

A thermosyphon solar water heater system for a hospital laundry.



I'm happy to be contacted with questions at [unclejosephiah at gmail dot com](mailto:unclejosephiah@gmail.com).
More of the as-we-went-along detail can be found on our blog [here](#).
Jo Wilson

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Background

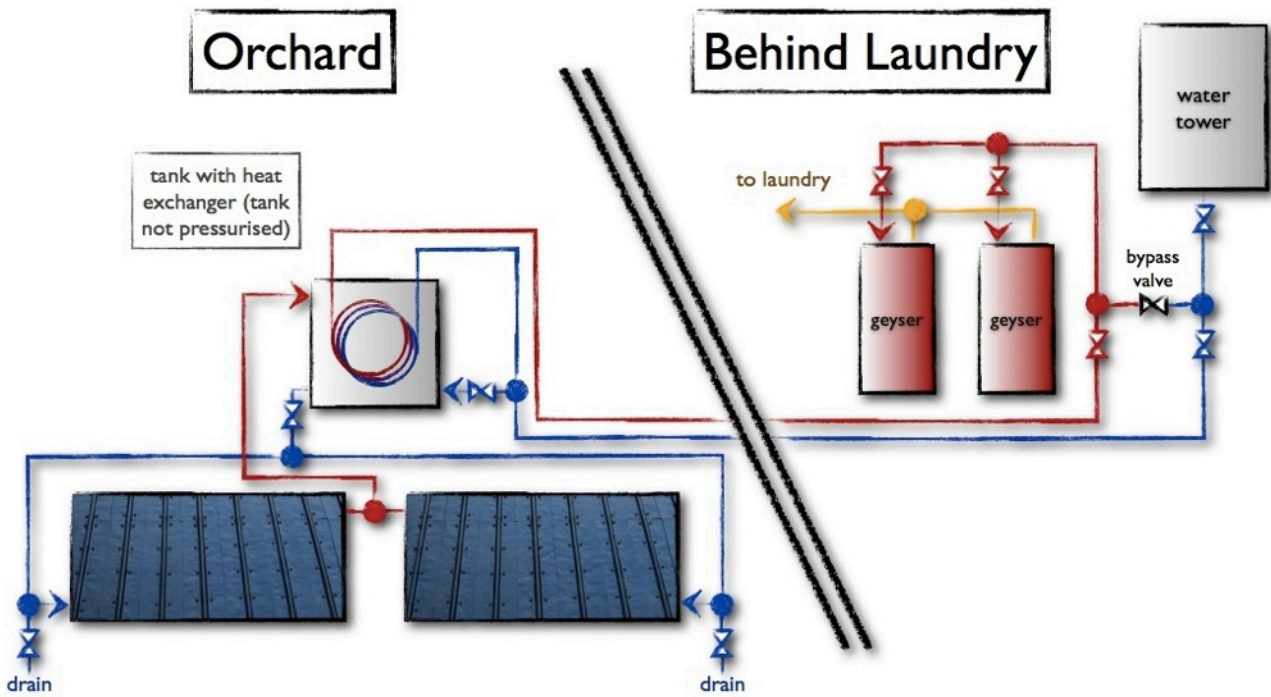
I've just spent the best part of a year working at a small mission hospital in northern Pakistan. They have been looking at ways of reducing their expenditure, so my role was looking at energy use. Aside from things like recommendations for insulating buildings, the main project took the shape of a solar water heater to provide hot water for the hospital laundry. It was found to use ~1000-1500 litres of hot water per day, currently provided by two gas geysers (boilers) - for which the gas bills are understandably huge (think Rs500,000/year, equivalent to around £3500/year).

We decided to make a small prototype first, in order to assess the feasibility of the project given the locally available resources (both materials and skills). It worked rather nicely - short summary report [here](#).

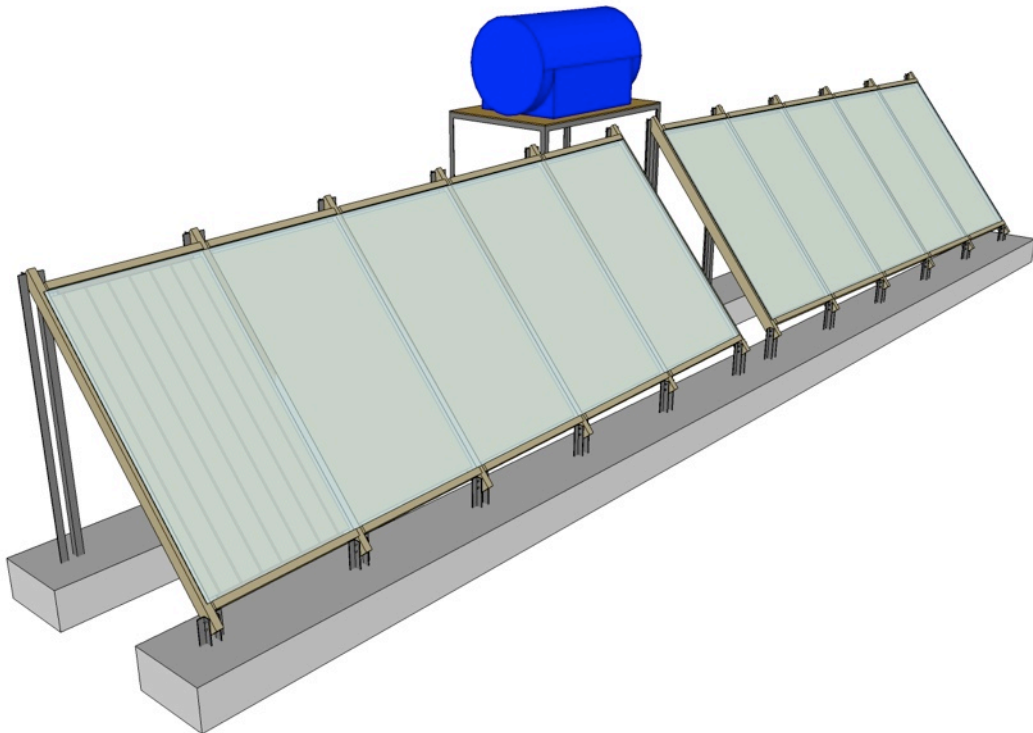
Design Overview

Our original hope was to build the system on the roof of the laundry building; however, initial calculations suggested a size/weight that the roof would be unlikely to take without extensive restructuring, so the system was placed on a piece of unused open space in the nearby orchard.

Wanting to keep it as simple as possible, I went for a thermosyphon system with a tank on a stand behind the panels. Pipes run in a trench from the water supply to the system and back the the laundry, supplying preheated water to the gas geysers. Pressure is supplied from an existing water tower behind the laundry.



The collectors are mounted at an angle of 50° (we're at a latitude of just over 34°, plus a ~15° increase to favour winter collection).



I initially aimed for around 200 square feet of collector area, but as I got into researching the different materials and their sizes, I ended up sizing the collector around the glazing, for a total collector area of around 224ft².

