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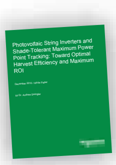

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On the Cover

Ashland, Oregon, homeowner and DIYer Jeff Heigle and professional PV installer Seaira Safady of Alternative Energy Systems pose in front of a 10 kW ground-mounted PV array.

Photo: Shawn Schreiner

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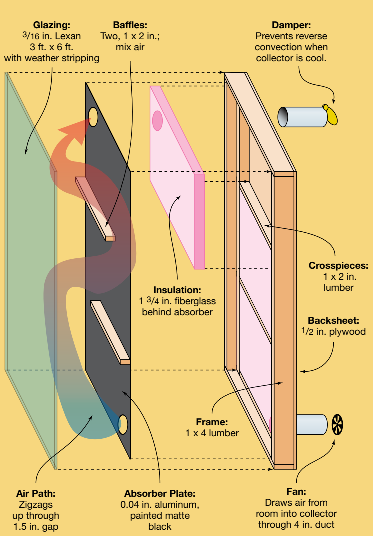

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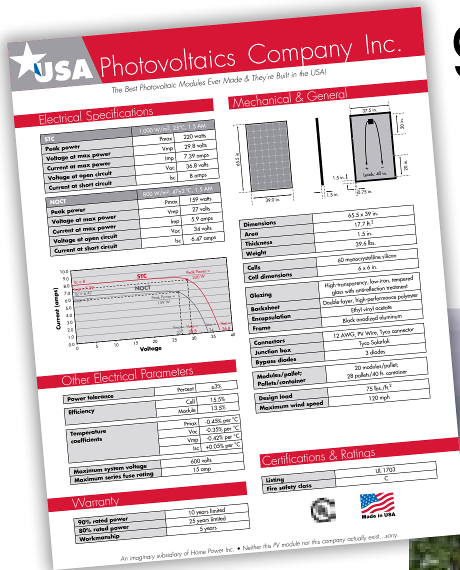
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Voltage at open circuit	Voc	36.8 volts
Current at short circuit	Isc	8 amps

NOCT		800 W/m², 47±2 °C, 1.5 AM
Peak power	Pmax	159 watts
Voltage at max power	Vmp	27 volts
Current at max power	Imp	5.9 amps
Voltage at open circuit	Voc	34 volts
Current at short circuit	Isc	6.47 amps

Other Electrical Parameters

Power tolerance	Percent	±3%
Efficiency	Cell	15.5%
	Module	13.5%
Temperature coefficients	Pmax	-0.45% per °C
	Voc	-0.35% per °C
	Vmp	-0.42% per °C
	Isc	+0.05% per °C
Maximum system voltage		600 volts
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Area	17.7 ft.²
Thickness	1.5 in.
Weight	39.6 lbs.
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Encapsulation	Ethyl vinyl acetate
Frame	Black anodized aluminum
Connectors	12 AWG, PV Wire, Tyco connector
Junction box	Tyco Solarlok
Bypass diodes	3 diodes
Modules/pallet; Pallets/container	20 modules/pallet; 28 pallets/40 ft. container
Design load	75 lbs./ft.²
Maximum wind speed	120 mph

Certifications & Ratings

Listing	UL 1703
Fire safety class	C

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More Features

In Back

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DIY PV Then & Now

When we launched *Home Power* magazine in 1987, the modern renewable energy industry was in the early stages of its development, and bore little resemblance to the industry today.

In the early 1980s, the cost of solar-electric (PV) system components had just dropped to a level that made them a possibility for remote, off-grid homesteads. Experienced PV designers and installers were few and far between. If you wanted a PV system, you probably installed it yourself.

Many early adopters were resourceful and skilled "back-to-the-landers" who intentionally sought to hone skills for a self-reliant lifestyle beyond the reach of the utility grid. While they got systems up and running to meet their energy needs, many also learned hard lessons along the way. Fortunately, these early low-voltage systems were fairly forgiving, and homesteaders were willing to take on the responsibility for their systems, challenges and all.

About a decade ago, battery-based and batteryless grid-tied PV systems made their entrance into the industry's landscape. Their numbers quickly eclipsed off-grid systems, with an enormous market of grid-connected homes and owners with a wide variety of motivations for purchasing PV systems.

As the market developed, some of the early adopters began installing systems professionally—the experience they gained installing their own and neighbors' systems offered livelihood opportunities. As the demand grew, mainstream electricians also began to enter the industry.

Today, most systems are professionally installed—a quick Internet search will uncover multiple PV installation contractors in most areas of the United States. In some respects, modern batteryless systems are simpler than their off-grid predecessors. But the technical, regulatory, and safety issues are more significant.

While very few of the original off-grid systems received permits, even in the early stages of the grid-tied market, incentive programs and authorities required permitted, inspected, code-compliant systems, and often required that licensed electricians install them.

The demographics of individuals buying PV systems have changed, too. Today's grid-tied PV system owners may be bankers, doctors, teachers, and many others with no construction experience who hire a solar contractor to achieve their solar goals.

Both DIY and professionally installed systems are parts of our modern industry, and there's an appropriate place for each. See the article on page 48 for perspectives on what's best for moving your home into its solar future, by doing it yourself or hiring a pro.

—Joe Schwartz, for the *Home Power* crew

Think About It...

Nature provides a free lunch, but only if we control our appetites.

—William Ruckelshaus, *Business Week*, June 18, 1990

contact us

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Exported Battery Recycling

Eventually, all lead-acid batteries will come to the end of their life and need to be recycled. The questions are: How, where, and by whom?

While the export of used lead-acid batteries (ULABs) from the United States is legal and a fairly common practice, this practice may be contributing to lead contamination and exposures in Mexico and other places around the world.

A recent report prepared by San Francisco-based NGO Occupational Knowledge International (OK International) and Mexico City-based NGO Fronteras Comunes found that increasing quantities of ULABs are being exported from the United States to Mexico for recycling, and contributing to increased pollution and worker health hazards.

The report's release came on the heels of lead battery and lead recycling plant shutdowns in China following cases of widespread lead poisoning in local communities. As part of a crackdown on 18 polluting industries, the Chinese government aims to shut down 585,500 tons of illegal lead-smelting capacity this year.

The findings show that, in 2010, 75% of all ULABs and lead scrap exported by the United States was shipped to lead battery manufacturers and recyclers in Mexico, up from 39% in 2008. According to the report, U.S. International Trade Commission data indicates that approximately 261,000 tons of used lead batteries—equivalent to 12% of all used lead-acid batteries generated in the United States—were exported to Mexico in 2010. This quantity represents a 112% increase over 2009.

But the numbers may be even higher, says Perry Gottesfeld, executive director of OK International. "There is no Mexican or U.S. system to track or inspect individual shipments across the border. We have seen international shipments that have had false labeling on them. Containers have been labeled as plastic, when they're lead batteries. It's definitely possible that shipments slip through customs."

A major issue, Gottesfeld says, is that there is no waste manifest system to monitor the ultimate destination of ULABs that enter into Mexico from the United States, and some exports are diverted to unlicensed recycling facilities—or to other countries. The report cites cases in which authorities in Hong Kong have returned mislabeled, leaking containers of ULABs sent from Pacific Ocean ports in Mexico.

Thought Mexico has a number of laws and regulations addressing ULABs, lead pollution, hazardous waste, and recycling practices, the report notes that there are no explicit requirements that monitor employee exposures or remove workers from high-exposure areas.

According to the report, the maximum permissible exposure limit for lead in air is 10 times higher in Mexico than in the United States (1.5 vs. 0.15 $\mu g/m^3$), and the occupational airborne exposure limit in Mexico is three times higher than in the United States (150 vs. 50 $\mu g/m^3$). And, in comparison of similar-sized lead plants in both countries, the researchers found that emissions from plants in Mexico are approximately *20 times* higher than those from plants of similar capacity in the United States.

OK International and Fronteras Comunes are calling for government intervention under the North American Free Trade Agreement (NAFTA) framework to close unauthorized plants and bring Mexican companies into compliance. Mark Thorsby, executive vice president of Battery Council International (BCI), a Chicago-based trade group, maintains that U.S. manufacturers uphold the same smelting controls in Mexico as in the United States, saying that "U.S. manufacturers are not shipping used batteries to Mexico to get around environmental regulations." The main drivers for shipping the batteries south, Thorsby says, are lower labor and operational costs.

Recycling lead in a lead-acid battery recovery facility.

Courtesy The National Institute for Occupational Safety and Health

Despite the fact that there is no federal law compelling manufacturers to recycle battery lead, nearly 98% of battery lead is recycled and reused in new batteries—the highest recycling rate of any raw material in the United States, Thorsby adds.

It is estimated that a typical new lead-acid battery contains 60% to 80% recycled lead and plastic. The rising price of "virgin" (mined) lead in recent years is driving the high recycling rate, says Michael Fraley, a product and process engineer at Crown Battery Manufacturing Company in Fremont, Ohio.

"It comes down to dollars and cents," Fraley says. "As the price of virgin lead has climbed higher and higher, scrap lead has become more and more valuable, motivating manufacturers to be more diligent about collecting used batteries and controlling the costs associated with lead smelting and recycling."

Lead prices have teetered around $1.20 per pound in recent months. Scrap lead costs about 70 cents per pound or less, depending on transport, labor, and conversion charges. With each battery holding 20 to 40 pounds of lead, the savings per battery can be substantial, Fraley says.

"The massive increase in spent lead-acid battery (SLAB) exports to Mexico and the appalling lack of government oversight indicate a disaster waiting to happen," says Diane L. Cullo, director of the U.S. advocacy group SLAB Watchdog. "Sending used lead-acid batteries to Mexico for recycling without any regard for the health of workers, the community, or the environment simply because it is cheaper is unconscionable and must stop immediately," she says.

More than 12 million people in the developing world are adversely affected by lead contamination from processing lead-acid batteries, according to the Blacksmith Institute, an international nonprofit working to solve pollution problems. If inhaled or ingested, lead can damage the nervous system and cause brain damage—especially in children, whose bodies are still developing. Lead-acid batteries, particularly the common wet cells, also contain electrolyte with significant amounts of sulfuric acid—a highly corrosive liquid that can burn the skin.

In the United States, lead-acid batteries are included under the EPA's Universal Waste laws, which provide collection requirements for certain hazardous wastes including batteries. Currently, battery recycling legislation and mandatory take-back programs exist in 45 states.

Moving forward, proposed legislation aims to limit the export of ULABs and create domestic recycling jobs. Rep. Gene Green (D-TX) and Rep. Mike Thompson (D-CA) introduced the Responsible Electronics Recycling Act earlier this year. The legislation would prohibit the export of electronic waste, including lead-acid batteries, to countries that are not members of the European Union or the Organization for Economic Cooperation and Development (OECD).

The fate of the bill remains uncertain, as it awaits committee review, but major electronics companies have backed the legislation. The bill also won support from 29 recyclers representing 74 recycling operations in 34 states.

Though hailed as a step in the right direction by the Electronics TakeBack Coalition and the Natural Resources Defense Council, the bill would not preclude ULAB exportation to Mexico, which is one of the 34 member countries of the OECD. However, it would stop exports to China, which is not a member of the OECD.

If passed, the legislation would fill a much-talked-about gap in a national e-waste stewardship plan that was released in July by an interagency task force—chaired by the U.S. Environmental Protection Agency, the General Services Administration, and the White House Council on Environmental Quality. The plan, which provides recommendations for the handling of e-waste coming from federal agencies, received mixed reviews from advocacy groups for failing to take a hard line on e-waste exporting and address foreign battery recycling.

One high point of the plan is federal support for U.S. ratification of the Basel Convention, an international treaty intended to prohibit the transfer of hazardous waste from developed to less-developed nations. The plan falls short of outlining any "concrete steps" toward doing so, according to a spokesperson for Basel Action Network, an American watchdog group that has sought to curb the export of toxic electronic waste from the United States.

Of the 176 parties of the convention, the United States, Afghanistan, and Haiti are the only countries that have not ratified the treaty since it was brought into force in 1992. The Senate provided its advice and consent for ratification in 1992, but implementing legislation has not been passed.

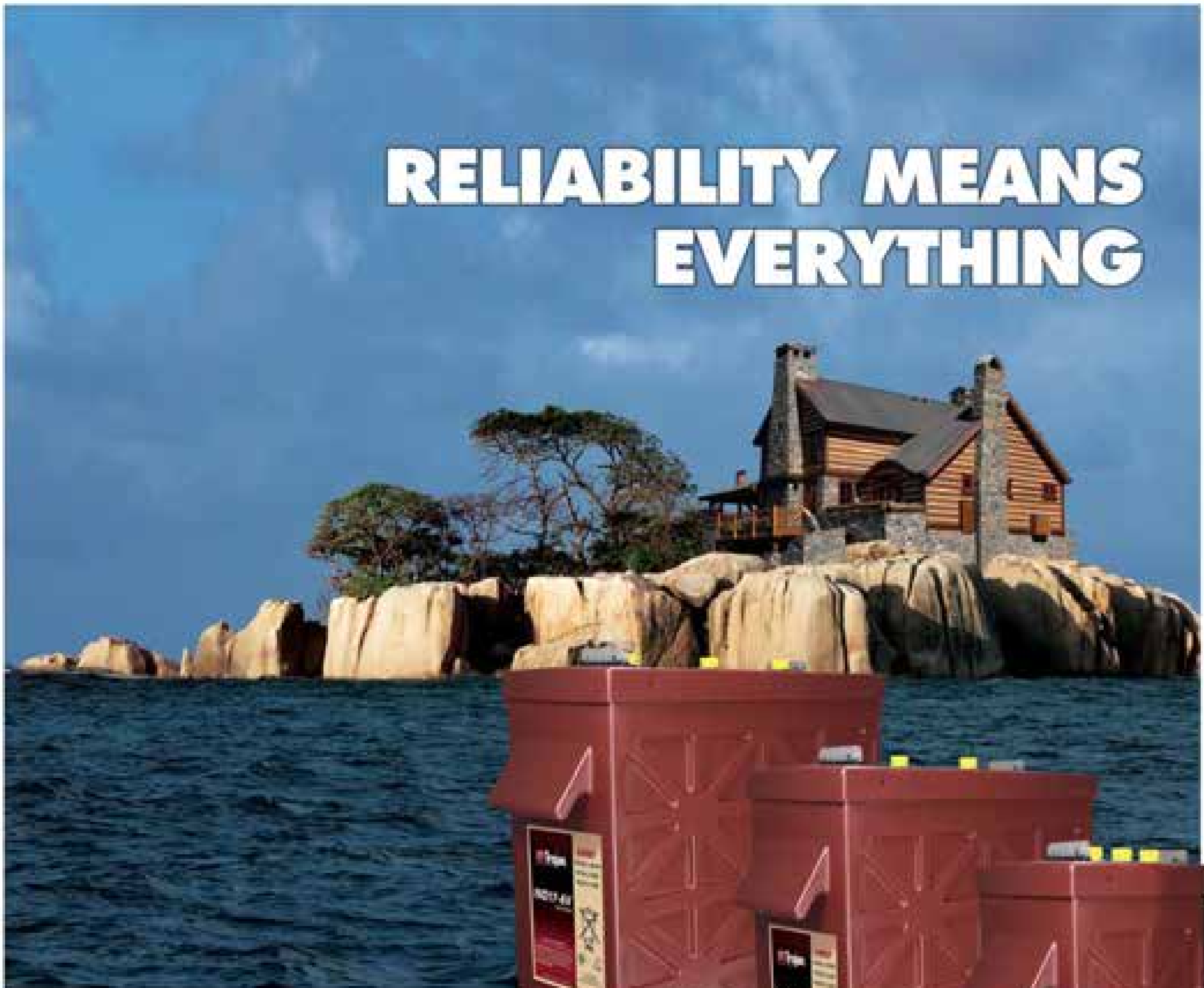
—Kelly Davidson

Behind Recycling

Recycling lead-acid batteries is a fairly straightforward process. A hammer mill pulverizes the whole batteries into smaller pieces. In a vat, the lead sinks to the bottom, and the plastic case pieces float. The plastic is scooped off, washed, and dried, then melted and extruded into pellets to be made into more battery cases.

The liquid is drained off and is usually neutralized with the addition of a base, but sometimes can be turned into more electrolyte. The neutralized water is further processed and released into a wastewater treatment plant. After testing, it can be released into the environment. Another way of treating the acid turns it into sodium sulfate, which is used in laundry detergent or glass and textile manufacturing.

The lead is melted in a smelting furnace and poured into ingots, where the impurities float to the top and are removed. The lead is then is shipped back to battery manufacturers for making into new batteries.



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IND17-6V	711	897	1090	6 VOLT
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Unirac Flat Flashing

Courtesy Unirac

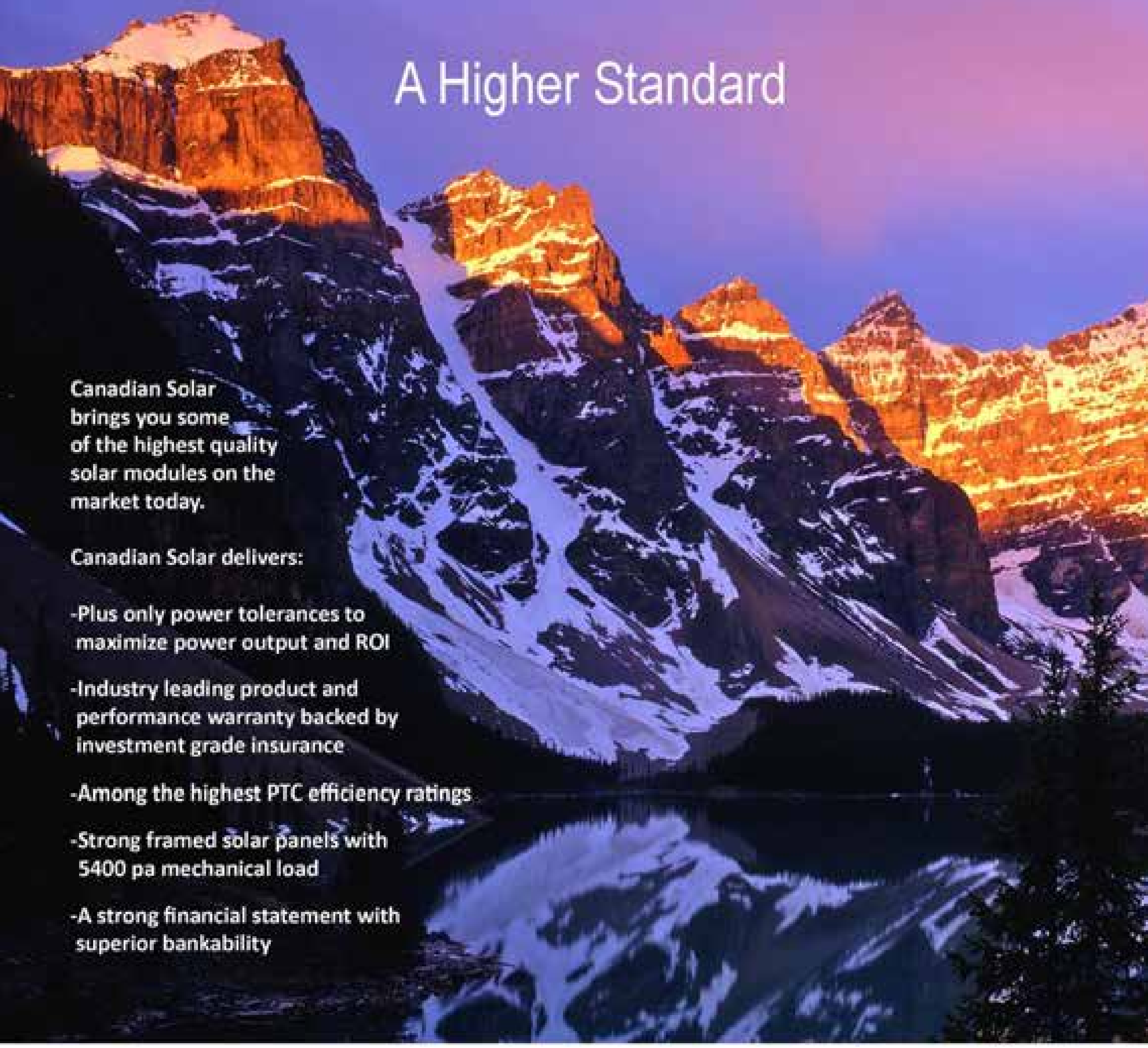
Unirac (www.unirac.com) now offers its Flat Flashing for asphalt composition shingle roofs. This flashing solution consists of a 2- by 2-inch compression plate and 8- by 12-inch flashing with preinstalled gasket to seal the lag-screw penetration. Flat Flashing provides the mounting attachment (i.e., “L-foot”) with a flat surface to sit on, reducing installation time by allowing the flashing, compression plate, and mounting attachment to be installed along with the lag bolt. The flashing is compatible with all Unirac roof mounts: SolarMount, SolarMount I, SunFrame, and tilt-up arrays, and was tested to withstand up to 70 feet of standing water.

Quick Mount PV 3 New Mounts

Courtesy Quick Mount PV

Quick Mount PV (www.quickmountpv.com) recently released three new products: the New Roof Composition Mount, the Universal Tile Mount, and the Low-Slope Mount. The New Roof Composition Mount is designed to be installed by a roofing contractor before the roofing material is installed (see pages 98 & 99 of *HP144*). It is available in three finishes: aluminum mill, clear anodized, and bronze anodized. The Universal Tile Mount is a similar product for use on existing or new tile roofs. It features two flashings: a subflashing for the roof deck and a top unit for the tile level. The top flashing is malleable and can conform to either curved tile or flat tile. It replaces the company's existing Curved Tile Mount. The Low-Slope Mount can integrate into existing or new single-ply membrane and built-up asphalt commercial roofs. All three products utilize the company's new Qbase for roof attachment points. The aluminum-cast base accepts standoffs as tall as 9 inches and provides up to four attachment points to the roofing substrate or structure.

—Justine Sanchez



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Microhydro Brings Light to Remote Afghan Villages

In Panjshir Province, about five hours north of Afghanistan's capital city of Kabul, families in the remote village of Daste Riwat now have access to clean, renewable energy—thanks to a microhydro plant built with support from the U.S. Army Corps of Engineers (USACE).

"The people here are very happy about the electricity," says Malay Ghalam Galani, the Daste Riwat school religious elder who donated some of his land to accommodate the plant. "It has brought brightness into the home, and this is a very good thing."

The Daste Riwat plant was installed in January 2009 as part of an USACE project to construct 105 microhydro units in seven of 34 Afghan provinces—one plant per village. The 130-kilowatt system was among the largest completed; the average system is about 10 kW. The last unit, in Parwan Province, is still under construction and awaiting additional funding for distribution lines.

The project was made possible by the Commander's Emergency Response Program, which enables U.S. military commanders in Afghanistan to fund rebuilding and reconstruction projects. "Projects like these gain the trust of the Afghan government and promote civil infrastructure improvements that positively impact villagers' lives," says U.S. Navy Lieutenant Commander Joel VanEssen, an officer assigned to the USACE as part of the U.S. military's Afghanistan Pakistan Hands Program, which aims to build partnerships with local communities.

One of 15 skilled Afghan workers employed by Remote Hydrolight in Afghanistan builds a turbine crossflow at a workshop in Kabul.

Courtesy Master Sgt. Michael O'Connor

Access to microhydro power has eased the villages' dependence on kerosene lanterns, diesel generators, and wood-burning stoves, which are health and environmental hazards.

Microhydro installer Owen Schumacher, who has lived and worked in Kabul for the past 18 years, completed the initial survey work and presented the idea to USACE back in 2005. "I was here when there was no electricity, and I know how depressing it can be," says the South Dakota native, who has been installing and developing microhydro power systems in Afghanistan for 15 years.

Schumacher first moved to Afghanistan to work for a solar energy organization, but after a few years, he saw the potential for hydro energy. "The high mountains receive snow that slowly melts throughout the year, forming streams and rivers. The many springs that flow down the hillsides make good sources for year-round hydro-power. Most villages are close to a stream or river and already use the water to power traditional stone water mills, so the concept of hydropower is not completely new to them," he says.

Since then, Schumacher has developed and tested multiple prototype systems—including a high-efficiency cross-flow turbine that was tested at the Waterpower Laboratory of the Norwegian University of Science and Technology. In an effort to grow support for microhydro projects, he also held workshops to train Afghans how to manufacture, install, and repair these systems.

In 2006, Schumacher's company—Remote HydroLight, a for-profit business that builds community-owned microhydropower plants in remote areas of Afghanistan—was chosen by the USACE to share the project contract with Engineering Associates, a microhydro power installation company in Kabul. For the USACE project, Schumacher and his crew of 15 Afghan workers oversaw the installation of 97 units, as well as designed prototypes and trained employees of private shops in Kabul to build the turbines and electrical boxes. All of the components, with the exception of imported alternators, were fabricated locally.


Courtesy Master Sgt. Michael O'Connor

Afghan workers in the village of Daste Riwat, Panjshir Province, conduct training on how to maintain the forebay.

Buy-in on a project by local elders is vital to the project's success, and village cooperation is key to a plant's future, VanEssen says. "We ask them for their opinion on where things should be," Schumacher says. "By contributing their labor, they feel they own the plant when it is all built, and it is *their* plant."

Once a project was approved, the community was responsible for providing the labor for the installation and transporting all of the equipment to its site, which often meant long hours hauling parts on mules through the mountains on footpaths. When necessary, the community also built new channel or reinforced an existing canal from the nearest water source—a considerable amount of work that often involved cutting into the hillside and erecting several hundred feet of stone wall.

Remote HydroLight provided installers, who worked side-by-side with the village laborers. Typically, one installer managed multiple installations in a watershed area, walking between the villages to check on the communities' progress and give instructions as needed. Some smaller systems were installed in as little as three weeks, while others took close to a year to complete, due to discord in the village.

Most of the plants are sized to provide power for lights and small electronics, such as televisions, radios, and battery chargers. The average village family needs only about 60 W to 100 W of power for two or three 20-watt fluorescent lightbulbs. In most cases, the operator turns on the plant from sunset to sunrise because the water is used for irrigation during the daylight hours.

After a plant is operational, the locals monitor the energy usage, keep the canal clean, and lubricate the turbine bearings regularly. Schumacher's crew returns to the site to handle major problems as necessary. Otherwise, villagers can bring broken parts to his shop or one of the private shops where his trained technicians can repair the equipment. Maintenance and repair costs are covered by nominal monthly usage fees that are collected: 20 to 30 cents for each light (or the equivalent—a TV equals three lights) per household. For larger systems, watt-hour meters track each household's consumption.

The Daste Riwat plant—with two 65-kilowatt turbines—relies on an 8-foot-wide, 1-mile-long canal off the Panjshir River, and runs around the clock. The electricity generated is distributed through a mini-grid that feeds the village's 110 compounds, which house two or three families each.

Each compound is equipped with two fuses: one for a heavy-duty socket in the kitchen for a high-watt appliance (such as a hot pot, water heater, or flat-bread cooker), and one for all the lights and other regular sockets (for items such as lights, televisions, washing machines, and computers).

To ensure everyone is charged accurately for usage, meters were installed in each compound. Every two months, the elders have a meter reader who writes down the amount used and then collects usage fees. The average family pays about $2.70 per month, which is used to pay the village operators and provide for any maintenance expenses, such as belts or grease.

Having seen how this project has transformed his village, Galani says he would like to see more projects like this that benefit his people.

With the USACE project complete, Schumacher and his crew have moved on to other microhydro installations in the region. They are currently installing four prototype "Kaplan" turbines in the Nangarhar Province near Jalalabad.

"Right now, it is getting more difficult to work in many areas of the country due to poor security. The Taliban are more organized and have sent cells all over this land, but we will continue to do what we can," he says. "The Afghan people are hard workers and have been very eager to help install our small hydro plants. These types of projects can flourish in peaceful provinces and bring not only work for the people, but power too."

