Solar Domestic Hot Water, with a Site-Built Drain-back Tank

By: David Posluszny (DavidPoz)

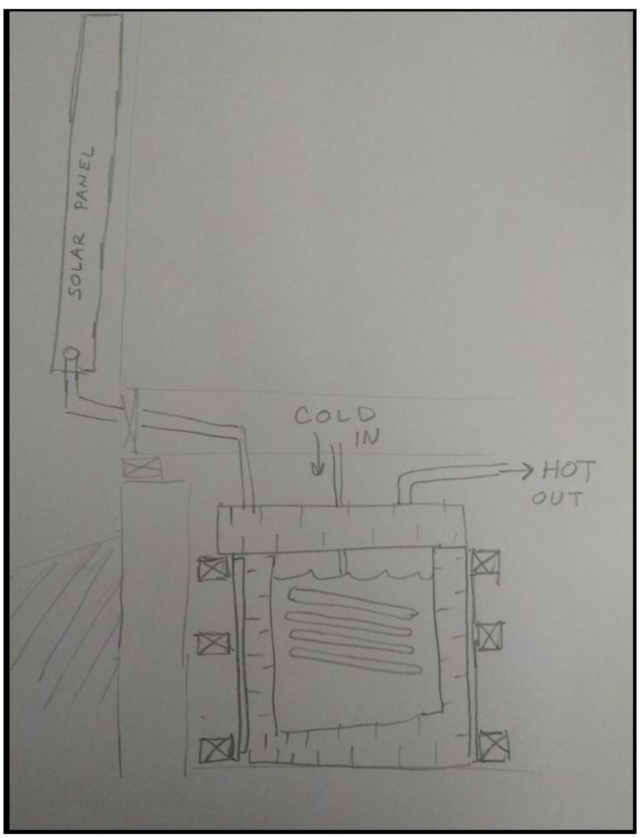
Built: Fall 2017

In this article I'll discuss how I made a solar thermal hot water system, and my decision making along the way. I have to give a big THANKS to Gary from builditsolar.com and everyone who has contributed stories over the years for the inspiration and knowledge.

Our house with flat plate solar collectors on wall.

Table of Contents:

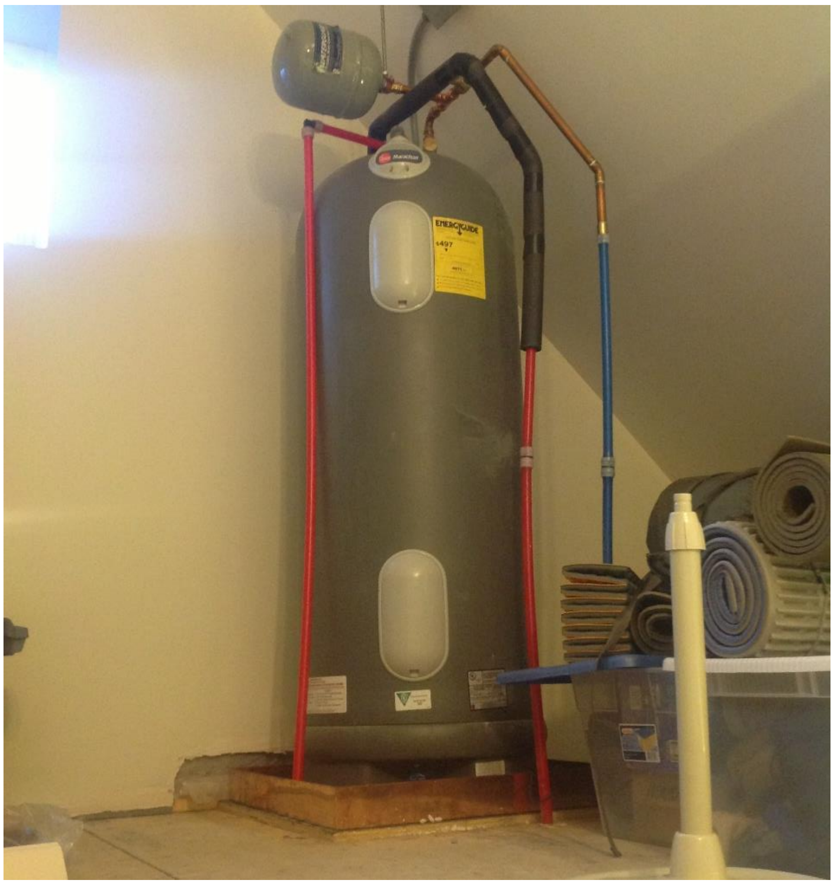
Backstory of WHY we wanted a Solar Thermal System:	3
Constructing the Tank:	5
Tank Insulation and Liner:	7
Heat Exchanger:	9
Solar Collectors:	11
Pump and Controller:	13
Filling the tank:	14
Wrapping Up:	15
Booster Tank:	17
Performance:	18
Cost Breakdown:	19



