Marrying solar thermal and photovoltaics to create a top notch closed loop solar hot water system

By Tom Lane

An interesting aspect of the solar industry has always been that there is little crossover between solar contractors. Most of the contractors involved in solar thermal systems have hardly any experience in solar electrical systems, and conversely, solar electrical contractors who are on top of "what works" in photovoltaics do not seem to have a clue about what is a good buy, or value, in a solar hot water system and what the pitfalls are in solar hot water system design.

In this article we'll marry both technologies and show you how to build a dependable, top quality solar water heater.

Presently, I am heating water for six people: my wife, three boys, my mother-in-law, and myself using a 120gallon closed loop solar tank, two 4xio black chrome U.S. solar collectors, a SX-20 photovoltaic module which functions as the controller and power to run a 12-volt Hartell HEH Brushless DC pump.

Collectors mounted on the north roof facing south. This strategy keeps the collectors from being mounted on the front of the house. Note the photovoltaic panel attached to the side of the thermal panel.

For circulating the solar loop, the Hartell HEH Brushless DC pump connected to a small photovoltaic module, is my personal preference. Because of its inherent simplicity, immunity from scaling and freeze damage, and low cost per square foot of collector area, this component configuration has shown itself to be the best solar water heater available today.

Some costs

Solar hot water systems can be an excellent investment; however, you owe it to yourself to make sure you are getting a good investment—not just a gimmick "token" solar system that heats a little water and makes you feel environmentally correct."

Solar hot water heating for showers, dish washing and laundry will cost about $110 per person per year if LP gas costs $1.15 a gallon, or if electricity costs $.07 a kilowatt hour. At $.10 a KV*rH it costs $646 a year to heat water for four "average" people. A solar hot water system with a 120-gallon tank and 64 to 96 square feet of collector area will typically save about $500 to $600 out of the $646.

Never forget that all savings are in nontaxable income which would be equivalent to $600 to $750 that you earned and paid taxes on-to the IRS. If you are heating hot water for two or more people and you are not hooked to natural gas pipelines, then you need to carefully evaluate solar hot water as an investment and loQk for value total BTUs delivered into storage. All you need is a sunny spot where you are not shaded from 9 o'clock to 3 o'clock on December 21st (the lowest the sun drops in the northern hemisphere) facing within 25 degrees of due south.

Closed loop and open loop system

There are basically two types of solar hot water systems. Open loop systems, in which the same water for your showers etc. goes through the thermal collectors and a closed loop system, which typically uses a glycol antifreeze and a heat exchanger built into the tank. The main criteria for these systems is how hard the freezing weather is where you live.

Open loop systems should be used where you don't get any freezes. If your local area can grow mangoes, avocados, or citrus groves without danger of being damaged by a mild freeze, then you are in an area that can directly circulate water through the collectors. If not, use a closed loop system or one day you will have a visit from Mr. Murphy and your collector will freeze and burst. Since 95% of the U.S.'s population, including central Florida and most of southern California and Arizona are in areas where freezing conditions do occur, I will discuss my experience with closed loop systems to show solar hot water as an investment.

System sizing-storage

The most important consideration for the homeowner is to make sure to get enough storage (gallons in tank) and enough collector area (square feet of collector) to give you a real return on your investment in solar hot water. Plan on at least 20 gallons per person for the first four people and 15 gallons for each additional person. Solar hot water tanks are manufactured in 80, 100, and 120 gallon sizes so the choice in tank selection is one of three. When choosing a tank, you'll find that the 120 gallon size tank typically costs only $125 to $150 more than an 80 gallon tank and the money is well spent considering you are adding 50% more storage capacity for a small increase in dollars.

System sizing—collector area

You should have at least 40 square feet of collector area for the first two family members and add 12 square feet of collector area for each additional family member in the sunbelt, and add 14 square feet of collector area for each additional family member in northern climates. However; never add more than 64 square feet to an 80 gallon tank or 96 square feet to a 120 gallon tank. Keeping tank size at a ratio of 1.25 gallons or more to a 1 square foot of collector area will keep the solar system from grossly overheating in times of little demand and assures that the collector to storage ratio is efficiently matched. In Arizona and southern Florida keep the ratio at least 1.5 gallons to 1 square foot of collector area. Overheating a hot water tank dramatically decreases its life span.

The typical sizes available for flat plate collectors are 4' by 6.5' (26 sq. ft.), 4' by 8'(32 sq. ft.), 4' by 10'(40 sq. ft.) and 4' x 13' (52 sq. ft.) The bare minimum collector area size worth investing in is one 4' by 10' in a closed loop system. I strongly suggest two 4' by 8's with at least an 80 gallon tank for more than three people, or two 4' by 8's, two 4' by 10's, three 4' by 8's, or two 4' by 13's with a 120 gallon tank for larger families.

Use copper

Always use thermal collectors that have all copper tubes and absorber plates for collecting the solar energy, and have a tempered glass cover above the absorber plate. Never use plastics or fiberglass covers instead of tempered glass or any other material than all copper collector plates for absorbing the heat. Avoid using evacuated tube collectors for heating domestic hot water. It is like hunting rabbits with a cannon and can grossly overheat your tank.

