
The south wall of my house faces about 10 deg west of south

Experimental Harry Thomason Collector:

In the late 1950s Harry Thomason built a house that used a novel type of drain down solar thermal collector for heat. Instead of piping water through tubes soldered to fins, water simply "trickled" down the surface of a corrugated roof with glass glazing over it. The advantages of this "trickle down" collector are low cost (Thomason claimed he built his whole system for a 1959 cost of $1/square foot--about $8.50 /square foot in 2017 dollars) and freeze tolerance. The disadvantage is higher heat loss due to the mixture of air and water in the space inside the collector.

One feature of these collectors is that they can be"site built". This can be an advantage or a disadvantage. Site built means the design of the solar heating system can be integrated into the design of the building and the roof, resulting in a lower cost system that is also pleasing to look at. However, site built also means that intelligence needs to be injected during the construction process, which sometimes is not possible.

This Summer I built an experimental trickle down collector system to play with the concept. The two 4'x8' collectors heat water in a 105 gallon bulk storage tank. My domestic hot water passes through a heat exchanger in the tank on the way to the on-demand gas hot water heater.

Though based on Thomason's idea, and built in order to explore his idea, this system is not a Thomason system. It is used to heat domestic hot water, and Thomason's systems were mostly for space heat. Also, my system uses a PV powered pump and a relatively small storage tank.

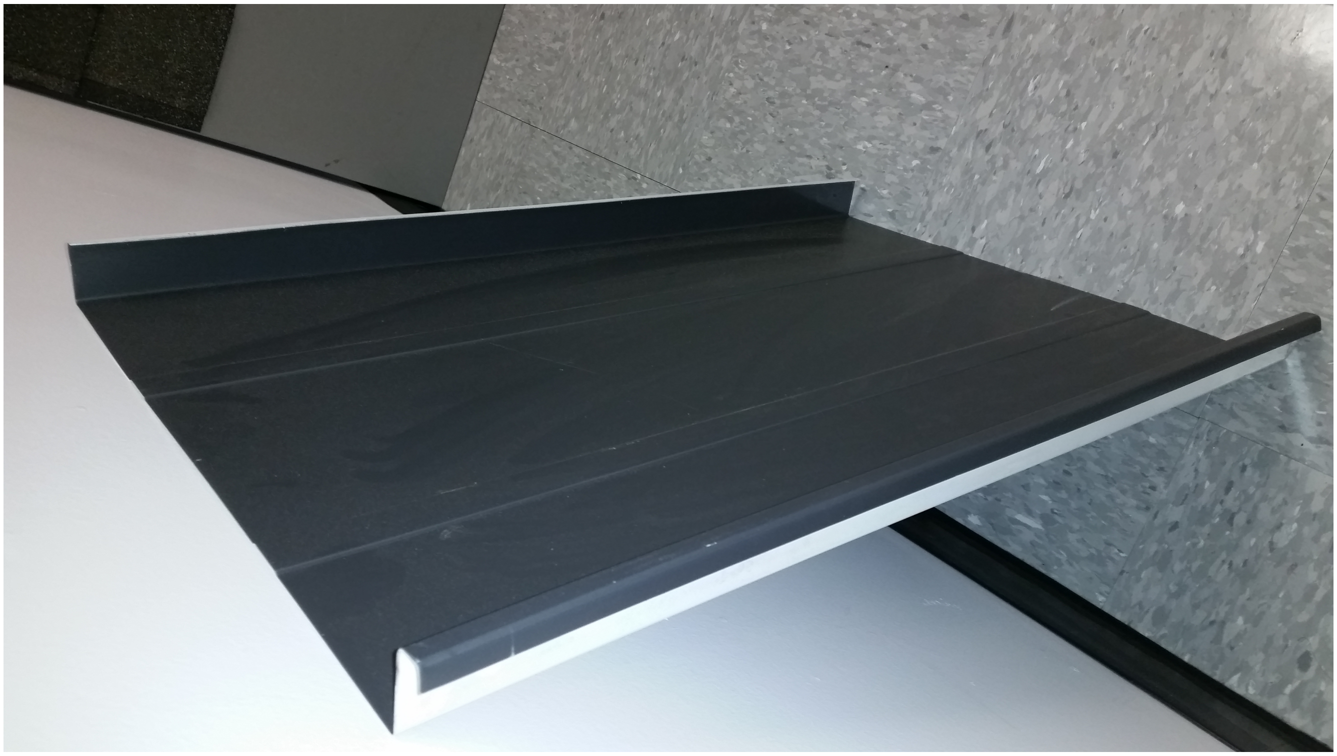
In addition to exploring the Thomason trickle-down collector, I also used this experiment to try two other innovations. The first is using regular cotton cloth painted with silicone as a tank liner for the solar bulk storage tank. The second is using a copper heat exchanger with a novel (I think) geometry. As with many site built solar projects, another goal is to use locally available ordinary construction materials, as well as materials that can be scavenged around building sites and dumps.

