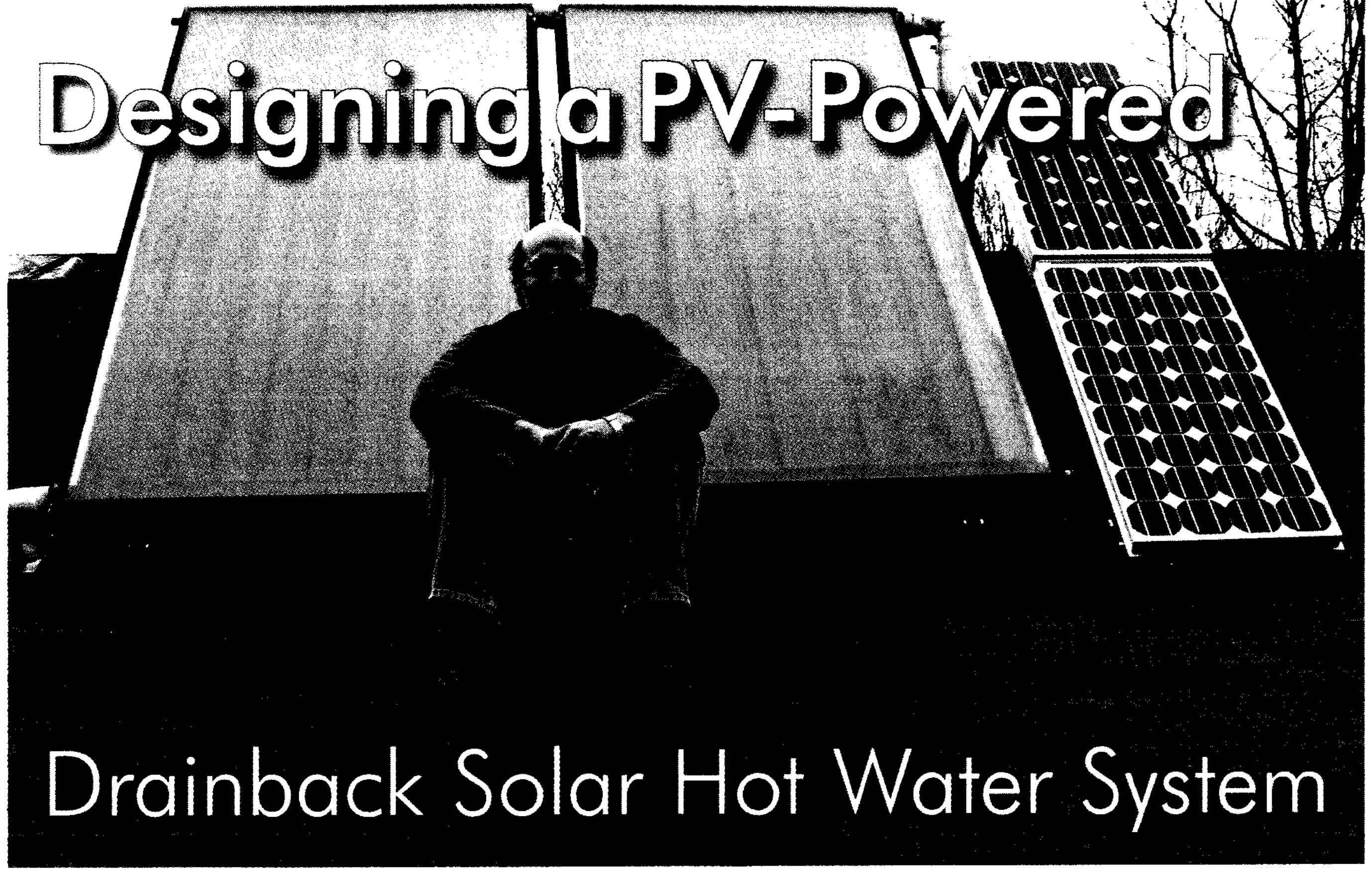


Designing a PV-Powered Drainback Solar Hot Water System

by James Dontje

I spend most of my waking hours at work, teaching college students about sustainability and the environment. So, like the plumber with leaky faucets at home, I don't get as many opportunities as I like to make a difference when it comes to my own house. But as someone who is acutely aware of the destructive effects of fossil fuel use and extraction, I feel a great need to walk my talk—especially here in Kentucky, where almost all electricity is generated by coal-burning power plants.