A 120 gallon tank with two 4' by 8' or 4' by 10' collectors is **the best investment in dollars per BTU delivered into storage**. Avoid like the plague companies that sell solar systems with less than 40 square feet of collector area. Even in south Florida or Arizona less than 40 square feet of collection is simply not worth the investment. All solar water heaters depend on capturing sunlight to heat water and no matter how exotic the bottom end of a solar water heater might be it cannot create more solar energy than falls on the collector area in less that 40 square feet just is not enough square footage in an active open or closed loop system.

Avoid external thermosyphon systems

Also avoid external heat exchangers that rely on thermosyphoning of heat. Thermosyphon heat exchangers that work off natural convection will typically only heat the top half of the tank **no matter how you plumb the tank.** External heat exchangers only work well if you double pump the heat exchanger in counter flow. Or as is the case with the Copper Cricket, pumping the water side of the heat exchanger through the tank and back through the heat exchanger.

Another serious problem for external heat exchangers is scaling due to hard water. If you have hard water, especially calcium and magnesium, do not use an external heat exchanger unless you have a water conditioner or an antiscale filter to condition the hot water system in your house.

Rheem/Rudd and State closed loop tanks

Fortunately the two largest manufacturers of hot water tanks in the country, Rheem/Rudd, and State Industries, manufacture 82, 100, and 120 gallon solar tanks with closed loop heat exchangers that are bonded to the lower half of the solar tank's wall. This enables you to use a closed loop system and avoid the two biggest problems for solar hot water systems - 1) freezing and 2) scaling due to hard water. These tanks also keep the system incredibly simple since you need only one pump to pump. the heat exchanger side of the system.

The Rheem or Rudd tanks use copper tubing bonded to the exterior wall of the tank. This enables you to use Prestone II car antifreeze (the best) in 2 gallons of antifreeze to 3 gallons distilled water mix ratio to run through the heat exchanger. If your coldest freeze on record is above 0 degrees F. use 1 gallon of antifreeze to 2 parts distilled water.

State Industries uses an integral single wall heat exchanger that is bonded to the Lower half of the outer tank wall. The State Heat Exchange Tank

works extremely well, however, you cannot use ethylene glycol (Prestone 11) but must use its cousin, inhibited propylene glycol a nontoxic antifreeze used in all soft drinks and many other foods. The mixture ratio is the same and the excellent heat transfer properties are identical for either ethylene or propylene glycol.

Never use hydrocarbon oils, silicone oil or alcohol as heat transfer fluid because they have low specific heat characteristics and are poor choices for heat transfer fluids. We have either the State or Rheem closed & open loop solar tanks available. The cost is about M for a closed loop 80 gallon tank, and $700 for a closed loop 120 gallon tank.

Caution on materials

The entire collector loop, all fittings and pipe, must be copper or brass. All copper fittings must be soldered with 95/5 tin/antimony, or brazed. Never use 50150 lead solder. The antifreeze/distilled water solution will not need to be changed for over five years if you do not mix metals in the loop to the collector and back and mix your antifreeze with distilled water only. Never use steel galvanized pipe. CPVC, or any plastic pipe or parts.

Solar electric pumping and control

The most efficient trouble free control and pumping system is to use the 12-volt Hartell HEH Brushless DC pump connected to a small solar electric module rated at a minimum of 1.2 amps to a maximum of 2 amps under full sun conditions (typically an 18 to 30 watt PV module). The solar electric module, pop-riveted to the side of the frame wall of the solar thermal collector, will slowly start pump ing at the correct solar intensity at a variable speed.

Solar thermal and solar electric energy are completely different forms of energy from the sun, however, they are always in the same proportion based on the intensity of the sunlight. The choice of a solar electric or PV module rated 1.2 to 2 amps matched to the Hartell HEH Brushless DC pump not only enables it to provide power to run the pump but also to act as a variable speed controller to start and stop the pump and vary the speed at the correct solar intensity. The Hartell Brushless Pump features a Panasonic D.C. motor without brushes to wear out, sealed dual ball bearings, and a graphite bearing impeller to ensure optimum reliability with an extremely long life.

A smaller PV module (less than 1.2 amps) will start too late and a module bigger than 2 amps would start too early and run too long. Use only single crystal or polycrystalline PV module—do **not** use an amorphous PV module. Just connect the positive and negative leads from the PV module to the positive and negative leads on the Hartell HEH Brushless pump with 16 gauge stranded PVC jacketed wire. This control strategy means no sensors to fail, no differential thermostats, (which means it cannot malfunction and run at the wrong time), no AC power outage problems from the utilities.

After the hurricane that hit Tallahassee, Florida in 1985 the city lost utility power for several days but the solar systems with solar electric powered pumps were still providing hot water to their homeowners. Do not let anyone try to sell you on the obsolete differential controls with sensors and an AC pump. Tell them to send their dinosaurs back to the city dump.

