Adventures

The author's daughter Emily shows off the Heliodyne heat exchanger.

in Solar Hot Water Efficiency

Jeffrey Beeman

When I was a kid, let's say a few decades before the twenty-first century, my friends and I were always messing around with stuff. Chemistry sets, model rockets, lawn mower engines, gunpowder…and none of these things were ever quite used as they were intended. Improvisation and wild entertainment were the goal of the day. I'd never let my kids do the stuff we did back then, and I'm happy that we made it into adulthood with all our fingers and toes.

Now that I'm in the "zenith of life," my motivations and sensibilities have changed quite a bit, but there seems to be a nugget of that same kid spirit that just powers on. I guess it's this passion to "tweak the status quo" that got me messing about with my hot water system.

In June 2003, my family installed a state-of-the-art, pressurized, glycol-loop solar hot water system on our house. The system diagram shows the setup. At the time, two 4- by 10-foot (1.2 x 3 m) collectors, a 119-gallon (450 l) preheat tank, a solar-powered glycol pump, and a thermosyphon heat exchanger all just sounded too cool to resist. This baby ran all by itself, without any complicated controls or 120 VAC electrical connection. All I had to do was install the system, live my normal life, and take as many hot baths as I could stand while the system took complete care of itself.

Unfortunately, this utopia came to a halt on day two of operation, when the pump up on the roof started to make a funny kind of squeal, and we started to see steam coming from the relief valves up on the panels. This was somewhat distressing to say the least, and I started to think about all the great steam-engine catastrophes I had ever read about.

Not only that, but my wife Carlene was giving me "the eye," which meant, "You spent all this money and it doesn't work?" I called my dealer–installer, who quickly came out, recharged the glycol loop, bled the system of all air, and got us up and running again—for about two weeks, anyway.

Eventually, the system halted again. My diagnostic bet was on the poor positioning of the pump in our system, at the very highest point of the entire glycol loop. If any air bubble whatsoever blipped its way through the system, it would eventually travel to this high point and cause the pump to lose its prime.

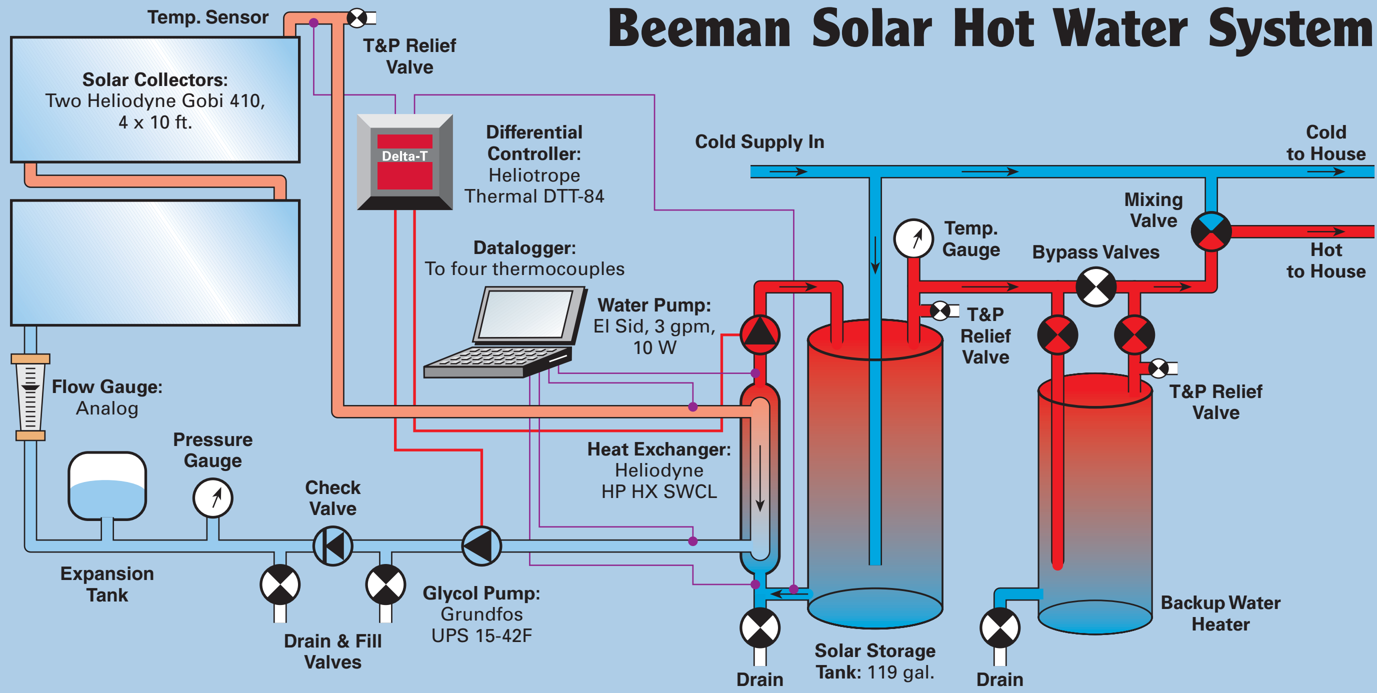
After several calls to the manufacturer of the system and our installer, I guilt-wrangled a new Grundfos 120 V pump and a conventional differential thermostat control box. The Grundfos was positioned on the return line of the glycol loop (at the low point in our system, down in our garage) and my hot baths and self-satisfaction returned. For a few more weeks, anyway, until that little "tweaking voice" started to whisper in my ear again.