When I heard about the Kentucky Solar Partnership's (KSP) program to provide homeowners with a $500 cash rebate and low-interest loans for solar hot water (SHW) systems, I decided to start planning my own project. Heating water with the sun is one of the most cost-effective ways to use solar energy, and it's a smart financial investment too.

Choosing a System

Although the climate here in Berea, Kentucky, is fairly temperate, winter nighttime temperatures routinely fall below freezing. That ruled out simple batch solar water heaters. It also eliminated open-loop direct systems, which circulate water directly from the collectors to a storage tank, leaving collectors and pipes vulnerable to freezing. A thermosyphon system was out of the question because locating the storage tank above the collectors was not an option at my two-story home.

One solution was a PV-driven, closed-loop system that circulates antifreeze through the solar hot water collectors and uses a heat exchanger to transfer this collected heat to household water. When the sun shines on the PV modules, the DC pump that circulates a propylene glycol solution through the pipes and collectors runs in rough proportion to how much energy the sun can provide—an elegant, grid-free solution. But dealing with the maintenance requirements of periodically checking the pH (acidity–alkalinity scale) of the propylene glycol antifreeze and recharging the system held little appeal for me.

Instead, I considered a closed-loop drainback system that uses demineralized or distilled water as the heat-transfer fluid. In these systems, a pump moves water through the collectors and circulates it through a heat exchanger. When the pump is off, the water drains from the collectors and outdoor piping to a storage tank, assuring freeze protection.

Drainback systems are effective and reliable—some systems can operate twenty years or more without needing service. Their only downside is that larger, higher power AC pumps—requiring more energy—usually have to be used. This is especially true if you're pumping water two stories or more, since the drainback pump has to lift the water to the height of the solar collectors.

In the pressurized loop of a glycol system, all the pump has to do is overcome the friction head of the piping itself. This isn't the case in a drainback system. When the pump first turns on, it has to move the water from the drainback tank to the top of the collectors to start the flow. This head (vertical lift) requirement is equal to the vertical distance from the water level in the drainback tank to the top of the collectors and is generally much more than the pipe friction head. But once the pipes to and from the collector are full, the amount of pumping energy required is nearly the same as a pressurized glycol system.

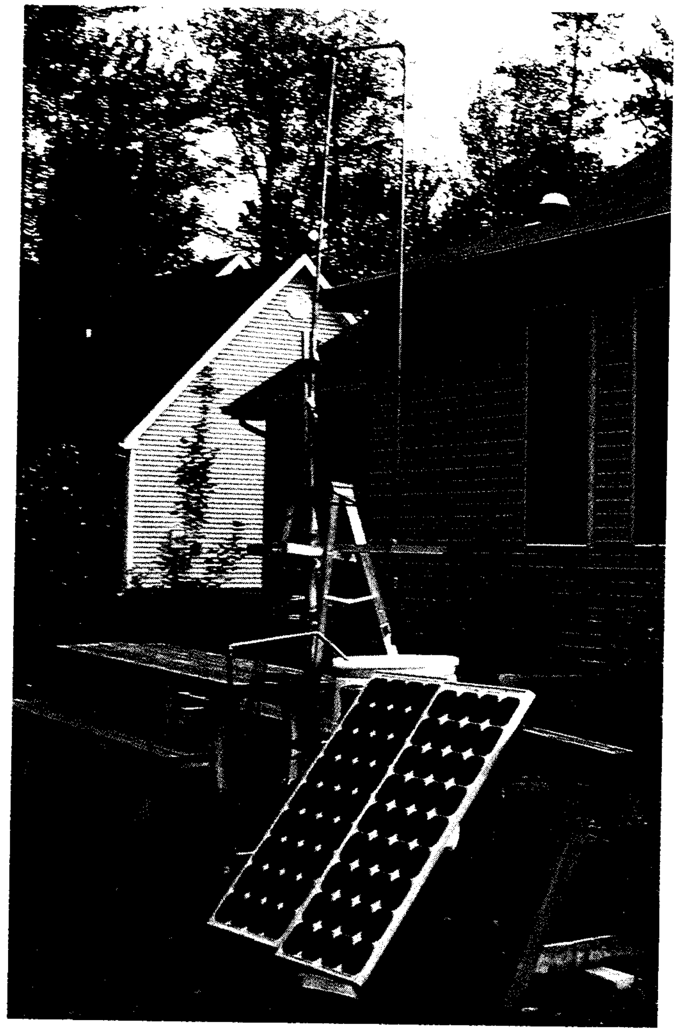
The energy penalty required to run the high-head AC pumps needed in drainback systems bothered me. When I described this issue to my wife Laura, she reminded me that using AC pumps would also mean that our solar hot water system—along with the rest of the appliances in our all-electric house—would be inoperable during power outages, which occur occasionally in our semirural location.

