Solar Hot Water for Cold Climates

Part II—Drainback Systems

Tom Lane & Ken Olson

Whether your climate freezes one day of the year or every day of the year, your solar water heating system must have 100 percent fail-safe freeze protection. If your freeze protection depends on either human intervention or the availability of electricity, you are living in the shadow of Murphy's law.

The heart of a drainback system—the reservoir tank stores the unpressurized water from the flat plate collectors that "drains back" whenever the circulating pump shuts off.

Two types of solar hot water systems are most appropriate for freezing climates—drainback systems and closed loop antifreeze systems. *Solar Hot Water: A Primer (HP 84)* covered the fundamentals of solar water heating systems. *Solar Hot Water for Cold Climates (HP 85)* covered the principles and components of the closed loop, antifreeze-type, solar water heating system.

In this article, you will learn the inner workings and components that make up the drainback solar water heating system. Some wrenches (system installers) of the frigid north have experienced drainback system failures due to flaws in design or installation. This article presents a culmination of knowledge and experience for freeze-free operation in cold climates. The drainback system is not to be confused with the strongly unrecommended draindown system mentioned in *HP84.*

Draindown systems rely on an electrically operated draindown valve to fill and drain the solar collectors with domestic tap water under household pressure. In general, draindown systems have had a poor performance history, with frequent freeze-related failures due to hard water, valve malfunctions, and other drain-related failures. By comparison, a drainback system uses a pool of unpressurized water that is completely separate from the pressurized domestic water in the solar storage tank.

Drainback Fundamentals

In a drainback system, the collector fluid, typically demineralized water, is circulated from a reservoir tank through the solar collectors whenever useful heat can be collected. When the pump shuts off, the water drains back by gravity to the reservoir tank. The collectors and all other piping exposed to potential freezing conditions are left empty.

The positive drain of collectors and supply/return piping is the key to the system's freeze protection strategy. This is an unpressurized closed loop—it is closed to renewed supplies of corrosive oxygen associated with replenishing water (see *Rust Never Sleeps, HP84,* page 49). Domestic water is heated by the collector fluid via a heat exchanger, which transfers the heat to water in an insulated storage tank for domestic use.

Below the drainback tank, a Ruud solar storage tank with an integral wrap-around heat exchanger stores the potable hot water.

Drainback System Components

The principle components of a drainback system include solar collector(s), circulating pump or pumps, 80 or 120 gallon (300 or 450 l) storage tank, differential control with sensors, heat exchanger, and reservoir tank. You may also include optional features such as temperature gauges, sight gauge, and flow meter.