Collector

Foundations

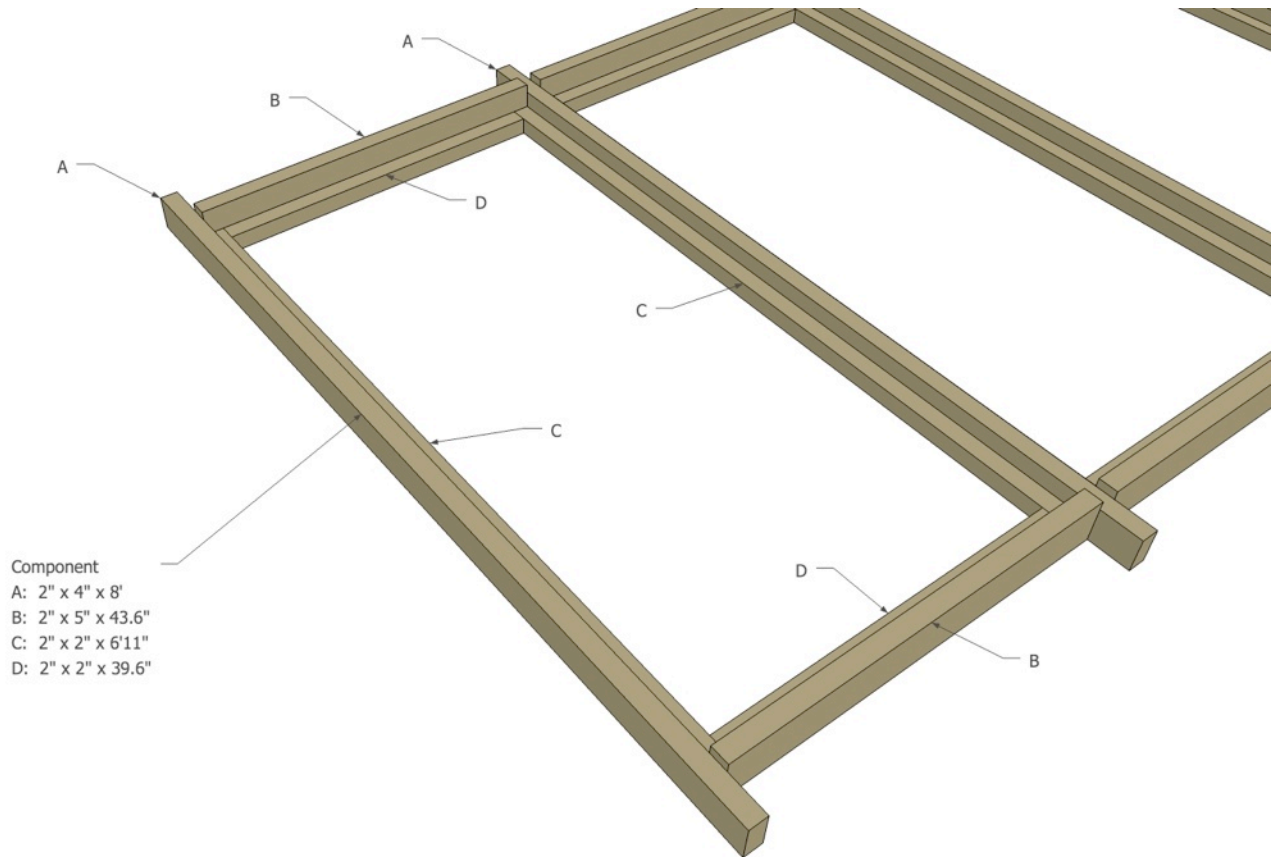
A large concrete foundation was laid, into which were set chunky angle-iron supports. In order to create the slight gradient required to prevent bubble traps, the supports increase in height by one inch each time. The positioning of the supports required some careful calculation to keep the frames square, but building in the gradient at this level simplifies the design of the panels themselves (i.e. in each individual panel the pipework can be done with everything straight).



Frames

Frames were constructed in portable sections in the workshop, before being mounted on the supports. The frames were given several coats of something (as far as I could tell, plain engine oil!) to keep the rain and the termites out.

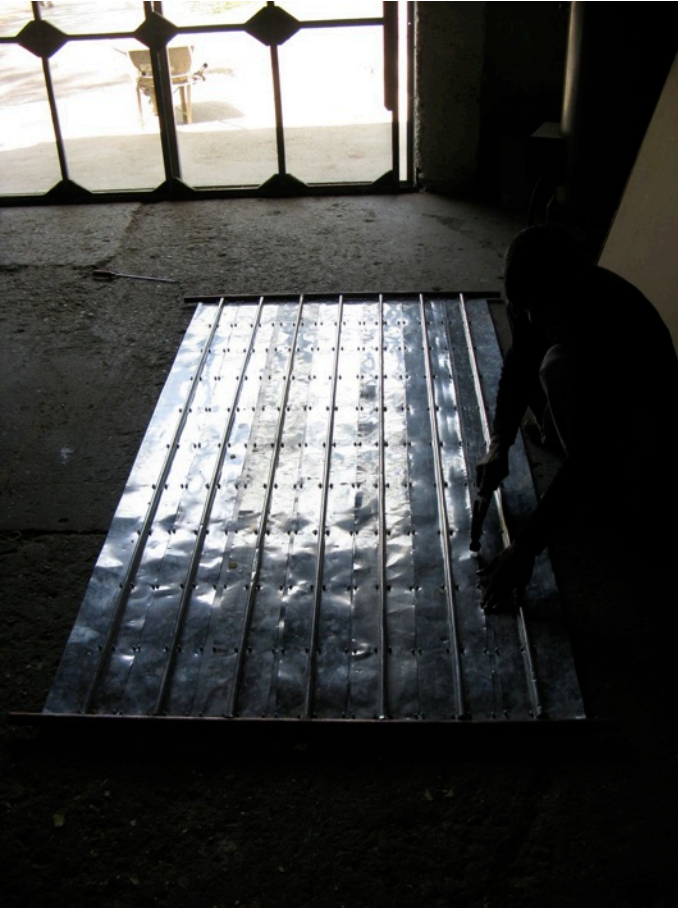
Note: our panels are sized around the most costly components: the glazing and insulation, so are a distinctly non-standard size (see diagram below - 39.6" is almost exactly 1m, the size our insulation came in). You might find the usual 4' x 8' size easier to work with and less wasteful of resources.





Collector Panels

The collector generally follows the BIS favourite Copper/Aluminium collector design, with a few minor differences to accommodate local resources and capabilities. We had some friends of my boss do the copper fabrication down in Lahore (where, incidentally, the copper price is 2/3 of what they were charging in Pindi, making the trip to collect it worthwhile). In the absence of staples and staple gun for attaching the fins to the backboard, we went for nuts/bolts/washers inserted through pre-drilled holes - fairly labour intensive, but actually produces a good tight fit between fin and tube. When we came to putting the grooves into the panels we hit one of the limitations of Pakistani engineering, which is better illustrated [here](#).





Once the panels were dropped into the frames, we got a chap with some brazing gear to come and connect it all together.





I asked for some black paint which was 'not shiny', and was brought some crazy bitumen compound you could probably surface a road with. Did the trick though.



Glazing & Insulation

We used glass for the prototype because that was all that was readily available; however, the difficulties of working with it (not to mention its durability in an area not renowned for seismic stability!) made me dig a little deeper in my search for an alternative. Eventually I unearthed one lonely [supplier of polycarbonate sheet](#)* based in Karachi, from whom we purchased 2 sheets of twin-wall. (This was only available in the frankly bizarre size of 6'11" x 19', so given the relative expense of the glazing I actually sized the whole panel design around these, and had them cut each sheet into 5 equal portions for cheaper shipping - about 1000 miles by [painted truck](#).)

[*link to supplier's site - no commercial interest, just the only place I found in the country that supplied it.]





The lighter blocks of wood are to keep the glazing off the panels if/when they bow due to thermal expansion. Yep, we probably should have painted them too, but we wanted to get on with the glazing and couldn't be bothered waiting. These blocks and the edges of the frames where the glazing will rest were topped with a thick bead of silicone which we allowed to dry before fitting the glazing.

For insulation, everyone here uses cheap styrofoam panels, which are obviously not suitable for this high temperature application. Polyiso is unheard of. Eventually I found [one supplier](#)* who would make us some 1m x 1m x 50mm polyurethane panels, which happily fit almost perfectly into the frames designed around the glazing once the thickness of the wood has been taken into account.