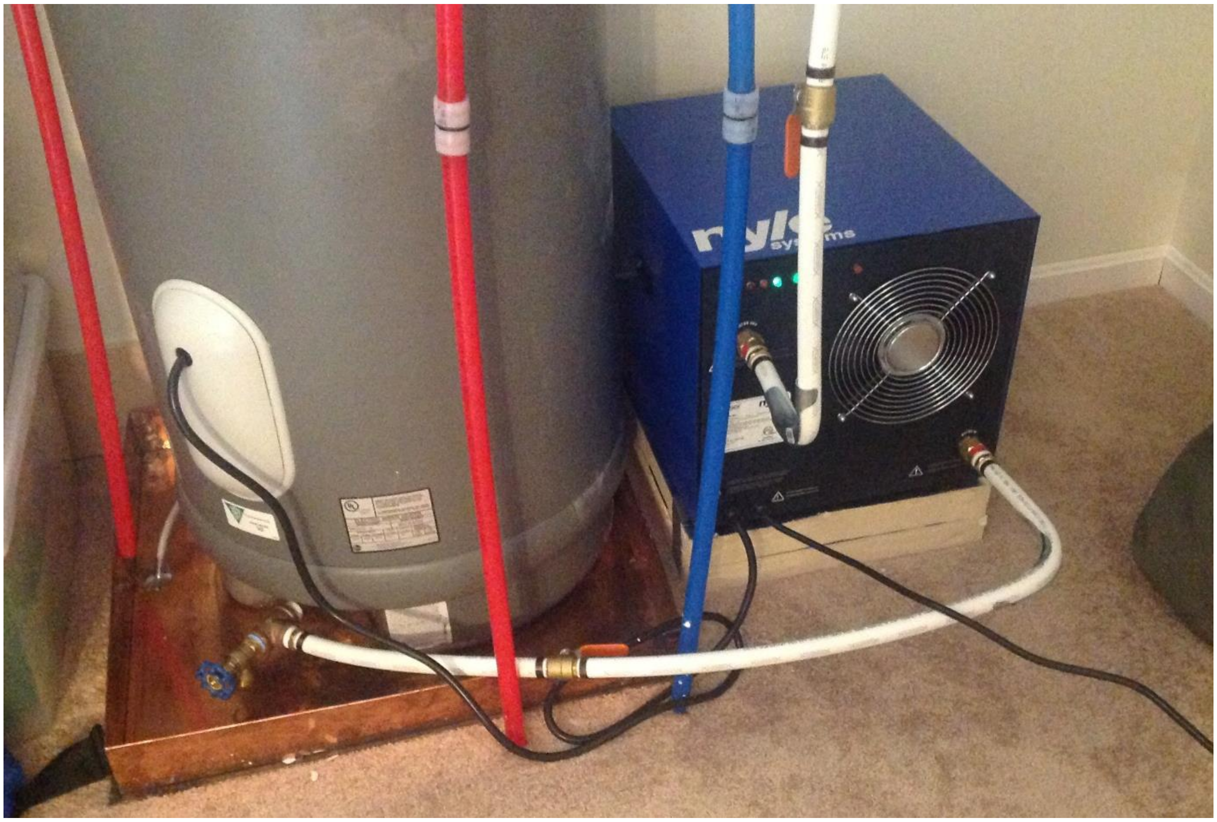
First Sketch of Design

<u>Backstory of WHY we wanted a Solar Thermal System:</u>

I built my house in 2012 (five years ago as of this writing). It is a small, super insulated home. The first few months we lived in the home we had only an electric water heater, 50-gallon tank style. It worked great. But, there was one final box to check before being 100% done with the build. I needed a sign off by a HERS rater. After paying this guy almost a grand he failed my home. I was shocked. He actually told me if I switch out the electric water tank with a propane one then I will pass. There was no way I was doing that. So, I wound up installing a heat pump water heater and getting the final sign off about six months in.