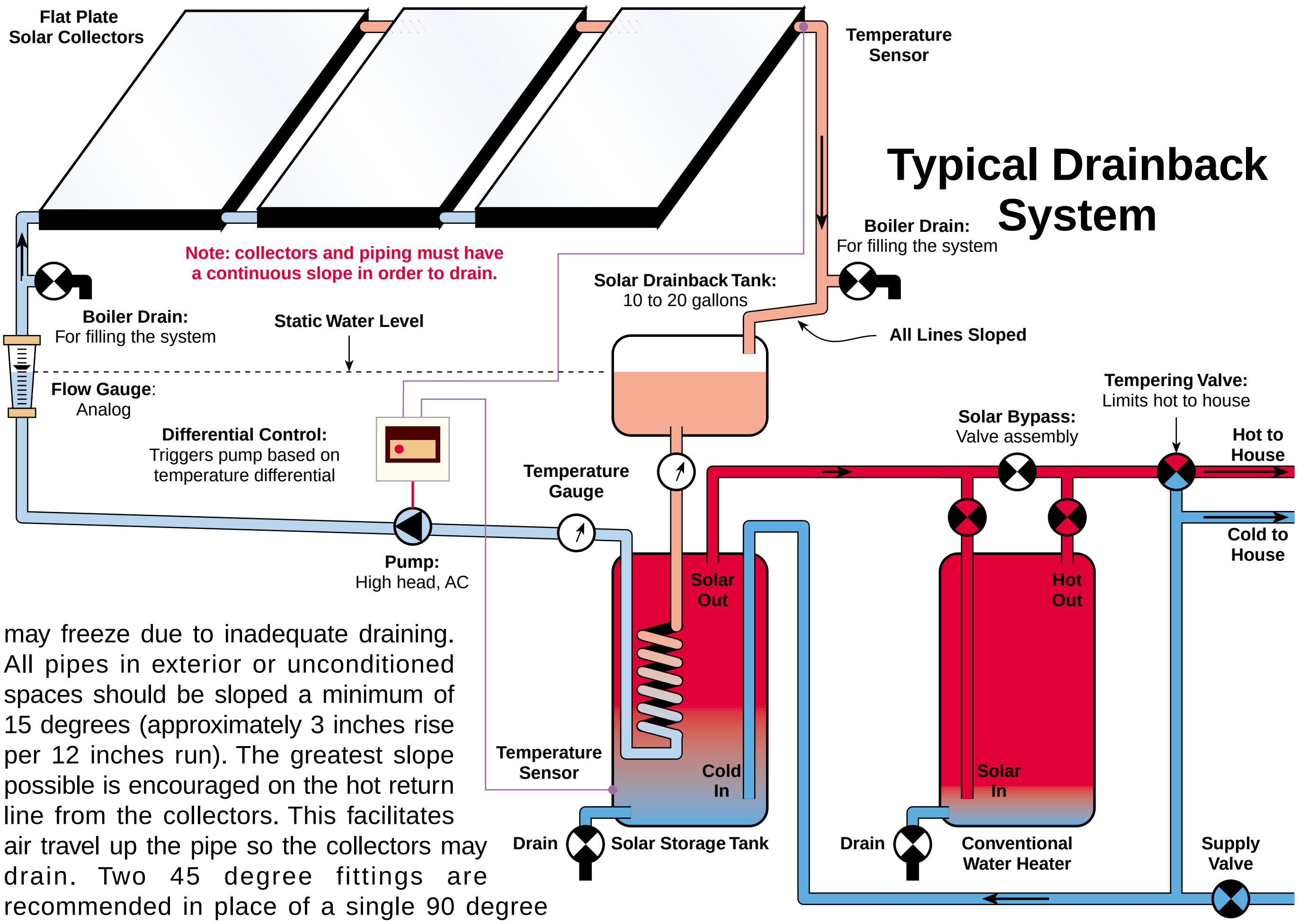
Some drainback systems do without a storage tank. Known as "whole house drainback systems," they have a very large reservoir tank that has the heat exchanger submerged inside of it. The heat exchanger is plumbed in series between the cold supply and the house DHW plumbing, and often an on-demand water heater designed to boost preheated water if needed. Frequently, large, single tank systems are used with two internal heat exchangers, one for DHW and the other for space heating. Let's take a closer look at the function, considerations, and recommendations for each of these components in a drainback system.

Collectors & Piping Must Drain

Flat plate solar thermal collectors are the most appropriate type of collector used with drainback systems. They are well suited to low temperature applications (under 150°F; 66°C), such as domestic water heating. They are constructed with parallel tubes connected at top and bottom by header manifolds. Multiple collectors are plumbed in parallel with each other. Flat plate collectors and parallel plumbing have been well described in the solar thermal articles in *HP84* and *HP85.*

The critical aspect in a drainback system is that the collectors and associated plumbing must always be able to freely drain by gravity when the pump shuts off. Collectors must be mounted facing true south (true north for locations in the southern hemisphere), with the parallel tubes (risers) of the absorber plate oriented vertically at a minimum 25 degree (approximately 5 inches rise per 12 inches run) tilt from horizontal. The risers should be a minimum of 1/2 inch ID. Never mount the collectors with the riser tubes oriented horizontally (parallel to the roof eaves). The top and bottom headers of the collector must be 1 inch. The collector's headers must be level and 1-1/2 inch headers must be used if more than three collectors are connected together in parallel.

