Two Year Report Card on the 'Khanh Master–Slave' Variant of the BIS $1K Solar Water Heater

Introduction:

During the fall of 2010 we implemented a variant of Gary Reysa's $1K BIS Solar Water Heater. Had it been feasible we would have preferred to have closely followed his design, but site constraints were rather severe. We had to improvise! Initial performance was quite good, certainly not as good as Gary had achieved – but certainly acceptable under the circumstances. We thought that the BIS readership might be interested in some of the means we used to circumvent our site constraints. Hey, if we could build a feasible $1K BIS Solar Water Heater – most anyone could do so! Thus an article was written describing our implementation, and Gary graciously posted it to his site in early March 2011. The article is entitled "Solar Water Heater Using a Unique Master and Slave Collector Design" and is available here:

http://www.builditsolar.com/Projects/WaterHeating/KhanhDHW/KhanhDHW.htm

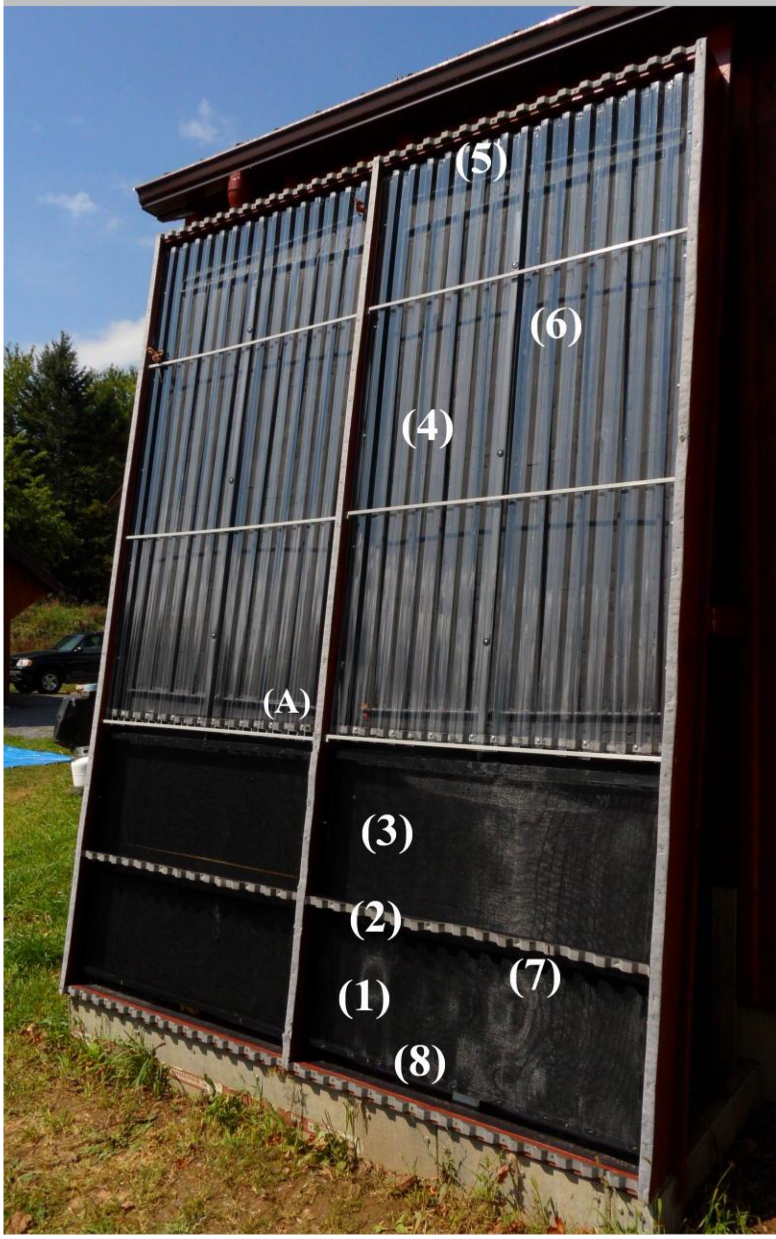
Now it's one thing to build something – but would it pass the test of time? And if not, perhaps the BIS readership can avoid our mistakes. The solar water heater has now been running about 28 months. In a nutshell, the major aspects have proved to be quite successful – but along the way, we've made improvements to some details.