—Michael O'Connor, with Kelly Davidson

Pole-Mounted Microinverters


Courtesy Khanti Munro (3)

Siting an array can often go well beyond shade mitigation. Accounting for roof size, orientation, and tilt; considering seasonal weather patterns (such as morning fog); meeting aesthetic criteria; avoiding otherwise usable space; and, of course, pleasing the customer are all considerations. An installer's lack of attention to the "bigger picture" can result in poor system performance—and an unsatisfied customer. Thankfully, new products and a little creativity are increasing design flexibility.

At the Letendre residence in Middletown Springs, Vermont, it became clear that a unique solution was required. The straw bale home's upper south-facing roof was already occupied by a large solar thermal system used for in-floor radiant heating. A lower south-facing roof was available, but would be subject to excessive snow and ice build-up from the upper roof. The front and back lawns were not considered due to aesthetic concerns and existing land use, i.e., parking, play space for children, etc. The remaining available yard space was a 10- by 20-foot spot west of the home.

The space was large enough to accommodate the specified system size on a pole mount, but had another challenge—it would incur some partial morning and afternoon shade. The eastern half of the array would be shaded until around 11 a.m. and the lower fourth of the array would be shaded from noon to 2 p.m. during two winter months. On the west side, about one-fourth of the array would be shaded after 4 p.m. The annual solar access for the array is estimated at 80%. Thankfully, microinverter technology could help address this, since

Overview

Project name: Letendre residence

System type: Batteryless grid-tied PV

Installer: Khanti Munro, Solarise Services

Commissioned: September 2010

State: Vermont; 43.48° latitude

Solar resource: 4.61 average daily peak sun-hours

System capacity: 2.38 kW STC

Average annual production: 2,500 AC kWh (estimated)

Average annual utility bill offset: 83%

Equipment Specifications

Number of modules: 14

PV modules: Sharp NE-170U1

Module rating: 170 W STC

Number of inverters: 14

Inverters: Enphase M190, 240 VAC

Rated output: 190 W

Array installation: Pole mount, DP&W TPM-14

Array azimuth: True south (194°)

Tilt angle: Seasonally adjustable

one microinverter is paired with each module. Because each module operates "independently," shading effects on one module will not affect the whole string or array.

However, microinverters are commonly designed to mount to the slotted rails of roof-mounted PV racks. Custom-mounting the micros to a pole-mounted array, although not difficult, added to the installation time and created some new challenges. Although the rack manufacturer was not willing to pre-drill the inverter mounting holes, they did confirm that drilling two holes per inverter in the rack would not void the warranty or cause any structural issues. To minimize the aesthetic impact of the array underside, extra time was taken to ensure that the inverters were mounted under the modules in a neat, organized manner. Wire management was also difficult given the long AC inverter cables and the under-array exposure. A combination of wire clips and rubber splicing tape with stainless steel zip-ties were used to organize the cables, and very careful coiling of excess wire on the top sides of rails helped conceal it.

Besides meeting the customer's siting requirements, the installation provided better airflow around the inverters and modules, helping them operate cooler and more efficiently. With this design, the roof peak's morning shadows and the afternoon tree shadows now only affect a portion of the array as opposed to all of it if we had used a string inverter.

—Khanti Munro • Solarise Services

Bus Bar Calculations

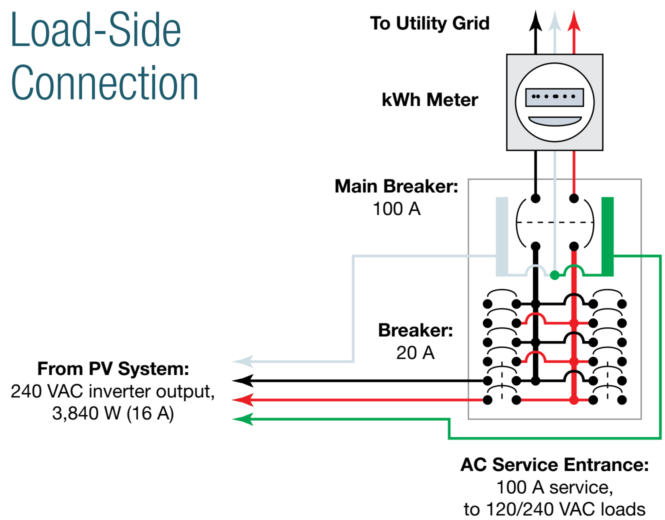
Is Your Service Panel Large Enough for Your Inverter?

Grid-tied PV systems supply solar electricity to your home, and the inverter's AC output must be connected to the household wiring. This is usually accomplished by connecting the inverter output so that it back-feeds a circuit breaker in your main service panel (called a "load-side connection"). However, in most cases, the service panel was in place before the PV system was considered, and only the grid input into the home was considered. So when planning your PV system interconnection, make sure your connection does not violate *National Electrical Code (NEC)* requirements.

Backfeeding a circuit breaker with a PV system's output adds a second source feeding the bus bars in your service panel. A service panel's bus bars are rated to handle only up to a certain amperage. If the service panel/bus bars are not large enough, then bus bar overheating is possible. The bus bars in the service panel must be adequately protected, and it's the supply circuit breakers that limit the overall current on those bus bars. So along with the service panel/bus bar rating, the rating of the grid and inverter circuit breakers must be considered.

The *NEC* stipulates that the sum of the circuit breaker ratings feeding a bus bar can amount to 120% of the bus bar rating, but no higher. For example, if we have a 100-amp service panel, the bus bars are rated to handle 100 A. The sum of both of the circuit breakers (from the grid and from the inverter) can be no more than 120 A (100 A × 1.2 = 120 A). If we have a 100 A main breaker, then we are left with a maximum inverter output breaker rating of 20 A. Additionally, because in this example we are exceeding the service panel's rating, the *NEC* requires locating the inverter's breaker on the opposite end of the service panel from the grid's main breaker. This ensures that the current coming in from the grid and the PV system are distributed across the service panel bus bars, rather than concentrated on one area.

Load-Side Connection



The inverter's output circuit breaker is sized so that the inverter's output is no more than 80% of the circuit breaker's rating. If our maximum inverter breaker is rated at 20 A, that means that the inverter output is limited to 16 A (20 A × 0.8 = 16 A). If the inverter output is 240 VAC, our maximum allowed inverter output is 3,840 watts (240 VAC × 16 A). You will not find an inverter rated at this exact value, so you will need to figure out what models will work. For this example, a 3,800 W inverter is appropriate; a 4,000 W model is not.

If the service panel is not large enough to accommodate the inverter, there are a few options. We can limit the PV system size, and the breaker, to fit within the limitations of the service panel. We can replace the service panel with a larger-amp unit. We can downsize the main breaker (although a household load analysis should be done to make sure that there won't be nuisance tripping of that breaker during normal conditions). Or we can connect the PV system via a supply-side connection (see *Code Corner 135* for more information).

—Justine Sanchez

Courtesy Khanti Munro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Kohl Christensen, Oahu, Hawaii
"I have been traveling to remote locations on surf trips for years and now, after becoming a solar contractor and teaming up with SolarWorld, it feels really good to be able to travel back to these spots and share some of my knowledge... I am glad I can help."
Partnering with America's largest solar panel manufacturer allows Kohl to chase big waves and spread his passion for solar. Find out how becoming a SolarWorld Authorized Installer can help you achieve a work-life balance at SolarWorld.com.
SOLARWORLD
Authorized Installer 2011

Courtesy Robert Boardman

Who is More Developed?

Shortly after I came back from a few weeks in Beijing, China, I received *HP144.* I was particularly interested in the cover story about electric motorcycles.

I estimate that there are hundreds of thousands, probably millions, of electric bicycles, tricycles, mopeds, and motorcycles in the city of Beijing. Two- and three-wheeled vehicles are extremely popular. They are used for commuting and for commercial delivery for everything from small packages to home appliances. They generate no fumes and they do not make noise, except for their horns.

The Beijing city government restricts internal combustion engines for two-wheeled vehicles to 150 cc; three-wheeled vehicles are restricted to 750 cc. These limits, plus the speed of city traffic, make EVs equivalent to gasoline vehicles for hauling. In the center of the city, gas-powered motorcycles, scooters, and mopeds are greatly outnumbered by electric vehicles and even by pedal power. From the look of many of the electrics, this is neither new nor emerging technology in China.

I remind readers that Beijing is the capital of the country with the second largest economy in the world—a large, sprawling city of about 23 million people. It is good to read of the growing market for electric vehicles in North America, but we have a long way to go in this area to catch up with what has been happening in "developing countries."

Robert Boardman • Toronto, Canada

Electric Motorcycles

I was very pleased to see articles on electric motorcycles and PEVs ("Kick-Started: Electric Motorcycles Gain Traction" and "Personal Electric Vehicles Get More Personal" in *HP144*), but a bit disappointed to scan them and find that the only vehicle with more than two wheels mentioned is an electric skateboard, which is not very practical for a rural commute.

I live in rural Michigan, with a 25-mile trip to town, one way, and would like to get a higher fuel economy vehicle, which is difficult given I already drive a Toyota Scion xA. Driving a two-wheeled vehicle on freeways and rural roads frequented by gravel trucks through a Michigan winter is suicidal. While there are a lot of things I will do for my planet, risking my life in that way isn't one of them.

I need an affordable, lightweight, but stable and ultra energy-efficient mode of transportation that can keep up with, and even pass, cars and trucks—even under slippery conditions. Yet the last time I searched the Web for electric trikes, they all seemed to cost twice what my car does despite being much smaller and with one less wheel. If I had that much cash, I'd have gotten a hybrid car instead of my Scion. While I love the efficiency and practicality of my compact hatchback car, what is affordable at $3 per gallon is not at $6 per gallon, and I'm trying to think ahead and kick the fossil-fuel habit while we still have a livable planet.

Can the experts cited in the articles offer any leads on affordable trikes that I can look forward to even if they aren't here now? Here's toward a clean, lean winter commute that is also good, clean fun!

Christina Snyder • www.michiganpassivehouse.com

You're absolutely right, Christina—the three-wheeled products are, at this point, either rare-collectible or prototypes (like the Corbin Sparrow, the Meyers Duo, or the Zap). Plus, they are fairly expensive. As far as trikes go, I'm not sure there's anything available that's not in the prototype or concept stages. The Can Am Spyder gas version is in production, but I know of no plans to go electric. At any rate, none of the three-wheeled vehicles (electric or otherwise) will meet your pricing needs.

I'm not sure an open vehicle would be the ticket for you anyway, what with the cold winters. I think that looking at a hybrid or an all-electric car is your best bet, and although they are pricey, there are incentives in Michigan that might help you out, which can be found at www.hybridcenter.org.

Ted Dillard

The Unraveling of Nuclear Energy

About three decades ago, the Swedes considered the risks of nuclear energy, added up the costs, and did the math. What they found was that the astronomical amounts that the Swedes were paying in subsidies to produce electricity from nuclear energy far exceeded what they were getting out of it.

Swedes aren't dumb, and voted in a national referendum to shut down and decommission all their nuclear energy reactors by 2010. The Swedish nuclear weapons program had already been terminated when Sweden signed the nuclear nonproliferation treaty in 1968. Sweden now operates three nuclear facilities, with a total of 10 reactors generating about 45% of the country's total electricity. A narrow two-vote conservative resolution extended the reactors' operation without new subsidies or construction. The opposing parties have declared their intention to continue with the shutdown.

About a decade ago, Germany arrived at identical conclusions, and the country voted landmark legislation to replace all fossil and nuclear fuels with solar, wind, geothermal, and biomass renewable

Courtesy Air Photo Service Co. Ltd., Japan

Nuclear plants in Fukushima suffered explosions and nuclear fuel meltdowns as a result of the March 2011 earthquake.

energy by 2030. Germany is already producing about 20% of its electricity from renewables, accounting for almost as much as its nuclear energy fraction. Recent reports from Germany indicate that the percentages from renewables may be too conservative, and that the country may have moved ahead much faster than was predicted.

The same feed-in-tariff (FIT) laws that were passed in Germany have already been approved by the 24 member nations of the European Union, and are being considered by some other 40 nations around the planet. Germany's Chancellor Merkel recently announced that her conservative government is moving to phase out nuclear energy by 2022 and accelerate the transition to a clean, low-carbon, non-nuclear energy future largely built on RE and energy efficiency.

The U.S., French, and Japanese nuclear programs are not different. These programs exist only at the expense of hundreds of billions in taxpayer subsidies, government loan guarantees, and tax exemptions. And with the U.S. Price-Anderson Act, in case of a nuclear accident, the owner-operator of the nuclear plant is liable to pay damages of up to about $12 billion. Any amount above that becomes public liability. Want it or not, we—the taxpayers—foot the bill and pay the damages, whatever they might be. Corporations pocket the profits, while the cleanup costs and losses are socialized—what a deal. One single accident could total upwards of $500 billion, and go up to $1 trillion—no one can tell.

National and international polls show the public's opposition and that they want the nuclear industries shut down. A recent landslide vote in Italy forced the Berlusconi administration to abandon plans to restart Italy's nuclear program.

Enter Fukushima: With six nuclear reactor cores packed in close to each other in a single nuclear facility, it is exceedingly clear that if even a single reactor suffers a minor accident, it becomes exponentially complex—if not altogether impossible—to maneuver around the plant in any normal way. This puts the other reactors at risk of a series of largely predictable cascading events—that is, successive meltdowns.

Three of the nuclear reactors were operating when a whopping 9.0 Richter scale earthquake hit just offshore; a series of powerful tidal waves followed shortly thereafter. We now know that the earthquake damaged the cooling systems of the Fukushima plant, and that fuel core meltdowns started before the ensuing tsunami hit Japan. Once cooling stops, temperatures rise very fast within the densely packed nuclear core fuel rods, and whatever cooling water is left rapidly boils and evaporates.

The International Atomic Energy Agency (IAEA), a staunch proponent and supporter of nuclear energy, routinely downplayed the amount of materials damage and loss of life at Chernobyl. A recent peer-reviewed publication originating from Russia puts the cancer death toll between 1986 and 2004 at a whopping 1 million human lives. The recent claim by the IAEA that "no one will die in Japan" is nothing but another criminal lie.

The complete cleanup costs and number of victims, as in Chernobyl, are extremely hard to estimate, and will likely escalate in the $100 billions and, as in Russia, may result in the possible downfall of Japan. Cancer victims due to the fallout of radioactive isotopes will continue for hundreds, thousands, hundreds of thousands of years. The Fukushima disaster is far from over.

It is beyond a shadow of any doubt that these are extremely dangerous, difficult, if not completely impossible situations to solve or deal with in physics, engineering, materials science, and chemistry. We do not have the technology to safely handle such high levels of concentrated radiation, temperature, and pressures—not now, not anytime soon. The melting fuel requires massive cooling that will send vast quantities of radioactive water into the global ocean food chain, local water tables, surrounding soil areas, food crops, and the global atmosphere for a long time, and a much longer time still to come, for present and future generations.

These are nothing short of crimes against the planet and against humanity perpetrated by the dissemination of torrents of unchecked lies and falsehoods that began at the end of WWII. "Electricity from nuclear power will be too cheap to meter," so the harp played. It is time to demand an answer from all those who have been perpetrators and accomplices in these crimes: "Is this the best you can do, lie?" and hold them accountable. (For more info, see www.nirs.org.)

Tony Pereira •
Lamar University, Beaumont, Texas

VAWT Blues

My new dental office will have wind power, solar electricity, and solar hot water. First up was a vertical-axis wind turbine (VAWT). It sure looked cool, and with help from my German-speaking patients, we had it imported and put it up—more on this later.

Second up was solar electricity—400 W of PV modules and Enphase inverters. We've had no problems, and we plan to add more.

Third up was a horizontal-axis wind turbine (HAWT), a Skystream. The installer "tuned" it over the Internet, and we've had no problems.

Back to my German VAWT—the inverter is blown out, and the company is out of business and nowhere to be found. Now it's just spinning "artwork." If you like artwork, go with a VAWT. If you just want work, go with a HAWT.

Dr. Richard Henry •
Mount Sterling, Kentucky

Errata

• The "grid-tied systems with battery backup" schematic in "PV Systems Simplified" (*HP144*) included an inverter model that is not designed for bidirectional utility-interactive systems. Inverters manufactured by OutBack Power Systems and SMA America (Sunny Island) are more commonly used for this type of system.

• "Is Wind Electricity Right for You?" in *HP 143* included information about the Xzeres 442SR that is out of date, with corrected manufacturer's data in the table. For more info, see www.xzeres.com.

Xzeres 442SR
Annual Energy Output

Avg. Wind Speed (mph)	kWh / Year
8	5,465
9	8,190
10	11,413
11	15,050
12	18,992
13	23,112
14	27,277

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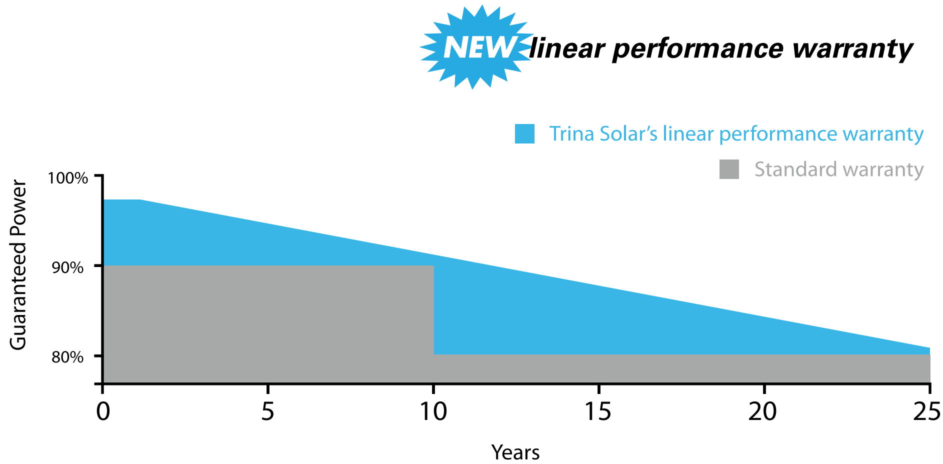

Trinasolar
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LOTUS RENAULT GP
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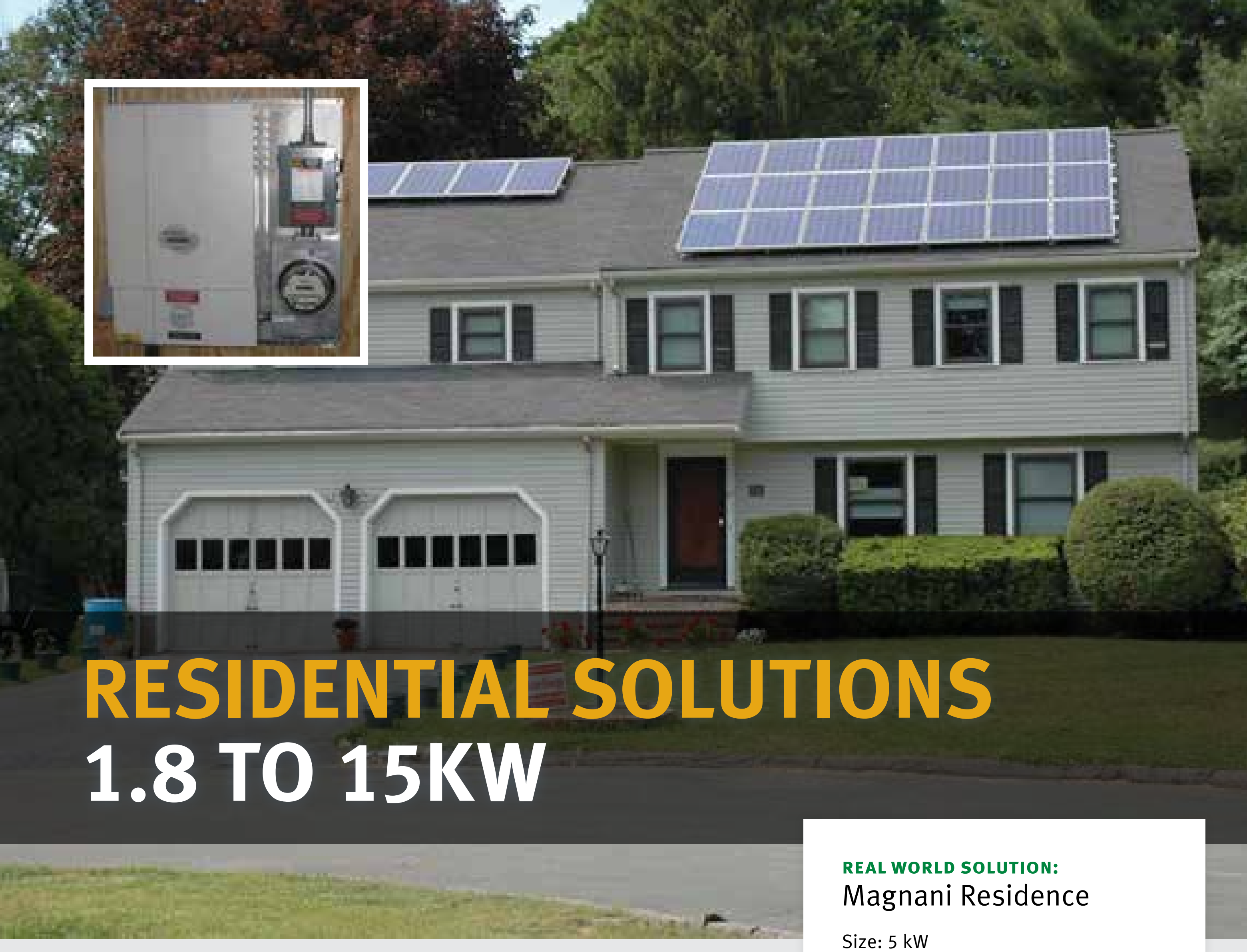

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Products: PVI 5000

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Cooling with Radiant Floor?

My wife and I are planning a new house, and we've decided we want radiant floor heat, since it's the most efficient. We have our own well, and it seems to me that if we have water circulating through the floor it could also be used in the summer to cool the house, but I've never heard of anyone doing that. Will it work? If not, what's the best way to cool the house?

Dawn Crawford • Rapid City, South Dakota

I'm not sure that radiant floors are the "most efficient" type of heating, though they are extremely comfortable in the winter. Most people who have lived with radiant heat in any of its forms—hot water radiators or baseboard units, radiant wall or ceiling panels, passive solar, and even wood heaters—tend to get a contented look when talking about the comfort of their homes in winter.

In theory, since a warm floor heats up your feet, you will be comfortably warm at lower air temperatures, so the heating system provides comfort using less fuel than a conventional system. In addition, warm surfaces—walls, windows, ceilings, or floors—tend to "suck" less heat from your body and will provide comfort, even if the air in the room is cooler.

That theory makes sense to me, but I haven't seen any evidence that homes with radiant floors actually use less energy. If, for instance, you spend much of your time with your feet propped up in the La-Z-Boy, I'm not sure the warm floor will have a big impact on your bill.

Part of the problem is the financial one you've identified. Is there a way to heat with radiant floors and not also have to spend the money for a forced-air cooling system? The idea of circulating cool water through the floor seems to come up a lot, particularly from folks who have their own wells and figure they can circulate 55°F water through the slab to pull heat out of the house.

The idea sounds good, but is not workable. We know what happens to a cool iced tea glass when set out in a hot, humid room. Water condenses out of the air onto the glass. Similarly, if your strategy worked, your floor would be cool enough to make moisture in the air condense, turning your entire house into a gigantic Slip'N Slide.

An air conditioner blows hot, humid air over a cold coil, the water condenses on the coil, drains into a pan, and then into the drain or the yard. Turning your entire floor into a huge condensate pan might be fun for the kids, but not so cool for the rest of us.

There are other strategies that can work. First, build your house tight and very well-insulated. Install a mechanical ventilation system for fresh air and moisture control. Use as many of the traditional methods of keeping heat out of the house as you can—minimize west- and east-facing windows, use properly sized overhangs, use shade trees, or shade the house with porches, particularly on the west and east sides.

Once you've reduced the cooling load, you can air-condition the house in several ways without ducted systems. High-efficiency window air conditioners mounted through the wall can be effective, low-cost, and reasonably energy efficient. The biggest problems are proper placement and noise.

A mini-split air conditioner or heat pump might work for your situation. It uses an outdoor unit very similar to conventional air conditioners, but instead of a big air handler and duct system, panels are mounted inside various rooms. They look like window-type air-conditioning units from the front, are only several inches thick, and can be mounted anywhere, including on interior walls.

These systems are not cheap, but could be less expensive than installing a whole-house ducted system. Units that provide heating and cooling are available, and when these functions are combined, they are very economical. Mini-splits are quieter than room air conditioners, and being able to install their outlets on interior walls is a big plus.

Arnie Katz •
Printed with permission from www.advancedenergy.org

The outdoor unit of a mini-split air conditioner and heat pump.

Understanding PV Output

In full sun, my eight Solarex modules, rated at 120 watts each, are putting out only 536 watts (10 amps x 53.6 volts) in my off-grid battery-based system—what's up?

Kevin Green • Anacortes, Washington

Your electrical math logic is right on—voltage times amperage equals wattage. In a perfect world, your 960 W-rated array should provide 960 W in full sun. There are several reasons why you aren't seeing the full rated output of your PV array. In fact, it's relatively rare to see the full rated output. Let's look at the reasons.

First of all, your battery bank is probably approaching full and in "absorb" at that voltage. In this situation, your charge controller is partially turning off the solar-electric array to prevent overcharging the batteries. Modern controllers use "pulse-width modulation" (PWM) to do this, turning the array output on and off very quickly, and changing the duration of the off and on times to maintain the desired charge rate.

If your batteries were at a lower state of charge (SOC) so that your controller was charging at its max, you *still* would rarely see the rated output of the array. The primary reason for this is the unrealistic rating system we use for modules. All modules are tested in what we call "standard test conditions" (STC)—1,000 watts of light per square meter at 25°C.

Both of these conditions are unusual for real-world PV arrays. A bright sunny day, with no haze, smog, or anything else to filter or obscure the sun, will produce 1,000 watts per square meter. But to get this much irradiance, the array also has to be perpendicular to the sun.

And 25°C is 77°F. Ask yourself how often a black or dark blue surface in the sunshine will be that cool—not often.

It's perhaps counter-intuitive, but when PV modules are hotter, their performance (specifically, their voltage) drops. So in most cases—except in winter—arrays don't witness 25°C conditions. When they do, the sun conditions are often not ideal (because of latitude, angle, weather, etc.).

While your charge controller does maximum power point tracking (MPPT), other readers may have non-MPPT controllers, which brings in another reason for less-than-rated performance. Without MPPT, a system is limited by the battery bank voltage. The array voltage will be clamped to just above the battery voltage, so the charging potential above battery voltage will not be available, resulting in lost array power. An MPPT charge controller can turn excess array voltage into usable amperage that the battery bank can absorb. During cool weather and when the batteries are at a low SOC, you will see the array wattage increase.

From the photo, I see that your array is tilted to a winter angle. This makes sense because you are off-grid, and winter is the time your system sees its biggest energy challenge. Your array's rack is adjustable, and you could tilt it flatter in summer and get more production, but many people don't find it worth the trouble, since you generally have more energy than you need during that season.

Output losses can also occur due to module soiling. Wash your modules at least once a year with mild soap and water. If you're in a dusty or high-grunge environment, you may need to clean them more often.

Then there are potential losses due to PV module production tolerance—i.e., depending on the manufacturer production tolerance (%), the actual module output, even under STC, may be less than

the wattage rating. For example, if your modules have a +/-10% production tolerance, the actual STC wattage can range from 108 to 132 watts. Also, as modules age, they degrade—an estimate of 1% power loss per year is often quoted. Additionally, voltage drop due to wiring runs is a factor (the loss depends on the wire gauge used) and controller inefficiency can also contribute to system losses.

