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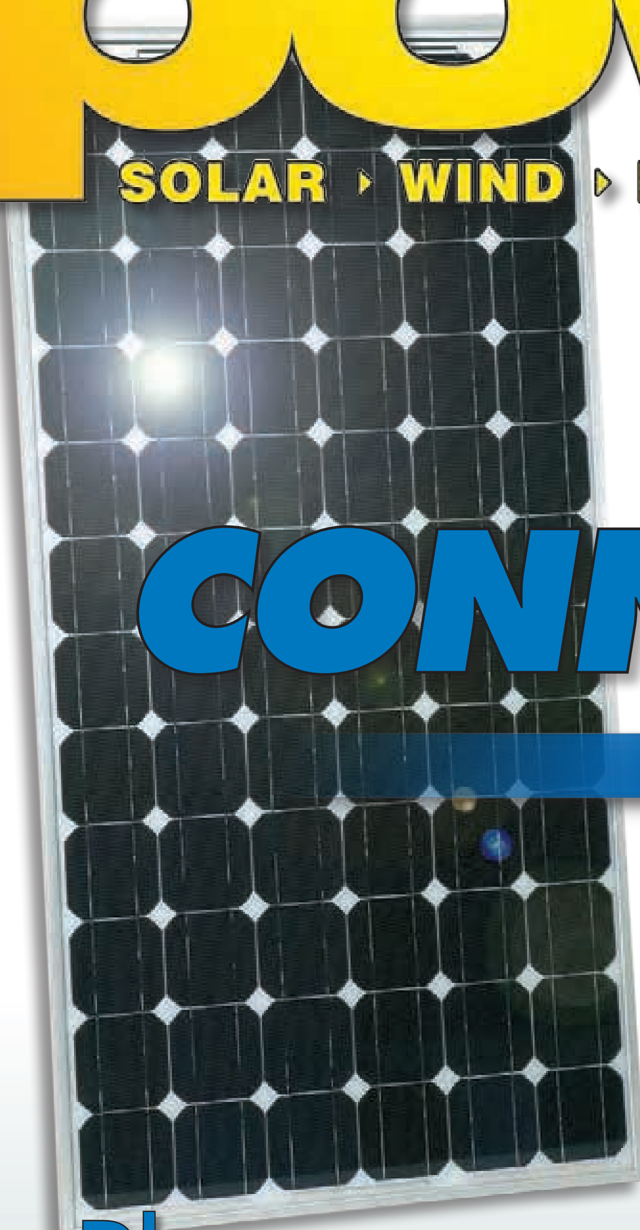

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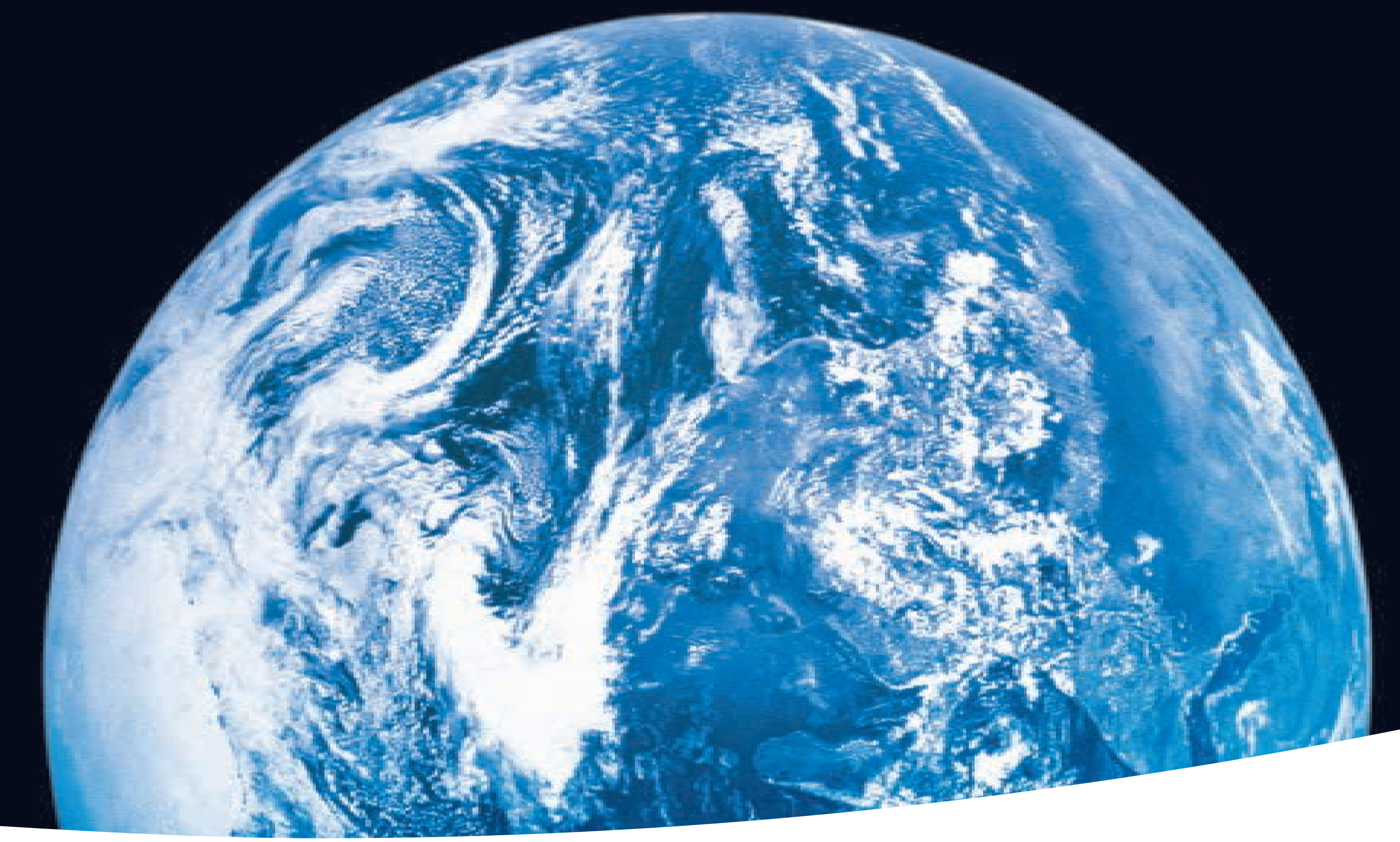

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August & September 2008

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On the Cover

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Regulars

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The Economic Impact of ENERGY

When it comes to the economic impact of energy, nothing gets people's attention like a big jump in the price of a gallon of gas. The national average price per gallon breached $4 in June—just shy of double the average price a year ago. The costs of other liquid and gaseous fossil fuels are following suit. Many residents in the Northeast are already sweating the looming expense of heating their homes with fuel oil next winter. And, in parts of the country, heating with grid electricity is now on par with natural gas. More than ever, the rising price of energy is impacting everything from how we get to work to what food we choose from the grocery store shelves.

As is well established in economic theory, large increases in cost send folks searching for alternatives. Impacts on our wallets tend to change our habits and open our minds. Here's a habit-changing example: According to *U.S. News & World Report*, total vehicle sales are down by 8% so far this year, and sales of trucks and SUVs have dropped 23% in the same time frame. On the open-mind side of the equation, hybrid vehicle sales are booming and commuter trains are filling with record numbers of people. The immediacy with which rising prices impact purchasing decisions is both fascinating and, taking the long view, encouraging.

When it comes to electricity generation, long-subsidized and low-cost conventional fuels like coal or natural gas have, until recently, always had an economic leg up on renewables. For most people, if it costs more or the perceived benefits aren't immediately apparent, the deal goes to the lowest bidder. But economics aside, who wouldn't rather get electricity from a PV array on their roof than from a coal plant down the road? Renewable energy has always been attractive for reasons ranging from independence to a clean environment, but economics has continued to be the biggest hurdle.

The cost of nonrenewable sources of energy will continue to increase—sometimes rapidly and sometimes at a crawl, but always upwards. Compare that trend to renewable technologies that are gradually dropping in price and increasing in terms of efficiency and performance. The costlier conventional energy gets, the more attractive the benefits of renewable sources become, and the harder people will push for clean energy.

—Michael Welch & Joe Schwartz
for the *Home Power* crew

Think About It...

"With 5,249 megawatts of wind power going in the ground in 2007, wind energy comprised 35% of the new electric capacity installed in the United States last year."

—Randy Swisher, Executive Director, American Wind Energy Association

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Tom Tomczyk/iStockphoto

PV Warranties

I've heard that solar-electric modules carry 25-year warranties. But what exactly does that mean? Is that for any mechanical or electrical failure, off-spec production, or what? How are owners compensated under these warranties?

James Houghton • Los Angeles, California

PV modules from reputable manufacturers carry production warranties between 10 and 25 years, with the majority coming in at 20 to 25 years. To find out what that actually means, you must review the fine print.

A typical module warranty provides an immediate remedy for "material defects and workmanship" for one year from date of purchase. After that initial warranty, most companies warrant their modules for an additional time with respect to power output. Often that addition will be worded to provide for a total term—say, 25 years from date of purchase. Most limit this guarantee by warranting module production to be within 90% of the minimum rated power output for the first 10 years and 80% for the remaining 15 years. So the warranties cover immediate failure and then "off-spec production" within their specified percentages of rated power and terms.

Owners are generally compensated (after the failure is confirmed by the manufacturer) by a repair or replacement of the failed module. The labor involved in confirming the failure, module removal, shipment to the manufacturer, and the installation of the replacement module is not covered under the warranty.

As a PV installer, I've had three experiences with manufacturer follow-through on warranties. My first experience was with the replacement of failed single-deposition amorphous modules that had failed to the degree of the manufacturer going bankrupt. With the company "gone," clients who called us in to troubleshoot their systems found no recourse. These folks had to buy new modules at their own expense to get their systems running again.

My second experience was with a large manufacturer that had identified a failure for a specific production run of their modules (with specific serial numbers), which had solder difficulties created during their lamination process. Once they identified the problem (through reported field failures), the company issued a notice of the series to watch out for. Failed modules were identified by inspecting that series—a good reason to always record serial numbers for customers—and the manufacturer replaced the modules after the failed units had been returned.

My third experience was with another major manufacturer. On this occasion, there was no notification of modules with a failure mode, but our company had a callback based on system underperformance of approximately 50%. Troubleshooting this took us to the inverter manufacturer first (identifying module failure when it is less than 100% can be difficult in the field). They suggested that we contact the PV manufacturer with our module serial numbers in hand. At that point, the PV manufacturer admitted a problem with that series of modules. The company took the modules back and replaced them all.

Warranties do not cover damage from shipment or improper installation. They do not cover failures caused by owners, installers, natural forces, or other unforeseen circumstances beyond the manufacturers' control. Warranty language can be difficult to understand—it is written by attorneys, after all.

All warranties contain exclusions. These vary and can have great effects on the warranty's value. One example found in most warranties is for installations in mobile, marine, or other "abnormal" environmental conditions (such as acid rain, other pollution, or salt damage). We regularly install modules on RVs and boats, and these installations void most warranties.

In the end, it pays to follow old rules. Work with companies that are well known and reputable. Warranties are only good if the companies survive the term of the warranty in question. Keep installation details, especially equipment serial numbers, at hand—with the equipment manuals, perhaps. (Yes, we have experience climbing roofs and getting under arrays to retrieve serial numbers!) And finally, always correctly follow the manufacturers' installation procedures.

Overall, my experience has been that PV failures are few and far between with modules purchased from major manufacturers. This is more than a matter of luck. PVs are well-made, long-term investments. I once asked an engineer at a PV manufacturer why they were willing to put 25-year warranties on their modules. His reply was that the same formula is used to determine the warranty for any other consumer electronic equipment: Estimate the life of the product, divide that number by two, and make that number the warranty term.

Chris LaForge, Great Northern Solar • Port Wing, Wisconsin

"Overall, PV failures have been few and far between when working with the major manufacturers."


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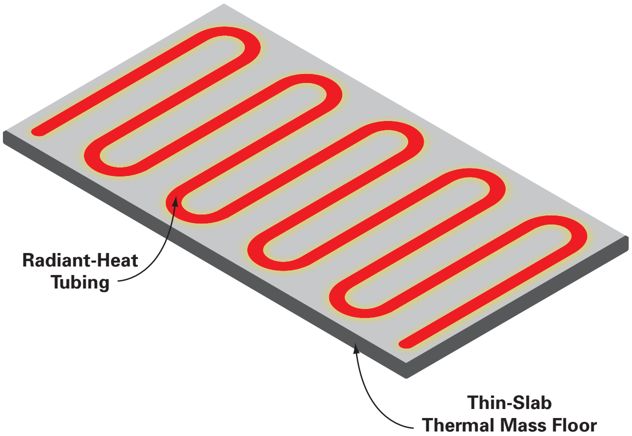

Radiant Floor with PSD?

I'm confused about some of the specifics of passive solar design (PSD). Specifically, what sort of secondary heating system is best used so that it doesn't interfere with the primary heat source (passive solar energy) for the thermal mass floor? Since we're already pouring a concrete slab, I'm thinking that it might make sense to put radiant tubing in the floor. But would the heated fluid circulating through the tubing interfere with heating the slab with passive solar energy?

Derek Dombrowski • New Glarus, Wisconsin

The importance of mass in passive solar design is not only a heating performance issue, but also a year-round comfort issue. On the performance side, in central Wisconsin (latitude 45 degrees north), our designs maximize south-facing glazing by orientating glass-heavy walls within 30 degrees of true south. If the amount of glazing on that wall rises above 8% of the total floor square footage, mass becomes necessary to store excess heat available through solar gain for nighttime use and to prevent uncomfortable temperature swings during daylight hours.

In the past, using Trombe or masonry walls within the building envelope—directly behind glazing and exposed to direct solar radiation—was a common strategy. In small house design, however, those walls occupy valuable living space and block views, so we are now using strategies that "hide" mass, like plaster on walls, thin concrete slab floors, tile or stone floors, and masonry structures such as masonry heaters. The idea is to provide large, thin active surface areas, taking advantage of the fact that most active heat transfer and storage takes place in the outer 2 to 3 inches of mass. Thin-slabs are typically $2^1/_2$ inches thick, laid over conventional wood floor framing slightly modified for the additional bearing required. These slabs are scored to prevent uncontrolled cracking and tinted for a nicely finished floor.

There is some debate among the passive solar design community over whether this same thin-slab should be also be heated with radiant, in-floor tubing, because raising the slab temperature might inhibit passive solar storage potential. While I think this is theoretically true, I would always choose to run in-floor tubing in the thin-slab for a couple of reasons.

First, the amount of usable passive solar gain is minimal in December and January in our climate, but there is great winter benefit in having tubing in the slab to circulate hot water from a storage tank supplied by a masonry heater, solar hydronic system, or a conventional boiler. Second, as we get into days with better passive solar potential, the static temperature of the slab, even when in a heating mode, is going to be in the upper 60s and will still absorb a large amount of solar radiation. Clients typically set thermostats in the mid-60s, taking advantage of the relatively high comfort levels radiant heating systems provide at lower room temperatures. Typically clients note that the temperature variation when bright sunny days follow an extended period of cloudiness range about 4°F to 5°F in the living space, even if the slab has been heated through the nighttime.

Jim McKnight, Gimme Shelter •
Amherst, Wisconsin

"There is some debate among the passive solar design community over whether thin-slab should be also be heated with radiant, in-floor tubing."

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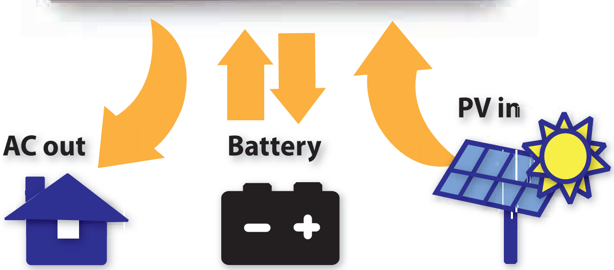

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Energy Audits

I want to find a company that I can hire to perform an energy audit. What should I be looking for in a company? What should I expect in an audit? And, if someday I want to go into the business of offering energy audits, where should I go for training?

Chuck Templeton • via e-mail

Some utilities and other companies will send out someone with a clipboard to do a cursory check of a home's energy consumption problems, but a growing number of professional energy auditors can give you a much more comprehensive view of your home's energy situation. They can even give you a prioritized list of suggested improvements so that you get the most bang for your buck.

The two places to check first are the Residential Energy Services Network (RESNET, www.resnet.us) and the Energy Star Web site (www.energystar.gov). The former maintains a list of certified home energy raters who can do complete energy modeling of your home based on a thorough inspection (see my article in *HP106*). Home energy ratings are mainly used to certify new Energy Star homes, but many raters also perform them on existing homes. On the Energy Star Web site under "Home Improvement," you'll find plenty of information and tools you can use to do some analyses yourself. Also on the Energy Star Web site, you can find links to organizations that can put you in touch with trained contractors.

When choosing someone to assess your home's energy profile, you should look for a person who understands building science and approaches the house as a whole system. They don't have to be a certified home energy rater as long as they know how to do a thorough home performance assessment that includes duct leakage and infiltration testing.

In most cases, you'll pay $200 to $800 for an assessment, depending on what's offered, and you'll get a detailed report showing your home's energy weaknesses. If a home-performance contractor does the assessment, you'll also receive a proposal for the recommended improvements.

Finally, if you want to become an energy auditor, your first step should be to get Home Energy Rating training. Check the RESNET Web site for organizations that offer this training. You might also consider attending the Affordable Comfort Home Performance Conference (www.affordablecomfort.org), where you can learn a tremendous amount and interact with a broad cross section of professionals who do this type of work.

Allison A. Bailes III, Southface Energy Inst. • Atlanta, Georgia

Courtesy: www.southface.org

A professional energy auditor runs tests to gather data, calculates the home's energy efficiency, and then recommends improvements that can be made.

"In most cases, you'll pay $200 to $800 for an assessment, depending on what's offered, and you'll get a detailed report showing your home's energy weaknesses."

Courtesy boB Gudgel (2)

Left: boB Gudgel works with the electronics inside the charge controller at his ham radio station while Squeakers the cat paws at a toroid choke. Inset: Close-up of ferrite chokes.

RF-Proof Controller

I am an active ham radio operator, and I think that I have already killed one solar-electric charge controller because radio frequency (RF) found its way in to it. Specifically, 20 watts out at 50 MHz was the problem. With that in mind, I'm wondering if you have ever encountered this problem, and what solutions you can suggest.

Rich, WD4RBX (ham for 30 years) • Townville, South Carolina

Unfortunately, we can't just "see" the near and far electromagnetic RF fields with our eyes, so we have to make educated but empirical guesses at this semi-black art. The RF from your ham transmitter is most likely entering the controller through the power input/output, remote control, or battery temperature-sensor cables. The trick is to figure out which cable is the culprit without damaging the controller in the testing process.

Many times, the RF-sensitive device will give you an outward sign of impending doom, such as flickering LEDs, a corrupt LCD readout, or some other indication that you can associate with the keying up of your transmitter, without going to the breaking or "smoking" point. If this is true in your case, key up your transmitter starting at a very low power level, raise the power until you or a knowledgeable assistant just start to see some indication of a problem, and then unkey the transmitter. A handie-talkie makes a great RF generating source used as a "probing" tool.

There are some indicators to look for during your testing. Sometimes the controller's microprocessor will crash and the unit will stop running. If this occurs, you may have to power down the charge controller and reset it. Next, try removing cables, one at a time or in multiples to see if the problem goes away at that last power level. If this stops the corruption, run the cables through a ferrite bead (clamp on) or toroid, then reconnect them and try the test again.

Since you need to keep the controller powered up for this test, you may have to use a big ferrite on the battery cables from the start. Remember to run *both* positive and negative wires through the toroid hole (common mode filtering). Not all ferrite is the same, so you may have to try more than one type.

Another thing to try is to physically move wires and cables around to see if RF sensitivity changes. Sometimes going inside the box is necessary. If you have experience working with electronics, you may try adding a capacitor. In fact, try grounding and ungrounding the chassis to see if anything changes. You might also try adding small capacitors from PV plus and minus terminals to the chassis to help the filtering action of the PV ferrite. Both caps should be of the same value, at about 0.01 or 0.001 microfarads, and leads should be as short as possible.

boB Gudgel, K7IQ • Everett, Washington

"Unfortunately, we can't just 'see' the near and far RF fields with our eyes, so we have to make educated but empirical guesses at this semi-black art."


It's not only a quality promise, it's a reliable partnership.

Mailbox

Better Power Supplies

With people trying so hard to save energy with compact fluorescent bulbs and by reducing phantom loads, the energy-wasting adapters we use really need some attention too. With cordless phones, battery chargers, etc., all powered 24 hours a day with inefficient "wall warts," we're consuming a lot of energy. Working with common consumer electronics is my job, so I've been able to do tests on a number of these adapters. It's amazing how much better the new switch-mode power supplies are compared to the old large transformer-type adapters.

The new ones are lighter and smaller, have better voltage regulation and filtering, and are more efficient. Even if there is no load on an old type adapter, they still get warm, wasting 3 to 8 watts. The new ones are barely warm and draw 0.1 up to 2 W without load. This high efficiency is obtained the same way as in modern power inverters. Voltage conversion is at high frequency, like 100,000 hertz, instead of the low 60 Hz coming from the grid. The transformers can be much smaller and convert the voltage with less loss. Because of the high efficiency, the switch-mode supplies don't heat up much when loaded hard—and the unwanted conversion of electric energy to heat loss is the root of inefficiency in appliances.

In my partly solar-powered home, I eliminate phantom loads with switched power strips, and recently I've changed all the adapters to switch-mode types. In most cases, it cuts the electricity consumption in half. It's great to see these supplied in many computers—desktops and laptops. Unfortunately, they are not yet supplied with lower-priced cordless phones, wireless speakers, and LED alarm clocks, which could all be using half the energy they do now. But with some know-how, these items can be easily refitted with a small switch-mode supply. Some voltage-adjustable switch-mode supplies are available in stores, for use with digital cameras or for powering small electronics in automobiles.

If you feel any heat coming from a unit plugged into the grid that is turned off or not doing much of anything, it's wasting energy. The table shows the differences between the two types of supplies. The load was a variable power resistor set to draw the same load for each adapter. The power in and out of the adapter was compared to show its efficiency.

Paul Melanson •
Dartmouth, Nova Scotia, Canada

AC-to-DC Adapter Comparisons

5-Volt Adapters

	Linear Power Supply			Switching Power Supply		
DC Output (mA)	AC Input (mA)	Output Voltage	Efficiency	AC Input (mA)	Output Voltage	Efficiency
0	16	6.70	—	11	5.20	—
250	30	5.50	38.2%	20	5.18	54.0%
500	42	4.70	46.6%	30	5.17	71.8%
1,000	75	3.50	38.9%	55	5.15	78.0%

9-Volt Adapters

	Linear Power Supply			Switching Power Supply		
DC Output (mA)	AC Input (mA)	Output Voltage	Efficiency	AC Input (mA)	Output Voltage	Efficiency
0	39	12.60	—	10	9.30	—
250	61	10.90	37.2%	28	9.30	69.2%
500	84	10.20	50.6%	49	9.28	78.9%
1,000	130	9.10	58.3%	93	9.25	82.9%

12-Volt Adapters

	Linear Power Supply			Switching Power Supply		
DC Output (mA)	AC Input (mA)	Output Voltage	Efficiency	AC Input (mA)	Output Voltage	Efficiency
0	43	15.80	0%	10	12.10	0%
250	70	14.10	42.0%	35	12.10	72.0%
500	98	13.30	56.0%	60	12.08	83.9%
1,000	150	11.80	65.0%	116	12.05	86.6%

Courtesy Solar Roast

Solar Coffee Update

You published a short article about our company ("Roasting on Sunshine" in *HP105*). That was when my brother and I were still based in Central Point, Oregon, and roasting coffee using our small system built from a satellite dish. I built that first roaster in the spring of 2004, and we started roasting coffee for a Fourth of July celebration. Four summers later, we have our own coffee shop in Pueblo, Colorado, where we have 300+ days of direct sunlight per year.

Our newest roaster system, the Helios 4, has some 30 times the capacity of the one featured in the 2004 article. We designed and built the new roaster from scratch. It is a drum-style coffee roaster attached to a large solar concentrator, which uses focused sunlight to heat air (up to 900°F). The 23 KW solar concentrator can be tracked in two axes. The hot air is ducted into a separate building, where it is used to roast the coffee. A 1 KW photovoltaic system (using six Mitsubishi 170 modules and an OutBack inverter with batteries) provides all of the electrical energy for the fans, motors, and other equipment.

We can also use propane as a heat source during cloudy or extremely cold weather. The coffee we make is consistent and has flavors favored by many because our roasters are designed and built around the idea of airflow recirculation and heat retention—for maximum efficiency. We tend to use less overall energy to roast the coffee, and it also retains more of the smoke and steam from the roasting process. The coffee beans are not allowed to dry out as much as with conventional gas roasters, which helps to bring out more of the flavors.

We plan to refine and improve our current roaster over the next year. Then it will be time again to begin seriously looking at ways to expand on our solar roasting process and build a bigger system—the Helios 5.

David Hartkop • www.solarroast.com

"We tend to use less overall energy to roast the coffee, and it also retains more of the smoke and steam from the roasting process."

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Oldest Solar-Electric Array?

Last April, I purchased this old black-and-white photo online from a New York dealer who specializes in old photographs. It appears to show some very early solar-electric modules on a flat roof.

This was in the dealer's description:

> ***Up for auction is this vintage photo of an array of solar collection panels on top of a New York City building... According to Encyclopaedia Britannica, the first genuine solar cell was built around 1883 by Charles Fritts, who used junctions formed by coating selenium (a semiconductor) with an extremely thin layer of gold. Now here we are, with this photo taken about 20 to 25 years after Fritts developed the first real solar cell, finding the application put to use.***

Who was the person using PVs at this time, and could this be the earliest photo of a real solar-electric array? Can anybody shed any other information or comments about the photo?

Anthony Skelton • Warwick, U.K.

The first solid-state solar cell was built by William Adams and Richard Day in 1876. They were the first to show that a solid-state device could produce electricity directly from light. They called this the photoelectric effect. Later, Charles Fritts built the world's first solar-electric modules, which are probably what you see in this photo. Both devices used selenium.

Because these inventors lacked insights that could only be gained through Einstein's Nobel Prize-winning work on light quanta (photons), they had no good idea how the cells worked nor the efficiency they could attain. Once Einstein's paper on light quanta was published and accepted, photovoltaics became an accepted field of study. People then learned that the selenium cell could never convert more than 0.5% of the incoming light into electricity—too little for practical purposes. It was only with the discovery of the silicon solar cell in 1954 that the practical use of photovoltaic technology became possible.

John Perlin, author of *From Space to Earth*

Best Heating System

I think you left out an important bit of information in the *HP123* article on "Home Heating Basics"—the cost of a heating system. I know that costs vary depending on the capacity, type, and extent of the system, but I think most contractor-installed systems on reasonably sized houses are in the $10,000 to $15,000 range.

I would like to suggest that if you insulate walls to R-30 and attics to R-50, build the enclosure relatively airtight, and incorporate even just a bit of passive solar design, you may not need a "system" to heat it, even in cold climates. A small gas or propane-fired, modulating, direct-vent space heater will do fine.

The efficiency of a particular unit that I've installed is 81% to 84%, and the installed cost might be about $1,500. Low efficiency, you say? Yes, but with a $65 per month gas bill for space and water heating in a 7,200 heating-degree-day climate, I don't think efficiency should be the issue you make of it. To quote Alex Wilson, "It doesn't make sense to put in a $10,000 heating system to provide $100 worth of heat a year."

Steve McCarthy, Starbright Energy Services • Wellsboro, Pennsylvania

Skip the Politics?

I was taken aback by Robert Montgomery's letter, entitled "Skip the Politics," in the *Mailbox* section of *HP125*, in which he criticized the editorial "Waiting for the Sun," (in *HP123*) for having an anti-Republican tone.

I reread the editorial and felt that it discussed U.S. energy policy-making fairly and without bias. That the editorialist, Joe Schwartz, talked about the politics of the Clean Energy Act of 2007 being dismantled didn't make him biased toward one political party or the other. Indeed, Mr. Schwartz pointed out that both parties played a part in scuttling the Senate's energy bill. The fact that more Republicans than Democrats were against the bill was just that—a fact. The point of the piece, as I read it, was that the power behind oil was greater than the power behind renewable energy sources, and that without electoral reforms, renewable energy will have to wait inordinately long to get its rightful "place in the sun."

In other words, Mr. Schwartz was asking our lawmakers to "skip the politics," a point that Mr. Montgomery, with some irony in my opinion, failed to grasp.

Wesley Palmer • Santa Barbara, California

"It doesn't make sense to put in a $10,000 heating system to provide $100 worth of heat a year."

What is Sustainability?

> *"A more useful definition…defines sustainability with four system conditions that apply like the laws of gravity."*

I am frustrated by how loosely we use the term "sustainable." In the "sustainable sailing" article in *HP125,* I would conclude that yes, while under sail, the boat's transportation energy is using a renewable resource. But coming to a port to restock usually requires turning on the motor, unless you can maneuver in and out of port under sail. Installing PV and a wind generator on a sailboat reduces fossil fuels, but does it make one sustainable?

My wife and I make 150% of our household electricity with sunshine, we heat 99.95% of our water with a solar thermal system, we drive fuel-efficient cars and buy green tags to offset our car and air travel, and we buy local food. We plan to install a solar air collector to supplement a high-efficiency wood heater, and to buy an all-electric car fueled by our solar-electric system. Yet even after all of that individual effort, I feel that we are not close to living a "sustainable" lifestyle.

A more useful definition by The Natural Step (www.naturalstep.org) defines sustainability with four system conditions that apply like the laws of gravity. In a sustainable society, nature is not subject to increasing:

1. Concentrations of substances extracted from the earth's crust (like oil, natural gas, or cadmium);
2. Concentrations of substances (chemicals) produced by people;
3. Degradations by physical means (breaking or diminishing nature's cycles);
4. And in that society, people are not subject to conditions that undermine their capacity to meet their needs.

We can't be sustainable even in complete isolation unless our *society* becomes sustainable, because of the interconnection of all living things. Almost every activity in our modern lives fails at least one of the four conditions and will eventually lead us to a dead-end. We are focused on "less bad" and tactical measures that do not address fundamental issues. Until we recognize where we are and where we need to go, we could make things worse with our good intentions.

I would like to congratulate the Youngs for their efforts, and for the efforts of all individuals working on developing renewable energy including the *Home Power* crew. My request is that we work toward the truth in our communications and build a common understanding of what "sustainable" means.

Randy Sadewic • Santa Fe, New Mexico

Courtesy Randy Sadewic

Subsidies, No!

I bet most *Home Power* readers agree with me—they value long-term freedom more than short-term payoffs. So, I cannot understand the presence of three articles in *HP124* promoting solar tax credits and subsidies.

Haven't the prices of propane and electricity increased enough that we solar people should be able to find plenty of business? Incentives always push the general public back farther than they thrust the favored group forward. It is the paperwork, the bureaucrats, the certification, and worse, the personalities that rise to the top in these contrived challenges. The subsidies are mostly aimed at electricity. They distort everything.

Home Power readers know that American society indulges in and is drunk on electricity. The unsuspecting public is enthusiastic about renewable energy mandates and subsidies on the mistaken belief that we can stay drunk on electricity, but escape a hangover if it is solar or wind electricity.

Can't we shop for our own energy and leave government out? This would encourage traditional, but forgotten, cost-effective uses of solar energy:

- Solar-powered children walking or biking—not riding in cars—to school
- Windows and skylights for daylighting
- Passive heating and cooling
- Solar drying—clotheslines

Big government, big business, and the banks have cast a spell to wean us from traditions that work for us, and shift us to a new energy order that works for them.

