

# Chapter Eight

## Types of Solar Water Heating Systems

Solar water heating systems are categorized as *passive* or *active* and *direct* or *indirect*. Passive systems have no electrical pumps. They rely upon convection to circulate hot water through the collector and storage tank. In passive systems, hot water is either stored in the collector itself (batch systems) or is transferred to a storage tank located above the collectors by means of a thermosiphon. In a thermosiphon, the natural tendency of hot water to rise draws hot water out of the collector into an elevated storage tank, while cold water in the tank sinks down into the bottom of the collector.

Active systems use electrically driven pumps to circulate water or another heat absorbing fluid, and sometimes use electrically operated valves for freeze protection. The advantage provided by most active systems is that they are specifically designed for year-round operation in areas that freeze.

Be aware that the exposed glass face of solar collectors makes them susceptible to freezing on clear nights when temperatures are in the mid to upper 30s, due to radiation to the clear night sky. Freeze protection strategies for solar water heating systems need to account for this factor.

Solar water heating systems are also classified as *direct* or *indirect*. Direct systems use the sun's energy to heat household water directly. The water that flows through the solar collector also flows to the various hot water taps and faucets in the house. Indirect systems heat a separate loop of fluid (typically a propylene glycol solution or distilled water) and transfer the fluid's heat to the household water supply via a heat exchanger.

The terms *open* and *closed* are also often used to characterize solar water heating systems. Open systems are typically direct systems in which the fluid being heated (water) flows through the collectors. Batch systems are open systems. In closed systems, the heat absorbing fluid is contained in a closed loop, and circulates continuously between the collector and a heat exchanger. Table 8.1 (following page) summarizes the different types of solar water heating systems.

### Batch-Type Systems

Batch systems are the simplest and historically the oldest type of solar water-heating system. In batch-type systems, also referred to as integral collector storage (ICS) or "bread box" systems, household water

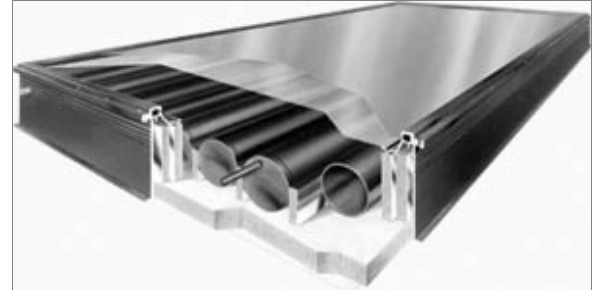


Figure 8.1: The Progressive Tube integral collector storage solar water heater  
[www.tctsolar.com](http://www.tctsolar.com)

is heated directly by the sun and the storage tank serves as the solar collector. Batch water heaters are almost always passive systems in which hot water is delivered from the solar heated tank to a backup tank or the point of use by the water pressure in the house.

Among all the types of solar water heaters, batch systems are the type most commonly built from scratch by home-owners. They are the least expensive type, especially when home-built, have few parts, and are often made with recycled materials. Batch systems typically consist of one or more tanks painted black and encased in an insulated box, with a glazed covering over the side facing the sun. Optional features include an insulated cover that can be placed over the glazed surface at night to reduce heat loss, and reflectors to



Figure 8.2: This home in Louisville has a batch solar water heater located inside the living space, which provides freeze protection and allows for year-round use. The water heater is located behind the high windows on the left.

Andy McDonald

concentrate additional sunlight onto the water tank. These systems are often mounted on the ground or attached to the side of a residence due to the weight of the tanks. If roof mounted, the roof needs to be structurally capable of handling the full weight of the tank(s). For detailed plans on building your own batch solar water heater, see the Resources list at the end of Chapter Six.

Having but a few simple parts, batch solar water heaters are highly dependable in regions that do not freeze. In Kentucky, with wintertime lows that often dip below 0°F, batch systems must be drained during the freezing season or significant measures taken to prevent the water in the tank and associated plumbing

from freezing. A system that is only used for six to nine months out of the year (known as a “three season solar water heater”) can still have a significant impact on annual energy costs, especially since the installation costs for these systems can be much lower than those of other solar water heater types.

