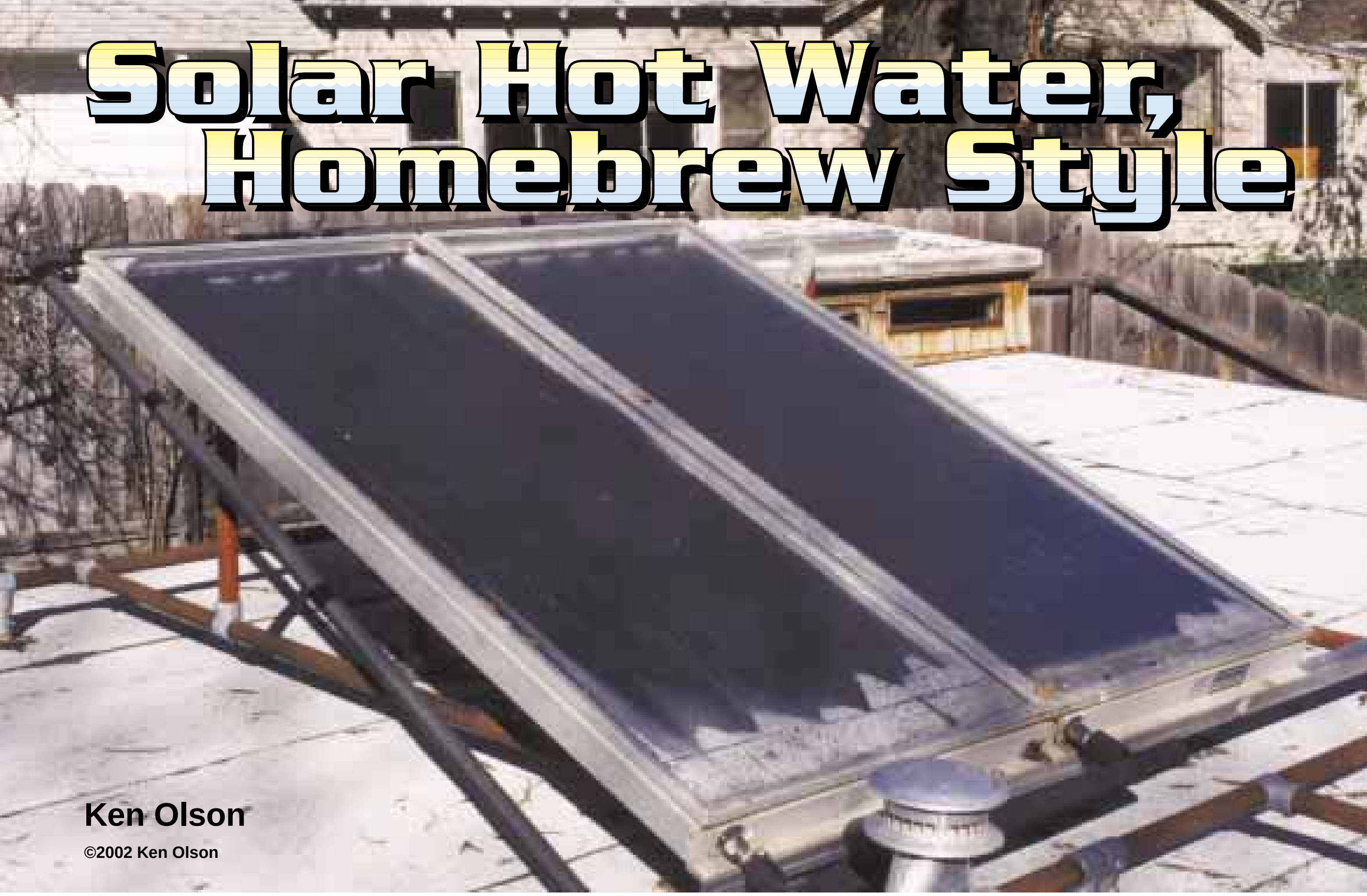
Solar Hot Water, Homebrew Style



Ken Olson

Two, 3 by 7 foot solar collectors make 70 percent of Jay's hot water—that's a 26 percent return on his investment. This home-built drainback system cost only US$800, and required just basic plumbing skills to assemble.