Steve Baer, Zomeworks Corporation • Albuquerque, New Mexico

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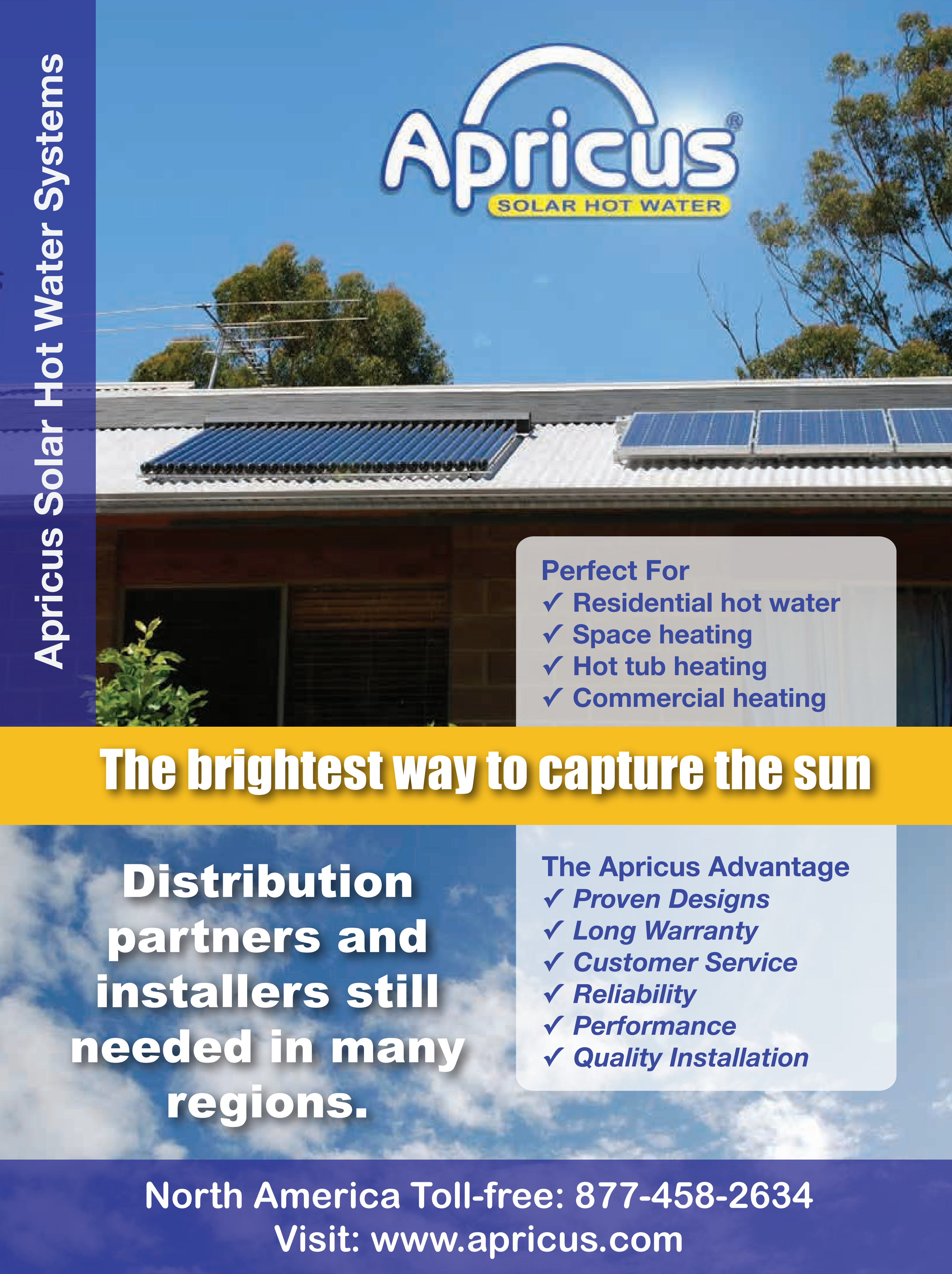
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SIDE-BY-SIDE solar

by Sandy George Lawrence
photos by Josh Root

Some landlords might scoff at the idea of adding a solar-electric system to a rental property. When it comes to investing time and money into any kind of improvement for rentals, "less-is-more" tends to be the favored approach. While my wife Barbara Schickler and I may err on the frugal side when making superficial upgrades, we never hesitate to do whatever it takes to improve the energy efficiency of our buildings—such as adding high-efficiency furnaces and windows. We see it as a win-win-win: for our tenants, the environment, and us. So when the opportunity arose to add solar-electric systems to our rental properties, we jumped at it.

Our situation is somewhat unique. We run a bed-and-breakfast that is part of our 4,600-square-foot home in the far northwest corner of Washington state, and we also own three adjacent 5-acre properties. Two of these have freestanding rental homes, and the other has a greenhouse that we use to raise seedlings for our tree farm. Altogether, our four properties occupy a 20-acre parcel in Whatcom County, about 15 miles from the Canadian border, at 48.9 degrees north latitude.

A year or two ago, we decided to add a workshop. Our plan was to build to a 2,000-square-foot structure on the parcel with the greenhouse. The new building would house a carpentry workshop, exercise area, and gear locker, as well as provide a south-facing roof space for a solar-electric system that could help power our home and two rental properties. As a self-taught carpenter with several projects under my belt, I felt confident that we could save on labor costs by doing the work ourselves—except for some help from subcontractors for the foundation, insulation, drywall, and plumbing.

The author with the three sets of utility meters, performance meters, and PV system disconnects.

Nailing down regulatory approval for the system was the first step. With its long history of involvement in RE, our utility, Puget Sound Energy, was open-minded about my idea for a grid-tied solar-electric system. What gave them pause was not the PV installation, but that I wanted to mount the electric meters for three separate residences on the wall of a workshop on a fourth property—one without a residence. They finally gave us the go-ahead with the explicit understanding that the meter bases would need to be transferred back to the other homes if we ever parted with one of the rental properties. While that was certainly a valid point, we weren't too concerned since our plan is to retire here and maintain our rentals for income. But should we ever sell our rental properties, the system can be reconfigured and the meters can be moved to their respective homes.

The three Xantrex GT5.0 inverters feed three different homes, each with its own utility service.

Solar-Ready Roofing

Given the constraints of our wooded property, we ended up paying an arborist to remove several large cottonwood trees to clear a solar window. Though we hated to see them go, we had more than adequately counterbalanced their loss by planting several thousand trees on our property over the previous decade. Construction of the workshop spanned 12 months, with several weeks devoted to readying the roof for solar.

Since I had no interest in climbing up on the roof to adjust the tilt of the PV arrays several times a year, I choose a fixed-mount racking system. To avoid roof penetrations, I routed my conduit from the arrays through the vertical clerestory wall. In retrospect, I wish that I had included three risers coming through the roof—one at the foot of each string—but I had not yet sized the modules and strings, and wanted to leave some flexibility. Conduit runs would have been shorter with vertical penetrations closer to the inverter room inside the workshop. I overcompensated by using #6 wire in the conduit. Only late in the process did I learn that the conduit between the PV array and the DC disconnect must be metal—not PVC—for its run through a wall cavity. This *National Electrical Code* requirement is an effort to better protect the wiring during any future construction, and reduces the risk of fire within the wall if a ground fault develops in the wire run.

System Assembly

Component Selection. After exploring various options and seeking bids, we decided upon Evergreen 190 W PV modules. We wired 16 modules in series for each of three arrays, and mated each string to a Xantrex GT5.0, 5 KW inverter. Each array is rated at 3,040 watts at operates at 427.2 volts at maximum power. Based on the historical low temperature here in Bellingham of 4°F, a maximum of 14 ES-190 modules in series is recommended by the inverter manufacturer. Hopefully we won't see temperatures below the historical figure, or damage to the inverters could result. We chose the larger capacity inverter to allow for future pole-mounted modules at the shop.

Inverter Setup. Celt Schira, my consulting electrical engineer, contacted Xantrex tech support and received a strong recommendation to site the inverters close to the utility's meters due to voltage drop concerns. Because the inverter has to have a higher voltage than the utility to export power, it is extremely important to minimize voltage drop on the AC side. This meant running the underground conduit to the more distant east end of the building, rather than to the adjacent west end of the shop as originally planned. If I had consulted with my electrical engineer before construction, I could have built the inverter room closer to where it needed to be. I also learned from the engineer that utility crews strongly prefer 3-inch conduit—as opposed to 2.5-inch—which would have made pulling the wire *much* easier.

Left: A portion of the 9.12 KW PV array.

Inset: Detail of the roof-to-array mounting system.

Inverter Mounting. Though these inverters are designed for outdoor mounting, I wanted to coddle them a bit and walled off a space from the rest of the shop to keep out sawdust and clutter. In an urban setting, this placement would also protect them from vandalism or theft. I installed additional bracing behind the drywall to support the inverters' weight, and then painted and finished the wall so they would better blend with the building.

I brought my cable runs from the roof into a large junction box recessed halfway into the wall to both accept the behind-wall conduit runs from the roof, and to allow outer conduit into the inverters, as opposed to using the knockouts in the back of the inverters. This will allow easier future changes to the system. I also added conduit runs below the inverters for the future PV arrays.

Module Layout. The arrays on the south-facing roof lie below a row of clerestory windows that provide daylight to the north half of the structure. I had the thought that light reflected from these windows might enhance the production of electricity from the top string, the array dedicated to our house. Within an interval around solar noon, this is actually so. I can see reflected light hitting the upper modules, and the readout indicates that the array is producing an additional 30 to 40 W. But the unintended consequence of butting this string up to the

Tech Specs

Overview

System type: Batteryless, grid-tied solar-electric

Location: Bellingham, Washington

Solar resource: 3.7 average daily peak sun-hours

Average monthly production: 762 KWH

Utility electricity offset annually: 50% of total consumed by primary residence and two rentals

Components

Modules: 48 Evergreen Spruce Line ES-190, 190 W STC, 26.7 Vmp

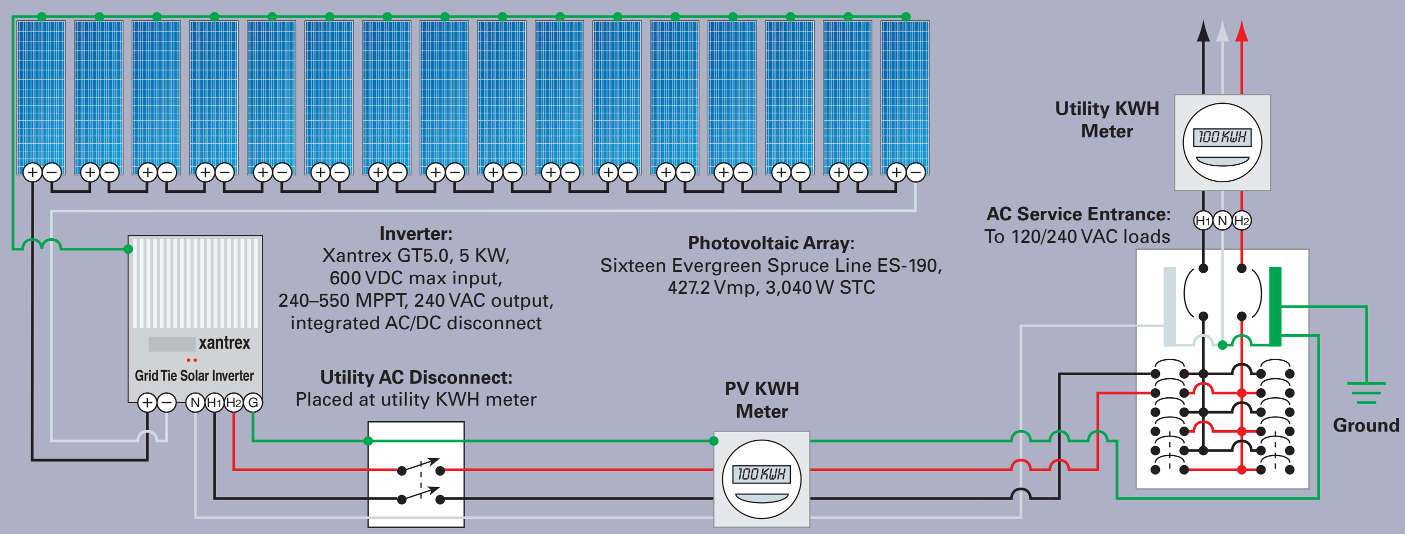
Array: Three arrays of 16 modules in series, 427.2 Vmp, 3,040 W STC, 9.12 KW total

Array installation: UniRac SolarMount rack with S-5! clamps, landscape orientation on south-facing roof, 18.5-degree tilt

Inverters: Three Xantrex GT5.0, 5 KW each, 600 VDC maximum input, 240–550 MPPT operating range, 240 VAC output

System performance metering: Onboard inverter meters; PV production meter and utility service meter for each system; inverter data cable installed for future data collection

Lawrence Grid-Tied PV System



Note: Array one of three shown. All numbers are rated, manufacturers' specifications, or nominal unless otherwise specified.

The workshop with its three independent arrays.

Landlord Economics

When it's your home, it's easy to justify spending thousands of dollars on a solar-electric system that will pay you back over time with reduced utility bills, possible rebates, and tax credits. But it's a little more difficult to fork over the dough when it's your rental property. There's nothing wrong with wanting to get some return on your investment—above and beyond the savings in fossil fuels—and the good news is that adding PV to your rental properties can put dollars back in your pocket. Here's how we made RE work for our situation:

Production Incentives. Because the majority of utility generation in the rainy Pacific Northwest comes from large-scale hydro plants, our electricity rates are relatively low. Therefore, our overall savings are not as impressive as they would be if we lived in an area served by fossil-fueled power plants. That said, the available incentives do add up nicely in our favor. With Washington state's net-billing regulations, two meters are installed for each system—one for total production and one for standard net metering. Puget Sound Energy pays us 15 cents per kilowatt-hour (KWH) until 2014 for *all* electricity generated—even if it is consumed on site. This payout will gradually increase as the electricity rates climb over the years. Had we purchased modules and inverters built in Washington state, the production incentive would have gone as high as 54 cents per KWH.

On top of the 15 cents per KWH, a green tags program operated by Northwest Solar Cooperative pays us 2 cents per KWH. When you add in the value of the energy we avoid purchasing because we use it ourselves (8 cents per KWH), and the price we are paid for energy we do not use but send to the grid (also 8 cents per KWH), that equals about 33 cents per KWH.

Added Value. Our tenants recognize the financial and environmental benefits of living in a home with solar electricity. Not only does the system save them an average of $180 per year in utility bills, it also allows them to live a renewable energy lifestyle without bearing the initial expense. Though our tenants cannot take advantage of the green tags incentive, they do receive the utility offset through the net metering agreement. One tenant reported that their October electric bill was only $3. Rising energy prices will make the solar-powered rentals that much more appealing to prospective tenants.

Tax Credits & Rebates. All of the tax credits and rebates add up quickly. Our PV project cost about $51,000. We received the maximum $2,000 federal tax credit (up to 30% of the installed cost) and a $5,244 rebate through a now-defunct program offered by the Bonneville Environmental Foundation.

B&B Revenue. Though it is too soon to tell how much effect the system will have on our occupancy rates, we hope the PV system, as well as our other energy-efficient choices, will attract visitors who are looking for *green* hospitality.

Depreciation. Thirty years' straight-line depreciation for the two rental homes' capital improvements equals $567 per year for each—a total of $1,134 per year in depreciation schedules.

Resale. Although we're not too concerned about resale value since we plan to retire in our current home and continue using our rental properties for income, it's a comfort to know that if we did need or want to sell, the solar-electric system and workshop have increased the property value.

clerestory wall is that early morning and late afternoon shading in the summer months leads to about 4% less net production from this string over the first eight months of operation.

Testing 1-2-3

Having three parallel strings allows a unique opportunity for comparing nearly identical systems in an actual installation. Since our systems went online in July 2007, each of the three arrays has averaged about 6.7 kilowatt-hours (KWH) of production per day. In eight months of operation, the net production of these systems reached 1,510 KWH for the upper array, 1,578 KWH for the middle array, and 1,575 KWH for the lower one. Though I came to expect that shading from the clerestory overhang would diminish production on the upper array, I was pleasantly surprised that the difference between all three arrays was small—and even more impressive, the difference between the middle and lower arrays (without the summer shading problem) was only 0.2%. These figures are, as I would argue, testimony to the quality of engineering that goes into these photovoltaic modules and inverters.

The average electrical load in our 4,600-square-foot home is about 10 KWH per day—well below the national average for a detached single-family residence—largely because propane provides the fuel for space and water heating, cooking, and occasional clothes drying. Our primary electrical loads are refrigeration, lights, electronics, a well pump, and small pumps for the heating system. Our PV systems provide about two-thirds of our own home's electricity, and probably a higher fraction for each of the two rental homes, which are less than half the size of our home/B&B and have fewer people. After I expand the PV system with pole-mounted modules to the east or south of the shop, we should have enough production to meet nearly all our electrical needs.

A system of this nature is not for everyone—or even every landlord—but we made it work. As a do-it-yourselfer, I was able to obviate one of the big costs of building the workshop: labor. As a landlord, I circumvented the classic economic problem of split incentives. My tenants have lower electric bills but are still motivated to conserve to reduce their bills even further. Meanwhile, I can justify raising the rent a bit, and the tax credits and depreciation schedules help pay for the

project over time. Even without all the financial incentives, I would have moved forward with the project—because, in the end, it's about saving resources, not dollars.

Access

Sandy Lawrence, M.D., (sandy.lawrence@verizon.net; www.axtonroadbedandbreakfast.com) was a professor of medicine at the University of California at Davis before retiring to upstate Washington. His wife, Barbara Schickler, is a certified nurse and midwife. Between the two of them, they have delivered 7,000 babies and raised three of their own.

Celt M. Schira, P.E. (schira@openaccess.org) is a licensed professional electrical engineer and LEED-accredited green building consultant. She has 21 years of engineering experience in electrical design, telecommunications, and renewable energy. She owns Schira Consulting in Bellingham, Washington.

Dana Brandt, P.E. • dana@ecotechenergy.com • www.ecotechenergy.com • Incentives consultant

Jeffree Utter • rfrenewable@nas.com • Installation consultant

System Components:

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Basics to Building a Better Home

by Rachel Connor

Before you build: Arm yourself with these building-science basics to achieve a high-performance home that is durable, efficient, and comfortable over its entire lifetime.

Homes built today are generally twice as efficient as their 1980s counterparts. Improved window technology, more efficient heating and cooling equipment, better control of air infiltration, and greater use of insulation are helping decrease energy use in today's homes. But building science—the physics of optimizing building performance and understanding why buildings fail—also plays a pivotal role.

Building science encompasses the study of heat transfer, airflow, and moisture movement through building enclosures; and how those factors affect the building's performance, durability, comfort, and air quality. It predicts and measures the relationship people have to the controlled environment of buildings. Building science encompasses home design, construction, diagnostics, repair, and operation—all pitching in to make better buildings.

Dealing with Heat Flow

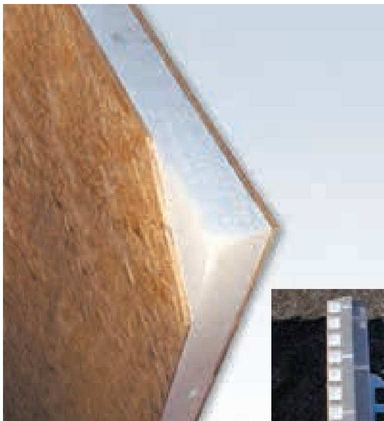
Insulation controls the flow of heat through a building assembly by slowing the conductive heat transfer through the envelope. Wherever floors, walls, ceilings, windows, and doors are exposed to differing inside and outside temperatures, heat conduction takes place.

The more insulation you pack into the envelope, the more heat transfer will be slowed. Building techniques have a particularly important role in this. In typical stick-frame construction, the large amount of framing material (i.e., studs, footers, and headers) not only means less opportunity for insulation but more conductive heat loss and gain. Framing members act as thermal bridging, reducing a wall's R-value by 10% to 25% in an average home.

To avoid thermal bridging, insulation should be installed in a continuous, unbroken manner from foundation to roof. Conventional stud-framing does not allow this, but wrapping, taping, and sealing rigid insulating sheathing around the exterior can offer one solution for a stick-frame house. Whole-wall systems that combine insulation and structure in one unit, such as structural insulated panels (SIPs) and insulated concrete forms (ICFs), are becoming a more common approach to providing a continuous layer of insulation, to reduce air leakage and thermal bridging.

In addition to reducing conduction, insulation also plays a role in keeping the wall assembly dry. For example, another benefit to wrapping the exterior walls with rigid board insulation is that if (or more likely, when) a small amount of moisture enters a warmed stud cavity, it would not come into contact with any cold surfaces and condense.

You may have an insulated stud-framed wall, but insulation exists only within the cavity. In a conventionally framed home, thermal bridges exist every 16 inches on center. Large thermal bridges are created by multiple studs at every corner and around the window and doors.



Courtesy Structural Insulated Panel Association, www.sips.org

Courtesy Green from the Ground Up, www.taunton.com

Alternative wall materials like structural insulated panels (SIPs, left) and insulated concrete forms (ICFs, below) can prevent transmission of heat, air, and moisture.

The Three Basics

Understanding the science of energy movement can help designers and builders predict how heat, air, and moisture will travel through the building envelope. Proper planning and detailing within these rules can reduce building failures and help improve a home's energy performance, comfort, and durability.

Heat Flow

- Heat is energy produced with the motion of molecules.
- Heat flows from warm to cold.
- The temperature difference between two adjoining surfaces drives the rate of heat exchange.

Airflow

- Air flows from higher to lower pressure.
- Heated air moves moisture.
- The amount of air in equals that of air out.

Moisture Movement

- Moisture flows from warm to cold within the same medium.
- Moisture flows from more to less.
- Things always get wet and must be allowed to dry.
- Air pressure induces flow of moisture-laden air.

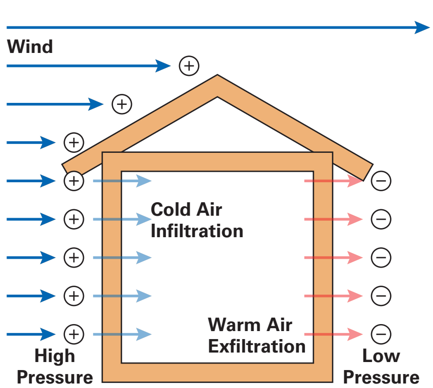
Addressing Airflow

What insulation does not do is stop air leakage into and out of a building. Although caulk, gaskets, and weather-stripping will reduce unwanted air leakage, understanding how air (heated and/or moisture laden) moves through wall assemblies will help you develop a more systemic approach to cut leakage.

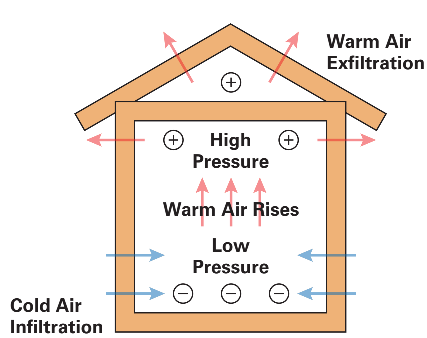
Use a three-pronged approach to gain control over the movement of air in and out of your home:

Seal the leaks (both the obvious and not so obvious). During construction, no one typically is responsible for sealing penetrations made in the framing or structure. Never assume that the electricians and plumbers are thinking about reducing the air leakage, so be diligent about sealing these leaks. Notorious air leak areas occur around electrical outlets, recessed light fixtures, and anywhere dissimilar materials come together—a window frame and wall, for instance, or where concrete meets wood.

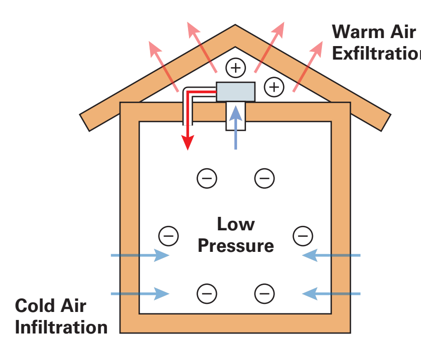
Three Main Driving Forces of Airflow & Heat Loss



Wind-Induced Airflow:
Wind blows on the outside of the home and pushes air through holes (infiltration). An equal amount of air will be pushed out of the holes in other places in the home (exfiltration).

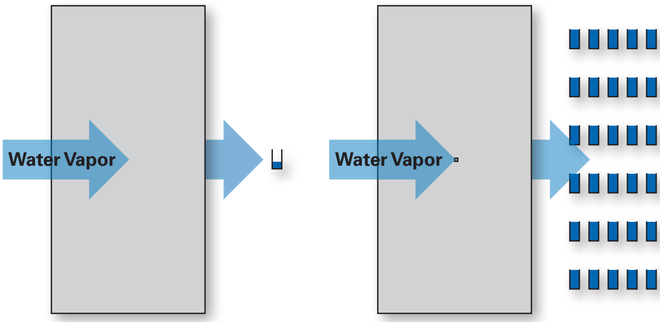


The Stack Effect:
Rising warm air causes pressure differences throughout the building envelope making warm air exfiltrate through ceiling and attic, while cool air infiltrates through crawl spaces and basements.



Mechanical Systems:
Heating and ventilation systems create positive and negative pressures within the building envelope. In this example, the heating/cooling mechanical system is leaking warm air into the attic.

Air Leakage & Moisture



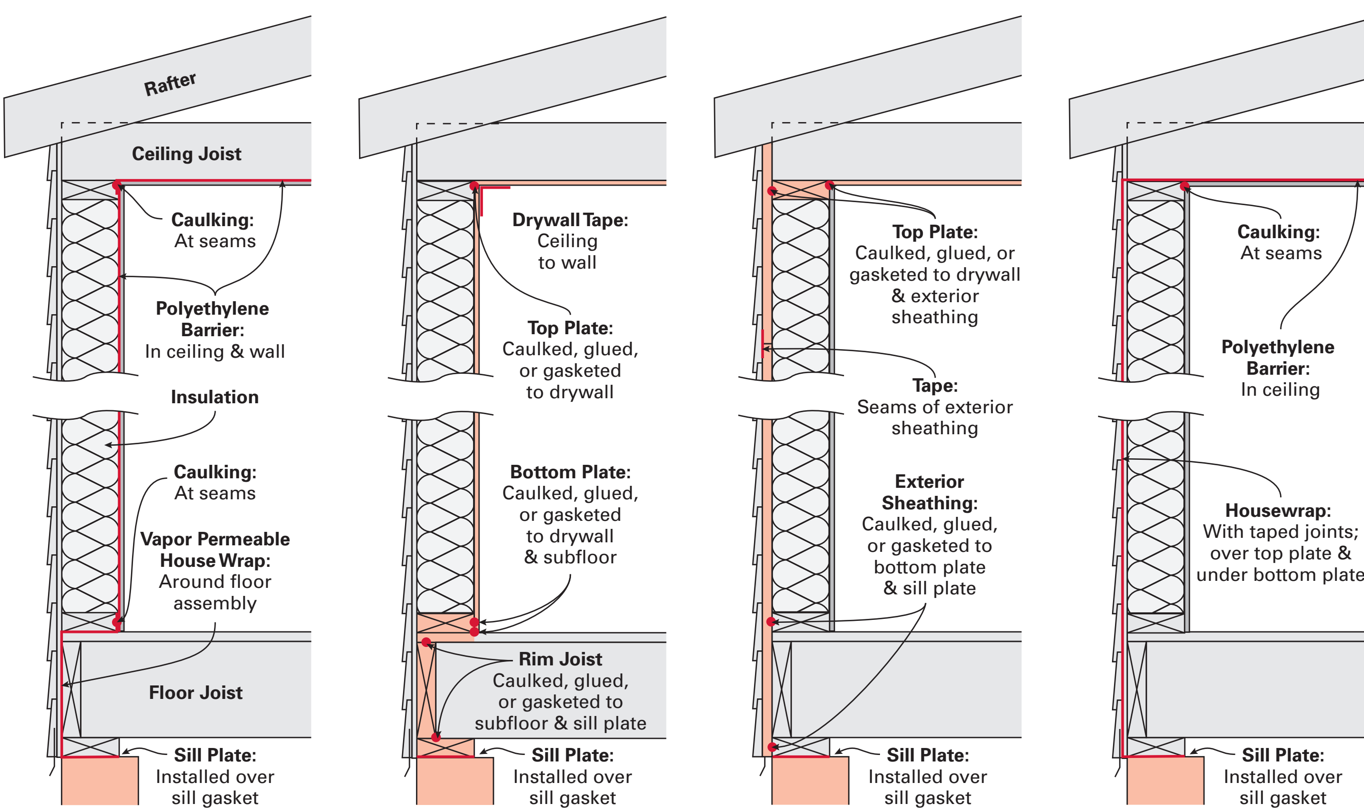
Only 1/3 quart of water vapor is transmitted through a 4- by 8-foot sheet of gypsum board during a typical heating season (left). But with a 1-square-inch open gap (right), more than 30 quarts of water vapor will be transmitted.

Provide a continuous air barrier that can resist air pressure differences. This is usually done with impermeable "house wrap," but can be done in conjunction with a continuous layer of insulation. Batt and blown-in insulation do not act as air barriers, so one should always be added. Spray foams and rigid insulation (with sealed joints) are the only insulation types that are also air barriers. Gypsum board and exterior sheathing that are properly installed are also effective air barriers.

Courtesy Green from the Ground Up, www.taunton.com

Properly installed house wrap acts as a barrier to the transmission of air and moisture.

Common Approaches to Air Barriers



Recommended for Very Cold Climates Only: No air conditioning

Source: *Builder's Guide to Cold Climates* by Joseph Lstiburek

Control air pressure. Sealing leaks and providing an effective air barrier can translate into an efficient house that saves both energy and money. However, "tight" houses need to be ventilated to exchange stale, moist indoor air with fresh outdoor air. Controlled or mechanical ventilation systems can be exhaust-only, supply-only, or balanced (a combination of the two). However, don't assume that just because you have one of these systems, you have control over your air pressure. Any ductwork and air-handling equipment must be sealed against air leakage to prevent unequal pressure in of your space. Your HVAC contractor may or may not have done this—it's your job to follow up!

Managing Moisture

Moisture accumulates in a building envelope when more enters than exits. When moisture accumulation is greater than a material's ability to store the moisture, problems result. There are three general strategies for avoiding moisture damage in a home:

- Control moisture entry at the roof, walls, and foundation
- Control moisture accumulation when a material gets wet by allowing it to dry
- Remove moisture by source control and ventilation

These strategies are best used in combination. However, making them work together effectively can be quite a balancing act.

Not all tradespeople pay attention to their effect on issues outside of their field of expertise. Note how the insulation is shoved aside for the wiring to this switch box.

What's R Got To Do With It?

An R-value is the measure of a material's ability to resist conductive heat transfer. The higher the R-value, the more resistant that material is to transferring heat. R-values are stated on a variety of insulation products, from fiberglass batts to loose-fill cellulose. Full values are given for products of a uniform thickness, and per-inch values are given for materials that are blown or pumped into cavities.

The R-value of any building assembly, such as the floor, walls, or ceiling, equals the R-value of individual components added together. A typical stud-framed wall with 5.5 inches of fiberglass insulation (about R-3 per inch) has an overall R-value of approximately 20. Likewise, an earthen wall (such as adobe or rammed earth) insulated on the exterior with 4 inches of extruded polystyrene (R-4 to R-5 per inch), has a similar R-value. Even though the R-values of these two different wall structures is the same, the earthen wall will typically have less air leakage and much more thermal mass than the wood-framed one.

Stud-Framed 2 x 6 Wall R-Values

Component	R-Value
Fiberglass batts, 5 1/2 in. (6 in. nominal)	17.27
Siding, wood bevel	0.80
Inside air film	0.68
Plywood sheathing, 1/2 in.	0.63
Drywall, 1/2 in.	0.45
Outside air film	0.17
Total	20.00

Source: Adapted from www.coloradoenergy.org/procorner/stuff/r-values.htm

The R-value of a studded cross section is less than a studless section because every stud is a thermal break that conducts heat faster than the insulated sections. Eliminating unnecessary framing has a direct effect on a wall's overall thermal performance, in addition to reducing the amount of wood used. When framing walls on 16-inch centers, as is most common, 15% to 25% of the wall's total surface area is wood (not counting windows and doors). When framing on 24-inch centers, this number shrinks to 10% to 20%. Of course, all of this depends on how the wall is built—for example, how many window jacks, extra studs in corners, trimmers, and jack studs are installed. How well the insulation is installed (no compression and no voids, and touching all six sides of the cavity), what type of insulation is used, and air leakage will also influence whole-wall R-values.

To determine the actual R-value of the walls in your home design, use the calculator at www.ornl.gov/sci/roofs+walls/AWT/home.htm. This program allows you to specify the wall type, the cavity insulation, thickness of any foam sheathing, and exterior finish type.

Exterior rigid foam board insulation with taped seams reduces airflow and moisture migration, and adds to R-value.

The first step to controlling moisture is to shed bulk water away from the building. Grading the site to channel water away from the structure and using appropriately sized roof overhangs, gutters, and roof flashing are the major methods. However, for maximum efficiency, this principle should also be applied to dormers, windows, doors, skylights, balconies, decks, and railings. Keep even more moisture at bay by designing simple roof structures instead of complex ones, locating the building, overhangs, and landscaping to protect against prevailing winds and rain, and making sure moisture-management architectural specifications are followed.

For moisture that does manage to work its way in, have a plan in place for draining bulk moisture out of the building. Drainage planes, such as building paper installed in shingle fashion with properly installed flashing, can be effective drainage tools.

Controlling water vapor is more complicated, and every climate calls for a different strategy. Many designers and builders don't understand the vapor profiles of the wall assemblies they specify. Instead, they rely on the use of impermeable membranes, which, when breached, trap moisture in assemblies and often cause the exact problem that they were trying to avoid.

Vapor barriers and retarders, such as foil-faced insulating sheathing or extruded polystyrene (thicker than 1 inch), are two technologies used in vapor control. Vapor barriers stop the movement of water vapor or are impermeable to water vapor through the wall system they are applied to. Vapor retarders are considered semipermeable to water vapor, allowing a small, measurable amount of water vapor to pass through them. They are made from a variety of materials, including polyethylene, foil, rigid-foam insulation, and even vapor-retarding paint. When to use vapor barriers/retarders depends on a variety of climate and site factors. In general, vapor retarders are most commonly used and are most effective in the more extreme hot and cold climates, where the differences between indoor and outdoor temperatures are large and humidity is great. In cold climates, installing vapor control to the inside allows moisture to dry to the outside. In hot-humid climates, installing vapor control toward the outside of the wall assembly allows moisture to dry to the inside.

In climates where you get a bit of both seasonally or if you live in a "mixed" climate, design the wall to dry to both sides. One common approach is called the "flow-through" method, which allows water vapor to diffuse through the wall assembly without accumulating. (See Access.)

Problem Areas

A difference in temperature, air pressure, and humidity between the inside and outside of the home will create a pathway for warm, moist air, which will condense as it contacts colder surfaces. If this is not addressed quickly, moisture damage within a wall is inevitable, and the occupants may not be aware that mold spores, like rotting studs, or saturated insulation may be developing.

Pathways for airflow can result where two dissimilar materials come together in a building envelope, i.e., where the often-uneven concrete foundation ends and the wood-framed wall begins or where a recessed light fixture sits within a framed and drywalled ceiling. That's why the integration of the building materials—often more than the choice of product itself—are crucial in preventing this and other problems.