[*link to supplier's site, included just in case it helps someone - again, no commercial interest.]





For pipe insulation, I struggled to find anything suitable whose supplier had a sufficiently small minimum order quantity. In the end we got hold of a large roll of foil-backed fibreglass wool. Not perfect, but better than nothing.



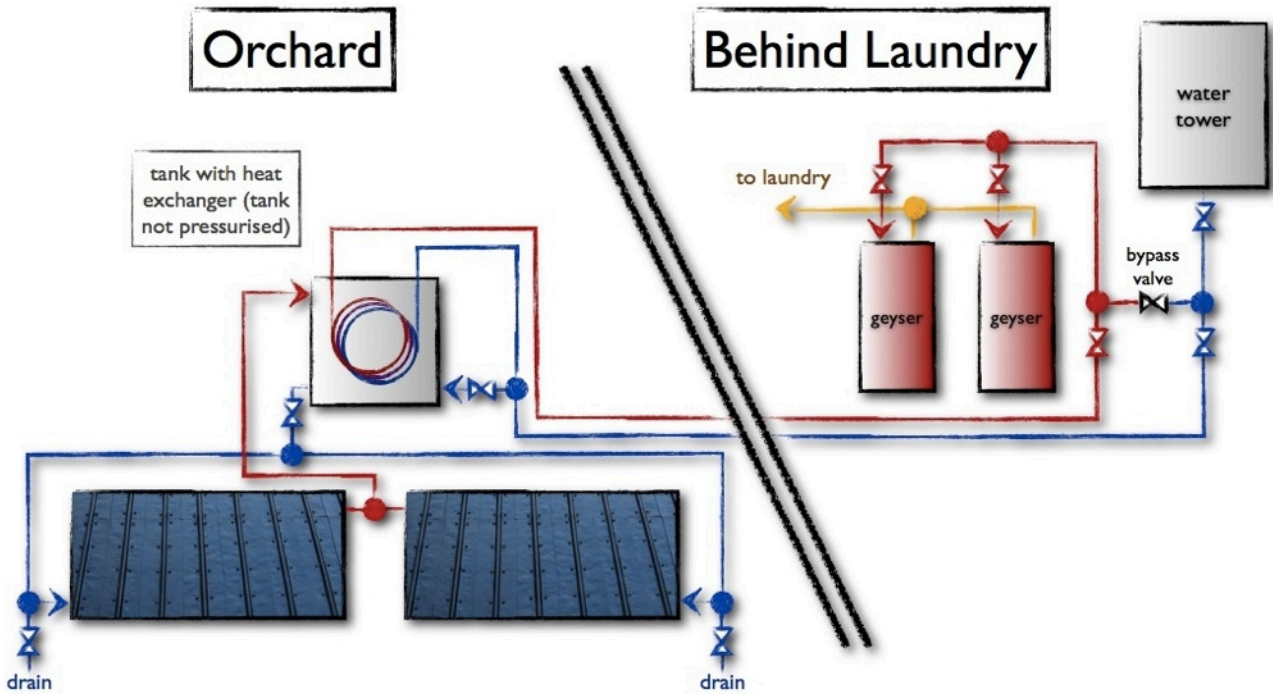
A cold and a hot (insulated) pipe run were laid in a 2 foot trench, along with conduit enclosing my sensor wires.

Tanks & Plumbing

As a first iteration, we used an old blue plastic* tank that was lying around unused on the roof of one of the hospital buildings. It has a capacity of around 600 litres - a bit small, but would do for a starting point. To me it looked as if this tank would be nigh-on impossible to seal effectively, leading me to go for an unpressurised system with the tank acting as a heat store, from which heat

would be extracted by the cold water passing through a heat exchanger. For this we procured two 50 ft lengths of copper refrigeration tubing. Initial tests gave a reasonable temperature rise for the water passing through.

[*what kind of plastic? Who knows. This is a persistent and annoying problem in this country - [see this blog post for a perfect illustration.](#)]



System diagram A - with heat exchanger and unpressurised tank.



Old 600l tank.



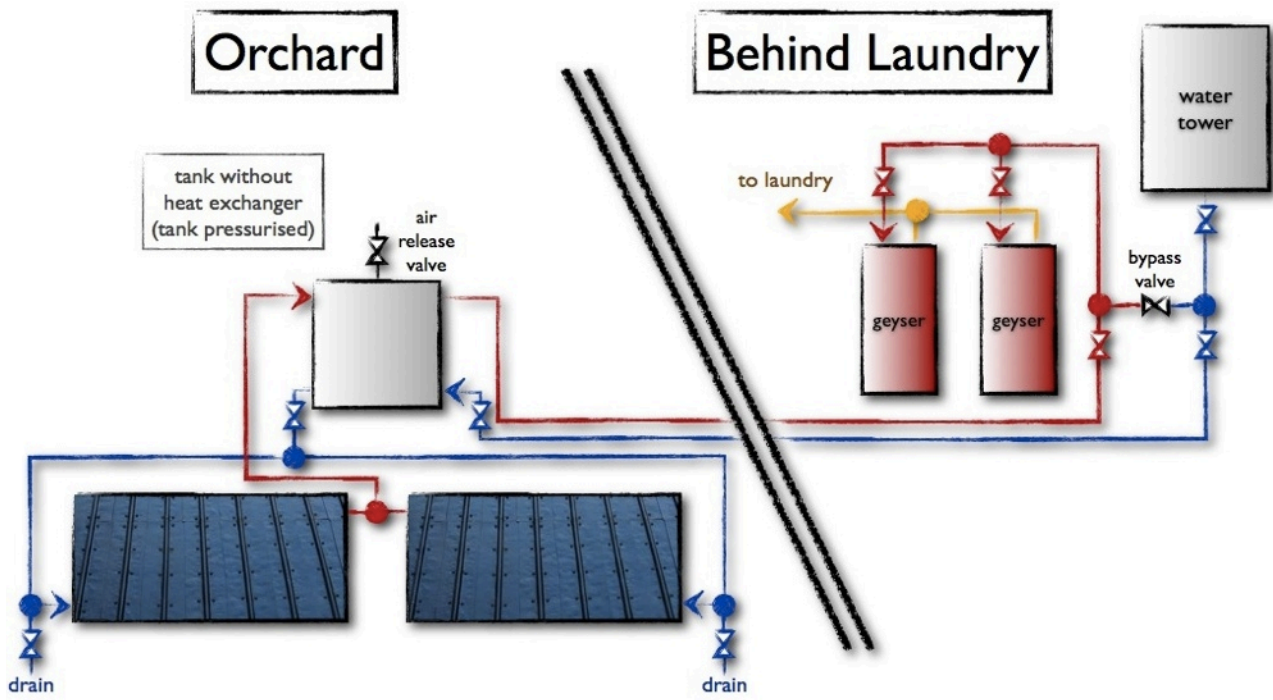
Heat exchanger winding.



Heat exchanger in place.

However, after a few days at 70-80°C, it became clear that this tank wasn't really up to the job (surface beginning to disintegrate), so we went out and purchased a better one**. This one is around 1200 litres (so will run cooler and with fewer losses) and has the advantage of a screw top, which might allow us to run it pressurised, with a direct connection instead the heat exchanger - a distinct advantage, as we'd been having problems with the copper coils kinking during installation.

[**allegedly. No one can tell me what the new one is made of either.]



System diagram B - with direct connections to pressurised tank (no heat exchanger).



New tank atop reinforced stand.