All piping to and from the collectors must have at least a 10 degree slope (approximately 2 inches rise per 12 inches run) and must be at least 3/4 inch. Smaller pipes



may freeze due to inadequate draining. All pipes in exterior or unconditioned spaces should be sloped a minimum of 15 degrees (approximately 3 inches rise per 12 inches run). The greatest slope possible is encouraged on the hot return line from the collectors. This facilitates air travel up the pipe so the collectors may drain. Two 45 degree fittings are recommended in place of a single 90 degree elbow to assist drainage in all exterior and unconditioned spaces. All pipes should be supported at least every 4 feet (1.2 m) to prevent sagging, which may contribute to inadequate draining.

Reservoir Tank

The drainback reservoir tank holds the collector fluid. It can be installed at any height above the solar storage tank, but must be within a conditioned or freeze-free environment. The reservoir tank is typically mounted on a strong shelf above the storage tank. It may also be placed on the second floor of a two-story home to reduce static head by decreasing the distance the pump must lift the fluid to the collector.

In the tax credit era, it was possible to buy an insulated copper drainback reservoir tank with a sight glass. This is a clear glass tube on the side of the drainback reservoir that enables you to view the water level before and after the pump starts up. The sight glass allows you to monitor the level of fluid so you can ensure that the fluid is always above the circulating pump, and so you can detect fluid loss from leakage.

A collector manufacturer, SunEarth, is making a copper drainback reservoir tank that is not equipped with a sight glass. Alternatively, you can simply buy a 10 or 20 gallon (38 or 76 l) conventional water heater to serve as a reservoir. Mobile home parts distributors sell these tanks inexpensively. Install the reservoir tank on the return line from the collector above the heat exchanger and storage tank. The fluid returning from the collector must enter the airspace at the top of the resevoir tank. This allows air to move up into the collectors and piping so they can drain. Caution! If you are using a conventional water heater as drainback resevoir, it is very important to remove the dip tube from the cold inlet port. Otherwise the dip tube will impede draining of the collectors by preventing air from rising up to the collectors.

You may use a clear flow meter as a sight glass. It should be on the feed side line to the collector located at the same exact height as the top of the drainback reservoir tank. Water will seek its own level after the pump cuts off, and it should be near the top 1/4 inch of the flow meter. Flow meters are available in 2 gallon (7.6 l) per minute (gpm) to 16 gpm (60 lpm) sizes from Letro (LE-LD359B or LE-LDF359T) or Blue & White (F-450LHB). Contractor prices are about US$40 each.

A true drainback system is an unpressurized closed loop. Some early drainback system designs incorporated vacuum breakers and automatic air vents in the collector loop. These features are mistakenly borrowed from the open loop, draindown system design. This atmospheric venting of drainback systems is unnecessary, often problematic, and not recommended.

Controller & Sensors

The controller turns the circulating pump on and off. It is a differential type control, identical to that used in closed loop antifreeze systems. A thermistor-type sensor is fastened to the collector outlet pipe. Another is fastened directly to the solar storage tank wall, under the insulation, at the bottom of the tank. The sensors are wired to the controller with #18 (0.8 mm^2), two-wire, stranded PVC double jacket exterior wire.

When the outlet temperature of the collectors is 20°F (11°C) greater than the bottom of the solar storage tank, the controller activates the circulating pump. The controller shuts the circulating pump off when this temperature differential is reduced to 5°F (2.8°C), and the system drains back by gravity to the reservoir tank.

Many controls have adjustable differential settings. Differential controls are also equipped with a high limit cut-out feature. If the temperature of the solar storage tank reaches a preset high limit, usually 180°F (82°C), the controller turns the circulating pump off, and the fluid drains back to the reservoir tank. High quality differential controls are manufactured by Heliotrope Thermal and Goldline Controls.

A typical differential pump controller— the Heliotrope Delta-T.

Photo courtesy of Heliotrope Thermal.

Photo courtesy of Taco, Inc

The Taco 009BF is a typical high head AC centrifugal pump appropriate for use in drainback systems.