A number of steps can be taken to combat freezing. Be aware, however, that just one freeze can damage quite a bit of hardware (not to mention the wet icy mess on the ground or, even worse, in the attic). One novel solution is to place the batch system in an attached solar greenhouse. Although the added layers of glass in a greenhouse will reduce water-heating capacity slightly, the added freeze protection can

**Table 8.1: Classification of Solar Water Heating Systems and Primary Characteristics**

	<b>DIRECT</b> Water heated in the collector flows directly to hot water taps	<b>INDIRECT</b> Heat transfer fluid is separate from the home water supply, requiring a heat exchanger.
<p><b>PASSIVE</b> Relies on natural convection to circulate hot water or heat transfer fluid. No electric pumps.</p>	<p><b>Batch, Bread Box, or Integral Collector Storage (ICS) Systems</b> Solar collector and storage tank are combined. These systems are less expensive and simple, but allow greater heat loss at night and do not provide adequate freeze protection. The most common home-made solar water heater type.</p> <p><b>Thermosiphon (Direct) Systems</b> Uses solar collector panels and a storage tank. Hot water circulates from collector to tank via natural convection. Tank must be elevated at least 18” above collector. Not suitable for areas that freeze* or that have hard water. (*Can be modified with pumps, making it a direct (open) system, to provide freeze protection in areas with very limited freezes.)</p>	<p><b>Thermosiphon (Indirect, with freeze protection) Systems</b> Uses solar collector panels and storage tank. Antifreeze fluid is circulated in collector panels and heat is transferred to water storage tank via a heat exchanger. Tank must be elevated at least 18” above collector. Suitable for areas that freeze. However, efficiency is low.</p>
<p><b>ACTIVE</b> Uses electric pumps to circulate heat absorbing fluid.</p>	<p><b>Draindown Systems</b> Water is pumped between collector panel and hot water storage tank. Freeze protection provided by an electric draindown valve with temperature sensors that drains water from collector and exposed plumbing before freezing temperatures are reached. Water empties into house drain. System automatically refills with water when temperature rises above freezing. Offers freeze protection.</p> <p><b>Direct (Open Loop) Systems</b> Pumps circulate heated water between collector panels and storage tank. System has very limited freeze protection. Can be set up to offer minimal freeze protection or used for three seasons and shut down in winter. Not suitable with hard water.</p>	<p><b>Pressurized Glycol Antifreeze Systems</b> Antifreeze fluid is circulated through solar collector panels and transferred to water storage tank via a heat exchanger. Offers freeze protection.</p> <p><b>Drainback Systems</b> Distilled water or antifreeze circulates between collector panels and storage tank and is drained from system during freezes. Fluid in collector panel is separate from the home water supply and is saved in a holding tank when drained. System drains by gravity without the use of an electric drain valve. Requires heat exchanger to transfer heat to storage tank. Offers freeze protection.</p>

extend use of the system into winter months. With an attached greenhouse, plumbing can be contained within the building's heated space. The home shown in Figure 8.2 has a home-made batch heater installed within the attic space of the house, which allows for year-round use and freeze protection.

In a well designed batch system the main component susceptible to freezing is the plumbing to and from the collector. These pipes need to be well-insulated (R-8 or higher). Running heat tape along these pipes can offer additional protection, but since power outages are not uncommon during freezing weather, heat tape is not a fail-safe solution.

One drawback of batch systems is that they can lose heat quickly at night or during cloudy conditions. An insulated cover placed over the glazing at night can help retain heat in the storage tank. Although a batch water heater that's drained in the winter cannot be used to heat water for space heating purposes, if the solar collector is wall-mounted, it is possible to blow hot collector air into the house during the cold season.

Manufactured batch units include the Servamatic™. Produced in the 1970s, many are still operational today. ProgressiveTube™ is a batch heater that's available on the market today (see Figure 8.1). Manufactured systems that are certified by the Solar Rating & Certification Corporation (SRCC) clearly state the temperature below which freeze damage can occur.

## Thermosiphon Systems

Thermosiphon systems are usually passive (no electric pumps), direct systems that use flat plate collectors and rely on natural convection to move the heated water from the collector up into the storage tank (see Figure 8.3). These systems are reliable and relatively inexpensive but their installation requires careful planning to ensure that the house can structurally support the weight of the water tank(s).