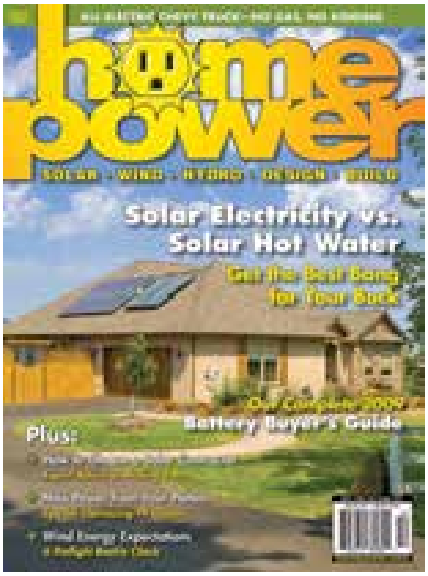
In the end, assuming a completely unshaded array (and on a sunny day with a battery not yet full), I'm pretty happy if my array produces 70% to 85% of its rated output. So have no fear, your PV array is likely on track, and all is well. If you want to start a campaign to get PV manufacturers to use a more realistic rating system, I will be on your advisory board!

Ian Woofenden • *Home Power* senior editor

PV or SHW?

I was looking forward to having a solar hot water (SHW) system installed at my house until I attended an informational seminar on solar water heating. The salesperson basically told us, "invest in PV" if you're a small household that practices water conservation and efficiency. His rationale was this: Where my husband and I live in the Pacific Northwest, winters are fairly cloudy and SHW production will be low in those months, stretching out the payback time for the system. With a water-conserving household (low-flow fixtures, water-saving appliances, etc.), he said we'd be wasting money on a system that would only be working optimally for us half

Courtesy Chuck Marken



of the year, and that we'd have to figure out what to do with excess hot water produced in the summer months.

What do you think? Are we barking up the wrong RE tree, and should we just invest our dollars in expanding the planned PV system to cover our water-heating needs rather than paying for a SHW system?

Sandy Wellington • via e-mail

See "PV vs. Solar Water Heating: Simple Solar Payback" in *HP127*, comparing the economics of small SHW and small PV systems. At the time, with prevailing costs, the SHW system appeared to have about a 2.5 to 3:1 advantage in return on investment (ROI) with no incentives and both technologies displacing electricity. This has probably been reduced to perhaps about a 2:1 advantage today due to PV prices continuing to fall.

The information you received regarding the seasonal diversity of the solar resource in the Pacific Northwest is accurate. At a tilt equal to latitude, the winter six months come in at an average of a little more than 2 sun-hours per day, with the six summer months having just more than 5 average sun-hours.

Maybe the PV salesperson was thinking of or passing on information regarding solar thermal *space-heating* systems; if that's the case, the advice is sound. The utility grid has almost unlimited storage capability for PV systems, while storage tanks have a much smaller storage capacity for SHW systems. In areas with wide differences in the seasonal solar resource, PV has a better ROI than home-heating systems using solar hot water collectors. The SHW home heating equipment will only be used half the year (or less) and at the time when there is less than half the solar resource compared with the summer. This wide seasonal diversity of the resource is not the case in much of the United States, and space-heating options can be viable alternatives in those places.

But *domestic* solar hot water systems are a different story. They're used the entire year and, as long as the system is sized to not overproduce significantly in the summer, the economic evaluation in *HP127* is still valid for even your region, albeit dated. The best way to address summer overproduction in any system is to configure it as a drainback system. If that isn't possible, there are many methods of controlling antifreeze system summer overproduction described in "Overcoming Overheating" in *HP142*.

Chuck Marken •
Home Power solar thermal editor

write to:

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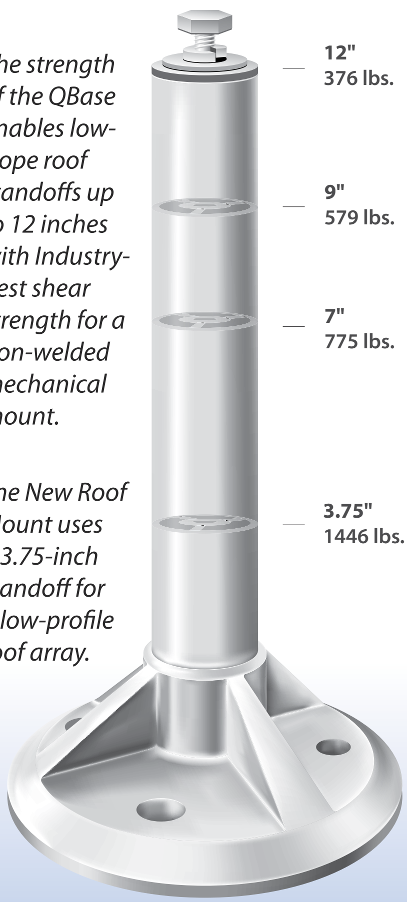
The New Roof Mount uses a 3.75-inch standoff for a low-profile roof array.



QBase

WHERE THE ROOF MEETS THE LOAD

The Low Slope and New Roof Comp Mounts are built around the all-aluminum QBase. With four buttresses to support the load, QBase makes these off-the-shelf solar mounts the world's strongest – *by far.*

Quick Mount PV announces new 100% code-compliant, waterproof mounts for low-slope commercial roofs and for new home construction and pitched roof replacement.

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New Roof Composition Mount

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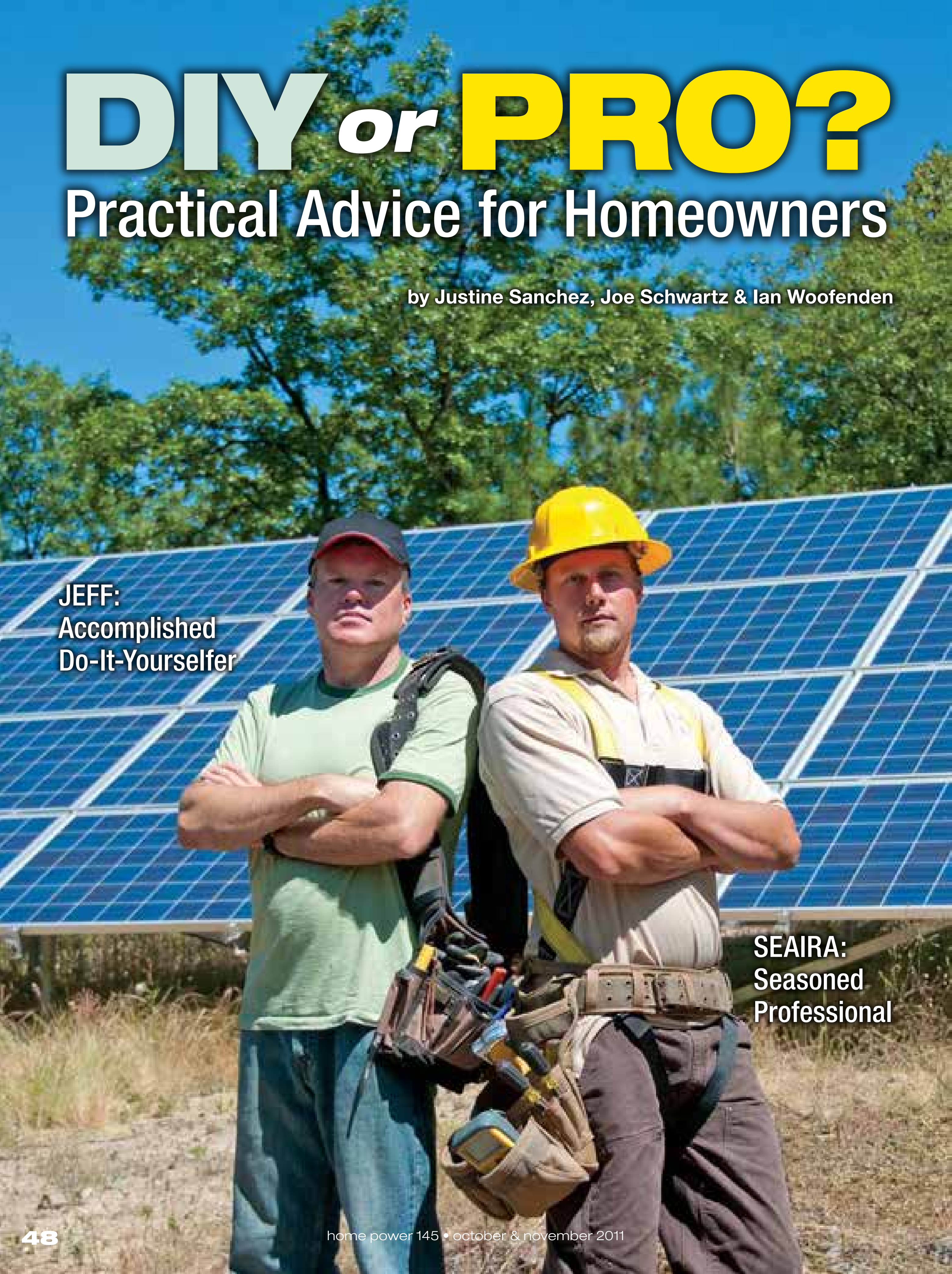
RESPECT THE ROOF

DIY or PRO?

Practical Advice for Homeowners

by Justine Sanchez, Joe Schwartz & Ian Woofenden



JEFF: Accomplished Do-It-Yourselfer

SEAIRA: Seasoned Professional

The installation of most residential PV systems is usually better left to the pros, but if you have the right set of skills and expectations, installing your own system can be a realistic goal.

Is it common for homeowners to design and install their own solar-electric systems? Should I install my system or hire a licensed professional to do the work? What skills and tools do I need to tackle a home-scale PV project? How much will I save if I install the system myself?

We frequently get questions like these from *Home Power* readers. Rather than defaulting to the obvious answer, "it depends," we explore a long list of variables you should thoughtfully consider before tackling the design and installation of your PV system.

Owner installation is definitely not for everyone. Like any home improvement project, it's important to realistically assess your skills, and weigh the benefits and potential pitfalls. Installing a PV system certainly isn't rocket science, but doing it well and *safely* requires experience working with electrical systems, some serious research, and plenty of sound advice.

System Scale and Type

First, it's important to consider the size of the PV system you want to design and install. There's a huge difference in the cost and complexity of a 12-volt PV system with a few modules, designed to power some tunes and a couple of lights, compared to a multikilowatt, roof-mounted, grid-connected system operating at up to 600 VDC.

The former small system can be a great DIY undertaking for most handy individuals. Unless you are working alongside a willing professional, however, the latter should not be tackled unless you have significant experience working with high-voltage wiring, a firm understanding of the *National Electrical Code (NEC)*, and access to the required safety equipment.

System type is also a consideration. Battery-based and batteryless grid-tied solar-electric systems are quite different, and require different levels of preparation and involvement. You need to understand the system type you want to install, and then assess your abilities and interest to determine if you can handle the job.

Grid-tied systems can be batteryless or battery-based. Batteryless systems are the most common, and are also the simplest, most cost-effective, and most environmentally friendly. You can find examples of this system type in *Home Power*, in supplier catalogs, and around your community. Batteryless PV systems can be bought as packages from suppliers and, with the proper support, can be almost color-by-number. These systems can employ one or more central string inverters or microinverters, where each module is paired to its own small inverter. Microinverter-based arrays operate at 240 VAC rather than at high-voltage DC, making electrical wiring a little safer to work with. Whether you are using microinverters or central inverters, you'll still need electrical skills, tools, and savvy, but batteryless grid-tied systems are actually quite straightforward, consisting primarily of racks, modules, disconnects, inverter(s), and wiring.

A grid-tied battery-based system is another matter. Introducing batteries involves more complication in planning, implementation, and operation. To start, you'll need to know how much battery storage you want or require, which means you'll need to know your backup load profile and how long a utility outage you want to protect against. Though you can buy some or even most parts of a battery-based power center pre-wired, you will still need to configure and wire your battery bank, tie it and your PV array into your power center, and then connect the system to your backed-up subpanel and the grid. Most will need someone assisting in person or on the phone as you plan and install the system. Operation of a battery-based system is more complex than a batteryless system, and the batteries will require varying levels of maintenance, as well as periodic replacement.

Shawn Schreiner

Techie Gear

Batteryless grid-tied PV systems may be the simplest conceptually, but they still require good design, mechanical and electrical skills, adherence to codes, and safety. Are you adequately prepared?

Ben Root

Critical Planning

The Solar Pathfinder (left) and the Solmetric SunEye (right) are professional-quality solar site assessment tools that provide valuable information for your system's design.

Shawn Schreiner

Going off-grid requires a commitment to providing all electricity to all of your loads, all of the time. The design phase is crucial—you'll need to understand your load profile, your resource, and the equipment capabilities. While many off-grid systems have been built by DIYers over the history of the RE industry, designing and installing a code-compliant system for a modern off-grid home is not a job to take lightly. All of the system users in the household will need to be involved from the beginning if you want a system that doesn't disappoint.

Designing Your System

There are many steps involved in designing a PV system—do your homework to make sure you cover all of your bases. Site-specific variables will dictate your system's type, size, and location, and several other variables will dictate the components you'll need.

Evaluate your situation and goals to specify the system type. First, observe your site closely to make sure there's a good solar window at your proposed array location (ideally from 8 a.m. to 4 p.m., but 9 a.m. to 3 p.m. is acceptable). Sometimes, that "open" solar window is not on your roof, but in the yard, making a ground-mounted system optimal. Or perhaps you want a 4 kW system, but your shade-free space can only accommodate 2 kW. Then there are the myriad individual equipment requirements with which you will need to be familiar. For example, if you found a good deal on a specific inverter, your site's high and low temperatures and the module specifications will play a role in how many modules you can string in series to connect to that particular inverter.

To comply with and pass your electrical inspection, you will need to be aware of all the various *NEC* requirements that pertain to your installation. Local requirements may also come into play. For example, while many inverters offer integrated DC and AC disconnects, your local authority having jurisdiction (AHJ) may require additional disconnects. In addition to the *NEC*, local fire codes can affect your installation. For instance, some mandate 3-foot setbacks on roof-mounted arrays to provide pathways for firefighter access and smoke ventilation.

Performance factors also need to be considered. Do you have enough know-how to optimize the system's design? For example, even minimal shading of a PV array during the prime solar hours can significantly reduce your system's output. Also, PV module output declines with increasing temperatures, necessitating a design with good airflow around the modules. The list of considerations goes on and on. That's why folks seek professional assistance—to ensure that their investment in a PV system isn't undermined by trying to save a few bucks on installation costs.

Buying Equipment

When it comes to buying equipment for your PV system, don't buy cheap! We mean this on two levels. First of all, buy quality equipment. Most of us are accustomed to having reliable grid electricity. If you want to have a reliable solar-electric system, you'll need high-quality gear. Find out what suppliers are selling the most of and what installers are buying. Be wary about a new product being sold only from

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Buying your equipment from a source that can offer technical support in the design, installation, and troubleshooting phases is worth the extra money.

one source. Wait until the pros in the industry start trying it, using it, and praising it before you spend your money.

Don't automatically go for the dealer with the lowest cost. Too often, DIYers end up with a low level of support along with a low price. *Especially* if you're installing your first system—you *will* need some hand-holding. Buy your gear from someone who can help you during and after the installation, and expect to pay more to include that level of support and service.

Second, if possible, try to buy locally. Being able to develop a relationship with your supplier is priceless. There's nothing like being face to face when it comes to a clear understanding of design, and when it comes to resolving issues with an order, product, or system.

Consider collaborating with a local, professional RE installer, if there is willingness. Buy your components through a local company, giving them their profit margin. Perhaps even hire one of the technical people at the company to review your design before purchase, and again before inspection. This can be a great partnership that will serve your system well. If you do run into problems during design, installation, or operation, you'll have someone to turn to who has walked the path before.

Don't buy discounted equipment and *then* go looking for an installer. These folks make their living selling and installing PV systems. They know the ins and outs of the equipment they prefer to install, and they know how to install it. They also need to mark up the equipment to make their living, just like all businesses. Trying to get something for nothing will most often result in hard feelings and poor relationships—and not the help you're looking for. If you do find a pro willing to install equipment you already bought, expect to pay top per-hour electrician wages—most likely eliminating the savings realized on the inexpensive equipment.

Most manufacturers are global companies that have little interest or dedicated resources to handle technical questions from homeowners, and this may include warranty claims and issues. So don't expect to call the manufacturer of your inverter for help with string sizing, or get the footing requirements for your ground-mounted array from the mount manufacturer, for example.

DIY PV modules

Thinking about building your own PV modules from scratch? Think again. While this has been done on occasion (especially in developing-world situations), we strongly recommend against it.

First of all, you won't be making the PV cells. This is high-tech, clean-room technology, not something you're going to do in your garage. And this is the most expensive and important part of the PV module manufacturing process.

You *could* buy cells and assemble your own modules. We see opportunists advertising plans to do this cheaply, but we suspect that the main benefit is to the plan producers' bank accounts. While a handful of companies are promoting DIY module building as a practical alternative, the realities of the actual cost and, more importantly, product safety, are being ignored. Without question, PV system components should be listed to applicable Underwriters Laboratories standards, just like any other electrical product in your home. These standards were developed to ensure the safety of you, your family, and your neighbors. Unlisted components are an accident waiting to happen.

PV modules are incredibly long-lasting devices *if* they are well-constructed. Most carry 20- to 25-year warranties on energy production and will continue producing electricity for 40 years or more depending on the quality of their construction. Trying to do this yourself will rarely, if ever, result in the durability and longevity you will find in well-manufactured modules. Building PV modules is best left to PV manufacturers.

Courtesy Helios Solar Works

Tooling Up

You will need a wide range of construction and electrical tools to install your PV system (see "Tools of the Solar-Electric Trade" in *HP105*). The basic construction tool list for a batteryless, roof-mounted, grid-tied system includes: drills (cordless and AC) with various attachments, including drill bits, hex bits, Phillips bits, and hole saws; a reciprocating saw; socket wrenches; a hammer; a level; and an assortment of screwdrivers and open-end wrenches (the ratcheting kind are great). Required electrician's tools include wire strippers, cutters, and crimpers; needle nose and lineman's pliers; a hole-punch kit; a conduit bender; and a fish tape.

The list grows if you are installing a battery-based system, as you will likely be dealing with constructing a battery box, and needing to cut and connect large battery cables and lugs. If the system is ground- or pole-mounted, you will need equipment for digging trenches and post holes (i.e., shovels and a post-hole digger, or access to a power auger and trencher).

Additional tools include a torque wrench to properly tighten wire terminations, and a digital multimeter for verifying voltage and polarity during installation and for ongoing system maintenance. A DC clamp-on amp-meter is also a handy tool for checking the output of individual array strings or circuits. Specific safety equipment is also required (see the "Safety, Safety, Safety" section).

You'll also need access to solar-specific tools for both site analysis and installation. While there are some wide-open solar sites where array shading is not a concern, the majority of sites, especially in residential areas, will have trees and buildings—so shade analysis will be necessary. Shading

Specialty Tools

While many of the necessary tools are common to the well-equipped homeowner, some specialty PV installation tools are either necessary or a great convenience. The cost of tooling up can negate the savings of doing the work yourself.

Shawn Schreiner

specifics impact component selection and array layout, and can influence the availability of some financial incentives. Excessive shading will have potentially crippling impacts on system output and your return on investment over the PV system's life. Tools such as the Solar Pathfinder ($269) and the Solmetric SunEye ($1,995) are used by the pros to determine shade factor, and/or compare the solar access of different array locations. The price of these shade analysis tools will likely put them out of reach of a homeowner working on a one-time installation. For iPhone users, Solmetric offers the Solmetric iPV app ($29.99). While it is not as accurate or quick as the SunEye, it offers users a simple shade analysis at an inexpensive price. Shade analysis tools have also recently been developed for Android-based smart phones and tablets.

If you're not already tooled up for significant home improvement projects, including electrical work, the cost of acquiring all of the necessary equipment could easily offset any savings you may be expecting from installing your own system. If you do have a good selection of tools in the shop, additional purchases may be minor, but should still be considered prior to embarking on a self-installed PV project.

Installation Experience

The skills you'll need to install your PV system will depend on the system's complexity. Overall, you will be doing conceptual, mathematical, mechanical, and electrical work. In some respects, the conceptual work may be the hardest. You'll need to understand your energy needs, your solar resource, the equipment available, and how the gear fits together into a full system. If you blow it here, no amount of mechanical and electrical savvy will rescue you from poor function. Plan to spend much more time studying, planning, and designing than you spend implementing. Professional installers get used to doing the same tasks over and over. You won't already have the benefits of learning from the inevitable mistakes.

Those who are used to undertaking major home-improvement projects will likely be the most prepared to pursue a DIY PV system. When it comes to the mechanical work, you'll need to know how to use tools and fasteners properly to make roof- or pole-mount attachments; install roof flashing; secure heavy electrical components to the wall; etc. Battery banks and enclosures require another level of mechanical work, involving security, hazard protection, and dealing with heavy weight.

The electrical work is more hazardous and more detail-oriented—and can be more crucial than the mechanical work. Note that licensed electricians study for *years* to gain the skills to bend conduit, pull wire, and make secure connections—all while meeting the strict requirements of the *NEC.* Consider your skills and experience carefully before jumping in. Having a mentor on the job or nearby may be your wisest decision. Once again, you are only doing this job once—electricians have the benefit of long experience and training. They have tricks and techniques that make the job go quickly and smoothly. Consider taking a basic wiring class at your local community or technical college, so you'll have some practice time on someone else's wire, and another source of mentorship.

Permitting Considerations

The appropriate building permits will have to be obtained and the system will need to pass an inspection. This can be a painful process if you are not used to performing electrical work. Inspectors will be on the lookout for all possible *NEC* violations, including sloppy work, improperly sized conductors, lack of conductor protection, and improper equipment grounding and labeling (see "Residential PV Systems: Common Code Violations" in *HP141*). If your system doesn't pass muster, you will usually be charged a reinspection fee each time the inspector comes out. Professional installers who have been in business for awhile have been through many inspections and have a good handle on what the local AHJ expects. They have the experience and the knowledge to work with inspectors if anything comes up that the inspector may not be familiar with. Homeowners will typically be greeted with a greater level of scrutiny from building inspectors. Additionally, there is a new section in the 2011 *NEC*, section 690.4(E) stating that PV equipment and systems, and all associated wiring and interconnections, shall be installed only by "qualified persons." See *Code Corner* in this issue for a discussion about what constitutes a "qualified person" in the eyes of the *NEC* and your local AHJ.

DIY Savings?

Installation labor costs typically account for 10% to 20% of a system's total cost. Labor costs for a simple 3 kW roof-mounted, batteryless grid-tied PV system might be between $2,000 and $3,500. The exact amount you could save by installing the system yourself will depend on your particular system type, and its size and mounting method. For example, battery-based PV systems are much more complex and require more time to install the extra components (such as the battery box, batteries, battery cabling, charge controllers, battery metering, extra disconnects, and overcurrent protection). Array size will dictate how many module mounts and inverters are required. This, in turn, will determine the time required to install the complete system. The array mounting method will be a major factor. For example, a ground-mounted system (see "PV Ground-Mounting" in *HP144*) requires much more prep work—such as digging footers and conduit trenches, setting posts, and pouring concrete—compared to a roof mount.

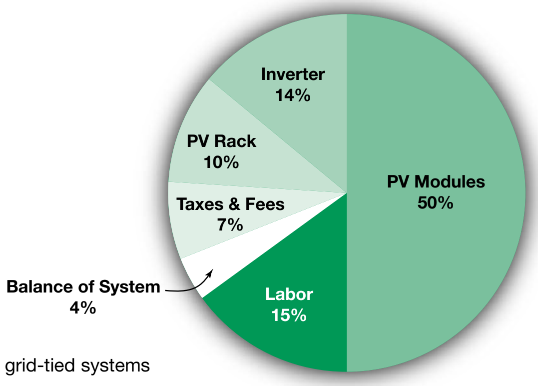
Education

If you are determined to install your own system, consider getting some training. Coursework and hands-on exercises can walk you through the steps of designing and installing a PV system and allow mistakes to be made in a classroom/lab setting rather than during your home system installation. Several organizations offer on-site and online courses to help you get the basic knowledge you need (see "Charting Your Solar Course" in *HP136*).

Kris Sutton

While you can obtain a lot of system design knowledge from online and classroom presentations, when it comes to installation specifics, nothing beats hands-on training. These courses are not short nor inexpensive, and are usually geared toward individuals wanting to become professional installers. Often, folks who want to install their own system are the same people who are pondering a career shift into the PV industry. Training followed by a home installation can be a great progression if you're considering entering the PV industry. The value of living with a PV system, for both homeowners and up-and-coming professionals, is priceless.

Typical PV System* Costs



*For batteryless grid-tied systems

A DIY system may impact your incentive eligibility. While you can still take the 30% federal tax credit, in some cases, you may not qualify for state, local, or utility rebates if you install the system yourself. A self-installer could lose out on thousands of dollars in state and/or utility incentives.

To find out what your system will qualify for, research the requirements for the various PV incentive programs in your area (see the Database of State Incentives for Renewables and Efficiency at www.dsireusa.org). For example, Xcel Energy's Colorado customers who install their own systems are eligible for the Xcel Energy Solar Rewards program, which currently offers a $1.75 per watt payment (and $0.04 per kWh production incentive) for systems under 10 kW. However, these systems are not eligible for the state

The Pro Perspective

Pros bring skills and experience to a project that a one-time installer does not have. The majority of installers have years—sometimes decades—of experience designing and installing systems. They know what works and what doesn't, and understand the subtleties of system design and changes in the *National Electrical Code*. They have relationships with building inspectors and equipment distributors, and have established peer networks for situations where even they may need advice. Professionals also can provide you with guidance and a streamlined process for navigating the typically complicated processes of applying for, receiving, and maximizing any available financial incentives. They may also offer system financing and leasing options that can minimize or even eliminate your up-front investment.

Solar contractors are specialized, but they are no different than any other building or trade professional. They offer products and services that enable the smooth implementation of high-quality systems. That said, keep in mind that the level of experience, support, and professionalism can vary greatly between contractors. If your system will be professionally installed, find someone whose experience you trust, and verify it by checking both customer and business references. Spending some time on the Internet researching customer feedback on potential contractors can be helpful.

rebate program (currently set at $1.50/watt) unless they are installed by a contractor listed in the rebate program database. In Oregon, to obtain Oregon's Energy Trust rebate, PV systems must be installed by a qualified Energy Trust solar trade ally contractor. Self-installed systems do not qualify. Any money you may be expecting to save by installing your system will be offset if you can't capture all of the available incentives.

Safety, Safety, Safety

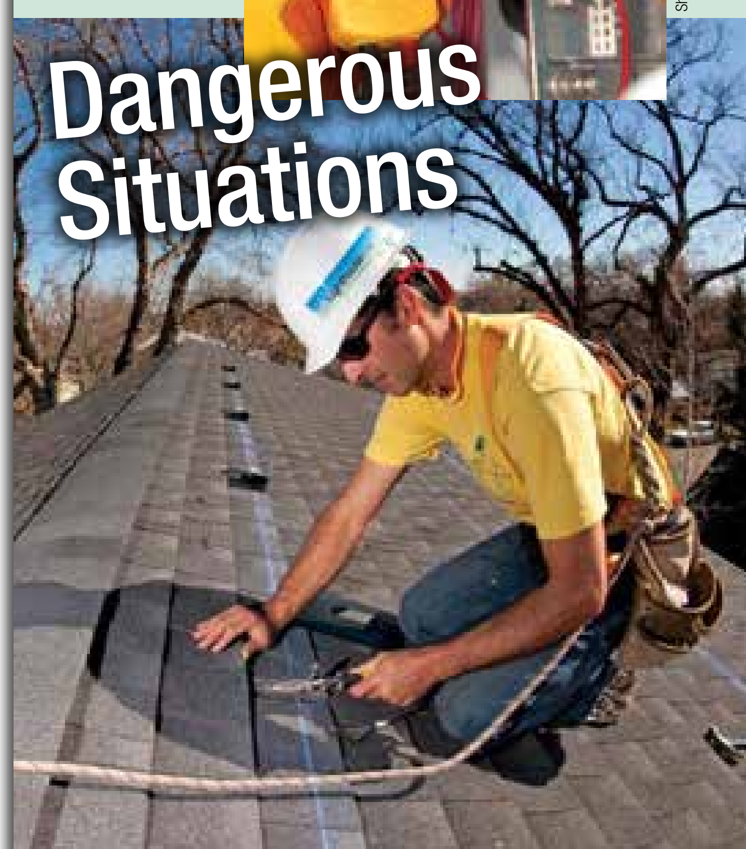
When you approach any new activity that's potentially dangerous, it goes without saying that you should proceed slowly, methodically, and with extreme caution. When it comes to PV safety, you need to consider both design safety and installation safety.