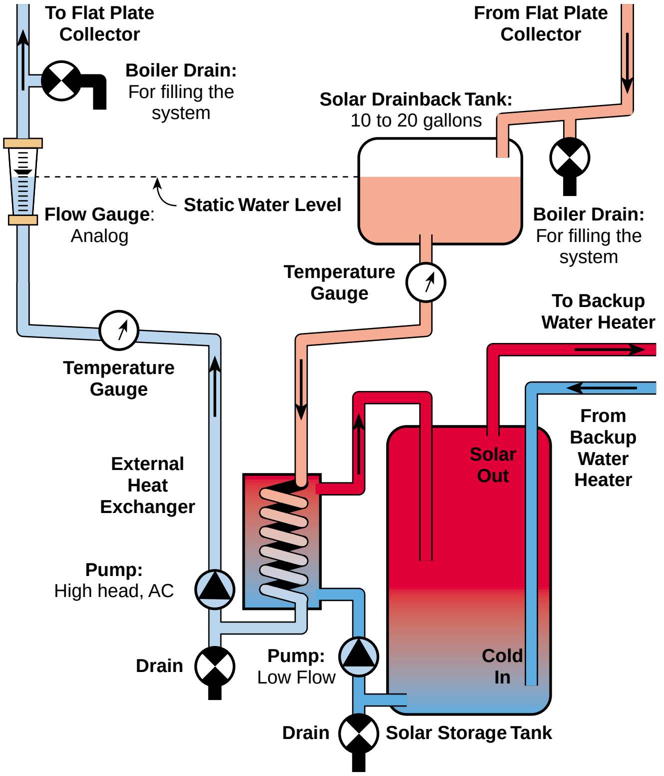
Circulating Pumps

Drainback systems use a high head, AC centrifugal circulating pump operated by a differential controller. Centrifugal circulating pumps are most commonly used in solar hot water systems and hydronic heating systems. These are appropriate because of their efficiency, reliability, low maintenance, and low energy consumption. They also permit backflow of fluid when not operating. This is a critical aspect of their function in a drainback system.

Head is the pressure that a pump must overcome to circulate the collector fluid. Static head is the pressure a pump must overcome to lift the water to the highest point in the system. The static head is equal to the vertical distance between the lowest water level and the highest point in the system. The lowest water level occurs when the pump has lifted water to the highest point in the system and before return flow has begun. Dynamic head, or friction head, takes into account the pressure a pump must develop in order to overcome the frictional resistance of the fluid moving through the pipes and fittings.

In the case of the drainback system, the circulating pump must start up at full speed and develop full head in order to lift the water to the highest point in the system and overcome the static head of the system. Once the fluid begins to fall down the return pipe, the syphon effect reduces the static head to a minimum, and the flow rate increases.

Side-Arm Heat Exchanger



This high head requirement generally precludes the use of a DC circulating pump powered directly by a PV module because the system will not fill until sufficient pressure is developed. So AC powered circulating pumps are most common. A battery powered DC circulating pump is an option, but not readily available in high head models.

The Grundfos UP 26-96BF, which can lift to a maximum head of 30 feet (9 m) of static head, or the TACO 009 BF, which can lift to a maximum head of 35 feet (10.7 m), are the two most commonly used pumps. The TACO 009 BF draws the least power. You can anticipate that these pumps should last fifteen years in a drainback system. They are lubricated by the fluid they pump.

The circulating pump should be located a minimum of 4 feet (1.2 m) below the lowest water level in the drainback reservoir to avoid sucking air into the pump. The formation of air bubbles on the suction side of the pump impeller, called cavitation, increases the load on the circulating pump. It can reduce or stop fluid movement altogether, and will burn out the pump motor. It is also preferable that the pump be mounted vertically on the cool side of the heat exchanger. Operating at a lower temperature may increase the life of the circulating pump.