Here is a photo on the roof looking north-east

The Collectors:

The frames for the collectors are 2x4 lumber and 1x10 rough sawn local pine. I insulated the inside of the collector pan with 1” of poly-isocyanurate foam insulation. On top of the insulation lies some black aluminum standing seam roofing panels that are the absorber. I chose the type of standing seam roofing that has two 1” ridges that divide each ~16” section in to 3 equal channels about 4.75” wide. The thickness of the aluminum sheet is .035”, however, this type of standing seam panel can be obtained in any length and out of a variety of materials, including thicker aluminum and copper. Across the top of the collectors passes a 1/2” copper pipe with 1/16” holes drilled in it (3 holes per channel of roofing panel-- roughly a hole every 1.5”). This copper pipe drips water on to the absorber at the top of the collectors. Across the bottom of the collectors passes a 1.5” piece of PVC pipe with a lengthwise slot cut in it in to which the roofing panels fit. Small aluminum tabs riveted to the roofing panels stand the roofing off of the PVC pipe so water can accumulate in the pipe. This PVC pipe is the “gutter” that collects the water trickling down the absorber. The top rim of the collector pans are lined with epdm gasket and tightly glazed with 6mm two wall polycarbonate greenhouse glazing (R=1.65). While normal solar collectors are single-glazed, with these collectors the benefit of a higher R value outweighs the detriment of lower transmissivity. The two collectors are on the roof at a 35 degree angle. Why 35 degrees when 55 degrees would be better? I don't want the panels to stick way up in the air and look ugly. Also, this type of collector loses less heat if it is more horizontal.

Here is a view of the collectors looking west



Here is a photograph of the standing seam roof panel. It is certified to have an energy star high rating for reflectivity, but luckily in this case, it's a lie!

Approximate cost of collectors: (two 4x8 collectors totaling about 60 square feet)
lumber: $75
insulation: $50
glazing: $180
aluminum standing seam roofing panels: $220
glue, tape, screws, gasket, paint: $100
Approximate Collector total: $625 Approximate cost per square foot (60square feet): $10.40
This cost could be reduced by scavenging building materials

The Tank:

The frame for the tank is built with 2x4s on 16” centers. The frame is sheathed on the inside with 1x10 rough-sawn pine at a 45 deg. angle. The tank is roughly 4' long x 3' tall x1.5' wide, though I played with the numbers to get it to just fit in my boiler room without blocking the door. The completed tank holds 107 gallons. The inside of the sheathing is insulated with 1” poly-iso' foam (2” on the bottom), and the 2x4 frame around it is insulated with fiberglass batting (R-13). The tank liner is a new idea. I sewed 18oz canvas to make a 10'x10' liner and then rolled silicone caulk (siliconeII) on to it to make it water-proof. I thinned the silicone caulk by mixing it with mineral spirits so it would be easier to roll and also so it would soak in to the weave of the canvas. The mineral spirits makes the silicone take longer to cure. It took a couple coats of thinned silicone on either side to give me confidence – especially in the seam! (to be thorough, I first siliconed the seam, then stitched through the two layers of cloth and silicone, then rolled both sides with thinned silicone) I know it is possible to obtain canvas in larger pieces with no seam, but I was interested in seeing if I could make a water-proof seam (so far it is...) If it works, this method is about the same cost as EPDM pond liner but I prefer the silicone—once cured it is non-toxic and does not smell bad. Once the liner was cured I folded it into the tank (which is not that easy!). The tank lid is made of more 2x4s and also seals to the tank with an epdm gasket. The pipes (supply, return, and heat exchanger pipes) enter and exit the tank through a foam and wood sill that sits on the lining.