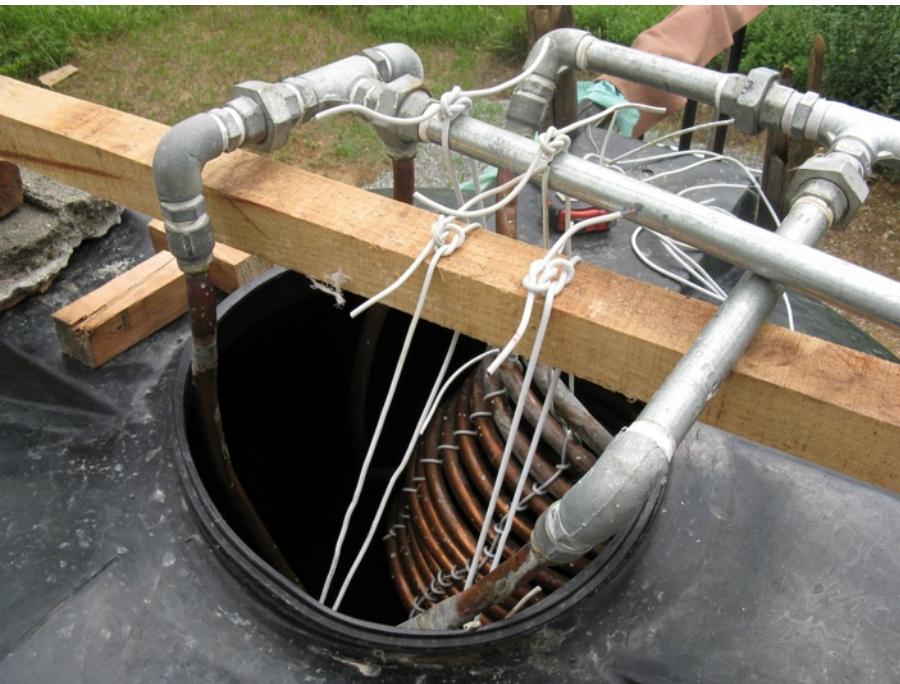
The first attempt at securing the lid was an interesting failure - there were no visible cracks or tears, so I think the pressure in the tank stretched the lid just enough for the teeth of the screw thread to slip over each other - and the top popped off. After re-silicone-ing and adding a bunch of jubilee clips around the top of the lid (with the idea of keeping the screw threads interlocked), the tank seemed to hold okay.



Bulging lid - the rest of the tank is similarly bloated.

However, I really wasn't happy with the way the tank was bulging (it was holding okay, but I had serious doubts about its future longevity). This tank clearly isn't designed for pressures much beyond what it experiences from the weight of the water it contains. At this point we have two options: 1. go back to the heat exchanger/unpressurised tank version; 2. find/buy a metal tank suitable for running under pressure.

Given that we have already obtained the heat exchanger components, option 1 is favoured as a starting point, and after a couple of days' work getting the kinks out of our copper tubes and reinstalling them in the tank, we had it up and running again. If I had a few more weeks here I would see about sourcing a metal tank that we could run under pressure - for now I'll have to leave that to the guys here for a future upgrade.





Copper coils suspended near the top of the tank.



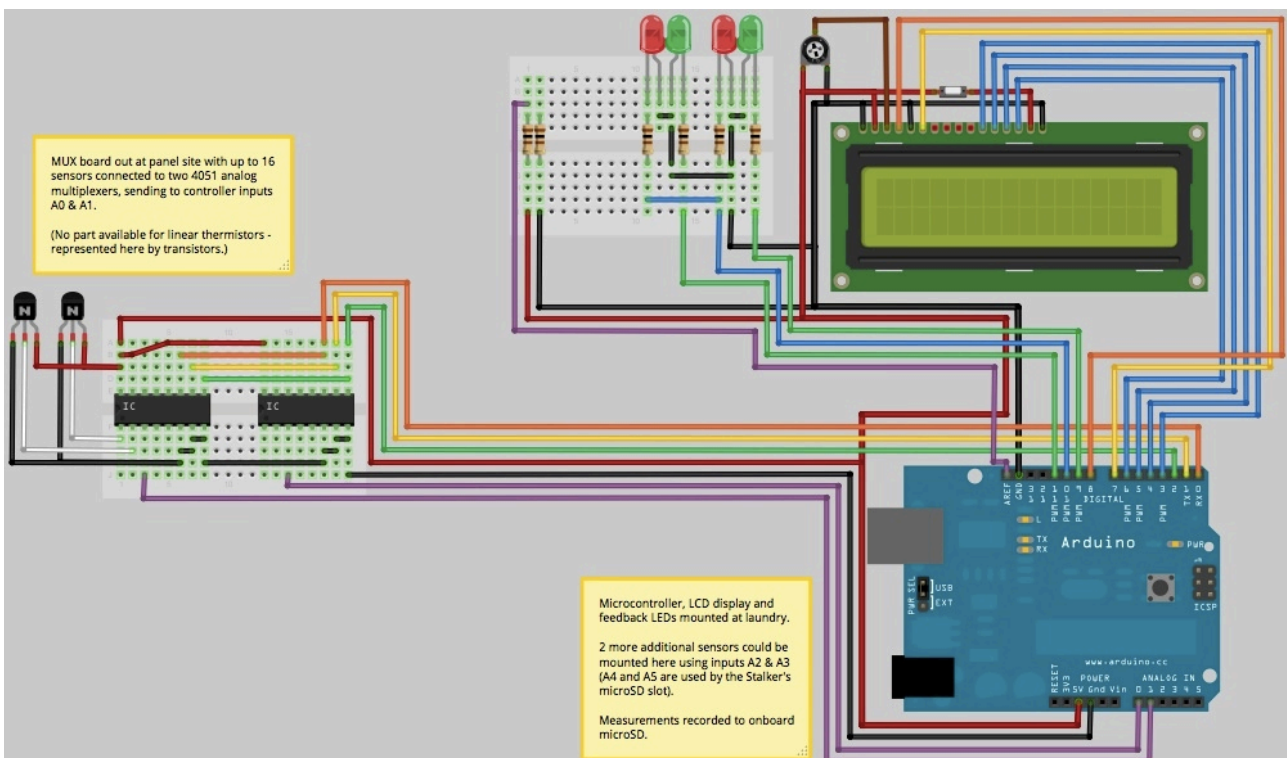
The tank was wrapped in a couple of layers of glass wool insulation.



“Finished” system.

Temperature Logging

Mainly as a keeping-myself-sane-during-the-inevitable-delays side project, I built a temperature monitoring system centred around a [Seeeduino Stalker](#) (an [Arduino](#)-based micro-controller with an onboard logging facility). I used 18 inexpensive MCP9700A linear thermistors connected through a couple of 4051 multiplexers to measure the temperature at various points in the system, and output the results to a small LCD screen and a microSD card.



Basic circuit diagram.