Original Water Heater, 50-gallon Tank, Marathon Line.



Heat Pump in blue, tied into original tank.

My wife and I hated that heat pump. We had been spoiled with the electric tank those first six months, but now our water would fluctuate in temperature during just one shower. The system was noisy, I mean really noisy. In our small house there would be no quiet space. It cooled the house, and then I had to run the electric heat more often to heat it. I monitored the electrical use and found no (total household) energy savings. So, I began looking at alternatives.

Solar thermal seemed like the answer, and I was experimenting with a single flat plate collector I had bought. There was also a nice section on my south-facing wall to mount panels. I considered adding a dedicated solar tank with heat exchanger and a glycol system. However, it would require more space in my loft for the additional tank. At the time, we were expecting our first child and my thoughts were on how to turn the loft into a bedroom.

In the end I decided to make a drain-back system. I would build a large, wood framed, tank in the crawlspace under the house. Then I could remove the electric tank in the loft creating more space to make a bedroom.

Constructing the Tank:

The crawlspace under my house is fully inside the thermal envelope. There is an R-26 of foam board insulation at the ground level, and no insulation in the joists. So, the crawlspace is always within a few degrees of the living spaces year-round. Being inside the thermal envelope meant I didn't have to worry about any freeze issues.

Dimensions of the tank were dictated by the space I had to work with. The height is 29 inches to the underside of the floor joists, and about 8.5 feet from wall to center girder. I still needed enough space to crawl around the tank. In the end I framed the walls 23 inches tall, and made the outside framing dimensions 66 inches.

The structure of the tank is held together with five "ribs" making a square around the tank. There is a layer of plywood inside, that spans from rib to rib, and holds the ribs in place. I'm not a structural engineer and never performed calculations on how much wood was needed for strength and stiffness. I just made what felt good to me.

Reclaimed lumber I saved from a building being demolished.

The ribs were made by from some old 2x6's I had salvaged from a building demo. I ripped a straight edge using a jig and my circular saw. Then I ran the boards through my table saw to get 2x3's. I used a dado stack in my radial arm saw to cut half/lap joints in the ends. I have a video on this here: https://youtu.be/jKr4An8m_tM

I brought down the individual pieces of wood through a trapdoor and assembled everything in the crawlspace. The ribs are glued together at the half-lap joints. I stapled the ends together with pneumatic 1.5-inch staples. Then I screwed the plywood to the inside face of the ribs. I spaced the ribs tightly near the bottom of the tank, and farther apart near the top. I figured there would be more water pressure at the bottom. To see all the details of framing the tank watch this video: https://youtu.be/jeXR7o68c0Q