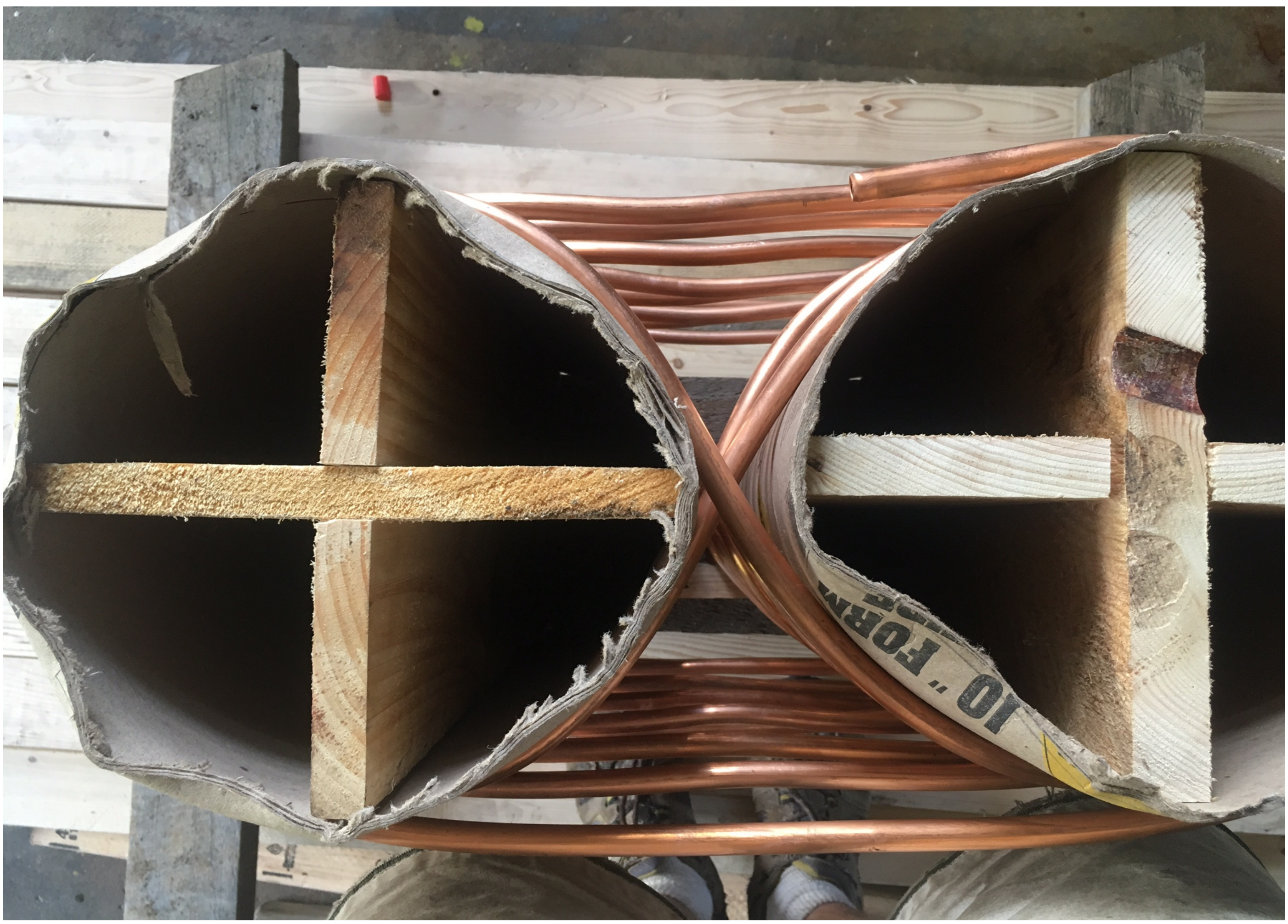
Approximate cost of tank:
lumber: $75
insulation: $75
18 oz canvas: $45
silicone caulk and mineral spirits: $100
glue, rollers, screws, etc. $25
Approximate Tank total : $320 Cost per gallon (105 gallons): $3.05

Here is a view of 100' of 3/8” soft copper wrapped around the armature. It's about 24” tall

Heat Exchanger:

Heat exchangers for these bulk storage tanks are usually made out of copper or PEX. For a larger storage tank PEX seems good, especially if 300' of 1” can be stuffed in the tank, thereby allowing a whole shower's-worth of hot water to dwell in the heat exchanger. The more expensive option is copper. I chose copper because there is limited space in my tank, and I wanted to see if I could make a heat exchanger that had good steady-state heat transfer. The classic copper heat exchanger is soft copper wrapped in to a coil and then soldered to make a cylinder. This shape is easy to make but I don't like the way it visits so little of the internal volume of the tank. Furthermore, by coiling around it is really visiting itself instead of the storage tank, which is just what you don't want a heat exchanger to do. Here is a place where a cost-free change of geometry could make a design improvement. The least expensive type of soft copper is 3/8” ID (sold as 1/2” OD for the refrigeration industry). This size is also easier to bend than the bigger sizes.   I bought four 50' rolls and made a heat exchanger that has two parallel and two series lengths of tubing for a total of 200' of 3/8” tubing. Each 100' coil is wrapped around an armature consisting of two 10” cardboard tubes. The geometry I used (suggested by my friend, John York) is an alternating pattern of “figure eights” and “racetracks”. The result is lots of horizontal runs Horizontal runs create convection-normal-to-flow that breaks up the boundary layers both inside the tube and outside in the tank. These horizontal loops tour around the tank while staying away from themselves. Before removing the wrapped tubing from the cardboard armature I soldered scrap copper pipe in a vertical position to hold the coils of tubing in their positions. The bottom of the scrap pipes turn in to legs to make a stand that holds the heat exchanger up off the bottom of the tank (so it is near the top where the hotter water is). The legs have soft bumpers (pieces of scrap pvc pipe) to protect the tank liner.

After I built the two parallel sections of heat exchanger, they were too wide to fit in the tank side-by-side, so I “nested” their facing coils together. This nesting or overlapping probably reduces the effectiveness of the heat exchanger slightly, but it does give the builder some way of adjusting the space they occupy to fit the tank.



Here's a view of a heat exchanger coil showing “figure-eights and racetracks”

Approximate cost of heat exchanger:
200' of 1/2” OD soft copper tube: $182
copper adapters and pipe, solder, cardboard tubes: $50
Approximate Heat Exchanger total: $232

Plumbing:

The low cost and ease of working with PEX tubing makes DIY solar hot water better today than when all the plumbing was sweat-soldered copper. From the boiler room I ran two insulated 1/2” pex (red) tubes up to the roof. They pass through the plumbing wall in our laundry room and in to the attic, then up on to the roof. The total vertical height is about 28'. The supply runs from the bottom of the storage tank up and out under the lid, then down again to the pump, and then up to the roof. The pump is a diaphragm pump designed for use on a boat. I chose a displacement pump (diaphragm) for its efficiency. Since I don't think the pump will reliably drain down, there is solenoid (Normally open) plumbed in parallel with the pump that opens when there is no power so the supply to the plumbing can drain down to the safety of the boiler room at the end of the day.

Cold water supply to the on-demand hot water heater is diverted to the heat exchanger (with a 3-valve bypass) that passes through the solar bulk storage tank. Then the solar heated water goes to the gas hot water heater. There are 4 unions so I can disconnect the whole plumbing complex and get it out to my shop if I need to fix it or work on the other plumbing and gas pipe in the boiler room. There are also two boiler drains on the heat exchanger so I can pump vinegar through it once a year to clean the inside of the heat exchanger tubes.

Approximate cost of plumbing:
PEX pipe and insulation: $150
Copper pipe and fittings: $150
unions, valves, solder, etc.: $100

Approximate Plumbing total: $400

Electrical:

The pump is a 24 volt diaphragm pump from a boat. Two 50 watt 12 volt solar panels on the roof are wired in series to provide 24 vdc to the pump. There is a water-resistant disconnect switch in the boiler room, and then power flows to the pump, the normally open drain down solenoid, and two small cooling fans that blow air on the pump motor (since it is a marine pump, the motor is sealed and gets hot). I chose a pv panel as both the power source and the logic for this system because I like this arrangement, not because it is the cheapest or best performing.

Approximate Cost of Electrical:
Pump: $65
Two 12 volt 50w solar panels: $135
solenoid: $15
two fans: $10
wire: $20
switch, fuse, etc. $25
Approximate Electrical total: $270

Approximate Cost of Whole System:
Collectors: $625
Tank : $320
Heat Exchanger: $232
Plumbing: $400
Electrical: $270
Approximate TOTAL: $1,847 Cost per square foot (60square feet) : $31
PLUS LOTS OF LABOR!!!