In all cases, the control mechanisms for heat, air, and moisture must work together. Additionally, wall designs, materials, and system choices need to be climate- and site-specific.

In this 1980s-era home built in Ontario, Canada, moisture-laden interior air is exfiltrating through and around an electrical outlet on an exterior wall and condensing on the back side of OSB sheathing, leading to material degradation.

Courtesy Energy, Mines, and Resources Canada & Building Science Corp.

Whole-House Mechanical Ventilation

Exhaust-only or spot ventilation systems are strategically placed exhaust fans that remove moist and polluted air. The fresh air either comes from open doors or windows or random leaks unless you have a tight house, where vents that passively open with negative air pressure can provide the needed fresh air.

Supply systems use forced-air heating or air-conditioning systems to supply fresh outdoor air through existing ductwork. These systems involve control mechanisms, and do not necessarily reduce energy consumption. Diligent use of exhaust fans is still needed.

Balanced systems capture the heat from exhaust air to condition the supply air, capturing the majority of otherwise lost energy.

The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) recommends that mechanical ventilation be no less than 50 cubic feet per minute (cfm) with 50 to 100 cfm requirements for kitchens and bathrooms.

Moisture is often easily controlled by managing it at the source. For example, perhaps the site's drainage is directing rainwater toward the home's foundation or residents aren't being diligent about using bathroom or kitchen exhaust fans, causing excessive humidity to condense on windows and rot the sills.

In "tight" houses, a controlled ventilation strategy controls air pressure but also helps maintain consistent interior humidity levels and provides fresh air to the occupants. The keys to a successful controlled ventilation strategy are to:

- Know how many cfm of air you need to move (see ASHRAE recommendation in the "Ventilation" sidebar);
- Avoid overventilating in the winter, which can increase heating needs and bills; and underventilating in the summer, which can cause rooms to be stuffy and uncomfortable;
- Provide ventilation only when the building is occupied.

Occupants want their homes to be comfortable and healthy, and not enslave them to high heating and cooling costs. Our household environment should not have to suffer for poor planning, dysfunctional designs, and a short-sighted approach to home building. By understanding the basics of how our homes operate and why they fail, we can move beyond "green building" and make superior building performance standard practice.

Access

Rachel Connor (rachel@solarenergy.org) teaches, coordinates, and develops sustainable building curricula for the online and hands-on programs at Solar Energy International (SEI • www.solarenergy.org).

Building Science Corporation • www.buildingscience.com • Building guides to various climates by Joe Lstiburek

Green from the Ground Up, by David Johnston & Scott Gibson, 2008, Paperback, 336 pages, ISBN 978-1-56158-973-9, $25 from The Taunton Press, PO Box 5506, Newtown, CT 06470 • 800-888-8286 • www.taunton.com


SMA

NO BATTERIES REQUIRED

Grid-Direct PV, Wind & Hydro-electric Systems



by Roy Butler, Ryan Mayfield, Jay Peltz & Joe Schwartz

If you have some experience with battery-based renewable energy systems, you're well aware of the power and energy that a healthy battery pack can provide. If you live off grid, batteries make it possible for you to live on that perfect piece of property beyond the reach of the utility lines. In town, being the only one on your block with electricity during a grid failure is an empowering event—cold beer never tasted so good.

But batteryless grid-tied systems have their own set of advantages. They require fewer components, operate at higher efficiency, and are significantly less expensive than battery-based systems. A batteryless system does not need batteries, a charge controller, battery interconnect and battery-to-inverter cabling, an enclosure for the batteries, and all the balance of system (BOS) assembly gear, such as enclosures, circuit breakers, and bus bars. Additionally, the AC wiring is simplified—no critical load subpanel or inverter bypass switch needs to be installed. Finally, because there are fewer components involved, batteryless grid-tied RE systems are comparatively easy for end users to understand and interact with.

These advantages, coupled with the elimination of inevitable battery replacement, make it easy to see why batteryless grid-tied systems are so popular. If your project is off-grid, you'll need batteries—period. If you live on grid, you'll want to consider a few things about your particular application to help you answer the question, "Batteries or not?"

Do I Need Batteries?

If you're considering including batteries in your grid-tied RE system, ask yourself three questions:

- How often does the grid go down at my site?
- How long does a typical utility outage last?
- How much do blackouts affect my lifestyle?

In most places, the utility grid is quite reliable and power outages are infrequent and short in duration. Exceptions are most likely in rural areas that have a lot of overhead power lines and experience regular wind or ice storms. In these situations, grid failures can be both frequent and long in duration—the power company isn't going to prioritize repairing a downed line that services only a dozen families over one in town that services hundreds.

The duration of the power outages you experience is more important to consider than the frequency. If brief power outages, say less than 15 minutes, are an annoyance when you're working on your computer, buy a small uninterruptible power supply from your neighborhood electronics store. This simple and inexpensive device will keep your computer and Internet connection alive long enough to properly shut things down and wait for the electricity to come back on. If outages last longer, such as a day or two, an appropriately sized battery-based RE system can provide backup for your critical loads, including lighting, communications, refrigeration, and even water pumping. If you experience outages that last for multiple days, a bigger battery-based RE system may be suitable to supply moderate energy demands. If you have significant loads that need to run for several days, the best approach may be to invest in an engine generator that can either meet all your loads or be run periodically to recharge batteries.

The final consideration is how much the power outages you experience at home affect your lifestyle. If the grid only goes down a few times a year for a couple of minutes and you don't consider resetting your clocks to be a big inconvenience, then a batteryless grid-tied system is a great fit. However, if you work from home and need reliable electricity, frequent or long-lasting power outages can significantly impact your productivity. In this case, a battery-based RE system is an excellent option. Finally, some people see the occasional power outage as fun—the kids think it's an adventure and you can settle down to a nice candlelight dinner, which is better than dealing with a bank of batteries any day.

If you decide that batteryless grid-tied RE is the way to go, the next question is, "Solar, wind, or water?" The following pages detail important considerations for each system type.

System Performance— Batteries vs. Batteryless

In terms of performance, batteryless systems will generate more energy than battery-based ones. How much more will depend on the charging source (solar, wind, or hydro-electric), and the power-conditioning equipment (inverters and controllers) used. The condition of the battery pack and how frequently and deeply the battery pack is cycled comes into play too. Some energy, in the range of 5% to 20%, will be lost in the electrical-to-chemical storage process that takes place when charging batteries. But because batteries are rarely cycled in most battery-based grid-tied PV systems, the overall system efficiency hit can be pretty minimal (5% to 10%) if high-quality equipment is used. Batteryless wind systems can significantly outproduce battery-based ones due to some interesting electrical details covered in the following pages.

Access

Joe Schwartz (joe.schwartz@homepower.com), Home Power Inc. CEO and editor, lives off the grid outside of Ashland, Oregon. All the electricity used on his homestead comes from the sun. He recently swapped out a set of 10-year-old flooded lead-acid batteries (still in working condition) for a bank of sealed AGMs to see how they compare in terms of off-grid service.

A wide selection of batteryless inverters are available to suit your specific grid-tied renewable energy application.

GRID-DIRECT PV SYSTEMS

by Ryan Mayfield

It's no wonder that the overwhelming majority of PV systems installed in the United States today are batteryless grid-tied systems. With only three main components—the modules, inverters, and production meter—these systems are more efficient, and less complex and expensive, than their battery-based counterparts.

Complexity & Expense

Compared to a batteryless grid-tied PV system, an installed grid-tied PV system with battery backup may be 20% to 40% more expensive depending upon the storage capacity of the battery bank. Besides the higher up-front expense of a battery-based system, in most situations, the batteries will need to be replaced every seven to eight years. This additional cost further reduces the economic viability of a grid-tied PV system with battery backup. It also is difficult to predict the future costs for batteries as the prices for lead have quadrupled over the last five years alone.

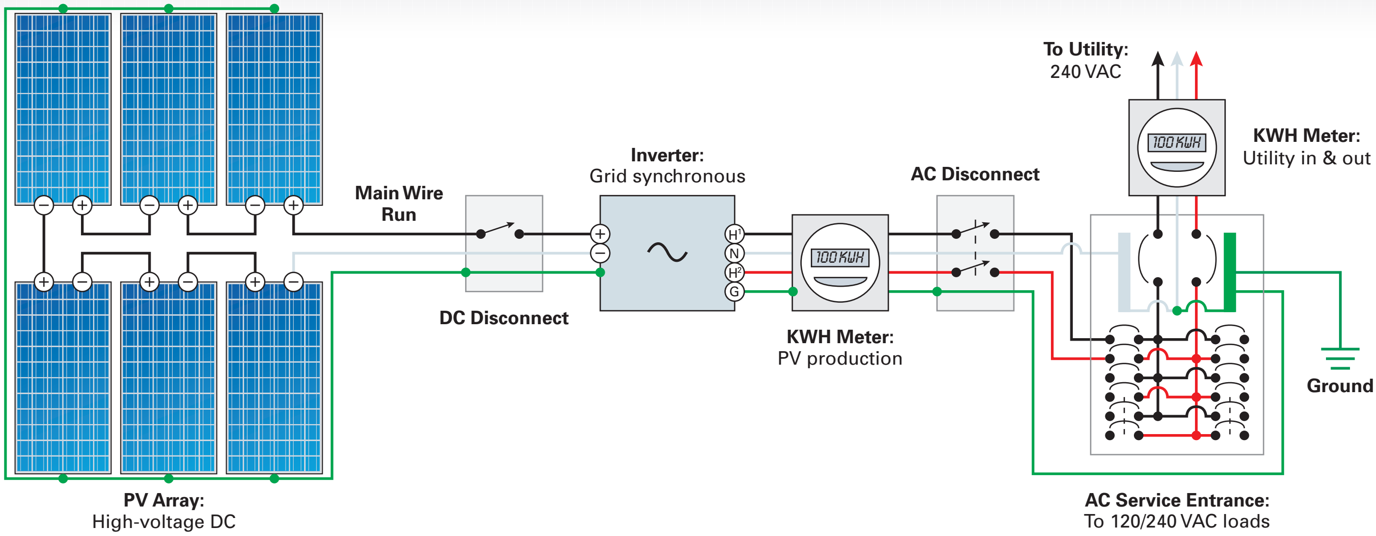
Batteryless grid-tied PV systems are commonly wired at high DC voltages (120 to 600 VDC), due to the voltage input requirements of the batteryless inverters. Wiring arrays for high voltage reduces the amount of current the wires must carry, which also reduces the wiring expense, since smaller-gauge wire can be used, along with smaller conduit and conduit fittings. Also, because grid-tied PV arrays are wired for higher voltages (which means more modules in series and fewer modules in parallel), this can reduce and sometimes eliminate the need for combiner boxes and series fuses.

System Efficiency

All PV systems have inherent losses due to temperature, module soiling, inverter efficiency, and transmission. But when you add a battery bank to this system, the necessity of keeping batteries fully charged and ready to supply backup energy takes a toll on overall system efficiency. A modern grid-tied system with battery backup will be 5% to 10% less efficient than a batteryless grid-tied system. These efficiency losses depend in part on the type of charge controller and inverter used, and how deeply and how often the batteries are cycled. One way to increase the efficiency of a battery-based PV system is to use a maximum power point tracking (MPPT) charge controller and avoid using older battery-based grid-tied inverters that are designed to float-charge the batteries overnight.

The power-conditioning and utility-feed components of a grid-direct PV system.

Typical Grid-Direct PV System



Battery Limitations & Maintenance

Most on-grid systems with battery backup use relatively small battery banks. When determining battery capacity, either the space available for the battery bank limits the amount of backup or the desired storage capacity drives the size of the battery bank. The decisions faced are similar to sizing battery capacity in off-grid systems, where days without solar are weighed against reliance on a backup engine generator. The up-front cost of battery banks of various capacities and quality will come into play too. But using a small bank will restrict the number of backup loads and/or the amount of time the backup loads can run. For example, a 48 V, 100 AH battery bank may only be able to deliver about 3.5 KWH to the loads. Roughly speaking, this amount of stored energy could power an efficient refrigerator, and some lighting and home electronics for 24 hours or so if the bank was discharged to a recommended maximum of 80%, with 20% capacity remaining.

Compared to battery-based PV systems, grid-direct systems require little or no maintenance. However, many small-scale battery backup systems now use sealed lead-acid batteries, which eliminates the need for regular watering, reducing maintenance requirements. If flooded lead-acid batteries are used, be prepared for regular maintenance, such as checking electrolyte levels and adding distilled water.

Batteries Later?

Another option for batteryless grid-tied PV system owners is to add batteries later without having to completely rewire the PV array or swap out an already-installed grid-direct inverter. This "AC-coupling" strategy synchronizes the AC output of a batteryless inverter to a utility-interactive battery-based inverter. If utility power fails, both inverters are disconnected from the grid as required, but unlike strictly batteryless systems, the grid-direct inverter will continue to capture solar energy for household loads and route excess energy to charge the battery bank. If the PV system is generating more power than is required by the load or battery bank, the output of the batteryless inverter is stopped, ramped down, or routed to a diversion load like an air or water heater. The exact control approach depends on the equipment used.

Inverter manufacturer SMA America pioneered AC-coupled systems. During a utility outage, the battery-based inverter controls the output level of the batteryless inverters based on load demand. However, many systems have been installed that use a variety of batteryless inverters AC coupled to utility-interactive battery-based inverters manufactured by OutBack and Xantrex.

An AC-coupled approach still requires purchasing a utility-interactive battery-based inverter, and a battery bank and all the accompanying battery BOS components. It also requires installing a critical load panel. However, the existing PV array and grid-tied inverter (and its higher efficiency) can then be utilized with the security of a battery bank for backup power.

Access

Ryan Mayfield (ryan@renewableassociates.com) has a degree in environmental engineering from Humboldt State University and lives in Corvallis, Oregon. He teaches PV classes at Lane Community College and Solar Energy International, and is a principal at Renewable Energy Associates, a firm focusing on PV system design, implementation, commissioning, and industry-related training. He holds a renewable energy technician license in Oregon.

Batteryless Grid-Tie Inverters:

Fronius • www.fronius-usa.com

Kaco • www.kacosolar.com

Magnetek • www.magnetek.com

PV Powered • www.pvpowered.com

SMA America • www.sma-america.com

Solectria • www.solren.com

Xantrex • www.xantrex.com

Battery-Based Grid-Tie Inverters:

OutBack Power Systems • www.outbackpower.com

SMA America • www.sma-america.com

Xantrex • www.xantrex.com

GRID-DIRECT WIND SYSTEMS

by Roy Butler

Direct grid-tie, batteryless wind systems are the fastest-growing segment of the U.S. small wind market. This growth is being fueled by demand for simpler, more efficient systems and incentive programs that compensate owners for the amount of energy their system produces. Wind turbines were previously used mostly by off-gridders, but the new market for residential-scale wind turbines is primarily for grid-tie applications.

Batteries or No?

The same arguments for batteryless grid-tied PV systems also apply to wind systems. Additionally, most direct grid-tie turbines are configured for higher voltages than their battery-charging counterparts (typically above 200 VDC, compared to 12 to 48 VDC nominal). These high-voltage turbines allow the use of smaller transmission wiring, which significantly reduces wire and conduit cost.

Batteryless wind systems offer an increase in operating efficiency that results in higher overall energy production compared to battery-based systems. Most grid-direct systems use a batteryless inverter with maximum power point tracking (MPPT) capability, which maximizes turbine output and can increase overall system production by 20% to 50% depending on turbine and wind conditions at the site.

Inverters for Grid-Direct Wind Systems

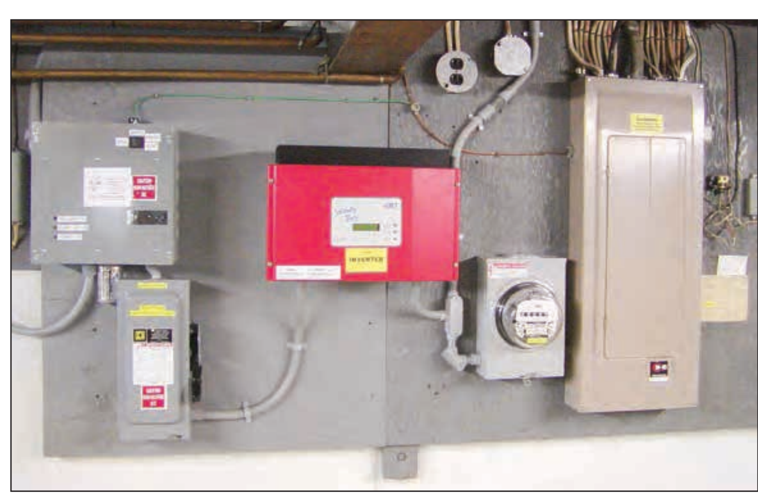
There are several models of batteryless grid-tie inverters for residential-scale wind systems. The best known is SMA America's Windy Boy, essentially a Sunny Boy PV inverter with firmware modifications that allow the MPPT function to work with the rapid voltage fluctuations unique to wind turbines. Several turbine manufacturers, including Abundant Renewable Energy (ARE) and Proven Wind Energy, have developed grid-direct systems using this inverter.

The Windy Boy requires an interface between the wind turbine and the inverter to protect it from overvoltage damage. The typical interface is a voltage clamp that consists of a rectifier to convert the turbine's wild (unregulated) three-phase AC output to DC, and a control circuit to divert energy to a diversion load—typically an air- or water-heating element.

The potential for overvoltage exists when the turbine is producing in high winds and the inverter is not connected to the grid due to a utility outage, or during the turbine start-up phase. In the event of a utility outage, the voltage clamp sends all power produced to the diversion load, preventing turbine overspeed and protecting the inverter. During the start-up phase, a pulse-width modulation (PWM) circuit sends some energy to the diversion load to keep the voltage within the inverter's DC input window.

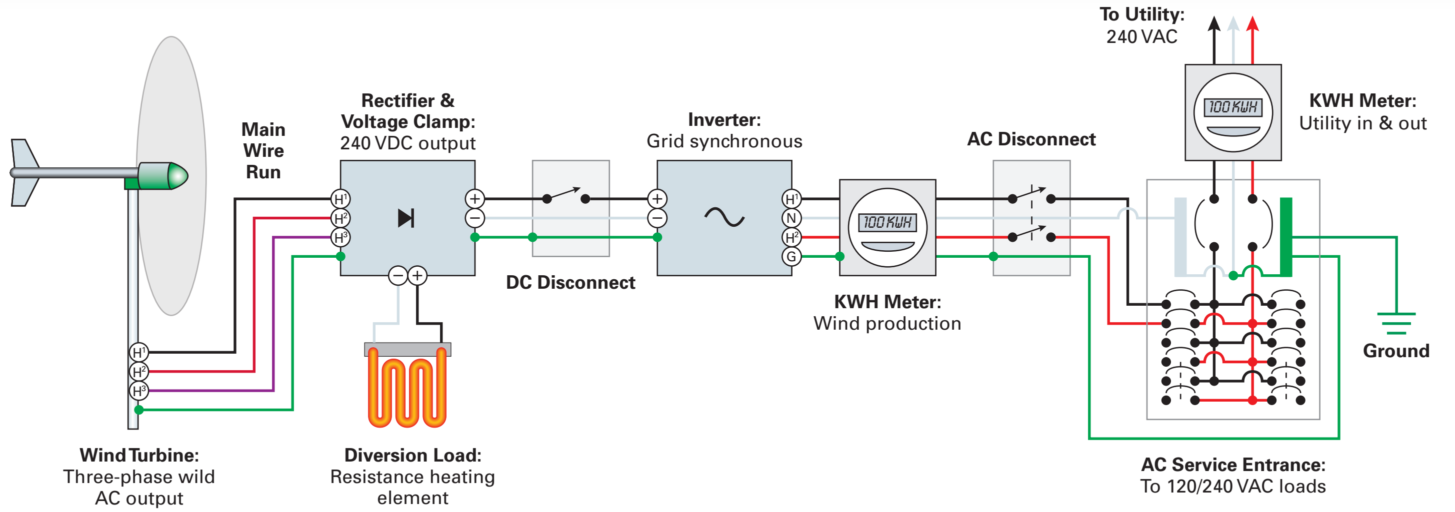
The ARE110 and ARE442 turbines use this type of voltage clamp and diversion load assembly. The Proven WT2.5 uses mechanical turbine governing instead of a voltage clamp assembly to keep the voltage in range. Kestrel turbines, distributed by DC Power Systems, have a proprietary control package for grid-direct applications. Eoltec turbines use the Aurora inverter manufactured by Magnetek. The Aurora is a true MPPT inverter with wind interface functionality that acts as a voltage clamp. Additionally, the inverter can be programmed to optimize the power curve to match the output of a specific wind turbine. The Bergey Excel uses the Grid Tek 10 inverter, which loads the turbine to the maximum safe power point at any given rpm.

Resistance air-heater diversion load, with protective guard removed to show the resistors.



A typical power wall configuration for a grid-direct wind power system.

Typical Grid-Direct Wind System



Specialized Grid-Direct Turbines

The S250 turbine by Endurance Wind Power does not use an inverter to interface with the grid. The S250 is an induction machine, similar in design to medium and large utility-scale wind turbines that use a speed increaser drivetrain to spin the generator above synchronous speed. This allows 60-hertz power to be delivered directly from the generator to the grid without the need for power conditioning or conversion. The overall efficiency between rotor power and grid-compatible electrical power is about 75% at 10% of rated output and 85% at rated output of 5 KW. An internal disc-brake system protects the turbine from overspeed if grid power is lost.

Southwest Windpower's Skystream turbine has an inverter integrated into the body of the turbine itself. The turbine's output is grid-synchronous 240 VAC that can be fed directly to a home's main load center. The turbine uses electronic stall regulation that begins to slow the blades when the rotor speed exceeds 360 rpm.

Maximum Power Point Tracking & Grid-Direct Wind Systems

Most batteryless wind systems use an inverter with maximum power point tracking (MPPT) to maximize system output. The inverter's MPPT algorithm allows the blades to spin at the ideal rpm and still produce the output voltage within the inverter's required range. Wind generator blades have a maximum efficiency at a specific ratio of blade-tip speed to wind speed. This is referred to as the tip/speed ratio (TSR). For example, if a turbine's blades have maximum efficiency at a TSR of 6 and the wind is blowing at 10 mph, the blade-tip speed should be at 60 mph (6 x 10) for best results.

A wind turbine's permanent-magnet alternator has an open-circuit voltage (no load) that increases with rpm. But doubling the turbine's rpm does not double the output voltage—the relationship is not completely linear. This is where the inverter's MPPT comes into play. It controls the load on the wind generator to keep the blades spinning at their optimal TSR and converts the voltage output of the wind generator to the voltage required for the inverter. Think of it as a variable-speed transmission for voltage, allowing the blades and alternator to operate at their maximum efficiency.

—Robert Preus

Access

Roy Butler (roy.butler@homepower.com) is a technical editor for *Home Power* and owner of Four Winds Renewable Energy in Arkport, New York. Roy is a NABCEP-certified PV installer. He sits on the NABCEP technical review committee for PV and wind system installer certification, as well as the Small Wind Certification Council board of directors.

Wind Turbine Manufacturers:

Abundant Renewable Energy • www.abundantre.com

Bergey Windpower Co. • www.bergey.com

Endurance Wind Power • www.endurancewindpower.com

Eoltec • www.pineridgeproducts.com • www.solacity.com

Kestrel • www.dcpower-systems.com

Proven • www.provenenergy.co.uk

Southwest Windpower • www.windenergy.com

Grid-Direct Inverters for Wind Systems:

SMA America • www.sma-america.com

Magnetek • www.magnetek.com

GRID-DIRECT LOW-POWER MICROHYDRO SYSTEMS

by Jay Peltz & Joe Schwartz

When people think of grid-connected hydro electricity, images of something really big—like Hoover Dam—come to mind. But on a residential scale, high-power AC-direct hydro turbines in the 10 to 25 KW range have been feeding electricity to the grid for decades. What is new in the hydro world is coupling batteryless inverters to low-power microhydro turbines generating anywhere from 500 to 4,000 W for grid-tied applications.

Batteryless Microhydro Basics

Like PV and wind systems, microhydro systems can be battery-based or batteryless, depending on your needs and specific site conditions. In the past, home-scale batteryless hydro systems were high-power units where the hydro plant and controller interfaced directly with the utility grid without an inverter. With the advent of modern batteryless inverters, hydro system designers have been pushing the envelope and installing systems using low-power hydro turbines that can feed the grid without including batteries in the system. (For more information on AC hydro turbines, see page 68 of this issue.)

The success of a low-power grid-direct microhydro system relies on matching a batteryless inverter to the hydro site's characteristics (head and flow), the output of the specific hydro turbine, and its voltage and power compatibility. Additional design aspects come into play. To control voltage and rpm, hydro turbines must be electrically loaded at all times. In grid-tied applications, diversion control is needed to shunt the turbine's output to a dump load in the event of a utility outage. A voltage clamp to eliminate a voltage spike in the case of grid failure is required in many systems to protect inverters. Currently, the only controllers available for batteryless hydro applications are ones originally designed for batteryless wind systems.

Batteryless Hydro Evolution

One of the earliest low-power batteryless hydro systems installed in the United States was covered in *HP80* in 2001. Installer Kurt Johnson designed an innovative system in North Carolina comprised of a Harris Hydro turbine that fed 57 VDC to an Advanced Energy Systems GC-1000 inverter. A Trace C-40 charge controller and an air-heater diversion load kept the turbine electrically loaded and its rpm regulated when the grid went down. System output ranged between 200 and 400 W depending on the seasonal creek's flow rate. (See the original article at www.homepower.com/johnsonhydro.)

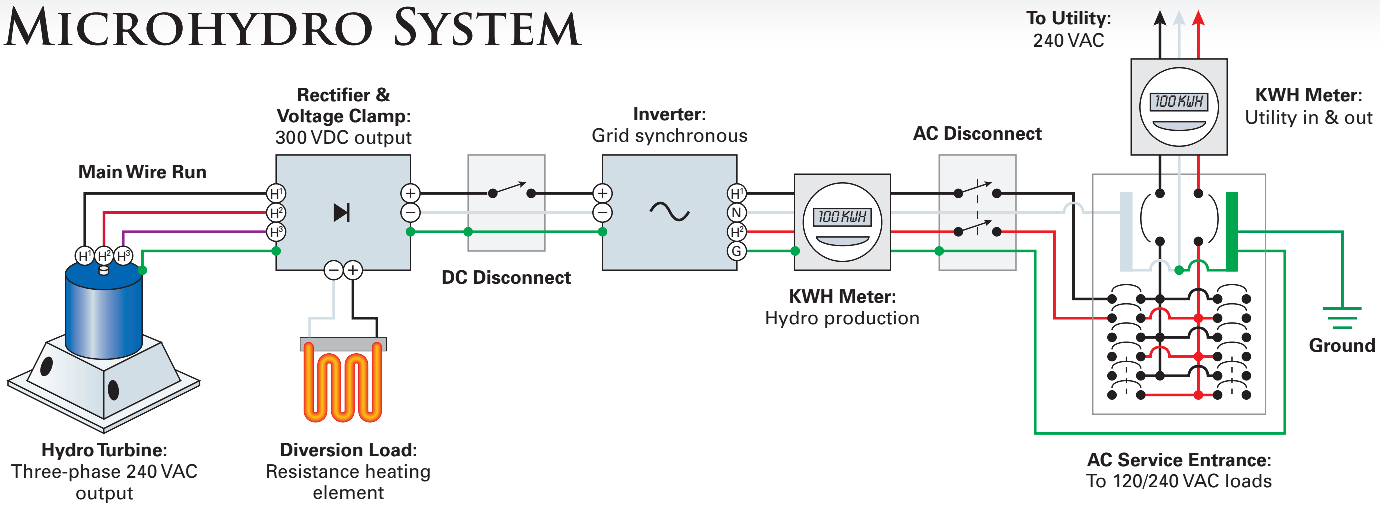
There wasn't much further movement in the low-power batteryless microhydro world until 2006, when Jeff Clearwater from Village Power Design teamed up with Derik Veenhuis from Hi Power Hydro to design and install a batteryless system in Colorado. The water source delivers approximately 70 gpm at 110 psi to two 2.3 KW Hi Power turbines. Each turbine is paired with an SMA America 2.5 KW Sunny Boy inverter. Turbine output is three-phase 240 VAC that is rectified to 300 VDC in the power room and fed to the Sunny Boys. The inverter manufacturer tweaked the inverters' software, lowering the start-up voltage from 300 to 240 VDC to ensure smooth operation with the turbines. Because the inverters have a maximum open-circuit design voltage of 600 volts, controllers manufactured originally for wind turbines by Abundant Renewable Energy were installed to limit output voltage and divert hydro electricity

Two 2.3 KW Hi Power turbines feed 100-plus KWH a day directly to the grid.

This microhydro system uses two SMA inverters and two ARE controllers, originally built for grid-direct wind systems.

Courtesy: www.nesolardesign.com (2)

Typical Grid-Direct Low-Power Microhydro System



to air-heating loads when utility power fails. Combined, the two turbines generate 4.4 KW continuous and feed 106 KWH a day directly to the grid.

Turbines, Inverters & Controls

There are no special hydro inverters on the market, but some off-the-shelf PV inverters can be used. The critical design component of low-power batteryless hydro systems is matching the turbine output voltage with a specific batteryless inverter. Low-power turbines come in two basic designs—lower-voltage DC alternators and AC alternators that produce unregulated three-phase AC power. The turbine output voltage is the main consideration when investigating a compatible inverter.

DC turbines are manufactured with nominal outputs of 12 to 120 VDC. The trick is selecting a turbine with a high enough voltage to meet the inverter's input voltage requirements. For example, PV Powered manufactures two batteryless inverter models (PVP1100 and PVP2000) that have operating voltage ranges between 115 and 450 VDC, with a maximum voltage limit of 500 VDC. A 96-volt nominal DC turbine will output approximately 120 VDC—enough voltage to integrate with the PV Powered inverters. If the turbine happened to become unloaded electrically during a grid failure and the rpm and output voltage increased, the inverter would not be damaged due to its 500 VDC maximum input voltage. With this design approach, a voltage clamp may not be necessary, but a diversion load should be included so the turbine does not run in an unloaded state for long periods of time. Batteryless inverters with lower input voltages are not currently being manufactured, but discontinued inverter models like the Xantrex SunTie (48 VDC nominal input voltage) can still be found online and used with 48 VDC nominal hydro turbines.

Alternatively, turbines with three-phase AC alternators can be configured for up to 480 VAC nominal output. Compared to lower-voltage DC turbines, the higher voltage makes it easier to integrate them with a variety of batteryless inverters designed for PV arrays operating at up to 600 VDC. The three-phase AC output is rectified to high-voltage DC, and then routed to the inverter. A controller with both diversion load and voltage clamping capability is required to eliminate the possibility of excessive system voltage if utility power fails.

Experience Required

Compared to grid-direct PV or wind systems, low-power batteryless microhydro is still an underdeveloped technology. That's not to say that the equipment and system designs are unreliable, but the limited number of installations to date reflects a general unfamiliarity with these efficient and durable systems. If you're considering a low-power batteryless hydro project, work with the hydro manufacturer to make sure that the turbine and the inverter will couple well. Matching turbines to inverters can be challenging, so experience is crucial.

Over the last decade there has been continual growth of batteryless renewable energy systems, related equipment, and design and installation expertise. Batteryless PV systems now dominate that market, batteryless wind systems are becoming very popular, and soon batteryless low-power hydro systems will likely become a common feature in the microhydro landscape.

Access

Jay Peltz (jay.peltz@gmail.com) is owner of Peltz Power, an RE design and installation company based in Redway, California. Jay specializes in off-grid PV, wind, and hydro-electric systems. He is currently working on one of the first residential-scale, grid-direct, low-power hydro systems in California.

Joe Schwartz • joe.schwartz@homepower.com

Low-Power Hydro Turbine Manufacturers:

Alternative Power & Machine • www.apmhydro.com

Energy Systems & Design • www.microhydropower.com

Harris Hydro • 707-986-7771

Hi Power Hydro • www.hipowerhydro.com

Voltage Clamp Controls:

Abundant Renewable Energy • www.abundantre.com

UNDER CONTROL

SOLAR WATER HEATING

by Chuck Marken & Doug Puffer

The kind of thermostat you're probably most familiar with—an ordinary room thermostat—works great atº keeping our homes and offices comfortable. Set the thermostat and it will keep the temperature hovering around the setting. Conventional water heaters have a similar thermostat that keeps the temperature of the water where the thermostat is set. But solar water heaters need more sophisticated controls to utilize solar energy most efficiently.

To get all the solar energy we can when it's available and needed, we have to measure the sun's energy and simultaneously measure the water temperature in the water heater or solar storage tank. When the solar-heated water (or, in some systems, the antifreeze solution) in the solar collector will *add* heat to the tank, we want a pump to turn on and move the warmer water from the collector to the tank. Measuring two temperatures at once and cueing a pump based on the temperature difference is a job for a differential thermostat—a.k.a. differential controller.

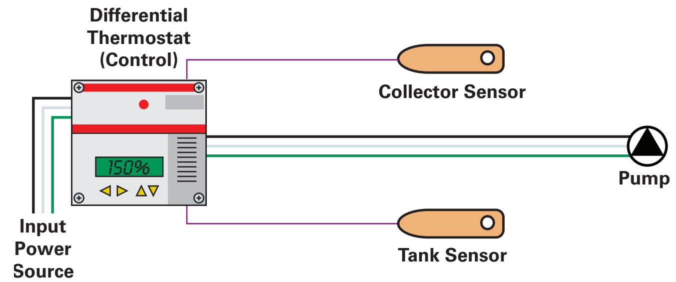
Multiple Controllers & Simple Priority

Most controllers incorporate a double-throw relay with three contacts—common (C), normally open (NO), and normally closed (NC). The differential thermostat's sensor circuit controls the relay. Electricity is always connected to the common terminal. The installer will normally connect the pump(s) to the NO terminal. Wiring the hot, neutral, and ground wires correctly will complete the high-voltage side of the controller wiring. The sensor wiring is on the low-voltage side. If a second control is needed for another pump, valve, or device, but the design calls for only one controller to be activated at a time, the NC terminal can be wired to the input of the second control. This gives the two controls a priority arrangement. When the first control's sensors energize the NO contact and the pump, the relay disconnects the NC contact. The second control has no power and cannot energize any devices it controls. When the first control is not energized (off due to hitting the high limit, for example), the second control uses the sensors that are attached to it and responds appropriately.