Heat Exchangers & Tanks

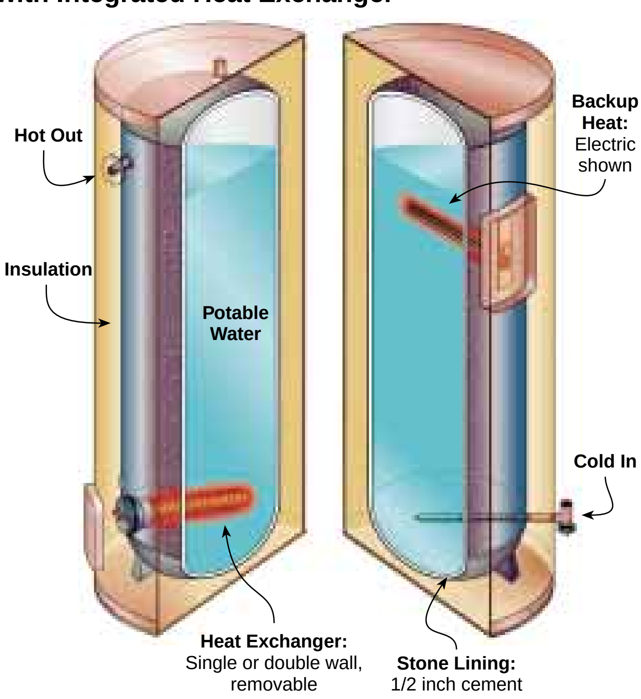
The heat exchanger transfers heat from the collector loop to the domestic water loop. A good heat exchanger will have a large surface area, and be constructed of a highly conductive material such as copper.

Heat exchangers may be integral to the tank's wall, or have a single or double wall between the two fluids. Of course, a single wall is more effective, but it may not be code compliant. Even using water as the heat transfer fluid, safety-minded mechanical inspectors recognize that a nonpotable heat transfer fluid might be used in the future. This would put occupants at risk of contamination of the potable water supply.

Heat exchangers may also be internal (within the storage tank), or external, as a separate component. An external heat exchanger, often referred to as as a side-arm heat exchanger, allows easier access for servicing (cleaning and descaling) if you add cut-off valves and a means of access.

A separate circulating pump on the water side of the side-arm heat exchanger is recommended. If you rely only on thermosyphon flow on the water side, it will be 30 to 40 percent less efficient than a double pumped system, and 20 percent less than a tank with a built in heat exchanger. When using an external heat exchanger, the two fluids should flow through it in opposite directions. This optimizes heat exchanger effectiveness by maintaining the maximum average temperature differential between the two fluids.

Cutaway of a Stone Lined Tank with Integrated Heat Exchanger



Graphic courtesy of Vaughn Manufacturing Corp.

An internal, integrated (and removable), fin-type heat exchanger.

As of 2001, there are only two brands of closed loop tanks with integrated heat exchangers that wrap around the outside of the tank wall (making it scale proof), and are foam-insulated in place—Rheem and Ruud. These are both made by Rheem Manufacturing. Rheem is one of the largest manufacturers of hot water heaters, and makes an 80 gallon (300 l) tank with a wrap-around copper heat exchanger. They are commonly available nationwide and generally adequate for a family of four. Ask for the 80 gallon Solar HE (heat exchanger) model. I hope that manufacturers will bring back the 100 and 120 gallon (380 and 450 l) tanks with heat exchangers that were available during the tax credit era of the ’70s and ’80s.

Always bring the collector return line into the top side heat exchange opening on the Rheem/Ruud tanks, and out the bottom to return to the collectors. This configuration ensures that you are supplying the collectors with the lowest temperature possible, and is 20 percent more effective than plumbing it in reverse.

Vaughn Corp., a small company in Salisbury, Massachusetts, makes 65, 80, and 120 gallon (250, 300, and 450 l) tanks (trade name Sepco) with bolt-on, removable, single or double wall, vented heat exchangers. The heat exchanger is located at the bottom of the tank and is finned to offer greater surface area, which increases heat exchange effectiveness.

Unlike the Rheem/Ruud glass lined tanks, Sepco tanks are stone lined. These tanks typically last much longer than a standard glass lined tank. The stone (1/2 inch cement) lining makes them heavy, so you will need two people and an appliance dolly to move them into place. Do not use the less expensive, higher performing, single wall heat exchanger unless you check your local codes for compliance, even with water as the heat transfer fluid.

System Sizing & Costs

System sizing is determined by the daily volume of water usage, required temperature rise, and the local climate. Performance will be affected by the size of solar collector and the size of the solar storage tank. A solar contractor in your area may have the means of providing a detailed performance analysis, which is beyond the scope of this article. Here are some useful guidelines to get you in the ballpark.

