Assorted Technical Expertise at

Rattlesnake Ridge Research

The Backwoods Solar Project

Our cabin in the woods of West Virginia, The Phoebe's Nest, is set up for solar heating. Right from the start I selected the site and orientation to give a good southern exposure to the sun. The idea of using fossil fuels to heat a home occupied only on alternate weekends struck me as being an inexcusable waste, and I have always been a fan of solar.

I had noticed a "solar dealer" in nearby Keyser, or at least that's what the sign at the used car lot said. With limited expectations, I dropped in to see what it was they had to sell. The owner laughed. He had gotten into the business during the brief tax-incentive-based boom in the 1970's. He bought one system and installed it on his father's home back behind the car dealership as a demonstrator. His father hated the thing as it did not give instant heat any time he nudged the thermostat, and said "take it out!" The one system had been stored in a barn for a couple of decades, and none had ever sold.

I went to look at the parts, and realized that these were top-quality panels, not the cheap plastic-glazed ones that had been slapped on homes in Northern Virginia and had deteriorated from the start. Among other things, they were glazed with excellent pebble-finish iron-free glass. I bought them for a dime on the dollar of what they sold for new. I got five 4 x 8 ft main panels and a little 3 x 6 ft demonstrator panel thrown in for free.

While waiting for the right time to install the big panels, I used the little one on a primitive hot water thermosiphon system for years. My measurements of the rate of water temperature rise in a 12-gallon tank indicated that the panel turned sunlight into heat at very close to the maximum theoretical limit. These panels are also capable of boiling water at no-flow conditions. I was impressed.

The site was originally totally off-the-grid, so I designed the installation to use minimal pumping power, run by photovoltaic (PV) solar power. This choice dictated placement of the panels at ground level below the cabin, where convection (thermosiphon) would assist circulation. The more common installation is a roof-mount system, but that location is not conducive to convection. Most roof installations circulate plain water in what is known as a "drainback system". Such a system avoids freezing by draining the water back inside the home when the pumps are not running, but consequently requires that the pumps lift the water perhaps 15 ft or more. This requires vastly more pump power than my system, and would have required a huge investment in PV power.

Because my system is constantly filled, it runs a propylene glycol (PG) antifreeze solution. PG is considered "non-toxic", and is safe enough to consume in small quantities that it is an approved ingredient in some medicines and is used to freeze-proof recreational vehicle (RV) water systems. This “non-toxic” rating requires some caution: PG is biologically inert, but it ain’t water, and one leak of the system killed a fair amount of grass below the panels. However, it is far safer than ethylene glycol, which is highly biologically reactive (two carbons rather than three makes the difference).

I tried various sources of PG antifreeze, and noticed a huge variation in the quality and concentration. The auto radiator formulations have extra ingredients I did not want to accidentally get into my domestic hot water system. RV antifreeze tends to be weaker than I wanted. I obtained some technical grade PG from my old test lab in exchange for some consulting work when they were so broke they could not pay me, but the supply was limited. I wound up using RV antifreeze (which does not have toxic additives) spiked to the desired concentration for our local winters.