Jay Peltz brews his own hot water, and solar energy is his fuel of choice. The sun goes to work for him each morning, and delivers hot water every day. Jay's homebrew style drainback system meets the need for freeze protection, and is the product of his practical resourcefulness and budget-minded philosophy. The result is a simple design that works.

Solar hot water systems with freeze protection have been covered in two previous issues of *Home Power* (See "Solar Hot Water for Cold Climates: Closed Loop Antifreeze System Components," *HP85*, and "Solar Hot Water for Cold Climates, Part II: Drainback Systems," *HP86*.) Those articles explained the principles of system design, and the function of each of the components. In this article, you will learn how Jay has applied the nuts and bolts of solar water heating principles to a homebrew drainback system.

Climate & Needs

Jay lives in northern California's coastal foothills. The climate is neither sunbelt nor arctic, but the mercury dips below freezing regularly between November and March, and as low as 10°F (-12°C) on rare occasions. Jay decided on a drainback system for its freeze protection, simplicity of design, and ease of installation. With some previous plumbing experience, he didn't hesitate to tackle it, do-it-yourself (DIY) style.

Jay's one-person household has modest hot water needs of 20 to 25 gallons (75–95 l) per day. He uses a little more in the summer when his hot water is 100 percent solar. The average two-person American family uses about 40 gallons (150 l) per day. Larger families use an additional 15 gallons (57 l) per person per day, on average.

Solar hot water system design begins with the daily water consumption figure. Jay knew that starting with a smaller number makes everything easier and more economical. So he addressed the conservation side of the equation first with low flow shower heads and faucet flow restrictors.

Low flow shower heads (under 3 gpm) reduce hot water use by 30 to 70 percent compared to the standard 5 to 6 gallon (19-23 l) per minute guzzlers. Flow restrictors reduce water flow at kitchen and bathroom faucets by approximately 50 percent over standard faucets.

Jay minimizes energy use for hot water in other ways too. He waits to wash full loads of laundry, and selects the cold water wash option on his front loading washer. Front loading washers use 30 percent less water than their top loading cousins. Jay's 1 gallon (3.8 l) per flush toilet saves water too, though only cold water, of course.

Savings Aren't All About Money

Jay does save money with a solar hot water system. He has reduced his hot water heating costs by 70 percent annually, a savings of more than US$200 worth of propane per year by his estimate. At a cost of less than US$800, including the DIY discount, that amounts to a 26 percent return on a tax-free investment—worthy of making headlines on Wall Street. Savings from the first two and a half years of operation paid for his system. Every year after that is a solus bonus (that's Latin for free lunch).

But it's not all about money. Jay saves more than that. He saves carbon—tons of it! His homegrown solar hot water system will avoid spewing 75 tons of carbon into the atmosphere over the next 30 years—a significant one-man stand against global warming.

System Operation

This drainback system uses a reservoir tank with a submerged copper coil heat exchanger. Water within the tank is circulated through the collectors when useful heat can be collected. When the stored hot water is up to temperature, or no more useful heat can be collected, the circulating pump shuts off, and the water drains back to the reservoir tank.

As domestic hot water is drawn from the tap, cold water passes through the heat exchanger, where it is preheated by the solar heated reservoir. From there it passes through a gas-fired, on-demand water heater. If necessary, the temperature is boosted by the heater on its way to the hot water tap.

In the summer, Jay gives his gas water heater a vacation. He shuts it off and uses 100 percent solar heated water. He has also arranged valves in such a way that he can bypass the solar hot water system for maintenance or repair if necessary.

Solar Recycled

Jay didn't have to look far for used solar hot water collectors. The solar heyday of the 1980s collapsed when Ronald Reagan allowed the solar tax credits to expire. Orphaned systems were neglected. Many fell into disrepair for want of basic maintenance. As a result, many systems were decommissioned, and used collectors became opportunities for recycling.