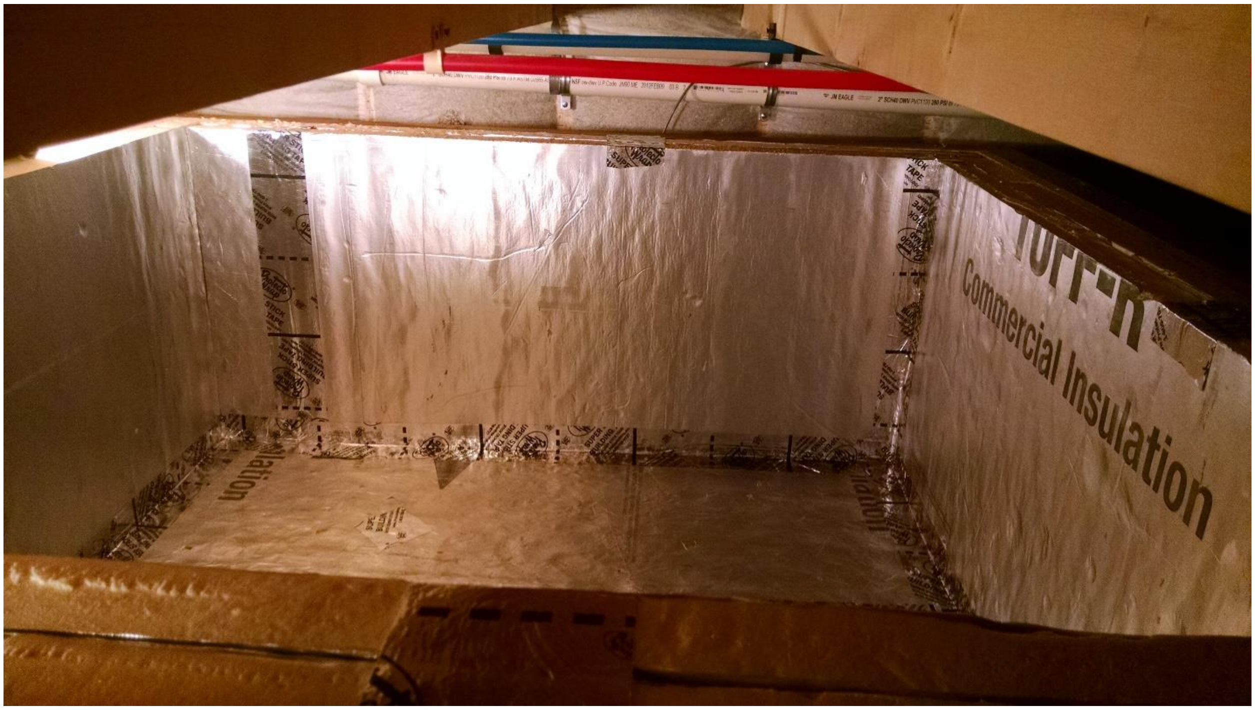
Tank Construction in Crawl space.

Tank Insulation and Liner:

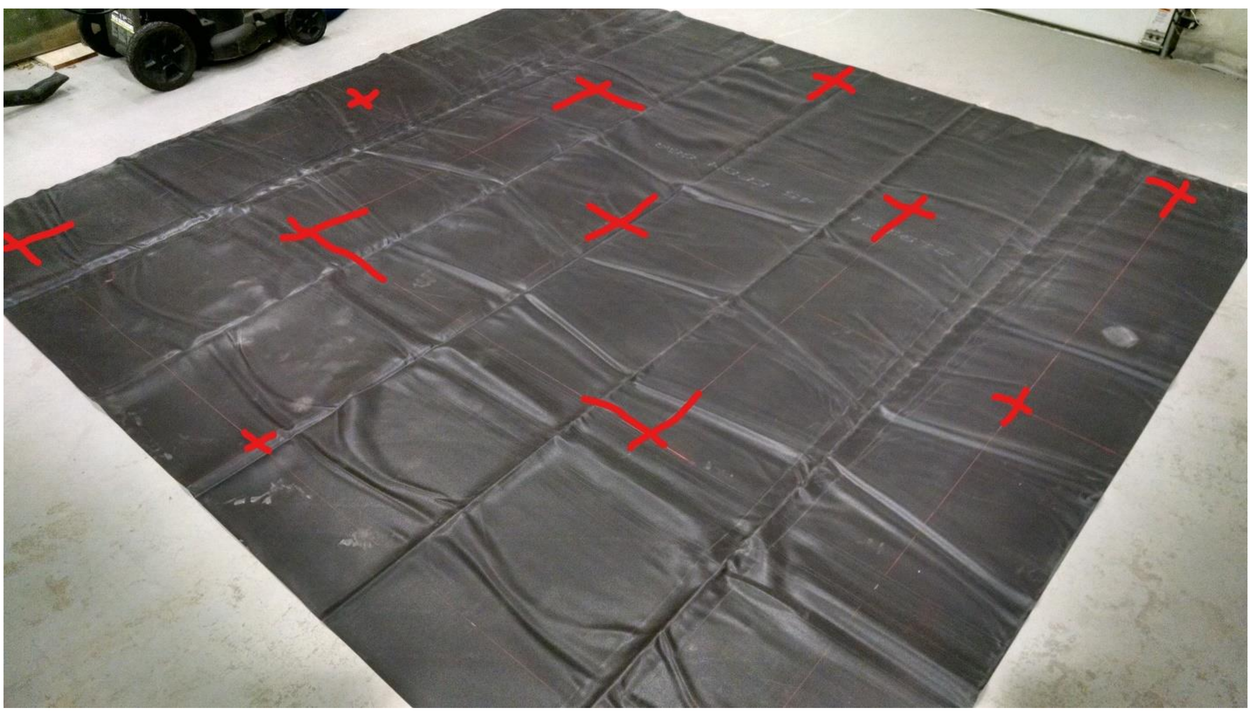
Inside the tank I lined the walls with Polyiso foam insulation board. I had extra board left over from the house build in the crawlspace. Actually, just enough insulation to finish the tank, which was lucky. There are two layers, each two inches thick, for a total R-26 on the walls. There is no additional insulation on the floor, just the existing crawlspace insulation of R-26.