During the design, many critical safety aspects must be considered. For example, array fastening systems and hardware must ensure a secure rack-to-roof attachment. Nothing will bring your efforts to a crashing halt like modules being torn off the roof during a heavy wind storm. System wiring and overcurrent protection devices must be appropriately specified to prevent fire hazards. Conduit size, the number of conductors running in a conduit, and the installation method should always meet *NEC* requirements. Appropriate ground-fault protection is a requirement for PV systems mounted on dwellings and for some pole- and ground-mounted systems as well. Batteries introduce additional safety considerations, since huge amounts of stored energy are present. They also require dealing with sulphuric acid, ventilating flammable hydrogen gas to avoid buildup, and taking precautions to avoid short-circuiting the batteries during installation or future maintenance.

Once the PV installation begins, a whole new set of safety requirements must be considered. (See www.osha.gov/dep/greenjobs/solar.html for an overview of installation hazards and precautions.) Most modern PV systems operate at dangerously high DC voltages and electrical shock hazards are present during installation. There are many precautions that must be taken to ensure you do not come into contact with these high voltages, like understanding and following safe installation order procedures. For instance, disconnect and inverter wiring should always be attached *before* the PV array circuits or grid are connected. Have a well thought-out plan for wire management and be on the lookout for array wiring that inadvertently gets pinched between the modules and the mounting structure. This

Electrocution from high-voltage DC electricity and falls from roofs are two of the hazards of PV system installation. For DIYers and professionals alike, safety must come first.

Shawn Schreiner



Topher Donahue

can damage the insulation and potentially lead to ground-faults and arcing once the system is connected.

Never underestimate the importance of suitable personal protective equipment—cutting corners here could have life-long impacts for you and your family. Basic safety equipment like eye protection, ear protection, and respiratory protection should be used when needed. High-voltage electrician's gloves and glove protectors should always be worn when working on live high-voltage DC circuits. Installing a roof-mounted system poses potentially lethal fall hazards. While many homeowners may be comfortable working on the roof unprotected, that doesn't mean that it's sensible. Fall-protection equipment, including harnesses, safety lines, and proper anchoring systems, should be used. Even if you're installing your system at ground level, ground-mounted systems often necessitate working with power augers and trenchers, which both pose operation hazards.

To DIY or Not to DIY

Over the last 20 years, PV installations have shifted from primarily owner-installed systems to professionally installed ones (see *From the Crew* in this issue). Should you install your own solar-electric system? To recap, the answer depends on the scale and type of system that will meet your needs; your understanding of system sizing and component selection; your skill level; and the range of construction and safety tools and equipment you have. A primary driver in the decision is also the potential impact that self-installation may have on any available financial incentives. If you decide to design and install your own system, be sure that you properly assess your abilities and have realistic expectations of the benefits and potential pitfalls of doing so.

PV systems typically require a significant financial investment and you'll want your system to function not only reliably, but also *optimally* over its more than 20-year service life. In many cases, the amount of savings you'll reap by installing your own system will be minor. If you consider the value of time you'll spend on the project, including up-front research and system design, as well as time spent wrenching, you may very well end up spending more time than you can afford.

So why would someone install their own system? What's the bottom line? The answer is probably similar to reasons for tackling any major home improvement project—for the fun of doing it and the sense of accomplishment. And those are two powerful reasons in and of themselves.

Access

Justine Sanchez (justine.sanchez@homepower.com) is technical editor at *Home Power*, a Solar Energy International instructor, a NABCEP-certified PV installer, and is certified by ISPQ as a PV Affiliated Master Trainer.

Joe Schwartz (joe.schwartz@homepower.com) is the editor of *Home Power* and *SolarPro* magazines. He began his career in RE as a PV, wind, and microhydro system installer in 1997.

Ian Woofenden (ian.woofenden@homepower.com) bought his first solar-electric module in 1984. Early projects were DIY, with more recent ones implemented by professionals—all effectively turning solar energy into electricity.

Advice for Successful DIY

- **Do your homework.** Study *Home Power* articles, books, websites, manufacturer literature, etc. Take courses and workshops. Find others who have installed their own PV systems and study their designs, successes, and failures.
- **Build a quality team.** Find the expertise you need to support your DIY effort. Your equipment supplier will be a key part of this team. You also may lean on industry consultants, teachers, colleagues, friends, neighbors, and solar groups.
- **Take your time.** Tackling a one-time project is risky, and it's more dangerous if you're in a hurry. The many DIY projects we've done have taught us that mistakes on slower and longer projects allow time for learning. Mistakes on quickly planned and implemented projects tend to multiply, because you don't have time to reflect on them, correct them while they are small, and learn from them.
- **Document.** Keep track of your design, the component specs and warranties, and installation progress and details. This will set you up for any troubleshooting needed, and will also give you information and expertise to share with others who may be interested in copying your success.

The more you understand about your PV system's design and operation, the better, whether you choose to go it alone, enlist the help of a pro at some level, or sit back and let the masters take care of things.

SOLAR/GRID PARITY

HAS IT ARRIVED?

by Jay Tyson

Grid parity—the point at which solar electricity, without financial incentives, will cost the same as conventional electricity from your utility's electric grid—has been the dream of the solar community for decades. Among many efforts to speed that up is the U.S. Department of Energy's SunShot Initiative, which has a goal of reducing the cost of solar electric systems by about 75%—to a little more than $1 per watt—by 2020.

This would make solar energy less expensive than grid energy in almost every U.S. market. However, unlike President Kennedy's Moonshot program, which reached its goal the moment Neil Armstrong first set foot on the surface of the moon, the SunShot goal of grid parity will be achieved at different times depending on your location, roof orientation, the local cost of electricity, and several other factors. Indeed, it may have already arrived in some locations.

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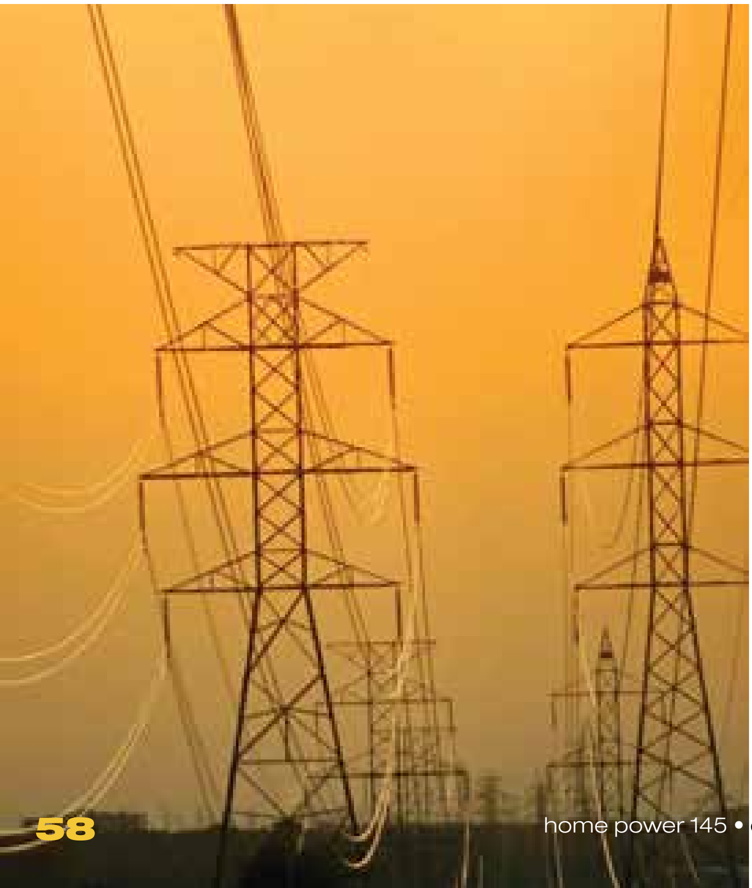
In some markets, solar-produced electricity, made right on your rooftop, is cost-competitive with utility-generated electricity.



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Determining Parity

If you know all of the details of a particular site and solar design, determining the kilowatt-hour (kWh) price point at which PV power is equal to grid power is not too difficult. I've developed a grid parity calculator spreadsheet to assist (see "Web Extras" below).

Don't be daunted by the 28 variables that go into this calculation—half of these are figured already by NREL's PVWatts calculator (see http://rredc.nrel.gov/solar/calculators/PVWATTS/version1). And all of the variables have explanations or suggested ranges, so if you don't have an exact figure for some, you can approximate, and update it later as needed.

web extra

Access the grid parity spreadsheet online at **www.homepower.com/webextras.**

Grid electricity is paid for as you use it, with payments stretching out forever. The majority of PV expenses are paid for at the time the system is installed. After that, the energy is essentially free.

Solar Subsidies Still Essential

There is a tendency to think that, as soon as apparent grid parity (GP_A) is reached, we can do away with subsidies that are solar incentives. But this is not the case.

First, it would be unfair to the solar technologies to remove these subsidies unless fossil-fuel subsidies are also removed. This includes not only the obvious subsidies, but also the hidden subsidies, such as free disposal of wastes in the atmosphere, soil, and waterways. If the government is treating all aspects of the energy industry fairly, a residual subsidy representing the difference between GP_A and true grid parity (GP_T) will always be required.

Defining Parity

Grid parity means that, at the end of the PV system's life cycle, you will have spent the same amount on your PV system as you would have spent on grid electricity, for the same amount of energy—i.e., the payback period is equal to the life cycle.

However, the nature of their costs is different. Grid electricity is paid for as you use it, with payments stretching out forever. The majority of PV expenses are paid for at the time the system is installed. After that, the energy is essentially free, with the exception of minor maintenance and insurance costs.

To accurately compare the two, we must translate all of the expenses into common terms. To do that, we must choose a "life cycle" period for the PV system. Typically, 25 years is chosen because this is the standard length of PV module warranties. To convert the value of payments that far in the future into today's values, we calculate those amounts based on their "present value." Therefore, each future payment is reduced to account for the assumed rate of future inflation.

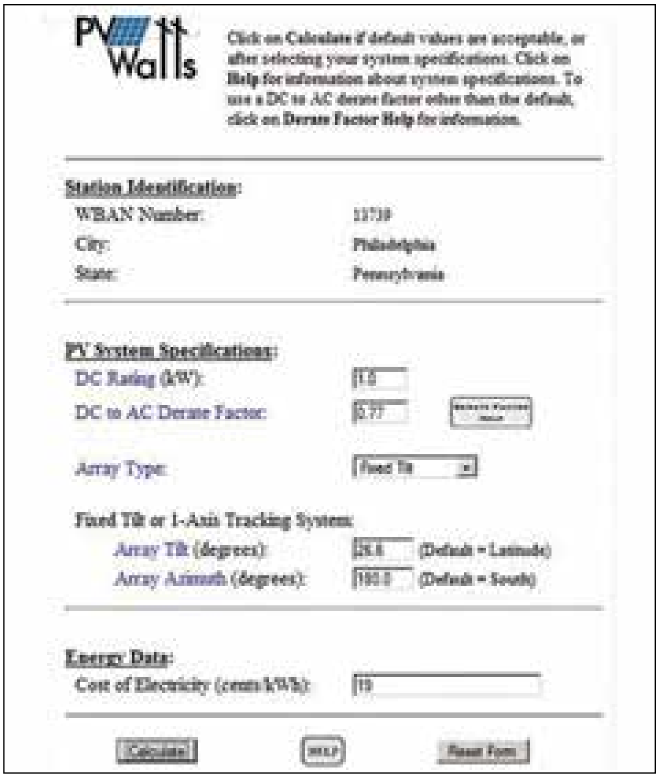
We should also distinguish between GP_A and GP_T. GP_A is based on the actual prices that the consumer pays, both for grid electricity and for solar electricity. GP_T attempts to account for certain factors that do not appear in the price. These include removing the subsidies that fossil fuels currently receive and charging for the externalities—e.g., free disposal of gaseous waste into the atmosphere; disposal of wastes into streams and rivers; the costs of fossil-fuel resource wars. These are complex policy issues that may affect the future price of grid electricity. But for the purpose of the individual home- or business-owner who is dealing with real costs now, this article focuses on GP_A.

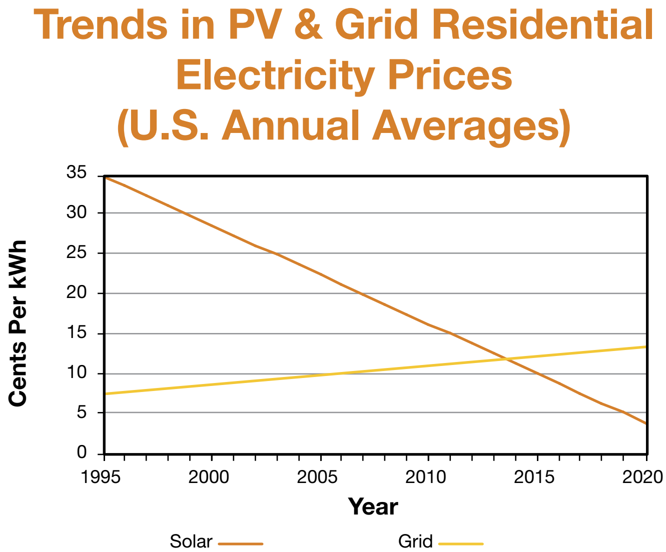
Subsidies will be needed as long as there are uncertainties in any of the variables in the cost-comparison calculations. The grid parity calculator identifies three speculative variables—future inflation rate, future energy-inflation rate, and the value of modules at the end of their life cycle. Since these cannot be predicted with any degree of certainty, incentives will be needed beyond grid parity to cover the "cost" of this uncertainty—to move the solar alternative from being "probably economical" to "almost certainly economical."

Incentives are also needed wherever PV systems are unusual or non-standard in a neighborhood. There is a natural resistance to change. Incentives beyond grid parity are needed to overcome this until rooftop PV systems become the norm.

Finally, incentives are needed to encourage people to invest their money at the beginning of the life cycle rather than buying electricity with the conventional pay-as-you-use method.

Supply the PVWatts online calculator with a few values—the system size, derate factor, type, tilt, and azimuth—and it will estimate your system's production performance.





Cost Factors

Grid Electricity. The cost of grid electricity (variable 1 in the GP spreadsheet) can be determined by reviewing your electric bill. Simply divide the total of the generation and transmission charges by the number of kilowatt-hours you've used.

Where utilities have time-of-use (TOU) rates in place, you'll need to estimate how much energy your PV system will generate at various times of the day. Fortunately, PV systems often tend to hit peak production at about the same time that electricity is most expensive, so TOU customers' PV systems will be producing a lot of the most valuable electricity. Where the utility's rate varies depending on the amount of energy used (tiered pricing), the solar alternative will also replace the most expensive grid electricity you would have used and may also reach down into lower tiers as well. With both TOU and tiered rate schedules, you'll need to study the system size and your usage patterns to arrive at an accurate estimate of the average cost per kWh of the electricity you'll be saving.

The cost per kWh may sound small (ranging between 7 cents and 30 cents in 2010), but don't let it fool you—it is a big factor in determining whether or not your PV system reaches grid parity.

Another major factor on the grid side of the equation is how fast the price of grid electricity will rise (variable 13) compared to general inflation (variable 12). Historically, energy prices have risen faster than overall inflation. But how much faster depends on which part of history you're looking at. Typical estimates range from 0% to 6.5% per year. Just a single percentage point or two over the life cycle of a PV system can make a big difference in the grid parity calculation.

And how similar will the past be to the future? New supplies of fossil fuels are being discovered, and new methods of extracting previously uneconomic fuels are being developed. At the same time, both the worldwide population and the per-capita energy consumption are growing dramatically, especially in India and China. Here in the United States, higher gasoline prices may push people into electric cars, placing increased demand on the electric grid. Will the growth of electrical demand outstrip the growth of supply and drive up the price?

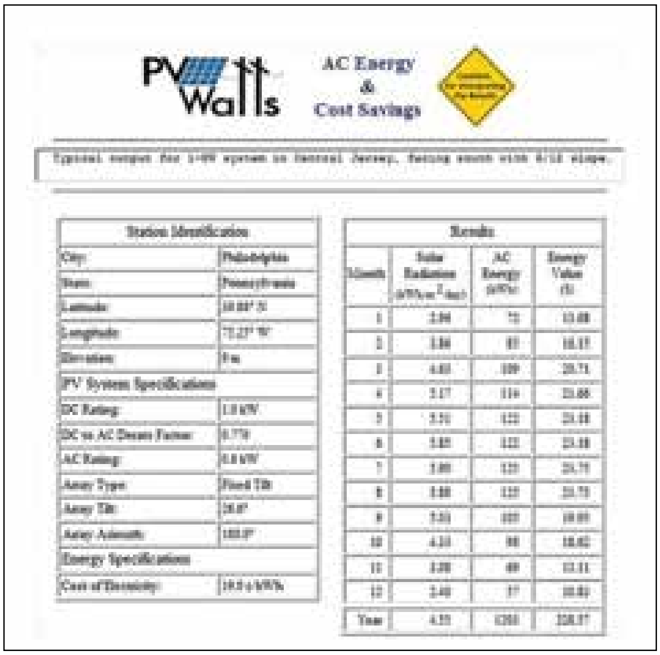
What about the cost of building additional power plants and transmission lines? How much will environmental concerns add to these costs? Will the government reduce fossil fuel subsidies? Will it add taxes to the fossil fuel industry, to reflect the true costs? Is the expansion of nuclear energy still a viable option after the crisis in Japan?

All of these factors play a role predicting the future price of electricity. While I agree that it's likely to be more than the general inflation figure, it's hard to say how much more. Perhaps the best approach is to try a few different estimates here, and see what the cost-per-kWh needs to be to reach grid parity at these points.

Solar Electricity. The cost-per-watt of solar-generated electricity (variable 2) is one of the biggest factors in determining when your system will reach grid parity. If you want the most accurate value, it's best to get a quote from a local installer in your area, who can take into account any special cost factors associated with your particular site.

If you need only a general idea of the recent cost-per-watt prices in your area, you can search the National Renewable Energy Laboratory's Open PV Project, and retrieve a list of local projects as a spreadsheet (see http://openpv.nrel.gov). Sort for recent, nearby projects about the same size as yours, and create a "cost per watt" column, which takes the total project cost on each line and divides it by the total number of watts (kW x 1,000) for that project. This will give you a good idea of local cost per watt—somewhere between $4 and $10.

PVWatts allows users to input various values to determine an overall derate factor.



PVWatts provides a monthly breakdown of your PV system's production, including kWh generated and the comparative cost of the energy produced.

Another significant variable is the PV system's life cycle (variable 6). Most people will choose 25 years, since this is the length of a typical module warranty. It may also be about the same as the lifetime of the roofing material itself, especially if you've got a standard composition shingle roof. The 25-year cycle assumes a single inverter replacement midway through the cycle. You can adjust the length of the cycle if you anticipate that your modules and roof will last longer or if you feel that you'll need to replace the modules earlier for any reason. Early replacement might also suggest that the salvage value (variable 14) will be increased as the modules will have some warranty life left.

System productivity (variable 4)—expressed in kWh per kW of system size—is also a major factor. This variable relies on NREL's PVWatts calculator (see http://rredc.nrel.gov/solar/calculators/PVWATTS/version1). This is where the location, module orientation and tilt, weather, shading, and several other site-specific conditions are considered. Explanations and typical values are provided for most of the terms. For the GP calculator, always use 1.0 for the "DC Rating (kW)," since the system size is entered separately as variable 3. Note that "Cost of Electricity" is also already considered. Review and adjust as needed the first 10 "derate factors" according to the specifics of your system. Leave the eleventh one (age) as 1.0, since this is adjusted separately as variable 5 in the GP calculator. If parts of your array will be shaded during parts of the year, you may need to have a shading analysis done for more accuracy. After clicking the "Calculate" button in the PVWatts program, find the "AC Energy (kWh)" for the year. Results may range anywhere from 600 or less to 1,800 or so, depending on the factors.

The rate at which the modules lose productivity each year is included as variable 5. This information is usually on module spec sheets, but if you don't have it, 1% is a reasonably conservative figure.

Although PV systems require little maintenance, it must be accounted for. The biggest cost is inverter replacement (variable 7), which is likely to be needed 10 to 15 years after the system is installed. One replacement at the midpoint of a 25-year life cycle is anticipated. If you are counting on a significantly longer system life cycle, this variable should be increased by about 8% for each year beyond the standard 25 years. The average inverter price, on a per kW basis, can be found at www.solarbuzz.com. If your system is designed already, you can plug in the actual cost of your inverter(s) divided by your system's size in kW.

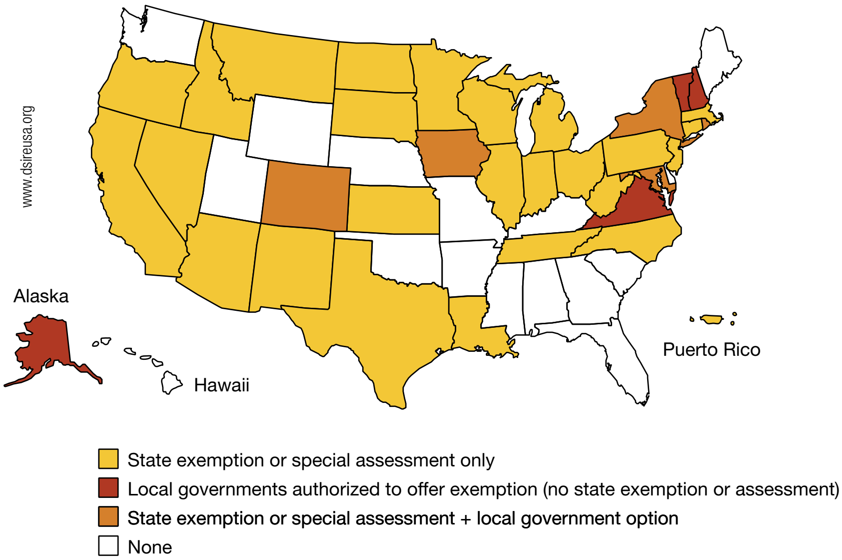
Miscellany. Tree trimming (variable 8) is included for sites where tree shade is an issue. This is simply the cost of having the trees trimmed, divided by the number of years between trimmings. Initial trimming or tree removal, or purchase of solar easements, should be included as part of the original installation costs in variable 2.

Occasional cleaning, plus monitoring and any out-of-warranty maintenance costs, are lumped into variable 9. Rainy areas usually don't need module cleaning. System monitoring can often be set up for free, or nearly so. Many people have no out-of-warranty repair costs, but you might want to set aside a little something for the occasional oddball occurrence. If you're spending your own time on doing any of the above work, you can estimate its value and add that into this variable.

Additional insurance costs (variable 10) should be included since it will now cost more to replace your home in the event of a disaster. Your homeowners insurance company

The cost per kWh may sound small (ranging between 7 cents and 30 cents in 2010), but don't let it fool you—it is a big factor in determining when your PV system reaches grid parity.

Property Tax Incentives for Renewables



In some states, the additional value that the PV system adds to your home may increase your property taxes. Fortunately, several states have eliminated these taxes.

should be able to give you a figure for the cost per $1,000 of additional equipment added.

In some states, the value that the PV system adds to your home may increase your property taxes. Fortunately, several states have eliminated these taxes (see map and www.dsireusa.org).

Finally, we need to subtract the "salvage" value of the PV system at the end of its life (variable 14). It is difficult to guess how much residual value modules will have after 25 years—they may have another 20 years of useful life. However, if module technology has improved greatly, and if their prices have come down significantly by the end of the life cycle, then perhaps rather than a net value, you will have a net *cost* of removing and disposing of them. Fortunately, this is not a major factor in either direction, so a guesstimate of "0" net value is often used here.

An Example Calculation

In my home state (New Jersey), 1 kWh from the grid costs 19 cents, and a 10 kW PV system can be installed for about $5 per watt. Facing anywhere from south-southeast to south-southwest, at tilts that are typical for roofs here (4:12 to 12:12), with no shading, and using equipment with reasonably low derate factors, I could expect to get 1,200 kWh per kW of PV modules. The productivity declines 1% per year and the life cycle will be 25 years. One replacement of the inverter at $715 per kW will add $7,150 in present-value dollars to the cost.

Nearby trees will need to be trimmed once every four years at $600 per trim, or $150 per year, and I've set aside $100 per year for maintenance costs—$25 for my time and water spent on the annual hose-down during pollen season, and $450 for an electrician's visit once every six years (something oddball, like replacing wiring that got chewed on by critters). My insurance costs an additional $1 per year for every $1,000 of equipment I've added, or $50 per year. New Jersey law gives property tax breaks for added PV systems, so that factor is 0%.

I assume that general inflation will be 3% per year and that the cost of electricity will rise at 5% per year—2% faster than general inflation. I assume that at the end of the system's life, my PV modules will be removed and sold for a residual value equal to the cost of removing the modules—i.e., the net salvage and disposal costs are zero.

After plugging the data into the GP calculator, it reports that at the end of 25 years, I would have spent $367 less on the PV system (in present-value dollars) than I would have spent for the same amount of electricity from the grid—just slightly past the apparent grid parity threshold. In this case, the tax credit and incentives available would serve as motivators to switch to solar energy, but would not actually have been needed to pay for any additional costs associated with the switch.

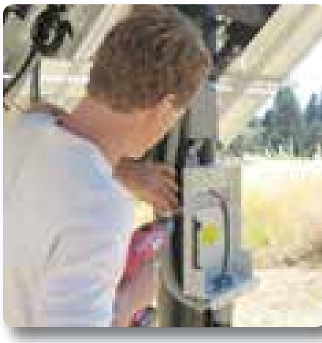
In most other areas, the cost of grid electricity has not yet reached 19 cents per kWh. But grid parity is still being reached in areas across the South and West despite lower grid electricity costs, since PV systems there receive more sunshine, increasing the annual kWh generated per kW installed, which offsets the grid electricity's cost difference.

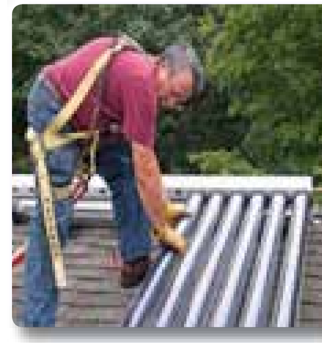
Tax credits and other subsidies help change potential solar sites from being financially marginal to financially viable. This creates demand, helping manufacturers and installers increase their economies of scale, bringing prices down further. Declining solar prices combined with increasing grid energy costs will be opening the solar/grid-parity window ever wider in the years ahead.

Access

Jay Tyson (jaytyson@cjsolarplanning.com) is a solar planner/solar project manager living in central New Jersey.

home power



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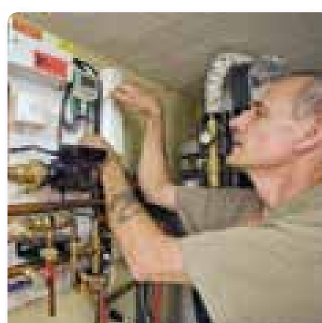


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Saving Water

Take advantage of modern technologies and smart-use strategies to save water.

by Claire Anderson

Whether you're on- or off-grid, household water-saving strategies are a smart idea, both from a resource- and energy-savings standpoint.

According to the U.S. Environmental Protection Agency (EPA), "the average household spends as much as $500 per year" on water and sewer bills. By changing the way water is used, the EPA estimates that the average household could whittle their water expenses by about 30%. The EPA says that if water-saving appliances were used in every household, "more than 3 trillion gallons of water and more than $18 billion per year" would be saved. The benefits are wide-reaching—when individual households use water more efficiently, the need for establishing new water-supply infrastructure and wastewater treatment facilities is reduced.

While those not on community water or sewer systems won't necessarily reap these cash savings directly, they will benefit by decreasing their well-pump run time, saving equipment wear and tear, and helping extend equipment life.