Thermosiphon systems require the storage tank to be elevated above the collector plate by at least 18 inches to prevent a reverse thermosiphon from cooling off the tank at night. A reverse thermosiphon is driven by the cool night sky, which cools down the collector, pulling heated water from the tank and circulating it back through the collector, where it radiates its heat to the sky. By elevating the storage tank 18 inches above the collector, the reverse thermosiphon is prevented.

Sometimes it is not possible to elevate the tank 18 inches above the collector. In that case, ensure that the top of the water tank, at least, is above the collector. Then install a check valve (a valve which allows water to flow in one direction only) to prevent the reverse

thermosiphon. (A check valve can be used even if the tank is optimally elevated to provide extra security against the reverse thermosiphon.) Avoid the standard pressure-type or swing check valves, which do not allow thermosiphon flow. Instead, use a spring-loaded inline check valve with a Teflon ball check. The check valve should be mounted vertically with the arrow pointing up, on the output side of the collector below the top of the storage tank. For standard spring type check valves, the spring should be removed in thermosiphon systems.

Heliotrope Thermal offers another check valve option, a low resistance solar check valve (SCV.75/.50) that can be mounted vertically or horizontally.<sup>1</sup> (Note: mechanical in-line check valves are notorious for losing their ability to seat properly when subjected to heated hard water, which is common in many Kentucky homes with well or spring water. If your home has hard water, we recommend an alternative that does not require a check valve on the hot output side of the collector).

Passive thermosiphon systems that directly heat household water are even more prone to freezing than batch solar water heaters. In areas that only have a few freezes each year, thermosiphon systems can be protected by a pump which re-circulates a small amount of heated water from the storage tank through the collector during those rare freezes. This is known as a re-circulation system and turns the passive thermosiphon system into a direct (open-loop) active

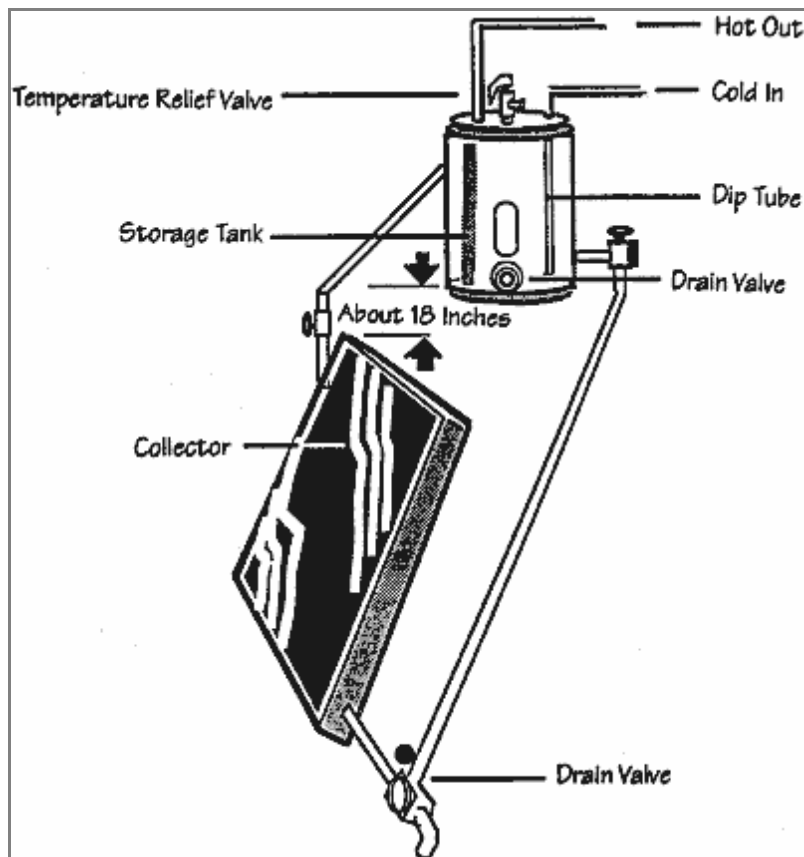


Figure 8.3: Thermosiphon Solar Water Heating System

type. If an AC pump is used, these systems would be at risk of freezing if power was lost during a freeze (because the re-circulating pump would not work). These systems also waste hot water that could otherwise be saved for domestic use.