I lined the tank with EPDM rubber, folding the corners, and stapling the top edge to the wood frame. I found this cost effective, purchasing from Amazon.com at $110 for a piece that was 10 feet by 15 feet, which gave me enough for the tank liner and the lid. Before bringing the EPDM down into the crawlspace I laid it out on the floor of my garage. I cut it to size, and snapped chalk lines where each fold would go. These layout lines helped me a lot when I was in the tank smoothing it out. There is a video of the insulation and liner install here: https://youtu.be/bI0T7ZegAPU

In the end the tank's inside volume is about 250 gallons. However, with the air space, there might be 230 gallons of water.



Foam insulation in place on walls.



Chalk lines snapped out on EPDM prior to installation.

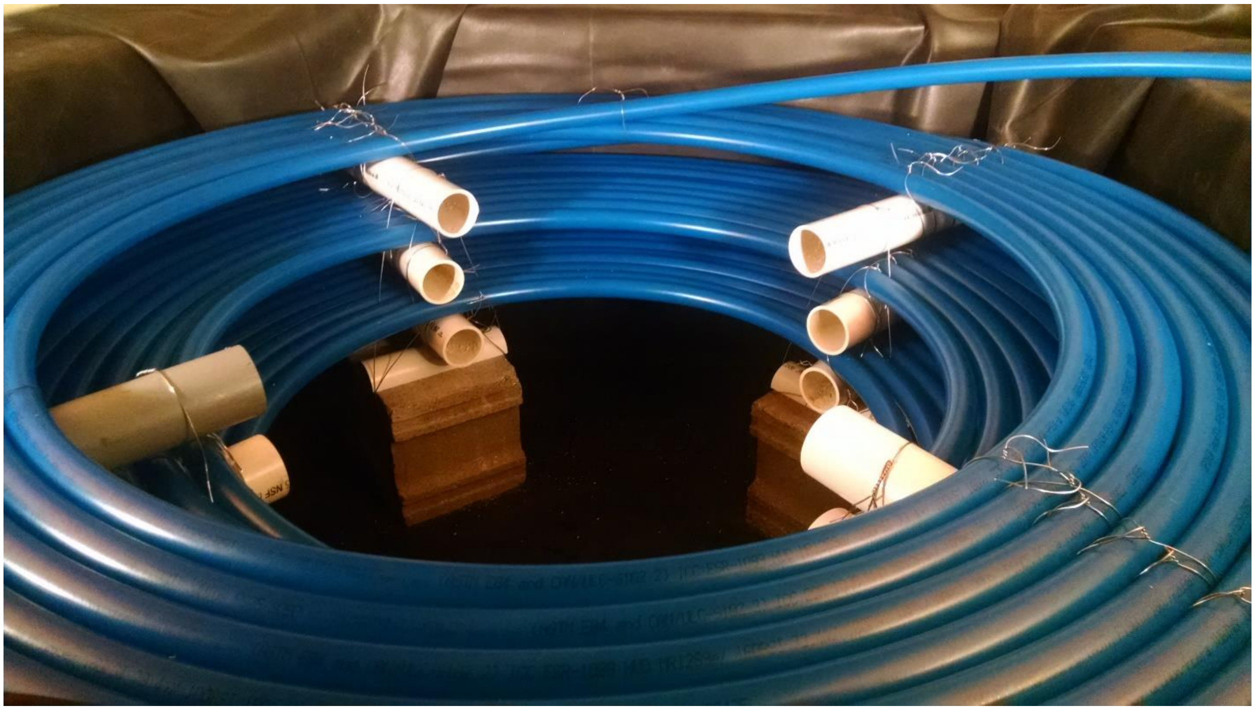
<u>Heat Exchanger:</u>

I went with a PEX heat exchanger. One coil, 300 feet long, one-inch nominal size. I liked the idea of having a large volume inside the tube. However, it did have a nasty plastic smell for the first three weeks of use. I'm not convinced it is any better or worse than a shorter copper coil, it's just what I went with (3/4"x60' copper was the same cost). I bought Uponor brand, and as I measured the inside diameter, there is 8.6 gallons of water inside. The coil was $300.

I installed four concrete blocks in the bottom of the tank, then put the PEX coil on top of it. I then spent about five hours inside the tank struggling to make a neat spiral out of the mess. The PEX is wire-tied to the concrete blocks and spacers. For spacers I used some 16-inch-long, 2-inch diameter PVC pipe. For wire I used aluminum wire sold for electric fences. These were just items I had on hand and didn't have to go buy items, but anything could have worked.

Coil of PEX tubing inside tank, 300 feet, one-inch nominal.

The ends of the PEX pipe run out the top of the tank. This way, all connections are made outside the tank. I used a funnel and gallon jug to fill the PEX heat exchanger with water. I was worried it may have floated when I filled the tank with water. Video on installing the heat exchanger is here: https://youtu.be/WwTsWUKr5VE



Finished Heat Exchanger coil.

Solar Collectors:

Craigslist is awesome! I was able to buy some new-old flat plate solar collectors for $200 each. These collectors are about 30 years old, but were never used and still in factory wrapping. I was very impressed with the quality of these: tempered glass, thick aluminum frames, thick insulation, and all copper pipes and absorbers. I don't think I could have built collectors for $200 in material. They are 4'x8' with typical 1" headers.

4'x8' collectors on south wall.

I had to buy some accessories to mount the collectors: unions, stainless steel lag screws, pressure treated wood, and a bar of aluminum. The aluminum was used to make my own mounts. The frame came with a groove meant for a hook-on type of mount. However, I could not find one to fit. I even bought two different brand mounts and tried them, but they did not fit the extrusion. So, I made my own by cutting up a bar of aluminum. For a video on how I did this click here: https://youtu.be/NDxmPl5jlVA

I mounted three panels vertically on the south wall of my house. Yes, I'm sure I will lose some performance by not having them at a tilt. I could not mount them on my roof because it is full of PV panels (4.4kw grid-tied). I could have angled them on the wall, but I walk past them to get to the water spigot and figured I would be constantly hitting my knees on them. So, I gave up a little there to mount them flush to the wall.

I was worried about debris and water being trapped behind the panels so I spaced them away from the wall using 1x6 pressure treated wood. This gave a ¾" air space behind the panels to the siding. Now everything can dry quickly after rain.

Custom made mounting brackets with a stainless-steel lag screw.

On the positive side to mounting the panels vertically, and flush: They never get snow on them! Massachusetts gets a lot of snow. What is interesting is that the snow will stick to all my solar panels until the sun heats them up for a few hours, then the snow slides off. Because there is no snow buildup on my vertical collectors I can capture the sun's energy all day. Bonus!

<u>Pump and Controller:</u>

The pump is a Grundfos stainless steel. I bought it used for $50. The pump came with a plastic check valve which I removed easily with a pair of pliers. It has three speeds; I keep it on the lowest, which uses 57 watts. I was a little concerned I might have cavitation given this is an un-pressurized system. However, it has been performing perfectly.