Although all the resources I found said that using a PV-driven pump to achieve the vertical lift my system would require just wasn't feasible, I was sure that a little ingenuity, paired with the right pump and a well-located drainback tank, could overcome this challenge.

Picking a PV Pump

I began researching DC pumps for SHW systems, examining their data sheets and performance curves to see which pumps could deliver enough water to meet the flow requirements of the collectors I'd chosen (0.5 to 1.8 gpm per 4- by 8-foot collector), and how much vertical lift they could provide (see Drainback Pumps table).

At the same time, I assessed our two-story house and explored the attic with a tape measure to determine the best location for the drainback tank. It needed to be placed high enough to minimize the head required to pump water to the collectors, and low enough to ensure adequate slope in the piping from the collectors to the tank. To protect it against freezing, the tank also needed to be located in a heated space. The best location in our house for the tank was in the upstairs bathroom, near the ceiling. From my rough measurements, this would require a 10-foot start-up head from the pump, which would be installed in the garage, along with the other balance-of-system components.



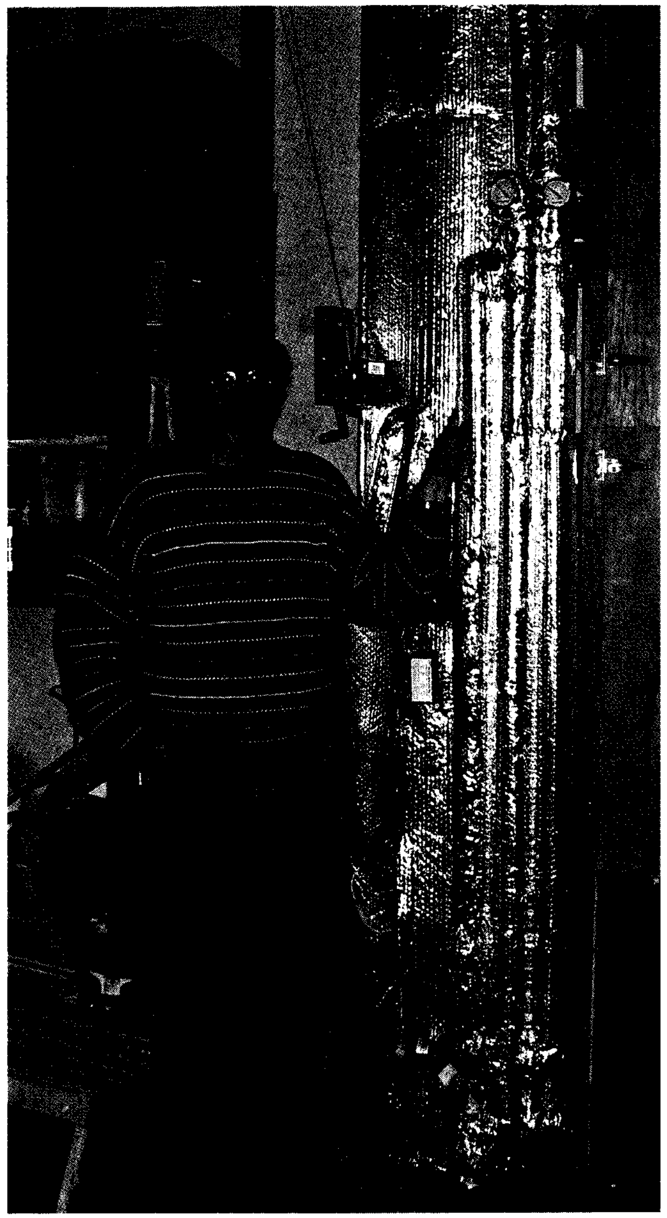
A backyard test determined that the PV-powered DC pump could provide adequate vertical lift for the drainback system.

Friends and family helped install the two AET solar collectors.

PV-Powered Drainback Pumps

Pump	Maximum Flow Rate (GPM)*	Maximum Head (Ft.)**
El-Sid 10PV-12V	3.00	3.50
March 809-BR 12V	4.25	7.00
El-Sid 20PV-12V	5.00	7.00
March 809-BR-HS 12V	6.50	15.00
Conergy Suncentric 7323	17.00	10.00

*At no head. **For starting pump.



