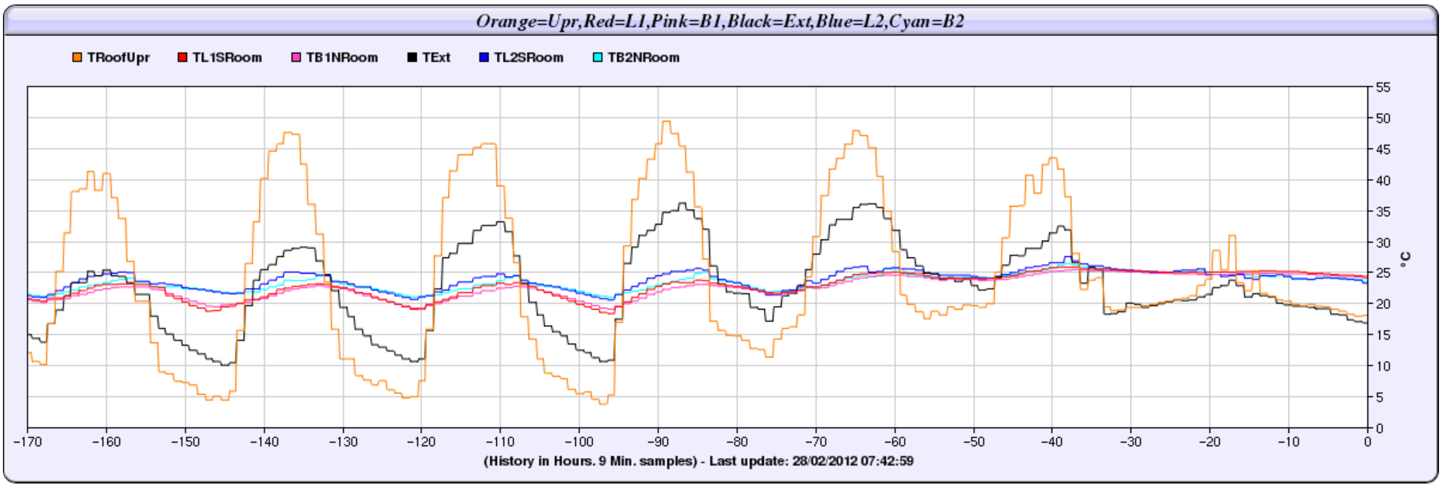
Night-time roof-cooled water

Introduction

I have long been tantalized by the knowledge that on clear nights, when the sun has gone, the loss of heat by radiation to the sky results in the roof being cooler than the ambient air.

Using sensors in my house temperature logging system, I have found that the metal roof on clear nights is typically 5 to 7 degrees C cooler than the air for several hours.

The following graph shows hourly average temperatures for the week leading up to 7:42 am on 28 February 2012. The external temperature is shown in black and the temperature from a sensor immediately under the Colorbond metal roof is in orange. (The other colours are the temperatures in five rooms).



A couple of points to note:

1. For the 4 days on which the day maximum external temperature (black) exceeded 30 degrees, the preceding overnight minima for the roof (orange) were 5, 5, 11 and 18 degrees C;
2. On the final 2 days in this period, the roof temperature tracked the external temperature closely for most of the time because the weather was cloudy for the most part.