The first step is to determine your hot water needs. Widely accepted estimates for residential hot water consumption are 20 gallons (75 l) per day for the first two people and 15 gallons (55 l) per day for each additional person. Size your tank according to your daily hot water requirement. Tanks come in standard sizes, so don’t fret over trying to be too exact. Just get the available tank size closest to your estimate.

The second step is to determine the square footage of solar collector, based on the size of your solar storage tank. You can use the following generally accepted rules of thumb offered by AAA Solar, for each of four climatic regions of the U.S.

- Sunbelt: 1 square foot (0.09 m^2) of collector per 2 gallons (7.6 l) of storage.
- Southeast and Mountain states: 1 square foot of collector per 1.5 gallons (5.7 l).
- Midwest and Atlantic states: 1 square foot of collector per 1.0 gallons (3.8 l).
- New England and the Northwest: 1 square foot of collector per 0.75 gallons (2.8 l).

Here’s an example. A household of four will consume an estimated 70 gallons (265 l) per day, so use an 80 gallon (300 l) solar storage tank. Based on your location, your collector area will be on the order of 40 square feet (3.7 m^2) in Arizona, 55 square feet (5.1 m^2) in Georgia, 80 square feet (7.4 m^2) in Kansas, and 106 square feet (9.8 m^2) in New Hampshire.

Typical Drainback System Sizing & Costs

Gallons HE Tank	*Collector Area (square feet)*	*Number of People*	*FSEC BTU Rating**	*WH Per Day*	*Cost (US$)*
80	2 @ 4x8 = 64	4 to 6	61,400	17,996	$3,205
120	2 @ 4x10 = 80	5 to 9	76,200	22,334	$3,558

* The Florida Solar Energy Center (FSEC) has developed performance ratings upon which the Solar Rating & Certification Corporation (SRCC) bases its solar collector thermal performance ratings.

Remember that collectors come in standard sizes too, so make your selection based on what is available. The drainback system components cost about 10 to 15 percent more than a glycol system. Current retail prices to homeowners for uninstalled equipment are shown in the table on page 67.

The watt-hours in the table come from the multiplier 0.2931, which converts BTUs to watts. This conversion may help solar-electric professionals put the savings in perspective. At US$0.10 per kilowatt-hour (KWH), the two systems will save approximately US$1.80 per day (US$657 per year) and US$2.25 per day (US$821 per year) respectively in nontaxable income, depending on specific climate and site. The equity value will last for twenty years, with simple payback less than five years.

Filling & Draining the System

Filling and draining the system is easy. It requires no special charging pump because the closed loop is unpressurized. Three boiler drains or hose bibs are sufficient to fill and drain the system. These fittings have male hose threads, which allow you to hook up a hose for draining or filling.

One boiler drain is installed above the sight glass (or visual flow meter) on the pipe feeding the collector. Another is installed above the reservoir tank in the return pipe from the collector. A third is installed at the lowest point in the collector loop.

With the two upper boiler drains open, connect a hose from a pressurized water supply (no hard water please) to the lowest boiler drain. Fill the system until the water level exceeds the sight glass, or overflows the upper two boiler drains. Close the lower drain, shut off the water supply, and disconnect the fill hose. Slowly drain water out of the lowest drain valve until it is at the correct level, which is at the top of the sight glass.

If you opt to charge the system with demineralized water or antifreeze solution, you can fill the system by pouring the fluid into a hose connected to one of the upper boiler drains. The volume of fluid required is approximately 1 gallon (3.8 l) per 40 square feet (3.7 m^2) of collector, plus 6 gallons (23 l) per 100 linear feet (30 m) of 3/4 inch copper pipe, plus 5 gallons (19 l) extra for the reservoir tank.

Advantages of Drainback Systems

The greatest advantage of a drainback system over the closed loop antifreeze type system is that overheating will not cause any problems. Once the high limit water temperature has been reached, the pump turns off, and the fluid in the collectors drains back to the reservoir tank.

By comparison, if a closed loop antifreeze system is shut off at the high temperature limit, high stagnation temperatures (up to 350°F; 176°C) will break down the heat transfer fluid, creating a sludgy, acidic deposit. Heat transfer capability is then reduced because of corrosion in the copper piping. This can be a problem if there is no flow in the system, such as when a pump fails or the grid goes down.