Thermosiphon systems have also been successfully freeze-proofed using an indirect design. An antifreeze solution circulates between the collector plate and the storage tank, where the solution transfers its heat to the household water supply in a heat exchanger. In a passive system it is preferable to use an internal or integral heat exchange tank instead of a thermosiphon external heat exchanger (see Chapter Seven for more information on heat exchangers.) This arrangement produces only about 45 to 50 percent of the hot water a direct (open loop) active system produces.

### Direct (Open Loop) Active Systems

Direct (Open Loop) Active Systems are similar to thermosiphon systems in that they are direct systems that use a solar collector separate from the storage tank. The difference with direct active systems is that they use an electric pump to circulate water from the storage tank to the collector, and back to the storage tank. These systems always require a check valve to prevent reverse thermosiphoning at night. Unlike thermosiphon systems, the check valve is now placed on the output side of the tank (the cold water pump side of the loop), instead of the output side of the collector, again with the flow (arrow) directed up. Remove the spring (or use a Heliotrope Thermal low resistance solar check) if a DC pump powered by a solar PV panel is used instead of an AC pump.

DC pumped systems rely on the varying amounts of sunshine on the PV panel to match the flow needed through the collector(s). AC pumped systems require a differential controller and temperature sensors to know when to turn the pump on and off (see Differential Controllers and Sensors in Chapter Ten for more information). Open Loop Active Systems are generally reserved for areas that receive on average less than one freeze per year. In

freeze-prone areas, they are drained and shut down during the cold season.

### Draindown Systems

A draindown system is a direct open loop active system which offers marginal freeze protection with a temperature controlled solenoid electric valve. The valve fills the collector loop with water for operation, then when freezing temperatures approach, the same valve opens to dump the water out onto the ground.

A draindown system has the high efficiency and merits of an open loop system with some additional protection against freezing. However, draindown systems have complex controlling systems and expensive parts. Since they are designed for areas with few light winter freezes, they may not be appropriate for Kentucky's climate.

Draindown systems have had freeze related problems, often the result of poor water quality. The solenoid valves and vacuum breakers can build up with scale which can keep them from seating properly. The solenoid and vacuum breakers need to be "exercised" or they can stick closed. To do this, install a timer on the power supply to the system, to cut electricity off at night. This will ensure that the solenoids and vacuum breakers will open at least once a day. The drawback of