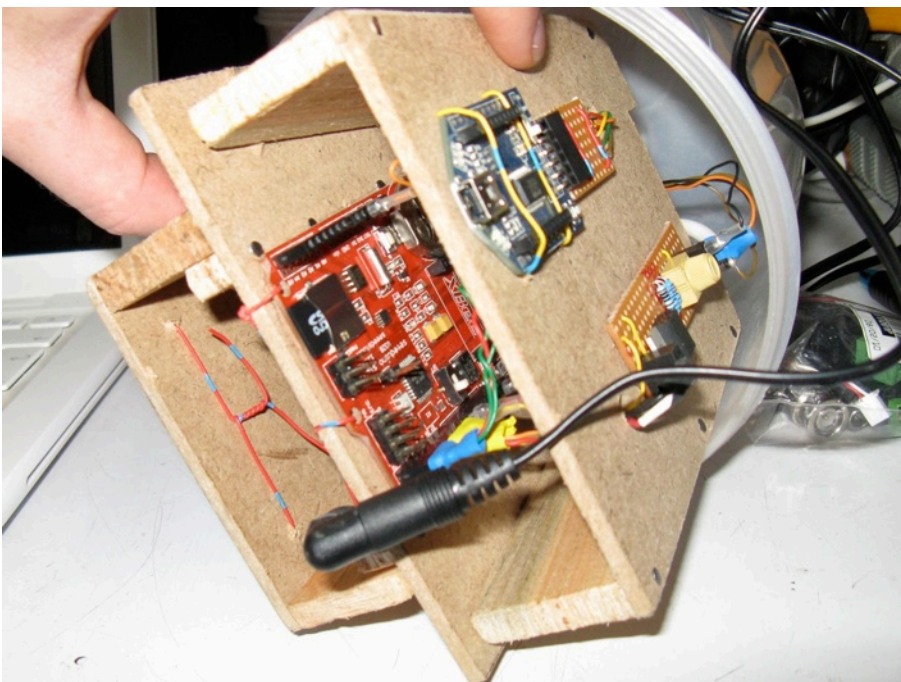
The ‘dry’ sensors (the ones in the panels or on the outside of pipes) were enclosed in heat-shrink insulation, while the ‘wet’ sensors (those inside the tank) were also enclosed in short lengths of

copper pipe which I had lying around and sealed up with silicone. Because of the extra distance between the sensors and the logger, I did have to do some careful calibration - easy enough with readings taken at various temps using an ordinary glass thermometer.

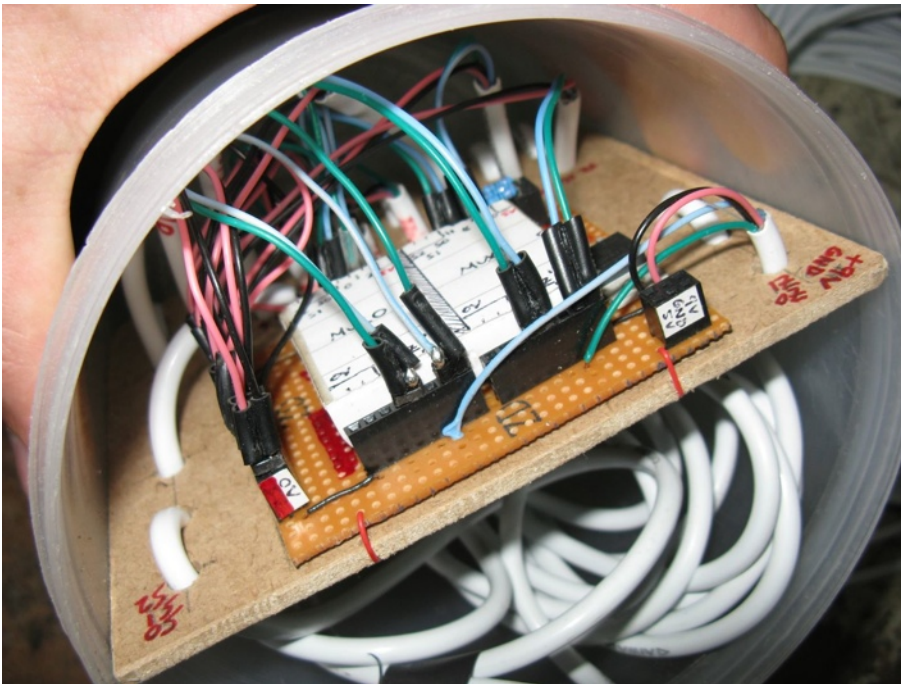
The sensor mountings are the one thing about this system I would reconsider (see lessons learned below). Other than that I'm very pleased with the results that this system has given me. Total cost was probably around £100 for an 18 sensor data-logging system with LCD display.



LCD display (before sensors connected, so readings are nonsense).



Micro-controller with microSD card for logging.



Multiplexer circuitry, to be mounted out at the collector site. (Some things you can cut corners on without adverse effect: a 30-rupee screw-top tub from the bazaar is just as waterproof as a £15 enclosure from my local electronics store at home! Admittedly mounting everything inside a tapering cylindrical tub was an interesting geometrical challenge.)



Sensors ('dry' in heat-shrink, 'wet' in copper/silicone).

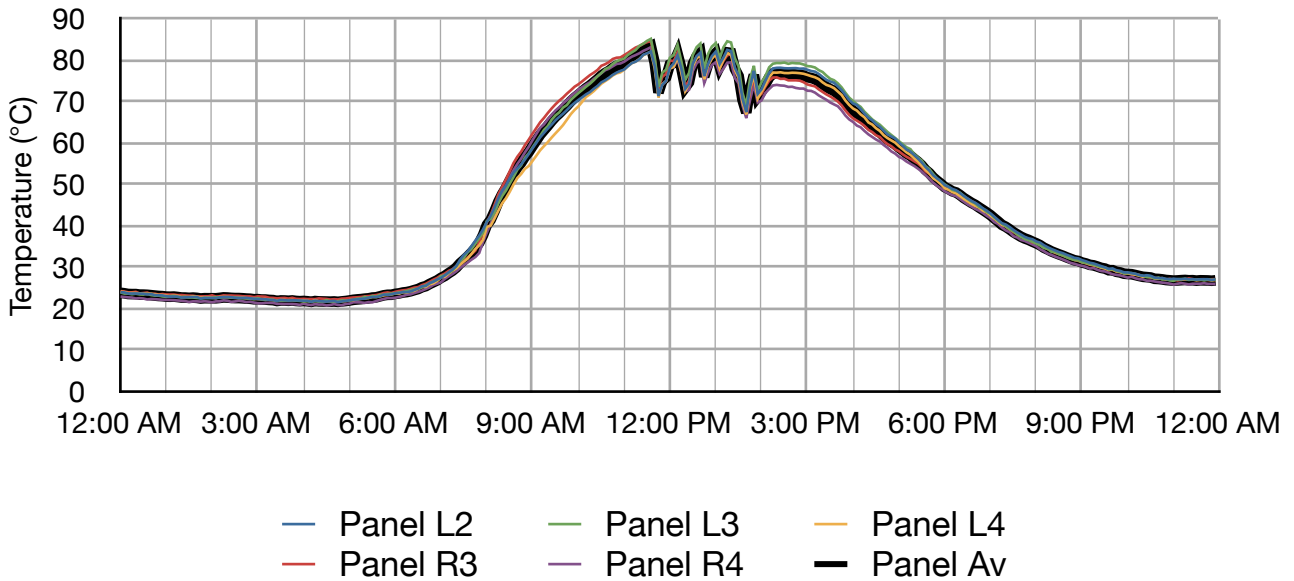
I'm reluctant to post my micro-controller code, simply because it has had so many modifications and additions over its lifetime that it is now rather difficult for anyone else to decipher - if anyone else is interested in following this route and wants to see my code, I'm happy to be [contacted](#) for a copy of it and with any questions. It was originally based on [this code](#) from the guys at [airsensor.co.uk](#), which might be easier to follow.