Two 4- by 10-foot thermal collectors (behind PV array) face due south on a west-facing roof.

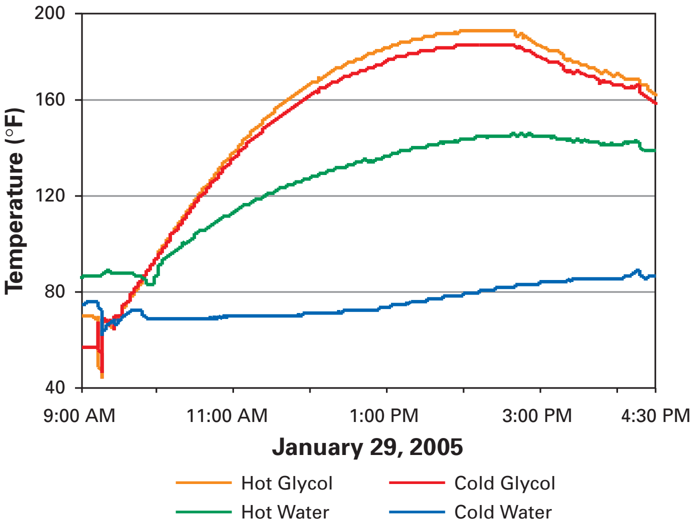
Instinct Takes Over

"Now what?!" Carlene exclaimed with a glint of impatience in her eyes. I was out in the garage climbing all over the solar tank with a gizmo in my hand, poking and probing here and there. The gizmo was a thermocouple meter, which is a very sensitive electronic thermometer that has a probe in the shape of a fine wire. I was checking the temperatures of the hot glycol solution coming from the roof, the cold glycol return, the cold water entering the heat exchanger, and the hot water being produced. "I don't know…" I replied, "Something still doesn't seem right."

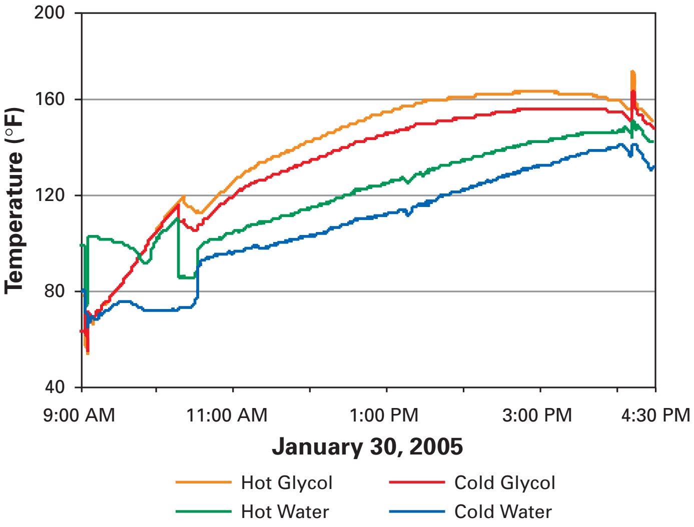
Beeman Solar Hot Water System



Thermosyphon System Performance



Pump System Performance



On this particular morning, I was measuring 128°F (53°C) hot glycol entering the heat exchanger and 116°F (47°C) glycol coming back out, but I was only making 102°F (39°C) hot water from the 93°F (34°C) water at the bottom of my tank. I poked around like this for several days and took a few pages of notes. It seemed kind of lousy to me that I was only making 102°F water when I had 128°F glycol coming from the roof.

I called the manufacturer and told them all about my measurements and my concern that our system just wasn't very efficient. I was told that "Yes, Mr. Beeman, you are very clever, but you simply don't understand how these systems work. Are you getting 160°F (71°C) water at the top of your tank on a warm, sunny day?" "Yes," I admitted, "but the heat exchanger doesn't seem to be very efficient." "Ah, well, Mr. Beeman, you simply don't understand how these exchangers work either." Maybe so, I thought, but I did understand how to search the Internet.

A little poking around revealed a paper presented at the 1999 American Solar Energy Society Conference. Researchers at the University of Minnesota (U of M) described several different styles of heat exchanger typically used on thermosyphon solar hot water systems, and predicted how these heat exchangers would perform under various conditions.