Part 1 -Basic Report Card:

	Mechanical Performance	Energy Performance
Khanh Solar Collectors	Excellent, No Issues, but Cloud Cover More Extensive Than Expected	Very Good Considering the Cloud and Shading Constraints
'Consumer' PV inside Solar Collector Slaves	Poor, Plastic Frames Degraded as Expected	Poor, 45 Pk Watts Insufficient, ~ 100 to 150 Pk Watts Would be More Appropriate
Simple Comparator Differential Temperature Control	Good, but No Flexibility & Difficult to Set-up	Very Good, Low Current Draw But No Control
Battery Back-up Using Old Car Battery	No issues, but a Tired Old Battery Doesn't Get Better	Good, but Charging Losses Gradually Increase so Plan to Swap Out Every 2 -3 Years
Swiftech MCP655 Circulation Pump	Fair, Flow Rate Gradually Degraded by ~28%	Very Good Initially, Later Somewhat Disappointing?
Solar Storage Tank (Pond Liner in Stock Tank)	Very Good, but Mold Issues around Plastic Decking	Very Good, Low Tank Losses as Expected
Electric Hot Water Tank (Post Heater)	Poor, Multiple Element Replacement Followed by Replacement of Entire Water Heater	Poor, Loss ~ 60 Watts 24/7, That's nearly $ 150 /yr. here
Timer Circuitry for DHWT (modified Furnace Thermostat)	Very Good, Clock Accuracy Could Be Better, Now Obsolete	Good, but New Timers Have Lower Capital & Operating Costs

Overall Mark:	Very Good 4 Happy Smileys Out of 5	Good, Saves ~ $450 / year ! 3 Happy Smileys Out of 5

The Hot Water Solar Collector Lives Within a Gardener's 'Cold Frame'



(1) Air near front is warmed by double wire screen.

(2) Air rises at back along face of black painted aluminum.

(3) Air rises up through screens again towards front glazing.

(4) Warmed air rises up between the inner and outer glazing, reducing conductive thermal losses from the front of the hydronic collector.

(5) Hot air passes back to rear of collector assembly.

(6) Air conveyed within insulated plennum, and slowly falls down the back side of the collector. Very little conductive loss at back side due to warm air bath.

(7) Air continues down rear of slave collector, preventing heat loss over the rear side.

(8) Air is drawn forward into bottom of slave air heater to recycle.

Note A: Lowest permissible height for gravity drain-back.

Part 2 - Electro-Mechanical Issues and Fixes:

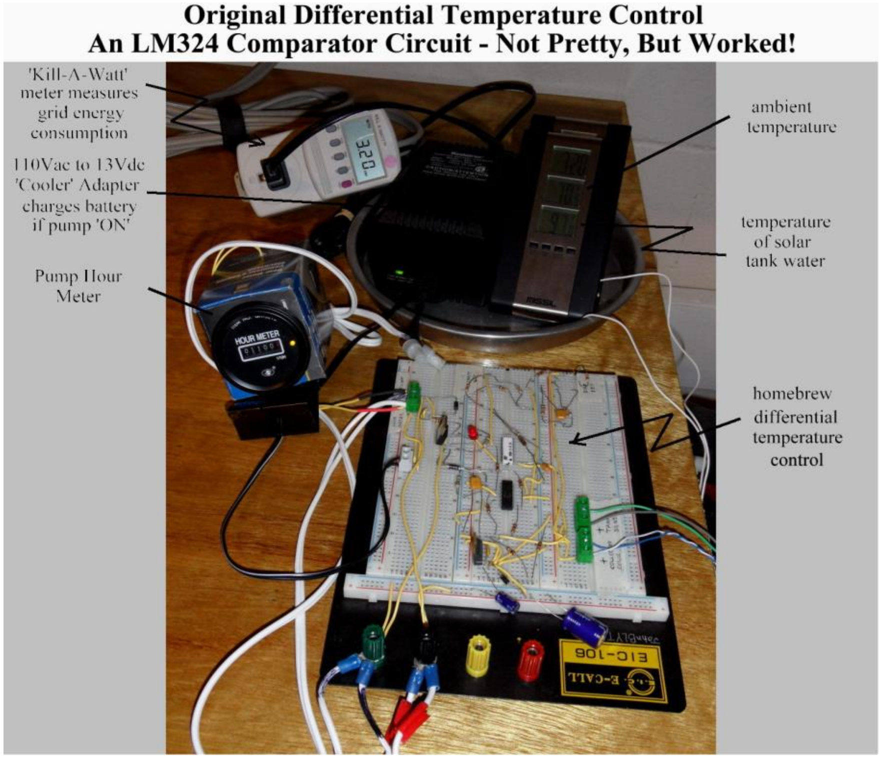
<u>'Consumer' PV Mounted within Slave of Thermal Collector:</u>

The three, old, 15 watt panels had plastic frames that were showing signs of UV deterioration. It had been hoped that by embedding the PV within the slave (out of the weather), they might last longer. Nope! The frames eventually softened and distorted with the heat. With one pump, the 45 W of PV recovered about a third of the pumping/battery charging power requirement.

