head varies with the size and length of the pipe, number of fittings and bends, and the flow rate and viscosity of the fluid.

Pump Curves for 5 Grundfos Brand Pumps



Circulating pumps are typically categorized for low, medium, or high head applications. Low head applications have 3 to 10 feet (0.9–3 m) of head; medium head applications, 10 to 20 feet (3–6 m) of head; and high head applications, over 20 feet of head.

A pump curve is supplied for each pump by its manufacturer (see the pump curve diagram above). The flow rate, in gallons per minute is shown across the horizontal axis. The vertical axis shows the pressure as measured in “feet of head.” Each pump has its own curve, which shows the volume of flow it will create at any particular head it must overcome. If you refer to the pump curves above you will see that the Grundfos model 26-96 F will push 20 gallons (72 l) per minute (gpm) against a resistance of 10 feet (3.1 m) of head. Ten feet of head is equal to 4.3 psi (10 ÷ 2.31 feet per psi = 4.3 psi).

For the solar closed loop, you can select a low head circulating pump with a cast iron or bronze body. You might consider the Grundfos model UPS 15-42 F to cover a wide margin of error. This model is a three-speed circulating pump that allows you to select the most appropriate speed once installed. A low head bronze pump will suffice for the water loop.

Whether open loop or closed loop; high, medium or low head; your local plumbing supply house probably carries an appropriate pump without special order. Most solar domestic hot water systems can be served by the Taco 008F, Grundfos 15-42 F, or Hartell MD-10IU pumps for the glycol closed loop; and by the Taco 006B, Grundfos 15-18 SU, or Hartell MD-3IU for the open loop domestic hot water.

Controller & Sensors

The controller is the brains of the system. It tells the pump when to turn on and off, based on collector and storage tank temperatures. All of its intelligence is based on determining whether the collector outlet is sufficiently warmer than the bottom of the tank to warrant turning the circulating pump on.

Sensors are located at the collector outlet, and at the bottom of the solar storage tank. These sensors are thermistors that change their resistance with temperature. The differential control compares the resistances of the two sensors. It turns the pump on when the collectors are sufficiently warmer (20°F; 11°C) than the bottom of the solar storage tank to collect useful heat.

The Independent Energy GL-30 is an example of a good differential control. It has an adjustable setting on the order of 5 to 25°F (3–14°C) temperature differential. These controls also have a high limit cut-out that will shut the system down once the tank reaches a predetermined high temperature, adjustable from 110 to 230°F (43–110°C). The GL-30 uses 10 K ohm sensors, which are the standard of the industry today. A 10 K sensor reads 10,000 ohms at 77°F (25°C). Temperature sensors must have the proper resistance to be compatible with a given controller. Sensors are available from the distributors who carry the controller you are using.

A differential pump controller senses temperature differences in various locations in the system.

Heat Exchanger

The heat exchanger transfers heat from the solar-heated closed loop to the domestic water. Factors that increase heat transfer are:

- Greater surface area
- High thermal conductivity
- Maximum temperature differential between the two fluids

Heat exchangers may be categorized as single wall or double wall, which refers to the number of barriers between the two fluids exchanging heat. Single wall heat exchangers are usually not permitted in potable (drinkable) water systems when a nonpotable heat transfer fluid is used. For example, systems that use glycol should not use a single walled heat exchanger because of the potential for contamination of the potable water.

Double wall heat exchangers are required to ensure that the heat transfer fluid will not contaminate the potable water. The space between the two walls of the heat exchanger is usually vented to permit detection of a leak.

A heat exchanger may be as simple as a copper coil within the storage tank, where single wall heat exchangers are permitted. Solar heated water is circulated through the coil with the help of a circulating pump. Heat is transferred by natural convection to the water within the tank.

External heat exchangers are generally less costly than a custom solar tank that includes an internal heat exchanger. External heat exchangers typically require two circulating pumps—one for the collector loop and another for the water loop. This uses more energy to run the second circulating pump, but it is more effective than an internal heat exchanger that relies solely on natural convection on the water side.

Heat transfer is driven by temperature differential. For this reason, heat exchangers are installed in a counter-flow configuration whereby the two fluids flow in opposite directions through the heat exchanger. This maximizes thermal heat exchange by maintaining the greatest temperature differential between fluids.

Air Elimination

Air is your enemy in a closed loop system. Air pockets can stop or slow fluid flow and defeat system performance. An air pocket on the suction side of the pump can cause the pump to burn out. All free air must be removed from the system when it is initially charged by the installer. A coin vent (you can open it with a coin or small screwdriver) is installed at the highest point in the system, which is usually at the outlet of the collectors. This allows you to manually vent air from the top of the system, and aids the installer or service technician in eliminating air from the system when charging it.