Wrapping the solar storage tanks and heat exchanger in radiant heat-barrier insulation improves the system's efficiency by slowing heat loss.

All the pumps I compared could provide sufficient flow for the two-collector system I wanted to install. But one pump I considered barely had enough head capacity. Although higher-head models were available, this would cause the flow (and power requirements) to be even more out of line with the system's need. Two other pumps I evaluated lacked the head capacity my system would require, which left the March HS ("high speed") model as the best option.

The pump search was a useful learning exercise in another way. While researching PV-driven water pumps, I stumbled across linear current boosters (LCBs), electronic circuits that better match PV output directly to a motor. LCBs boost the current available to the pump, enabling start-ups even under low sunlight conditions. This translates into earlier pump start-ups and longer run-times.

Over the Hurdles

Although the numbers looked good on paper, skepticism remained that the head requirements would overwhelm the pump's abilities. And to receive the rebate and loan, KSP had to approve my system. I detailed the PV-direct system design and provided additional calculations to account for pipe-friction losses. To assuage their concerns (and mine), I agreed to test the PV pumping capacity before installing the system. If the test results weren't in line with the calculations, or the system didn't perform as expected, I would reconfigure it along more conventional lines, using AC pumps.

I put together a test system in my backyard, placing my two 75-watt PV modules at the same orientation and tilt angle that they would be set on my roof. I connected the modules to the pumps (the second pump serves the heat exchanger-to-storage loop) via the LCB, and connected the pumps to a vertical copper pipe that simulated the head required of the pump. The pipe then dumped the water back into a barrel connected to the pump inlet.

I'm sure my neighbors thought this rocketlike arrangement was a bit odd, especially when I set up my test at 6 a.m. to catch the early morning sun. After a few hours of testing, it became clear that the PV and pumps combination could drive the water to more than the required 10 feet of head. Success!

Integrating the Parts & Pieces

After the pumps had passed their test, it was time to install the system. I chose two 4- by 8-foot AET collectors based on reports of their reliability and long history, and purchased them locally from Sunbelievable Services. A couple of friends helped me mount the collectors on our roof. Because Laura and I are often gone during Kentucky's steamy summers, I set the collectors at a 52-degree angle (our latitude—37.58°N—plus 15 degrees) to maximize winter sunlight collection.

To save money and resources, I plumbed two used tank-style water heaters together. These quality tanks had been replaced long before the end of their useful lives. Now they provide 90 gallons of solar hot water storage, supplying preheated water to my backup electric tank-style water heater.

System Costs

Item	Cost
2 AET MSC-32 collectors, 4 x 8 ft., plus mounts	$1,541
Misc. pipe, insulation, fittings, wire, etc.	1,071
2 PV modules, 75 W ea. (Shell SP75 & BP 275)	500
March 809-BR-HS pump, 12 V	195
Whirlpool water heater, 12 gal.	189
March 809-BR pump, 12 V	175
Hardware for PV mounts	142
Solar Converters linear current booster, 7 A	85
Tempering valve	57
3 Thermometers	53
Sight glass for drainback tank	46
2 Used hot water tanks (50 gal.; 40 gal.)	40
Total	$4,094

I purchased a 12-gallon water heater from a home improvement store to serve as the drainback tank, and suspended it from the ceiling by threaded rod, bolted through 2 by 4s laid across the ceiling joists. A tank half that size would have been adequate, but I hope someday to expand the system to provide hydronic space heating.

I used Bert Echt's homebrew heat exchanger plans (*HP97*) to create my own "pipe inside a pipe" heat exchanger, running a 3/4-inch copper pipe for the drainback loop inside a 1-inch-diameter copper pipe. The 10-foot run of the heat exchanger is configured in a U-shape to help it fit in the available space.

The PV modules deliver their electricity to the LCB and pumps via a disconnect switch. Following the LCB manufacturer's recommendations, I installed a 10-amp fuse in the pump circuit as additional insurance, in case the internal fuse failed. The thermostatically activated switch (snap switch) connected to the LCB remains open until the temperature of the collector outlet reaches 88°F. It closes at this setpoint and energizes the pump. When the outlet temperature drops to 73°F, the switch opens, deactivating the pump. This causes the circulating fluid to drain back to the tank, preventing it from freezing in the collector or pipes, as well as minimizing the possibility of the pump running too long and actually cooling the water stored in the solar tanks.