Performance

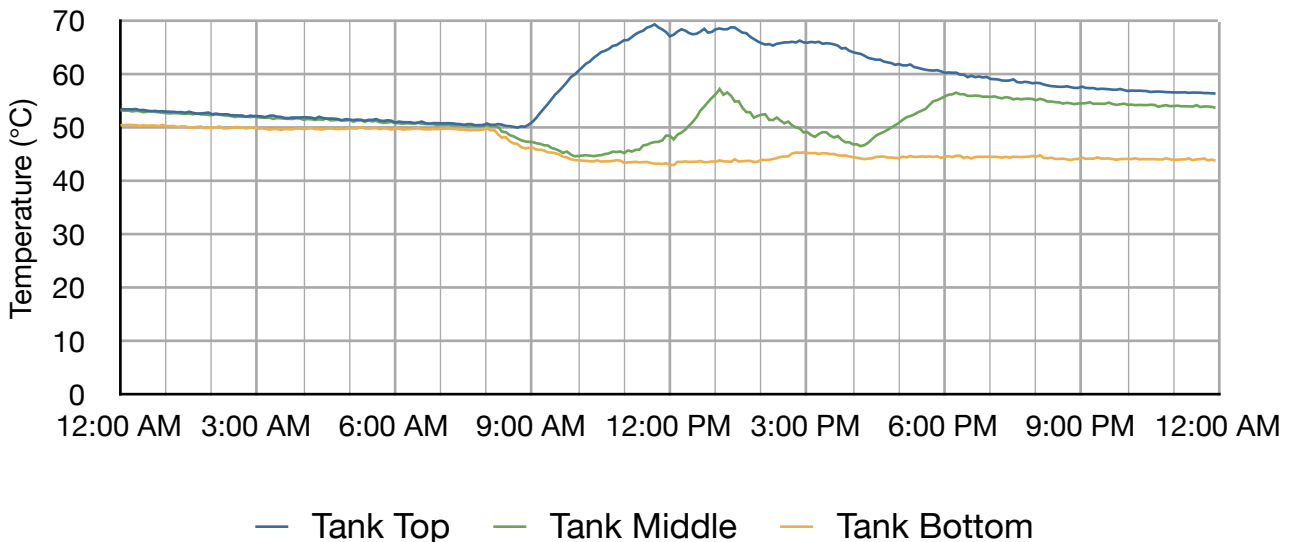
Overall, I'm very happy with the way the thermosyphon section of the system is performing, with the panels peaking at ~80°C on a typical clear day, getting the 1200 litre tank to around 60-70°C. The bottleneck is in the extraction of the hot water from the system and getting to where it is needed.

Here are the temperature charts from a typical day (mostly clear with bright sunshine, with a few small clouds passing by in the early afternoon).

Panel Temperature

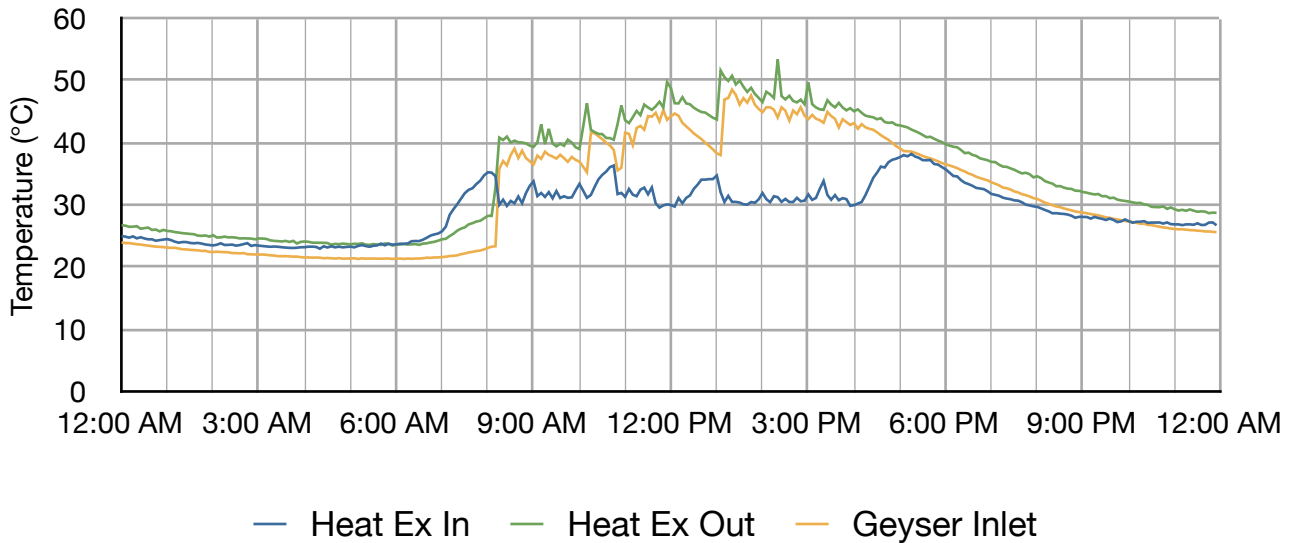


Tank Temperature



At present the system is outputting water at around 40-50°C consistently for most of the working day. This is then topped up in the gas geyser to whatever they've set the thermostat to (I think around 60°C).

Input/Output



Ideally of course, I'd like to get to a point where we can switch the geyser off for the summer, which I think might well be achievable if we move to the pressurised, non-heat-exchanger version. (The output could also be improved somewhat by using a longer heat exchanger, though would introduce more pressure loss between the supply and washing machine.)

In the thermosyphon section itself in the middle of a clear day we're seeing an increase of at least 30°C (probably more like 40°C) as the water travels from the bottom of the tank through the panels to the top of the tank.

The tank has been keeping its temperature up fairly well overnight, with a typical overnight drop from ~62°C to ~54°C (this drop will obviously be greater in winter).

Lessons Learned

Heat exchangers or not?

In a climate where freeze protection is not an issue, the decision on whether or not to go with heat exchangers comes down to the question of 'can we make a pressurised system work?'. In the time frame available and with the kind of tank we were able to get hold of, this was not possible, hence the necessity of working with the heat exchangers (as in [System Diagram A](#)).

With the heat exchangers I suspect we lose a reasonable amount of efficiency (less energy extracted per given volume of water passing through the system -> tank and panels run warmer -> higher losses; also, more gas used in the geyser to top-up the water temperature), so it would be preferable to replace the plastic tank with a metal one which can be run under pressure, and lose the heat exchangers in favour of direct connections (as in [System Diagram B](#)).

If I had a few more weeks here to work on this project, this would be my first priority.

Tolerances

It's no good designing things to millimetre precision when the guys in the workshop only really work to a tolerance of about half an inch!

Build some slack into the design.

Temp sensor mountings

The day after I mounted my temperature sensors we had a big storm. This would not have been an issue had it occurred after the glazing was in place, but in this case meant that several of the sensors shorted out (I'm down to 12 out of 18 still functioning). I'm still slightly surprised at this, since the sensors were encased in a big blob of silicone - I think the water must have done some amazing capillary action where the wires enter. I also had (more expected) problems with a couple of the sensors inside the tank, particularly when the tank was under pressure.

Waterproof your sensors *really* carefully.

Also, in retrospect, I might have sacrificed having a sensor in every panel in order to have a few spare, for example to put on the input/output of the collectors.

Pipe material and sizing

One thing that I am a little worried about is the possibility of corrosion. I think the panels themselves will be fine (should keep dry; layers of paint/silicone between the copper and aluminium), but there are a couple of places where they have copper directly brazed onto galvanised steel fittings. No-one had heard of dielectric unions, copper was too expensive for our long pipe runs, and while PPRC pipe is starting to come in, the workshop guys wouldn't be swayed from their 'we know how to do GI pipe, so we'll use that' stance. Still, at least the parts that are likely to go first are easily accessible and inexpensive to replace.

Also, if you have long runs of pipe like we do, make sure you do your pressure loss calculations to check that you'll still have the required pressure at the end. By the time we'd added a few hundred feet of pipe (and associated fittings), the washing machine the system is supplying wasn't getting enough supply pressure (it's a bit fussy). We solved this by raising the height of the water tower by 5 feet. Adding a pump would have been another option.