That is not the end of the saga on air. Over time, high temperatures and low pressures tend to drive dissolved gases out of solution, forming air bubbles. The air bubbles collect to form pockets in high spots within the plumbing, particularly at 90 degree elbows and fittings where fluid turns downward.

Coin vents can be installed at any place within the system where air is likely to collect. For large closed loop systems, air can also be eliminated automatically by use of an air eliminator and vent. The air eliminator has a washboard-shaped baffle to shake the air bubbles free from the fluid stream. A small reservoir space above the baffle allows air bubbles to collect where they can be vented out by either an automatic air vent or manually operated coin vent. Air eliminators are usually unnecessary on small closed loop systems.

Coin vents at high points in the system allow easy release of trapped air bubbles.

Selection of a heat exchanger is based on its capacity to transfer heat (in BTUs per hour) produced by the solar collectors. The manufacturer or distributor of the heat exchanger will specify which model is adequate, depending on the total square footage of collector to be installed. They will also specify a recommended minimum flow rate on the water side of the heat exchanger to achieve an adequate rate of heat transfer.

Check Valve

A check valve permits fluid to flow in one direction only. It prevents heat loss at night by convective flow from the warm storage tank to the cool collectors. Check valves may be of the “swing” type or the “spring” type.

Swing-type check valves should not be installed vertically upside-down, since they can hang open. If you are powering your circulating pump directly from a PV module, you should use the swing-type check valve. Low sun conditions produce lower flow rates, which may not be strong enough to overcome a spring-type check valve. For systems using AC circulating pumps, spring-type check valves are preferred. The spring provides a positive action against thermosiphon flow in either direction.

A check valve allows flow in only one direction, (see arrow).

Expansion Tank

An expansion tank allows for the fluid in the closed loop to expand and contract in the cycle of heating and cooling. Without the expansion tank, the plumbing would easily burst when the fluid is heated.

Diaphragm-type expansion tanks use an internal bladder and pressurized air chamber precharged at 12 to 15 psi. The solar-heated fluid expands in the closed loop against the bladder and pressurized air chamber. As the fluid contracts while cooling, the air chamber maintains pressure in the closed loop.

Diaphragm-type expansion tanks may be installed in any orientation, but if inverted such that the air chamber is above the fluid, it will continue to function even when the bladder eventually fails.

An expansion tank maintains pressure in the closed loop as system temperature changes.

The size of the expansion tank must be able to handle the expansion based on the volume, coefficient of expansion, and range of temperature fluctuation. These factors are considered in the rule-of-thumb recommendations below, which you may use to estimate expansion tank size based on total fluid volume.

The size and number of collectors, and the size and length of piping and fittings determine fluid volume. Use a #15 expansion tank for volumes up to 4.7 gallons (18 l), and a #30 expansion tank for volumes up to 12.5 gallons (47 l). Multiple expansion tanks can be used to increase capacity if necessary. Extrol diaphragm-type expansion tanks are readily found in most plumbing supply houses.

Pressure Relief Valve

Every hydronic heating system must allow for protection against excessively high pressures due to high temperatures. A pressure relief valve of 50 psi is typically adequate to protect closed loop plumbing from excessive pressures.

Temperature/pressure relief valves are not commonly used in the closed loop because high temperatures can be a frequent occurrence. Pressure-only relief valves are most commonly used. Once one of these valves opens, it is wise to replace it, since they often may not reseat, leaving a slow but persistent leak. Pressure relief valves should be fitted with a vent tube to direct vented fluid to a bucket or floor drain.

Gauges & Meters

A pressure gauge will tell you if the closed loop is within an acceptable range of pressure. A typical system pressure is on the order of 12 to 15 psi. So a gauge that registers up to 30 or 50 psi is suitable. The system pressure normally does not need to exceed 25 psi. A pressure gauge is used as a diagnostic tool to monitor the state of the glycol charge.

Two temperature gauges in the closed loop and one in the water loop are optional indicators of system function. One gauge on each side of the heat exchanger in the collector loop will show the temperature rise across the collectors and the temperature change across the heat exchanger.

A pressure gauge can show leaks in the loop.

Multiple temperature gauges help keep track of system funtion.

A temperature difference of 15 to 20°F (8–11°C) indicates effective operation. One temperature gauge in the water loop between the exit of the heat exchanger and the entry to the storage tank will display the current temperature of solar heated water.