One hitch with using a snap-switch as a controller is that the factory setpoints can cause the pumps to cycle in colder weather. If the tanks contain cold water in the morning, they quickly cool the collector water to below 73°F, causing the system to shut down until the collectors warm again. After a few more cycles like this, the drainback water loop stays above 73°F and the pumps stay on. To eliminate the inefficiency of those on–off cycles, I'm considering replacing the switch with a limit switch with a lower threshold or just using a single-point snap switch that will turn off the pumps at temperatures below 40°F. Another option would be to use a DC differential controller available from Art Tec.

Tech Specs

Overview

System type: PV-direct, drainback solar hot water

Location: Berea, Kentucky

Solar resource: 4.5 average annual peak sun-hours

Production: 240 KWH per month (average)

Percentage of hot water produced annually: 82 percent

Equipment

Collectors: Two AET MSC-32, 4 x 8 ft.

Collector installation: Roof-mounted on south-facing roof, 52-degree tilt angle

Heat exchanger: Custom-built

Heat transfer fluid: Distilled water

Circulation pumps: March 809-BR-HS (collector loop); March 809-BR (exchanger loop)

Pump controller: Klixon fan limit switch

Photovoltaic modules: Two: one BP275, one Shell SP75; 75 W STC, wired in series for 150 W at 24 VDC nominal

Linear current booster: Solar Converters, PPT 12/24-7V

Storage

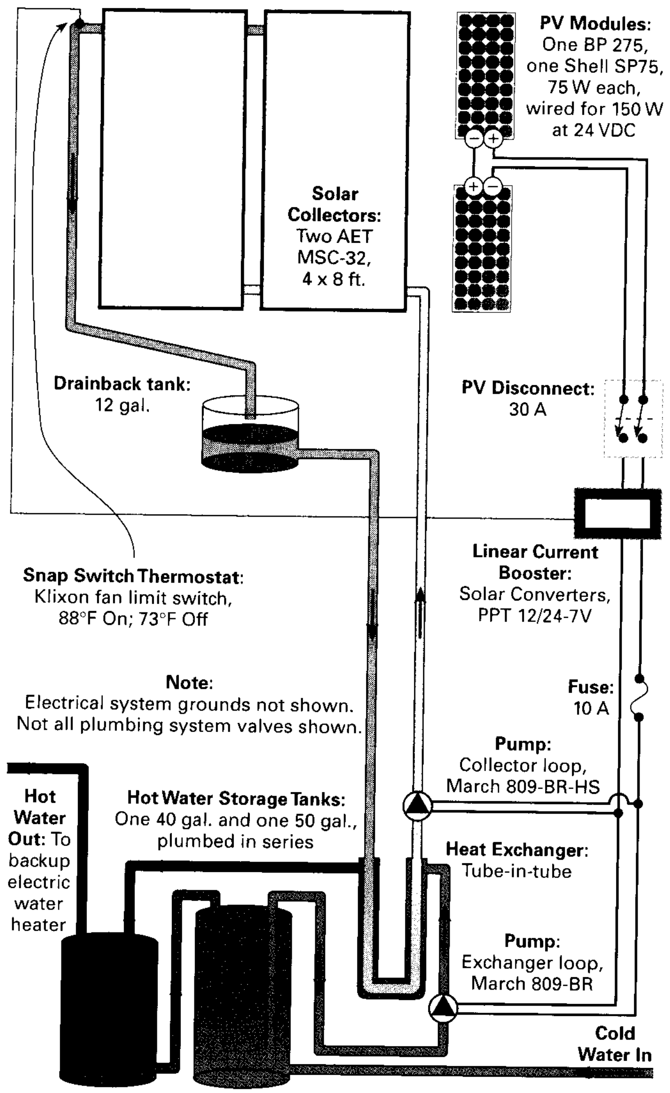
Solar tanks: Two used; 50 gal. and 40 gal.

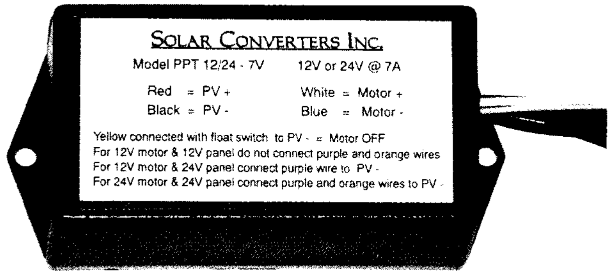
Backup water heater: State Select, 47 gal., electric

System performance metering

Thermometer: Three, Honeywell dial (required by KSP for system performance verification)