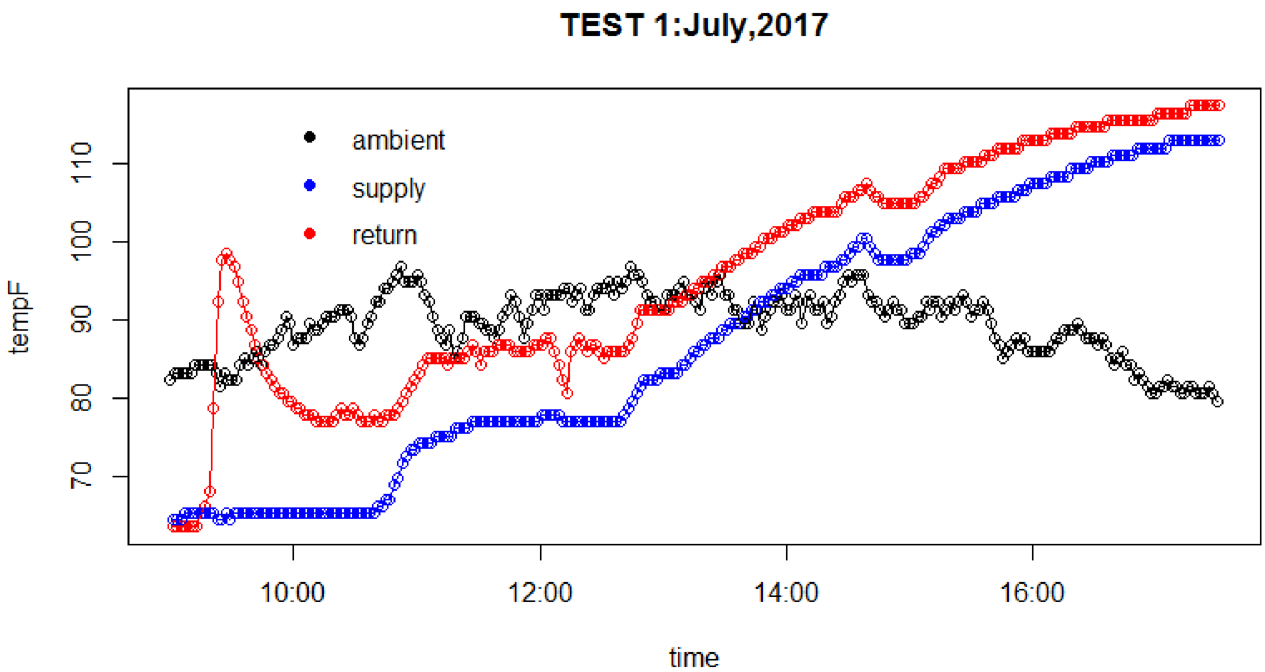
It is important to remember when considering cost/square-foot that this home made trickle-down collector is probably at best 45% efficient (as measured over a single day with an initial tank temperature of 65degF.). Manufactured tube-and-fin collectors are more expensive but have efficiencies closer to 65%. For comparison, photovoltaic panels are about 10% efficient. So the big question is always which scheme gives greater value, or useful energy per dollar spent.

I think the materials cost is still too high, although contractors and DIYers can often obtain these ubiquitous construction materials cheaper than retail. I think $1000 dollars in materials cost is a good number to shoot for. That would require lowering the cost of each domain (Collector, tank, heat exchanger, plumbing, and electrical) to $200. Is this possible? Integrating the roof with the collector as Thomason did would save on the collector cost, and scaling up the system to a home heating system would also reduce the per-square-foot cost a little. Using an arduino based controller, grid-powered pump, and sensors might bring down the electrical cost a bit. The storage tank would be cheaper if a thinner cloth was used thereby reducing the amount of cloth and the amount of silicone. Finally, regular corrugated galvanized steel roofing panels are much cheaper than aluminum standing seam. It would be worth it to see it their performance is acceptable.