Jay was able to purchase used collectors from a contractor in nearby Mendocino, California. The collectors had been used in a commercial solar hot water system, which had been dismantled. Jay carefully inspected each of the collectors for damage. He used an air compressor to pressure test them for leaks. When the collectors held 50 pounds per square inch (psi) of air pressure for 30 minutes, he knew they were in good working order.

Collectors

The two, 3 by 7 foot (0.9 x 2.1 m), flat plate solar collectors are about the right size for a two-person household, so Jay has more than enough hot water for himself. The collectors are plumbed in parallel for a total of 42 square feet (3.9 m^2) of collector area. This approximates the rule of thumb of 1 square foot (0.09 m^2) of collector area per gallon (3.8 l) of solar storage for his climate.

The Goldline controller and AquaStar backup heater above the drainback tank enclosure.

Jay Peltz' System at a Glance

Item	*Description*
Location	Redway, California
System	Drainback for domestic hot water
Daily hot water usage	25 gallons (95 l) per day
Solar storage tank	50 gallons (190 l)
Collector area	42 square feet (3.9 m^2)
Backup water heating	AquaStar on-demand propane

The collectors are mounted on the roof, facing true south, with the long dimension tilted up at a 30 degree angle from horizontal. Although conventional wisdom calls for collectors tilted to "degrees of latitude" for year-round uses, Chuck Marken of AAA Solar recommends a steeper tilt angle of "lattitude plus 15 degrees" for solar hot water systems. This increases winter performance and lessens variation of seasonal performance. The long dimension of the collector is tilted up as recommended for drainback systems, so the parallel tubes can freely drain.

The flat plate solar collectors consist of a black absorber plate of selective surface copper sheet. The selective surface (discussed in *HP84,* page 48) combines high absorptance in the visible spectrum of light with low emissivity in the infrared spectrum of radiation. These qualities give a selective surface the high heat radiation gain and low radiation heat loss that makes them so much more efficient than flat black, painted absorber plates.

The copper absorber is continuously soldered to 1/2 inch (13 mm) diameter copper tubes that are spaced 4 inches (10 cm) apart and run parallel the length of each collector. A 1 1/4 inch (32 mm) diameter header pipe runs across the ends of the parallel tubes at top and bottom. The two collectors are plumbed together in parallel. The header pipes serve as the inlet and outlet manifolds of the collector array. Jay also tilted the collectors slightly at 1/4 inch (6 mm) per foot so the headers would drain toward the collector inlet.

The rack for the panels is made of 1 1/2 inch (38 mm) steel pipe. The fittings are Kee Klamp brand. These are UL listed, and come in all shapes and sizes. The feet are standard feet for steel pipe. They were attached with ten, 5/16 inch (8 mm) galvanized lag bolts, and were then sealed with mastic.

Jay used these fittings because it was the easiest way to make the rack fit his roof. The roof structure on his older home is 2 by 4 rafters, 24 inches (61 cm) on center, with a 10 foot (3 m) span. There was no way to mount anything in the middle of these!

So he constructed a mount that would attach at the support walls, spanning the 10 foot distance. When he installed his solar-electric array a few years ago, he included the necessary parts to add the future solar thermal panels. Jay is very happy with the way it turned out, though he dreads having to remove the rack to fix the roof!