The (Proposed) Fix: The PV panels were removed the summer of 2012. At some point they will be rebuilt with aluminum frames, and mounted separately. Now (2013) with two pumps, and an even older battery, it would make sense to acquire a larger PV capability.

<u>Differential Temperature Controller:</u>

The 'comparator' control had no major issues, but it lacked the ability of accurate temperature adjustment.



The Fix: It has now been replaced by a homemade digital controller based upon a Comfile Cubloc CB210 – an article covering the new controller is coming soon on Build-It-Solar..

New Digital Differential Temperature Controller Based Upon Cubloc CB210 Microcontroller

<u>An Old Car Battery as Battery Backup:</u>

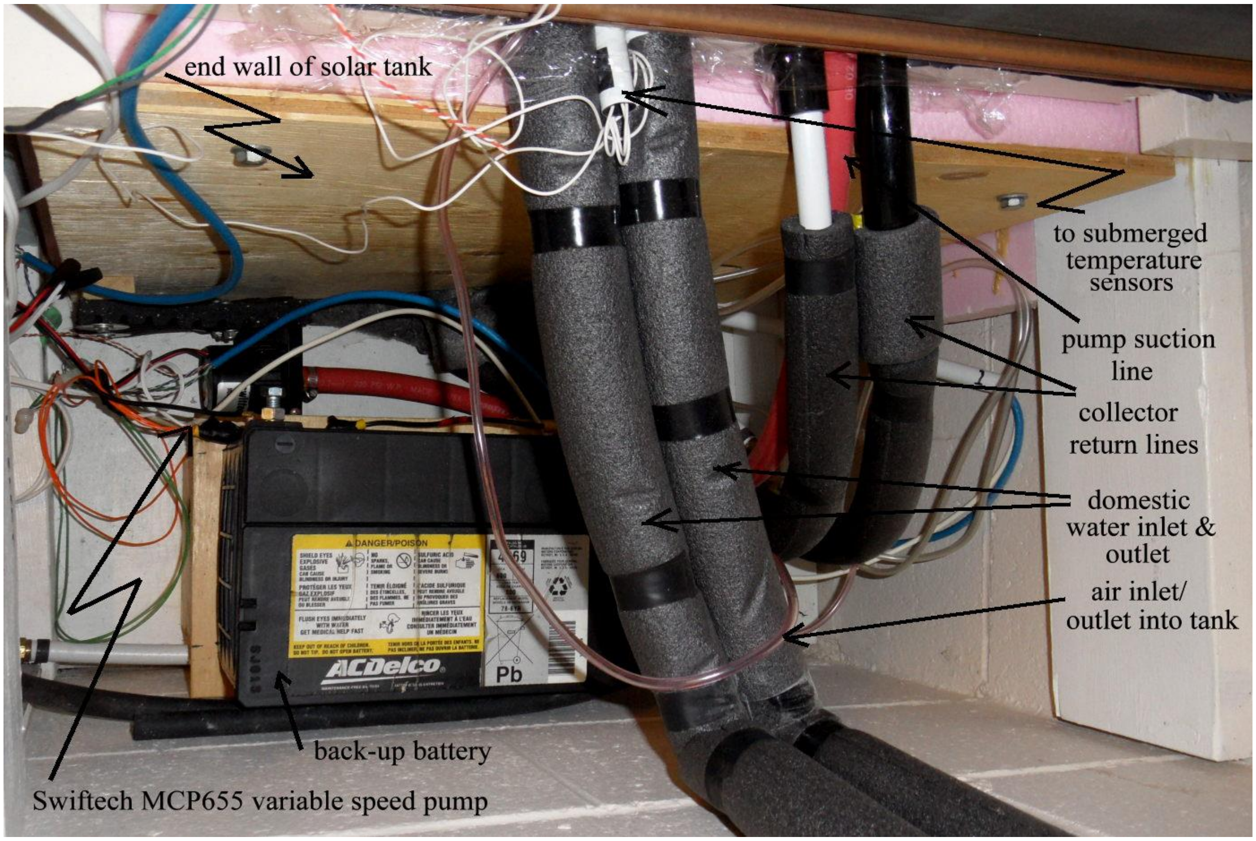
The reuse of an old car battery incapable of dependable winter cranking proved reasonable – but one can't expect more than a few of years use in a solar pumping system.