How everything is working:

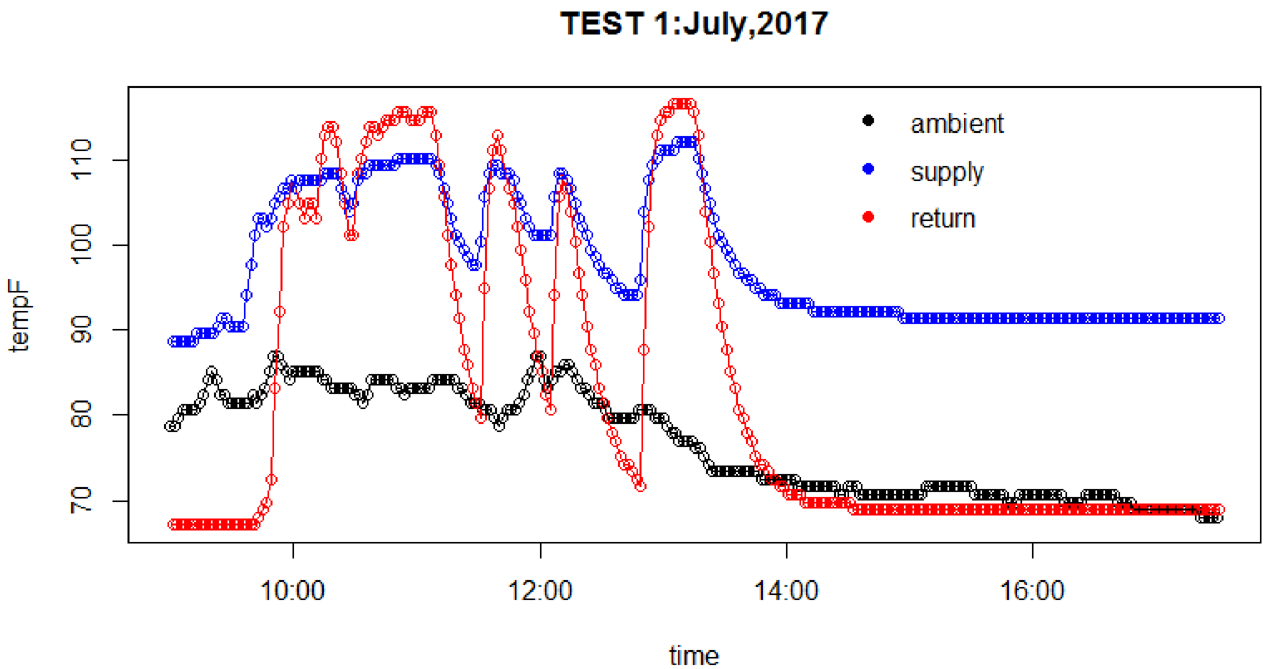
The system is making hot water. However, July is not the right month to test a solar hot water heater. Also, I don't have a pyroheliometer (yet), so an actual quantitative test will have to wait. Here are three consecutive days of data, taken with i-buttons. The supply temperature is an i-button taped to the outside of the supply pipe near the tank. The return temperature is an i-button taped to the return pipe near the tank. The ambient temperature is an i-button taped to the underside of a piece of aluminum on the roof. Therefore the “ambient” temperature is affected (strongly) by solar radiation, making it a lame proxy for the strength of the sunshine. I was away Thursday and Friday so I can't characterize the sunshine conditions. Wednesday was sunny with cumulus clouds, and, since we were all home, some hot water use.

Wednesday, July 26:

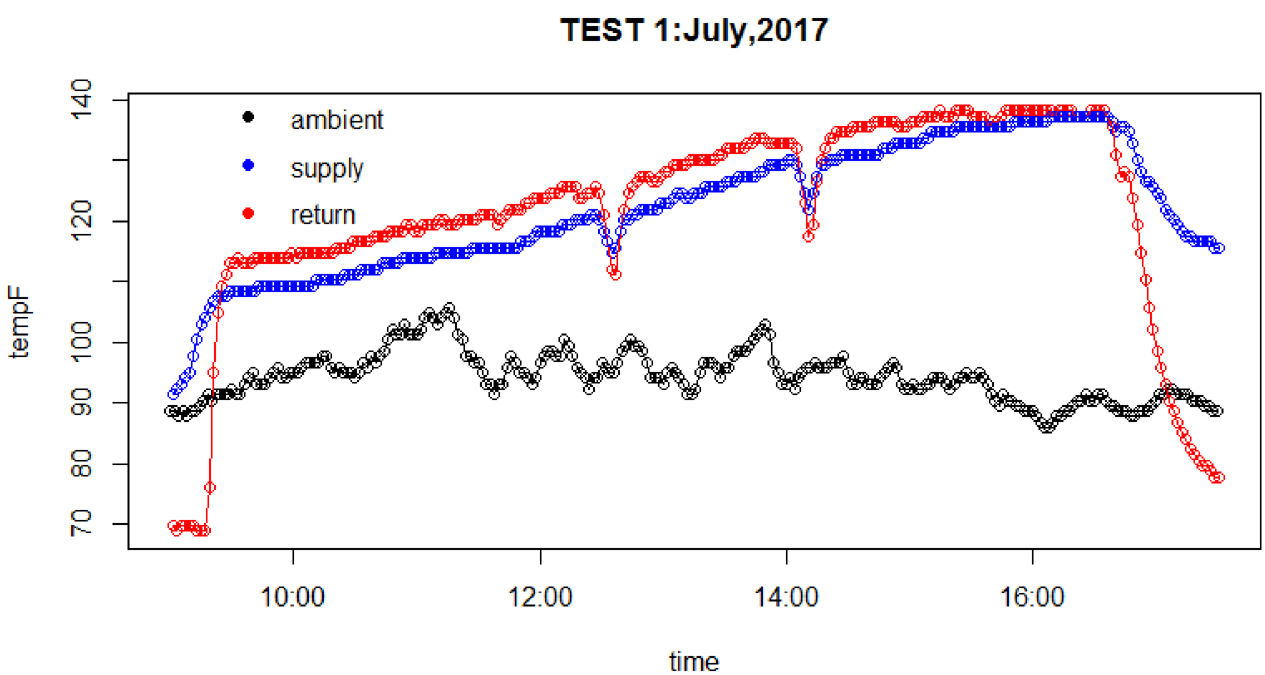


Between 1300 and 1500 (when someone took a shower!) on Wednesday the tank (105 gallons) makes a run in the 8,500 btu/hr range-- a spot efficiency of approximately 47% if an insolation rate of 300btu/hr-square-foot is assumed.

Thursday, July 27:



Friday, July 28:



Since we were away Thursday and Friday, the tank started at a relatively high temperature Friday morning.

Collectors:

I'm cautiously optimistic about the potential of trickle-down collectors. The problem of building a cheaper, tighter, better-made, collector will easily be solved by contractors and artisans with skills. The problem of optimizing the flow channels in the aluminum absorber can be solved by a DIY tool that rolls two or three grooves in to each flat section of the standing seam shape. Of course, this problem can also be solved if a manufacturer makes a custom roll former that is engineered for solar absorption—don't hold your breath. The problem of heat loss through the glazing is thornier. It serves to remind the designer/builder that collecting heat at a lower temperature will always make any solar collector more efficient, and this one especially so.

The collectors as I built them suffer from a couple of problems. First, the water trickling down tends to form a rivulet that stays to one side or the other of the little channel. Sometimes these rivulets "meander", which is good. But it looks like "hot spots" on the collector surface form domes which deflect meandering rivulets instead of attracting them. One possible fix for this is to make a "denter" that rolls grooves in the channels so that each channel is occupied by three little channels each of which captures one rivulet. I think it would help to distribute the rivulets more evenly over the surface of the collector.

Secondly, the collectors "slobber" a little. This is due to my haste and shoddy construction practices. Water cascading down the collector splashes a little and misses the PVC gutter at the bottom. Also, it's possible that some condensation running down the underside of the glazing also slobbers out. The fix for this is more careful construction and possibly a better gutter that catches all drips. Ultimately, perhaps a water-tight collector pan with a bulkhead fitting for an exit would be better than a gutter.

Another detail of the collector is a mismatch in the glazing and roofing panel sizes. Ideally, the standing seam roofing panels would have a geometry that had a standing seam at 48" on center. Then the standing seam would line up with the edge of the greenhouse glazing which comes in 48" widths. To get around this mismatch I built the collector pan at 48" wide to make full use of the glazing and then trimmed the extra roofing panel off and had a shop bend a lip on its edge. For a large roof-wide system, this problem would result in a small amount of waste-- most likely a pieces of glazing that gets trimmed.