Save Water, Save Energy

A lot of energy is spent to treat and convey water to our homes. According to the EPA's WaterSense program, public water supply and treatment facilities consume about 56 billion kilowatt-hours (kWh) per year to convey water from the source to the sink. In a household connected to a public water supply, letting your faucet run for five minutes wastes about 12.5 gallons and uses about as much energy as burning a 60-watt lightbulb for 14 hours.

Curbing your household water use translates into reduced energy demands in supplying and treating public water supplies, which also translates into less pollution, since most of the energy in the United States is generated with fossil fuels. WaterSense also says that:

- If water-efficient fixtures were installed in just 1% of U.S. homes, 100 million kWh of electricity per year could be saved—cutting greenhouse gas emissions by 80,000 tons, which is equivalent to removing nearly 15,000 automobiles from the road.
- If old, water-wasting toilets in 1% of U.S. homes were replaced with water-efficient models, more than 38 million kWh of electricity could be saved.

The savings could be dramatic, so where should you start?

Starting to Save: Indoors

According to the American Water Works Association, the average U.S. household uses 127,400 gallons of water per year. But where is all this water going?

A significant portion—69.3 gallons per person, per day—is used indoors. The graph (lower left) breaks down household usage by category.

Flushing Toilets. Toilets are the largest water-wasters inside most homes, accounting for about 25% of the daily indoor water use. If your toilet was installed before 1992, it likely uses too much water. Check out your toilet's vintage by lifting the lid and looking at the manufacturer's imprint. Sometimes, the stamp will also include a "gpf" (gallons per flush) value, such as "2.2 gpf," which indicates the amount of water used for each flush.

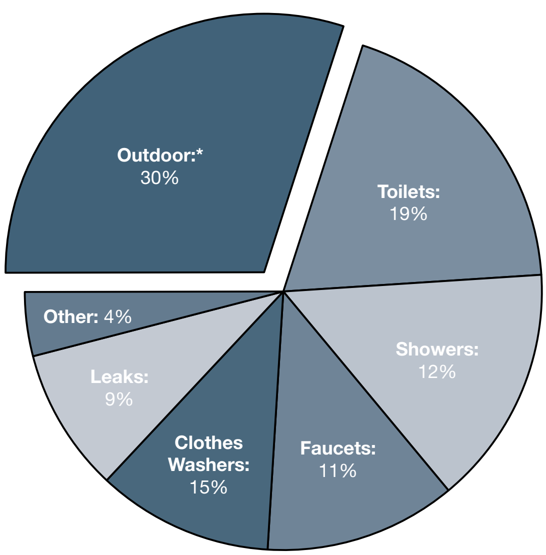
In 1992, federal legislation mandated that all toilets manufactured or imported into the United States be 1.6 gpf or lower. Today, you can do even better—dual-flush units let you select how much water to use, usually 0.8 gpf or 1.6 gpf. For reviews of low-flush and dual-flush models, check out expert plumber Terry Love's forums at www.terrylove.com. Although this is a commercial site, the forums offer insight on models that people love, and ones people love to hate.

If you're not ready to replace your old toilet, there are modifications that can improve its efficiency. The first is a simple adjustment: On some toilets, you can adjust the tank water level by moving the spring clip on the rod that hangs down from the refill valve. This then determines how much water is needed in the tank to shut off the refill valve.

Another inexpensive method is to displace some of the water in the tank with a supplemental bladder or similar device. This reduces the amount of water needed to refill the tank and the amount of water used per flush. At $10 or less, toilet bladders and dams quickly recoup their up-front costs. Of course, your toilet needs a certain amount of water in the tank to flush. You'll have to experiment to strike a balance between adequate flushing and water savings. Note: Do not try to offset water in the tank with items not designed for the purpose—you can easily end up using more water than you would without them or cause damage to your toilet. Commonly used water jugs can move around, getting in the way of refill parts. Bricks may not have that problem, but they can disintegrate into abrasive grit over time, possibly damaging the flapper valve and causing leakage.

Dual-flush retrofit kits are available to make your old toilet more efficient. You'll need to have some mechanical skills to tackle this project, since some of the units involve removing

Average Annual Water Use



*As much as 70%, depending upon region and season.
Source: WaterSense, U.S. EPA

and then reinstalling the toilet tank. For $25 to $50, they are a significantly cheaper option than buying a new dual-flush unit. Plus, you'll avoid putting another toilet in the landfill (though many regions have toilet recycling programs).

A clever toilet-water reduction concept—the toilet-top sink—uses reclaimed hand-washing water for flushing. Upon flushing the toilet, water flows automatically from the sink-top faucet, allowing ample time for hand-washing. The hand-washing water is then routed to the toilet bowl via the overflow pipe. The "light" graywater can then be used a second time—for flushing. Besides reusing water, toilet-top sinks offer a germ-reducing advantage—since water flows from the faucet automatically, there's no need for touching the fixture.

Composting toilets are the most water-efficient of all, since they use no water. They typically consist of a standard seat that empties into a chamber. "Deposits" are usually covered with peat moss, coconut husks, or sawdust to stymie odors and aid in composting. Once full, the chamber contents can be emptied into a separate, outdoor composting bin or buried around vegetation.

If you're handy, dual-flush retrofit kits are a fraction of the price of a new dual-flush toilet, but offer similar water savings.

Courtesy One2Flush

Water that does double-duty: This toilet-top sink routes handwashing water to the bowl via the overflow pipe, where it is reused for flushing.

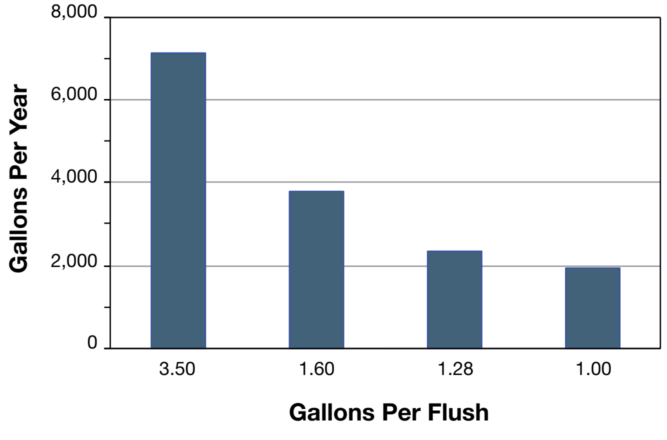
Courtesy Sink Positive

The simplest system is a "sawdust" toilet. Popularized by Joe Jenkins, author of *The Humanure Handbook,* it consists of a 5-gallon bucket, sawdust for cover material, and an outdoor composting bin. When the bucket is full, it is emptied into an outdoor composting bin with other yard and food scraps to finish decomposing.

While most composting toilets don't use water, some commercially produced composting toilets use electricity to run fans or small heaters to evaporate excess moisture. Be sure to check out these requirements before you buy.

In some areas, so long as you have a flush toilet or septic system installed, a composting toilet may be allowed. Check with your local building authority, human health services office, or department of environment.

Annual Toilet Water Usage




© iStockphoto/Dominik Pabis

Front-loading (horizontal-axis) washing machines offer both water and energy savings, compared to a conventional vertical-axis washer.

Washing Clothes. The average U.S. family washes almost 400 loads of laundry each year, according to the U.S. Department of Energy.

After toilets, washing clothes consumes the most water in a typical household. This is mostly due to older vertical-axis machines (commonly known as "top loaders"), which may use 35% to 50% more water than newer horizontal-axis machines.

If your machine is 10 years or older, you may want to consider replacing it for both water and energy savings. Choose a model with a high modified energy factor (MEF) and a low water factor (WF). MEF is a measure of energy efficiency that considers the energy used by the washer, and the energy used to heat the water and run the dryer. More efficient washing machines have high MEFs. WF measures water efficiency in gallons of water consumed per cubic foot of capacity. The lower the WF, the more water-efficient the clothes washer.

You can get a list of Energy Star-rated clothes washers from www.energystar.com. But if you're interested in seeking out higher-efficiency units, the Consortium for Energy Efficiency has developed even more stringent ratings through its CEE Super Efficient Home Appliances Initiative. You can download its list of qualifying clothes washers from www.cee1.org.

Front-loading clothes washers are a bit more expensive than top-loaders, but users will usually recoup the additional up-front cost in a year or so of water and energy savings. Plus,

Dishwashing: By Hand or Machine?

Comparing the efficiency of hand-washing versus using an automatic dishwasher is a difficult, if not fairly impossible task, since it all boils down to user habits. A water-miser who uses one basin for lukewarm wash-water and another basin filled with cold for rinsing may come closest to beating or even exceeding a dishwasher's energy and water use. But most studies and sites conclude that if you run your dishwasher when it's full, a dishwasher is likely to be more efficient.

At the University of Bonn in Germany, one study measured the dish-washing habits of 113 people from seven different countries, and found that water use from hand-washing dishes varied considerably. The study grouped individuals as "superwashers" (the people who preclean, soap clean, and rinse); "economizers," who put soap on a sponge, using as little water as possible; and "carefree" washers, who were profligate water and soap users.

In the study, each person washed 12 place settings. On average, hand-washing used 27 gallons of water and 2.5 kWh of water-heating energy. The automatic dishwasher used approximately 4 gallons of water, and consumed 1 to 2 kWh of total energy, which agrees with U.S. DOE statistics on Energy Star-rated dishwashers' water and energy usage.

Whatever method you use—manual or automatic—here are some tips for saving water and energy when it comes to dishwashing:

- Remove large food scraps before you wash.
- Don't delay, if you're hand-washing.
- Skip pre-rinsing the dishes under running tap water, whether washing them by hand or in a machine.
- Manual dishwashing is best in two sinks: one with hot water and detergent; the other with cold water for rinse.
- Use the amount of detergent recommended by the manufacturer.
- Run your dishwasher with full loads only.
- Use your dishwasher's air-dry feature instead of its heat-dry cycle.
- Use a dishwasher that's fairly new—made in the past few years. Some newer units also have "booster heaters" that heat the water on demand versus from your water heater, helping save energy.

Aerators are an inexpensive, easy retrofit that can provide water savings in a snap.

some utilities and local or state governments offer rebates for purchasing efficient clothes washers to offset higher costs (see the Energy Star website and www.dsireusa.org for more information).

Faucets & Fixtures. The fourth largest household water consumer (behind outdoor use, toilets, and clothes washers) is at the tap—kitchen and bath faucets, and showers. Of course, user behavior is tantamount to water-saving success. Things like shutting off the water while you're brushing your teeth and taking shorter showers are water-saving behaviors that a water-efficient fixture will help, but not shape.

According to the U.S. Department of Energy, federal regulations stipulate that new showerhead flow rates can't exceed more than 2.5 gallons per minute (gpm) at a water pressure of 80 pounds per square inch (psi). New faucet flow rates can't exceed 2.5 gpm at 80 psi or 2.2 gpm at 60 psi. Using these new fixtures can help boost your overall water savings by 25% to 60%.

Showerheads. For maximum water efficiency, select a showerhead with a flow rate of less than 2.5 gpm. Two basic types of low-flow showerheads are available: aerating, which mixes air with water; and laminar-flow, which forms individual streams of water. Laminar-flow showerheads put less moisture into the air compared to aerating ones.

Consider replacing showerheads that are more than 9 years old—before the water-saving standards went into effect. To determine how many gallons per minute your showerhead uses, you can place a bucket—marked in gallon increments—underneath the fixture. Next, turn on the shower at its normal setting. Record how many seconds it takes to fill the bucket to the 1-gallon mark. For instance, if it took 15 seconds to fill the bucket to the gallon mark, your showerhead would have a flow rate of about 4 gpm.

Modern low-flow showerheads include atomizers that deliver water in many small droplets to cover lots of area; pulsators that vary spray patterns; and aerators. Some water-saving showerheads come with valves to reduce or stop the water flow while you're lathering up.

Faucets. Low-flow faucets designed to federal standards may use sensors, as well as aerators, to reduce water consumption. For households, one of the newest innovations is the touch faucet, which allows users to control flow and operation with a quick touch of the faucet.

Fixture retrofits include simple and inexpensive aerators, which screw into the end of the faucet. At $5 to $10, they are an easy, quick retrofit that offers a quick payback. Total flow adaptors can also help save water by easily allowing you to shut off the tap while sudsing your hands or brushing your teeth, for example, while keeping the water temperature setting the same.

Foot controls allow homeowners to activate a faucet at a set temperature by tapping their foot to a pedal (or pedals), which control hot and cold taps. Although they can save water, most units require electricity to operate, however minimal it may be.

Find & Fix Leaks. The EPA projects that 36 states are expected to face varied levels of water shortages by 2013, which makes water conservation essential. It also reports that water leaks "may now account for more than 1 trillion gallons of water wasted each year in U.S. homes." Studies have shown homes can waste more than 10% due to leaks, which costs both you and the environment.

If you're on metered water, you can figure out if your home is a water waster by checking the meter over a two-hour period when no water is being used. If your meter registered that some water flowed during that period, you likely need to track down leaks. Before you start sleuthing, be sure to locate your main water shutoff valve, which controls all of the water coming into your house. Knowing where this is located will be helpful if you locate leaks—you'll be able to determine whether the leak is inside the house or lies before the main shutoff.

- Leaky toilets can account for 95% of all water waste. Defective float arms and flapper valves are common causes of toilet leaks. To see if the float arm is working properly, remove the toilet lid, flush, and listen. The tank should refill and the water should shut off. If it doesn't, you may need to make adjustments to the arm or replace the float. Worn or obstructed flapper valves are another common problem that can cause your toilet tank to drain and refill continuously, and can waste up to 200 gallons per day. You can check for flapper valve failures by adding a few drops of food coloring to the tank water. If there's a leak, you'll see colored water in the bowl within 15 to 30 minutes. First, make sure the chain from the handle to the flapper is not getting in the way of the flapper closing. Then, make sure that the surface of the flapper and its seat are smooth and not obstructed.

Low water-use (xeriscaped) landscapes can be lush and full of color, as this photo of a xeriscaped yard in Colorado shows.

- Leaky faucets are another common water-waster. A worn seat washer may be the cause of a dripping faucet. It can be replaced with a few simple tools. Sometimes, parts for washerless faucets can be difficult to find or expensive, so it may be more cost-effective to replace the entire faucet.

Outside the Home

Most household water use—about 30%—occurs outside the home, and goes toward watering lawns, landscape plantings, and gardens. The EPA estimates that more than 7 billion gallons a *day* are used for these purposes. Some estimates report that up to 50% of commercial and residential irrigation water is wasted, due to evaporation, wind, improper system design, or overwatering.

Irrigation. Most people love their lawns too much, watering too often and for too long. Give your lawn the "step" test: If the grass springs back readily, it can wait awhile for watering. Avoid sprinklers and overhead watering systems—they are big water wasters, losing a lot of water to evaporation.

If you have an irrigation system, check it thoroughly before putting it back in business. It's estimated that, with regular maintenance, watering waste due to irrigation systems could be reduced by about 15%. Irrigation systems can be large water wasters. Inspect your sprinklers and drip sprayers regularly for leaks, and do so during the daytime, when you're not watering. A telltale sign of a malfunctioning irrigation system is soft, mushy spots in your lawn.

Water during the early morning or late evening, when evaporation will be lowest. Consider installing soil moisture sensors, which sense the amount of water in the ground that's available to plants. Sensors can be connected to an irrigation system to automatically water when it's needed.

Lose Your Lawn. Getting rid of your turf—or reducing its size—is one way to drastically reduce your household water use. Consider replacing grass with drought-tolerant and native plants. Once they are established, they'll need little watering beyond normal rainfall. Native plants usually have the added benefit of being more pest- and disease-resistant.

Xeriscaping is the practice of using water-conserving principles in the landscape so that supplemental watering is greatly reduced or eliminated. It includes using drought-tolerant plants and efficient irrigation equipment, such as subsurface irrigation systems or drip irrigation systems; minimizing turf areas; harvesting rainwater; and using mulch and soil amendments to slow evaporation and hold the water in the soil.

Saving the Rain. Beyond water conservation, consider water *harvesting* strategies—ways to keep water on-site and reduce stormwater runoff.

Rainwater H2OG's innovative modular vessels store a maximum amount of water (51 gallons each) in a minimal footprint. Easy connections mean design flexibility and lots of storage capacity.

Rain barrels, which connect to the downspouts of your home, are some of the simplest (and least expensive) rainwater-saving devices. Most barrels are designed to hold 40 to 75 gallons, and prices usually start at $50.

In areas with consistent rainfall, rain barrels can provide some backup water for hand-watering and limited garden watering. Planning for overflows is important, as even as little as 1/4 inch of rain falling on an average-sized house can easily fill two 100-gallon rain barrels.

Rain barrel volume can be determined by calculating the rooftop water yield for any given rainfall, using the following equation:

$$V = A^2 \times R \times 0.90 \times 7.5 \text{ gal./ft.}^3$$

where:

V = volume of rain barrel (gal.)

A^2 = collection area of roof (sq. ft.)

R = rainfall (ft.)

0.90 = system loss factor

7.5 = conversion factor (gal./ft.^{3})

Example: One 60-gallon barrel would provide runoff storage from a rooftop area of approximately 215 square feet for a 0.5-inch (0.042 ft.) rainfall.

$$60 \text{ gal.} = 215 \text{ ft.}^2 \times 0.042 \text{ ft.} \times 0.90 \times 7.5 \text{ gal./ft.}^3$$

For long-term water storage and in areas that receive only seasonal (not year-round) precipitation, larger storage tanks are appropriate. Tanks can be sized using the same formula. For instance, in some parts of Oregon, rainfall is limited to the winter months. For example, one area averages 18.37 inches of precipitation, but most of it (14.87 inches; 81%) falls within a span of seven months. Let's say we're harvesting rain from an average-sized home's roof, in this case, 2,169 square feet, for a little more than half of the year .

Using the formula,

$$2{,}169 \text{ ft.}^2 \times 1.24 \text{ ft.} \times 0.90 \times 7.5 \text{ gal./ft.}^3,$$

we'd be able to collect about 18,154 gallons during that time period—and need some big cisterns to store it all!

Cisterns can be constructed on-site or pre-manufactured in a range of capacities (and prices, depending on the material).

Reuse: Graywater in the Landscape

Graywater (or greywater) is water discharged from bathroom showers and sinks, washing machines, and kitchen sinks. In some areas, this water is permitted to be conveyed separately from toilet water (blackwater), and can be used in the landscape.

If you compost your food scraps, don't use a garbage disposal, and avoid chlorine and other harsh chemicals, you can safely reuse all of your graywater. However, in most areas

Graywater from this washing machine is directed through the movable drain hose to water fruit trees (olive/pomegranate, orange, fig, and white sapote) in the landscape. The drain hose is placed in a different pipe with every load of laundry.

where graywater use is allowed, only subsurface irrigation systems are permitted, preventing users from coming into contact with the water. Untreated graywater should never be stored, as it can quickly become anaerobic and carries the risk of pathogen transmission.

For specific, no-nonsense recommendations for designing and implementing graywater systems, visit Art Ludwig's website at www.oasisdesign.net and read his detailed books, *Create an Oasis with Greywater* and *Builder's Greywater Guide.*

The simplest graywater system that is now allowed in parts of Arizona and California is highly effective and simple. The branched drain-to-mulch basin system routes graywater directly from a washing machine to a filter and then to a pipe that empties into a large basin filled with a thick layer of mulch. Typically, a tree or other planting is established in the mulch basin. More complex subsurface distribution systems can also be used, but at a higher price.

Residential graywater system regulations vary from region to region. Call your county health department, and your local building or plumbing authorities, to determine what systems, if any, are allowed. Locations lacking specific graywater guidelines sometimes allow new systems under an "experimental systems" clause.

A handful of states have rules governing residential graywater systems. If your state doesn't have any rules and you want to pursue a system, consider sharing the Arizona code rules with your permitting agency to start a dialogue, recommends graywater expert Ludwig.

Access

Home Power Managing Editor **Claire Anderson** (claire.anderson@homepower.com) is tackling further water-conservation efforts to optimize her home's efficiency. Planned projects include a xeriscaped garden and a rainwater catchment system.

Heat & Energy
RECOVERY VENTILATORS

The heat recovery ventilator (HRV) and its close cousin, the energy recovery ventilator (ERV), can often make a home more efficient. Find out here what these boxes do and if your house needs one.

by Neil Smith

A heat recovery ventilator (HRV) or energy recovery ventilator (ERV) is an important component for keeping the air fresh in a tightly sealed energy-efficient home.

Homes Need to Breathe

A house built to modern standards of tight construction will allow only a very small amount of outside air to leak in. But fresh air is needed to dilute the products of human habitation (cooking, cleaning, breathing, combustion, etc.), as well as the chemicals that offgas from building materials, such as particle board and paint. According to the U.S. Environmental Protection Agency, indoor air pollution levels are as much as five times higher than outdoors. And good ventilation is an important part of maintaining good indoor air quality.

Dilution and at-source (spot) exhausting are the main methods for ensuring good indoor air quality. It is possible to remove particles (by filtration), volatile organics (by adsorption), and other harmful products from indoor air, but these technologies are energy-intensive and very expensive (think spacecraft and submarines).

Although houses can be designed to "self-ventilate," this process depends upon local climate conditions and wind shading—protection by tall walls and trees—which are not controllable. So the practical choice for many of our homes is mechanical ventilation.

Why not just open the windows? In some very mild climates, this might be a fine strategy. But in most of the United States, trying to ensure adequate air exchange defeats the energy-saving intent of a well-sealed building envelope.

The energy cost of exhaust-only or natural ventilation versus energy recovery ventilation can be easily demonstrated. Take a 2,500-square-foot house with indoor conditions of 70°F and 40% relative humidity, and outside air conditions of 30°F and 50% relative humidity. If we ventilate the house with 120 cubic feet per minute (prevailing wisdom of 0.35 air changes per hour) of outside air (as compared to no fresh air at all), here is how much the ventilation will cost us per month. This is due to the additional heating energy required because of the ventilation.

120 ft.^{3}/min. × 60 min./hr. × (25.3 Btu/lb. – 9.06 Btu/lb.)* × 0.074 lbs./ft.^{3} × 1.25 efficiency × 24 hrs./day × 30 days/mo. × (1 × 10^5 therms/Btu) × $1.50/therm = $116/mo.

*Enthalpy of indoor vs. outdoor air (see psychrometric chart)

If we provide the same amount of ventilation, but instead of using exhaust fans only, we recover the airflows through an HRV/ERV with a recovery rate of 70%, the monthly heating cost drops to $35. An HRV/ERV's only energy input is electricity to run the fans. For this situation, using average residential electricity costs, the monthly cost to run the HRV/ERV would be approximately $12.

The average power draw of an HRV/ERV is 150 watts. If it runs 24 hours a day for 30 days each month, then the monthly energy consumption would be

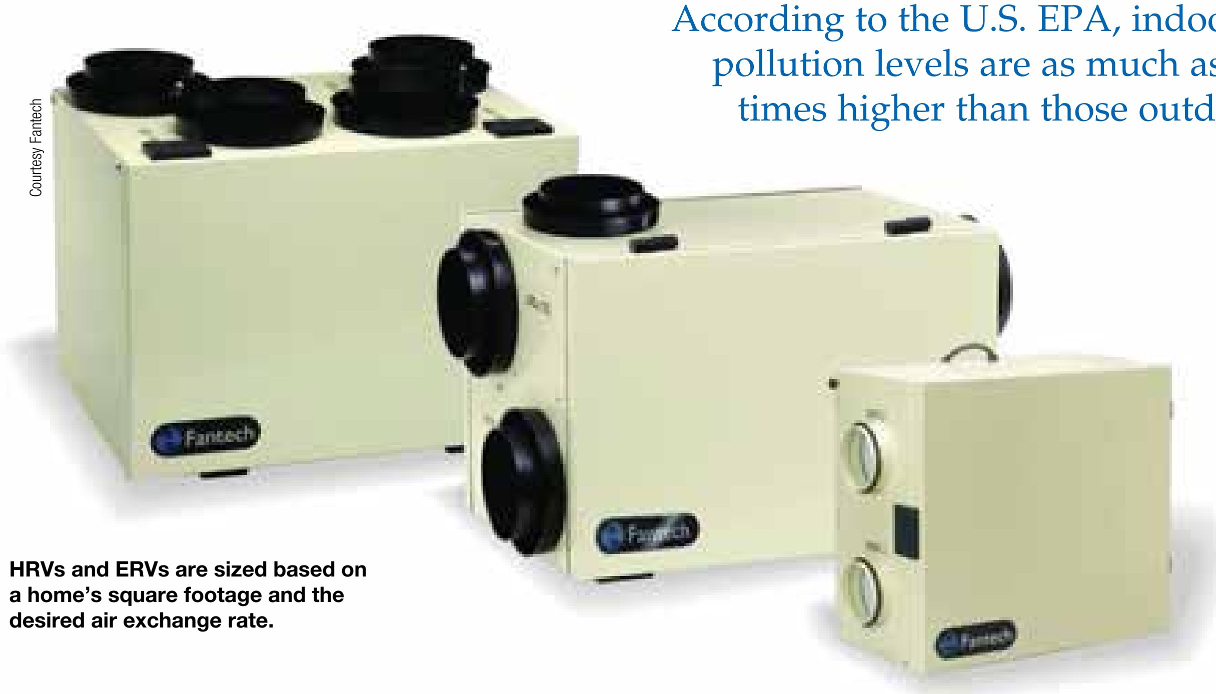
150 W × 24 hrs./day × 30 days/mo. × 1 kW/1,000 W = 108 kWh/month

HRVs and ERVs use a fan to bring in outside air and another to exhaust air, balancing the amount of air in versus out. This air balance minimizes airflow through the building envelope—by reducing the pressure differential between inside and outside. While doing this, they recover energy from the outgoing airstream via a heat exchanger, which allows heat to move between the two airstreams without mixing or cross-contaminating them.

During the heating season, warm inside air is exhausted and pulled through the heat exchanger, while a separate fan brings in cold outside air. The outside air is warmed by the heat of the exhaust air. During the cooling season, the opposite occurs. ERVs take this energy recovery a step further by allowing moisture transfer between the two airstreams.

If heat recovery is such a good idea, why not recover the heat from every exhaust source, like clothes dryers and

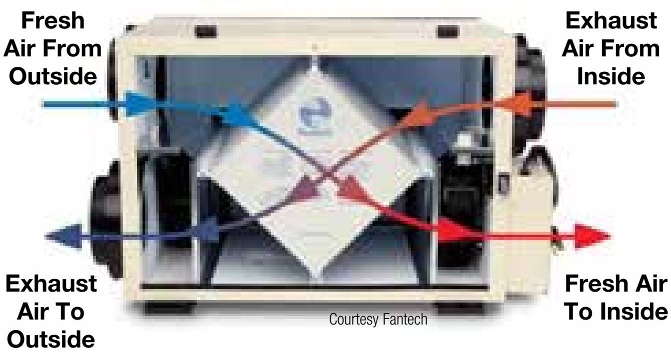
According to the U.S. EPA, indoor air pollution levels are as much as five times higher than those outdoors.



Courtesy Fantech

HRVs and ERVs are sized based on a home's square footage and the desired air exchange rate.

Airflow through HRVs and ERVs transfers heat, while replacing stale air with fresh, functioning in both heating and cooling seasons. (Heating season function shown by flow arrows.)



cook stove hoods? This is definitely not recommended or permitted. Both sources have contaminants in the airstream that will foul the heat exchanger and decrease its efficiency. Furthermore, there are fire risks associated with cooktops and their combustion products. The heat recovery potential from an intermittent exhaust source is negligible, since residential appliances do not continuously run.

HRV/ERVs should be used in any new, tightly sealed home. Most older houses are so leaky that they self-ventilate. Although an HRV/ERV can improve ventilation within a leaky structure, it cannot be expected to save a significant amount of energy, since the unplanned ventilation will still occur.

Assessing Airflow

The purpose of ventilating a building with outside air is to dilute the odors, chemicals, particles, and humidity that are introduced by human activities and offgassed by building materials. If we can also exhaust fouled air at the source, the ventilation system can be more efficient. When the outdoor conditions are right, we can even reduce unwanted humidity by introducing more outside air—typically during the winter.