The (Proposed) Fix: At such time as a vehicle doesn't start, battery replacement will enable the old battery to be retired.

<u>Swiftech MCP655 Circulation Pump:</u>

The original Swiftech pump ran about 1290 hours per year, and consumed only about 50 kWh net per year. It seemed to have worked flawlessly – but the introduction of a Koolance flow meter (Feb. 2013) suggested that the flow rate had degraded significantly (either that or the flow meter was inaccurate, or the degradation was due to the flow meter?). As the outside of the copper heat exchanger was no longer shiny bare copper, perhaps there had been an increase in pipe friction on the inside of the PEX and copper tubing. There had been an issue with mold identified in June 2012. Could it have contributed to the pipe friction/flow issue?

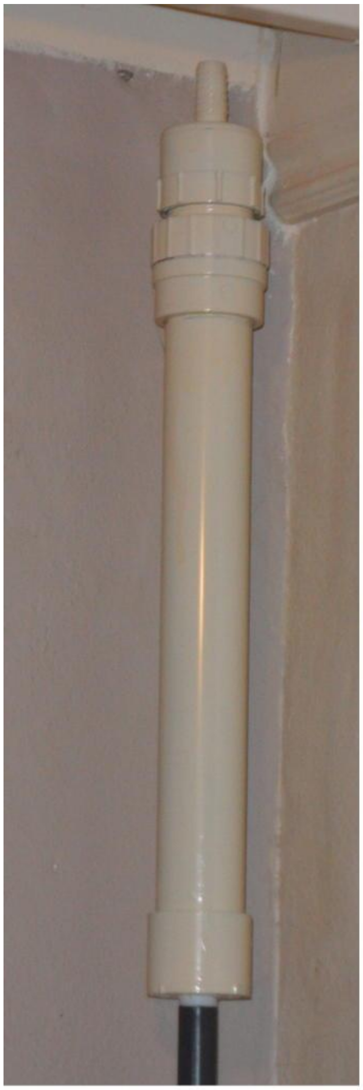
The (Attempted) Fix: In Feb. 2013 a small amount of bleach was added to the system (~25ml) for the first time, but whether there has been a flow improvement is not yet evident.



Implication of Adding a Second MCP655 Pump – Vacuum Breaker/Float Valve:

In view of the reduced flow rate, and the introduction of the new digital differential controller, it was feasible to install a second pump to significantly improve flow rate. In the original construction article (see Introduction for web link), there is reference to the initial difficulty of initiating gravity drain-down at pump shut-off. The fix at the time was to introduce a 'vacuum breaker'. It was simply a thin vinyl tube running up to the ceiling, connected to the two collector return lines as they entered inside the house. Two valves were provided at this junction and cracked open just enough that air would enter the return lines to assist the starting of gravity drain-down. This worked well as the pump never had enough pressure to lift the water level near the ceiling. Not so with the addition of a second pump! If the controller engaged both pumps at start-up, occasionally a burp of several ounces would spill out the air vent – and into the boss's wool cupboard!

The Fix: A float valve was constructed that would close tightly when the water level rose to within two feet of the ceiling, and otherwise remain open as an air inlet. A 1 1/4" ABS inline valve (commonly used with sump pumps) was configured up-side down so that the rubber valve hung downward. A simple float was made from a foot of 1" PVC (capped both ends), and positioned within an ABS drain pipe and connected to the top of the vinyl vent tube. The float valve works flawlessly, and saves a lot of grief.



A new float actuated valve has been added to the top of the vacuum breaker tube to prevent collector return water from occasionally spilling into the house under the extra pressure of the second pump.

It was constructed from 1 1/4" black ABS drain fittings (top & bottom) and an inline, sump pump valve (positioned upside down near the top).

Inside, a float closes the valve. Float is simply a 12" length of 1" PVC with end caps.

Solar Storage Tank Seal Problem (A Pond Liner in a Stock Tank):

The solar storage tank had been constructed like most of the BIS $1k systems – except that a steel 'agricultural stock' tank replaced the plywood box. To provide a tight seal with the lid, it has been common to use 'plastic' decking planks around the top of the tank. In our case, all readily available plastic decking had saw kerfs along the edges (to facilitate cleats for non-visible fasteners). In June 2012, a tank inspection revealed mold build-up along these interior kerfs. The kerfs had exposed the interior saw-dust composite, and it was now supporting mold growth!