Drainback Reservoir & Heat Exchanger

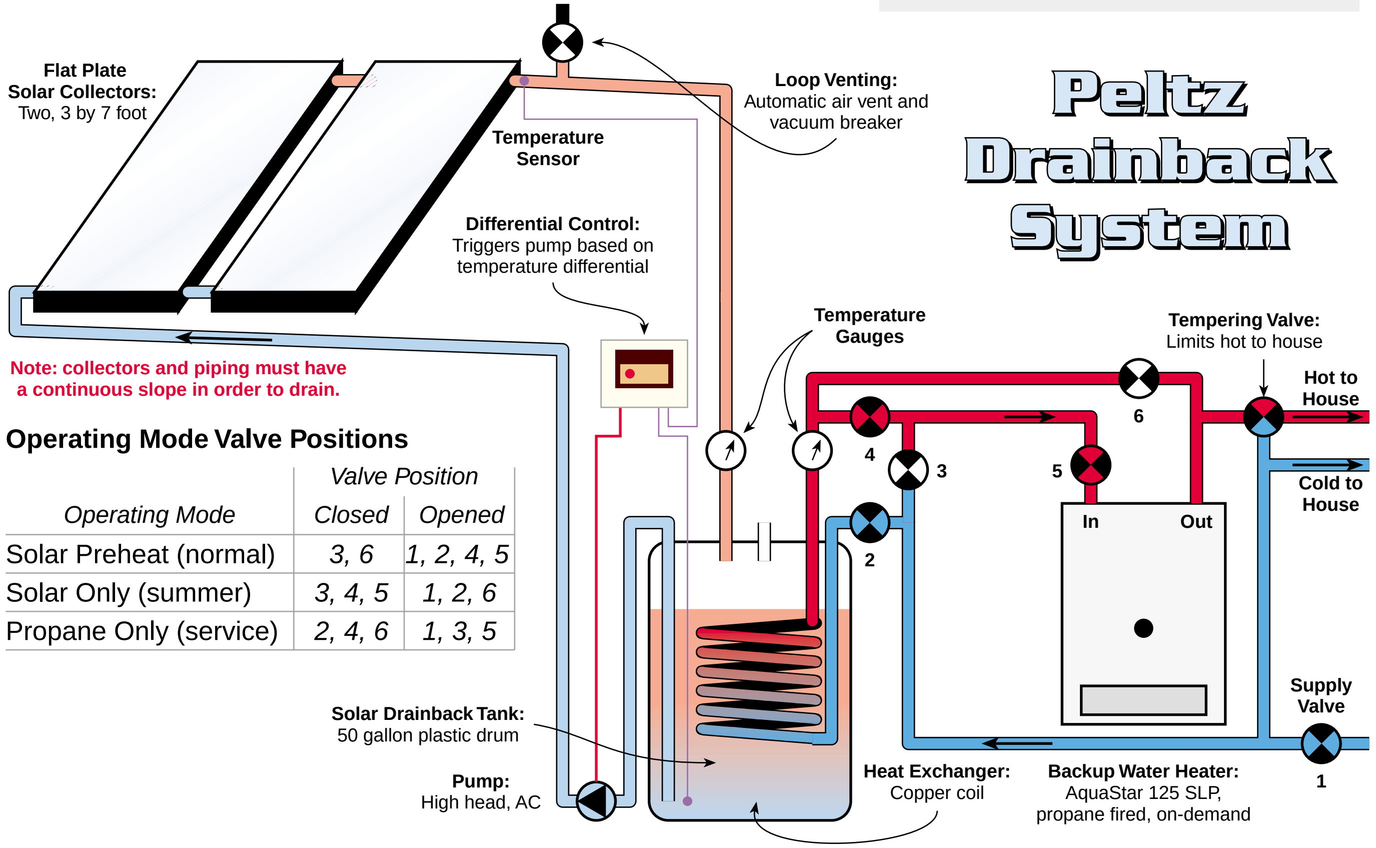
The drainback reservoir is also the solar storage tank. Jay used a recycled, 50 gallon (190 l), plastic olive barrel with lid. Water held in the reservoir tank is circulated through the collectors. Domestic water circulates through a copper coil heat exchanger submerged within the reservoir tank.

The heat exchanger consists of a 50 foot (15 m) coil of 1/2 inch, soft (type L) copper tubing. This is adequate for Jay's modest hot water use. Larger households would benefit from a greater heat exchange capacity in order to heat water in a single pass. Type L soft copper is purchased in coils and can be easily bent into gentle sweeping curves or coils. Type M is rigid copper pipe, which comes in 20 foot (6 m) straight lengths and is used for most plumbing runs. Both types of copper pipe are readily available at local plumbing supply houses.

As domestic hot water is used, the cold inlet water passes through the heat exchanger, where it picks up solar heat by conduction through the wall of the heat exchanger pipe. The 50 gallon (190 l) reservoir tank is 90 percent full when the system is at rest. When the pump is circulating water through the collectors, the water level drops to approximately 85 percent full.