The significance of this advantage of drainback systems is that a system may be oversized to achieve a greater annual percentage of solar contribution without creating overheating problems in the summer months. It also permits upsizing for additional needs such as space heating or spa heating. The differential controller will automatically turn the system off in the summer when the tank sensor reaches the high limit, draining the water back into the reservoir.

An advantage of using water as a heat transfer fluid is that it never needs to be changed like antifreeze systems, which should have fluid replaced at least every ten years, or whenever overheated by stagnation conditions. Since drainback systems are unpressurized closed loop systems, they are simpler to maintain than antifreeze glycol systems. The drainback system also has fewer parts—no check valve, air vent, pressure gauge, or expansion tank.

Drainback systems are much easier to install than glycol systems. And they are immune to utility blackouts. The water drains back to the reservoir when there is no electricity to run the pump. The controller will cut power to the pump when the storage tank reaches its predetermined high limit temperature setpoint (usually 180°F; 82°C).

Water has a higher heat capacity than other heat transfer fluids, and is typically 15 to 20 percent more efficient in collecting BTUs than a 50:50 glycol/water mixture. Water's lower viscosity (it's thinner) means that it pumps more easily than glycol/water mixtures at low collector temperatures. A homeowner can easily maintain a drainback system by adding fluid when necessary. It takes proper equipment and knowledge to charge a pressurized antifreeze system.

Disadvantages of Drainback Systems

The greatest disadvantage of a drainback system as compared to a closed loop antifreeze system is that the system's collectors and piping must all be above the reservoir tank, heat exchanger, and storage tank. It is imperative that the system be installed such that collectors and piping freely drain back to the reservoir tank. Larger piping (3/4 inch copper pipe, minimum) and insulation must be used. Glycol systems often use 1/2 inch copper pipe.

Although drainback systems offer a high degree of reliablilty if properly installed, systems using water as a heat transfer fluid have little tolerance for error in freezing climates. It is, therefore, imperative that the system complies in detail with all principles of sound design and installation.

The efficient heat exchange properties of water are offset somewhat by the higher power requirements of the high head AC circulating pumps that are used with drainback systems. To run the pumps requires 140 watts for the TACO 009 BF, or 205 watts for the Grundfos UP26-96 BF. This represents about an 8 percent reduction of solar savings due to the energy required to run the pump and the differential control.

The average pump run time is about 4-1/2 hours per day. The TACO 009 is preferable due to the lower power consumption. On rare occasions, you may have to put two pumps in series if the static lift to the collector is over 30 feet (9 m) above the reservoir water level. The second pump can be turned off after startup using a timer. It is far preferable to design for single pump use, however. The second pump presents a measure of risk. If the upper pump were to fail, the lower pump may lift a static water column to a level where it may freeze. With the lower pump operating, a freeze-bursted pipe could potentially dump the contents of the reservoir.

A drainback system may also run the risk of a freeze-related failure if the controller fails to turn off the circulating pump. A damaged sensor, sensor wire, or controller failure in the “on” position could result in the circulating pump operating under freezing conditions.

These failures are quite rare, but in the interest of a 100 percent fail-safe system, you may consider either or both of the following two measures:

- Use a 30:70 propylene glycol/water mixture in place of the water. This may sound like giving up one of the advantages of a drainback system, but consider that this heat transfer fluid will be fail-safe from freezing and will not be subjected to high collector stagnation temperatures.
- An aquastat with a sensor bulb on the return side can be set to turn off the pump if the sensor bulb detects freezing water. An aquastat is a thermostat with a remote bulb type sensor. They are commonly used in the heating and cooling industry, and are readily available at any plumbing and heating contractor supply house.

Drainback systems can be a little noisy—like a coffee percolator. Make sure that the water returns through one or two 90 degree turns in a conditioned space above the water reservoir to reduce the noise of water falling into the reservoir tank. Adding a water heater insulation jacket to the reservoir can help minimize noise and reduce heat loss from the reservoir.