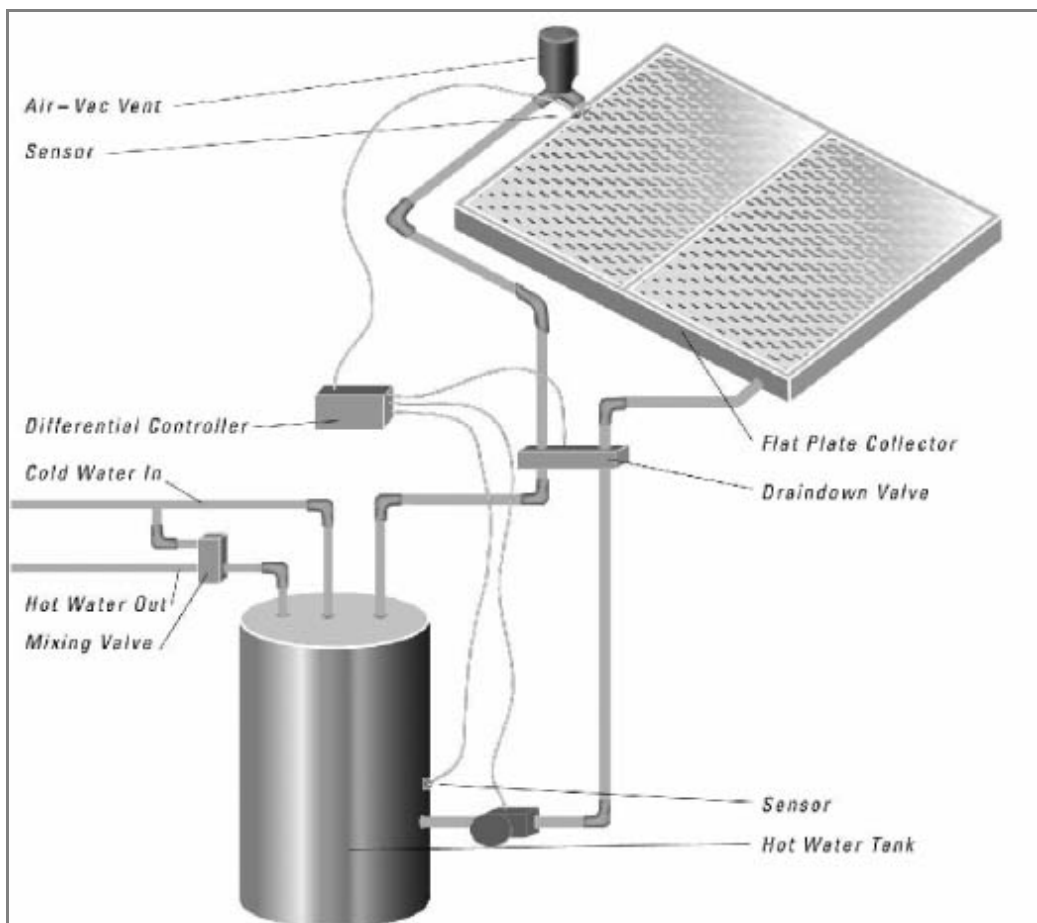


Figure 8.4: Draindown systems are direct active solar water heating systems. North Carolina Solar Center

this strategy is that the collector loop will be drained once a day.

## Indirect Active Systems Glycol Antifreeze Systems

Glycol antifreeze systems are active, indirect systems with a heat exchanger (see Figure 8.5). Freeze resistant propylene glycol is circulated through the solar collector(s) and heat exchanger, while household water is circulated from the storage tank through the heat exchanger. The household water is heated inside the heat exchanger and then stored inside the tank until needed. (Note: if a storage tank is used which has a built-in heat exchanger, only the propylene glycol is circulated).

The antifreeze and water (if an external heat exchanger is used) are circulated using either AC pumps powered from the utility grid or DC pumps powered by a solar electric PV module. For AC pump systems, a controller allows power to the pump(s) only when the collector's temperature (measured at the header outlet) is sufficiently warmer than the temperature of the water in the bottom of the storage tank. The temperature sensors change resistance with changing temperatures. The sensor at the collector is clamped with stainless steel hose clamps to the collector outlet pipe within two inches of the collector. The collector sensor, as well as inlet and outlet piping are all insulated with elastomeric (Armaflex and Rubbatex) insulation. The sensor at the tank is slid between the metal tank surface and the tank's insulation near the lower thermostat (for an electric water heater).

Although solar electric DC pumping systems are



Figure 8.6: This flat plate solar collector (left) is mounted on the ground outside a home in northern Kentucky. This glycol antifreeze system uses a small PV panel (center) to pump the antifreeze through the system, *John Robbins*

more expensive than AC pumping systems with a controller, they offer many advantages:

1. Solar DC pumps will keep operating even if power from the grid is lost. When pumps are dependent on the utility grid, if grid power is lost during a sunny period, the propylene glycol solution will sit stagnant in the collector and can start to overheat and degrade, losing its buffering qualities, which warrants replacement.
2. AC pumps require controllers and sensors. If the controller fails, stagnation can occur.
3. Controllers and sensors have more service problems and shorter life spans than solar PV modules.
4. Testing from TVA during the early 1980's found that an average glycol system using AC pumps and controllers consumed six to nine percent of the solar "harvest" to operate pumps and controls.

If AC pump(s) with a controller are used we recommend that a six-hour uninterruptible power supply be installed in case the power goes out on a sunny day. Other components that make up a glycol antifreeze system include a check valve to prevent nighttime heat loss. The valve should be a spring type with the spring removed (if using DC pumps), mounted vertically above the pump (arrow pointing up towards the collector). If AC pumps are used the spring does not need to be removed.