This approach is a bit different from most drainback solar hot water systems. Three tanks are commonly used: a reservoir tank, a solar storage tank, and a backup water heater tank. The more typical 10 to 20 gallon (38–76 l) reservoir tank simply holds the water that drains back from the collectors when the circulating

The 50 gallon drainback tank is enclosed in an insulated box and surrounded by foam beads.



Operating Mode Valve Positions

	Valve Position	
Operating Mode	*Closed*	*Opened*
Solar Preheat (normal)	*3, 6*	*1, 2, 4, 5*
Solar Only (summer)	*3, 4, 5*	*1, 2, 6*
Propane Only (service)	*2, 4, 6*	*1, 3, 5*

pump is not in operation. The solar storage tank, with capacity equal to daily hot water consumption, holds the solar preheated domestic water. A conventional hot water heater tank boosts the temperature as necessary for final delivery. A heat exchanger transfers heat from the collector loop to the solar storage tank.

Jay has integrated these functions into one space-saving, energy efficient tank that doubles as reservoir tank and solar storage tank. His AquaStar on-demand heater takes the place of the conventional water heater tank and its associated standby heat loss. Even though Jay's initial cost (US$800) for an on-demand water heater is higher than for a standard water heater (US$250), his savings in gas usage over time will more than make up for the additional expense.

The heat exchanger is placed in the hottest water near the top of tank, but always below the lowest water level. It then heats incoming domestic water with only one pass through the coil on its way to the AquaStar on-demand heater.

The storage tank is enclosed in a box made of 1/2 inch (13 mm), exterior grade (CDX) plywood screwed together with 2 by 2 inch corners. It is insulated with 1 1/2 inches (38 mm) of foil-faced, polyisocyanurate rigid foam on all four sides. The foil face is placed toward the warm side (facing the tank) for maximum effectiveness. The tank has a minimum of 3 inches (7.6 cm) of clearance from the plywood enclosure. Jay filled the voids between tank and enclosure with polystyrene from a beanbag chair.

All plumbing connections to the reservoir tank are made through the plastic lid of the tank. These connections include collector in and out, heat exchanger in and out, and a plastic breather tube that is vented outside. There is also a 1 1/2 inch plastic pipe with cap, used for observation and filling.

Jay installed the breather tube to vent moisture-laden air to the outside, as air and water expand and contract with temperature variations. This venting to the outdoor atmosphere makes Jay's system an open loop, with constant renewed exposure to oxygen. This means that all of Jay's plumbing must be resistant to corrosion by oxidation.

The breather tube is unnecessary in a standard drainback system design that uses a sealed reservoir tank. Drainback systems are typically unpressurized, closed loop systems, unvented to the outdoor atmosphere. Jay's olive barrel has an unsealed top, which would have vented moisture into the insulated tank enclosure. So he had good reason to vent in this case.

Pump—Head & Flow

Jay used a TACO 009F circulation pump in the collector loop. Since the collector loop is unpressurized, the pump must be able to lift water the total vertical distance (static head) from the low water level in the reservoir tank to the top of the collectors. The total static head for this system is 11 feet (3.4 m). This Taco pump will lift to a maximum head of 34 feet (10.4 m), which is more than adequate. It is installed at a level near the bottom of the reservoir tank, where it is always below the water level.

The Taco 009F has a cast bronze body that is resistant to the dissolved oxygen present in open loop systems. It provides about 7 gpm (26.6 lpm) flow rate, which is more than sufficient. Solar collectors should have a minimum flow of approximately 0.015 gallons (0.057 liters) per minute per square foot (0.09 m^2) of collector. That translates to 0.64 gpm (2.4 lpm) for this system, which has 42 square feet (3.9 m^2) of total collector area. The high flow rate is typical of drainback systems, a consequence of the requirement for a high head pump to lift water to the top of the collectors. Once the water begins to fall down the return pipe, the siphon effect reduces operating head, and the flow rate increases.

The pump is installed with flanges (hence the designation “F” in the model number) for ease of removal for maintenance or repair. One side of each of the flanges is cast to the pump body. The other half of the flange is connected to the pipe. The two sides of the flange are bolted together to compress an O-ring seal between them.