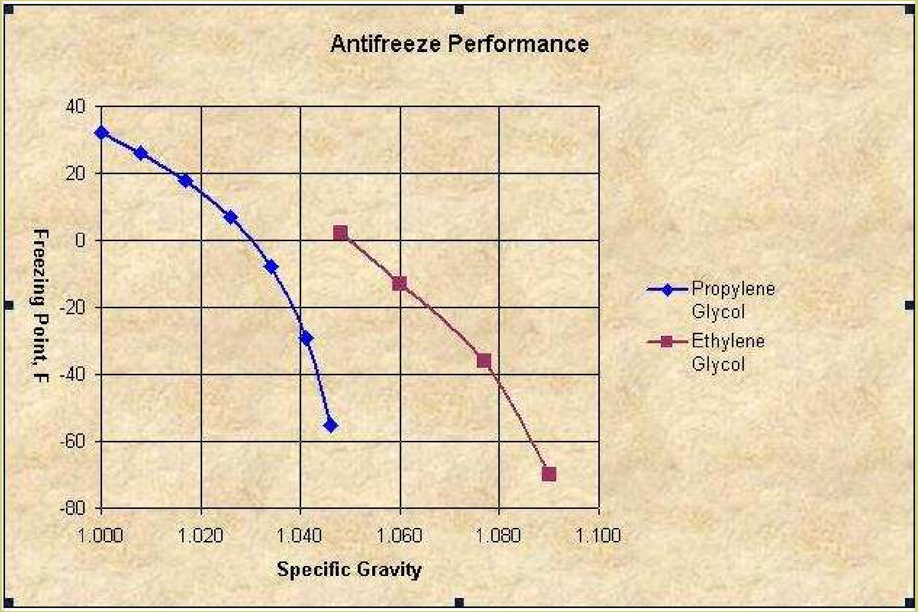
On this accidental contamination issue: my system uses an open reservoir for each loop, something which appears to be rare. Most PG systems I’ve seen used a pressurized reservoir, something that adds cost and complexity. There may be a fire concern since pure PG is combustible, but I’ve flash-tested the solution and it seems to be non-flammable at any reasonable temperature (a spark won’t ignite it). My system has a heat dump to keep the antifreeze temperature below 180 F, and never puts hot PG into the reservoir. It is highly unlikely that an open reservoir system with just a few feet of head would ever leak into a domestic hot water system running at water main pressure. Instead, if a pinhole developed in the heat exchanger, water would leak back into the PG loop. Thus, some way of monitoring the level and handling overflow are a very good idea.

Most RV antifreeze claims that it is rated to -50 F. Use this value with caution. For RV water system protection, all they really mean is that the antifreeze will keep the system from

being damaged by freezing. It is rare for any of these makers to list the actual concentration of PG, or the guaranteed specific gravity. Some mixtures may go slushy slightly below 32 F, and will become thicker slush as the temperature drops. Slush does not pump very well in a low-head pumping system, and I wanted antifreeze that would stay fluid to -20 F or lower. I tried several brands of RV PG. One was dirty and smelled strongly of solvents, with a specific gravity barely denser than plain water, probably recycled stuff being sold as new. Another brand was OK but somewhat weak. The brand I like best so far is Easy-Going -50, which varies in specific gravity from lot to lot but is consistently the densest I’ve seen, in the range of 1.036 to 1.040. If a particular batch is weak, I spike it with a little pure technical grade PG to get my target specific gravity. Also be aware that an unscrupulous supplier or counterfeiter might use other means to get a specific gravity reading, so the sniff test, an antifreeze test kit, and a quick test in a deep freezer are worthwhile. A bargain deal on antifreeze may be a bad deal.

You can find data for PG and EG on line. I used the data from Engineering Toolbox, but uncovered an error in it. I informed them of it, and it appears to have been corrected. The plot below shows that the density I've measured for Easy-Going -50 is adequate for my -20 F temperature target without adding any pure PG, and if you need lower temperatures you don't need to add much.

http://www.engineeringtoolbox.com/ethylene-glycol-d_146.html
http://www.engineeringtoolbox.com/propylene-glycol-d_363.html



When estimating the lowest temperature of a system with black panel collectors, hit the internet and find a local weather station with good temperature records, and find out how cold it can really get. Then subtract about 7 F. Solar collectors are typically also excellent blackbody radiators, and on a clear night they tend to radiate to the cold of space. They can easily get around 7 F colder than ambient, and record cold nights tend to be clear nights. Hopefully, if your antifreeze is good and you reach a new record low, the worst that will happen is that your system becomes slushy, and is slow to start the next day. However, you will really be wanting some heat the morning after a cold night, so you don't want slush in the system very often.