Frame construction

We did a much better job of keeping the 2nd set of frames (the left set) aligned correctly. At every following stage (fitting and brazing the collector panels, fitting the insulation and the glazing) it was clear how much more easily the left side worked. The right side took a lots of adjustment with saw and hammer to make it all fit together; on the left side the panels and glazing just dropped beautifully into place.

Another minor problem was that of getting the wood the right size. When the guys cut the planks from the timber, they cut them beautifully to the 2" thickness (or whatever), but neglected to account for the little bit that would be removed when they ran them through the planer. So all the pieces of wood were a little narrower than they should have been.

Taking the time to get your initial steps right will make all subsequent steps go that much more smoothly.

Tank stand construction

The tank stand (knocked together from pieces of old angle iron by one of the workshop guys), while strong enough to hold up the 600l tank, demonstrated its inadequacy when we filled up the new 1200l tank. Fortunately we spotted one of the legs beginning to bend in time to avert a complete collapse, and the stand was then beefed up considerably with an extra central support and some proper diagonals made of some nice new chunky angle iron to stop it flexing.

The tank stands are the one part of the project I would definitely suggest you DO NOT COPY! - do your research and build it properly.

[These problems partly stem from the way people are taught to learn parrot-fashion and the general low standard of education here - the guys have an idea what a structure should look like,

but often without really understanding *why* you need to put a particular strut in a particular place. Hence you will end up with something which *looks* similar to a strong structure, without necessarily having the function of one.]

Appendix A - Prototype report

Here's some thoughts about a thermosyphon SWH project I've been working on at a hospital in Pakistan. We could have just bought a commercial evacuated tube system for a price not too dissimilar to that of the raw materials we used, but we went for the DIY option so that the workshop guys who help build it will thus know how to maintain it in years to come. Besides, it's more fun this way.

This is a prototype system, which we hope to expand for use with the hospital laundry, for which hot water is currently heated using a gas geyser. We'll use the warmer water output from the panel as the input to the geyser, thus using the geyser's thermostat as a regulator to hopefully reduce the gas bills somewhat. Sticking a water meter on the water supply told us that it was using anything between 400 and 1600 litres a day, with an average of around 1150 litres. For the full-size system, we'll be aiming for around 200 sq. ft of collector, probably 4 panels in parallel.

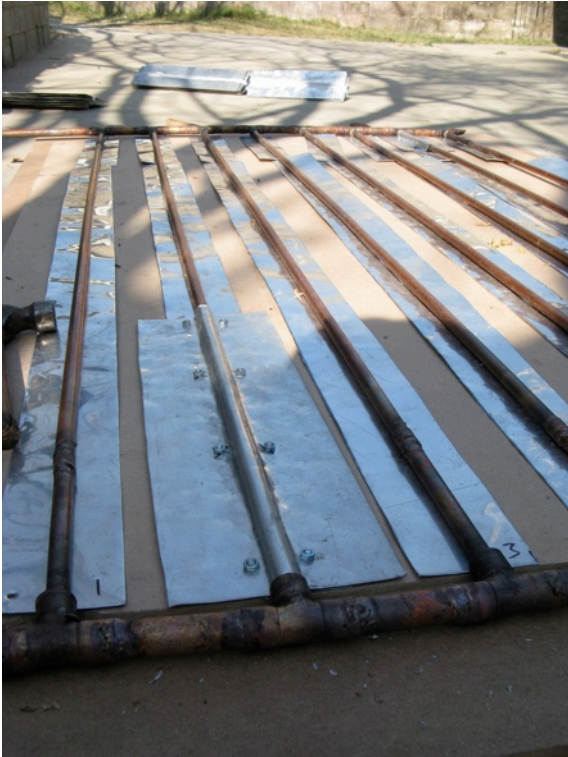
The glass being the least workable material, the prototype panel was sized around the 6x4' glass sheets.

In terms of materials, what we expect to be readily available at home is often unobtainable (or wildly expensive) here, so this is a story of many compromises and workarounds!

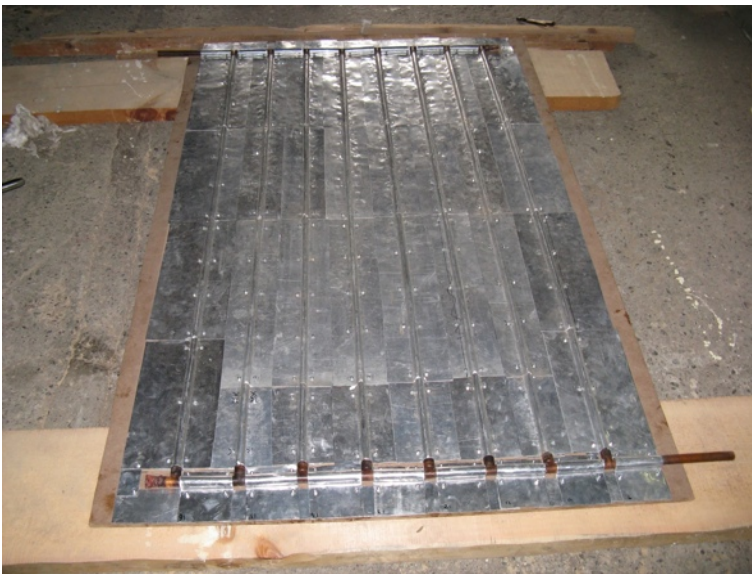
1. The wood comes in big chunks, so the first job was to cut planks of a useful size.



2. The only aluminium sheet we could get hold of was about 1.2mm thick (0.05"). This caused all sorts of problems:
 - a. cutting all that sheet up with only a pair of tin snips is hard work. Really hard work.
 - b. working with it is a pig - forming them into fins took a huge amount of sledgehammering. I'm jealous of all your beautifully smooth dent-free fins! Next time we'll try and get hold of some thinner sheet, even if we have to import it.
 - c. even if we had a staple gun, there's no way the staples would punch through it. After experimenting with nails and various kinds of rivets, we eventually went for nuts and bolts through pre-drilled holes. This was very labour-intensive, but actually enabled a very nice tight fit between the fins and tubes as the aluminium sheets were pulled together. Which is a distinct advantage given the general batteredness of our fins.



3. While we managed to find copper tube in both 1/2" and 3/4" sizes, getting hold of copper fittings (and in particular, reducing tees) was a whole different story. Eventually, one of my boss's contacts came through with 3/4" tees with a short length of 1/2" copper tube carefully soldered into the middle outlet. Combined with some copper socket connectors, these did the trick. Next time, I might simplify things by using 1/2" tube throughout.



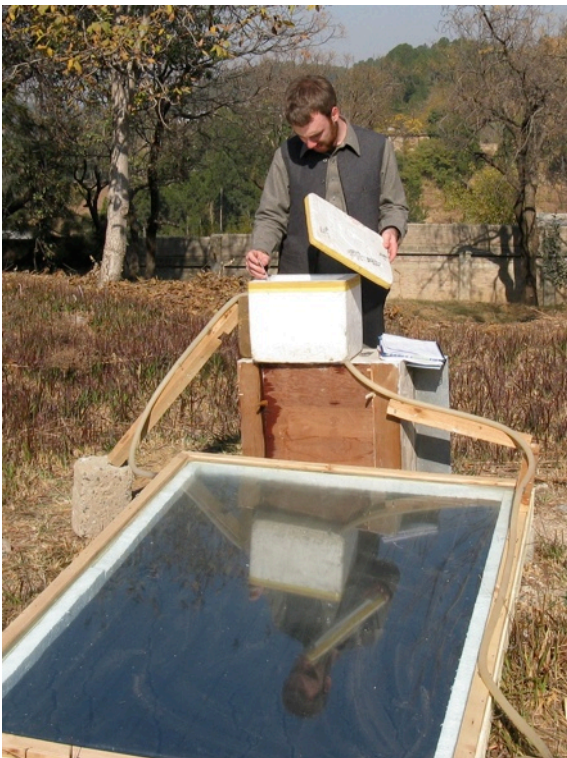
4. Window glass is by far the cheapest & most available option here, and we went for double glazing. We sliced up some old innertubes for gasket material and nailed it all down with strips of wood making an overlapping frame. One small corner got cracked in the process, but to be honest I had expected worse...
5. Most of the projects I've followed said ~3 tubes of silicone is sufficient. I don't think we put an excessive amount on, but by the time we'd done all the fins and sealed up around the glazing we'd gone through 8 tubes. Maybe it just comes in smaller tubes here...