A Goldline GL-30 controls circulation pump operation.

A sensor measures temperature of water leaving the collectors. Another measures tank temperature.

Controller

The system is controlled by a Goldline GL-30 differential controller. The controller senses the difference in temperature between the outlet of the collectors and bottom of the reservoir tank. When the temperature of the collector outlet is 20°F (11°C) higher than the bottom of the reservoir tank, the controller turns the pump on to circulate water through the collector loop.

As water circulates, it removes heat from the collector and increases the temperature of the water in the reservoir tank. When the temperature differential falls to 5°F (2.8°C), the pump turns off and the water drains back to the reservoir tank.

The controller also has an adjustable, high limit cutout. This will shut the pump off once the reservoir tank reaches a predetermined high temperature. The high limit setting is adjustable between 110 and 170°F (43 and 77°C). Jay has set the high limit to 145°F (63°C) to keep the tank from getting too hot.

He doesn’t know what temperature the olive barrel will handle. Will high solar temperatures melt it? The 145°F (63°C) maximum temperature setting is a conservative measure to minimize the risk of using materials with unknown characteristics. So far, so good, after one hot summer. The system has no trouble producing 145°F water on a regular basis.

Chuck Marken says that two commonly used plastic materials are suitable for hot water storage—polypropylene and high density, cross linked polyethylene (HDPE). Polypropylene is the best choice because it will typically handle temperatures up to about 200°F (93°C) before becoming soft. HDPE will begin to deform at about 160°F to 180°F (°71C-82°C), requiring some support from its insulated enclosure.

The controller uses 10,000 ohm, thermistor-type sensors. The electrical resistance of the thermistors changes as the water temperature changes. At a temperature of 77°F (25°C), the sensor has a resistance of 10,000 ohms. As temperature increases, its resistance decreases. The controller continually compares the temperatures at the sensors, and turns the circulating pump on or off according to the controller's set points.

Jay used a stainless steel hose clamp to fasten one sensor directly to the copper pipe at the outlet of the collectors. The sensor is fastened as close to the collector frame as possible, and is covered with pipe insulation so it measures collector outlet temperature as accurately as possible.

He used #18 (0.8 mm^2) two-wire, stranded, PVC double-jacketed, exterior thermostat cable routed along the pipe to connect the sensors to the controller. Jay soldered the sensor connections to the cable with rosin core electrical solder, and protected them from the elements with heat shrink tubing. The connections were then covered with pipe insulation.

On-Demand Water Heaters

Often referred to as "tankless" or "instantaneous" water heaters, on-demand water heaters do not store water. They await your demand, and heat water only as it is used. This eliminates all standby heat loss, and saves 20 to 30 percent compared to a tank-type heater. Gas models operate at a high efficiency (80+ percent). Units with electronic ignition eliminate the need for a pilot light. Models are available for propane or natural gas, or for electricity.

Operation & Performance

The on-demand water heater is activated by flow rate. As the hot water tap is opened, the heater senses the pressure differential and resulting water flow. This activates the flame to continuously heat water on its way to the tap. Water flows through a high-efficiency copper heat exchanger. The unit shuts off when the flow rate stops as the tap is turned off.

An on-demand heater is rated for the maximum flow rate it will produce. This depends on the maximum BTU input rating of the unit and the desired temperature rise. The higher the incoming water temperature, the greater the flow rate it may produce.

Standard and large units are designed to heat water for the whole house. They typically have a maximum flow rate of 4 to 6 gallons (15–23 l) per minute. This could be a limitation for large families and heavy users of hot water. A single, high flow shower head (4 to 6 gpm; 15–23 lpm) could stress household relationships in the competition for the right to hot water.

A typical on-demand water heater: the AquaStar 125B.

Image Courtesy of Controlled Energy Corporation

The solutions are low flow shower heads (1 to 2½ gpm; 4–9 lpm) and faucet flow restrictors. Water conservation allows the on-demand heater to accommodate other simultaneous hot water uses, such as clothes washers, dishwashers, sinks, etc. Smaller on-demand heaters with flow rates of 1½ to 3 gallons per minute (6–11 lpm) are designed for point-of-use applications, such as a single sink.