Select a temperature gauge with a range of 0 to 250 or 300°F (-18 to 120 or 150°C). A hot summer day may produce water temperatures exceeding 200°F (93°C), although normal high temperatures are usually around 180°F (82°C).

Antifreeze

The collector loop circulates an antifreeze solution. Propylene glycol is the most common heat transfer fluid. It is a non-toxic substance, and more commonly used as a food additive, though it is not considered a potable fluid. Propylene glycol is usually mixed in a

50:50 solution with demineralized or distilled water. Inhibitors may be added to increase the life of the fluid, which breaks down over time due to overheating. It then forms a sludgy deposit that can clog the collector loop, as well as reduce the solution's effectiveness as an antifreeze.

Ethylene glycol should never be used. It is the common antifreeze used in automobile coolant systems. It is highly toxic, and will cause a great deal of discomfort and death if consumed.

At the time of installation, the collector loop is charged to operating pressure with a positive displacement pressure pump. Positive displacement pumps have the capability of creating sufficient pressure to lift the fluid the full height of the system, and bring the system to operating pressure, typically about 20 psi. Positive displacement pumps also create sufficient suction head to draw the charging fluid from the bucket.

The charging pump is not a fixture of the system. It is a separate piece of service equipment used by the plumber or mechanical contractor. It is connected to the drain/fill assembly in the collector loop, which consists of two boiler drains with a shutoff valve between them. Alternatively, you can save yourself a valve by replacing the shut-off valve of the drain/fill assembly with the system's check valve. This ensures that upon charging the system, fluid flows in one direction only, expelling air from the system.

Solar Storage Tank

Two tanks are more efficient than one. A solar storage tank may be installed in addition to your conventional hot water tank. Solar storage tanks are commercially manufactured with four ports at the top of the tank. This makes plumbing easy and convenient. You probably won't find the solar storage tank in stock locally unless you live near a metropolitan area, or there is a solar contractor with a steady volume of work in your area. So plan to special order that tank.

You can, however, easily modify a standard tank to perform just as well. It's easy, and it doesn't cost anything. But I'll leave the details for another time.

For those summer months when you can be satisfied with solar hot water alone, you can install a "bypass valve assembly" between the solar storage tank and the backup water heater. The solar bypass consists of three valves (or two 3-way valves), which allow you to give your conventional water heater a summer vacation and supply the house with solar heated water directly.

If you like that idea, you should add a measure of protection for those days when you just might get water hotter than you can handle. A tempering valve can keep you from getting scalded when your solar heated water is hotter than you normally enjoy from a thermostatically controlled conventional tank. The tempering valve is installed between you and your hot water system. With it, you can set the desired maximum temperature of the water delivered to the tap. Hot water enters one side, cold water, if necessary, enters from the bottom and mixed water goes out to the tap.

Three valves make up the drain/fill assembly.

Every component mentioned so far in this article, with the exception of the solar collectors, solar storage tank, and heat exchangers, is commonly available at your local plumbing or heating supply house. You can special order these items, but you'll probably find more knowledgeable service at a solar supply house. Of course, most solar supply houses will carry the common parts as well, and can give you better advice when it comes to solar heating systems.

Putting the Parts Together

As you can see, closed loop antifreeze systems have quite a few components. In this article, I've discussed the function of each component within the system, along with principal selection criteria for each.

For the solar closed loop, you'll need a low head cast iron or bronze circulating pump, double wall heat exchanger, expansion tank, check valve, one or two coin vents, pressure relief valve, pressure gauge, and two temperature gauges.

For the open water loop, you'll need a low head bronze circulating pump and a temperature gauge. A differential control with two sensors will turn the system on and off, and a solar storage tank will hold your daily catch.

Of course, you'll need a bunch of fittings and valves, and don't forget an insulating blanket for that tank and pipe insulation to make it efficient. With good plumbing skills and an understanding of how the parts go together, you can find yourself in hot water too, from the sun that is.

Access

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AAA Solar Supply Inc., 2021 Zearing NW, Albuquerque, NM 87104 • 800-245-0311 or 505-243-4900 • Fax: 505-243-0885 • info@aaasolar.com • www.aaasolar.com All types of solar hot water equipment, including Taco, Hartell, and Grundfos brands of circulating pumps

SunEarth Inc., Rick Reed, 4315 Santa Ana St., Ontario, CA 91761 • 909-605-5610 • Fax: 909-605-5613 info@sunearthinc.com • www.sunearthinc.com

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