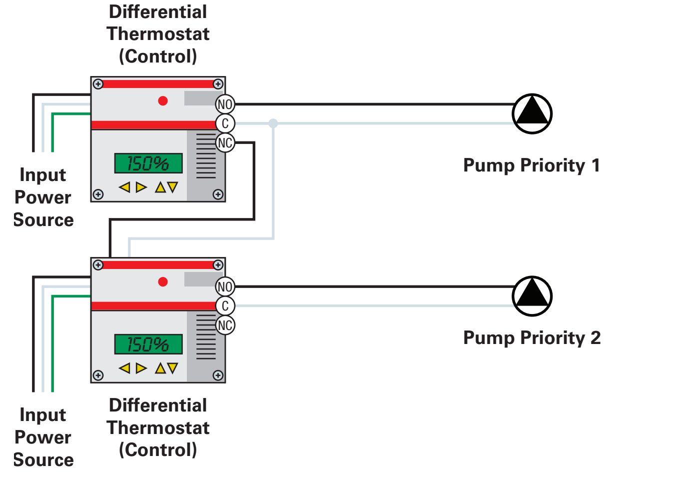
Getting Control

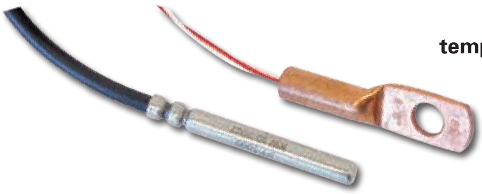
Differential thermostats have two sensors that are constantly monitored by the electronics in the controller, which turns equipment on and off based on the temperature differential. When the controller determines that one sensor is warmer than the other sensor, it energizes a relay (an electromagnetic switch) that can activate an electric device, usually a circulator pump. When not enough difference in temperature exists, the differential thermostat turns off the pump or other device.

Basic Controller Operation



Dual Controller Priority Operation





Typical 10K ohm temperature sensors.

In a solar hot water (SHW) system, one sensor (known as the "hot" or "collector" sensor) is placed on the piping, very close to the collector's outlet, and the other sensor (the "cold" or "storage" sensor) is placed near the bottom of the storage tank where the water is coolest. Sun shining on the collectors causes the outlet temperature to increase quickly. The sensor's resistance will change (see discussion of sensors below) and the controller's electronic circuits will activate the relay, turning on the pump. When solar energy eventually lessens on the collectors, or the storage tank water becomes hot enough, a large "differential" will no longer exist between the two sensors, and the thermostat will shut off the pump.

Making Sense of Sensors

The sensors that measure temperatures for a differential thermostat are thermistors, a type of resistor with resistance that varies with temperature. The industry standard in the United States is a 10,000-ohm inverse thermistor, which measures 10K ohms at 77°F. As the temperature rises, the resistance drops, hence the "inverse" designation.

You can't mix sensors of one value with a controller designed for a different sensor, and beware—not all 10K sensors are the same. Each thermistor has a "curve" of resistance at changing temperatures. To ensure two sensors are equal, you need to compare the curves and verify they are the same. If resistance curves are too different, they can cause the control to have imprecise on and off differentials. Some thermostats require different sensors—make sure the sensors used are compatible with the chosen controller.

Care should be taken in how and where the sensors are placed. The collector output sensor should be placed within 1 inch of the collector, clamped to the hot pipe going to the storage tank. Clamp the flat part of the sensor to the collector tube with a hose clamp and insulate it well with closed-cell, high-temperature insulation. If the sensor has no flat section, don't clamp it so tightly that it will crush the sensor housing—thermistors are much smaller than their housing and are delicate. Manufacturers typically house the sensors in metal cylinders, usually copper, and encapsulate the thermistors to protect them from water and weather.

The tank (or storage) sensor should be placed inside the bottom access cover on the tank—behind the insulation and making direct contact with the tank. It may also be clamped to the tank drain valve if it can be insulated. Some solar tanks have a threaded lug at their bottom where a sensor can be bolted. Incorrect sensor placement will create an inefficient system, causing a pump to run when it shouldn't or not run when it should. Individual controller manufacturers may have specific instructions for sensor placement.

Solar Pool Heating Controllers

Controllers for solar-heated swimming pools are very similar to SHW differential thermostats. Pool systems have much higher flows than domestic solar hot water systems, and the on and off differentials are adjusted for this. The typical on-differential of a pool control is about 5°F, with the off differential being just 2°F. Pool differential thermostats usually control a three-port motorized valve that diverts the pool water to the collectors when the on-differential is reached. Pool pump timers are set to filter only in the daylight hours when the sun can heat the pool. As long as the sun-heated pool collectors can add heat to the pool, the differential will keep the valve positioned to divert water to the collectors.

SunEarth's digital flow meter helps you keep tabs on your system's operation.

Setting the Differential

Parasitic loss occurs when energy is consumed or lost in order for a system to make more energy. A good example of a parasitic loss is the amount of energy that bearing friction consumes in the common internal combustion engine. In grid-powered SHW systems, the pumps and controllers take a certain amount of electrical energy to operate, and there are some heat losses through the piping and other points in the system. If the parasitic losses are greater than the solar energy being put into the SHW system, a net loss of energy results.

In PV-direct DC systems, the pump energy losses are inconsequential because the energy from the PV module is there regardless, and at no cost. But in AC systems, a wider temperature differential is used to ensure that the parasitic losses are not greater than the solar energy gained. Many manufacturers set their AC controllers with a 4°F or 6°F turn-off differential. With any smaller differential, there is no net energy gain because of parasitic pump consumption and system heat loss. Any greater differential would waste valuable solar energy by turning the pump off too soon. Since there is no utility-generated parasitic power consumed with a PV-powered DC differential control, the turn-off differential is lower—sometimes zero is appropriate if the pipe losses are negligible.

The pump turn-on differential is usually adjustable in both AC and DC controllers. The turn-on differential is set higher than the turn-off to make sure that the solar input can be sufficiently maintained to add heat to the tank and to avoid excessive on–off pump cycling. With minimal sun, the collector temperature will increase somewhat. But the possibility is that when the pump goes on, the temperature won't be maintained when the barely warm liquid from the bottom of the collector reaches the sensor at the top. A higher turn-on differential makes that possibility less likely,

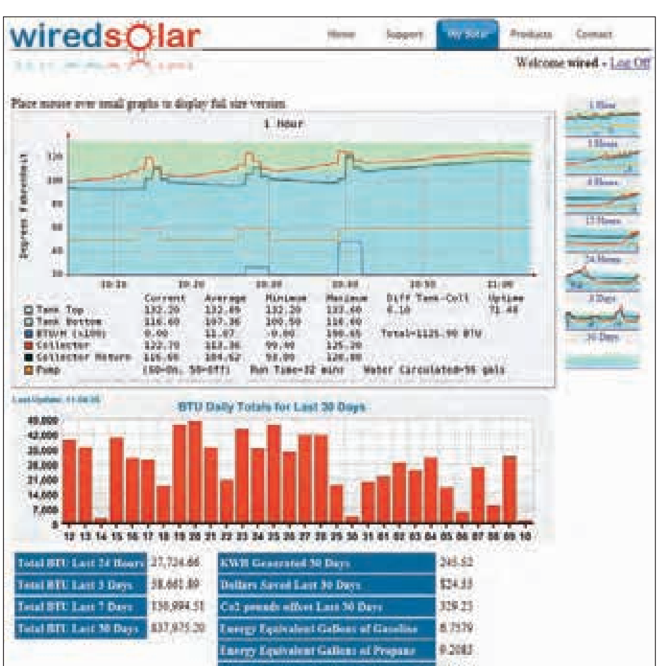
ArtTec's DC differential controller, suitable for PV-direct pump operation.

and decreases the likelihood that the system will cycle on–off repeatedly during times of reduced solar input, like during the morning and evening.

A low turn-on differential setting (8°F to 10°F) is most efficient for direct forced-circulation systems that don't have a heat exchanger. A somewhat higher differential setting (14°F to 18°F) is recommended for indirect forced-circulation systems (antifreeze and drainback) with heat exchangers. This is because these systems have higher pipe and system heat losses, making it necessary to assure enough heat input to overcome those losses before turning the pump on.

The Basics & Beyond

A basic differential controller needs only an input power source, an output, and two sensors. A few such basic units were made in the past—they didn't even have a single LED to



IMC Instruments's Eagle 2 differential controller works with a transceiver (above) to send system data to the Web (left).

Table Specs & Definitions

Voltage In—Voltages for input to the control

Voltage Out—Output voltage and options

Power Out—Given in amps or hp, and specified by the manufacturer; tells what size pump or other equipment can be powered directly by the controller. Larger pumps will require added, higher-capacity relays.

Unit Power Consumption—What the control uses in power; both standby and energized are noted

Sensor Ohms—Sensor resistance at 77°F

On-Differential—Difference in temperature when the control turns the pump on

Off-Differential—Difference in temperature when the control turns the pump off

High Limit—Tank temperature that turns the pump off. Some controllers do not have this option.

Low Limit—Low tank temperature that turns the pump off

Recirculation—A freeze-protection feature that will turn on the pump and circulate storage tank water through the collector to keep it from freezing

Overtemperature Protection (a.k.a. "vacation mode")—A feature that activates the circulator pump at night to circulate cooler water from the collectors to lower the storage tank temperature. Some controllers feature a diversion load for overtemperature protection.

Number of Differentials—Most controllers have a single differential, but some have more than one to control two pumps at different times. For example, one differential would control a collector loop pump heating a tank; another differential would control a pump heating the domestic hot water, if the large tank was hot enough.

Digital Display—Any option for digital display of temperature

Data-Logging Capability—Capability of the control to be connected to a computer and/or data logger to record performance

Remote Monitor—A feature to add a remote digital display for ease of monitoring operation

Warranty—Full or limited; length of warranty

Street Price—Estimated retail price

indicate if the unit was on. In the past, thousands of these basic thermostats had been produced—many are still working after twenty years or more of service.

The controllers listed in the guide have many more features than this basic design. LED lights are useful to indicate the control and system status, but digital displays are now common. Another popular feature is multiple differentials—the ability to control two or more pumps at different times is used in systems supplying both domestic hot water and space heating.

The Lineup

Our table of differential thermostats includes all of the U.S. manufacturers and six overseas products that are available in North America. Control freaks and data junkies are sure to be happy with recent innovations in some controllers. Lots of goodies are available—digital displays, remote displays, computer interfaces, and data logging capabilities. Even if you're not a number nerd, you'll find many of the new features handy.

Left: IMC Instruments's remote display for its controller.

Bottom: SunEarth's differential controller provides a graphical digital readout.

SOLAR HOT WATER CONTROLLER

U.S.-Made AC Controllers	Model	No. of Differ-entials Included	Power Draw Standby / Running (Watts)	Voltage In (AC)	Voltage Out (AC)	Max Current Out (Amps)	Sensor Resistance at 77°F
Hayward/Goldline	GL-30	1	<1 / <2	120/240	120/240	20	10K
Heliodyne	Delta T (DTT-85)	1	<6	120	120	2	10K
Heliodyne	Delta T Pro (DTT-95)	4	<6	120/240	120/240	4.45	10K
IMC	SOLR-1EHW-30	1	2	120	120	30	10K
IMC	SOLR-2EHW-30	1	2	120	120	30	10K
IMC	SOLR-2EIW-30	1	2	120	120	30	10K
Imported AC Controllers							
Resol (Caleffi)**	BS/1 (257 iSolar 1)	1	<1 / <3	120	120	2	1K
Resol (Caleffi)	BS/2 (257 iSolar 2)	1	<1 / <3	120	120	2	1K
Resol (Caleffi)	BS/3 (257 iSolar 3)	1	<1 / <3	120	120	2	1K
Resol (Caleffi)	BS/4 (257 iSolar 4)	1	<1 / <3	120	120	2	1K
Resol (Caleffi)	BS Plus (257 iSolar Plus)	2	<1 / <3	120	120	2	1K
Steca (SunEarth)*	TR0301U	1	<1	120	120	3.47	1K
Steca	TR0502U	2	<4	120	120	3.47	1K
Steca	TR0603mcU	3	<4	120	120	3.47	1K
Tekmar	D155	1	NA	24 VAC / 30 VDC	120/240	10	10K
Tekmar	D156	1	NA	24 VAC / VDC	240	10	10K
Tekmar	D157	2	NA	24 VAC	120	5	10K
Thermomax	SMT 100	1	6.6 / NA	110	110	3	100
Thermomax	SMT 400	3	5.72 / NA	110	110	5.5	100
Viessmann (Resol)	Vitsolic 200	4	6	120	120	10	500
DC Controllers							
ArtTec	DTC-1	1	.036 / .3	3.5-30 VDC	3.5-30VDC	6	10K
Caleffi	257 iSolar 1 DC	1	<1 / <1.4	24 VDC	24 VDC	2	1K
Caleffi	257 iSolar Plus DC	2	<1 / <1.4	24 VDC	24 VDC	2	1K
IMC	SOLR-2EDW-D1	1	1.5	10-15 VDC	10-15 VDC	6	10K
IMC	SOLR-2EDW-D2	1	.25	7-24 VDC	7-24 VDC	20	10k
Pool Controllers							
Hayward/Goldline	GL-235	1	<10 / <60	120/240	12/24 option: 120/240	20	10K
Hayward/Goldline	AQ-SOL-LV (-TC)	1	<10 / <60	120/240	24 option: 120/240	20	10K
Heliotrope Pools	HM 4000D	1	NA	110/220	12/24	2	10K
Heliotrope Pools	HM 5000D	1	NA	120/240	12/24 VAC	2	10K
Pentair	SunTouch	1	NA	120/240	120, 277	20	10k

*Steca produces a unit that SunEarth markets. **Resol produces units that are sold by SunSpot Solar, Caleffi, Viessmann, Apricus, and Thermomax. Note that specifications for some controllers were not available.

BUYER'S GUIDE

On-Differential (°F)	Off-Differential (°F)	High Limit (°F)	Low Limit (°F)	Recirc-ulation	Overtemp. Regulation	Data Logging	Remote Monitor	Digital Display	Warranty (Years)	Sug-gested Price
8–24	4	110–230	110–230	Yes	No	No	No	Option	3	$159
5–18	4-9	180	80	Yes	No	No	No	No	1	158
Adjustable	Adjustable	Adjustable	>70	Yes	Yes	Yes	Option	Option	1	296
8–24	4	110–200	50–70	Yes	Yes	Option	Option	No	5	172
8–24	4	110–200	50–70	Yes	Yes	Option	Option	Yes	5	203
8–24	4	110–200	50–70	Yes	Yes	Option	Option	Yes	5	227
2-40	1-38	50–195	15–50	Yes	Yes	Yes	Yes	Yes	2	$450
2-40	1-38	50–195	15–50	Yes	Yes	Yes	Yes	Yes	2	500
2–40	1–38	50–195	15–50	Yes	Yes	Yes	Yes	Yes	2	550
2–40	1–38	50–195	15–50	Yes	Yes	Yes	Yes	Yes	2	605
2–40	1–38	50–195	15–50	Yes	Yes	Yes	Yes	Yes	2	760
16	8	266	NA	Yes	Yes	No	No	Yes	2	179
4–100	0–96	68–356	32	Yes	Yes	Yes	No	Yes	2	NA
4–100	0–96	68–356	32	Yes	Yes	Yes	Option	Yes	2	NA
2–90	2–45	-4–248	-22–185	Yes	Yes	Yes	No	Yes	2	NA
20–90	2–45	-4–284	-22–185	Yes	Yes	Yes	No	Yes	2	NA
2–90	2–45	50–200	70–190	Yes	Yes	Yes	No	Yes	2	NA
5.4–36	7.2	194	36 / -22	Option	Yes	No	No	Yes	1.25	329
7.2–18	7.2	194	36 / -22	Option	Yes	Yes	No	Yes	1.25	715
9	5	140	NA	NA	Yes	Yes	No	Yes	2	1,264
0	0	None	None	No	No	No	No	No	5	$85
2–40	1–38	50–195	15–50	Yes	Yes	Yes	Yes	Yes	2	450
2–40	1–38	50–195	15–50	Yes	Yes	Yes	Yes	Yes	2	760
8–24	4	110–200	50–70	Yes	NA	Yes	Yes	Yes	5	192.50
8–24	4	110–200	50–70	Yes	NA	Yes	Yes	Yes	5	192.50
4	1.5	70–104	70–104	Yes	Yes	No	No	No	3	$295
4	1.5	70–104	70–104	Yes	Yes	No	No	Yes	3	394
4, 6	3,6	70–104	70–104	Option	Yes	No	No	No	5	377
4, 6	3,6	70–104	70–104	Option	Yes	No	No	No	5	440
3-9	2-5	40-104	40-104	Yes	NA	No	No	Yes	1	NA

Choose Your Control

The wide selection of differential thermostats is a welcome sign of a growing, mature industry. Reliable controllers with lots of options can make design and installation easier and more attractive. The information provided by the new crop of controllers will be welcome by many system owners. Some of the controllers on our list have data logging capabilities, such as recording sensor temperatures over a period of time. Add a flow meter to the temperature data and you can compute Btu for tracking total output.

A good differential thermostat puts you in control of your hot water system and collects as much of the sun's energy as possible. For most systems, a basic differential control is all that is needed. The addition of a digital display is helpful if you want a good understanding of system operation and the data is meaningful to you. A digital display is helpful in troubleshooting problems if the system is inoperable or losing efficiency—it's hard to have too much data in these cases. Two or more differentials in one controller are useful for collectors doing more than one job.

Access

Contributing editor **Chuck Marken** (chuck.marken@homepower.com) is a New Mexico-licensed plumber, electrician, and heating and air conditioning contractor. He has been installing and servicing solar thermal systems since 1979. Chuck is a part-time instructor for Solar Energy International and the University of New Mexico.

Home Power Data Manager **Doug Puffer** (doug.puffer@homepower.com) holds a master's degree in Environmental Studies from Clark University and an associate's degree in Software Engineering. He has installed SHW systems and worked in other areas of the RE industry.

SHW Differential Controller Manufacturers:

ArtTec • www.arttecsolar.com

Caleffi • www.caleffi.us

Hayward/Goldline •www.goldlinecontrols.com

Heliodyne • www.heliodyne.com

Heliotrope Pool • www.heliotropethermal.com

IMC Instruments • www.imcinstruments.com

Pentair Water Pool & Spa • www.pentairpool.com

Steca • www.steca-solar.com

Sun Spot Solar • www.sssolar.com

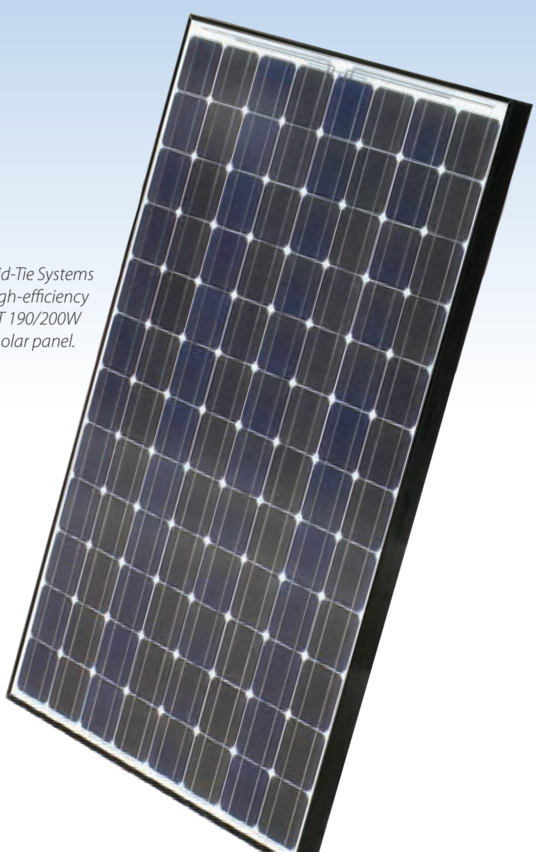
SunEarth • www.sunearthinc.com

Tekmar • www.tekmarcontrols.com

Thermomax • www.solarthermal.com

Viessmann • www.viessmann-us.com

Saving Solar Installers Time and Money



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SunWize pre-packaged grid-tie systems and grid-tie systems with battery backup contain everything you need for a complete installation. SunWize Grid-Tie System are easily installed on any type of composition or tile roof. Multiple systems can be installed for higher power output and some systems may also be expanded in the future as budget or electrical requirements grow.

Many SunWize Grid-Tie Systems are certified by the Florida Solar Energy Center (FSEC) for high quality, reliable and safe operation compliant to the NEC. The FSEC certificate is useful for permitting and field inspections of installed systems. Contact us and find out how we can help your business. Be successful, choose SunWize!

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THE ELECTRIC SIDE

Power Transmission

by Jerry Ostermeier & Joe Schwartz

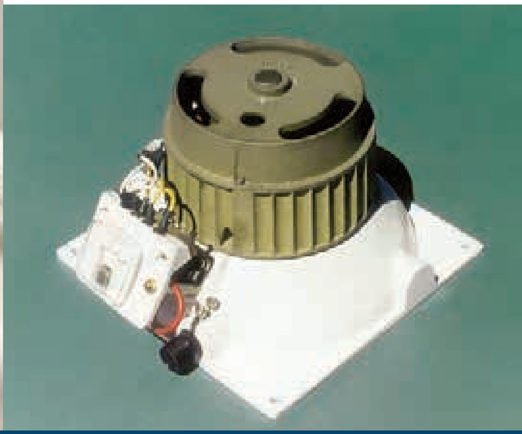
When people dive into developing hydro-electric systems, a lot of thought goes into diverting debris-free water from the creek and sizing the pipeline to carry it from the intake to the turbine. Both of these topics have been covered in recent issues of *Home Power* (*HP124* & *HP125*).

Designing the electrical side of your hydro system deserves equal attention. When it comes to transmitting and regulating the energy generated by your hydro turbine, making the right design choices for your site will result in maximum energy production and minimize up-front costs.

One of the smaller turbines from Canyon Industries, this 16 KW Pelton unit powers 120 and 240 VAC loads directly without batteries or inverters.

Shawn Schreiner

Alternative Power & Machine manufactures a variety of turbines that produce up to 3.3 KW and transmit up to 480 volts AC or DC.



The Harris Hydro Pelton turbine uses a permanent-magnet alternator to produce up to 2.5 KW and transmits at 12, 24, or 48 VDC.

Choosing a hydro turbine with the optimal mechanical characteristics (runner type and flow capacity) for your particular application is an important step in system design. So is designing the ideal intake and penstock setup. But all these will be for naught if the electrical side of your system is poorly thought-out.

Turbine Output Options

There are two basic types of hydroelectric turbines—high-power AC-direct plants and low-power DC or AC/DC turbines. Generally, high-power AC direct turbines are suitable for sites that have enough hydro potential to meet the peak demand of the combined electrical load on the system—most or all of the appliances running at once. Appropriate sites often have high flow rates (think cubic feet per second rather than gallons per minute). In a residential application, and depending on the water source and site characteristics, these turbines may generate from 4 to 15 KW (or more) continuously. Batteries are not necessary in these systems. Instead, the turbine produces 120 or 240 VAC at a controlled frequency (60 hertz in the United States) and output is fed directly to the electrical loads. Any excess power output beyond what the appliances require is routed to an electrical diversion load, typically either a water- or air-heating element.

Since most people don't live on a property with enough hydro potential for a high-power AC-direct turbine, the majority of residential hydro systems utilize low-power DC or AC/DC units. The output of this range of turbines may be from 100 to 1,500 W (and up) depending on the

OF HYDRO POWER

& Regulation Considerations

hydro resource. In most cases, the turbine charges a battery bank, and an inverter (instead of the turbine itself) is sized to meet the peak electrical demand. Another relatively new design approach using low-power turbines in grid-tied applications involves coupling the turbine with a batteryless inverter that, in turn, synchronizes system output with the utility grid (see page 48 of this issue for more information).

Low-power turbines are available in an array of output voltages, 12 to 120 VDC, and 120 to 480 VAC. The ideal turbine voltage for a given site will depend on the transmission

The Nautilus Francis-style turbine is designed for low-head applications and produces up to 3.4 KW. It can be used with a variety of generators and voltages.

The Hi Power hydro unit matches a Harris Pelton turbine to an induction motor to generate wild three-phase AC at up to 480 V, and 3.6 KW.

Energy Systems & Design turgo turbines use permanent-magnet alternators to produce up to 1 KW at 12 to 240 VDC.

distance between the turbine and the batteries. It's important to note that the output of low-power turbines at higher voltages (120 to 480 VDC) is almost always three-phase and the frequency will vary with the rotational speed of the turbine. Unlike high-power AC-direct turbines, the electricity generated is not compatible with your electrical loads without some additional power processing—the variable frequency three-phase AC output is rectified (converted) to DC and used to charge batteries.

Transmission Basics

If your turbine will be located within a couple of hundred feet of your home, you are fortunate—your wire routing, wire sizing, and associated costs will be relatively easy to deal with. But in many situations, geographic circumstances necessitate locating the turbine far from where the electrical energy needs to end up. Transmission distances of 1,000 feet are common, and distances up to 1 mile or more are surmountable with today's hydro and control technology.

Similar to penstock design, longer wire runs require larger diameter wiring—the pipeline for electrical energy. The power equation (watts = volts x amps) shows us that voltage and current share an inverse relationship to each other. Higher turbine/transmission voltage results in lower amperage for the same amount of power (watts). Lower amperage means less energy loss in transmission and smaller-diameter (and therefore, less costly) wire can be used. To drive the point home, take a look at the Conductor Sizing table. The transmission distances, wire sizes, and conductor costs are based on a turbine output of 500 W.

Higher-voltage transmission strategies will keep wire costs down, and allow you to site the turbine farther from the electrical loads, which may also give you access to additional vertical drop (and power output) along the stream course. In the field, most hydro system installers end up making a lot of trade-off decisions based on cost, topography, the amount of energy that's required, and the distance between the turbine and the batteries. For example, siting the hydro plant a little closer to the house may shorten the wiring run enough to make it affordable, and not result in a significant reduction in turbine output. Or maybe an extra 50 feet of cable will make it possible to move the whole penstock upstream far enough to use a natural spillway for an intake. The bottom line is that there is a lot of give-and-take during the design process. This is where experience-based advice will result in optimal system production.

Conductor Sizing for 500-Watt Turbine

100 Ft. to Batteries

Turbine Voltage	Conductor Gauge Needed (AWG)	Phase	Conductors Needed	Total Wire Cost
12	0000	Single	2	$960
24	2	Single	2	230
48	8	Single	2	78
120	14	Three	3	30
240	14	Three	3	30
480	14	Three	3	30

500 Ft. to Batteries

Turbine Voltage	Conductor Gauge Needed (AWG)	Phase	Conductors Needed	Total Wire Cost
12	*	Single	2	*
24	*	Single	2	*
48	2	Single	2	$1,150
120	12	Three	3	240
240	14	Three	3	150
480	14	Three	3	150

1,000 Ft. to Batteries

Turbine Voltage	Conductor Gauge Needed (AWG)	Phase	Conductors Needed	Total Wire Cost
12	*	Single	2	*
24	*	Single	2	*
48	00	Single	2	$4,800
120	10	Three	3	690
240	14	Three	3	300
480	14	Three	3	300

2,500 Ft. to Batteries

Turbine Voltage	Conductor Gauge Needed (AWG)	Phase	Conductors Needed	Total Wire Cost
12	*	Single	2	*
24	*	Single	2	*
48	*	Single	2	*
120	6	Three	3	$4,275
240	12	Three	3	1,200
480	14	Three	3	750

5,000 Ft. to Batteries

Turbine Voltage	Conductor Gauge Needed (AWG)	Phase	Conductors Needed	Total Wire Cost
12	*	Single	2	*
24	*	Single	2	*
48	*	Single	2	*
120	2	Three	3	$17,250
240	8	Three	3	5,850
480	14	Three	3	1,500

Notes: *Sizes larger than 0000 AWG not viable due to expense. All sizing for 5% maximum voltage drop. Prices for THHN/THWN copper conductors. Ground wire & conduit not included in cost. 14 AWG is smallest wire size recommended.

Turbine-Specific Strategies

Before you get to work installing your hydro system, make sure you're up to speed on all of the available turbine and transmission options. The most common approaches are listed below, and the specific characteristics of your site—primarily how far you need to move the energy generated—will be the main driver in your transmission design.

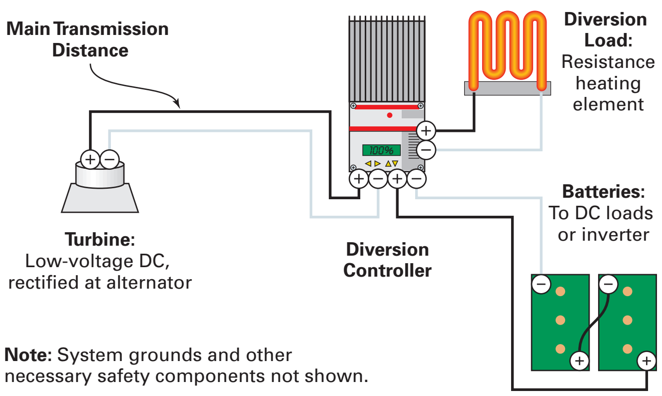
Low-voltage DC. If your turbine will be located within a few hundred feet of your home, choosing a hydro plant with output at the nominal voltage of the battery bank (12 to 48 VDC) is the simplest approach. Some home-scale hydro plants use generators that produce low-voltage DC directly. But most modern turbines have brushless permanent-magnet alternators that produce wild three-phase AC, which is rectified to DC at the turbine. The output of both turbine types can be routed right to the battery bank without further processing or conversion.

High-voltage DC. Some manufacturers offer turbines with DC output voltages above the standard battery voltage in most modern residential systems (48 V). The higher the transmission voltage, the smaller the wire size required. At the battery bank, a maximum power point tracking (MPPT) controller with voltage step-down functionality can convert the higher transmission voltage down to the nominal voltage at the battery, just like it's done in many battery-based PV systems. UL-listed controllers manufactured by Apollo, OutBack Power Systems, and Xantrex all have this functionality.

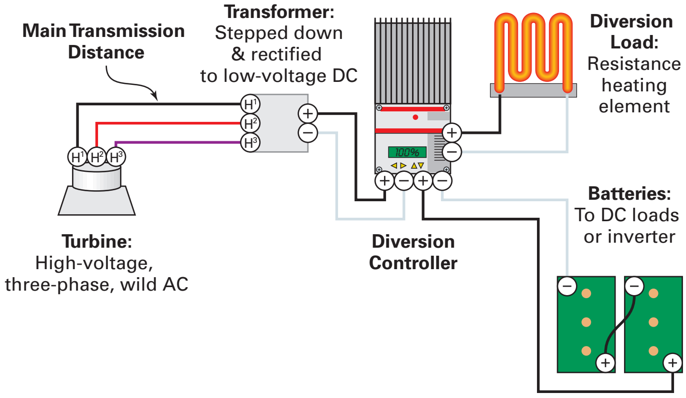
While high-voltage DC transmission is an option to consider, the controllers needed to step down the voltage are sophisticated and relatively expensive electronic devices. Most importantly, they will be damaged if they're subjected to voltages that are higher than they are designed to handle. Most of these controllers max out at 140 to 150 VDC open circuit. If the hydro turbine ever generated a greater voltage, or a breaker was inadvertently shut off, allowing the turbine to overspeed, the controllers will be damaged. Because of this, the simplicity of using a high-voltage alternator with a step-down transformer at the battery may be preferable—reliability is better, net efficiency is about the same, and the cost is less.

Wild three-phase. If you're facing a long wire run between the turbine and the batteries, one option is to purchase a turbine with a high-voltage alternator and transmit the three-phase AC output over the wire run. At the battery bank, a transformer drops the AC voltage down to the battery voltage, and it is rectified to DC for battery charging. A transformer/rectifier used in this application will typically have a conversion efficiency of about 90%. This approach will require a third power conductor for the third-phase, but is almost always cost-effective compared to DC transmission due to the smaller wire size required. Turbines with AC output voltages between 120 and 480 V are available.

Low-Voltage DC Transmission



High-Voltage AC Transmission



AC-coupled systems. The vast majority of off-grid systems are DC coupled—PV arrays, and wind and hydro turbines ultimately feed DC to the battery bank. In contrast, AC coupling uses one or more batteryless inverters to parallel charging sources on the *AC* side of the system. An additional battery-based inverter sets a baseline voltage and frequency to which the batteryless inverters synchronize. In an AC coupled hydro application, a dedicated batteryless inverter can be located at the turbine. The inverter's 120 or 240 VAC output will in turn be synchronized with the AC waveform

MPPT controllers, like OutBack's Flexmax, can step down high-transmission voltage to match the nominal battery voltage.

Hydro Wiring Tips

Bury It. Local codes may vary, but, typically, conductors in conduit need to be buried 18 inches deep, and direct-burial runs need 30 inches of cover.