Installation

On-demand water heaters usually weigh under 50 pounds (23 kg) and are wall mounted. Gas models have a flue, which must be vented outdoors. Optional power vents allow for horizontal flue runs up to 100 feet (30 m) long for some units.

Some models are designed for open loop domestic water heating applications. Other units are designed for closed loop hydronic heating systems. On-demand water heaters also require a minimum flow rate to activate.

The sensor for the tank was inserted inside the tank, since Jay didn't have a good way to fasten it to the exterior of the plastic tank. With standard steel tanks, the sensor is usually placed in contact with the bottom of the tank wall under the tank insulation. Another approach in drainback tanks like this is to place the sensor at the bottom of a copper dip tube with a cap soldered on the bottom. In this case, the submerged wire connections were soldered and protected from the water with silicon and waterproof heat shrink tubing.

Submerged sensors are more than a little risky, and not recommended. If the water corroded the connections or caused them to come loose, the controller would interpret a high resistance in the storage tank sensor as a very low temperature, causing the pump to run continuously. A short between the two wires (low resistance) would be interpreted as a very high tank temperature, and the pump would not turn on at all. These conditions in the collector sensor would have the opposite effect. Extreme care must be taken to protect the sensors, sensor wire, and connections to ensure that the controller has accurate temperature readings.

AquaStar On-Demand Heater

Jay's system uses a propane, on-demand water heater to boost the water temperature when necessary. The unit is an AquaStar model 125 SLP (S stands for solar; LP is for liquified petroleum, commonly called propane). It is designed to operate with open loop solar hot water systems.

The S model AquaStar is able to sense the temperature of incoming solar preheated water. Then it boosts the temperature of the water to meet its thermostat setting. The AquaStar unit is located very close (2 feet; 0.6 m) to the reservoir tank to minimize heat loss in the pipe. The pipes are well insulated with closed cell polyurethane pipe insulation.

Jay offers his eyewitness account of the AquaStar in operation at the end of a sunny day: "When the hot water tap is opened, the heater turns on full flame height. As it senses the water temperature coming in, the flame height lowers and then goes out. This all takes about 15 seconds or less."

A Unique Open Loop Drainback

Jay's drainback design differs somewhat from the standard closed loop drainback system design described in *HP86.* He has vented the collector loop to the atmosphere to assist with system draining and moisture venting. This drainback system is therefore an open loop system.

An automatic air vent and vacuum breaker are installed at the top of the system. These fittings, not normally installed in a closed loop drainback system, are borrowed from the draindown system design. The air vent allows air to escape as the collector loop fills with water. The vacuum breaker allows water to drain back to the reservoir tank because air can enter at the top of the collector loop when the pump shuts off.

Peltz SDHW System Costs

Item	*Cost (US$)*
2 Solar collectors, 3 x 7 feet	$200
Taco 009F pump	200
Miscellaneous plumbing parts	200
Barrel, plywood, insulation	100
Goldline GL-30, differential controller	60
Total	$760

You have probably experienced the same phenomenon by dipping a straw into a glass of water. Remove the straw with your thumb covering the top end, and the straw remains full even though the bottom is open. Atmospheric air pressure (15 psi at sea level) prevents the straw from draining until you break the vacuum by removing your thumb.

The Case for a Closed Loop Drainback

Automatic air vents and vacuum breakers have a history of malfunctioning in more extreme winter climates with repeated freeze-thaw cycles, snow, and freezing rain. The solution is to eliminate the air vent and vacuum breaker altogether, operate the system as a closed loop, and allow air from the top of the reservoir tank to rise up the collector return pipe to break the vacuum. The vacuum must break without fail.

For this to work properly, several conditions are absolutely necessary:

- The return pipe from the collector outlet must be of adequate diameter to pass air flowing up while water is flowing down; 3/4 inch is minimum, 1 inch is preferred.
- The reservoir tank must allow air to enter the collector return pipe. This requires that an airspace is always present at the top of the reservoir tank and open to the return flow of water.
- The air must be able to freely rise up a constantly steep, sloping pipe (steeper the better) to the top of the collectors.