There are various recommendations for sizing mechanical ventilation systems. An older one called for 0.35 air changes per hour (ACH). Alternate recommendations are based upon a recommended airflow per room. Recommendations vary by manufacturer, but the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), which sets standards for good residential indoor air quality, recommends continuous ventilation of 0.01 cfm per square foot of living space, plus 7.5 cfm per person. So a 1,500-square-foot home with four residents would require 45 cfm.

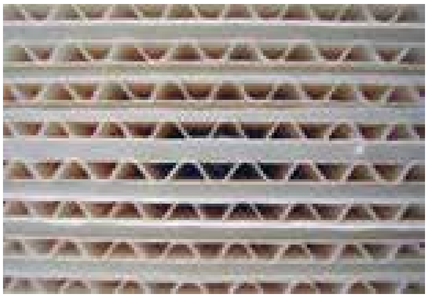
It's difficult to measure indoor air quality without expensive tests. Rigorous testing would consist of air sampling and analysis by a laboratory. However, a "smell test" can provide at least the first level of measurement. Since our olfactory system readily acclimates itself to new odors, it's important to "test" the air after being out of the house. However, with lower occupant density (bigger houses), bioeffluent (contaminants generated by the human body) effects are diluted, and we must ventilate to reduce common pollutants (such as formaldehyde found in some building materials) that may not be detectable by the human nose.

Many ventilation codes are minimums, based upon ASHRAE standards. Each code or standard will yield different airflows, but none take into account building materials that may offgas more than others, nor outside air quality, which can vary depending on your locale (local outdoor pollution). To help ensure the best indoor air quality, it is prudent to size airflow liberally—using the standard that results in the most air exchanges. Most HRV/ERVs have multiple speed settings, so airflow can be easily changed as needed.

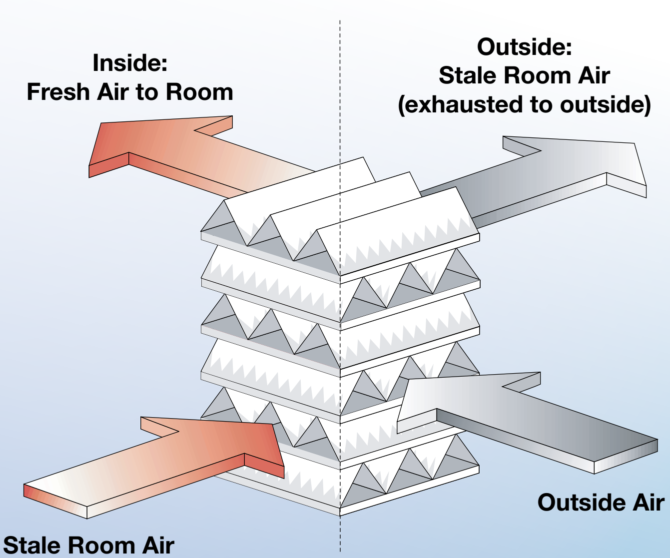
Unknowns include what the inhabitants do. Since airflow recommendation minimums are largely based on occupant loads, a sparsely populated house will likely require more ventilation for building material toxins. A house full of people who cook, bake, and take lots of showers will have its ventilation requirements set by the need to reduce humidity and carbon dioxide. The standards are minimums, so size your system generously.

Before designing whole-house ventilation, remove contaminants at the source (spot exhaust ventilation) with

A closeup of the air-to-air heat exchanger core.



Courtesy Soler & Palau USA (2)



Dealing with Wintertime Dryness

The air inside most houses is drier in the winter because homes are leaky. Cold air has very little capacity to absorb moisture. Take a situation where the outside air is at 40°F with a relative humidity of 50%. As that air moves into your house and is warmed to 70°F, its relative humidity changes to just 16%. How did that happen? The actual amount of moisture in the air did not change. This is reflected on the Y-axis of the graph labeled “Humidity Ratio: Grains of Moisture per Pound of Dry Air.”

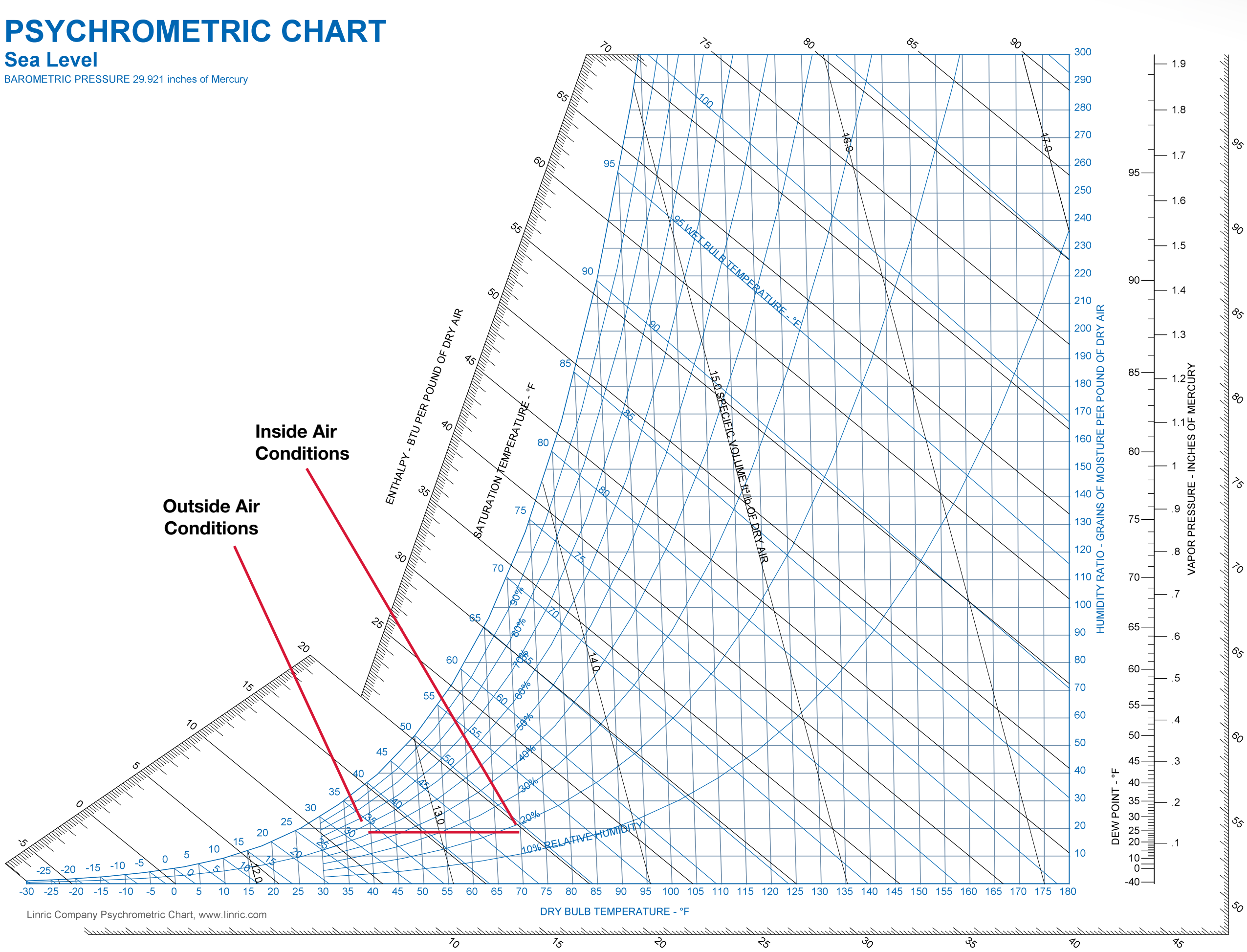
The term *relative humidity (RH)* is a percentage of how much moisture the air could hold at saturation (for example, right before it rains). Dew point is the temperature to which the air must be cooled for condensation to happen, or in other words, 100% relative humidity. This is best illustrated by a psychrometric chart.

The type of heating system does not affect a home’s RH levels. Hydronic (hot water) or hot air systems will not “dry the air out.” With few exceptions, these are closed systems and do not add or subtract humidity from the building air.

On the other hand, a very tight house without outside air ventilation may end up with moisture issues, such as condensate on windows and doors. This is because in the absence of any significant outside air entry into the building, moisture levels increase in what is effectively a closed system. Condensation occurs when the temperature of a surface is below the dew point of the air. Typically, this happens on windows, since they have the lowest thermal resistance and therefore are the coldest surfaces.

Room condition No. 2 shows the air temperature at 70°F and 50% RH. To illustrate the dew point of this air, a horizontal line is drawn to the left until it intersects the 100% RH curve. This shows that the dew point is about 50°F. So a surface at or below 50°F will have condensation on it from moisture in the air.

Psychrometric charts show the properties of air and water mixtures for the conditions that we encounter in our environment. This chart shows two conditions: cold outside air entering a house and the effects of heating that air.



fans over kitchen ranges and in bathrooms. Allow enough ventilation for peak loads. Bathroom ventilation should be sufficient to avoid condensation on surfaces at any time. Kitchen ventilation must have enough draw to capture the majority of smoke and odors at the source. Continuous low-level ventilation that is "good on average" won't be suitable.

Make sure the ventilation systems are quiet—otherwise occupants will only use it under the most extreme conditions. HRV/ERVs cannot be expected to handle the peak odor, smoke, and humidity loads from bathrooms and kitchens. Direct-mounted fans or in-line fans, which are acoustically preferable, should be used.

HRV or ERV?

The decision of whether to use an HRV or ERV can be confusing. Traditional wisdom suggests ERVs in climates where there is a significant mechanical cooling needed and dehumidification is required, such as in the Midwest, in the eastern United States, and the Southeast. During summer, it's desirable to retain the coolness and the aridity of the inside air. Moisture and heat from incoming outside air is transferred to the exhaust airstream, and the ERV becomes a *cool* recovery ventilator.

Well-sealed houses in heating-dominated climates can experience high indoor humidity levels. Therefore, HRVs are recommended, since additional moisture isn't usually desired.

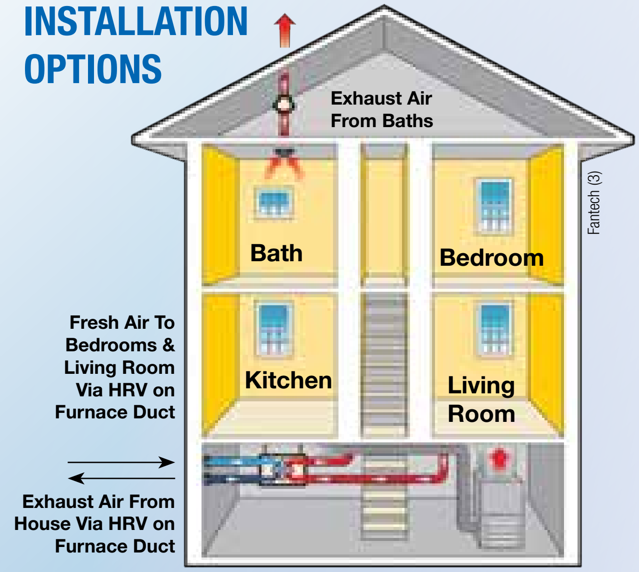
ERVs take the process of recovering energy in the exhaust air one step further. Besides capturing the sensible heat (energy used to raise or lower the temperature) of the air, an ERV transfers latent heat—the energy that is used to add or subtract moisture from air. Typical examples of this are dehumidification and humidification. The ERV recovers the latent heat by allowing moisture to travel across its core. Similar to heat flow, the path is from high humidity to low humidity.

A situation in which an ERV is more useful than an HRV would be energy recovery during the summer months. Your

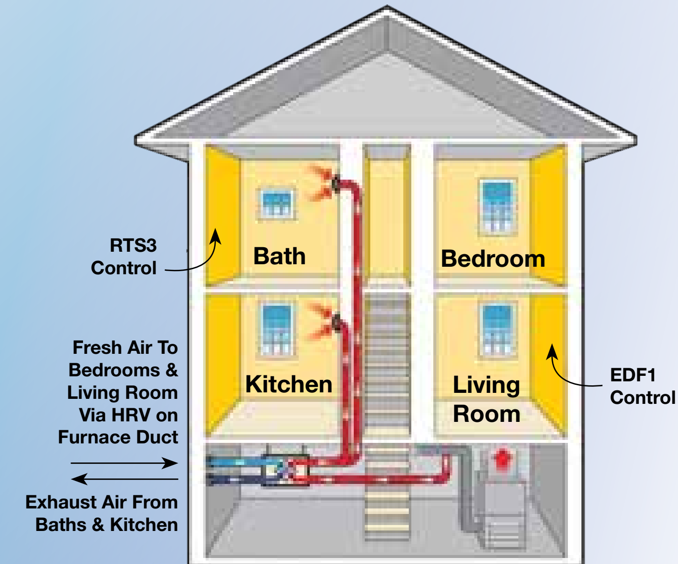
Ways to Improve IAQ

- Reduce the release of pollutants
- Use nontoxic, natural cleaning products (vinegar and baking soda, for example)
- Use and store paints, stains, and glues outside of the home
- Do not smoke
- Make sure your gas and wood-burning appliances are properly vented
- Make sure you have proper spot-ventilation for cooktops and stoves, and in bathrooms

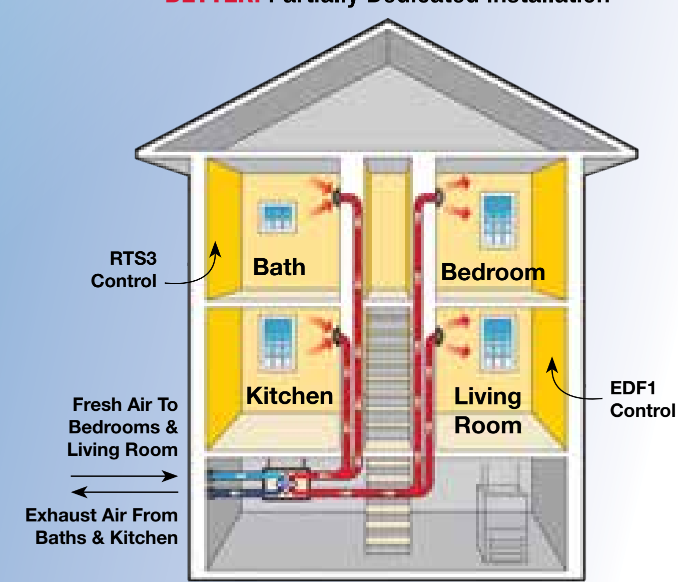
INSTALLATION OPTIONS



GOOD: Simplified Installation Using Existing HVAC Duct and Premium Bath Fan

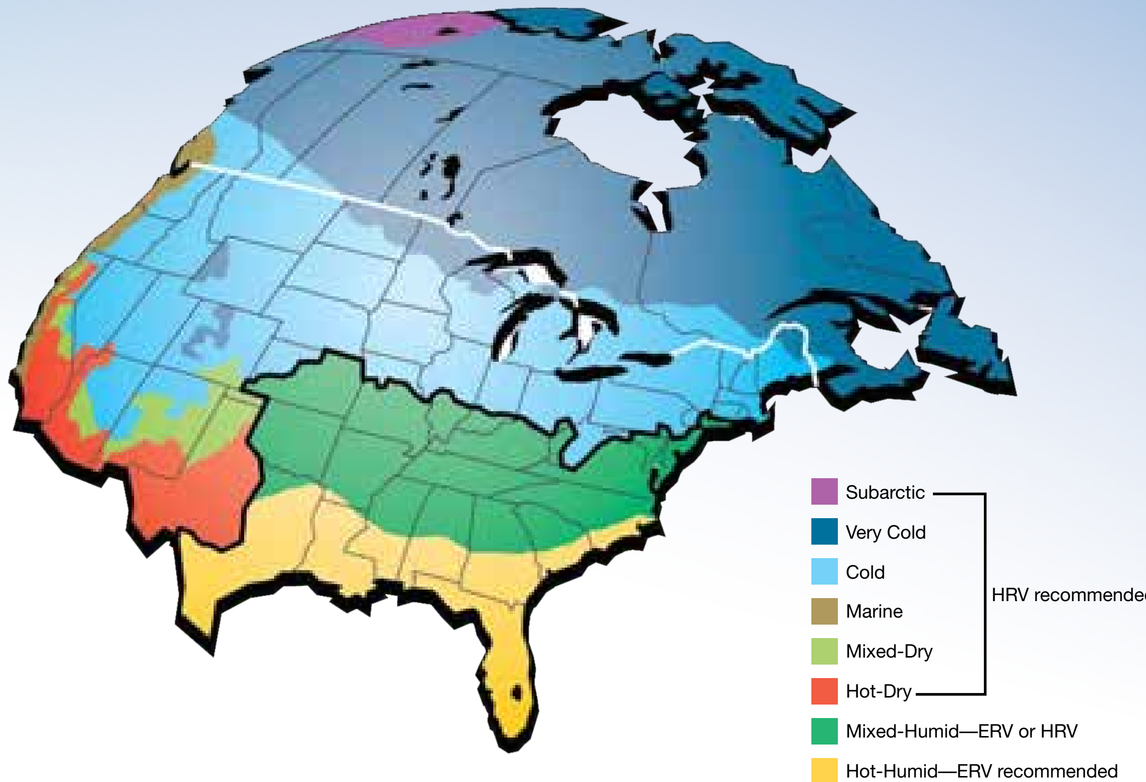


BETTER: Partially Dedicated Installation



BEST: Fully Dedicated Installation

Climate Zones for HRVs & ERVs



Courtesy Fantech

air conditioner has worked hard to dehumidify the inside air. The outside air is hotter and more humid than the inside air. As the ERV exhausts inside air and brings in outside air, two processes are at work. The outside air transfers some of its sensible (temperature) heat to the exhaust air, since the exhaust air is colder. At the same time, the outside airstream transfers some of its moisture to the exhaust airstream. In this way, the air exiting the ERV is cooler and less humid than the outside air. You could call this a "cold recovery" and "arid recovery" unit.

If ERVs do all that HRVs can, then why not always use ERVs? The heat and/or moisture exchanger is typically referred to as the "core." It's more difficult (thus more expensive) to fabricate an ERV core, which exchanges moisture as well as heat. Also, since these cores are moisture-permeable, they do not have the longevity of the plastic or aluminum HRV (heat-only) cores.

Configuring the System

Combining the HRV/ERV system with the existing air distribution system may be the only alternative for existing homes. Depending upon the design, the furnace or air-handling unit may have to run in conjunction with the HRV/ERV, which could add considerably to energy usage. For homes that rely on a central air heating/cooling system, the method I prefer is to run every piece of ducting to the HRV/ERV. This means that the duct arrangement looks like an octopus—although it's not elegant on the surface, the advantage is that the flow to/from intake or supply grilles can be controlled from a central location, with more precision. Oversize the legs and add a balancing damper (a manually operated butterfly damper) to each. Choose oversized insulated flex duct to minimize pressure drop and keep the system quiet. The grilles should be generous to reduce air noise.

The outside air ducts (exhaust and intake) should be separated by several feet to prevent cross-contaminating the airflows. Place the outside air intake high enough above grade, so that the HRV/ERV isn't bringing in excess humidity or dirt and dust or be blocked by snowfall, and locate it away from exhaust vents.

Another option is to run a dedicated duct system for the HRV/ERV. This arrangement may be the only choice for houses without other air distribution. A technique that I favor is to pull exhaust air from one or more bathrooms. The HRV/ERV is sized so that it runs continuously, but at a low speed, and can be speeded up from a bathroom-mounted override switch. Each bathroom should have at least 75 cfm (preferably 100 cfm) of airflow to allow for peak exhaust requirements. Using an HRV/ERV with bathroom air input will eliminate the need for bathroom fans and provides balanced ventilation. Otherwise, ventilation will not be controlled.

Some advanced technologies offer further efficiency improvements, such as a defrost function. Although more expensive, they may be appropriate, depending upon the building requirements and the efficiency goal. In conditions of severe cold, HRV/ERVs may require defrosting. This situation occurs when very cold outside air brings the temperature of the exhaust air down so far that the moisture in the air condenses and freezes. The frost level will eventually build up and block airflow. Manufacturers address this in one of two ways. The simple method is to turn off the fresh air fan for a few minutes. In this way, warm inside air remains warm, flows through the HRV/ERV, warms the core, and thereby defrosts the unit. A more sophisticated method uses a fifth port and a series of operable flaps. This method forces inside air through the core and back to the house. This method is recommended in climates with severe cold, since less heat is wasted. One manufacturer claims that its ERV does not require a defrost cycle due to the efficiency of its moisture transfer.

Units with electronically commutated motors decrease the full load power by about 30%, and can reduce part load power consumption by about 75%. Such units are appropriate where the HRV/ERV is the sole source of ventilation and must run continuously.

Typically, most existing houses are so leaky that an HRV or ERV is pointless. For new construction, the installation cost of an HRV/ERV is not much more than the cost of the equipment ($550 and up), so long as the duct runs and installation are planned from the beginning.

Properly applied, HRV/ERVs are a great way to improve indoor air quality by introducing outside air, while recovering much of the energy in exhaust air. Although there is a higher capital cost compared to simple exhaust fans, the HRV/ERV system will save energy (and money) over the long term, while providing a quieter, healthier indoor environment.

Access

Neil Smith (neil@hvacquick.com) is a professional mechanical engineer. Neil's interests include HVAC and energy efficiency, and he currently runs the AirScape whole-house fan company.

HRV/ERV Sizing Calculator • www.hvacquick.com/sysbuilder/hrvbuild.php

Residential HRV/ERV Manufacturers:

Carrier • www.residential.carrier.com

Fantech • www.fantech.net

Lennox • www.lennox.com

Nu-Air • www.nu-airventilation.com

Soler & Palau USA • www.solerpalau-usa.com/res_rv.html

UltimateAir • www.ultimateair.com

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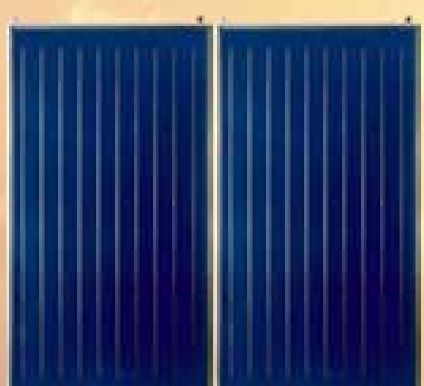

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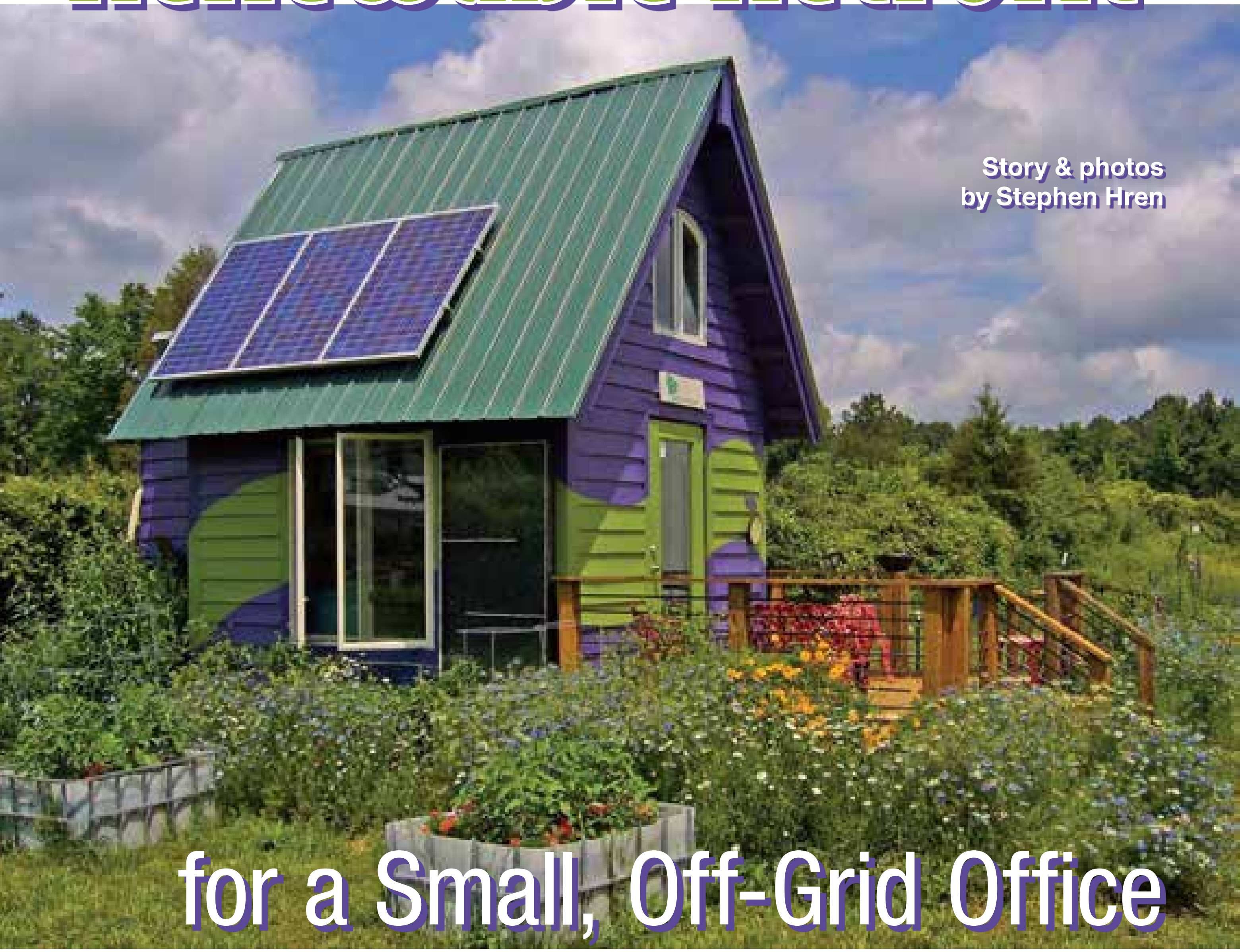
Renewable Retrofit for a Small, Off-Grid Office

Story & photos by Stephen Hren



The Abundance Foundation's PV-powered, solar-heated, off-grid office.

When you think of the word "office," what usually comes to mind is a sterile cubicle in a large boxy building surrounded by a parking lot, totally dependent on fossil fuel infrastructure for its existence. But when you're a nonprofit organization like The Abundance Foundation (TAF) in Pittsboro, North Carolina—educating people about sustainability through workshops, green tours, and local food and renewable energy events—residing in such sterile surroundings goes against your mission. You want to create an "office of the future."

Building Renovation

The group was starting to feel cramped in the existing space, an office shared with Piedmont Biofuels—a local biodiesel cooperative (see *HP122* and *HP132*) that was expanding and needed to occupy more of the converted warehouse for its own employees. TAF employees imagined an office that would help showcase the organization's commitment to sustainability—something beautifully crafted using locally sourced lumber, powered by renewable energy, and situated on the edge of the organic farm that surrounded the property.

As luck would have it, a 10- by 12-foot screened-in sleeping shed, intended to house summer interns for the organic farm, was sitting unused. TAF moved the building close to the existing quarters so the staff of three could use the kitchen and bathrooms in the adjacent structure. The small building was large enough for an office, yet small enough to make heating and cooling relatively easy. TAF hired local designer-builder Green Door Designs (GDD) to retrofit the small structure for year-round occupancy. GDD built the block foundation, and used local, Forest Stewardship Council-certified lumber to build out the frame.

TAF's three work stations, designed with forethought and attention, use a scant 1.8 kWh per day.

The small office was wired for AC, then spray foam insulation was added to the beefed-up frame (2 by 4 walls; 2 by 6 roof rafters) to create a tight building envelope with a higher insulation value than conventional fiberglass insulation (about R-6 per inch). The floor received a few inches of spray foam and was also covered in reflective foil. Recycled doors and windows, purchased from a Habitat for Humanity reuse store, were installed. Unfortunately, the energy labels on these windows were missing, which led to incorrect assumptions about their passive solar capabilities (see "Window Shopping" sidebar). The interior was finished with locally milled pine bead-board, making the structure drywall-free. GDD also built an accessibility ramp and a loft for storage. They then protected the structure with a colorful paint job using zero-VOC paints purchased from the local building supply store.