Protect It. Running wire without conduit on top of the ground may be tempting, but it is a bad idea for the safety of critters (two-leggeds included) and the cable. Any depth of burial is preferable to none, with or without conduit. In addition, breakers should be installed to protect the wiring in the event of a short circuit. Always size the breakers based on the wire's rated amperage. Because the conductor size is specified with voltage drop over a long transmission run in mind, the ampacity rating of the conductors usually ends up being significantly higher than the actual amperage generated by the turbine. Because of this, you can often use a breaker that's two times the turbine amperage, which will eliminate nuisance breaker tripping, and minimize the possibility of the breaker tripping and allowing the turbine to overspeed.

Ground It. Hydro turbines can produce lethal voltages and should be grounded to minimize risk. Drive a ground rod at the hydro plant and connect it to the ground terminal provided on the turbine. A dedicated equipment-ground conductor should be run along with the power transmission wiring so your entire system is bonded and has the same voltage potential to ground. In lightning-prone areas, it's a good idea to include surge protectors at each end of the transmission run.

Don't Bond It. Do not connect the negative power conductor to the equipment ground at the hydro turbine. The *NEC* requires that only one negative-to-ground bond exists on the DC side of the system. This should only be done at the DC breaker panel located near the inverters and battery bank. Some low-cost hydro plants use modified automotive generators that are already grounded to negative, which puts the generator at risk if there's a close lightning strike and can also result in a ground differential throughout the power system that may damage components.

of the battery-based inverter. While this approach is still uncommon in single-household off-grid applications, it does offer some potential advantages in village-scale applications, or when a single battery-based system is charged by multiple power sources that are not located close to one another. Because multiple inverters are required, AC-coupled systems are usually more expensive. The main advantage is that, in some cases, this type of system can overcome design hurdles that a DC-coupled system can't.

Diversion controllers, like Morningstar's TriStar, divert excess energy to a dump load when batteries are at full charge.

Voltage Control

Because hydro turbines run 24 hours a day, most systems produce a lot of energy. As a result, the battery bank spends much of the time completely charged and in float mode. To keep the batteries from being overcharged, voltage control is required. Unlike PV arrays, hydro plants must remain electrically loaded at all times to keep both the turbine's rpm and the peak output voltage in check. That means that series-type voltage regulators, like the one in your car, cannot be used because they simply open the circuit when they hit their voltage set point. In a car, this isn't an issue because the alternator speed is limited by engine speed—but hydro plants have no such limitation.

Conductors, Conduit & Connections

Conductors. Two main kinds of conductors can be used for the transmission run—aluminum and copper. Aluminum has more than 1.6 times the resistance per gauge (diameter) than copper. Because of the higher resistance compared to copper, aluminum requires a larger wire size to handle a given amount of current. Even so, aluminum conductors can still be less expensive than copper depending upon current metal prices.

If the wiring will be run in conduit, larger wire size means larger conduit and increased overall cost. Aluminum wire is stiff and more difficult to pull through conduit and route into electrical boxes, and is not flexible enough for direct connection to the power terminals of most hydro plants. Finally, moisture has a greater corrosive effect on aluminum than copper. If conductors rated for direct burial are used, aluminum wiring will be more susceptible to damage if a wire is nicked. For all these reasons, copper is the preferred choice. For direct burial, the wire type should be USE, RHW, or UF. In conduit, THHN/THWN is typically used.

Conduit. Using wire rated for direct burial is tempting for hydro systems with long transmission runs, since skipping the conduit means less expense up-front, and makes installation a bit faster. However, protecting the conductors in conduit is recommended. In the case of direct burial, unless care is taken to bed the conductors in sand and remove rocks that might come in contact with the cable, damage can occur during backfilling. Trust us—trying to locate a broken conductor in a 1,000-foot wire run buried 30 inches deep isn't something you want to experience. In addition, it's desirable to use conduit for high-voltage transmission runs so there's one more layer of protection for both the conductors, and for anyone that might inadvertently come into contact with them.

Connections. For making electrical connections at the turbine, soldered copper-lug connectors are ideal. If the transmission run is aluminum, use a short length of copper wire from the turbine's output terminals to a junction box, where split bolts can be used to join to the aluminum and copper conductors. Apply a corrosion inhibitor wherever dissimilar metals are joined. Wound-field hydro turbines (which use modified vehicle alternators) have electrical terminals that are somewhat exposed, so caution is advised when servicing them.

Diversion loads are usually electric heating elements to dump excess energy in the form of heat to air (left) or water (right).

Shawn Schreiner


Courtesy Hi Power

Transformer/rectifier units convert high-voltage, wild three-phase AC hydro turbine output to lower-voltage DC for battery charging. This package, manufactured by Hi Power, includes overcurrent protection, an amp meter, and terminal strips for system wiring.

Electrically unloaded, a hydro turbine's rpm will almost double, and output voltage may triple. Most turbines can handle the increased rpm, but the extremely high output voltage will destroy system controls. To avoid this scenario, hydro systems rely on diversion controllers that shunt (route) the turbine's output to a diversion load when the battery bank is fully charged. The TriStar controller manufactured by Morningstar is a very popular diversion controller, as are the C-series controllers manufactured by Xantrex. MPPT controllers manufactured by Apollo, OutBack, and Xantrex all have an auxiliary output-control feature that's capable of driving a separate high-current relay to shunt excess power to the diversion loads. In addition, several battery-based inverter models feature auxiliary control functionality.

In off-grid hydro systems, resistive loads like water- or air-heating elements are used to dissipate excess energy. These diversion loads are usually sized to handle the turbine's full power output. The *National Electrical Code (NEC)* requires a second independent diversion setup to protect the battery bank from overcharging if one controller fails. One common approach is to use a dedicated controller and water- or air-heating element as the primary diversion system. The secondary diversion setup can utilize the inverter's auxiliary output and a relay to dump AC power to a standard 120-volt space heater.

In battery-based grid-tie applications, the grid functions as the primary diversion load, with excess hydro-generated energy fed back via a utility-interactive inverter. But even grid-tied systems require a separate, dedicated diversion controller and load as a backup. Without it, in the event of a utility outage, the system's battery bank would still be vulnerable to overcharging since the primary diversion load (the grid) is no longer available.

The Best Approach for Your Site

There are a lot of design options to consider when it comes to the electric side of your hydro-electric system. Every site is different, and many pitfalls and unnecessary expenses can be avoided by getting some expert help when the time comes. Most hydro manufacturers are willing to work hand-in-hand with the customer or a professional installer to design a safe, durable, and efficient system that will not only work, but also work hard for years to come.

Access

Jerry Ostermeier (altpower@grantspass.com) owns Alternative Power & Machine in Grants Pass, Oregon (541-476-8916 • www.apmhydro.com). He has been designing and installing microhydro and off-grid power systems since 1979. He also manufactures a user-friendly residential-scale microhydro turbine.

Joe Schwartz (joe.schwartz@homepower.com), *Home Power's* CEO and editor, lives off grid outside of Ashland, Oregon. While PV currently supplies all the electricity for his homestead, there's a hydro site, with 140 feet of vertical drop (and an 1,800-foot transmission distance), waiting to be developed.

Hydro Turbine Manufacturers:

Alternative Power & Machine • www.apmhydro.com

Canyon Hydro • www.canyonhydro.com

Energy Systems & Design • www.microhydropower.com

Harris Hydro • 707-986-7771

Hi Power • www.hipowerhydro.com

Diversion Controller Manufacturers:

Morningstar Inc. • www.morningstarcorp.com

Xantrex • www.xantrex.com

MPPT Controllers with Auxiliary Output Functionality:

Apollo Solar • www.apollosolar.com

OutBack Power Systems • www.outbackpower.com

Xantrex • www.xantrex.com

OFF THE BEATEN PATH

by Jonathan Mingle

The last few steps to Zealand Falls Hut are steep and can be taxing. With each push up the stone staircase, your legs seem to grow heavier while your knees and joints whisper a plea for mercy. Motivating you at every turn? A cooling breeze sweeping down from Mount Hale, the warm sun breaking through the afternoon clouds, and the soothing sound of Whitewall Brook. But the ultimate reward after the journey: Resting your weary bones in a warm, well-appointed hut powered by the same elements that kept you inspired every step of the way—wind, sun, and water.

Perched on a mountainside deep in the White Mountain National Forest (WMNF) of New Hampshire, Zealand Falls Hut is one of eight off-grid alpine huts spaced roughly a day's walk apart on the Appalachian Trail and operated by the Appalachian Mountain Club (AMC). Ranging from altitudes of 2,700 to 5,050 feet, and built to accommodate anywhere from 36 to 90 people, the huts host more than 40,000 guests each year.

For the past 120 years, since the first hut was built at Madison Spring, these mountain refuges have imparted backcountry hospitality to hikers in the White Mountains. AMC staff assist hikers and maintain the facility year-round. During the busy full-service season from late spring to early fall, an enthusiastic crew prepares warm meals. The rest of the year, three of the huts, including Zealand Falls, stay open on a self-service basis, staffed by a caretaker.

In the past, the huts relied on propane and kerosene for water heating, cooking, and lighting. But in recent decades, the AMC has come to embrace renewable energy systems as part of its mission to "promote the protection, enjoyment, and wise use of the mountains, rivers, and trails of the Appalachian region."

Today, a variety of RE strategies and energy-efficient appliances help provide comfortable accommodations for guests and crews. Although propane is still used for cooking, some refrigeration, and backup generators, solar and wind systems now generate electricity for the huts' emergency radio systems, water pumping, most refrigeration, and lighting. At Zealand Falls, a microhydro system also lends to the cause.

Grounds for RE

The operating context of the AMC high-country huts gives new resonance to the term "off grid." Each hut is 2 to 5 miles from the nearest road, nestled deep in the forest or squatting high on exposed ridges, in an area that gets some of the worst weather in the country. Moving supplies to such remote locations is costly and difficult, especially since there are only two ways to bring provisions in and out—by helicopter or on the sturdy backs of AMC staff.

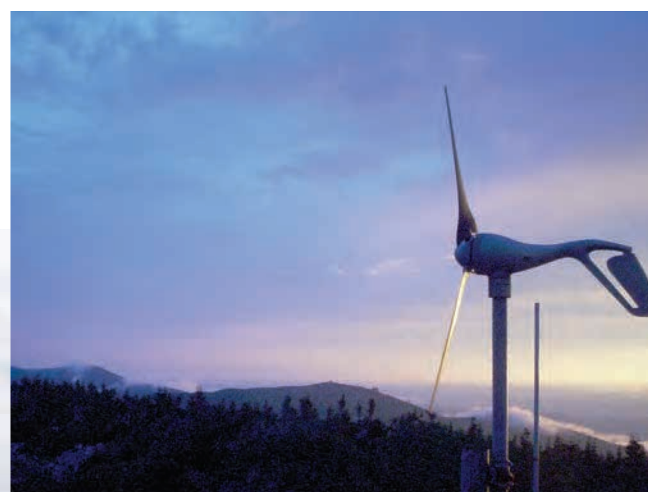
"With the remote location of our huts and operations, we need to work with what we have to make sure the huts operate comfortably for our guests," says Eric Pedersen, the AMC's huts manager and a former hut crew leader. "That means we have to be creative in how we get energy."

In the past, helicopters made dozens of trips each year to fly in full propane tanks and fly out empties, in addition to ferrying food and other supplies. Referred to as "bombs" by AMC hut crews, the tanks are heavy and unwieldy, and loading and unloading them from the helicopter's net can be a delicate process. Hiring the helicopter and pilot costs about $1,250 per hour, and rising fuel and insurance costs are driving this number higher each year. Some propane is necessary to operate the huts, but minimizing its use made sense both for the budget and risk-management. The risk, coupled with the close proximity of the huts to federally designated wilderness areas, was a key factor in the AMC's decision to invest in renewable energy systems.

Left: In New Hampshire's White Mountains, year-round cascading streams abound—perfect sources for hydro-electricity.

Right: A roof-mounted wind turbine on Greenleaf Hut looks west toward Cannon Mountain.

Below: The Lakes of the Clouds Hut is perched at 5,012 feet on the southwest shoulder of Mt. Washington.



Courtesy www.outdoors.org

The RE Path

Although the electrical loads at each hut are pretty minimal, a few are critical either for safety or for guest comfort: a fire alarm system; water pumps; and a radio system for communication with AMC headquarters, Forest Service personnel, and emergency response units. Other loads include refrigerators, compact fluorescent lights, and small fans to ventilate the composting toilets.

The AMC's first step into renewable energy came in the early 1980s, when staff members rigged a microhydro setup at Zealand Falls. This makeshift system ran for several years before falling out of use. Staff later swapped out the system's original 120-volt AC alternator for a 12-volt DC one for battery charging. The microhydro system now puts out a steady 300 W, or 7.2 KWH per day, from May through October.

AMC Huts' Sustainable Technologies

Hut	Solar Electricity	Solar Water Heating	Wind Electricity	Hydro-Electricity	Composting Toilets
Carter Notch	✔		✔		✔
Galehead	✔		✔		✔
Greenleaf	✔		✔		✔
Lakes of the Clouds	✔		✔		
Lonesome Lake	✔	✔			✔
Madison Spring	✔		✔		
Mizpah Spring	✔	✔			✔
Zealand Falls	✔		✔	✔	✔

In the late 1980s, the AMC made the leap to solar electricity, hooking up small PV modules directly to chargers for batteries used by the radios. Small-scale success led to the installation of larger systems at the Mizpah Spring and Madison Spring huts in 1988 and 1989, respectively. Today, all eight huts have PV systems, ranging in size from 340 watts to 900 watts.

Six of the huts supplement their solar electricity with energy from small roof-mounted wind turbines (Southwest Windpower's Air 303s or the newer AirXs). Roof mounting a turbine is rarely recommended because of noise, vibration, and turbulence issues, and very importantly, the turbine will rarely be high enough above surrounding objects to produce meaningful energy. But for the huts' extremely windy wilderness settings and the lack of staff with tall-tower and turbine maintenance experience, roof mounts made sense.

All of the huts get significant winds, but none as extreme as those which bear down on the two huts above the treeline in the Presidential Range—Madison Spring and Lakes of the Clouds. In fact, several turbines have been blown off the roof of the Lakes of the Clouds hut, which sits on the rocky shoulder of Mt. Washington, the highest mountain in the Northeast and site of the highest recorded winds on the planet (231 mph). The AMC budgets for an average lifetime of two years for a wind turbine at Lakes, compared to 10 years at a hut like Zealand Falls.

For energy storage, most huts use a bank of deep-cycle, lead-acid batteries. Charge controllers moderate the energy input from the PV modules to prevent battery overcharge. During cloudy weather, propane-powered, 8-horsepower

(continued on page 80)

Over the years, renewable energy sources have reduced the AMC huts' reliance on propane.

Courtesy Lori Duff

Propane lighting has been replaced with energy-efficient compact fluorescents powered by renewables.

Courtesy Lori Duff

Zealand Falls Renewable Energy Systems

During the full-service summer season, Zealand Falls Hut accommodates up to 250 guests and five crew members each week. Renewable energy systems provide electricity for refrigeration, lighting, the composting toilets' ventilation fans, and a radio and fire alarm system. The combined electrical demand adds up to about 1.8 KWH per day.

Solar. Four 85-watt PV modules contribute to the total system output. The small array, tilted at 40 degrees and oriented south toward the dramatic Zealand Notch, sits on the roof of a nearby outbuilding. Along with some generator and propane use, the PV and wind systems are the primary power sources in the wintertime, when the microhydro system is off line.

Courtesy Jonathan Mingle

Wind. A Southwest Windpower Air 303 turbine sits about 10 feet above the roof ridge, mounted on a pole bolted to the back of the hut. The hut is located in a small, sloped clearing, and the turbine is squarely in the wind path from all directions except south, where trees tower above the hut. In winter, when loads are reduced and the microhydro system is down, the micro-wind turbine and PV array typically provide ample energy to keep the batteries charged, but occasionally, the staff may need to run the backup generator during cloudy spells.

Courtesy Lori Duff

Hydro. The microhydro system starts in one of Whitewall Brook's deep pools, a few hundred yards above the hut. An intake pipe brings water into a metal tank fitted with a screen to keep out debris. An intake valve lets staff control the water level in the tank, and shut off flow during storms or maintenance. The homebuilt turbine sits about a quarter-mile below the intake point, in a small shed about 10 yards from the stream. A buried pipe runs from the intake tank parallel to the brook, and down to the turbine. The 100 psi water passes through a nozzle, directing a jet of water at a 6-inch-diameter Pelton wheel. The wheel drives a car alternator, which sends energy to the hut's battery bank. Once the water has run through the turbine, gravity returns it to the stream.

The microhydro system puts out 300 watts continuously from May until the freezing of the brook forces a shutdown in mid to late fall. With an average output of 7.2 KWH per day, the system provides more than three times as much as the hut needs for its critical loads during peak usage. Excess power is diverted to a heating element that preheats water that's routed through the hut's on-demand, propane-fueled water heater.

Hydropower is also harnessed for another crucial need—providing drinking water for the crew and guests. From May to October, the energy of the brook is used to mechanically pump well water into a 500-gallon storage tank. Water is diverted from the main penstock to drive a separate 6-inch-diameter Pelton wheel with two 1/4-inch nozzles with 30 psi of pressure behind them. This "water motor" drives a piston pump, bringing up deep well-water at about 0.5 gallons per minute. For caretakers and crew who have had to hand-pump enough water for a full house of close to 40 people, this apparatus—dubbed the "salad shooter"—is a thing of beauty.

Courtesy www.outdoors.org

Together, the PV, wind, and microhydro systems charge a 12-volt bank of 10 Trojan L16 lead-acid batteries, with 1,950 amp-hours of storage.

backup generators feed the electrical loads and recharge the batteries with Xantrex inverter/chargers.

Crew members diligently check the TriMetric state-of-charge battery monitors throughout the day, and minimize unnecessary use of electric lights and small appliances. Typically cool weather reduces the energy demand of the highly efficient Sun Frost DC refrigerators. For the better part of the year, the PV and wind systems provide more than enough energy to power the critical hut loads during the summer's peak visitor season.

More Than Room & Board

In 2006, hut crews started leading guests on "green tech tours" to explain the renewable energy systems and other sustainable technologies, such as the composting toilets, compact fluorescent lighting, and food composting systems. For many visitors, it's their first exposure to these sustainable technologies and approaches to waste management. "Most people are surprised at how much we do with how little, and how sustainable we are," notes Pedersen. "They say how they never would have learned about renewable energy technologies if they hadn't gone to the huts."

Since the first simple stone hut was built in 1888—just six years after Thomas Edison opened his first power generating station in Manhattan—the hut system has evolved to strike a fine balance between encouraging conservation through recreation, and putting conservation and clean energy generation into real practice. Renewable energy has become an integral part in achieving both. These systems, says Pedersen, "show the AMC's mission of moving forward, with low impact, while keeping the tradition of the huts alive."

Zealand Falls Hut Summer Loads

Load	Watts	Hrs./Day	WH/Day
Sun Frost refrigerator–freezer, RF19	75	10	750
18 CFL 12 W lights	216	3	648
Two composting toilet ventilation fans	10	24	240
Radios & fire alarms	3	24	72
		Total WH/Day	1,710

Access

Jonathan Mingle (mingle@berkeley.edu) is a master's degree candidate in the Energy and Resources Group at the University of California–Berkeley. He is a former Zealand Falls Hut caretaker.

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How Tall is Too Tall?

Maximizing the Return on Your Wind System

by Brian Raichle & Brent Summerville

While it looks lost in the trees, the ARE turbine in the distance is actually on a 165-foot, guyed lattice tower that places the turbine more than 40 feet above everything near enough to affect its exposure to the wind.

For a homeowner installing a wind generator, the first question is often, "Which turbine?" The second question is, "What type and how tall of a tower?" The often-repeated mantra is that "taller is better," but taller is also more expensive. So the more relevant question for most on-grid homeowners is, "What tower maximizes my energy output and the return on my investment?" It's this question that we'll answer in this article. (See Access for more tower economics reading.)

According to the experts, the bottom of a wind generator's blades should be at least 30 feet above the tallest obstacle within 500 feet—be it a tree, building, or ridge. For example, if the mature height of a grove of trees that sit 300 feet from your proposed tower site is 60 feet, the minimum height to the bottom of the rotor is 90 feet (60 + 30). For a wind turbine with 6-foot blades, the minimum tower height would be 96 feet (6 + 90).

This rule applies to most locations, but not all. One exception is if you plan to site your turbine near an abrupt change in height of a continuous obstacle, such as a cliff or dense forest next to a field. In this case, you should allow not 500 feet, but 0.6 miles (1 km) for the "edge effect" to subside.

Your tower must be tall enough to at least meet the 30/500 rule. Violating this rule will put your generator in turbulent, low-speed wind, resulting in lower energy output, and increased wear and tear on the wind turbine from turbulent winds.

Wind Shear

Wind generators are installed on towers because the wind speed is always higher and there is less turbulence at increased heights above Earth's surface. This is due to decreased friction between the moving air mass and Earth's surface. As height above the surface increases, surface effects decrease and wind speed increases. This increase in wind speed with height is called wind shear. The most commonly used equation to represent the wind-shear model is a power law relationship:

$$\frac{V_2}{V_1} = \left(\frac{H_2}{H_1}\right)^{\alpha}$$

In this formula, "V" represents wind velocity, and "H" represents height, with the subscript numbers representing a specific height and its wind speed. Alpha (α) is the wind-shear coefficient—the wind speed increase with increasing height.

Placing wind generators on taller towers exposes them to higher wind speeds and also reduces turbulence-induced wear

Wind-Shear Coefficients

α	Description
0.1	Perfectly smooth (calm water)
0.2	Flat grassland or low shrubs
0.3	Trees or hills, buildings in area
0.4	Close to trees or buildings
0.5	Very close to trees or buildings
0.6	Surrounded by tall trees or buildings

and tear—and associated maintenance costs. Just as carpet creates more dragging friction than a polished hardwood floor, rough terrain causes more friction with the air than a smooth field. A smooth, flat topography (open fields; water) has a low wind-shear coefficient ($\alpha = 0.1$ to 0.15), while a hilly, wooded, or developed region with lots of buildings will have a higher wind-shear coefficient ($\alpha = 0.3$ to 0.6). Similarly, your turbine will experience higher wind shears if you don't obey the 30/500 siting rule. Knowing the wind-shear coefficient at your tower site is key to evaluating tower economics. Read

System Costs

Bergey Excel-S

Tower Manufacturer	Tower Type	Height (Ft.)	Cost
Bergey	Monopole	120	$77,720
Bergey	Monopole	90	67,110
Bergey	Freestanding lattice	120	63,170
Bergey	Monopole	60	60,010
Bergey	Freestanding lattice	100	58,900
Bergey	Tilt-up lattice	100	58,600
Bergey	Tilt-up lattice	80	56,430
Bergey	Freestanding lattice	80	55,430
Bergey	Tilt-up lattice	60	55,210
Bergey	Freestanding lattice	60	52,660
Bergey	Guyed lattice	120	52,620
Bergey	Guyed lattice	100	50,900
Bergey	Guyed lattice	80	49,730
Bergey	Guyed lattice	60	48,960

ARE110

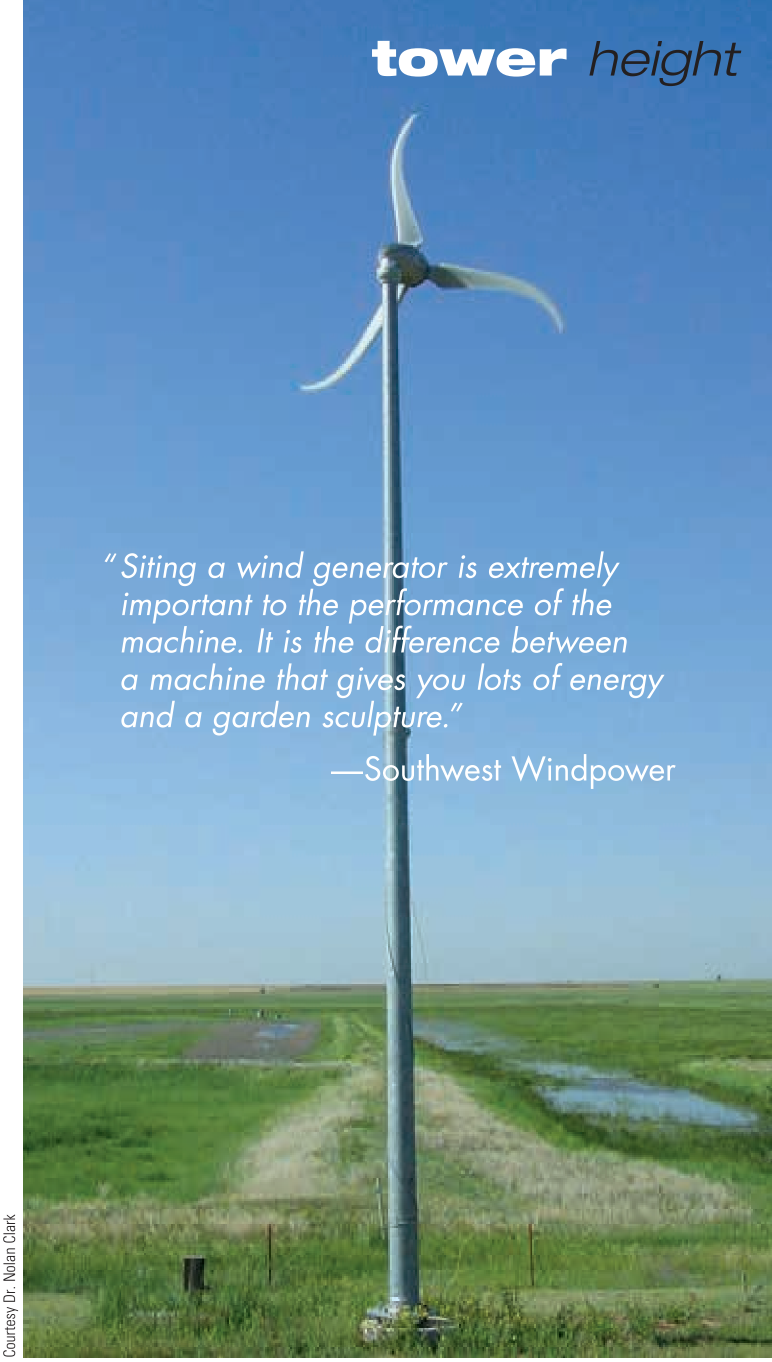
ARE	Tilt-up tubular, 4 in.	127	$22,235
ARE	Tilt-up tubular, 4 in.	106	21,470
ARE	Tilt-up tubular, 4 in.	85	19,700
ARE	Tilt-up tubular, 4 in.	64	19,450
ARE	Tilt-up tubular, 4 in.	43	18,750

Skystream 3.7

ARE	Tilt-up tubular, 5 in.	127	$18,550
ARE	Tilt-up tubular, 5 in.	106	17,500
ARE	Tilt-up tubular, 5 in.	85	16,000
SWWP	Tilt-up tubular, 5 in.	70	15,000
ARE	Tilt-up tubular, 5 in.	64	14,600
SWWP	Monopole	45	13,750
SWWP	Monopole	34	12,250

"Siting a wind generator is extremely important to the performance of the machine. It is the difference between a machine that gives you lots of energy and a garden sculpture."

—Southwest Windpower



Courtesy Dr. Nolan Clark

At this low wind-shear site, a 34-foot tower is all that's needed to keep the Skystream in fairly nonturbulent wind.

Paul Gipe's book, *Wind Power*, or Mick Sagrillo's article in *HP40* for help in estimating your wind-shear coefficient (see Access). The Wind-Shear Coefficients table (above) gives general guidelines for estimating wind shear.

Tower Types

Your generator will sit on a tower, but what type? Be sure to follow the turbine manufacturer's recommendations and select a reputable tower manufacturer and installer. Commonly available towers are tilt-up, fixed guyed, or freestanding (each including tubular or lattice types). (For more on tower types, see Ian Woofenden's "Wind Generator Tower Basics" article in *HP105*.) Various combinations and permutations within these categories exist, but we'll review the economics of these tower types: tilt-up tubular, tilt-up lattice, guyed lattice, freestanding lattice, and monopole, at heights ranging from 34 to 127 feet. The System Costs table provides basic information about the analyzed towers, including a full system cost for the given turbine and tower.

To provide a useful example, we've compared the economics of installing three wind generators—Bergey Windpower's Excel-S (22-foot-diameter rotor), Southwest Windpower's Skystream 3.7 (12-foot-diameter rotor), and Abundant Renewable Energy's ARE110 (11.8-foot-diameter rotor)—on readily available towers of different heights and in different wind-shear regimes. All machines are for batteryless, grid-tied systems. Economics are reported for an annual average wind speed of 11 mph at 33 feet (10 m) above ground level and at wind-shear coefficients of 0.1 to 0.6. Locations with different shears and the same annual average wind speed at 33 feet will have different wind speeds near the ground, with the low-shear location being much windier.

Calculating Wind Speed from Known Data

Assume a Midwestern farm site, which is mostly flat grassland, has a wind-shear coefficient of 0.2 ($\alpha = 0.2$) and your 50-foot-high anemometer (H_1) has recorded an annual average wind speed of 15.6 mph (V_1).

What annual average wind speed (V_2) can you expect at turbine hub height on a 75-foot tower (H_2)?

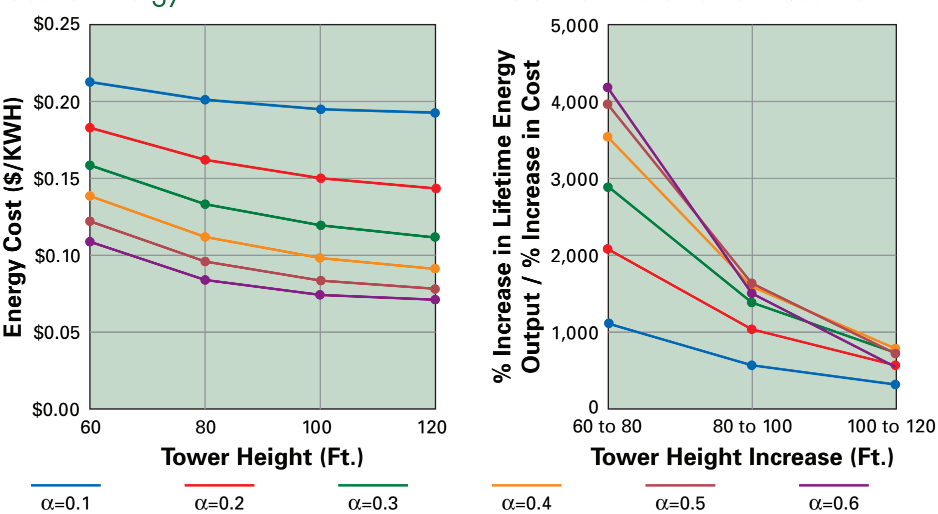
$$\frac{V_2}{V_1} = \left(\frac{H_2}{H_1}\right)^{\alpha}; \; V_2 = V_1\left(\frac{H_2}{H_1}\right)^{\alpha}; \; V_2 = 15.6 \text{ mph}\left(\frac{75 \text{ ft.}}{50 \text{ ft.}}\right)^{0.2}$$

V_2 = 16.9 mph

Excel-S on Guyed Lattice

Cost of Energy

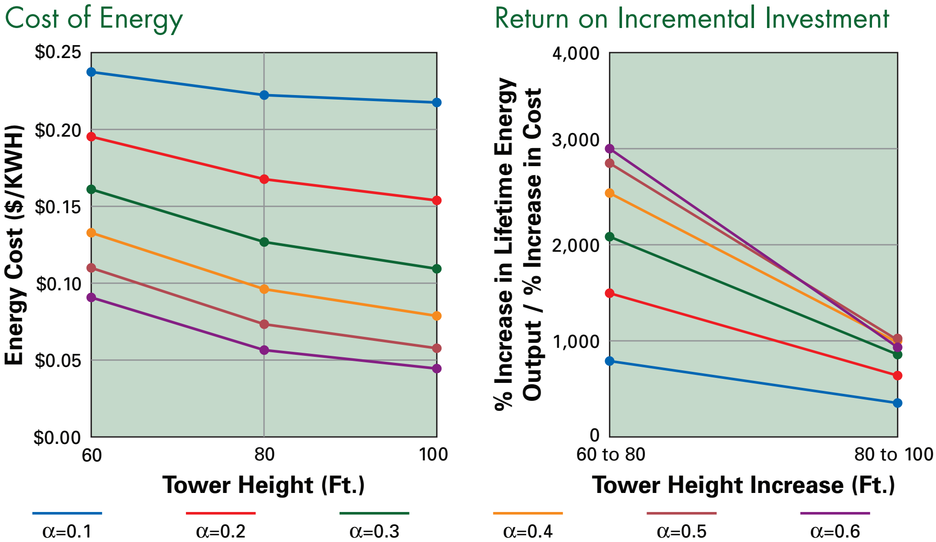
Return on Incremental Investment



Excel-S on Tilt-Up Lattice

Cost of Energy

Return on Incremental Investment



The annual energy output—the number of KWH of energy the turbine will produce in one year—was calculated using each turbine's power curve (provided by the manufacturer) and a typical distribution of wind speeds, with an average annual wind speed of 11 mph at 33 feet. The annual energy outputs in KWH (assuming air density for an elevation of 1,000 feet) are shown on the Annual Energy Output table on the opposite page.

System cost estimates include turbine, controller, inverter, tower, wiring, concrete, shipping, and installation. These costs can vary significantly.

The cost of energy in dollars per KWH was calculated by dividing the total system cost by the energy output over an estimated lifetime of 20 years. The original spreadsheets used to perform these calculations are available from the authors.