These attributes will break the vacuum and allow the system to freely drain back. Shallow slopes or dips must be avoided because air can be trapped, preventing water from draining freely. Jay could easily eliminate the air vent and vacuum breaker from his system. He doesn't need them. His plumbing already meets the above criteria for reliable drainage. Removing the vacuum breaker and air vent would simplify Jay's system, but it will still be an open loop because his tank is vented to the atmosphere.

Plumbing and Roof Penetrations

Jay used 3/4 inch, type M rigid copper pipe on the collector return. The collector supply pipe and all other domestic water lines are 1/2 inch, type M rigid copper pipe. Copper joints and fittings were sweat soldered using 95/5, tin/antimony solder. Lead/tin, 50/50 solder is no longer allowed by most plumbing codes in potable water lines. All pipes in the collector loop and hot water lines are insulated with closed cell pipe wrap that is slit along its length to fit over the pipe. Once in place, the seam is glued.

Penetrations through the roof use a sheet metal roof jack with a neoprene boot. These units are commonly used in the plumbing industry to pass pipes through the roof, while keeping the weather out. On shingled roofs, the sheet metal base slides under the row of shingles above, and over the top of the shingles below to effectively shed water. The neoprene boot fits snugly around the pipe and seals out water.

Avoid nailing the sheet metal base in place unless the nails can be covered by the shingles above. That's easy for new construction, but very tricky for installing on an existing roof. Metal roof systems usually have their own proprietary fittings for handling roof penetrations.

Jay used a plastic pipe insulator at each place where he needed to pass a pipe through wall sheathing, roof sheathing, studs, floor joists, or rafters. These pipe insulators act as sleeves to prevent the pipe from coming in direct contact with wood. This protects the pipe from physical stress and structural damage. It also avoids vibrations in the pipe that can be transmitted through the structure of the building. These insulators are specified for the pipe size being used.

Optional Modes of Operation

Jay plumbed the system so he can operate it without gas backup or without solar input. In summer, he can bypass the AquaStar, turn it off, and run on 100 percent solar heated water. He installed a tempering valve in the hot water line to avoid delivering excessively hot water to the tap. The tempering valve (also referred to as a mixing valve) is adjustable, and is set to limit the water temperature to avoid scalding.

If the temperature of the solar preheated water is higher than desired, the valve will automatically mix cold water to temper the water temperature delivered to the tap. This antiscalding strategy is somewhat redundant with the adjustable high temperature limit on the solar control; but when it comes to safety, Jay says that his "belt *and* suspenders" approach pays off.

Two sheet metal roof jacks with neoprene boots make roof penetrations weatherproof.

Solar Farming

Jay installed his system mostly by himself in about sixteen hours time. Those hours were spread out over the course of a week, and didn't include the time spent rounding up components and materials. Half of that time was consumed getting the collectors mounted on the roof with help from a friend.

Jay is proud of his daily harvest of 50 gallons (190 l) of 145°F (63°C) water. He estimates that this system will provide approximately 70 percent of his annual hot water needs—100 percent in the summer months and 40 to 60 percent in the winter. Jay has measured electrical consumption of about 150 to 180 watt-hours per day to run the pump and provide 24/7 power to the controller.

Do It Yourself?

When it comes to homebrewed energy, you can do it yourself, too. If you aren't an expert but have a sense of practical willingness, issue yourself a learner's permit, study the principles, follow good advice, get some help where you need it, and do it. If you are all thumbs or not quite so adventurous, hire a solar contractor.

Whether you do it yourself or hire a professional, your system should comply with local safety codes. In most places, a permit is required and you'll need to pass inspection. Visit with the local building or mechanical inspector before you get started. You'll probably get some good advice, and it always helps to have a positive relationship with your inspector.

Drainback systems are not rocket science, but they are not forgiving to the careless installer. They are relatively simple, and lend themselves to the well directed, do-it-yourself installer. But if you want your experience to be a pleasant one, you'll take all the good advice you can find and follow it closely.

Access

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