Variations in System Design

We have described the most common drainback system for solar domestic water heating. Of course, you can make numerous variations to this design. You may consider double pumped drainback systems, space heating to a single zone, pool heating, or PV powered circulating pumps.

Remember that double pumped systems involve using an external sidearm heat exchanger and a second pump to circulate the water loop. Although heat exchange efficiency is greater, you must also consider that the second circulating pump draws power, and increases the likelihood of maintenance and repair.

If you use a double pumped system, always pump the water in the opposite direction of the closed loop’s return flow from the collector. The water side must pump slowly, so as not to disturb tank stratification (see *Maintain Temperature Stratification in Your Tank, HP84,* page 48,). You may use a 1/100 HP circulating pump with a very low flow rate, such as the March 809 oil-free model or the Taco 003.

Solar hot water and small supplemental space heating systems can be combined if the system is a drainback system. Drainback systems are ideal for supplemental space heating. Systems with AC controls with a high limit feature can use the tank sensor to turn off the pump when a preset high limit temperature is reached in storage. This prevents overheating the storage tank. Systems designed for space heating should use a collector tilt angle of latitude plus 15 degrees to optimize winter season performance. Summer performance is not compromised because the system is oversized without the space heating load.

The high static lifts required by most drainback systems do not usually lend themselves well to using PV power direct to a DC circulating pump. With conscious consideration for minimizing lift requirements, it is possible. Powering the low head, low flow circulating pump on the water loop is an easier matter. Use a five or ten watt module directly wired to the El Sid DC or March 24 volt DC circulating pump.

Simple Yet Versatile Design

We have discussed the function and design criteria for selection of each component of the system. For the collector loop, you’ll need a high head AC circulating pump or pumps, reservoir tank, and heat exchanger. Three strategically placed boiler drains will allow easy filling of the system. You may choose to install a visual flow meter or sight glass to aid in filling the system. You will have to be sure that collectors and piping have fail-safe drainage back to the reservoir tank.

If you choose a solar storage tank with an integral heat exchanger, you won't need anything else for the open loop side of the system, which handles the potable domestic water. You can increase system efficiency over an integral tank heat exchanger by 15 to 20 percent if you use a double pump external heat exchanger. Beware—your system will perform 25 to 30 percent *lower* than an internal tank heat exchanger if you use a single pump, external thermosyphon heat exchanger. Your heat exchanger will also have to be descaled frequently.

A drainback solar water heating system is a straightforward design that offers reliable freeze protection for cold climates. It is a simple design, yet versatile for additional applications, such as space heating or pool applications, because it is not vulnerable to the problems of overheating. All the components are readily available, and it is an easy system to install for do-it-yourselfers with basic plumbing skills.

In future issues of *Home Power,* we'll explore the nuts and bolts of a drainback solar water heating system installation. It's not often in today's world that simplicity and reliability come in the same package.

Access

Tom Lane, Energy Conservation Services, 6120 SW 13th St., Gainesville, FL 32608 • 352-377-8866
Fax: 352-338-0056 • tom@ecs-solar.com
www.ecs-solar.com • Note: Much of the technical content of this article is based on *Solar Hot Water Systems: Lessons Learned, 1977 to Today* by Tom Lane.

Ken Olson, SoL Energy, PO Box 217, Carbondale, CO 81623 • Fax: 559-751-2001 • info@Solenergy.org
www.solenergy.org

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 • Distributor of solar energy components and systems

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800-978-6327 or 909-605-5610 • Fax: 909-605-5613
leslieplett@yahoo.com • www.sunearthinc.com
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Fax: 334-260-2529 • www.rheem.com • Solar storage tanks

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www.us.grundfos.com • Hydronic circulating pumps

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401-942-8000 • Fax: 401-942-2360 • marcha@taco-hvac.com • www.taco-hvac.com • Hydronic circulating pumps

Heliotrope Thermal, 4910 Seaport Ave., Richmond, CA 94804 • 510-237-9614 • Fax: 510-237-7018
info@heliotropethermal.com
www.heliotropethermal.com • Check valves for PV powered DC pumps, and differential controls

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Fax: 401-885-1500 • sales@goldlinecontrols.com
www.goldlinecontrols.com • Differential controls

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