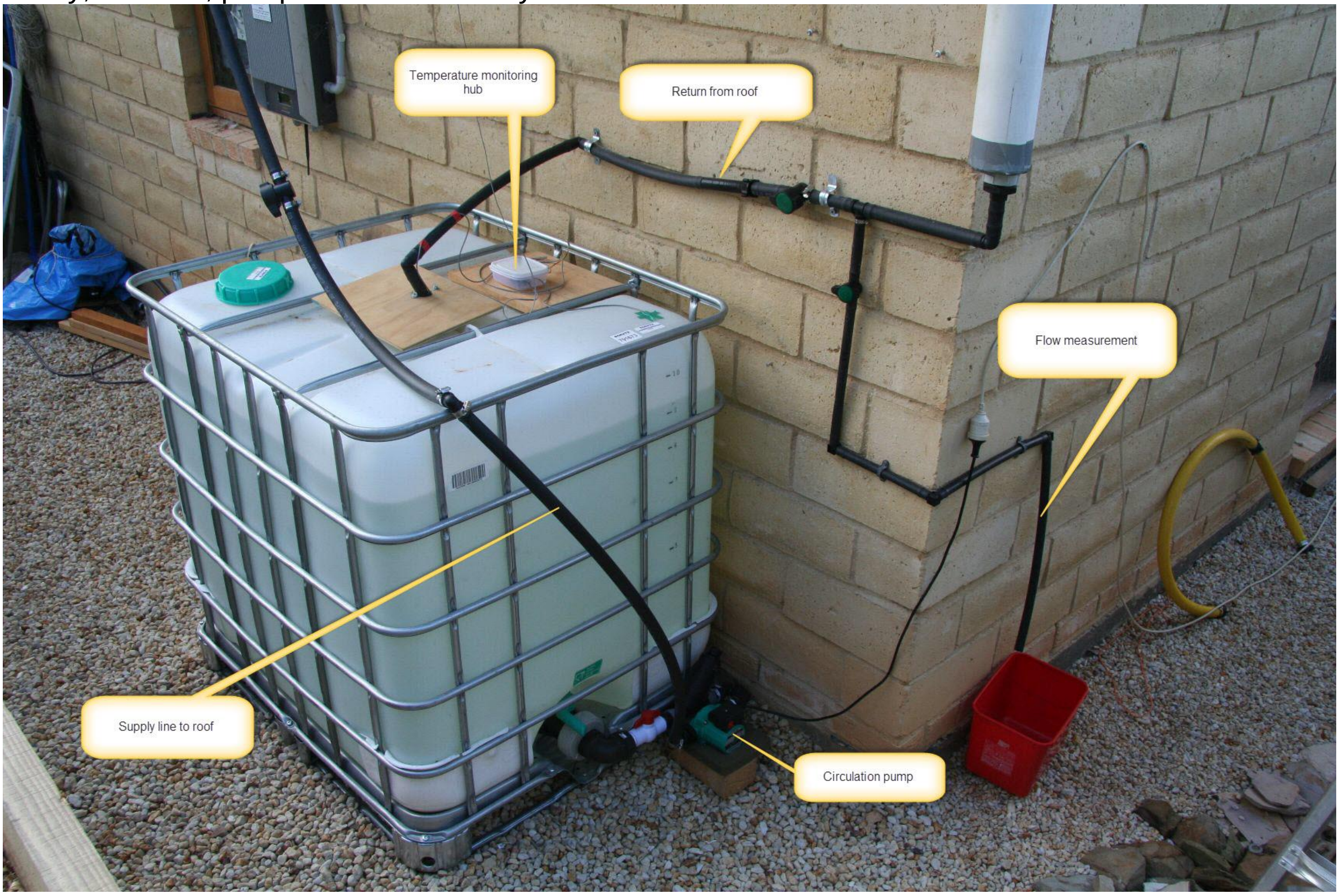
The first of these points prompted the thought of using the roof to cool a tank full of water to a temperature at which it might be usefully employed in cooling a domestic space.

So I decided to do a trial in which I pump the water in a 1000 litre tank to the top edge of a low-pitch roof, gently spray/dribble it onto the roof, intercept the returning water which would normally go to the rainwater tank and divert it back to the tank.

System Description

The following photos show the elements of the system.

Firstly, the tank, pump and circulation system:



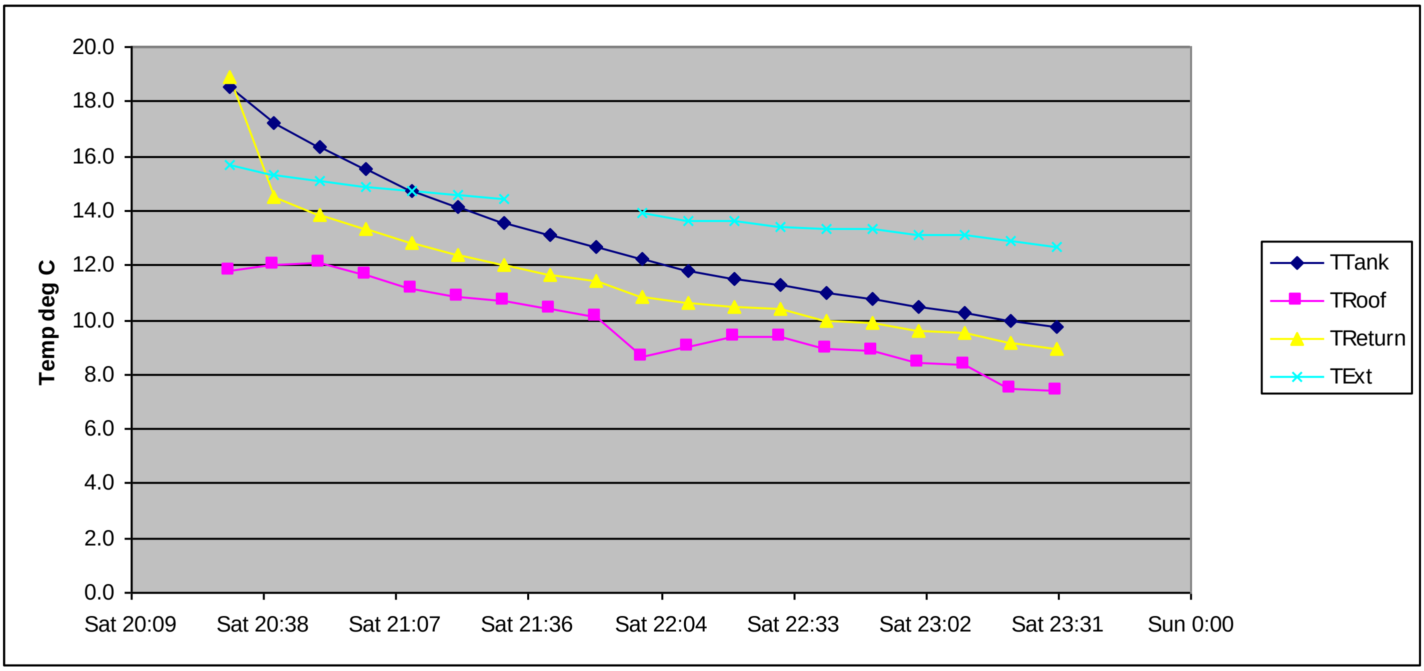
Secondly, the "spray header":


Ignore - not part
From the pump
Loop to equalize pressure along the spray pipe
Spray pipe, 15m long, fed at mid point, spray holes ~1.5mm dia, every 3rd valley.

Close-up of 3 spray jets:

Water enters the gutter:

Results of a recent trial with about 800 litres:



The plots are:
TTank – sensor about 100mm below the surface;
TRoof – a stainless steel sensor taped to a colorbond "peak" to keep it out of the returning water;
TReturn – a sensor in the return line immediately before the water re-enters the tank;
TExt – the external air temperature measured in a close-to-standard Stevenson screen.
Note: the TRoof temperature is measured differently from the one shown in the first graph but it similarly shows a 4-5 degree difference below the air temperature, even tho the roof is being slightly warmed by the water as the roof cools the water.