Polycarbonate greenhouse glazing is easy to work with. As great as glass is, I prefer lifting polycarbonate sheets on to the roof to lifting large pieces of glass. Polycarbonate glazing can be easily obtained in 16' lengths. One problem with it is that UPS does not ship it; however, many greenhouse supply companies deliver it. One trick for cutting it is to put a plywood blade on a skillsaw *backwards.* The backwards plywood blade cuts the glazing nicely.

One concern about a larger roof-size system like this is that the pipe along the top of the panels that drips will not drip evenly along it's length. This is more likely as the pipe gets longer, but could be solved by varying the hole sizes.

Tank:

SO far, the tank hasn't leaked. Silicone caulk can be obtained in bulk and is very easy to work with. Once cured it is safe. It's happy to get hot. And it makes the cloth it is doped in to even stronger and tougher.

Also, I think using a thinner canvas might even work better and would be cheaper as it would require less silicone.

In the future I would like to sew a pre-shaped liner and try to silicone it in place. That would use even less materials and might actually be easier.

Heat exchanger.

With the shower on full blast the heat exchanger works well, supplying water at about the average tank temperature with no noticeable decline in temperature over the duration of the shower. The pressure drop due to the heat exchanger is noticeable but not especially significant.

Plumbing:

The access to the plumbing in the boiler room is tight, as the tank is in the way. I added a few unions so the whole plumbing manifold could be lifted out. This immediately paid off as I had a couple of problems that required removing it once after testing it (a valve I scavenged had been discarded for a reason!).

One interesting possibility for larger systems (that Thomason explored) is using two storage tanks (a large space heating tank and a smaller domestic hot water tank. In the Summer, the pump runs during the day heating the small DHW tank, and at night, the pumps run to cool the water in the space heating tank for use as a source of cooling the next day. I'm not sure how the glazed collector would work as a radiator, but I do know that as far as trickle-down collectors are concerned, they need to stay covered so leaves and debris don't get in to the plumbing system.

Electrical:

Although it is more expensive, I love using a PV powered pump, and wrapping the logic and the power source in the pv panel. One of the advantages of having a solar hot water heater that is totally independent of the electrical grid is that the house may still have hot water during a black-out. The pv pump could probably be improved by using a smaller panel and a linear current booster (LCB). The fact that the pump runs so fast at mid-day probably adds to the slobbering problem the collectors have. However, running lots of water through the panels makes them work well and also makes the tank work well, since the whole tank will be closer to the same temperature which means it will store more heat.

In a large system covering a whole roof, using a grid-connected pump and a logic controller would be smart. Today a ten-year-old can program an arduino with a sophisticated algorithm that drives the pump at the perfect speed to optimize collector efficiency, final water temperature, or whatever the user wishes (problem is, my kid isn't ten yet). Using a solar panel for the power and the logic is a little more expensive, but it pleases me to have a system that doesn't depend on the grid nor electronics (as dependable as some electronics are).

Conclusions:

One unexpected delight of this system is that it makes a faint and unusual gurgling sound when it is working. It is not a sound like a leak, but a sound of air and water mixing together. I have a solar hot air heater that has a pv-powered circulation fan, and it also makes a whirring that changes pitch as clouds pass by. I find this gentle connection to the weather pleasing on the rare occasion that I am working inside during the day.

Germany succeeded in being the first industrialized country to lower its per capita energy consumption while growing its per capita gdp. But Germany will have trouble continuing to reduce its energy use. I decided to build the Thomason collectors while listening to an interview with the German energy minister. He described the biggest problem for energy conservation in Germany is now space heating. Building new better houses would cost too much (in energy and economic terms), and improving the existing houses is difficult. Of course, PV and wind can't make up for inefficient furnaces and poorly insulated houses. I wonder if Thomason collectors combined with insulation and better windows could make a difference when retrofitted to existing houses with suitable roofs.

One of the reasons site-built solar never caught on is that there is a certain amount of grace and engineering required in addition to highly skilled construction. In the sixties and seventies it was hard for contractors to acquire this knowledge and skill, and harder still for pioneers to share with others what works and what doesn't. Today the internet solves this problem. Also, we badly need jobs that *are* site specific—those are the only jobs that can't be outsourced! Insulating houses, replacing windows, and re-roofing with integrated solar heating can create jobs that can't be more cheaply done overseas. For all of these reasons and the imperative to stop using so much fossil energy, I think now is a good time to revisit site-built solar.