The Fix: The decking was removed and replaced with a 5/8" thick by 5 inch wide, foam rubber seal (cut from a 'Roots' camping mattress). The pieces were rubber cemented together. The seal is far tighter now.

Electric Hot Water Tank (Post Heater):

Over the two year period, the conventional electric hot water heater (DHWT) was the least reliable aspect of the entire solar water system. One element had previously failed, a second failed and was replaced. The other element developed a leak, corroding the tank at the seal.

1st Fix: After several failed attempts to repair the leak, the electric water tank was replaced (at the ripe old age of four years).

Both the new and old tank had about an inch of foam insulation and the claimed standby thermal losses were said to be about 90 watts 24/7 (perhaps at 140 deg. F. and ideal conditions?). With a new tank, it seemed appropriate to build a proper thermal blanket for the tank.

2nd Fix: Using a table saw, strips of 2 inch thick, foil faced urethane insulation were cut in a trapezoidal shape (3 3/4" on the outside, 3 1/4" on the inside), and taped with 'red' construction tape into a blanket. A circular top and bottom were also made from the 2" urethane. The entire blanketed tank was then wrapped in surplus neoprene foam fabric (wet suit material) and laced up to be easily removable for tank servicing. The net result is a tripling of the insulation, and hopefully a two thirds reduction in tank heat loss.

Insulation Blanket for DHWT

2 inch foil faced foam cut in strips, taped together with 'Red' construction tape, and covered with neoprene 'wet suit' material.

Timer Circuitry for DHWT (modified Furnace Thermostat)

Electricity is very expensive in Ontario. With 'smart' meters and variable rate pricing, off-peak (night-time & weekend) pricing is half of the peak rate. Restricting electrical consumption to off-peak times - especially water heater electrical usage, is important! Two years ago, 230 volt ac electrical timers with accurate clock mechanisms were difficult to source. The home-brew fix was to acquire a programmable furnace thermostat, and use it as a clock to trigger an optically isolated, zero crossing solid state switch. Construction involved a back-up power supply and boxes, fittings and a fair amount of work – at a cost of about $125. Running the DHWT at 115 volts (rather than 230Vac) enabled the documenting of energy consumption using a common 'Kill-A-Watt' meter. Powering a resistive load at half voltage reduces the consumption rate (and heating capability) to one quarter power – and is far gentler on the heating elements.

The Fix: As of Feb. 2013, heavy duty, accurate electronic timers have become available here at very reasonable cost – but they too, are 115 volt. The home-brew furnace thermostat/timer has now been replaced by a heavy duty UL listed 'Intermatic' programmable timer – total cost now $ 7 !!

Part 3 - Thermal Performance, Issues and Fixes:

BIS $1k solar water heating systems can be implemented at very reasonable cost. Most implementations are quite efficient and provide adequate, if not superb, solar share performance. When planning an installation, if one's situation suffers from serious constraints, performance could be disappointing. Building a slightly larger unit, or at least incorporating the flexibility to do so later might be an option to consider.

In our case, there were numerous constraints. Many were identified at the outset, some became evident much later. The Khanh master-slave variant was chosen as a means to overcome some of the severe constraints – it was just not feasible to significantly increase the size of several key components (collector & storage tank). Thus it was no surprise that system performance was less than spectacular.

We are very envious of the performance Gary Reysa achieves in sunny Montana – an annual 'solar share' approaching 95% ! Using the same computational methodology, our solar share during extended sunny weather was as high as 83%, but extended sunny weather here is pretty rare!   Performance averaged about 74% for the last two years. While not wonderful performance – it has produced three quarters of our hot water needs, in a very cost-effective manner.

Notice the underlining of the word 'produced'. About six months after system start-up, it became evident that while the 'solar share' for the production of hot water was quite reasonable, actual performance at the faucets was less than so. Efforts were then made to identify where the major thermal losses were occurring, the extent of these losses, and how they might be reduced.

In a nutshell, there were major thermal losses in the hot water lines between both (i) the solar storage tank and the DHWT, and (ii) the DHWT and the faucets. Computations suggested that by the time the water reached the DHWT inlet, the 'solar share' was down to an average of 59% ! Except for long draws like showers, by the time the water reached the taps, it was usually fairly cool !! Thus in 2012 efforts were made to reduce these thermal line losses:

Reducing the Excessive Thermal Loss Between Solar Storage Tank and DHWT:

It had not been possible to locate the storage tank adjacent to the DHWT. While not physically far apart, the plumbing lines had been run up to the ceiling so as to avoid a doorway and a concrete partition wall. A distance of 10 feet had thus become lines 26 feet long. To make matters worse, 3/4 inch PEX with conventional plastic foam insulation had been used – a fairly large volume of water was exposed to ambient indoor air temperatures.