Ten-minute interval observations for the above trial

						Cum from start of trial			**Logging Period**			
Mydatetime	TTank	TRoof	TReturn	TExt	DeltaT ie TRet - TTank	Temp Fall from Start	Time cum mins	**Ave kW from start of trial**	Temp fall in period	Mins in period	**kW for logging period**	TTank - TRoof
22/02/2014 20:30	18.5	11.8	18.9	15.7	0.4							6.7
22/02/2014 20:40	17.2	12.0	14.5	15.3	-2.7	1.3	10	7.4	1.3	10	7.4	5.2
22/02/2014 20:50	16.3	12.1	13.9	15.1	-2.4	2.2	20	6.1	0.9	10	4.9	4.2
22/02/2014 21:00	15.5	11.7	13.3	14.9	-2.2	3.0	30	5.6	0.8	10	4.5	3.8
22/02/2014 21:10	14.8	11.1	12.8	14.7	-1.9	3.8	40	5.2	0.8	10	4.2	3.6
22/02/2014 21:20	14.1	10.8	12.4	14.6	-1.8	4.4	50	4.9	0.6	10	3.5	3.3
22/02/2014 21:30	13.6	10.7	12.0	14.4	-1.6	4.9	60	4.6	0.6	10	3.1	2.9
22/02/2014 21:40	13.1	10.4	11.7		-1.4	5.4	70	4.3	0.4	10	2.5	2.7
22/02/2014 21:50	12.7	10.1	11.4		-1.3	5.8	80	4.1	0.4	10	2.5	2.6
22/02/2014 22:00	12.3	8.6	10.9	13.9	-1.4	6.3	90	3.9	0.4	10	2.4	3.6
22/02/2014 22:10	11.8	9.0	10.6	13.6	-1.2	6.7	100	3.7	0.4	10	2.5	2.8
22/02/2014 22:20	11.5	9.4	10.5	13.6	-1.0	7.0	110	3.5	0.3	10	1.7	2.1
22/02/2014 22:30	11.3	9.4	10.4	13.4	-0.8	7.3	120	3.4	0.3	10	1.4	1.9
22/02/2014 22:40	11.0	8.9	10.0	13.3	-1.0	7.5	130	3.2	0.3	10	1.4	2.1
22/02/2014 22:50	10.8	8.9	9.9	13.3	-0.9	7.8	140	3.1	0.3	10	1.4	1.9
22/02/2014 23:00	10.5	8.4	9.6	13.1	-0.9	8.0	150	3.0	0.3	10	1.4	2.1
22/02/2014 23:10	10.3	8.4	9.6	13.1	-0.7	8.3	160	2.9	0.3	10	1.4	1.9
22/02/2014 23:20	10.0	7.5	9.2	12.9	-0.8	8.5	170	2.8	0.3	10	1.4	2.5

22/02/2014 23:30	9.8	7.4	8.9	12.7	-0.8	8.8	180	2.7	0.3	10	1.4	2.4

Observations

Cooling mechanism

I presume the water is cooled by the combined effects of:

1. Conduction from the water to the roof
2. Evaporation of a percentage of the water in a valley cooling the water left behind
3. Radiation from the water to the sky

In turn, the roof is cooled by:

4. Radiation to the sky
5. Conduction/convection to the air
6. Evaporation of water in contact with the roof.

Determinants of system performance

The test run whose results are shown above is one of three I've done with the small circulating pump. On its highest setting, it's running at 110 watts and delivers about 15 litres per minute. I've also done six runs with a more powerful 400 watt pump which delivers 40 litres per minute.

Flow rate may be one of the main determinants of the system's performance though the lower flow rate tests have yielded comparable results with the higher rates. Another and unequivocal determinant is the temperature difference between the tank water and the roof. The air temperature may also play a part other than being the "base temperature" of the roof, i.e. before the other cooling effects kick in. The air temperature influences the temperature of the circulation system, the piping, the gutter and the tank.

The flow rate is presumably determined by (a) the pump's capacity (b) the physical head (c) the number and size of the spray holes and (d) friction. The current hole diameter (1.5mm) and spacing (every 3rd valley) represent a gut feeling about the minimums in both respects. Though increasing the number and/or the size of the holes in the existing spray line is a one-way journey, I'll probably experiment with another couple of combinations. The risk of course is that if I go "too far", I will have to replace the spray line to reinstate the optimum combination of diameter and spacing. No great expense (about $20) but doing something a second time rarely appeals!

Hopefully, after enough trials, I'll be able to discern the main performance determinant(s). Getting a handle on these will make it possible to decide whether, on any particular night, running the system will produce a useful final tank temperature given the initial tank temperature and the anticipated weather conditions.

Implementation issues

Water filtration

The water returning from the gutter has to be filtered if the condition of the tank water is of any concern. I have several concerns: to protect the pump, to minimize clogging up of the 1.5mm spray holes and to minimize the amount of organic matter in the tank water.

Following a suggestion from my very helpful irrigation supplies merchant, I constructed the filter shown below which is supported by the plywood to hang in the opening in the top of the tank. The return water pipe lodges in the hole in the plywood.

100% exclusion of undesirable substances from the tank appears to be impossible with simple technology so I also have a filter between the tank and the pump.