Piping the system in

All lines in the solar loop from the tank to the collectors and back should be in type L soft and/or hard 34' (inside diameter) copper pipe. Use hard type L copper around the tank and collectors and use soft type L coils on the long attic pipe runs. Insulate the lines with 3/4 inch thick elastomerie insulation (trade name Rubatex: or Armaflex) available at air conditioning and heating parts distributors. Use I" wall thickness on the pipes in northern climates.

Do not slit your insulation and tape. Slide it over the pipes. Do **not** use polyethylene rigid pipe insulation! The heat from the solar thermal panel can melt it. All exterior insulation exposed to sunlight must be protected from UV light. One way to accomplish this is by encasing the pipe and insulation in PVC or ABS plastic pipe..But the best way is to spray it a couple of times with automotive undercoating spray and touch up as needed in the future.

Seven basic parts

Besides the pump, there are only seven simple parts in the system. 1) A pressure gauge (0-69 PSI) to simply let you know your system has not lost its charge of antifreeze and water. 2) A solar expansion tank (about the size of a basketball) that allows the solar solution to expand into it as the antifreeze fluid heats up. 3) A check valve above the pump to prevent reverse flow thermosyphoning at night. 4) A pressure relief valve rated at 75 PSI (not a pressure and temperature relief valve). 5) One boiler drain (hose, bib) valve at the lowest point in the system for filling and draining. 6) A two way ball valve, to create a bypass around the check valve. This item, #6, enables you to fill and also drain from a single drain hose bib, and if you go on vacation you can let the system dump all the heat back to the roof each night by reverse thermosyphoning if.the ball valve bypass is open. If you vacation for a week or more and do not have a means to keep your tank from overheating you will definitely shorten the tank's life. 7) A 100 PSI air vent at the highest point in the system to vent during charging.

Once the system is completely installed it will be time for charging. All you will need for system charging is two washing machine hoses, a drill pump for the end of a ⅜" or ½" power drill, and a bucket.

Charging the system

Add your antifreeze/distilled water mix, to the bucket as your drill pumps the water into the washing machine hose connected to the lower boiler drain. (If the collectors are extremely high, cover the collectors, remove the

air vent, and slowly fill from the top with a funnel). Each collector will require about 1 gallon of mixture; the tank one gallon, and each 100 feet of pipe about 2 gallons.

Keep charging until your pressure gauge reads 20 PSI plus I pound of pressure for every 2 feet the solar collector is higher than your tank. One way to -crank the pressure up is to connect the washing machine hose to a 100 feet garden hose that you fill with your mixture through a funnel. Connect that garden hose to a hose bib on the tank drain or an outside spigot and let your city or well water pressure crank your pressure up by forcing the extra mixture in by water pressure through a washing machine hose connected to the boiler drain at the bottom of the system.

Two weeks after the system has been running check your pressure. Add more mixture if necessary and then tighten down the air vent cap on top of the system.

The winning decision

An 80-gallon closed loop system with two 4' by 8' collectors and components will cost about $2000 for the equipment and save about $556 a year at $.10 a KWH or LP gas at $1.60 gallon. A 120 gallon tank with two 4' by 10' collectors and components will cost about $2300 and save about $720 a year at $.10 a KWH or LP gas at $1.60. Piping and insulation will cost about $1.25 a foot. The tank and heat exchanger should last 20 years with no maintenance other than to change the antifreeze mixture every 5 to 10 years. However, the absorber plate in the thermal collectors may need ~to be replaced every 50 years, about twice in the 150 year life of a good flat plate collector. The Hartell pump should last 15 years with no maintenance.

It is ironic, a family of four that has LP gas or high electric rates will pay for a solar hot water system in utility bills over the next 4 to 8 years, whether they get one or not. You can invest, wisely, in a solar hot water system and have something to show for your money or send the money you would have saved on solar each month to the utility company and have nothing to show for your money but more NOa, SO2, and other air borne pollutants or more nuclear waste.

The winning decision is to stop paying each month to be hooked on utility power and start owning what you are already paying for and not getting. Your savings will more than offset the monthly payment on a five year loan and you'll actually own a solar system at the end of five years instead of feeding it to the utility.

Tips on installing closed loop systems

Flush the system out with water through the top of the collector without the air vent for 10 minutes to get all the flux out of the system before charging.

Use a street 45 degree elbow and regular 45 elbow instead of a 90 degree elbow on long pipe runs to reduce pressure drop.

If you cannot find a solar contractor to help you install the system try to get an air conditioning contractor since the techniques for dealing with installing and charging a solar hot water heater are known concepts in that trade.

Do not use dielectric union or any type of plumbing unions. Use only couplings and fittings that can be soldered or brazed to prevent leaks. Keep threaded fittings to a minimum, and use liberal amounts of teflon tape or paste when making this connection.

One or two weeks after the system has been charged with anti-freeze and operating, close the air vent down tight. At this point all the air left over from charging the solar loop would have been expelled.

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"A free people ought to be armed."

George Washington