Results—Excel-S

The cost of energy (COE) in dollars per KWH was calculated for six wind-shear scenarios for the four available tower configurations: guyed lattice, tilt-up tubular, freestanding lattice, and monopole. These towers are available from Bergey Windpower at heights of 60, 80, 90, 100, and 120 feet. The results are shown for an average annual wind speed of 11 mph at 33 feet.

For guyed and tilt-up lattice towers (see graphs at left), the COE generally

Annual Energy Output (in KWH) for Various Wind-Shear Coefficients

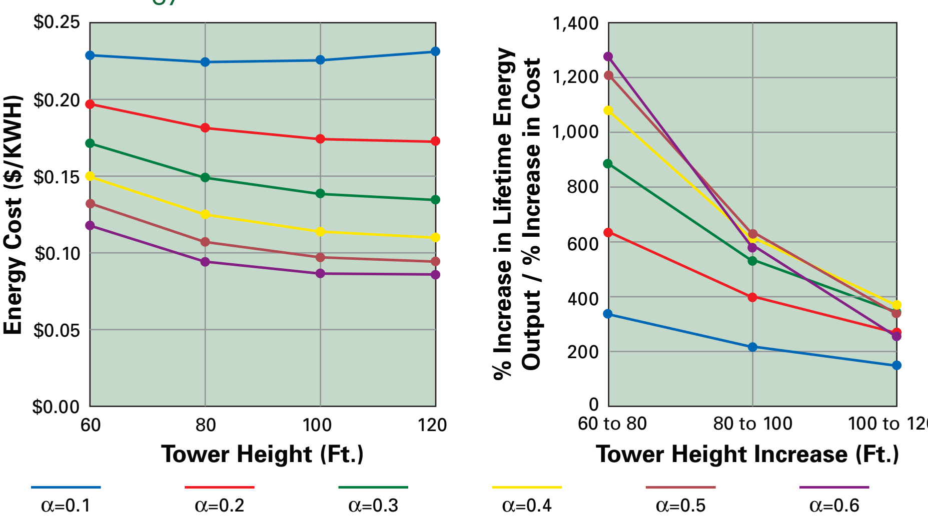
Height (Ft.)	Bergey Excel-S α=0.1	α=0.2	α=0.3	α=0.4	α=0.5	α=0.6	Skystream 3.7 α=0.1	α=0.2	α=0.3	α=0.4	α=0.5	α=0.6	ARE110 α=0.1	α=0.2	α=0.3	α=0.4	α=0.5	α=0.6
34	–	–	–	–	–	–	3,017	3,048	3,080	3,112	3,144	3,177	–	–	–	–	–	–
43	–	–	–	–	–	–	–	–	–	–	–	–	4,262	4,549	4,848	5,157	5,476	5,804
45	–	–	–	–	–	–	3,269	3,569	3,885	4,217	4,563	4,922	–	–	–	–	–	–
60	11,506	13,369	15,423	17,649	20,021	22,497	–	–	–	–	–	–	–	–	–	–	–	–
64	–	–	–	–	–	–	3,604	4,294	5,048	5,854	6,696	7,554	4,688	5,455	6,278	7,140	8,022	8,900
70	–	–	–	–	–	–	3,692	4,490	5,367	6,302	7,271	8,240	–	–	–	–	–	–
80	12,369	15,321	18,651	22,260	25,984	29,605	–	–	–	–	–	–	–	–	–	–	–	–
85	–	–	–	–	–	–	3,889	4,931	6,081	7,294	8,507	9,639	5,006	6,151	7,381	8,637	9,847	10,928
90	12,736	16,167	20,056	24,226	28,402	32,234	–	–	–	–	–	–	–	–	–	–	–	–
100	13,070	16,946	21,342	25,988	30,469	34,293	–	–	–	–	–	–	–	–	–	–	–	–
106	–	–	–	–	–	–	4,119	5,453	6,922	8,420	9,806	10,921	5,262	6,714	8,256	9,762	11,083	12,066
120	13,661	18,337	23,613	28,968	33,667	36,970	–	–	–	–	–	–	–	–	–	–	–	–
127	–	–	–	–	–	–	4,312	5,896	7,619	9,298	10,697	11,592	5,475	7,185	8,965	10,608	11,877	12,573

Based on annual average wind speed of 11 mph at 33 ft (10 m).

Excel-S on Freestanding Lattice

Cost of Energy

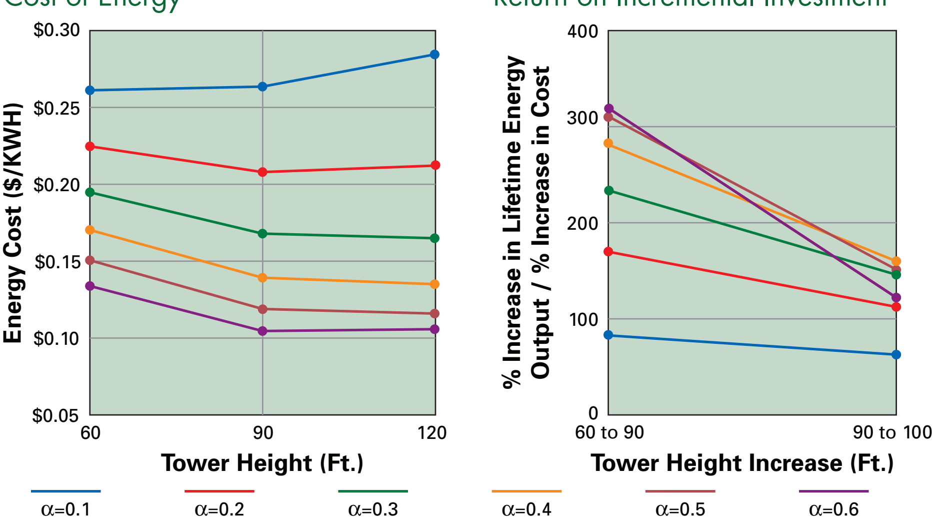
Return on Incremental Investment



Excel-S on Monopole

Cost of Energy

Return on Incremental Investment



decreases with increasing tower height across the wind-shear range. With the freestanding lattice tower, COE increases at the lowest shear. Cost of energy with the monopole tower increases with tower height at the lowest two shears and bottoms out with the 90-foot tower.

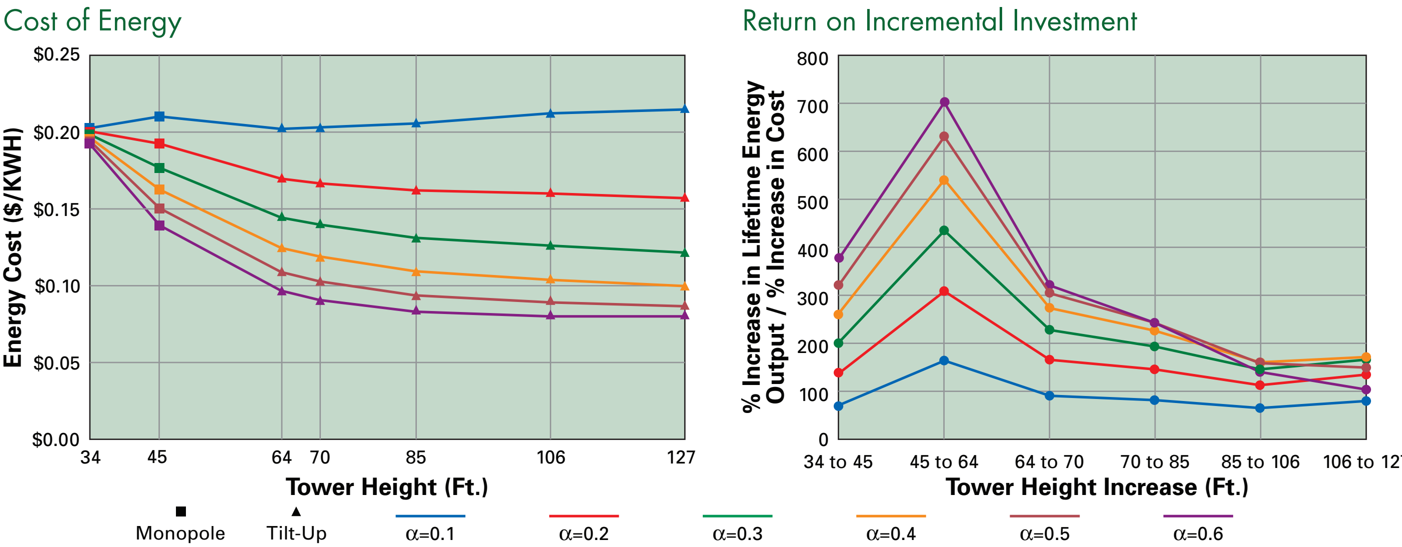
An alternative way to evaluate the economics of using a taller tower is to compare the incremental increase in lifetime energy output to the incremental cost associated with purchasing the taller tower, or in other words, the return on incremental investment (ROII). By "incremental increase," we mean the additional KWH generated on a taller tower. By "incremental cost," we mean the additional cost to invest in a taller tower.

As an example, the cost of Excel-S installed on an 80-foot tower is 1.6% higher than on a 60-foot tower. However, the taller tower system will generate 6.2% more energy in a 0.1 shear, and 26% more energy in a 0.6 shear. That's a 388% and 1,640% ROII, respectively. The ROIIs are shown for an Excel-S on the four tower types at similar heights over a range of shears for each tower.

What investor wouldn't be happy with a 1,000% return on their investment? While the ROII decreases with further increases in tower height, the return in all cases is greater than 200%. It's worth noting that with all towers, the ROII for the

Skystream on Monopole & Tilt-Up

Cost of Energy / Return on Incremental Investment



highest shears increases at a lower rate for taller towers. However, if you're not driven purely by economics—for example, you need to maximize energy generation—then a decreased ROII and increased cost per kilowatt-hour shouldn't be a deterrent.

Results—Skystream 3.7

For this turbine, monopole tower kits are available at 34 feet and 45 feet, and tilt-up tubular tower kits are available at 64, 85, 106, and 127 feet. As a result, not all the tower kits could be consistently compared at similar heights. Instead, cost of energy was calculated for shears of 0.1 to 0.6 at each of these heights. COE for an annual average wind speed of 11 mph at 33 feet are reported in the graphs.

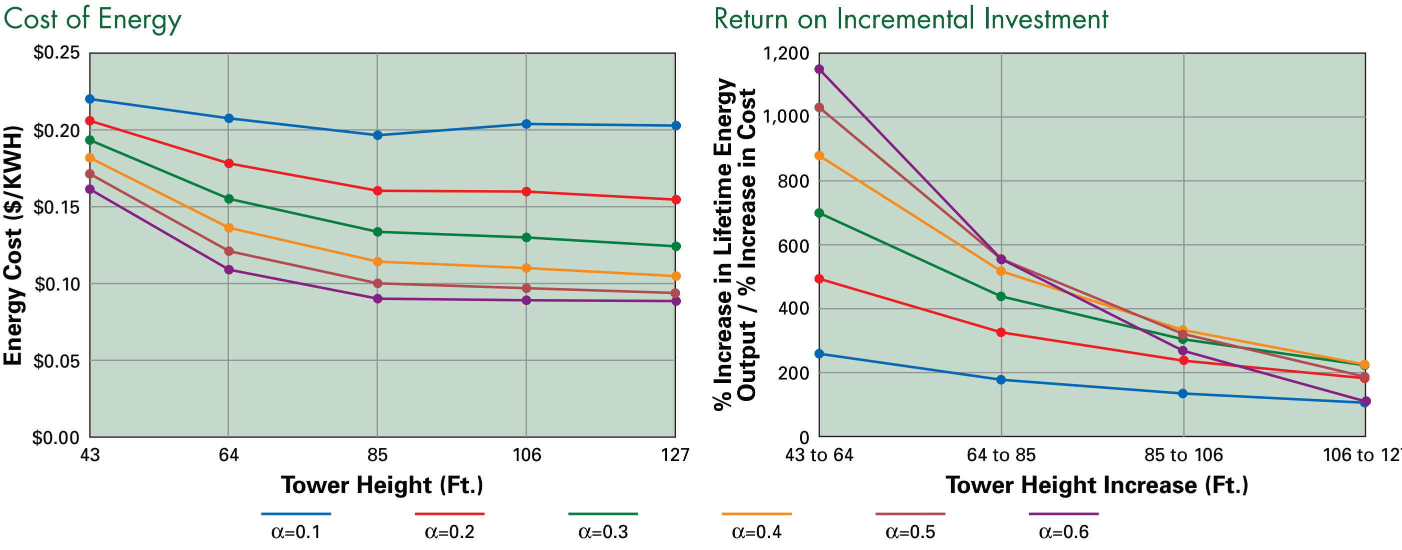
The graphs show a slight upward trend in COE at the lowest shear, but improved economics otherwise. Cost of energy decreases rapidly for the short monopole towers and decreases slowly for taller tilt-up towers. A significant improvement in ROII is seen when going from the tallest monopole tower (45 ft.) to the shortest tilt-up tower (64 ft.). Notice the similar tower costs in the Systems Cost table. The ROII then steadily decreases to a still-respectable 100% return at the tallest tower height, except at the very lowest shear.

Results—ARE110

The ARE110 was evaluated on ARE's 4-inch-diameter tilt-up tubular towers, which range in height from 43 to 127 feet. As with the previous systems, there is economic disincentive to purchase the tallest towers for low wind-shear conditions; otherwise, using a taller tower provides a

ARE110 on Tilt-Up

Cost of Energy / Return on Incremental Investment



lower cost of energy. The very best ROIIs are above 1,000% and result when "upgrading" from the shortest tower in high wind shears. In all cases, a doubling of incremental investment should be expected. Surprisingly, the lowest ROII for the tallest tower "upgrade" occurred at the highest shear.

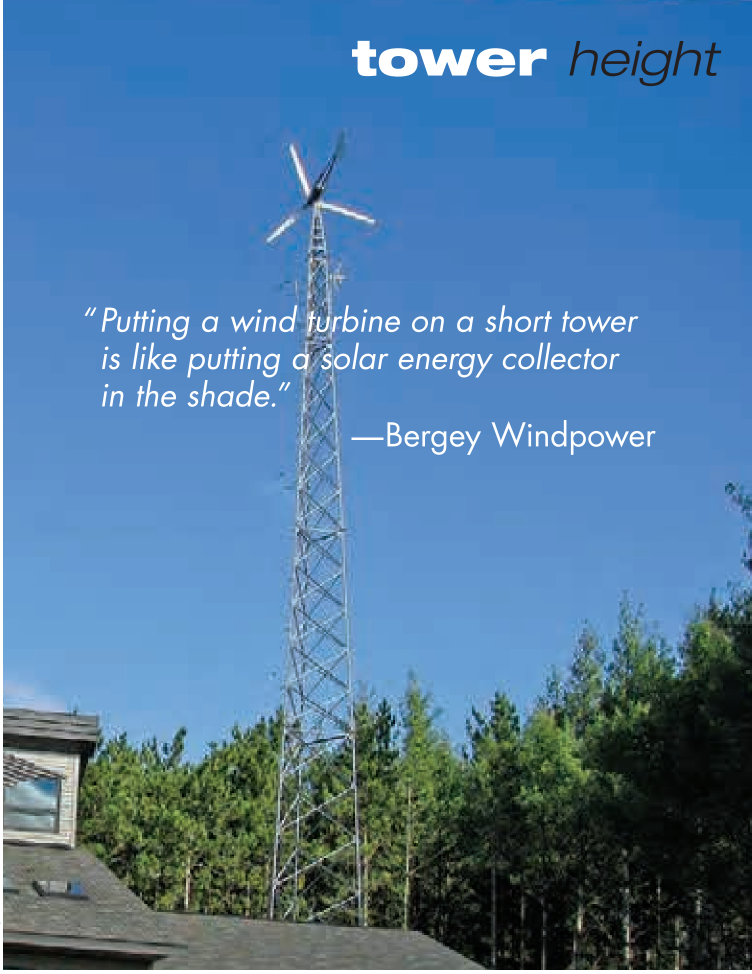
Shear Genius

In terms of straight economics, is taller better? It depends. In low-shear conditions—on the plains and in coastal regions, for example—simply satisfying the minimum tower height rule may maximize the return on your system investment. In high-shear conditions—in wooded hills and mountainous areas—buy the tallest tower you can erect. The general trends presented are typical for residential-scale systems. Factors not considered in this economic analysis include turbine repairs and reduction in energy production due to greater turbulence at higher shears.

So how can you make practical use of this information? Once you have selected a wind turbine, follow these steps to determine the best tower height at your location:

1. Use sound siting rules to find the best spot to locate the wind turbine (i.e., look at high spots on property, consider upwind obstructions, etc.).
2. Determine your minimum tower height based on the height of the surrounding obstructions, such as trees and buildings. The general rule is that the bottom of the blades should be a minimum of 30 feet above the tallest obstruction within 500 feet.
3. Choose a tower type that meets your budget, site conditions, and aesthetic and practical preferences.
4. Estimate your local wind-shear coefficient using the wind-shear table on page 85.
5. Analyze how incremental increases in tower height impact your cost of energy. Unless your site experiences very low wind shear, investing in a taller tower results in significantly more energy output, which will pay for this incremental investment and result in a quicker payback for the additional expense incurred.
6. Keep in mind that these are general rules that apply to most potential sites. An experienced turbine installer or professional site assessor can determine if your site is an exception to the rule, and help maximize the return on your investment.

As with clothing and beer, cost is not the only factor to consider when choosing a tower. Other factors to consider include local zoning ordinances, aesthetics, size of footprint, and crane access. Make sure you choose a system that suits your wants, not just your needs, and one that you'll enjoy living with for many years to come.



Courtesy MIREA

A 100-foot freestanding lattice tower was chosen to clear the 0.6 shear site at the Midwest Renewable Energy Association headquarters in Custer, Wisconsin.

Access

Brian Raichle (raichlebw@appstate.edu) is an assistant professor in the Appropriate Technology program at Appalachian State University. He is involved in wind resource assessment and solar thermal research.

Brent Summerville (wind@appstate.edu) is a renewable energy engineer at Appalachian State University where he manages their Small Wind Research & Demonstration Site and their Anemometer Loan Program, and leads public workshops and presentations on wind energy.

Further Reading:

Wind Power: Renewable Energy for Home, Farm, and Business by Paul Gipe (2004, Chelsea Green Publishing)

"Wind Generator Towers," Ian Woofenden, *HP105*

"Wind Generator Tower Height," Mick Sagrillo, *HP21*

"Tower Economics 101, 102 & 103," Mick Sagrillo *HP37, 38, & 39*

"Site Analysis for Wind Generators, Parts 1 & 2," Mick Sagrillo, *HP40 & 41*

"Small Wind Electric Systems: A U.S. Consumer's Guide," U.S. DOE • www.eere.energy.gov/windandhydro/windpoweringamerica/small_wind.asp

Small Wind Toolbox • www.renewwisconsin.org/wind/windtoolbox.html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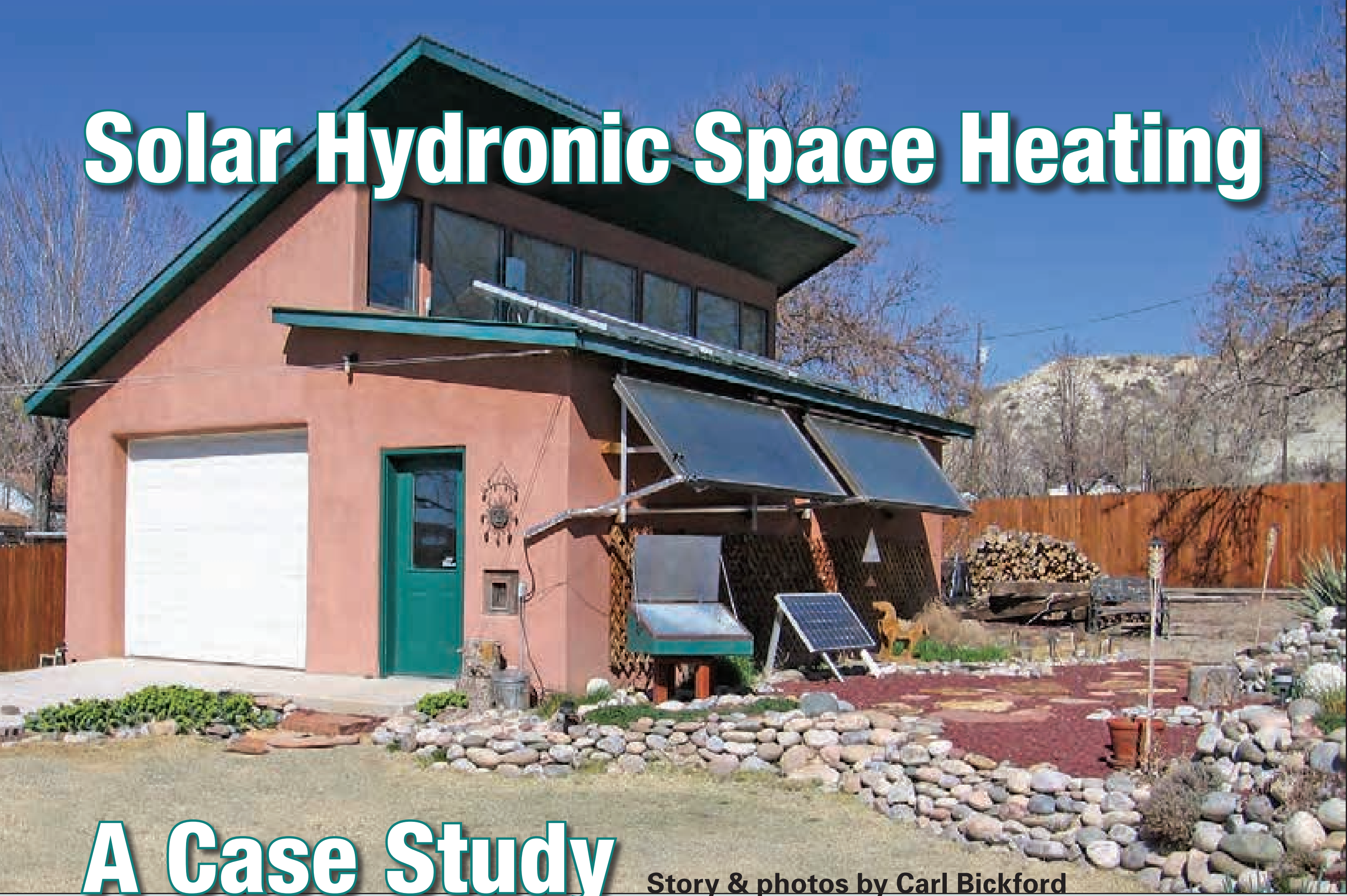
Solar Hydronic Space Heating



A Case Study

Story & photos by Carl Bickford

I'm fortunate to live in a sunny climate that averages 5.8 peak sun-hours per day. But I also live at 5,600 feet above sea level, where the heating season is much more significant than the cooling season (5,700 heating degree-days versus 700 cooling degree-days). Despite this, and that my 620-square-foot shop's south face receives morning shade from a neighbor's house and tree, my two solar systems—passive solar heating and a solar hydronic floor system—provide enough heating to make the building comfortable in all but January, the coldest month of the year. Even then, the relatively warm surface temperatures and warm floor allow me to work without gloves in air temperatures as low as 45°F (the lowest recorded interior temperature). During the coldest times of the year, solar heating typically keeps temperatures between 50°F and 65°F. At first light, due to the previous day's solar heat collection and storage, temperatures are generally 40°F above ambient, a testament to the power of the sun and a little RE technology. Paired with passive solar, my drainback hydronic heating system offers two main benefits:

- **Simplicity.** The system is easy to assemble and operate, and homeowner friendly. Distilled water is used as the heat-transfer fluid, and the unpressurized fluid loop is easy to drain and fill. There are no overheating or freezing issues with the collector fluid because the collectors are empty (drained back) when there is no solar heat. This system requires no differential controller, saving about $200 up-front on equipment. When you don't want heat, just turn off the pump. There's also no heat exchanger or storage tank to increase complexity and cost.

- **High efficiency.** Extremely low collector inlet temperatures of the heat-transfer fluid maintain high efficiency by lowering losses to the outdoor environment. The floor temperature in the winter varies from 50°F to 70°F.

System at a Glance

From the two 4- by 10-foot, flat-plate collectors mounted on the shop's south-facing wall, water flows through a small drainback tank and then directly into the radiant tubing embedded about 3 inches deep in the 4-inch-thick concrete floor. As it circulates through the tubing, the solar-warmed water gives up its heat to the slab and then returns to the collector for reheating. In turn, the slab transfers heat to the shop's interior by convection and radiation.

This straightforward system has only two control mechanisms: the sun shining on the PV module that drives the circulator pump, and a manual switch used to turn off the pump (and therefore, the system) during the summer months when additional heating is not needed.

Solar Sizing Strategies & Best Performance

Designing any energy system is all about the load. With a solar-electric system, it's your electrical loads you're concerned with. With solar heating, either passive or hydronic, that load is what it takes to heat an interior space. It's a little less straightforward than sizing a PV system. Knowing the size of the heating load requires intimate knowledge of your climate and your building envelope, including the thermal resistance of all the surfaces.

- **Reduce building envelope air leakage** by sealing all penetrations during construction, and making sure all windows and doors are weather-stripped and will close tightly.

- **Include thermal mass and insulate the outside of it.** Use rigid foam board (extruded polystyrene) both under the slab and around the perimeter. Any type of insulation can be used on the outside of walls that are used as thermal mass.

Right: Two refurbished 4- by 10- foot thermal collectors designed for horizontal mounting.

Below: A 95-watt PV module controls and powers the thermal fluid cycle.

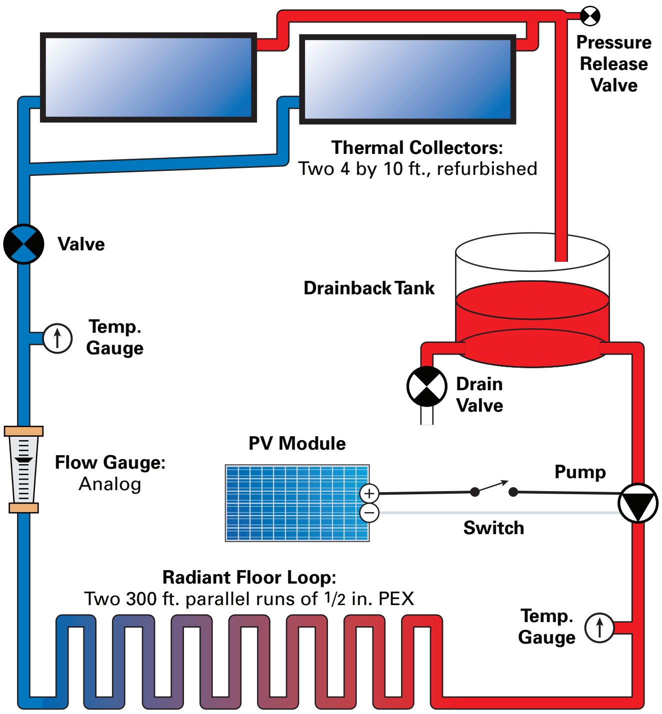
All heat transfer is driven by temperature difference (delta T or ΔT). The *rate* of that heat transfer depends on the ΔT and the amount of thermal resistance (R-value) at the locations of those temperatures. Lower R-values will result in *higher* heat transfer rates.

When the rate of heat loss through a structure equals the rate of heat gain (from the sun, in this case), a balance is reached and the interior temperature is stable. With solar gain, the strategy is to put heat in during the day at a much higher rate than it's lost, increasing the temperature of the mass while the sun is shining and storing heat in that thermal mass. After the sun has set and no more gain is available, interior air and surface temperatures will begin to drop. As the temperature difference is created, heat will begin to be released from warmer surfaces—in this case, the floor slab.

Solar space-heating is not magic, but it is a delicate balance between heat losses and gains. For building design, following a few simple principles will allow you to reap the benefits of passive or active systems:

- **Insulate the building envelope well**—if possible, beyond the U.S. Department of Energy's standards. Currently, the energy supplied by active solar systems is more expensive than fossil fuel, but the payback on insulation is quicker than solar.

SOLAR HYDRONIC SYSTEM

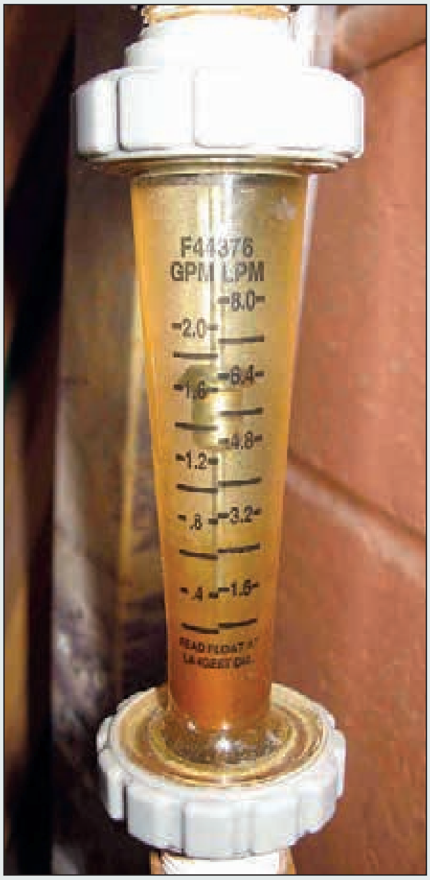


SOLAR THERMAL

The only way to truly know how well your solar thermal system is working is to collect data. This can be as simple as writing down a few temperatures each day from thermometers installed in the collector loop, or as complex as monitoring every possible variable and logging them many times an hour. If you want to determine your collector and system efficiency, here's the minimum amount of information you'll need to gather:

- **Collector loop flow rate (gpm)**
- **Fluid temperature entering collector (°F)**
- **Fluid temperature exiting collector (°F)**
- **Ambient temperature (°F)**
- **Solar irradiance (W/m^2)**

Site tube flow meter, showing 1.6 gpm.

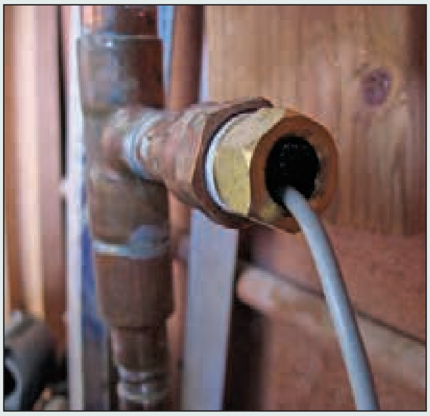


Collector flow rate and fluid temperature in and out are the data needed to calculate the amount of power being delivered by the collector loop. Adding those values together over a period of time will give us the *energy* collected. Ambient temperature and solar irradiance, with the previous data, will provide enough information to determine the efficiency of the collector loop and to compare performance to SRCC test results. Plus, you'll get a much better feel for how the system operates, and perhaps use the data to troubleshoot or improve the design.

Taking Measurements

Flow rate (gpm) in the loop you're testing is often hard to estimate—it really needs to be measured. If your system uses an AC pump, the flow rate will be fairly constant—once you know it, it won't need to be logged. With a PV-direct pump, this isn't the case. In my system, the voltage to the PV pump is regulated by a linear current booster so that, in full-sun conditions, the pump runs about the same speed most of the day. I'm able to measure that flow with an in-line flow meter, but as a result of not being able to constantly log the flow from my PV-powered pump, my flow rate information is only applicable to sunny days. Flow meters for data loggers are available, but are more expensive than the other data collection sensors in the system.

A temperature gauge well can also be used to place a temperature probe.



The ambient temperature probe hanging in the shade behind the collectors.

Collector fluid temperatures are relatively easy to obtain. The data logger I used has standard temperature probes and you can choose to download the information in either degrees Fahrenheit or degrees Celsius. I placed the probe tips into thermal wells that usually house temperature gauges in the collector loop. Insulation stuffed into the well holds the probes in place and blocks the ambient temperature from influencing the measurement. The probe measuring *ambient temperature* should be positioned out of direct sunlight, but near the collectors.

The most complicated data to collect is **solar irradiance**, which requires using a pyranometer. Finding an affordable model for home use can be challenging, but I chose to use an Apogee PYR-P Class 2 pyranometer ($170), which uses a silicon PV cell to produce electrical current proportional to irradiance. Because the PV

DATA LOGGING

Solar irradiance is measured with a pyranometer.

cell is not sensitive to all the wavelengths of sunlight, a calibration is required. The results are generally quite accurate (within 5%) as long as the pyranometers are exposed to natural, unobstructed daylight conditions and pointed skyward.

The data logger will only record voltage (in the 0.0 to 2.5 V range), which must be converted to irradiance. The output of the pyranometer is too small to be used directly, so it must be amplified. A handy amplifier is the AMP04EP integrated circuit chip (about $11) built by Analog Devices. It requires a single supply voltage of 5 to 15 VDC, which is a nice match for a standard 9 V battery. It consumes just over 0.7 mA of current, so a rechargeable nickel metal hydride (NiMH) cell (8.4 V, 180 mAh) will run it for about 10 days. Six AA rechargeable batteries in series would be enough to keep the amplifier running for several months, and most data loggers will run for much longer than that on their own internal batteries. The logic and calculations are applicable to a wide variety of data acquisition situations.

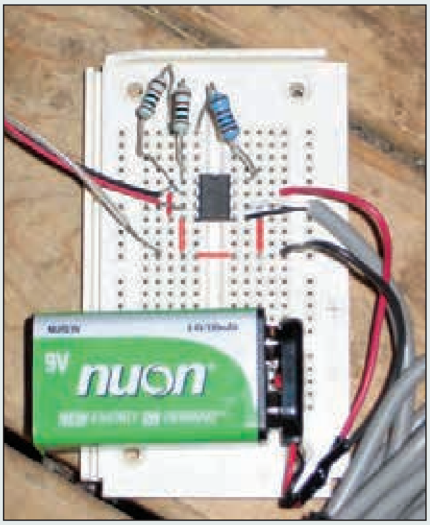
The data logger records three temperatures and irradiance.