Spray foam provides gap-free insulation for the old structure.

Courtesy The Abundance Foundation

Window Shopping

One crucial mistake was not paying enough attention to the coatings on the double-pane windows. The windows were purchased new at a reuse center but no longer had the National Fenestration Rating Council (NFRC) sticker on them, leaving us "in the dark" about their transmittance characteristics. Once I stood inside, in front of these windows on a sunny fall day, the lack of warmth coming through clued me in that the low-e coating was hobbling the passive solar gain of the small cabin.

While the south-facing wall had almost 43 square feet of solar collection area for the interior space of 120 square feet (or roughly 35%; well above a 7% to 10% ratio of collection area to living area), most of the window area was barely adding to the heat gain. Given that the wall space occupied by the windows was of a substantially lesser R-value than the surrounding walls and thereby losing much more heat, the total contribution of the windows to heat gain was probably a wash.

Passive solar heating won't work if window coatings are keeping the sun out. So be sure to check out the NFRC label carefully. Any window being installed for passive solar must meet the following criteria:

- Have a solar heat gain coefficient (SHGC) greater than 0.60
- Have a U-factor of 0.35 or less
- Have a visible transmittance (VT) greater than 0.65
- Be certified by the NFRC

With a little attentive load management by the staff, 510 W of PV modules provide all the electrical energy for the little office.

Energy Retrofit: PV System

The group wanted to use solar electricity and as much supplemental solar heating as possible. They drafted board member and PV expert Rebekah Hren to help design and install the solar-electric system, and asked me to help with a solar air heater for space heating. Keeping to their educational mission, the staff turned the installation of both systems into workshops.

One decision TAF faced was whether to tie the PV system to the grid or to go with an off-grid battery-based system. If the staff wanted to create an "office of the future," then tying into the grid would make sense. Grid-tied systems are less expensive, require less maintenance, and send any excess renewable electricity out to the grid. But grid-tied systems require access to the grid and extra paperwork that can make their implementation more onerous initially. Running the additional wiring from the existing building to tie it to the grid proved too expensive for such a small space. Since there were few examples of off-grid systems in the area, and learning about off-grid solar has more appeal to the DIY crowd that routinely signs up for TAF workshops, the staff decided on an off-grid system.

The office has only a few loads, so sizing the system was straightforward. A few laptop computers, a ceiling fan, lights, printer, and a wireless router are the primary loads. Rebekah interviewed the office staff about what loads they needed and expected to run (how many laptops, printer, router, etc.), and sized the system accordingly with a system sizing spreadsheet.

A DC distribution panel, an OutBack 60 A charge controller, and a MagnaSine 2 kW inverter round out the power system.

On a weekend in November 2009, Rebekah and I ran simultaneous workshops to install the off-grid PV system and the solar air heater. With almost 30 people attending, it was a little crowded around the small cabin, but we managed to get everything done.

The PV system consists of three Evergreen ES-170 SL modules totalling 510 W. The modules are wired in series, for a maximum output of 76 V. An OutBack MX60 charge controller steps this voltage down to 12 V for the MagnaSine 2,000 W inverter/charger and the battery bank, which consists of two 6 V Trojan L16E-AC batteries wired in series. Key was making the system components as accessible as possible for future workshops where the system will be disassembled and reassembled. The battery box, inverter, and DC panel are all located in a small, weather-tight enclosure on the outside of the building.

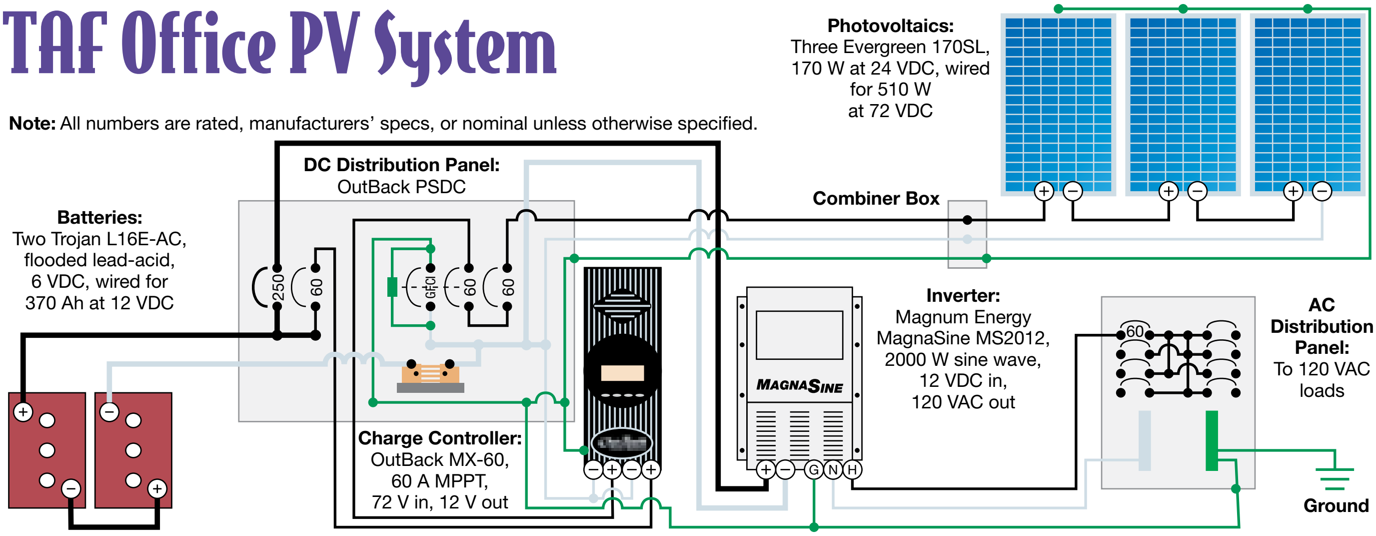
A TriMetric meter keeps track of the battery bank's state of charge, and the office staff were all given instructions for how to work in an off-grid environment. There is no backup generator, and if there are multiple days of clouds—and with little PV charging—the office staff implements load management to keep the battery bank healthy. It has proven

System Loads

Load	Watts	Hours per Day	Days per Week	Avg. Daily Watt-Hours
Lights	25	6	5	107
Fans	100	8	5	571
Computers	80	8	5	457
Printer	200	1	5	143
Wireless router	15	24	7	360
			Average Total Daily Load	1,638

TAF Office PV System

Note: All numbers are rated, manufacturers' specs, or nominal unless otherwise specified.



Tech Specs

Overview

System type: Off-grid, battery-based PV

System location: Pittsboro, NC

Solar resource: 4.71 average daily peak sun-hours

Production: 44 AC kWh per month

Photovoltaics

Modules: 3 Evergreen ES-170 SL, 170 W STC, 25.3 Vmp, 6.72 Imp, 32.4 Voc, 7.55 Isc

Array: One series string, 3 modules per series string, 510 W STC total, 75.9 Vmp, 6.72 Imp, 97.2 Voc, 7.55 Isc

Array combiner box: A Ready Watt pass-through box transitions wiring from USE-2 input from PV modules to THWN-2 output

Array disconnect: OutBack 60 A OBDC breaker (plus 60 A ground-fault protection breaker)

Array installation: Direct Power & Water Power-Fab rail installed on south-facing roof, 45° tilt

Energy Storage

Batteries: 2 Trojan L16E-AC flooded lead-acid, 6 VDC nominal, 370 Ah at 20-hour rate

Battery bank: 12 VDC nominal, 370 Ah total

Battery/inverter disconnect: 250 A breaker

Balance of System

Charge controller: OutBack MX-60 A, MPPT, 76 VDC input, 12 V nominal output voltage

Inverter: Magnum Energy MagnaSine MS2012 sine wave, 12 VDC nominal input; 120 VAC, 2,000 W output

System performance metering: Bogart Engineering TriMetric meter & Magnum ME-RC50 remote control inverter meter

relatively easy to keep the system fully charged, since the office is closed at night and on the weekends, and loads are switched off then. One of the staff members has been instructed in how to safely water the flooded batteries on a regular schedule, and she checks them monthly and adds distilled water when necessary, taking the appropriate safety precautions.

Two Trojan L16E-AC batteries provide 370 Ah of energy storage.

A Bogart Tri-Metric battery monitor and the Magnum Energy remote display keep track of system performance.

Active Solar Heating Retrofit

The Piedmont area of North Carolina has a relatively mild climate overall, but winters get cold, with about 3,000 heating degree days on average. TAF hoped to provide for as much of their heating needs as possible using the sun. GDD had previously added two casement windows to the south side of the small building to capture some solar gain in winter, but there was room on the south-facing wall for additional solar gain, and TAF wanted to demonstrate both passive and active solar heating.

Passive solar heating is accomplished by installing windows with appropriate solar heat gain values in a south-facing wall, with thermal mass (usually stone or concrete) to absorb and store the resulting solar gain. A roof overhang (or other shading) of the appropriate depth allows the winter sun in, but helps block unwanted sun in the summer. A well-designed passive solar home is attractive and functional, with significantly reduced need for mechanical space heating. Plus, it has the additional benefit of eliminating or reducing the need for artificial lighting during the day. The drawback is that, during the night, when temperatures plunge, heat can be lost through the glazing.

Active solar air heaters are generally inexpensive, can be easily added to an existing building's south-facing wall, and only operate when the sun is out (and hence don't lose heat at night or during cloudy weather). The drawbacks are that they can be less aesthetically appealing than a passive solar designed space, they do not have heat storage, and they don't contribute to daylighting.

The first decision TAF had to make was whether to purchase a premanufactured solar air heater or to build one from scratch. DIY solar heaters can be made inexpensively, and can incorporate recycled or reused materials. Premanufactured solar air heaters are likely to be more durable, quicker to install, and may qualify for federal and state incentives that can make them as inexpensive as homemade ones. For many incentive programs, the collector must be rated by the Solar Rating and Certification Corporation (SRCC).

Above: The homemade 3- by 6-foot hot air collector augments space heating.

Left: A 30 W PV module, mounted vertically for the low winter sun, directly powers the hot air collector's circulation fan.

The staff decided on a DIY heater so workshop participants could get hands-on experience with building one—and understand in detail how they function. Because access to the wiring inside the building was limited by the spray-foam insulation, we decided to power the heater's DC blower with

Left: A backdraft damper vents warm air into the office space from the top of the collector, but prevents reverse convection at night or during cloudy weather.

Right: The DC circulation fan draws cool room air into the bottom of the collector. Powered PV-direct, the air flow is proportional to the amount of sun.

Fiberglass insulation forms the back layer of the collector, preventing unwanted heat transfer into the space during the summer, or outwards at night or during cloudy periods in the heating season.

a small PV module. A DC fan, powered by the module, pushes air from the interior of the room into the bottom of the heater. As the air flows through the heater, it warms and returns into the room from the top of the heater. A wall-mounted heater is ideal because having the inlet and outlet heights far apart promotes air circulation, which is more difficult to do with a roof-mounted unit.

Baffles in the heater slow the air and create turbulence for better heat exchange between the collector's hot interior surfaces and the air. A backdraft damper at the top of the heater keeps air from flowing into the heater when there is not heat to be gained. The design assumption is that if there is enough sun on the PV module to run the fan, then there is enough heat in the box to make it worthwhile to move air. The PV module must be placed so that it has solar access at the same time as the air collector, so it is mounted on the same wall. The more sunlight that is on the PV module, the more power goes to the blower, so more air is moved through the heater. A switch can turn off the blower if heat is not needed.

There are a myriad designs for a DIY solar air heater, and we chose a simple, 3- by 6-foot rectangular box. We sheathed one side of the 1-by-4 frame with $^{1}/_{2}$-inch plywood. Inside the box, we put in some 1 by 2s for baffles and fiberglass

A black aluminum sheet acts as the absorber plate, converting sunlight to heat. The collector will be covered with Lexan glazing.

TAF Off-Grid Office Costs

PV System

	Cost
3 Evergreen PV modules SL 170 W	$1,797
Magnum MS2012 inverter, 12 V, 2 kW	1,320
2 Trojan L16E-AC batteries, 6 V, 370 Ah	540
Rough wiring & labor	350
PV mounts (combination of DP&W & UniRac)	330
Shipping	260
AC breakers & box, incl. labor	250
OutBack PS2DC breaker box w/ GFP (used)	250
OutBack MX60 charge controller (used)	225
Ready Watt MC cable to wire Pass-Thru box	180
Misc. boxes, breakers & cabling	173
TriMetric TM-2020 battery monitor w/ shunt & cable	171
Misc. conduit & hangers	168
Inverter battery cables 4/0, 10 ft.	150
Magnum ME-RC50 remote inverter control	140
Battery interconnects	138
Battery box misc.	75
OutBack remote temp. sensor w/ cable	24
Total PV System Cost	$6,541

Solar Air Heater (see the article on page 112)

Total Solar Air Heater Cost	$610

Building

Purchase structure	$4,500
Labor	4,330
Deck, ramp & rail materials	2,654
Interior paneling	1,665
Foundation, concrete block & labor	1,500
Concrete sidewalk	1,317
Spray-foam Insulation	1,100
Exterior paint job	825
Engineering for building	600
Floor finishing	503
Backhoe work	424
Engineering for deck & ramp	300
Breaker box, ground rods, other electrical	270
Building permit	245
Engineer-required framing	245
Battery closet materials	210
Exterior commercial door	165
Rough-in wiring	100
Total Building Cost	$20,953
Grand Total Project Cost	$28,104

TAF staff—Camille Armantrout, Tami Schwerin, and Jamie Kozlowski—love their energy-efficient and energy-independent office.

batt insulation. A matte-black, prepainted sheet of aluminum serves as the absorber plate, which sits on top of the baffles. A clear acrylic sheet serves as glazing.

The Proof is in the Performance

A year and a half later, the little office has performed admirably. Powering all of the electronics with the PV system has not been a problem, and the solar air heater helps keep the building warm on sunny winter days, typically raising the interior temperature by 10° to 15°F. On colder, cloudier days, a small auxiliary propane heater is needed. During our hot, humid summers, the building is excessively warm, so some kind of air conditioning, if not necessarily required, would make the space more comfortable (although this would probably overtax the existing PV system). Keeping the batteries full has not been a problem, but requires a bit of mindfulness on the part of the TAF crew, like using a power strip to shut off phantom loads at the end of the day; using laptops instead of desktop computers; and using efficient fans and compact fluorescent bulbs. While there are still kinks to work out, the workers at TAF are happy to occupy a small part of a renewable future.

Access

Stephen Hren (stephenhren@gmail.com) is a builder, teacher, and author focusing on sustainable design. He is the author of the upcoming book *Tales from the Sustainable Underground* and coauthor of The *Solar Buyer's Guide for the Home and Office* and *The Carbon-Free Home.*

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Understanding PV Module Specifications

by Rebekah Hren

Courtesy SolarWorld USA

Specification sheets are readily available from manufacturers and distributors for the thousands of PV modules on the market today. Spec sheets—or cut sheets—serve as marketing material for the manufacturers, but also contain a large amount of technical information necessary for PV system design—and for choosing which module serves an application best.

A module spec sheet needs to be thoroughly investigated to ensure compatibility before purchasing any PV system equipment. Once a module has been chosen, be sure to follow the complete manufacturer's installation instructions, which are separate from the spec sheet. This article defines and explains the pertinent technical data listed on a spec sheet.

The Marketing

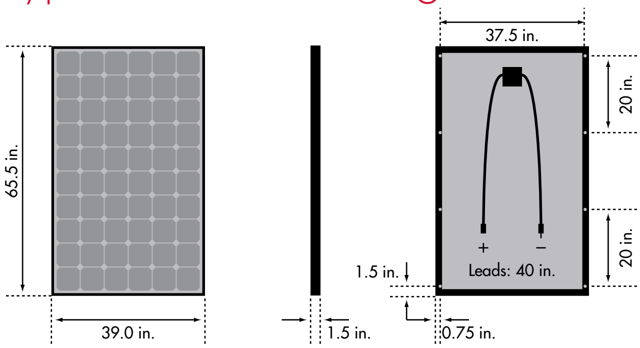
Spec sheets usually start off with a few glossy pictures and advertising about the module's quality, efficiency, or a special design aspect. This is just marketing, surrounding the technical data the spec sheet delivers. Not every spec sheet follows the same layout, but at minimum, the sheets contain electrical and mechanical data.

Mechanical & General

Dimensions

Given in inches and/or millimeters, a module's size determines how many can fit in a given space, whether on a roof or on a ground- or pole-mount. If rack information is also known, the number of rows and each row length can be determined, based on the space intermodule clips add between modules (typically 1/2- to 1-inch per gap). Many manufacturers will also diagram the appropriate rail positioning for their modules, such as how much of the module can overhang the rails, and whether rails can cross the module in a landscape or portrait orientation or both. Be sure to follow the complete manufacturer's instructions, as required by the *National Electrical Code* [110.3(B)].

Typical Technical Diagrams



Technical diagrams identify module dimensions and other important details, like the location and size of mounting holes, grounding points, and lead wire length.

Area

Simply width times length, the area of a module is useful for checking power density (watts per ft.^{2}). The total module area can be used along with site-specific data to calculate wind uplift forces and thus lag bolt requirements, or to calculate weight loading on a structure.

Thickness

The frame thickness determines what rack components to use, like slip-in racks, or the required size of end and intermodule clips. Typically, thicker frames result in sturdier, although heavier, modules.

Weight

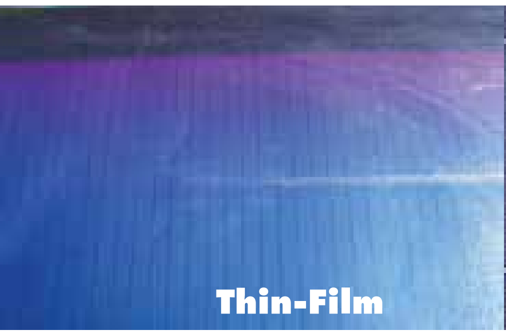
Most permitting authorities will ask for basic structural engineering data for roof-mounted PV arrays, and there will be a limit to the weight that can be added to a roof structure. Module weight, rack weight, and engineering data will restrict the quantity of PV modules that can be installed. Crystalline, glazed modules with plastic backsheets typically weigh about 3 pounds per square foot.

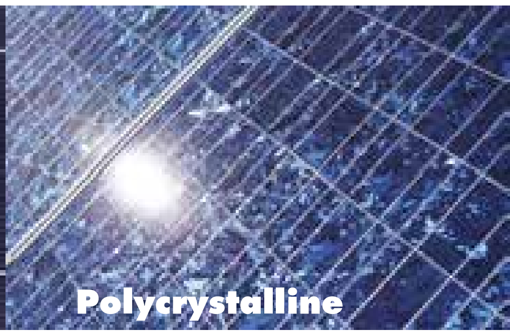
Many jurisdictions allow PV modules to be installed on pitched residential roofs without a professionally engineered design, as long as there is only one layer of existing roofing material present.

Cells

Cells will be either monocrystalline, polycrystalline, ribbon silicon, thin-film, or even multiple silicon layers, such as with Sanyo's HIT module. Electrical characteristics, efficiencies, and appearance vary by cell type (see "A Peek Inside PV," *HP132*).

Modules can have variable numbers of cells (usually between 36 and 108), with each crystalline cell operating at around 0.5 VDC,





Kris Sutton (3)

Courtesy Florian Solar

Topher Donahue

Sanyo, Lumos Solar, and Silicon Energy make modules with transparent backsheets, which allow light to pass through between the cells.

wired in series or series-parallel configurations. For example, a 72-cell module with all cells in series will operate at a voltage of about 36 volts. But a 72-cell module with two series strings of 36 cells paralleled will operate at about 18 V, perfect for charging a 12 V battery.

Cell Dimensions

While all crystalline PV cells operate near 0.5 volts per cell, the diameter of the cell (normally 5 or 6 inches) will partially determine the current output of the cell, with larger cells producing higher current.

Glazing

Most crystalline modules use low-iron, high-transparency tempered glass with an antireflection surface treatment. Low-iron glass has high clarity, and tempered glass shatters into small fragments, instead of sharp shards, if broken. Modules are strenuously tested for weight loading and impact resistance, and the front glazing of a module is extremely durable. Thin-film modules may use a polymer film (plastic) as the front sheet, which is designed for arrays in high-impact environments.

Backsheet

Most crystalline modules have a plastic backing material that seals the cells against environmental infiltration. The most common material is Tedlar, a polyvinyl fluoride film. This backsheet is the fragile underbelly of the module, and care must be taken not to scratch it.

Some crystalline modules have a glass backing (such as bifacial modules that can also utilize light reflected to the back side). Thin-film modules have a wider range of backings, including glass, stainless steel, and varieties of tough plastic polymers.

Encapsulation

A glue laminate, such as ethylene vinyl acetate, is used to seal and protect the back and front of cells within the module glazing and backsheet.

Frame

Some crystalline modules are frameless (Lumos Solar; Silicon Energy), with a glass front and back, similar to the technique used for many thin-film modules. But most crystalline modules have anodized aluminum frames, with clear-coated aluminum and black being the most commonly available colors. Noting the frame information can help with other decisions, for example making sure that the color of the frame matches rack and clips, and to help blend with the roof color.

The anodized clear-coated aluminum frames and white backsheets of traditional PV modules may provide slightly better performance due to lower heat absorption.

More and more, modules are being released with dark anodized frames and dark backsheets, which create a contiguous surface that is aesthetically pleasing to some.

Kris Sutton (2)

Topher Donahue

Silicon Energy (left) and Lumos Solar (right) frameless PV modules may shed snow better and have less dust buildup at the module edges. In both cases, proprietary racking methods add to clean wiring and array aesthetics.

Connectors

The module lead's connector type is important. Often called "quick-connects," many new products are on the market. The old standard—Multi-Contact (MC) 4—has been joined by Tyco, Radox, Amphenol, and others. The 2011 *NEC* mandates that these connectors be touch-safe and, for circuits greater than 30 volts, require a tool for opening. Most of these connectors are not cross-compatible, so mixing modules will require properly mating connectors, as well as for wire runs to combiner or pass-through boxes.

Factory-installed module leads will be listed in the spec sheet with wire size, insulation type, and length of the leads (positive and negative leads are not always the same length). Wire diameter generally ranges from 14 AWG to 10 AWG; or they may be listed in square millimeters (mm^2). For low-voltage systems, less power will be lost to voltage drop if using modules with heavier-gauge wire.

Insulation type on the conductors may be a single listing, such as PV wire, or have multiple cross-listings, including USE-2, RHW-2, XHHW-2, and/or PV wire. All factory-installed module lead insulation types are tested to be sunlight-resistant and flexible at low temperatures, and are heavily or even double-insulated for installation in extreme outdoor environments. However tough these single conductor leads may be, they still must be protected in a raceway when they leave the vicinity of the array.

The MC4 connector has been joined by other viable alternatives, including ones by Tyco, Radox, and Amphenol.

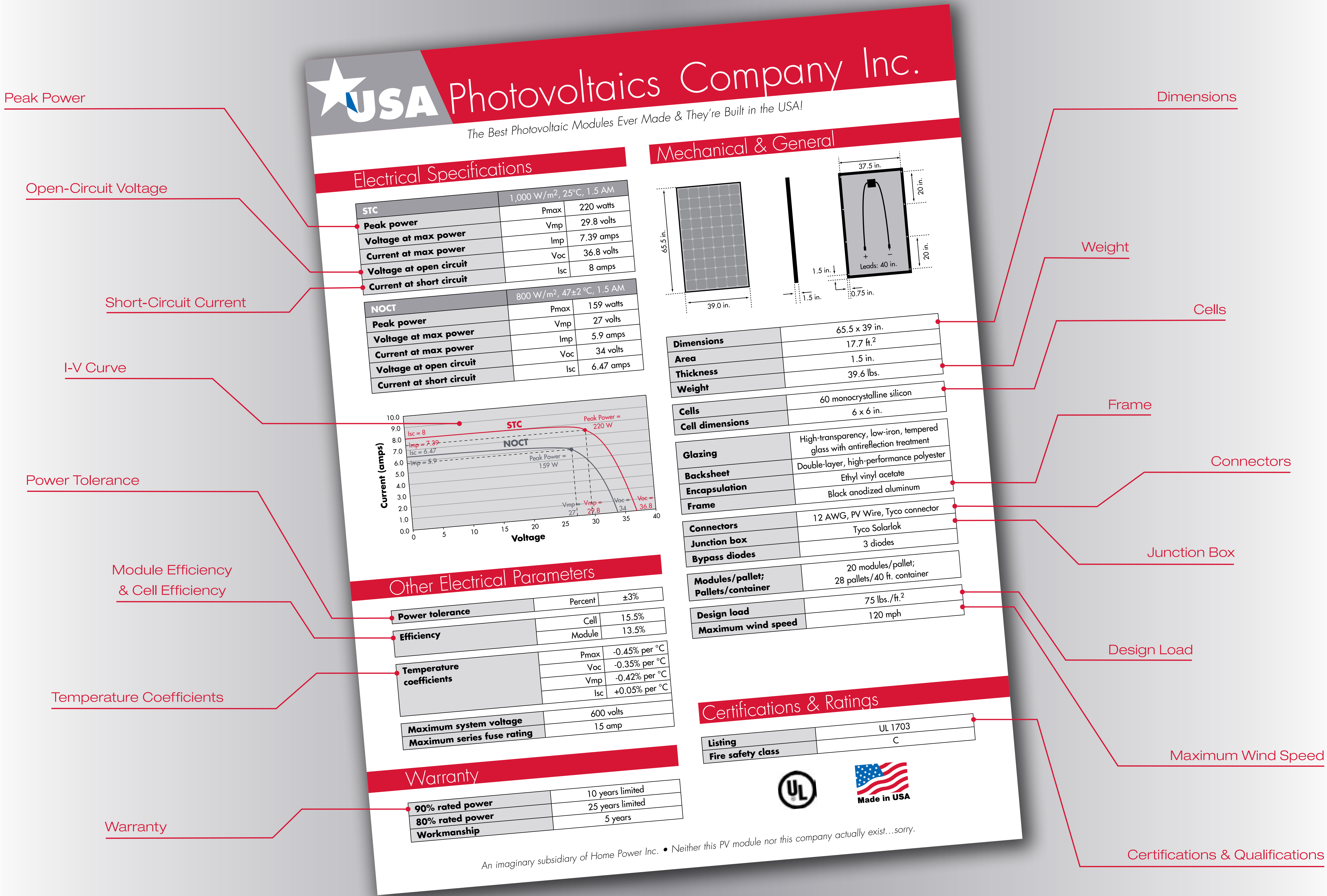
Junction Box

A junction box is factory-installed on the back of modules for the connections. Many are sealed and inaccessible to the end user. If it is specified as field-serviceable, the junction box can be opened, and leads and bypass diodes can be installed or replaced. For arrays that are readily accessible (for example, a ground-mounted array), field-accessible and conduit-ready junction boxes can allow for fittings and protective raceways to be installed and meet *NEC* 690.31(A) code requirements for accessible arrays.

A field-serviceable junction box may accommodate custom wiring decisions, the use of conduit, and replacement of failed bypass diodes.

A sealed J-box can't be opened, but may better withstand harsh outdoor elements.