It is also important to keep glycol antifreezes from overheating. The reason automotive antifreezes become acidic is because these pressurized systems run at temperatures above the normal boiling point, where ethylene and propylene glycol tend to break down to organic acids. I try to keep my coolant below 180 F. The domestic hot water loop tends to do this naturally, as I've never seen the water in the storage tank get above 155 F. I use a Honeywell thermostatic mixing valve on the tank output to hold the outlet temperature to a safe level.

The radiant heat floor system requires regulation, which I accomplish with a pair of thermostatic mixing valves. The first is installed on the outlet of the collector panels. It is a high-temperature model set to open at about 140 F. This valve is installed "backwards", with the panel outlet going to what would normally be the thermostatic valve outlet. When the water is cool, the valve closes what is normally the “cold” inlet and opens the “hot” inlet, sending warm fluid to the house. If the fluid gets above the set point, the “cold” side begins to open, diverting flow to the heat dump circuit, a radiator made of finned baseboard tubing mounted behind the panels. A thermostat on the panel outlet kicks in a circulating pump at 145 F, in case convection is inadequate to dispose of the excess heat.

Figures 1, 2. Heat Dump (baseboard radiant tubing).

A second thermostatic mixing valve, set at about 90 F, is installed indoors at the radiant floor heat manifold. This valve is installed in the conventional mixing configuration, with the cold inlet hooked to the return loop, hot inlet hooked to the hot fluid from the panels, and the mixed outlet feeding the radiant heat floor manifold. 90 F is the maximum recommended temperature for radiant heat floors.

The second floor system is not yet installed. I anticipate the second floor will be hot water baseboards, which can safely operate at 145 F or higher. This loop will operate on fluid from before the 90 F mixing valve, allowing the use of heat that would otherwise have to go to the heat dump. When the second floor loops are installed I will install the remaining two 4 x 8 ft collector panels, and upgrade the PV system to provide more power for the pumps.

I am running the domestic hot water and floor heat systems independently. I considered running them with a common return line, but finally decided that was foolish. Assuming the domestic hot water would regularly be at a comfortable temperature (above 107 F), the return antifreeze from the hot water tank would be hotter than allowed for the inlet of the radiant heat floor system. Mixing the two would just make it more difficult to heat the domestic hot water loop sufficiently. By keeping the loops separate I can get more hot water.

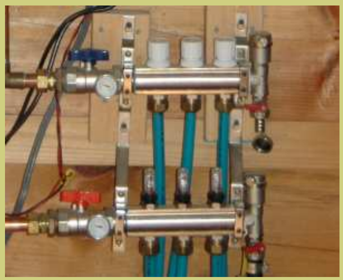
The domestic hot water panel is angled for optimal heat around the equinoxes, so that it gives good hot water for most of the year. The tank is a 40-gallon electric with the heating elements removed and a home-made heat exchanger run between the two heating element holes. I've gotten the tank to 155 F, and usually have hot water available if there has been good sun within the last day or two. To avoid scalding danger, I use a third Honeywell mixing valve on the output of the tank, mixing in a little cold water to set the house water temperature to a safe and comfortable level. This maximizes heat storage safely. The tank has an extra insulation blanket for efficiency, and retains the pressure-temperature relief valve for safety.

The floor heat panels are angled for optimal use at the end of January, when heat is needed the most.

The two loops do presently share a small solar panel, mounted between the two floor heat panels, which I use to judge sun intensity at the panels. I run the output to a load resistor and pair of comparator-based Schmidt triggers I built to judge when the panels were receiving enough sun to be worth turning on.   A Schmidt trigger is an analog comparator with a feedback system. Turning the comparator on requires a slightly higher input level than turning it off. The system works, but a differential temperature controller would work better, and I expect to replace the PV sensor in the next year or two. The system should only be run when the panels are warmer than what they are heating, not just when the sun is shining.

The remaining shared element of the control system is a Trace C-30 charge controller on the PV system. This is another Schmidt trigger comparator set to energize the heating controls when the battery reaches nearly full charge, and turn it off before it is badly discharged. This keeps the system from running the battery down. The control system also has float switches in the antifreeze reservoirs to shut the system down if the level drops, and a conventional wall thermostat for the floor heat system. The heat dump has a fixed-temperature disc thermostat on the output of the panels, to kick in the heat dump pump if convection is not doing the job.