The Fix: Drilled through the concrete wall so that the line (with the solar heated water) would be half as long. Replaced the 3/4 inch PEX with 3/8 inch OD PEX to reduce the water volume. Insulated the line with 3 tightly taped layers of conventional foam plastic insulation.

Reducing the Excessive Thermal Loss Between DHWT and Faucets:

The renovation had enabled (i) placement of the two bathrooms adjacent to the kitchen – thus tightly confining the plumbing, and (ii) very minimal exposure of plumbing to exterior walls (just at the DHWT).   Unfortunately, the house had been plumbed with 3/4 inch PEX. About one third of the hot water line was exposed (and recently conventionally insulated), about a third was inaccessible, buried within gypsum walls, and a third was buried within the ceiling and partially accessible – with great effort. Fully two thirds of hot PEX line was uninsulated.

The (Partial) Fix: The fully accessible portions were replaced with 3/8 inch PEX and insulated with triple layers of foam plastic insulation. The partially accessible area was insulated with a layer of pipe insulation. Some months later, a water leak developed in the wall adjacent to a bathroom. Repair of the leak required opening up portions of the gypsum panelling – enabling additional insulation to be added. Unfortunately, much of the PEX remains uninsulated.

Some people have expressed concern regarding reducing the PEX size. In this case, when the tub faucet is fully 'on' with both cold (3/4 inch PEX) and hot (extensive portions of 3/8 inch PEX) the flow rate is about 9.2 litres per minute. In the hot water only position, flow is 6.6 litres per minute and cold only is 7.6 litres per minute. With our low flow shower heads configured for maximum flow, the flow is 4.7 for both, 3.9 for hot only and 4.3 for cold only. At no time has the use of 3/8 inch OD PEX on the hot water line been seen as providing an insufficient flow rate. On the contrary, the wait time for warm water at the faucets is now much improved. It should be noted that these flow rates occur with a well pump having a pressure control operating between 26 psi (ON) and 36 psi (OFF) – which is believed to be somewhat lower than typical.

The Fix: Go for it! The use of well insulated 3/8 inch PEX for domestic hot water lines is highly recommended!

Increasing the Performance of the Solar Collectors:

The outer glazing had to be removed to allow access to remove the failed PV panels. This provided an opportunity to consider improving the collector performance. Until that point, the slave interiors were plain, black painted aluminum panels. They certainly got hot, but that implies radiation losses. Did they offer the optimum means to warm the upward convecting air?

The Fix: Gary and Scott's air heating collector testing (http://www.builditsolar.com/Experimental/AirColTesting/Index.htm) suggested that a double layer of black wire screening was about as efficient as the best of other configurations. Thus the slaves were modified accordingly, and the outer glazing was re-installed.

Other Efforts to Improve Performance:

Over the two year period a number of means to reduce thermal losses have been tackled. The extent to which each has been successful is not readily apparent. The interior PEX lines are definitely warmer, the water temperature at the faucets is now generally acceptable all day long. Unfortunately, the measurements of 'solar share' improvement do not seem to fully track the efforts to reduce the thermal loss.

The one aspect we clearly did not anticipate was climate change. Historical records suggested an expectation of an annual sunshine average about 3.1 kWh per square metre per day of vertical south facing collector. We do suffer from some shading issues, but we were not expecting sunshine levels of two thirds to near half of that expected. Full sunny days are now quite rare (one to three per month), and half sunny days are hardly more frequent. What to do?

The (Preferred) Fix: Had it been feasible, it would have been better to have built a larger conventional BIS $1k solar system.

The (Partial) Fix: At this point, the only seemingly feasible thing to do is to make a better effort to grab every bit of solar heat as we get it. This led to replacement of the 'comparator' differential temperature controller with a more accurate digital controller (Feb. 2013), and to provide a second pump to enable increased water flow in the collectors when greater heat was available. It will take some time to determine the extent of success, but the early indications are favourable.

Bottom Line:

We are now very pleased with this variant of the BIS $1k solar water heater. If only the weather would co-operate, we might be doubly so :)

Gordy and Bailey
March 28, 2013