Clogging up of spray holes

After only half a dozen trials, I've already had to redrill the holes to have all 50 functioning. Hopefully, the clogging up was mainly due to the last remains of the tank's original contents, now hopefully all washed out, rather than organic matter from the gutter. Anyhow, re-drilling 50 holes occasionally is but a small maintenance task.

Loss of water

As the system charges, the tank water level drops by 40-60 litres depending on the water level in the rarely-totally-empty gutter. I leave the return and supply lines open after turning off the pump and the level typically returns to within 10-20 litres of the starting level.

The duration of the runs I've done so far range from about one to three hours.

There are two modes of loss: evaporation and physical. The latter results from water from some valleys running back up the underside of the low (6 degree) pitch roof and dropping through the millimetric gap between the back of the gutter and the fascia. (I'm about half way through siliconing this gap across the 16 metre gutter. Once I've remedied this, I'll know the evaporation loss. I don't think it will be a concerning amount.

The sprays/dribbles are a short, non-aerated stream. I imagine this reduces the evaporation loss.

Material and component data

The tank is a re-cycled IBC.
The piping is black low-density polyethylene 25mm internal diameter.
The circulation pump is Chinese, bought on ebay for less than half the price of a Grundfos. Whether the choice of pump is wise, only time will tell.
The house temperature logging system (which produced the graph in the Introduction) is a Web Energy Logger (welserver.com).
The tank trial temperature logging is done with a Midon Design TEMP08 (midondesign.com).

The gleam in my eye

OK, it's the height of summer and I've got 1000 litres of water at, say, 15 degrees. Question: what do I do with it? Answer: put it in the living room in a slim-line rainwater tank. The dimensions are 260mm thick, 1850mm high and 2400mm wide. It so happens I have a wall against which the tank can be conveniently placed. It is also the case that I **don't** have a co-resident interior designer whose tastes must be considered!

I hope the large surface area of the tank will make it function as an effective radiant heat "sink", cooling both the fabric and the occupants of the room. The tank will be black to assist this effect.

The water in the tank also serves as additional thermal mass, so even if I were just to let the temperature of the water fluctuate with the temperature of the room, it would slow down the warming of the room. The thermal mass of 1000 litres of water happens to be almost the same as the thermal mass of the room's concrete slab, and the water adds approximately 60% to the total existing thermal mass (slab plus walls).

The normal drawback of thermal mass which has been raised to a higher-than-desirable temperature, e.g. after a run of 3 or 4 hot days, is that it is slow to cool down. However, the part of the total thermal mass represented by the water could be simply removed by pumping it out to a holding tank. It's removable thermal mass!

I'm more ambitious in my use of the water. Most of the time it will function as passive thermal mass. But, in summer, with the living room (and the water) at say 24 degrees, when a run of days is in prospect with forecast temperatures that would otherwise raise the living room temperature to 25 and above, I hope to be able to cool the water to a temperature which will forestall the undesirable temperature rise. Exactly what that temperature will be I will have to find out by trial and error.

Another way to capitalize on the water's coolth may be to box in the tank, have inlet air vents at floor level and a tangential fan at the top to draw room air around the tank, hopefully cooling the air and the room. This may be a more finely controllable arrangement than merely bringing the water temperature each night down to a value estimated to be low enough to forestall the next day's heating up.

Finally, I hope to automate the system to some degree by the use of a solar system controller. Though I will be using the controller in a cooling, rather than a heating system, it does appear doable. It involves putting the sensor which is normally on the heating collector in the tank instead. Conversely, the sensor normally in the tank is on the collector, i.e. the metal roof.

I have simulated this situation and the relay which switches on the pump does get switched on and off appropriately. But wait, there's more! The controller has a "collector low temperature protection" function which in normal use, switches off the pump if the collector temperature drops below (an adjustable) 10 degrees C. I propose to use this function to turn off the pump when the tank temperature falls to the temperature I have chosen to give me perfect comfort the following day.

It’s all too good to be true!!! I’ll let you know how it turns out in practice ….. that might be next (southern hemisphere) summer.

During our winter, I’ll be seeing if I can get enough heat out of a collector to usefully warm the aforementioned water.

Thanks to Gary and contributors for this wonderful site.

PS. If the tank somehow deposits its contents inside the house, I’ll be flooded to a depth of …………12mm!