Closed loop systems often incorporate a "vacation bypass," which allows the water in the system to cool off at night. This may be desirable if no one will be using hot water for multiple days at a time. During cloudless weather, it is quite possible for the water in the storage tank to reach temperatures of 180° to 190° F. These temperatures can reduce the life of the storage tank if they are consistently reached. The "vacation bypass" consists of a valve placed in parallel to the line with the check valve. With the "vacation bypass" valve open, hot water flows out of the storage tank through the heat exchanger, and thermosiphons

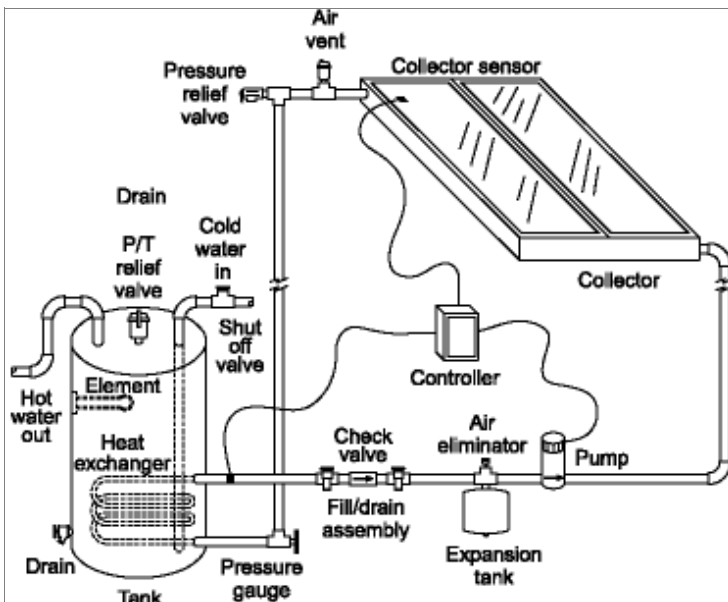


Figure 8.5: Pressurized glycol solar water heaters are active indirect systems.

*Back Woods Home Magazine, www.backwoodshome.com*

up to the collector, where its heat is released to the cool night sky.

Glycol antifreeze systems, like all pressurized indirect systems, require an expansion tank in order to handle the change in volume of the propylene glycol solution, which will expand and contract as it heats and cools each day. Without the expansion tank, the expanding glycol would blow the pressure relief valve, spraying glycol all over the place.

### Drainback Systems

Drainback systems, like glycol systems, are active indirect systems with a heat exchanger, but in drainback systems the heat collection loop is unpressurized. Of all solar water heating systems, drainback and glycol systems offer the greatest freeze protection. Drainback systems typically use distilled water as the heat collection fluid, although regular water or a propylene glycol solution can also be used. The heat collection fluid is pumped between the solar collector panels and a heat exchanger, which transfers the heat to the water storage tank.

The unique feature of drainback systems is the reservoir incorporated in the heat collection loop (see Figure 8.7). For residential systems, this reservoir is usually a 10 to 15 gallon tank, and it must be located within the building envelope and protected from freezing temperatures (if water is used as the heat collection fluid). On sunny days, or whenever the temperature of the solar collector is sufficiently warmer than the temperature in the hot water storage tank, a pump lifts water out of the reservoir and circulates it through the heat collection loop.

When the collector cools during cloudy weather or as evening approaches, the pump in the heat collection loop shuts off and the collector fluid drains out of the collector back into the storage reservoir. The system drains by gravity, without the use of electric pumps, sensors, or controls, and is certain to drain whenever freezing temperatures approach. This provides guaranteed freeze protection. One can tell if the system is gaining heat and the collection loop pump is on by looking at a site glass on the side of the drainback reservoir. If the solution level in the site glass is low, then the system is gaining heat. If the solution level is

high, the fluid has drained into the reservoir and the system is not gaining solar heat.

While the heat collection loop is closed in drainback systems, some reservoir tanks are vented to the atmosphere. In air-tight living spaces (such as super-insulated homes), un-vented (air-tight) reservoirs should be used to prevent excess humidity from building up in the living space.

The pump for the heat collection loop in a drainback system must be more powerful than the collector loop pump in a glycol system. This is because in a drainback system, the collector fluid has to be lifted up to the collector, whereas in a glycol system the pump only has to circulate the propylene glycol solution.

Due to this difference in size, it is not economically feasible to power the collection loop pump in a drainback system directly from a solar electric PV panel. Grid-powered AC pumps are required in these systems.

A drainback system also incorporates sloped piping to and from the collectors, which allows the solution to drain back to the reservoir. This gravity drain is the key to the system's freeze protection, and installers must take great care to ensure that all piping and the collectors drain properly.