Although the paper was based on a mathematical model, the authors predicted rather crummy thermosyphon performance for the exact style of heat exchanger that I had. The paper also showed that while there are more efficient heat exchangers on the market, the most effective way to boost these systems is to add a low-flow pump to the water circuit. What? This didn't make sense at all! Several solar energy gurus report that thermosyphon systems are the best thing since sliced bread—there are no moving parts, they deliver the hottest water to the top of the solar tank, etc. It all made sense to me. Not so, said the researchers from U of M.

Next thing I know, I'm sitting on a stool in my garage, staring at my hot water tank like Rodin's *The Thinker*. Sitting over in a corner, I notice the leftover parts from the original system configuration, including a little 10-watt El Sid water pump. Hmm. Isolate, drain, saw, solder, hook up—the El Sid practically leaped into my water circuit by itself!

A computer logs data from the solar hot water system's final configuration using four thermocouple sensors.

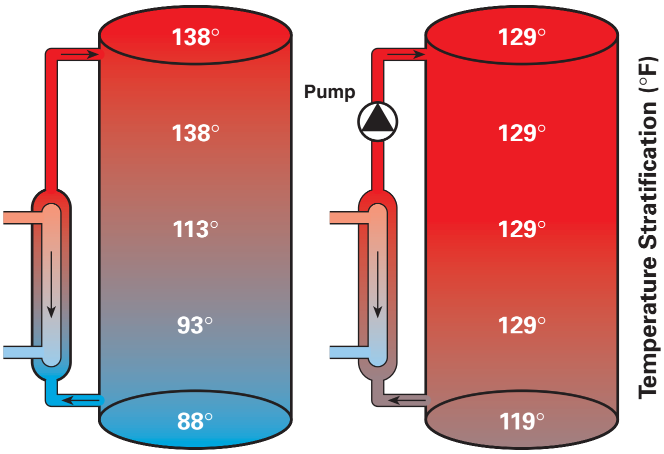
Around this same time, I also purchased a four-channel thermocouple monitor from National Instruments that connects to the USB port of a computer. It reads four thermocouples simultaneously and dumps the data to my computer. It's a very handy gadget when you have hot glycol, cold glycol, hot water, and cold water to measure. Now I can see exactly how the system works with the water pump on or off.

The graphs show that the ultimate temperature of the solar-produced hot water is indeed higher for the thermosyphon system, given similar water starting temperatures and similar solar energy hitting the panels. They also show that the cold-water side is getting warm on the pumped system, indicating that the tank heats all the way to the bottom in this case. But how are we supposed to know which is more efficient? Enter thermocouple No. 5. (Yes, I am in love with thermocouples.)

Thermocouple Madness

This time I purchased a thermocouple unit that's 6.5 feet (2 m) long. I can lower it into the solar tank and read the water temperature at various heights in the tank before and after a day's run. (If you don't remove all of the pressure in the tank before trying this, you can blow steaming water all over your garage and totally crack up your kids.)

Temperature Gain by Circulation Type



Thermosyphon Heat Exchanger Loop: Yields 32,000 Btu

Pumped Heat Exchanger Loop: Yields 53,000 Btu

I know that my tank is 119 gallons (450 l), and I know that the shape of the storage area is roughly an upright cylinder. With a little math, I can chop up the water column into 1-foot (0.3 m) "slices," figure out the average temperature per slice, and calculate the Btu that this represents. If I take the temperature-versus-depth readings in the morning and again in the evening, I've got the daily Btu harvest and can now compare the "pump on" and "pump off" configurations, right?

Well…this is only partly true. Heat exchanger-based systems rely on temperature differential to transfer heat. The greater the difference in the temperatures between water and glycol, the more effectively the heat transfers. If I want to compare the two configurations fairly, I would have to start with exactly the same temperature stratification and

The author checks the stratification of the solar tank with a 6.5-foot-long thermocouple. Daughters (and sons) make great dataloggers.

A simple, handheld temperature meter with a fine-wire, Type K thermocouple is a great tool for quick diagnostics.