I used Onset Computer's Hobo data logger to collect and store the four streams of data. Standard temperature probes were plugged into the first three ports, and the signal from the amplified irradiance meter is plugged into the fourth.

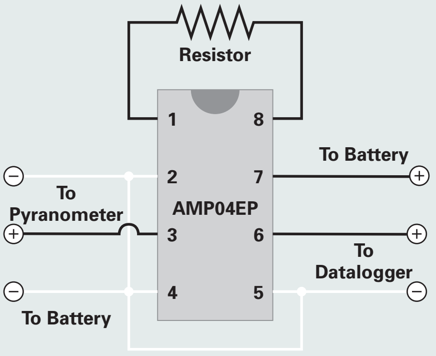
Number Crunching

For this round of testing, I chose a 5-minute time interval to sample and store all three temperatures and irradiance. This allows me to see the response to transient events such as system start-up and passing clouds. Downloading the data to a computer and exporting that information to a spreadsheet file is simple with the software supplied with the logger. Once in a spreadsheet, the data must be manipulated to calculate thermal power for both the sun (on the collector array) and the plumbing loop. To get the total solar power, multiply irradiance in watts per square meter (W/m^2) times the surface area of the collectors (m^2).

For the plumbing loop, multiply flow rate (gpm) by 60 (minutes per hour) by water density (8.33 pounds mass per gallon) by specific heat of water (1.0 Btu per pound mass per degree F) by the ∆T (°F) to get power in Btu per hour. Now divide that result by 3.412 to convert from Btu per hour to watts.



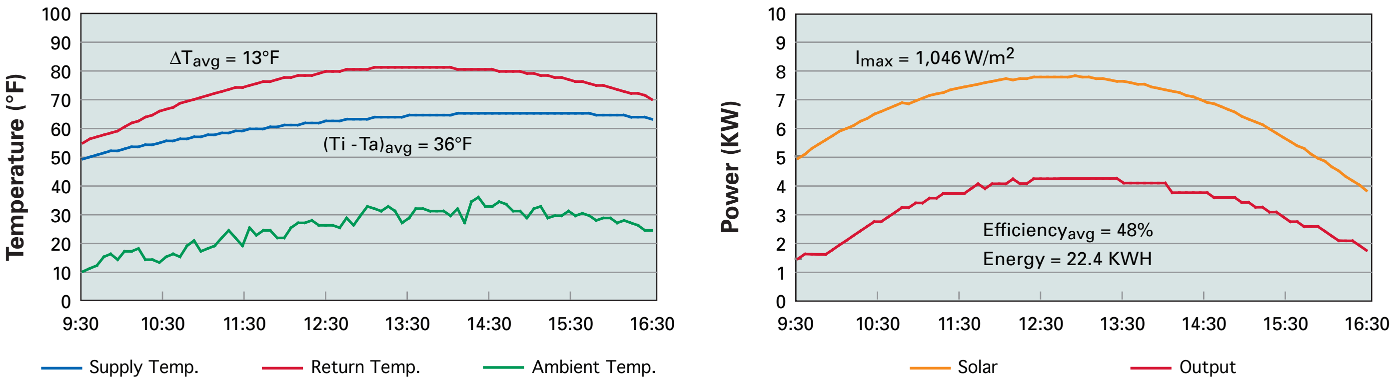
A signal amplifier built on a bread-board adjusts the pyranometer signal for the Hobo.



Wiring the AMP04EP.

Then the power values can be multiplied by the time interval to get energy (WH), and added up over the day. On the temperature graphs, make sure the supply and return temperatures are very close before and after the test, so you'll have confidence in the ∆T values. On the power graph, the system power should be substantially lower (at least 40%) than the solar power because of the inefficiency of the collectors and other losses. The system power curve should closely parallel solar power during a clear day. In both cases, toss out the transient portions of the data before using them to determine efficiency or energy collected.

JANUARY 18, 2008 PERFORMANCE



Collector Case Study

A solar thermal collector's performance is crucial to an *active* system's efficiency. This performance can be expressed in graphical form as efficiency (fluid power out divided by solar power in) versus a combination of ΔT and solar irradiance. The Solar Rating and Certification Corporation (SRCC) tests collectors for performance efficiency and for average daily energy output. I didn't have this data for my collectors, which were reclaimed units with new absorbers and insulation. So besides getting a handle on the collector's unknown efficiency, measuring the actual performance of the entire system would allow me to get a much better idea of how well it was operating so I could improve the system's output.

To get reliable data, the system must operate in steady conditions of consistent flow rate and irradiance, so I only used data from sunny days during the heating season, and disregarded data during start-up and shutdown conditions. Fluid temperatures were measured going into (supply) and coming back from (return) the collectors. Solar irradiance was measured and then converted to total power, in watts, landing on the collectors. Fluid power in the loop was calculated with the flow rate, and ΔT (return minus supply temperatures).

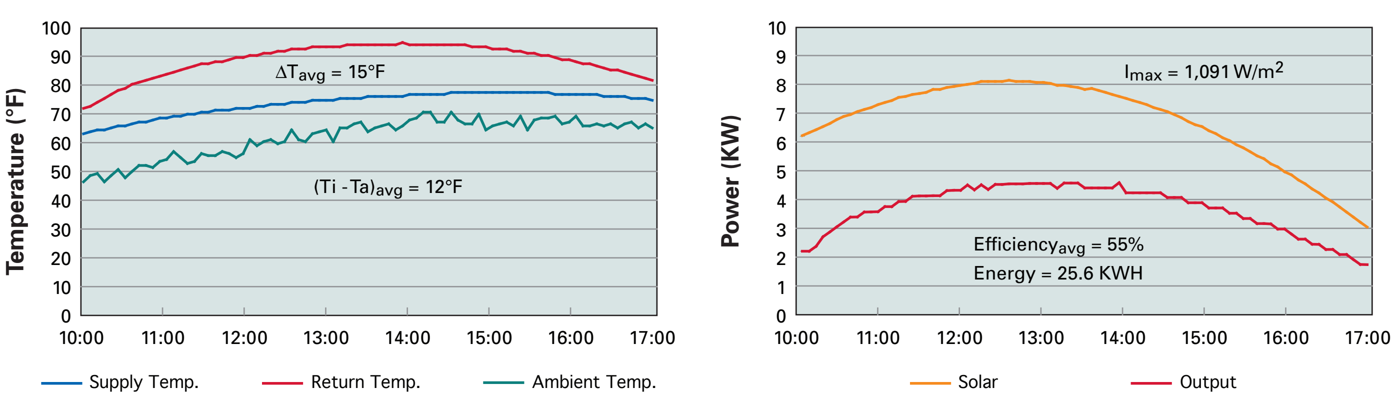
The data shown in the January 18 graphs was collected on one of the year's coldest days; the ambient temperature was -3°F at sunrise and the average ambient temperature during the test was 25°F. The ΔT (at a constant flow rate of 1.6 gallons per minute) is proportional to the amount of heat going into the floor. It includes the drainback tank losses and two short runs of uninsulated pipe inside the building. The difference between supply and ambient temperatures ($T_i - T_a$) represents the potential for heat loss from the collectors. SRCC uses this value, and the irradiance (I) to characterize the "harshness" of the collector operating conditions. Higher $T_i - T_a$ translates into lower collector efficiency, and higher "I" values mean higher efficiency.

The average efficiency for the heating system over this day was 48%, and that's not too shabby, especially if you consider that these collectors are refurbished. They only use flat-black paint on the absorber, and are put together without any welds between the riser tubes and absorber plate. (Having a selective coating on the absorber and a solid bond between the riser tubes and absorber plate would be even more efficient.)

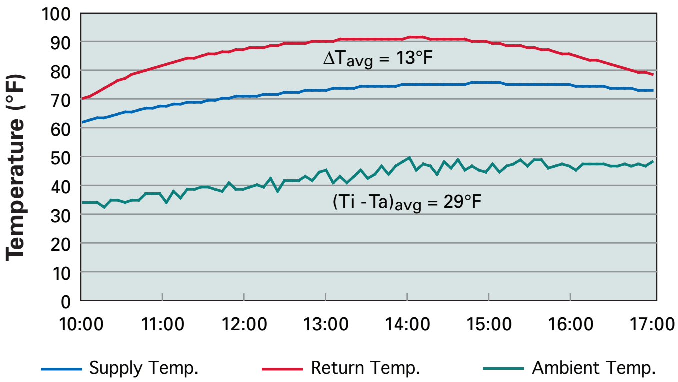
Let's look at the same data for two warmer days during the year. The February 29 graphs show data collected on a day when the average ambient temperature was about 62°F. Again, the irradiance is about the same, but a higher efficiency is evident. This is due mainly to the much lower $T_i - T_a$ value. More energy is the result.

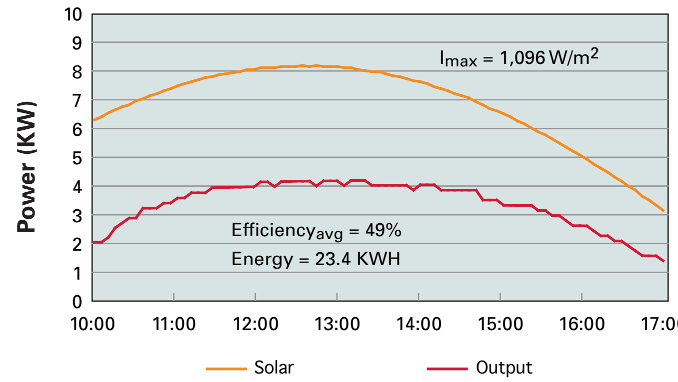
For the March 3 graphs, the average ambient temperature was 43°F—almost 20°F higher than the first scenario. However, the average irradiance, ΔT, and energy output are almost the same. How can this be? Remember that the shop temperature

FEBRUARY 29, 2008 PERFORMANCE



MARCH 3, 2008 PERFORMANCE





is allowed to float—there are no thermostatic setpoints, so the interior temperature increases as the ambient temperature increases—and notice it is much warmer this time around, as evidenced by the higher supply temperature. The energy output is probably higher due to the lower average $T_i - T_a$. Basically, the system puts in about the same amount of energy whether it's warm or cold outside because the interior temperatures will adjust to maintain a certain level above ambient.

I was surprised to see how consistent the efficiency and energy output were over the heating season, since the general expectation would be to see higher output with warmer ambient temperatures. I doubt this to be a general result, and it is mostly due to a seasonally variable building interior temperature.

Practical Solar Heating Considerations

Now that you've seen how my system performs, let's ask a critical question: "Is it worth it to put solar thermal space heating in a building?" I've been a fan of these systems my entire career and I wish I could answer with a resounding, "Yes!" However, from experience with design and performance in residential applications, the answer is a more qualified, "Maybe."

Here's a consideration: Would an active solar hydronic system add more heat energy to the building than an equivalent passive system of vertical south-facing windows? In my case, during the coldest period of the year, such glazing would put in about 80% of the active system's heat on a sunny day—and that includes the 24-hour losses that windows experience. During warmer times of the heating season, the contribution from passive solar heating would be even higher, because of lower heat losses through the windows.

My calculations included the insulation levels in my building envelope and double-paned windows with U-values of 0.5 and solar heat-gain coefficients of 0.6. There are some other considerations, however. On cloudy days, the windows lose energy 24 hours per day, while the active system just shuts down. If you have a lot of cold, cloudy days during the heating season, an active system starts to look more appealing.

Passive solar windows will be net losers in cloudy weather, and the active system will only contribute energy when there's enough to be collected. Active systems provide heat without nighttime and inclement weather losses. In my case, the passive solar window area is just about equal to the area of the active collectors (about 80 square feet for each). In my climate, the contributions of each are going to be roughly equal, with an advantage going to the active system. This combination of passive and active heating allows me to have a combined collection area equal to 26% of the building's floor area. This is a high percentage, but is acceptable because I have sufficient thermal mass to store the incoming energy during sunny days. It would be difficult to deal with all of that area if I had only passive windows, because of excessive light and structural issues.

If I had to build the shop all over again, I would have included more envelope insulation, which would slow heat escape during the winter and let in less heat during the summer. There's plenty of thermal mass in the concrete floor and concrete-filled block walls, but that's no substitute for insulation, even in the sunny Southwest. I'd also be more careful to control losses from air leakage—there's a large insulated garage door on the building that doesn't seal well. Finally, I'd buy SRCC-rated collectors, which would offer better performance and higher output mostly due to the absorber construction and surface coating.

Access

Carl Bickford (bickfordc@sanjuancollege.edu) is a professor of engineering and renewable energy at San Juan College in Farmington, New Mexico.

SRCC • www.solar-rating.org

Data Logging Equipment Manufacturers:

Analog Devices Inc. • www.analog.com • AMP 04 instrumentation amplifier chip

Apogee Instruments Inc. • www.apogeeinstruments.com • Pyranometer

Li-Cor Inc. • www.licor.com • Pyranometer

Onset Computer Corp. • www.onsetcomp.com • Hobo data loggers & sensors

Other Resources:

"Principles of Radiation Measurement" • www.licor.com/env/PDF_Files/Rad_Meas.pdf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Battery Desulphators
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• Recovers Sulphated Batteries
• Single unit 12 to 48 V
• Adjustable Pulse Strength
Linear Voltage Boosters
Keeps a Constant Battery Voltage to your Equipment
• Charge a Battery from a Lower Voltage Battery or PV
• Water Pump Booster and Controller
Generator Starters
Starts / Stops Gensets based on Battery Charge
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• Controls any Generator
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On-the-Road SOLAR

Story & photos by Lynne Allen

While the last streaks of daylight slipped behind the rolling hillsides of Virginia's Blue Ridge, I snapped a few rolls' worth of digital pictures, trying to savor the "magic light" that photographers cherish. It was a moment like this—perched on the Blue Ridge Parkway, nary a soul in sight—that brought my journey full circle. Here I was, far from home, capturing in pixels the same light that charged the PV-powered digital photography studio that traveled with me in my 32-foot RV.

Ken Dilello, a friend of the author's, relaxes with his dog and a cold drink, while the PV array grabs the last few rays of sun.

The mobile photo studio's roof-mounted PV array was designed with adjustable legs to optimize the tilt angle when the rig is parked, and to lay flat when the RV is rolling.

For as long as I can remember, I've wanted to pursue photography more seriously, but whether it was a job, money, or family, I always found one reason or another not to go for it. Life, however, has a funny way of forcing experiences on us—for better or for worse. One day, little more than a year ago, I woke up to discover that I was 47 years old, finalizing a divorce, leaving my job in PV sales, and selling my off-grid, solar-powered home. Though I had no real plan, I also had no more excuses. All I knew was that I wanted to find a way to see the country while working as a photographer and remaining true to my off-grid sensibilities. But how? My off-grid, mobile solution: Hit the road in a 1989 RV retrofitted with a PV system to power a digital photography studio.

Having worked in PV sales for more than 15 years, I understood the technology and the general mechanics of a system. But since I spent more time in the office than out in the field, the installation process was still fairly intimidating. As luck would have it, I met another semi-professional photographer, Ken Dilello, who shared my passion for solar energy and my vision for life on the road. He had six Siemens 100-watt PV modules, and I had the RV. His strengths in carpentry and fabrication complemented my weaknesses, and vice-versa, so we decided to join forces. From North Carolina, we headed for Florida, where Ken had connections with owners of a metal shop who agreed to let us camp out while we worked on the vehicle.

Our plan was to remove the dining area table and cabinets in the RV and transform the space into a work area for my digital photography studio. We sized the 600 W system to provide enough electricity for both our professional and domestic loads—a desktop computer and a printer, two laptops, various battery chargers, a flat-screen TV with a stereo system, a microwave, and other small household appliances.

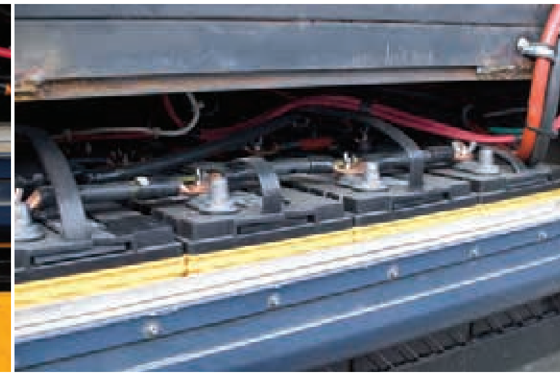
Metal Fabrication & Mounting

The first, and most time-consuming, part of the process was making room for additional battery capacity and fabricating a roof rack for the PV array. The RV came equipped with only two, 90 amp-hour, 12-volt batteries for its DC loads—not nearly enough storage for the potential energy generation of the six-module array. The existing batteries were located in the front engine compartment, where there was no room for additional batteries. To accommodate 10 new 12 V batteries, Ken, a tile and stone setter by trade, devised a plan for a battery cage that attached to the undercarriage and dropped down, when unbolted, to allow easier access to the batteries.

Over the course of a few weeks, Ken fabricated the 2.5- by 3-foot battery box from a mix of expanded and extruded steel, and then welded the lid of the box in place. Essentially, the bottom of the box is bolted into the lid, which is welded to the RV's chassis. He also cut and welded the pieces for the roof rack, which provided not only a sturdy, aerodynamic support system for the modules but also a means for reducing the number of holes that we'd need to put in the roof. Ken's

Ken works on the drop-down battery tray.





Assembling the interconnects and battery overcurrent protection. Far right: The neatly wired battery bank.

design also accommodated the TV antenna and left room for an observation platform at the front of the roof.

While Ken secured the roof rack, I worked on the ground, wiring the PV arrays and attaching them to the aluminum rails that Ken had fabricated. I ran wiring through conduit throughout the system, making for neat and tidy connections that can withstand the elements. Next, we raised the arrays onto the roof and mounted their aluminum frames to the roof rack. Though I had dreaded the logistics of raising the modules onto the roof, we moved them in less than 30 minutes—thanks to the shop's forklift and Ken's experience with running one.

Wiring the Controller

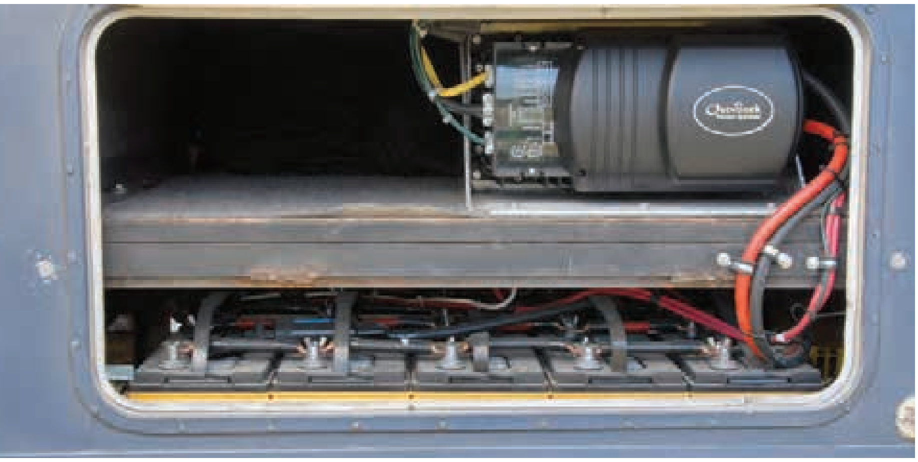
The output cabling of each PV module was routed through a combiner box installed on the roof. For a weather-tight seal, we included a double-sided elastomeric membrane on the roof beneath the combiner box. Six-gauge wire was run in EMT conduit from the combiner box to a Trace C-60 charge controller, which we mounted alongside an OutBack inverter in a storage compartment under the interior floor (known as the "basement compartment" among RVers). At some point, we'll upgrade the controller to a maximum power point tracking unit to optimize the output of our PV array.

Using a hole that we drilled for the array cables, we ran the AC conductors up from the inverter to the house mains, located in the cabin beneath my desk. To cut down on costs, Ken had rummaged for cable at the junkyard and came back with a few choice pieces from an old BMW—a pretty good find considering that the same cables would have cost us more than $150 in the store. The cable that runs from the charge controller to the batteries is a #4 wire that he salvaged.

The charge controller is mounted horizontally next to the inverter to save space in the RV.

The OutBack Mate displays inverter settings and status.

The OutBack inverter fits neatly above the battery bank.



The modified circuit panel is readily accessible.

Though probably overkill for our power generation, this size helps minimize losses in our small system.

Wiring Up the Battery Bank

When it came to choosing a battery, we entertained a few ideas, namely T-105s and similar deep-cycle and marine batteries. In the end, we went with 10, 125 AH, 12 V deep-cycle batteries from a big box store. In retrospect, one drawback related to our decision was that we ended up with 10 batteries in parallel. Large numbers of batteries (or series strings of batteries) wired in parallel are subject to unequal charge/discharge rates and premature failure. Most system designers recommend limiting the number of batteries wired in parallel to three. A better approach would have been to install higher-capacity 6 V or even 2 V batteries to minimize the number of battery strings in parallel.

We used copper lugs and a large crimper to make the interconnects for the batteries. Instead of ordering pre-made battery connectors that never quite fit right, we fashioned our own connectors out of 2/0 cable—some of which I bought at the local hardware store ($15 per foot) and the rest Ken found at the junkyard. To prevent corrosion, we sealed each crimped lug with heat-shrink tubing. Once we wired up the bank, we had 1,250 AH of storage at 12 VDC nominal at our disposal.

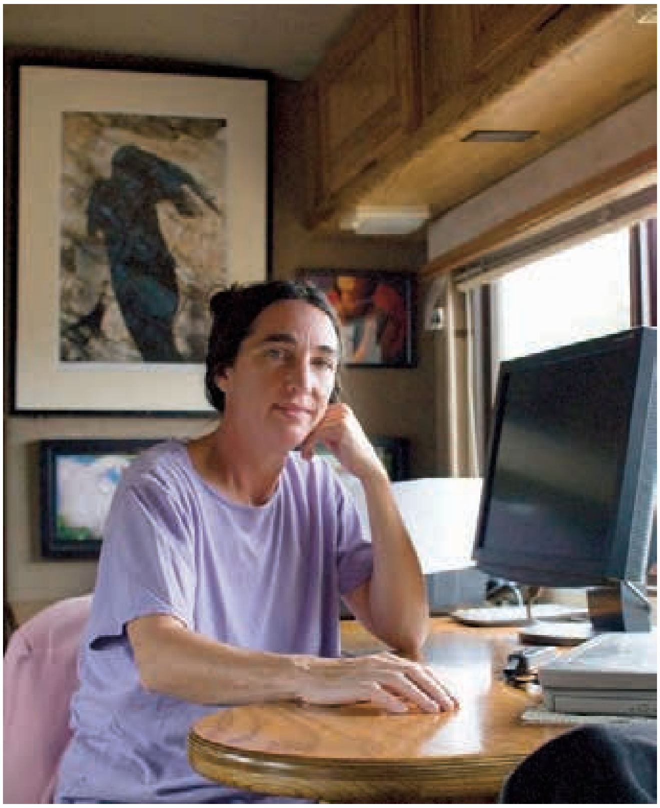
We built two inverter cables the same as the battery cables—with lugs, crimped and sealed with heat-shrink tubing. We also added a 200-amp fuse for overcurrent protection and to serve as our DC disconnect in line on the inverter-to-battery connection. Although a disconnect switch would have been better, this was what fit into our budget.

Rewiring the Rig

Finally, we were ready to rewire the main house lights (DC loads) from the original battery bank in the front of the coach to the newly installed bank. Almost all of our major loads now run off the new battery bank—except for some cargo bay lights that still run off the original battery bank, which only charges when the engine is running.

On the inside, we reconfigured half of the house system. Ken customized a store-bought standard circuit panel to fit our space by cutting it down with a band saw and welding it back into shape. Fortunately, the RV came equipped with a transfer-switch that allows us to switch power input from the onboard gas generator to the grid when we hook up somewhere. This is a particularly important feature because if we're ever running low on solar energy, we can either plug into the grid or turn on the gas-powered generator. I'd rather eat a bug than turn on the gas generator, but on occasion, it's a necessary evil.

We ended up hooking up the inverter at dusk, by flashlight—admittedly not the best light for working with power cables. We carefully attached each cable to the opposite ends of the battery bank. When we went inside, we switched on the main circuit breaker to the inverter. The inverter was on, and we had *solar* electricity.



The author in her PV-powered solar studio.

Focused on Horizon

For the final touches, we installed a desk in the RV's dining area, which is a perfect space for my growing portrait business. All told, it took about four to five weeks to install the system and finish the remodel. We're still tweaking the rig here and there, upgrading to LEDs and energy-efficient appliances. Our small system, which produces about 1.5 KWH per day, doesn't leave us with much excess energy, but we're just fine with that. We make every watt count. Besides, it's a trade-off for the freedom that we now have to roam the country and pursue our passion.

Access

Lynne Allen (lynsbox@embarqmail.com) operates an art and portrait photography business out of her solar-powered RV. Her specialty is human-form images in nature and nudes. She and her partner Ken Dilello spend most of their time in the Carolinas and Maine.

Major System Components:

OutBack Power Systems • www.outbackpower.com • Inverter

SolarWorld • www.solarworld-usa.com • PVs

Xantrex • www.xantrex.com • Charge controller

Changing Codes

& Grid Connection

by John Wiles

The final connection between a utility-interactive photovoltaic (PV) system and the electrical utility grid is an area of importance to PV system designers and installers. Due to the varying sizes of PV systems and configurations of existing service-entrance equipment, these connections vary significantly among PV systems. Differences in Section 690.64 of the 2005 and 2008 editions of the *National Electrical Code (NEC)* make these variations even more complex.

Load-Side Connections

Section 690.64(B) establishes the load side (of the main service disconnect) connection requirements for the utility-interactive inverter output. The key to understanding this section is to carefully read 690.64(B)(2) and note that the ratings of overcurrent devices *supplying* a bus bar or conductor must be added so that the sum of these ratings does not exceed the rating of the bus bar or conductor. The ratings of overcurrent devices supplying loads are *not* counted. Also note that the overcurrent device (normally a circuit breaker) *rating* is used in this calculation—*not* the current flowing through the circuit. Overcurrent devices to be counted are the main breaker and all breakers backfed from utility-interactive PV inverters. This equation expresses this ratings requirement:

PV + Main ≤ Bus or Conductor

In the *2005 NEC*, this requirement applies only to commercial (nonresidential) PV installations. Here's an example: Say the site has a 400 A main service panel with a 400 A main breaker. In this case, no PV can be added to the panel. In many commercial installations, this limitation forces the installer to use a supply-side connection (see "Supply-Side Connections" section).

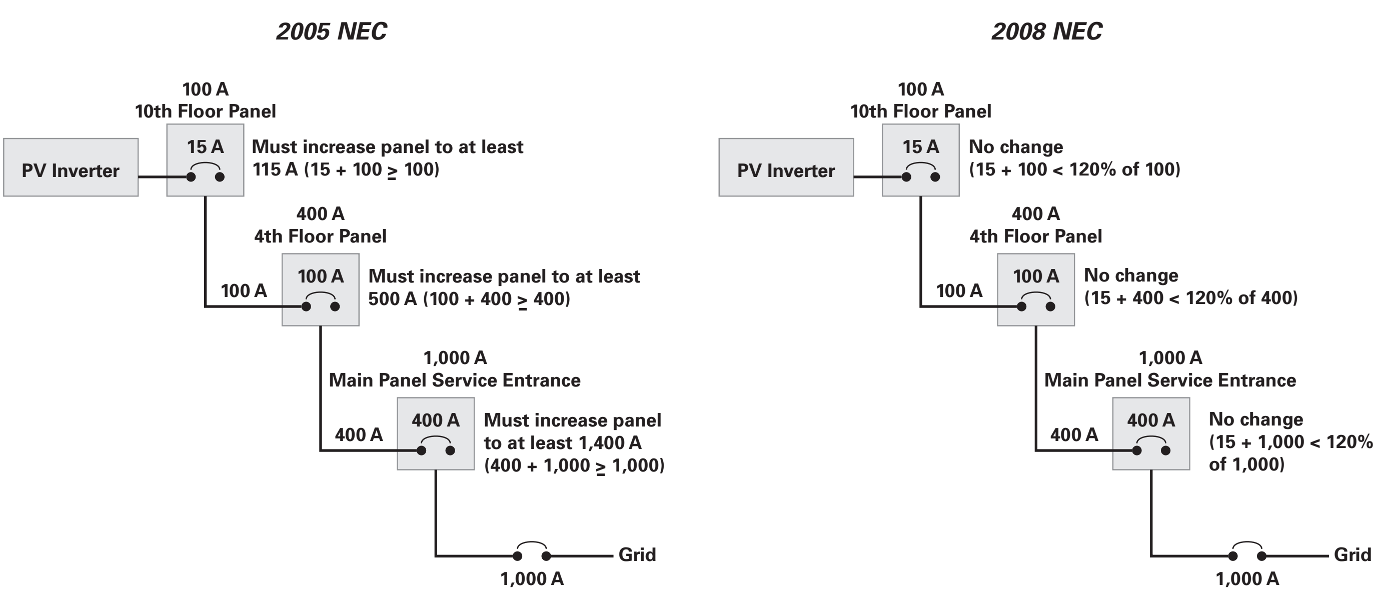
For residential installations, a 120% allowance is included. This exception makes installations somewhat easier:

PV + Main ≤ 120% Bus or 120% Conductor

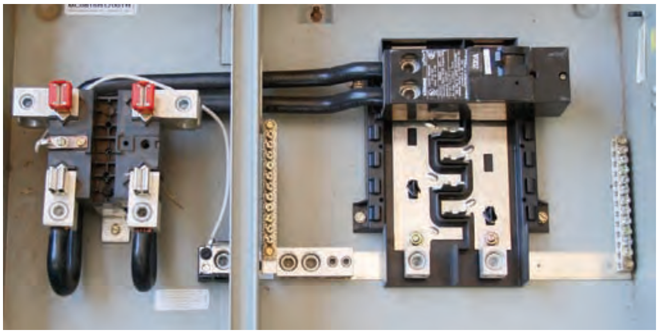
In this residential example, a 200 A mains panel with a 200 A main breaker could have up to 40 A of backfed PV breakers connected.

Section 690.64 was rewritten in the *2008 NEC* to apply the 120% allowance to commercial installations—but only

Requirements for Commercial Grid-Tied PV Systems



Combined meter/load centers can only be tapped with permission and instructions supplied by the manufacturers.



if PV backfed breakers are mounted at the opposite end of the bus from the main breaker or feeder (Section 690.64(B)(7)). Locating breakers in this fashion prevents overloading the bus bar. If this requirement cannot be met, then the sum of the breakers will be limited to no more than the bus bar rating on commercial installations—the same as the *2005 NEC* requirement. The requirements apply to both the bus bars in a panel or load center *and* to any conductor that is fed by overcurrent devices from multiple sources. The 120% allowance remains in effect for residential installations in the *2008 NEC*.

In the illustration (opposite page), the *2005 NEC* requirements are applied to a multistory building with a PV system that requires a 15 A circuit breaker in a 100 A main lug panel on the tenth floor. This panel is fed through a 100 A breaker in a 400 A main lug panel on the fourth floor. This, in turn, is fed by a 400 A circuit breaker in the 1,000 A main distribution panel that has a 1,000 A main disconnect.

Since this is a load-side connection, 690.64(B) applies to each panel board and conductor supplied through an overcurrent device from multiple sources. To meet the requirement in the top floor's panel, it would have to be replaced with at least a 115 A panel. The feeder between the 100 A panel and the 100 A breaker would also be required to have an ampacity of at least 115 A. If that top floor panel had a 100 A main breaker (instead of a lug connection), then the feeder would need to be rated at 200 amps, since the sum of the circuit breaker ratings attached to this conductor would be 200 A (100 A breaker from the tenth floor panel + 100 A breaker from the fourth floor panel), to meet the 690.64(B)(2) equation.

At the fourth floor panel, the sum of the rating of the breakers is 100 + 400 = 500, which exceeds the panel rating of 400 amps. The panel would have to be replaced with one rated at 500 amps or more. The feeder between the fourth floor panel and the main panel would also have to be rated at 500 amps with a main lug panel. If that fourth floor panel had a 400 A main breaker, then the feeder would be required to be rated for 800 A. Now look at that 1,000 A main service panel. The sum of the rating of breakers supply is 1,400 (400 + 1,000), which is significantly larger than the 1,000 A panel rating. The existing panel needs to be replaced with at least a 1,400 A rated panel.

These requirements were established with the concept that they would help protect those buses and conductors from overloads even when the PV system was expanded, the electrical panels had excessive loads placed on them, or when the feeders were unknowingly tapped.

Under the *2008 NEC* requirements, the 120% allowance is permissible by 690.64(B)(2). In this case, the 100 A panel on the top floor is allowable because 100 + 15 = 115, which is less than the allowed 120 amps. The same equation applies to the cable when the top floor panel is a main lug panel and the feeder does not need to be changed. If the top floor panel had a 100 A main breaker, then the equation for the feeder conductors would still be 15 + 100 = 115 ≤ 120 A, and the conductor would remain unchanged. Under 690.64(B)(2) of the *2008 NEC*, only the first overcurrent device connected to the inverter output is required to be counted in subsequent equations.

At the fourth floor 400 A panel, the allowance would be 480 A (120% of 400 = 480), but the additional rule in 690.64(B)(2) requires that only the first overcurrent device connected to the inverter output be counted for subsequent equations for the first and subsequent panel boards. The equation becomes 15 + 400 ≤ 480 and no changes in the panel are required. With a main lug 400 A panel, the same equation applies to the feeder and to the main panel. Also, even if a 400 A main breaker were installed in that 400 A panel, then the cable ampacity would not need to be changed.