Drainback systems have significant advantages in

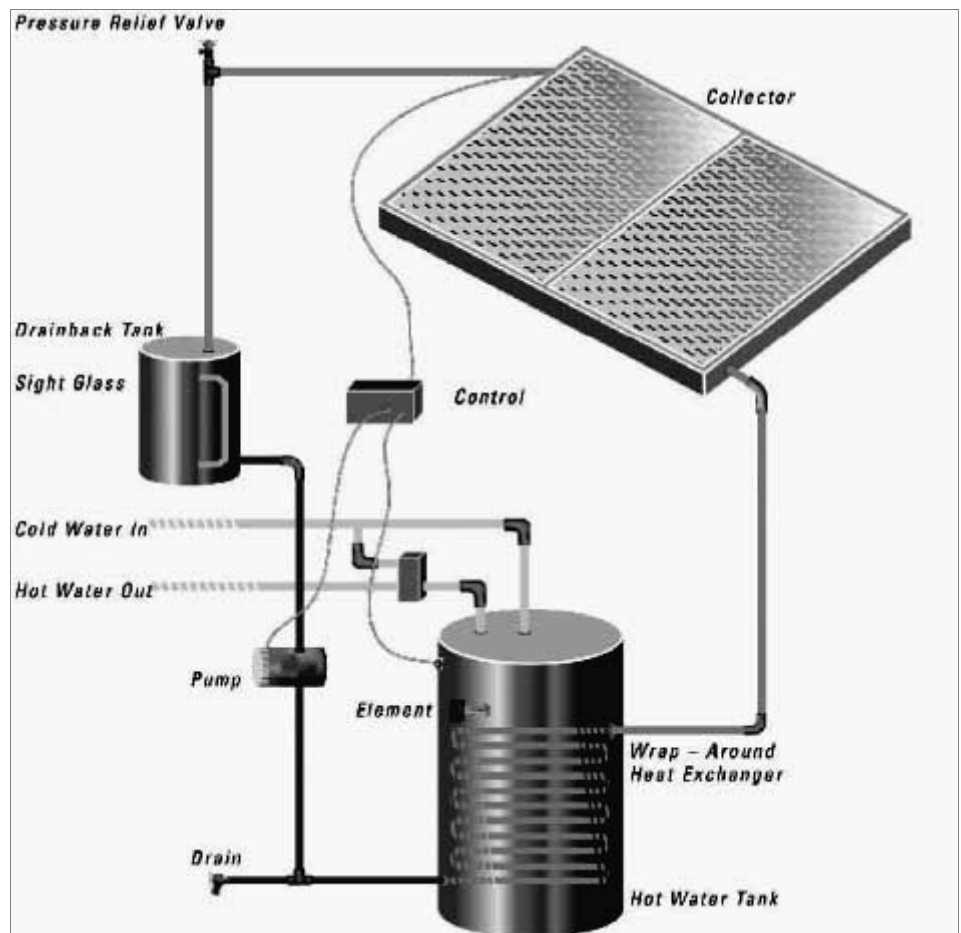


Figure 8.7: Drainback solar water heating system, North Carolina Solar Center

comparison with glycol antifreeze systems:

1. Fewer parts, even with the addition of a reservoir tank and sight glass. Drainback systems don't have the expansion tank, pressure gauge, collector loop temperature/pressure relief valve, collector loop check valve (and associated vacation bypass valve), nor an air vent (for purging air), all required for glycol antifreeze systems. With fewer parts, installation can be faster and easier, especially with designs which allow the reservoir to be placed on top of an electric storage/backup tank.
2. Drainback systems are not at risk of the collector solution stagnating in the collector on sunny days if the utility power goes out. Without power, the collector solution drains by gravity out of the collector to the reservoir. (This feature also provides additional freeze protection. If the power goes out during a freeze, the collector will drain automatically.)
3. Even though they require a more powerful collection loop pump, drainback systems can still be more efficient than glycol antifreeze systems. This is only true when pure water is used in the collection loop. Pure water has a greater heat transfer capacity than a glycol antifreeze solution.

---

End Notes

1. Heliotrope Thermal, Inc., [www.heliotropethermal.com](http://www.heliotropethermal.com)