I used a dip-tube method instead of a bulk-head method of drawing water out of the tank. The dip tube is ¾" copper, and goes down to the bottom of the tank on the inside. It then rises up, over the top edge of the frame, and down to the pump. This keeps the prime in the pump even though the top of the tube is above the water level.

The controller is a Heliodyne. Very simple unit. I bought it from eBay for $55. There is no display on the controller. On the back there are several dip switches for adjusting on differential, high limit, etc. It has been working great. The controller came with two temperature sensors (simple resistor type). The sensors are not water proof, so I couldn't drop one into the tank to read water temp. Instead I secured it to the copper dip tube just outside the tank, and insulated around it.

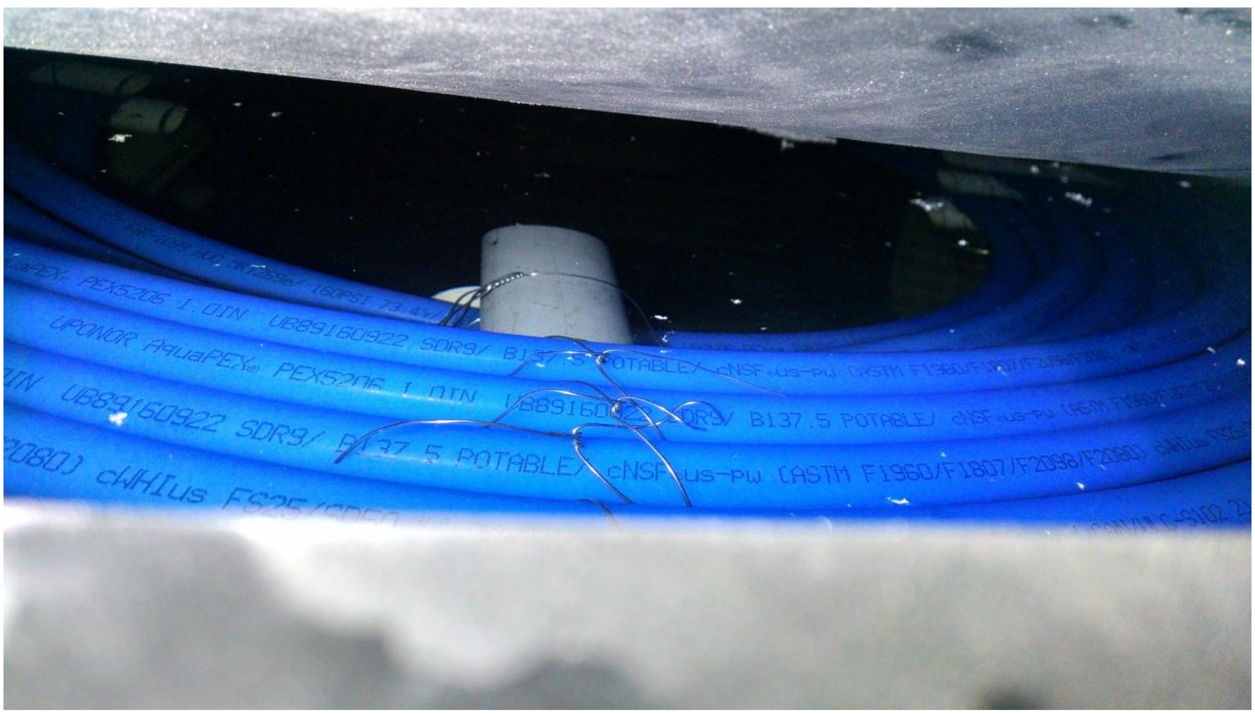
The pump is red, near the floor, and the controller is the white box mounted on side of tank.

Filling the tank:

In between the pump and the solar panels, I tied into the pipe with the cold-water line. There is a vent and check valve so no water from the solar system can back feed into the potable house water. This allowed me to fill the tank with just turning a ball valve. It also meant that the pump was primed automatically.