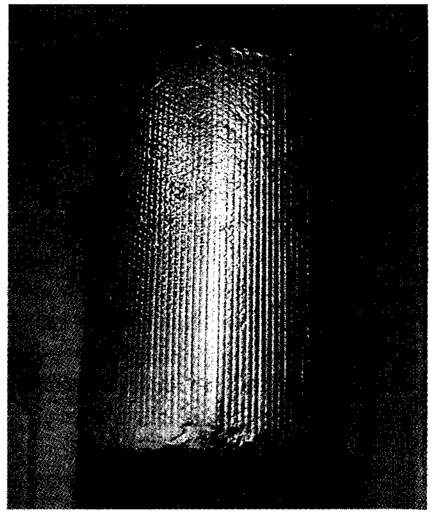
Dontje Drainback Solar Hot Water System





Courtesy www.solarconverters.com

A linear current booster boosts the current available to the pump, enabling start-up in low sunlight conditions.



To minimize pump head, the drainback tank was mounted near the ceiling in the second-floor bathroom.

Lessons Learned

Retrofitting a drainback system into an existing home can be challenging. In my case, the collectors and plumbing had to be precisely placed to minimize the vertical lift needed, and plumbing sloped enough to achieve good drainback. With copper prices on the rise, the plumbing complexity translated into high balance-of-system costs, and the layout of the storage tanks and heat exchanger in the garage resulted in some extra twists and turns. Because I used PV modules from two different manufacturers, I had to design and build my own aluminum roof mounts, which also added to the system's costs.

Although this system requires more PV capacity than the 10- or 20-watt module used in most PV-direct glycol systems, having two 75 W modules is probably overkill. The rated power of the pumps is about 70 watts, and they run for about 6 hours each day, consuming about 420 watt-hours. Factoring in efficiency losses, with an average daily solar resource of 4.5 sun-hours, the modules typically can produce about 600 watt-hours on a sunny day. One 100 W module would probably have been optimal, but I'd picked up the used modules for a song. I am currently exploring ways to piggyback a charge controller into the circuit to charge a battery with the surplus electricity the modules produce during portions of the year.

Electric Water Heater Energy Consumption

With SHW	No. of Days	Total KWH	Avg. Daily KWH
First week	6.13	21.58	3.52
Second week	6.03	19.59	3.25
Third week	5.98	35.04	5.86
Fourth week	6.69	42.11	6.29
		Avg. Daily KWH, with SHW	4.77
Without SHW			
Mar. 13–14, '03	1.07	9.61	8.98
Nov. 23–27, '05	3.76	35.68	9.49
Nov. 29–Dec. 3, '05	3.76	36.13	9.61
Mar. 15–19, '06	3.76	38.39	10.21
		Avg. Daily KWH, without SHW	9.70

Solar Success & Troubleshooting

On the first sunny morning after I completed the connections, the thermostat switch activated the pumps, which circulated water through the collectors. By late afternoon, the system had heated 90 gallons of water to 120°F—providing ample hot water for our household.

Several measurements I'd taken before the SHW system installation showed that our electric water heater typically used about 9.7 KWH per day. During 24 days of testing after the system installation (most of which were in November, a cloudy month in Kentucky), the backup water heater averaged 4.7 KWH per day—more than a 50 percent reduction in consumption due to the SHW system (see Consumption table).

Coal is king in Kentucky, and electricity is cheap. We pay about $0.06 per KWH, so our savings from the SHW system was about $9 a month during the winter. When sunshine is more abundant, the system should meet almost all our water heating needs, providing an annual savings of about $175. But the payback goes beyond greenbacks. Coal-generated electricity contributes to acid rain and smog formation, and mountaintop removal mining for this finite resource carries its own set of environmental consequences. By using the sun's energy to meet most of our water heating needs we're minimizing our reliance on King Coal and making a difference right at home.

Access

James Dontje • jamesdontje@gmail.com

Kentucky Solar Partnership • www.kysolar.org • SHW incentives

System Components:
Alternate Energy Technologies • 800-874-2190 • www.aetsolar.com • Flat-plate solar collectors

BP Solar • 301-698-4200 • www.bpsolar.com • PV module

March Manufacturing Inc. • 847-729-5300 • www.marchpump.com • DC pump

Solar Converters Inc. • 519-824-5272 • www.solarconverters.com • Linear current booster

SolarWorld AG (purchased Shell Solar) • 800-947-6527 • www.solarworld-usa.com • PV module