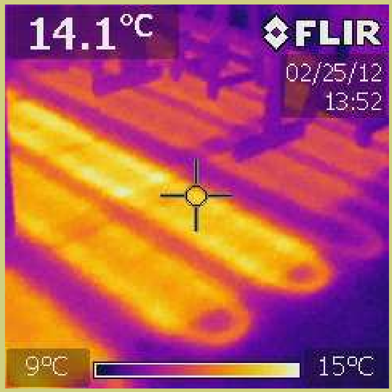
I use low-power pumps designed to work with photovoltaic power at 12-volts nominal. My domestic hot water system runs a small El-Cid pump which utilizes only 5 watts. The floor system uses two Laing pumps, one for inside circulation and the second on the heat dump. A third will be added when I add the second floor system. The first floor pump will probably be upgraded to more flow, as the radiant heat loops are running about 2/3 the recommended flow.



The radiant heat system was ordered from Radiant Max. They have excellent technical materials on their website, and will do the calculations for you to design a good system. My one problem with them was that the manifold set they shipped is not the one their instructions cover. I stumbled across it on an internet search, and it turns out to be an Italian model, made by ICMA Rubinetterie, with connections for three floor loops, each with its own adjustment and flowmeter. Each manifold also has a temperature gage. The means of adjusting the flow is not obvious without an instruction sheet. Also, the threads on the two ball valves turned out to be nearly impossible to seal correctly, due to a poor fit to US standard plumbing threads. This required some really nasty pipe thread compound. All told, I like Radiant Max, but wish they'd drop that particular manifold.

The manifolds seen above come with a pair of air bleeds. The system will need air bleeds at any high point. Bubbles are the mortal enemy of any low-power pumping loop. Air pockets in high points in the plumbing will totally kill convection, and rob pumping power. I added float-type Taco air bleeds at several points in the system. You are unlikely to find air bleeds, mixing valves, or bare radiant baseboard tubing at the "big box" building supply stores. Find a really good local plumbing supplier that will let you into their catalogs to find the parts you really need. The high-temperature mixing valve I used with the heat dump was a particularly difficult item to find. In Manassas, VA, I have a long-standing good relationship with Yorkshire Plumbing Supply. They indulge my eccentric plumbing needs, and have even proved to be handy in supplying materials for nuclear fusion research!

The one really unusual feature of my floor heating system is that I decided not to use a storage tank. It is in the nature of a log home to hold an even temperature. This is not, as often stated by the ignorant, due to the fantastic insulation provided by logs. In fact, wood has a mediocre R value, and my 6-inch thick logs only have an R-value of around 8, less than a cheap stud wall with fiberglass. What logs have is thermal mass. Our cabin enhances that with a concrete floor over 60 tons of gravel. R-13 foam insulation is installed between the gravel and the foundation walls. Dry gravel is not as thermally conductive as earth or concrete due to the air spaces in it, but it has huge thermal mass. Basically, if you get a home like this comfortable, it will stay comfortable for days. If you get it cold, I sure hope you like it cold. Depending on the temperature, a rough guess is that half the heat from the radiant heat floor goes into the gravel bed. However, at night, that heat perks gently back out. With no other heating, the air temperature in the house rarely goes much below the floor temperature, and it is quite easy for a little heat from the wood stove to bring the place back to a comfortable level.



Over the last two winters, even the half-completed system, with inadequate insulation on the roof and second floor and some weather sealing still needed on windows and doors, has almost been adequate to prevent freezing over the course of West Virginia winters. I'm confident that adding two panels and finishing the upstairs insulation will make the place freeze-proof, the initial intent of the system. But as we spend more and more time up there, we're also gratified that, once warmed up, the place stays comfortable in cold weather with very little use of the wood stove. Our firewood use is way down from earlier years.