The pump pushes water up to the bottom of the solar collectors. The water then rises up, gets heated by the sun, and returns from the highest point. All three collectors are installed with a slight slope so when the pump turns off the whole system drains back into the tank.

Video with filling the tank: https://youtu.be/W03zjGPCjjE



Filling the tank with water above the heat exchanger.

Wrapping Up:

The cold-water main goes into the heat exchanger in the tank. It first goes to the bottom of the heat exchanger, and the coil rises to the hot side, and hopefully the hottest water in the tank. When the water comes out of the tank it could sometimes be hotter than allowed by code. So, there is a temperature mixing valve set to 130 degrees.

I installed another piece of EPDM rubber as a lid. I caulked it in place with silicon and then stapled it down. This was to keep evaporation in the tank. Each pipe was pulled through the lid, allowing the EPDM to make a seal around it. Then for good measure I used more silicone and tape.

Pipes entering the tank through the lid with gasketed seals. Note the temperature sensor is taped to the copper pipe.

There are three layers of foam board on top of the tank, totaling about R-39. I cut around any pipes and obstacles as tightly as I could. The foam is held in place by wedging it down with wood between the foam board and the floor joists above.

Video: https://youtu.be/W03zjGPCjjE

First layer of foam is screwed in place, and cut to fit around pipes.

Booster Tank:

Coming out of the mixing valve, the water then enters a 19-gallon electric water tank. This small tank is also set to 130 degrees. It will boost the water up to temperature if needed.

I insulated the 19-gallon electric tank by making a box around it out of foam board. This is to cut down on standby losses.

To see this step, check out this video: https://youtu.be/yTHlD6JUHzs

Electric booster tank inside an insulation box.

Performance:

The solar DHW system is still very new so I don't have long-term data to share. Our initial reaction is overwhelmingly positive. For the first three weeks we only had the solar tank, no electric booster tank. This means that 100% of our hot water was supplied by the sun alone during November of 2017. This worked fantastic… until the tank reached about 110 degrees F. At that point our showers were turning warm by the end.

Video on this: https://youtu.be/g0_-zAskgnE

Starting in December I had the 19-gallon booster tank installed and now we have plenty of hot water. I installed an electric watt meter on the wires for the booster tank to monitor electrical use. The most electricity we used in one day has been 2.3 Kw*hrs. when the solar tank was 105. However, the last week of December 2017 was fairly sunny and the tank came up between 130-140. During that week we averaged 0.8 kw*hrs. per day. I expect our use to be less in summer, but don't yet have the data.

Let's compare that to our electrical use with the old system. I had monitored the electrical use during summer and winter, with no change between them. Our average daily electrical use was 7kw*hrs. to heat water. Our electrical rates are higher than our nations average, at $0.24/kw*hr. I'm predicting a savings around $500 per year.

Noticeable items: Since the hot water supply is in the crawl space, and not the loft our hot water supply pipes are shorter. In order to bring hot water to the kitchen sink, I used to have to waste 1.5 gallons of water. Today, the hot water is at the tap after just 0.3 gallons down the drain. The distance to the vanity is also shorter, and the shower is un-changed.

Cost Breakdown:

Solar Collectors, 4x8, flat plate, $200 each (Craigslist):	$600
Tank Liner, 10x15 EPDM (Amazon):	$110
Framing Material, one sheet of Plywood, the rest was reclaimed:	$32
Pump, used (Craigslist):	$50
Controller (Ebay):	$55
Pipes and Fittings, estimated (Plumbing Supply):	$300
Mounting, Stainless Steel Screws and Aluminum (Amazon):	$90
Heat Exchanger, 300'x1" PEX (Plumbing Supply):	$300
Temperature Mixing Valve (Plumbing Supply):	$75
Insulation Board (leftover from house build):	$0
Electric Water Tank, 19 Gallon, discontinued model on sale (Lowes):	$160
Misc. screws, glue, wires, etc. estimated (Home Depot)	$100
Total:	$1,872

For more energy related building projects check out my website: www.davidpoz.com

Or view my YouTube channel at: https://goo.gl/yFuuXQ

Written by: David Posluszny (DavidPoz)