Tech Specs

System Overview

Type: Pressurized glycol with two-loop heat exchanger; glycol and water loops both pumped

Location: El Sobrante, California

Solar resource: 5 KWH per square meter per day

Production: 2,700,000 Btu per month average (27 therms)

Percentage of hot water produced annually: Approximately 70 percent

Equipment

Collectors: Two Heliodyne Gobi 410, 4- x 10-foot panels

Collector installation: Roof, due south orientation, 45-degree tilt angle

Heat transfer fluid: Heliodyne Dyn-O-flo HD

Circulation pump: Glycol pump, Grundfos UPS 15-42F; Water pump, El Sid, 3 gpm, 10 W

Pump controller: Heliotrope Thermal, model DTT-84

Storage tank: American Water Heater Company, model SE62-119R-045S, 119-gallon capacity

Heat exchanger: Heliodyne HP HX SWCL

System Performance Metering

Thermometer: Omega HH11 thermal meter with Type K thermocouple, later switched to National Instruments four-thermocouple/USB interface, model NI USB-9161

Flow meter: Letro 5 gpm sight glass meter (glycol side)

Pressure: BCS pressure gauge, 160 psi max

starting Btu (not to mention having exactly the same amount of solar energy shining on the collectors every time). Given these conditions, and the forecast of a clear, sunny week in January, I decided to put my tinkering to the test.

During two consecutive sunny days, I isolated our solar tank from the house, and partially drained and refilled the tank. I started with an 83°F (28°C) average water temperature in the tank in "thermosyphon mode" the first day, and 89°F (32°C) average tank temperature in the "pumped mode" the second day. I also monitored the system with the four-thermocouple setup to make sure that the solar profile was similar for the two days (no cloud cover throughout the day, for instance). The diagram and graphs on the previous pages show the final tank stratification and Btu harvest in each case. The pumped system is the clear winner.

Since making the measurements above, I have also mounted a snap switch on the hot glycol pipe. This little gadget, normally found on hot-air heating systems, closes an electrical contact when it senses a preset temperature. It opens again when the monitored temperature drops by 20°F (11°C) or so.

This switch, in series with the system "turn on" signal, controls the El Sid water pump so that it only starts when the hot glycol is above 120°F (49°C). If we don't use this, there is a slight chance (on a partly cloudy day, for instance) that the system will start the El Sid when the glycol isn't all that hot. This would only serve to mix up the tank, ruining the nighttime stratification.

The Bottom Line

These results confirmed my suspicions (and the predictions from the U of M) that thermosyphon systems stratify nicely, but they are likely to be much less efficient than double-pumped systems. In addition, we have seen that our present system typically delivers a full tank of 130°F (54°C) water during a sunny winter day, which is plenty hot enough to fully heat our water, preventing the backup element from running. In the summer, we reach 160°F (71°C) or more,

Beeman System Costs

SDHW System	Cost (US$)
Installation	$3,734
2 Gobi 410 collectors	1,900
American Water Heater Co. solar storage tank, 119 gal.	1,260
Heliodyne HP HX SWCL heat exchanger	450
Misc. copper pipe, vent valves, three-way valves, etc.	350
El Sid, 3 gpm, 10 W pump (for water)	205
Heliotrope DTT-84 differential controller	150
Antiscald valve	135
Grundfos UPS-15-42F pump (for glycol)	130
Heliodyne Dyn-O-flo HD propylene glycol, 4 gal.	116
Total System	$8,430
Data Collection	
National Instruments thermocouple monitor	395
Omega HH11 thermal meter	65
Omega 5SC-GG-K-30-36 thermocouple	58
Omega Type K thermocouple extension wire, 25 ft.	29
Total Data Collection	$547
Grand Total	$8,977

and since we now have a full 119 gallons of solar hot water during summer or winter, we can preheat over a greater number of subsequently cloudy days.

(Almost) No End to Tinkering

As time goes on, I find that I am continuing to mess with our system. The U of M article indicates that better heat exchangers are available, so we may try this upgrade next. I'm also working on software that can perform real-time efficiency monitoring so that I won't have to constantly dip thermocouples into the solar tank. After the "production end" is as efficient as possible, I want to play with hydronic heaters in my house. We currently produce quite a few more Btu than we typically use, and our ultimate goal is saving natural gas, money, and reducing our production of carbon dioxide (CO_2), not just producing hot water for the sake of hot water. Using some of the excess for home heating makes sense. For now, though, I'm quite happy with the cheap-but-effective improvements to date, and my wife, arms still crossed, seems to be finally showing a hint of a smile.

Access

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Heliodyne Inc. (also Heliotrope Thermal) • 510-237-9614 • www.heliodyne.com • Hot water system manufacturer

National Instruments Inc. • 888-280-7645 or 512-683-0100 • www.ni.com • Computer-based test & measurement instrumentation

Omega Engineering Inc. • 800-848-4286 or 203-359-1660 • www.omega.com • Temperature meter, thermocouples & thermocouple wire

W. W. Grainger Inc. • 847-535-1000 • www.grainger.com • Adjustable snap disc fan control switch, Therm-O-Disc, model 3F05-1

"Comparison of Natural Convection Heat Exchangers for Solar Water Heating Systems," by W. Liu & J.H. Davidson, proceedings of the 1999 American Solar Energy Society Conference, Portland, Maine, June 1999 • www.me.umn.edu/~weiliu/ms.html

"Solar Hot Water Simplified," by John Patterson in *HP107*