6. While our black spray-paint claimed to be flat black, it has a distinctly satin finish to it. Not as bad as full gloss, but next time we'll search a bit harder for the real deal.



7. All insulation here is polystyrene panels - other things are impossible to find or hugely expensive. After reading a few of other peoples' experiences, this is the part I'm most nervous about at the moment. There are a couple of layers of board between the fins and the polystyrene, so we'll try it out and see what happens - we can always prise the back panel off and replace it with something better later.

As a very first I-just-want-to-see-if-this-works test we dragged it out into the sun (this thing took 5 of us to lift - so we'll have think about the practicalities of construction for the big system!) and connected it to a small temporary tank made of styrofoam cold transport box with a capacity of about 13 litres.

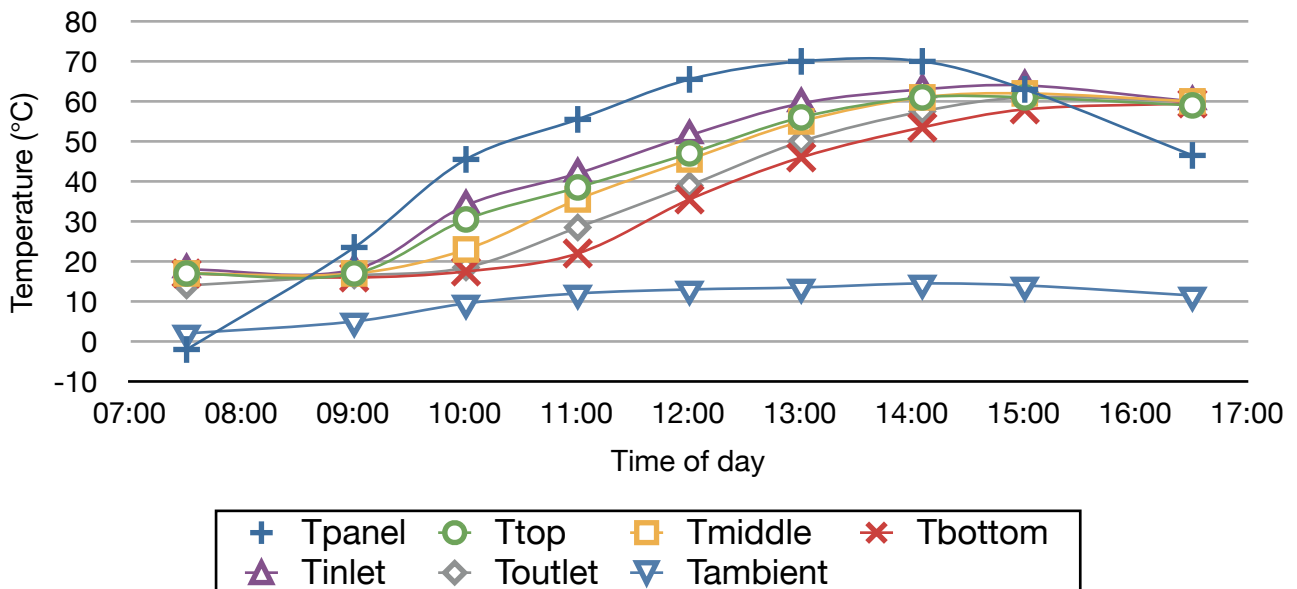


We then made a larger (~59 litre), more waterproof tank and set the panel at an angle of about 50° (our latitude is about 34°, plus another 15° or so to favour winter collection, this being December) by making some legs out of a couple of old door frames nailed together.



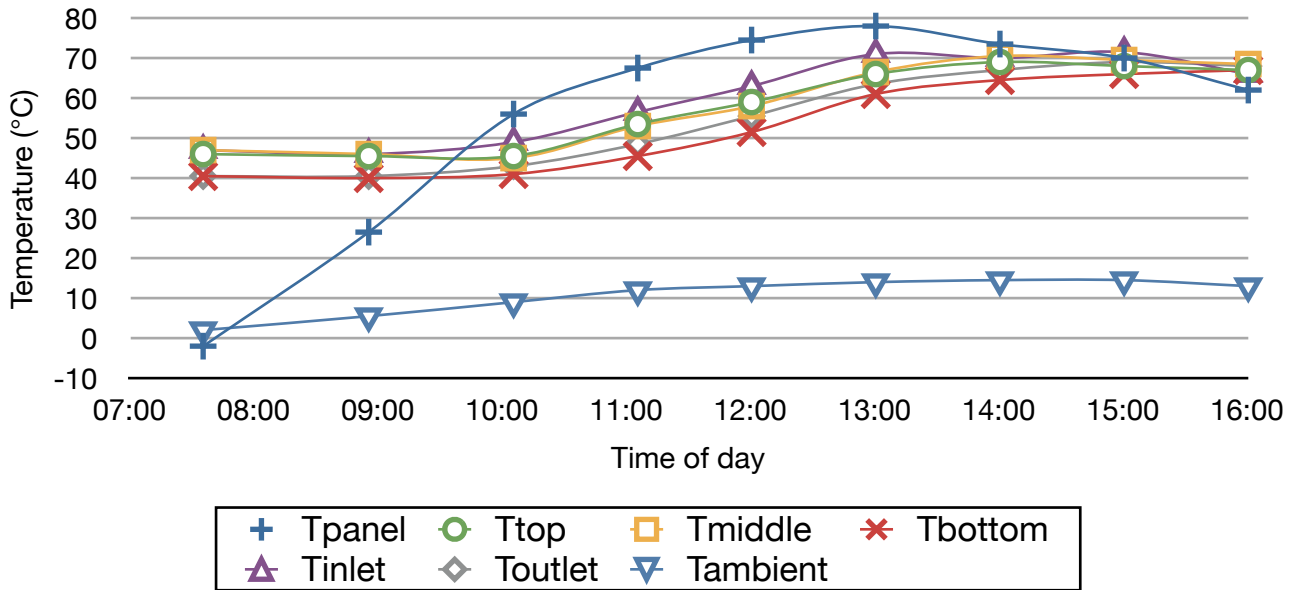
The purpose of this setup is purely experimental, so it is a simple closed system with no plumbing to supply/extract water.

Day 21 (4th Jan 2011) - cold start, clear



Starting from cold, we hit 70°C in the panel and 63°C or so in the tank, and estimating from the temperature readings at various points in the tank this equates to a net energy collection over the course of the day of ~10.6MJ (or just under 6MJ/m² of collector).

Day 22 (5th Jan 2011) - clear



From a warm start (the water lost $\sim 15^{\circ}\text{C}$ overnight), we got to around 70°C in the tank. Since the system is running warmer, the losses are greater, giving a net energy collection of 5.9MJ ($3.3\text{MJ}/\text{m}^2$) for the day. Obviously for a real system in use, we would be extracting energy from it all the time as we extract hot water and replace it with cold, so the system will be running cooler, so we might expect to get nearer to the values obtained on day 21.