Even with the allowances in the *2008 NEC* for load-side connections, many systems are large enough to exceed the 120% allowance, resulting in replacing existing load centers and feeders—a costly upgrade. To avoid this scenario, installers may utilize supply-side connections, which are allowed by 690.64(A) with no changes between the *2005 NEC* and *2008 NEC* editions.

Supply-Side Connections

The supply-side connection (690.64(A)) is essentially a second service entrance on the facility that is connected on the load side of the existing meter to allow for net metering. (See "Code Corner" in *HP111* and *112* for more details on supply-side connections.)

The Section 240.21 tap rules don't apply to these service-conductor taps; these requirements were developed for a circuit with currents flowing one way from a single source protected by a single overcurrent device. The service entrance tap with a utility-interactive PV inverter may have currents flowing in *both* directions from *two* sources, with one of them (the utility) having very limited overcurrent protection.

A main-lug-only panel, with no single main breaker. Use an empty breaker position for PV system input.

Actually making the tap will depend on the type of equipment involved. Many load centers do not have adequate space to splice to the incoming service conductors. The same holds true for the limited space in meter socket enclosures. In these cases, the supply-side tap will require that a new enclosure be added between the meter and the existing load center.

Combined meter/load centers can only be tapped with permission and instructions supplied by the manufacturers. The cables and bus bars may be exposed with plenty of room for the tap, but in most cases, the manufacturer will not allow tapping because this would violate the UL listing on the device. Instead, adding a supply-side tap to this type of installation may require adding a new external meter socket and a tap enclosure before the existing meter. The existing meter is bypassed with an appropriate set of jumper bars.

Some dwellings have main-lug-only panels. There is no single main breaker feeding the panel, but up to six main breakers are allowed. Empty breaker positions can be used as supply-side connections. The basic restriction (which will be in the *2011 NEC*) that would apply to this type of main service panel is that the sum of the overcurrent devices from the PV inverter(s) should not exceed the rating of the panel bus bar or the rating of the service entrance cables.

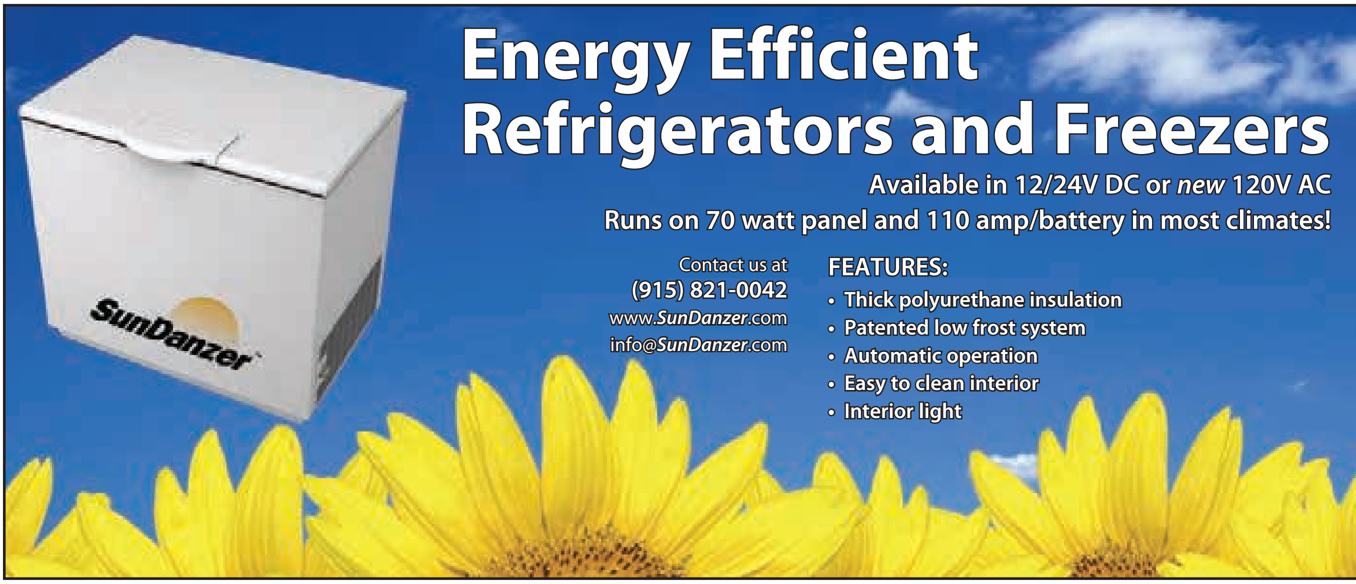
Connections from a PV system to the utility are still somewhat complex. However, the requirements in the *2008 NEC* have allowed smaller systems to be more easily connected in the commercial environment. In either residential or commercial PV installations, the requirements of the code should be studied in some detail to ensure a safe and durable system.

Access

John Wiles (jwiles@nmsu.edu) works at the Institute for Energy and the Environment, which provides engineering support to the PV industry and a focal point for code issues related to PV systems. A solar pioneer, he lived for 16 years in a stand-alone PV-powered home—permitted and inspected, of course. He now has a 5 KW utility-interactive system with whole-house battery backup. This work was supported by the United States Department of Energy under contract DE-FC 36-05-G015149.

Photovoltaic Power Systems and the 2005 National Electrical Code: Suggested Practices by John Wiles • www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/PVnecSugPract.html

PV Systems Inspector/Installer Checklist & previous “Code Corner” articles • www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html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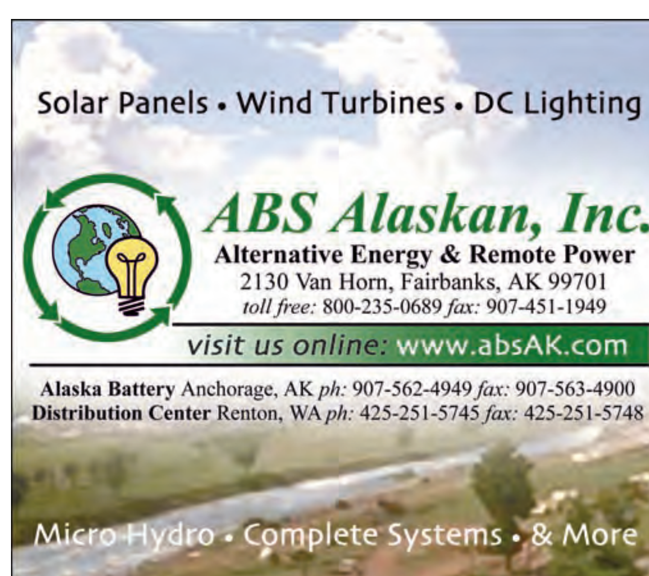
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Carbon Offsets

Climate Hero or Villain?

by Michael Welch

It's the general scientific consensus that climate change is moving forward more rapidly than previously thought, and many of our planet's citizens are rightfully concerned. There is no longer any credible doubt that humans are causing the climate to change at a rate that is much greater than might have occurred from natural global cycles. And there is no longer any doubt that if we do not curb our greenhouse gas (GHG) emissions, we risk irreparably harming life on Earth, causing extinctions that may include even our own species.

Using renewable energy sources, such as the wind, water, and sun, improving your home's energy efficiency, and figuring out more sustainable transportation options all can help decrease your carbon footprint—the amount of GHGs your activities produce. But these methods can be seen as inconvenient or too costly.

Carbon offsets are another option designed to decrease your total carbon impact—without changing your lifestyle. Some carbon offsets are voluntary investments in programs that pool those funds and reinvest them to support nonpolluting energy generation plants like solar, wind, or even methane collection from landfills. Other carbon offset programs invest in energy efficiency efforts for developing regions, reforestation, urban tree planting, or saving ancient forests from clear-cutting—all designed to help slow increases in carbon dioxide (CO_2) pollution.

The Carbon Confusion

When you buy carbon offsets from any one of hundreds of brokers or directly from the organization using the funds, what you're really buying is a piece of paper intended to assure you that the money you just spent is used as promised. Usually, your money is pooled to increase the scope of the offsetting investment. But it is often difficult to compare programs to find out which are most effective, and which have the questionable primarily purpose of generating income for someone.

Carbon offsetters usually sell their programs by putting a price on the tons of CO_2 kept out of the atmosphere. The more you buy, the more carbon you "save." Most of the available programs support carbon sequestration efforts—planting trees or preserving forests. Others are focused on pooling funds to build new RE projects or energy efficiency projects. Comparing programs can be difficult, as they often couch their carbon savings and pricing in much different terms. For $10 per tree, the Mississippi Project promises to plant 10 loblolly pines on its 500 acres in Mississippi. For about $7, the Conservation Fund's Go Zero program says they will plant one native tree in a designated protected area.

But the devil's in the details. Using the Conservation Fund's carbon calculator, my carbon footprint is 6.1 tons per year. (The "average" American's footprint is about 20 tons per year.) They suggest that planting five trees, for a total fee of about $37 each year, will make up for my footprint in 100 years of those trees' lives. According to the Mississippi Project, one tree will absorb 15 pounds of CO_2 per year over its lifetime (of about 100 years), which would mean I should buy at least eight trees per year under their program. Since their program offers tree purchases in blocks of 10, I'd have to shell out $100 up front to fully offset my year's footprint.

So, how does one explain the 40% disparity in price between these two programs? By added value, or merely by the profit strategy of the seller. The per-tree price difference is at least partially explainable because the Mississippi Project will send you photos of your trees being planted and a document commemorating your contribution to the global warming fight, place a plaque with your name and message at "your" stand of trees, and, finally, send you a photo each year showing the growth rate of your trees. The Go Zero fund just plants the trees without any hoopla. Another value difference between the two is that the more expensive one is a for-profit partnership intent on making money, and the other is a registered nonprofit that will use any funds to further their environmental goals.

Reading the fine print may reveal still other things that may be important to you—like the trees may be planted in monoculture-type tree farms for future harvest. Others may intend to reforest clear-cuts within ancient forests to eventually restore the forest. The value of each strategy is a judgment that we make as individuals. What's right for one person may not fit for another, but one point is that these differences make the costs per amount offset difficult to compare.

Gaining Some Carbon Clarity

How can we possibly trust the purveyors of carbon offsets with such a disparity in both costs and methods? How can we trust that the shysters have not worked their way into this market for such intangible goods? We can't, really—according to the *San Jose Mercury News*, the industry is a $100 million a year market—and growing. Dollar signs light up in the eyes of both legitimate and illegitimate businesspeople.

There must be some sort of independent certification and verification processes to help the public decipher it all and not get duped.

One method that has been developed is to treat carbon credits as a commodity, and the Chicago Climate Exchange (CCX) has been set up to do just that. However, the traders must be members—you or I cannot just walk in and purchase offsets. According to CCX, their members and transactions represent "the only [carbon] reductions made in North America through a legally binding compliance regime, providing independent, third-party verification."

Another method is for independent, third-party nonprofits to analyze and certify offset programs. This makes the programs more trustworthy for end-consumers who do not have the time and wherewithal to investigate every program. Perhaps the most prominent of independent certifiers is the Green-e program, which personally certifies some projects that offset carbon by investing in 100% renewable energy. Green-e climate certification guarantees no double-selling of GHG emission reductions, and sellers must make appropriate disclosure. Green-e certified offset programs use standard sets of protocols to make sure GHG reductions are real, verifiable, enforceable, permanent, and that the projects would not have happened anyway.

If you're looking to purchase personal carbon offsets, you either have to do your homework very carefully, or rely upon the three Green-e certified companies:

- 3Degrees—sells methane capture and RE credits in various developing nations;
- Bonneville Environmental Foundation—sells clean energy offsets primarily from wind projects; and
- Community Energy—sells wind-generated offsets.

Because of the consumer-protection issues of program comparison and legitimacy, our government is also getting involved to increase the viability and trustworthiness of individual carbon offset programs. In California, a bill is working its way through the state legislature that would require verification of voluntary carbon offsets sold in the state. Other states will likely follow, and the United States Congress has several bills that deal with carbon trading or offset verification. And finally, the Federal Trade Commission is under pressure to update its green marketing guidelines to provide more oversight for the offset market.

Buyer beware: Check out the available carbon offset programs carefully to make sure your money is being spent appropriately.

Cure for Climate Guilt

But aside from verification processes, programs that are hard to compare, or those meant primarily to remove your money and put it into someone else's wallet, do offset programs really have the net positive effect that concerned folks are hoping for? That question is being debated by the environmental community, and the answer is not entirely clear.

One of the largest concerns is that offsets are being used to avoid making needed lifestyle changes. Instead of slowing down on the freeways or driving a more fuel-efficient vehicle, they offer an easier way out—all you need to do is shell out some bucks to buy enough carbon credits to offset your carbon footprint. A close friend of mine who is a forester manages the privately owned van Eck forest near my home in rural Humboldt County, California. The forest is managed sustainably but sells its carbon credits to people who want to offset their GHG emissions. California Governor Schwarzenegger has purchased these and other credits to justify (oops, I mean "offset") a wasteful lifestyle, including flying around California and the world in private jets and maintaining his fleet of Hummers (goliath, dreadfully inefficient SUVs).

Like many who truly understand the climate change situation, Schwarzenegger seems unwilling to give up the lifestyle that he has gotten used to. Carbon offsets offer the perfect out—he can still be a jet-setter, yet avoid the appearance of a net positive contribution to global warming. The governor is a radical example, but thousands of others use carbon credits to offset everything from annual vacations to driving three blocks for a six-pack.

Not all offsetting is used to justify carbon excesses. Another friend, who has been a climate activist since before most of us even heard of global warming, carefully considers the environmental consequences of his actions and tailors his lifestyle accordingly. He walks and buses around town, but as an observer in international negotiations involving the Kyoto Protocols, he had to fly to participate, and purchased carbon credits to offset the flying he could not figure out how to avoid.

Smokescreens & Sensibility

Most of the offsets for sale to consumers are coming from planting trees or restricting the cutting of ancient rainforests. If you invest your offset dollars in saving Amazon rainforest, who's to say that particular forest plot would not have been saved anyway, or that the loggers will not just move to the next tract? While rainforests are of huge value in converting atmospheric CO_2 to sequestered carbon and atmospheric oxygen, environmental groups like Greenpeace and Friends of the Earth fear that the widespread availability of the resulting carbon offsets are clouding the need for individual and government efforts to reduce GHG production. Others fear that when isolated U.S. citizens buy rainforest credits, there is no consideration of local impacts, like the livelihood of indigenous locals. Uninformed meddling by foreigners in local land-use issues can lead to invasions, evictions, destruction of croplands, and violent conflict, according to Survival International, which supports tribal peoples worldwide.

The forestry-related offset programs I reviewed were all up-front about the trees taking about 100 years to sequester one's annual tonnage of carbon emissions. But this brings up a major question that is being left undiscussed—how can one justify taking 99 extra years to make up for the current year's carbon excesses? To answer this question, it's necessary to make a value judgment of what length of time is reasonable for sequestration to make up for a year's worth of carbon releases. And it can become a difficult research project to figure out how much carbon is sequestered early versus later in a tree's life.

In working on your own personal carbon footprint, first and foremost put effort into reducing GHG emissions. Taking my own advice, I will be investing in energy efficiency, more RE for my home and office, and a more fuel-efficient vehicle—before buying offsets. Then when further reduction and efficiency efforts are not options, I will take a closer look at offsetting my carbon footprint, buying from certified nonprofits that use funds to build new renewable energy projects.

Access

Michael Welch (michael.welch@homepower.com) has been working for a clean, safe, and just energy future since 1978 as a volunteer for Redwood Alliance and with *Home Power* magazine since 1990. He's starting to think that Redwood Alliance could make a few bucks selling carbon credits from its PV systems. Any takers?

Green-e • www.green-e.org • Carbon offset certification & endorsements

Casa Verde

by Kathleen Jarschke-Schultze

This past spring, I pored over the seed catalogs with an intense fervor. Reading Barbara Kingsolver's *Animal, Vegetable, Miracle*, a chronicle of her family's year-long odyssey to procure their food from neighboring farms and their own backyard, had given me new resolve to not only grow open-pollinated seeds, but to save said seed and use that seed for the next year's garden. I decided that if we liked a variety in particular, I would see if I could grow it and then save its seed.

Salad for Rodents

I had tried to start my own plants from seed before. Years ago, I created a tiny greenhouse space on the southeast side of the house by attaching a light, wooden framework to our roof's 3-foot overhang. With corrugated translucent fiberglass panels for the southeast-facing wall, a door on each end, and an old screened window for venting, I had a greenhouse. I built a long two-tiered shelf from 2 by 4s. A hose bib on the corner of the house, now inside the greenhouse, supplied water.

I found I could start some seeds—broccoli, lettuce, cabbage, beets, and spinach—out there. It seemed like I had everything I needed. The problem was I had more than I needed: I had varmints. As soon as the first leaves appeared on my starts, the mice would eat them down to a nub. Sometimes they would dig up the moisture-swollen seed and eat it before it could break ground. I gave up.

Jewel of a House

This spring, I found my gem—the Solar Gem, that is. The one-piece greenhouse is made of molded fiberglass in a Gothic arch shape. The front door is a sturdy metal storm door with a screened window. The roof vent is powered by beeswax—and the sun. The wax, contained in a black tube attached to the vent itself, expands with heat and pushes the roof vent open. As it cools, the wax contracts, the mechanism slides back down, and the vent closes. Way clever.

The greenhouse has a 10-inch lip, turned inward, on the bottom edge. To prepare for delivery, I had to level an area and dig a 10-inch-wide trench for the perimeter of the greenhouse. The place I chose was on an incline, so my trench was 3 inches deep on one side and 18 inches deep on the other. I had to dig a walkway to the door so I would be able to open it.

Ground Zero, Kathleen One

Merely trying to eyeball the places to trench was just not going to work. I ended up using a long level atop a 2 by 4 to get an accurate grade. I have a buddy who helps me on occasion, but prefers anonymity. I called Friend and asked what the equation was for figuring out the diagonal measurement of my foundation excavation. That way I could measure each kitty-corner and see if the pad was square. I waited, poised with calculator in hand. I think he said something like, "That would be A plus or minus B times C without D." Whenever someone starts talking like that, my brain starts crackling like bacon. I ended up placing a stone on each corner, and measuring with my tape and moving stones till the diagonals matched. After leveling and squaring, I covered the ground in 1-inch chicken wire to keep ground-diggers out, and then covered that with black weed cloth.

The greenhouse arrived on March 14. Luckily, the snow had melted the week before and the road was pretty much dry. The guys who delivered it just took it off the truck, walked it over, and set it in place.

After the greenhouse was in place, I laid a walkway of pavers down the middle and laid 3 inches of gravel on either side. My husband Bob-O had to cut one paver to fit around the hose bib that was already in place when we set the structure down.

Sowing & Growing

Even though Oregon's Rogue Valley is just over the Siskiyou Pass from us, the plants there are a month ahead of ours in bloom time. On my next trip to town, I bought some lettuce starts, cole-crop seedlings, and some potting soil. I already had my seeds, which I sowed in pots and flats. I started tomatoes and peppers on a heated seedling mat in the house.

I divided and repotted six packs. I've found that if you get your seedling six packs early in the season, there is more of a chance of finding multiple plants in each cell. This year, from one six-pack of broccoli, I separated out and repotted 24 seedlings. A six-pack of Swiss chard bought at the same time yielded 29 individual plants. If you look, you can usually find two-fer tomatoes, peppers, and squash. I consider that a good investment. In my experience, if you get plants young enough, repotting or transplanting is 97% successful.

Courtesy Kathleen Jarschke-Schultze (2)

The Solar Gem's footprint and walkway had to be cut on the upper sides of the sloped ground. Inset: The passive vent mechanism opens when interior heat expands the beeswax in the tube.

Heating Up the Night

Despite the calendar's proclamation that spring was official, it was still getting very cold at night. I needed to be able to monitor my new greenhouse environment. I had a digital recording thermometer designed for indoor/outdoor use, but the outdoor sensor had died. Rather than tossing it, I just clipped that wire off and mounted the unit on the plant shelf in the greenhouse. Bob-O bought me a cheap, outdoor recording thermometer, which I also mounted on the opposite shelf with the sensor outside.

I found there was a difference of only a couple of degrees between the inside and outside temperatures at night—not good conditions for delicate baby plants. To protect them, I needed to figure out how to better regulate the greenhouse temperature at night. At our house, in early spring we have all three renewable power sources producing. The wind is blowing down our little canyon, the sun is shining more than not, and the creek is running strong. I could use electricity all day long since the batteries are always full. With full batteries and an abundance of RE production, without the grid to feed back into, not using the excess electricity is essentially wasting it.

I snaked an electrical cord out the guest room window, across the driveway, and into the greenhouse. Bob-O said it would be fine—if I protected the run across the driveway. I found two old barn planks and made a speed bump with the cord between the boards. Once the greenhouse was wired, I topped a small square of plywood with an electric heating pad and set a 5-gallon carboy filled with water on that as thermal mass. After stringing the upper shelf bars with some white LED holiday lights, I was ready.

With this setup, I found I could keep the greenhouse about 8°F warmer than ambient. The heating pad and lights were plugged into a plug strip on a timer, which was set to turn on a couple of hours after dusk. At night, the LEDs made the whole greenhouse glow wonderfully gold. Plus, I could look out at the greenhouse and tell at a glance whether the heating pad was on or not.

This worked well for a few weeks. The seedlings grew. I harvested lettuce and chard from pots and flats. I moved my tomatoes and peppers out to the shelves, with their seedling mat for night warmth. Then the temperature hit 17°F inside the greenhouse one night. I lost most of my tomatoes. Here I was thinking about how I had so many I would have to give some away. Pride goeth. I had to do something more proactive to get my plants through the cold snap.

When our RE system batteries are full, the excess energy is shunted over to our hot water tank. With three consistent springtime energy sources, our water is very hot this time of year. Every night, I filled eight 1-gallon jugs with hot water and placed them among the plants. I also threw a large shade cloth over the top of the greenhouse. It worked, I was able to keep the temperature 11°F above the outside temp. It did not get down to 17°F again inside, and I did not lose any more plants.

Casa Verde

I love the greenhouse. I can see that this is going to be a wonderful tool in my quest for a more self-sufficient life. My garden is full of plants I've started or reared. In the morning, I go out just to check on the plants, and I find myself still there an hour and a half later, "playing in the dirt." I look at seed catalogs with a new and brighter eye. We've been eating greenhouse salads for weeks. Our diet is now open to many homegrown possibilities. Life is good (and green).

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is getting harder to pry out of her off-grid home in northernmost California.

Solar Gem Greenhouses • www.solargemgreenhouses.com

RE happenings

CALIFORNIA

Aug. 10–14, '08. San Diego, CA. Solar Energy Applications. Tech presentations & courses on PV; R&D of solar concentrators & solar H2. www.spie.org

Aug. 16–17, '08. Hopland, CA. SolFest. RE booths, workshops & kids' activities. Food & entertainment. www.solfest.org

Sep. 29–Oct. 1, '08. San Francisco. PV System Design for Engineers & Designers. Course on producing PV design documents. www.sunengineer.com

Oct. 13–16, '08. San Diego, CA. Solar Power 2008. Conference & expo. SEIA • 202-296-1688 • mglunt@solarelectricpower.org • www.solarpowerconference.com

COLORADO

Aug. 14–17, '08. Crestone, CO. Solar Heating Design & Natural Building workshop. www.crestonesolarschool.com

Aug. 30–31, '08. Crestone, CO. Crestone Energy & Sustainability Fair. 719-256-5572 • info@joinLAS.com • www.joinLAS.com

Sept. 20–21, '08. Fort Collins, CO. Rocky Mt. Sustainable Living Fair. 970-224-3247 • kellie@sustainablelivingfair.org • www.sustainablelivingfair.org

FLORIDA

Melbourne, FL. Green Campus Group meets monthly to discuss sustainable living, recycling & RE. fleslie@fit.edu • http://my.fit.edu/~fleslie/GreenCampus/greencampus.htm

ILLINOIS

Aug. 9–10, '08. Oregon, IL. IL RE & Sustainable Lifestyle Fair. RE booths, workshops, tours & kids' activities. Food & entertainment. www.illinoisrenew.org

IOWA

Sep. 13–14, '08. Cedar Falls, IA. I-Renew Energy Expo. Workshops, exhibits, food, entertainment. www.irenew.org

MASSACHUSETTS

Sep. 15–17, '08. Boston. Alternative Energy Sources & Technologies. Conf. & exhibition on biomass, biofuel, geothermal, hydro, hydrogen, solar, wind & waste-to-energy. www.cardellexpo.com

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West Branch, MI. Intro to Solar, Wind & Hydro. 1st Fri. each month. System design & layout for homes or cabins. 989-685-3527 • gotter@m33access.com • www.loghavenbbb.com

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New Bloomfield, MO. Workshops, monthly energy fairs & other events. 800-228-5284 • info@moreenergy.org • www.moreenergy.org

MONTANA

Whitehall, MT. Seminars, workshops & tours. Straw bale, cordwood, PV & more. 406-494-9875 • www.sagemountain.org

NEW HAMPSHIRE

Rumney, NH. Green building workshops. 603-786-2366 • info@dacres.org • www.dacres.org

NEW MEXICO

Sep. 20–21, '08. Albuquerque. Solar Fiesta. RE & EE exhibits & workshops. www.nmsea.org

NORTH CAROLINA

Aug. 22–24, '08. Fletcher, NC. Southern Energy & Environment Expo. RE displays, exhibits & presentations. www.seeexpo.com

OHIO

Sep. 1, '08. Johnstown, OH. Ohio Green Living Fayre. RE, sustainable building, alternative fuels, food, music, kids stuff & more. jay@bluerockstation.com • www.ohiogreenliving.org

OREGON

Cottage Grove, OR. Adv. Studies in Appropriate Tech., 10-week internships. 541-942-8198 • apro@efn.org • www.aprovecho.net

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Sep. 19–21, '08. Kempton, PA. PA RE & Sustainable Living Festival. RE, natural building & sustainable ag; workshops, speakers, exhibits, vendors, music & kids' activities. www.paenergyfest.com

Philadelphia Solar Energy Assoc. meetings. 610-667-0412 • rose-bryant@verizon.net • www.phillysolar.org

TENNESSEE

Summertown, TN. Workshops on PV, alternative fuels, green building & more. 931-964-4474 • ecovillage@thefarm.org • www.thefarm.org

TEXAS

Aug. 1–3, '08. Marathon, TX. Sustainable Living & Green Building Festival. Lectures, workshops, tours & vendor displays on eco-construction, off-grid living & more. 432-386-4257 • sowelo2000@yahoo.com • www.livingwithnature.net

Sep. 26–28, '08. Fredericksburg, TX. RE Roundup & Green Living Fair. Exhibits, speakers & workshops on RE, green building, green ag & EE. www.theroundup.org

WISCONSIN

Custer, WI. MREA '08 workshops: Basic, Int. & Adv. RE; PV Site Auditor Certification Test; Veg. Oil & Biodiesel; Solar Water & Space Heating; Masonry Heaters; Wind Site Assessor Training & more. 715-592-6595 • info@the-mrea.org • www.the-mrea.org

Amherst, WI. Artha '08 workshops: Intro to Solar Water & Space Heating System, Installing a Solar Water Heating System, Living Sustainably & more. 715-824-3463 • chamomile@arthaonline.com • www.arthaonline.com

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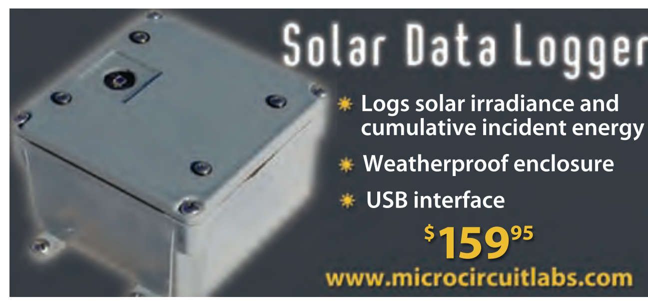
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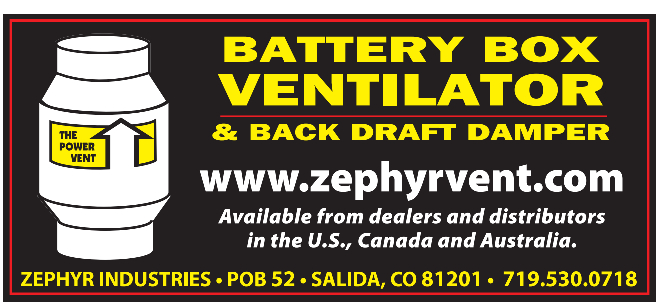
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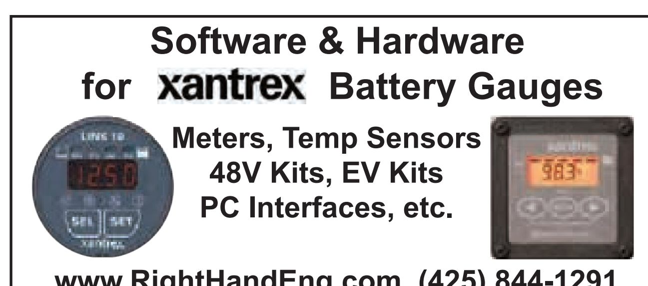
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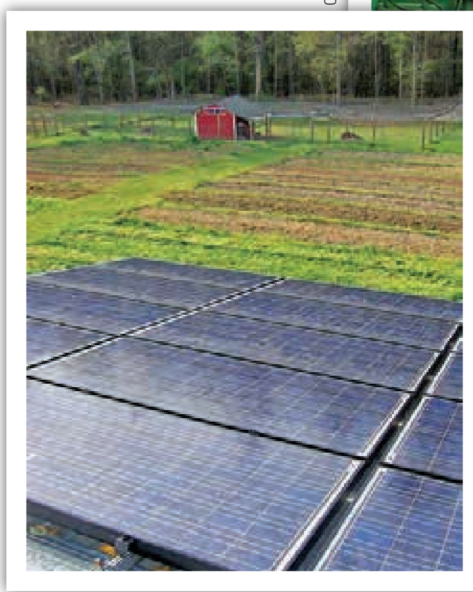
RE *People*

Who: Larry & Twila Dove
Where: Fayetteville, Georgia
When: March 2007 to present
What: Solar-electric system
Why: Just one more way to harvest the sun

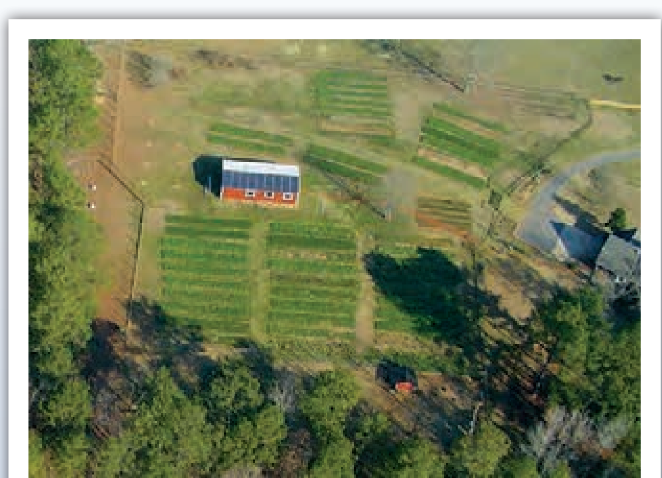
Courtesy Larry & Twila Dove (2)

Up with the sun: Larry and Twila Dove prepare for another day in the fields, while their PV system generates clean, renewable electricity for their household and farm.



Larry and Twila Dove didn't set out to be an example for others. It just happened. Last year, the husband-and-wife team installed a grid-tied 7.2 KW solar-electric system at their organic farm just south of Atlanta. They didn't do it for the rebates, because the state of Georgia does not offer any. And they didn't do it for the payback, because it could take decades at current electricity rates. They did it because, as they say, "It was, and is, the right thing to do."

After "far too many years in suburbia," Larry and Twila—country kids raised in rural Virginia—longed to get back to living closer to the land. They got the chance in 2003 when Larry's work as an airline pilot moved them to Georgia. About 20 miles south of Atlanta, along one of the few country roads left in Fayette County, the couple stumbled upon a rare gem in the suburban landscape—a 15-acre farm complete with a two-story brick house, open fields perfect for growing vegetables, and a pole barn, which would be essential for their day-to-day operations but also central to their renewable energy aspirations.



Courtesy George Andrews/Solar Source

A commitment to caring for the land and concerns about global warming spurred Larry and Twila to investigate their RE options. The couple found George Andrews of Solar Source in Barnesville and devised a plan to take advantage of the abundant sunshine that hit the south-facing barn roof. They managed to squeeze in 45 PV modules on the roof. With an average of 4.97 daily peak sun-hours, the system produces approximately 912 KWH per month—roughly two-thirds of the electricity needed to support their two-person, all-electric household and the farm operations.

Although they didn't set out to be solar pioneers, Larry and Twila found themselves negotiating a net-metering agreement with EMC Coweta-Fayette, their electric cooperative. "We were the first to ask for net metering. The concept was completely foreign to the co-op board. They didn't have a contract in place, so they hired a consultant to draft one," Larry says. "It took months of back-and-forth to nail down a fair buy-back contract."

In the Peach State, where installed solar capacity is dismally low by comparison to most states, almost anyone who adds PV to a home or business becomes a poster child for solar power. "It's hard to convince people to buy into solar in Georgia. There is no real economic argument. You have to do it because you genuinely care about the planet," Larry says. "We did it because we feel a sense of responsibility to reduce our carbon footprint by doing what we can."

—Kelly Davidson