Kris Sutton (3)



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Electrical Specifications

STC	1,000 W/m², 25°C, 1.5 AM	
Peak power	Pmax	220 watts
Voltage at max power	Vmp	29.8 volts
Current at max power	Imp	7.39 amps
Voltage at open circuit	Voc	36.8 volts
Current at short circuit	Isc	8 amps

NOCT	800 W/m², 47±2 °C, 1.5 AM	
Peak power	Pmax	159 watts
Voltage at max power	Vmp	27 volts
Current at max power	Imp	5.9 amps
Voltage at open circuit	Voc	34 volts
Current at short circuit	Isc	6.47 amps

Other Electrical Parameters

Power tolerance	Percent	±3%
Efficiency	Cell	15.5%
	Module	13.5%
Temperature coefficients	Pmax	-0.45% per °C
	Voc	-0.35% per °C
	Vmp	-0.42% per °C
	Isc	+0.05% per °C
Maximum system voltage		600 volts
Maximum series fuse rating		15 amp

Warranty

90% rated power	10 years limited
80% rated power	25 years limited
Workmanship	5 years

Mechanical & General

Dimensions	65.5 x 39 in.
Area	17.7 ft.²
Thickness	1.5 in.
Weight	39.6 lbs.
Cells	60 monocrystalline silicon
Cell dimensions	6 x 6 in.
Glazing	High-transparency, low-iron, tempered glass with antireflection treatment
Backsheet	Double-layer, high-performance polyester
Encapsulation	Ethyl vinyl acetate
Frame	Black anodized aluminum
Connectors	12 AWG, PV Wire, Tyco connector
Junction box	Tyco Solarlok
Bypass diodes	3 diodes
Modules/pallet; Pallets/container	20 modules/pallet; 28 pallets/40 ft. container
Design load	75 lbs./ft.²
Maximum wind speed	120 mph

Certifications & Ratings

Listing	UL 1703
Fire safety class	C

UL — Made in USA

An imaginary subsidiary of Home Power Inc. • Neither this PV module nor this company actually exist…sorry.

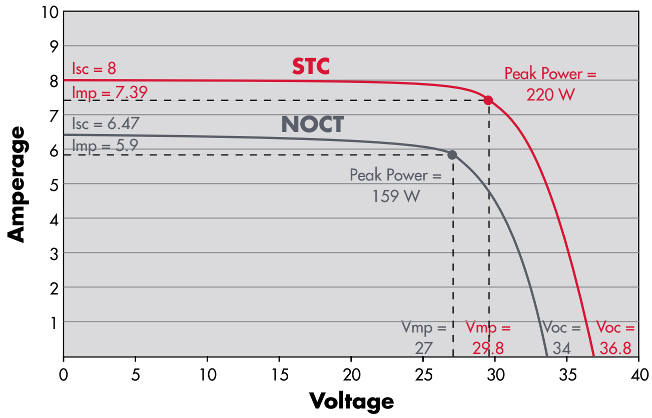
Bypass Diodes

Shading a small part of a PV module can have a disproportionally large effect on its output. Additionally, when a module is partially or completely shaded, the current flowing through the module can reverse direction and create hot spots, which can lead to deterioration of the cell, the internal connections, and the module backsheet. A bypass diode stops the reverse flow of current and also directs electrical flow around the shaded section of the module. Nearly all modules come with factory-installed bypass diodes, with the exception of some thin-film modules. A typical 72-cell module with all the cells in series will have three bypass diodes, each bridging a series of 24 cells that can be bypassed if any or all of those cells are shaded. Depending on where they are located on the module and the type of junction box, diodes may be field-accessible. Regardless of the benefit of diodes, shading should be avoided whenever possible.

Modules per Pallet; Pallets per Container

A pallet of modules isn't a standard quantity. Details on packing information is important to help calculate point loading if pallets are to be placed on a roof, or for staging large job sites.

Typical IV Curves



IV (current-voltage) curves at least show PV module performance characteristics for STC (*Standard Test Conditions:* 1,000 W/m² irradiance, 25°C cell temperature, and an air mass of 1.5). Often variations of typical conditions are graphed as well. All are important for system design.

Electrical Data

I-V Curve

Standard test conditions (STC) are the conditions under which a manufacturer tests modules: 1,000 W per m² irradiance, 25°C (77°F) cell temperature, and 1.5 air mass index. Real-world operating cell temperature is often 20 to 40ºC above the ambient temperature. STC (bright sun and a relatively low cell temperature) are not typical for field operation of modules, but they do provide a consistent standardized reference to compare modules.

An I-V curve (current-voltage) curve is generated at STC for every cell and module manufactured. The I-V curve contains five significant data points (Pmax, Vmp, Voc, Imp, and Isc; discussed below), which are used for system design, troubleshooting, and module comparisons. I-V curves can also be diagrammed for any operating temperature and irradiance level, but the points listed on a module specification sheet and those printed on the back of the module are at STC unless otherwise stated.

Peak Power (Pmax or Pmp)

The specified maximum wattage of a module, the maximum power point (Pmax), sits at the "knee" of the I-V curve, and represents the product of the maximum power voltage (Vmp) and the maximum power current (Imp). This wattage is produced only under a very specific set of operating conditions, and real environmental conditions (changing irradiance and cell temperature) will alter a module's Pmax.

Vmp

At STC and tested under load, voltage at max power (Vmp) is the highest operating voltage a module will produce. Vmp, adjusted for highest operating cell temperature, is used to calculate the minimum number of modules in series.

Voc

Open-circuit voltage (Voc) occurs when the module is not connected to a load. No current can flow in an open circuit and, as a result, Voc occurs at the point on the I-V curve where current is zero, and voltage is at its highest (Note: the module produces no power under open-circuit conditions.)

Voc is used to calculate the maximum number of modules in a series string. Because voltage rises as the temperature drops, calculations are performed for the coldest expected operating conditions. This ensures that *NEC* parameters and equipment voltage limitations are not exceeded.

Imp

At STC, and tested under load, the maximum power current (Imp) is the highest amperage a module can produce. Imp is used in voltage drop calculations when determining wire gauge for PV circuits. This is a design consideration rather than an *NEC* ampacity calculation, for minimizing voltage drop and maximizing array output.

Isc

Short-circuit current (Isc) is the maximum amperage that the module can produce. There is no voltage when a module is short-circuited, and thus no power. Isc is the measurement used to size conductors and overcurrent protection, with safety factors as required by the *NEC*.

NOCT

Frequently, nominal operating cell temperature (NOCT) specifications are also listed on a manufacturer's sheet. These are measurements calculated at different conditions than STC, using a lower sunlight intensity (800 W per m²); an ambient (not cell) temperature of 20ºC; and a wind speed of 1 meter per second; with the module tilted at 45°. The NOCT value itself is the cell temperature—given in degrees Celsius—reached under these conditions, Compared to the STC 25ºC cell temperature, the NOCT value will always be higher, usually by about 20ºC. NOCT values are used to mathematically calculate other test condition data points without resorting to further laboratory tests. NOCT conditions tend to more closely resemble the field conditions PV arrays generally operate in, and so give a perspective on "real-world" module operation.

Other Electrical Parameters

Power Tolerance

Power tolerance is the range within which a module manufacturer is stating the module can deviate from its STC-rated Pmax, and thus what the manufacturer warranty covers. Common values are +/-5%, -0%/+5, and up to +/-10%. A 200-watt module with a +/-5% power tolerance could produce a measured output of 190 to 210 W. Finding modules with a -0% power tolerance can ensure the best value per dollar spent, and keep arrays operating at closer to predicted output.

Module Efficiency & Cell Efficiency

Efficiency is the measure of electrical power output divided by solar input. At STC, power in is equal to 1,000 W per m^2 and power out is the rated Pmax point. Assuming a module sized at exactly 1 square meter, and rated at 150 W Pmax, module efficiency would be 150 W per m^2 ÷ 1,000 W per m^2, which equals 15%. The typical crystalline efficiency range spans 12% to 15%, but there are high-efficiency modules over 19%, and amorphous silicon modules on the low end with efficiencies around 6% or 7%.

Cell efficiencies will be slightly higher than module efficiencies because there is usually a small amount of empty space between cells. When deciding what module to purchase, if W per square meter (known as power density) is the driving factor, then a module with high efficiency should be chosen. But in many instances, there is plenty of room for an array and price per watt will be given higher priority than module efficiency.

Temperature Coefficients

Modules are directly affected by both irradiance and temperature, and because of environmental fluctuations, also experience power output fluctuations. When exposed to full sun, the cells will reach temperatures above the STC temperature of 25°C. And sometimes cell temperatures are lower than 25°C, such as on cold winter days.

Temperature coefficients are used to mathematically determine the power, current, or voltage a module will produce at various temperatures deviating from the STC values.

The temperature coefficient of open-circuit voltage is used to figure out the PV array's maximum system voltage at a site's lowest expected temperatures. The temperature coefficient of power can be used along with pyranometer-measured irradiance to calculate the power an array should be producing, which can be compared to actual output to verify proper performance.

Maximum Ratings

Maximum System Voltage

For residential PV systems, the maximum allowed voltage is 600 volts (per *NEC* 690.7(C)), but ratings on equipment are just as critical to abide by. While most of the equipment—including modules—in PV systems is rated for up to 600 V, they are generally tested to higher voltages, usually twice the listed maximum plus 1,000 V. Maximum system voltage is calculated using the Voc at coldest expected temperatures (see "Back Page Basics" in *HP128*) so as not to exceed the *NEC* limit and any limits imposed by the ratings of inverters, disconnects, or conductors. Modules sometimes list a 1,000 V limit, but that is for European installations or engineered commercial and utility-scale systems.

Kris Sutton

Temperature extremes affect PV performance, and thus *temperature coefficients* are instrumental in system design.

Maximum Series Fuse Rating

This is the maximum current a module is designed to carry through the cells and conductors without damage. While modules themselves are current-limited, excess current can come from other sources (series strings) in parallel, or from other equipment in the system such as some inverters or charge controllers. A fuse or breaker for a series string must be no larger than the maximum series fuse specification.

Design Load

The weight (in lbs. per ft.^{2}, PSF) that a module has been tested to hold without damage. Modules will usually handle 50 PSF. In areas with heavy snow loads, modules with a higher design load should be used and may be required by the permitting authority.

Maximum Wind Speed

This is the maximum wind speed a module can handle without damage, and 120 mph is a common rating. Your local building authority can provide the design wind speed you need to use. In areas with higher-than-normal wind speeds, thin-film or frameless, glass-on-glass modules may be the only choice with a high-enough rating.

Certifications & Qualifications

For a code-compliant installation, modules need to be tested to UL standard 1703, and stamped by a nationally recognized testing laboratory (NRTLs, as listed by OSHA) as meeting this standard. Other NRTLs include CSA, TUV, and Intertek (ETL). Modules often list other compliances and qualifications, including International Standard for Organization (ISO) 9001:2008 which is an international standard for a quality management system.

Richard Perez

PV modules are durable goods, and have the potential to last a very long time, as these old still-operating modules prove. Protect your investment by choosing a brand with a good warranty.

Fire Safety Class

Plastic-backed modules with glass fronts are nearly always listed as "Fire Safety Class C," which means they are potentially energized electrical equipment, and no conductive agents (such as water) should be used to fight the fire.

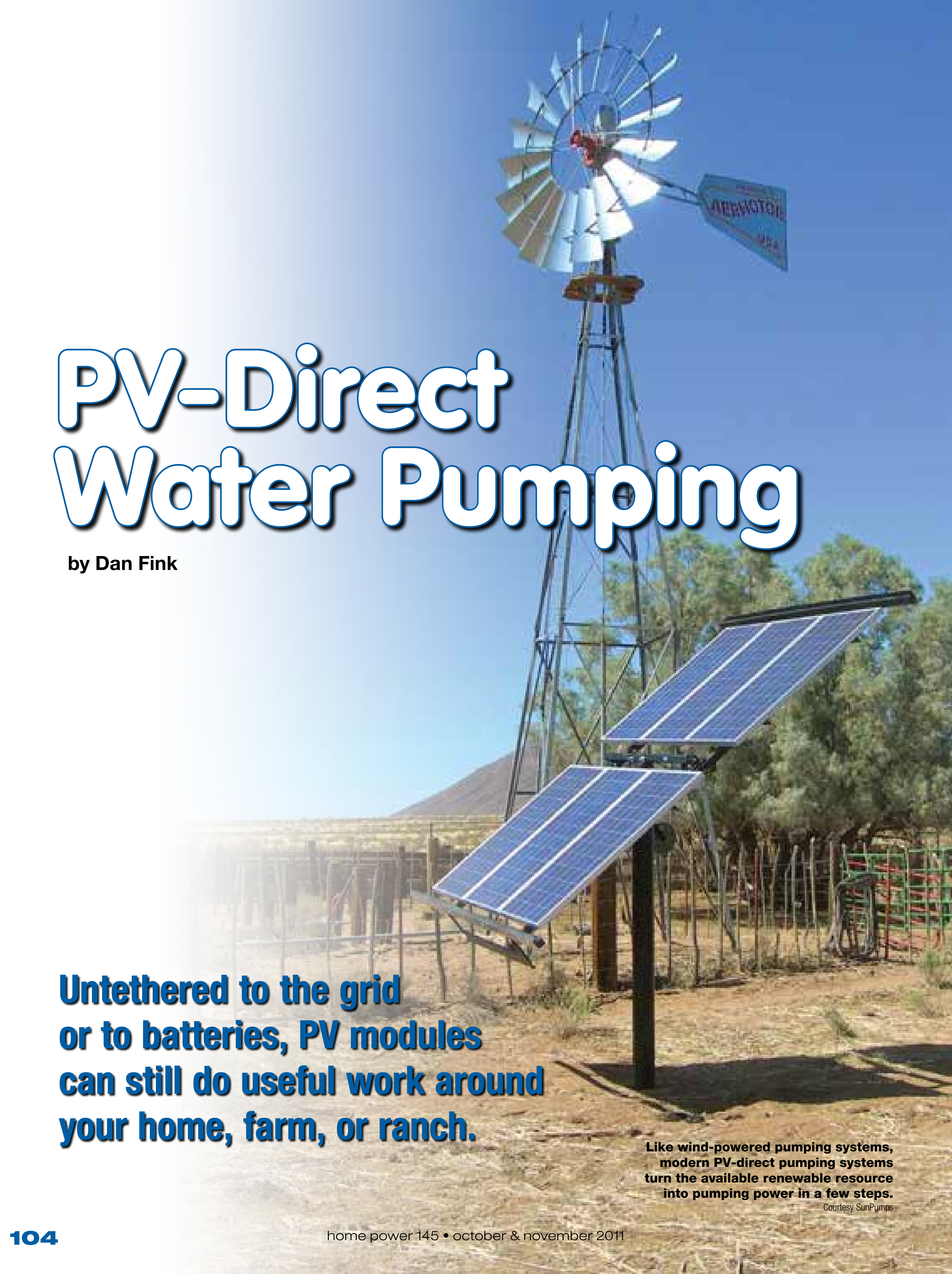
Warranty

Modules list separate workmanship and power warranties. The workmanship warranty is a limited warranty on module materials and quality under normal application, installation, use, and service conditions. Certain parts of modules, including quick connects and some junction boxes, have only short warranties from their manufacturer, and this is reflected in overall workmanship warranties of one to 15 years. Manufacturers may offer replacement or servicing of a defective module under the workmanship warranty.

A limited warranty for module power output based on the minimum peak power rating (STC rating minus power tolerance percentage) means that the manufacturer guarantees the module will provide at least a certain level of power for the specified period of time. Many warranties are stepped—covering a percentage of minimum peak power output within two different time frames. For example, a common warranty guarantees that the module will produce 90% of its rated power for the first 10 years and 80% for the next 10 years. A 200 W module with a power tolerance of +/-5% means that the module should produce at least 171 W (200 W × 0.95 power tolerance × 0.9) under STC for the first 10 years. For the next 10 years, the module should produce at least 152 W (100 W × 0.95 power tolerance × 0.8). Module replacements are frequently done at a prorated value according to how long the module has been in the field. More manufacturers are now offering linear power warranties, which are represented by a maximum percentage power decrease per year for a set number of years, for example, that module power output shall not decrease by more than approximately 0.7% per year after the initial year of service, for the first 25 years.

Access

Rebekah Hren (rebekah.hren@gmail.com) is a licensed electrical contractor, NABCEP-certified PV installer, and ISPQ-certified PV instructor for Solar Energy International. She lives off-grid and has experience installing and designing PV systems ranging from 10 watts to utility-scale. Rebekah has coauthored two renewable energy books: *A Solar Buyer's Guide* and *The Carbon-Free Home*.



PV-Direct Water Pumping

by Dan Fink

Untethered to the grid or to batteries, PV modules can still do useful work around your home, farm, or ranch.

Like wind-powered pumping systems, modern PV-direct pumping systems turn the available renewable resource into pumping power in a few steps.
Courtesy SunPumps

PV systems that power loads directly from a PV module or array are called "PV-direct," and operate only when the sun is shining. These systems are much less expensive and easier to install than battery-based or grid-tied designs. They do not require batteries, charge controllers, or inverters, all of which are expensive and reduce overall system efficiency.

The most common PV-direct application is solar water pumping for irrigation, livestock, and domestic use. If water is what you need, why bother with batteries? Water tanks are far cheaper than battery banks, and last for decades. These systems work well as long as you can store enough water to get you, your plants, and your animals through periods of no sun. PV-direct pumping is not used to provide domestic water pressure, but usually to fill a tank. Gravity or a separate, inexpensive water pressure-pump system is instead used to push stored water to your household faucets, shower, etc.

Water pumps for PV-direct use come in a several varieties:

- **Surface pumps** are used to move water from sources like shallow wells, ponds, streams, and tanks, where the pump itself is located no more than 20 feet above the water level. There are many types available; your choice will depend on how much water per day you need to move, how high, and how far.
- **Submersible pumps** are for deeper wells, where the pump can't be installed within 20 feet above the water level. These pumps are suspended below the water level in the well and connected to an output pipe that extends up to the surface. Once again, the right pump for your application depends on your needs for quantity of water and pumping height and distance.
- **Circulation pumps** are used to move water around in a closed system, such as solar water heating for domestic water, space heating, pool, or spa. They generally lift water only a short height.

Why is there a 20-foot height limit from a water's surface to pump? Pumps can *push* water up hundreds of feet and move it horizontally over great distances, but must rely solely on atmospheric pressure to "suck" water up to their level for pumping to the final destination. The theoretical limit is 33.9

This SunPumps submersible pump is designed to be suspended deep in a well, and can be powered directly by a PV array.

Courtesy SunPumps (2)

A DC surface pump (below) is often built for higher flows, but usually cannot draw water more than 20 vertical feet, making it highly suitable for moving water from surface sources like the irrigation pond (at right).

Courtesy Innovative Solar

PV-direct systems turn the sun's rays directly into useful work, but a pump controller is used to turn the pump on and off, and can optimize the system's performance.

feet (10.3 meters) at sea level, but even the slightest vacuum leak will drastically reduce that limit, as will high altitudes. As little height as possible, with a maximum of 20 feet (at sea level), is a realistic guideline.

Pump Controllers

In the simplest PV-direct application, a controller may not be required—when the sun shines, the pump runs, and when the sun sets, the pump stops. But in most systems, a controller is wired between the PV array and the pump to stop water flow when the tank is full and to prevent running the level of the water source so low as to run the pump dry.

To sense water level, float switches are wired to the controller and they use gravity to open or close contacts as the float angle changes with water level. Most are intended to switch the entire current of a typical 120- or 240-volt AC pump, and may not function properly with the low-voltage, low-amperage sensing circuit in the solar pump controller. Be sure to get the right switch for your application. For irrigation, there are other switches available, such as soil-moisture sensors to prevent over-watering, and high-wind sensors to shut the system down when winds might spread water to where it's not wanted.

System Sizing

The easiest way to determine the size and cost of a PV-direct water-pumping system is to ask your favorite renewable energy dealer! They will have spreadsheets and product specifications handy, and be able to do the math quickly for you. It never hurts to do your homework, though, so you have a rough idea of how much you'll have to invest. In any case, you'll need some critical information to get an accurate cost estimate.

First, you'll need to know how much water you need to move per day, and size your storage tank to get you through both nighttime and periods of cloudy weather when the pump won't be running (or is running slowly). Next, you'll need to calculate your system's total dynamic head (TDH). This is the sum of the **static head** (total vertical distance from water surface to discharge outlet), **friction head** (friction losses from pipe walls and bends in the pipe), and **pressure head** (losses from any nozzles or filters in the lines). Head can be expressed in either feet of water or pounds of pressure per square inch.

Head (in ft.) ÷ 2.31 = psi
Head (in psi) × 2.31 = Head (in ft.)

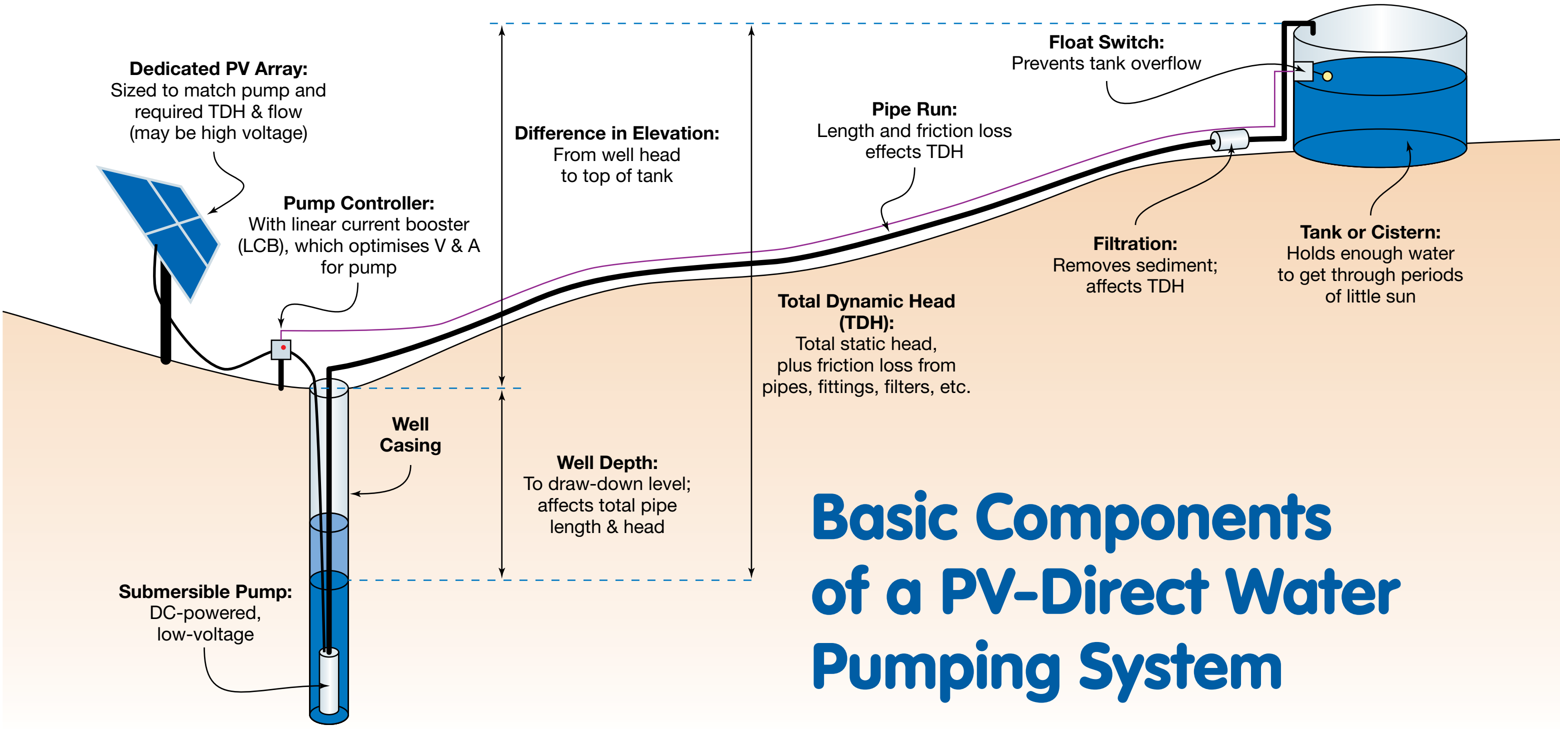
Static head needs to be measured to an accuracy of ±1 foot, which can be done using a level and rod. Topographic maps or GPS measurements are not accurate enough. A sight level with a measuring rod or some other means is necessary. (For more info on measuring head, see "Intro to Hydropower" in *HP104*). If you have a deep well, the driller should have provided you with the distance from ground level down to water level. If not, they can come back to measure it (they use a special sensor) or you can come up with your own measurement solution. Well draw-down—how far the water surface level drops while you are pumping water—also affects static head measurements. Your well driller should have also provided you with this information right after the well was drilled and the pump installed, and also the rate (in gallons per minute; gpm) at which the well refills.

PV-direct pumping systems can provide domestic water at remote sites, utilizing only a small PV array.

Courtesy SunPumps (2)

Linear Current Boosters

Electric pump motors require extra power to start spinning—up to four times the power used to just run. Many pump controllers have linear current booster (LCB) circuitry, trading volts for amps (and vice versa) to run the pump at its most efficient rate for the amount of power the PV array is producing. On an overcast day, a pump with no LCB may be sitting idle, while a pump with an LCB can overcome the required startup load and then run all day, albeit at a slower rate, proportional to solar intensity.



Basic Components of a PV-Direct Water Pumping System

Example Pipe Friction Loss

Flow (GPM)	Polyethylene (PE): PSI per 100 ft. 1/2 in.	3/4 in.	1 in.	1 1/4 in.	1 1/2 in.	2 in.
1	0.49	0.12	0.04	0.01	0.00	0.00
2	1.76	0.45	0.14	0.04	0.02	0.01
3	3.73	0.95	0.29	0.08	0.04	0.01
4	6.35	1.62	0.50	0.13	0.06	0.02
5	9.60	2.44	0.76	0.20	0.09	0.03
6	13.46	3.43	1.06	0.28	0.13	0.04
7	17.91	4.56	1.41	0.37	0.18	0.05
8	22.93	5.84	1.80	0.47	0.22	0.07
9	28.52	7.26	2.24	0.59	0.28	0.08
10	34.67	8.82	2.73	0.72	0.34	0.10
11	41.36	10.53	3.25	0.86	0.40	0.12
12	48.60	12.37	3.82	1.01	0.48	0.14
14	64.65	16.46	5.08	1.34	0.63	0.19
16	82.79	21.07	6.51	1.71	0.81	0.24
18	102.97	26.21	8.10	2.13	1.01	0.30
20	—	31.86	9.84	2.59	1.22	0.36
22	—	38.01	11.74	3.09	1.46	0.43
24	—	44.65	13.79	3.63	1.72	0.51
26	—	41.79	16.00	4.21	1.99	0.59
28	—	59.41	18.35	4.83	2.28	0.68
30	—	67.50	20.85	5.49	2.59	0.77
35	—	—	27.74	7.31	3.45	1.02
40	—	—	35.53	9.36	4.42	1.31
45	—	—	44.19	11.64	5.50	1.63
50	—	—	53.71	14.14	6.68	1.98
55	—	—	—	16.87	7.97	2.36

Source (includes tables for other pipe types):
www.hunterindustries.com/Resources/PDFs/Technical/Domestic/LIT091w.pdf

Horizontal distance from pump to discharge outlet can be measured with a tape, but **friction head** calculations involve complicated math that includes flow rate; pipe diameter, length, and smoothness; and any fittings in the line. Fortunately, friction head can be estimated using tables provided by pipe manufacturers. There are also numerous friction-loss calculators available online. If you are pumping from a well, be sure to include the pipe length from the pump to ground level in your total distance.

Because typical, home-sized PV-direct systems pump slowly, you can safely assume a pipe diameter of 3/4 to 1 inch, and adjust this later as you narrow down which pump you need. Using very large diameter pipe (greater than 2 inches) is not recommended in small systems—it's expensive, and with low flow you may have sediment buildup inside the pipe.

For **pressure head**, the manufacturer of the irrigation nozzle or water filter you are planning to use will provide you with pressure drop data, in pounds per square inch (psi).

Lastly, you'll need to find out the average number of full-sun hours your site receives each day. You can look up your location on an insolation map online (http://rredc.nrel.gov/solar/pubs/redbook), or use PVWatts, NREL's online calculator. With this information, you can get a quote from a solar pump dealer.

Selecting a Pump

The common design philosophy behind PV-direct water pumping is simple: Pump slowly with as few PV modules as possible, and install a big storage tank. PV-direct pumps in home-scale systems generally operate in the range of 1 to 4 gpm, while typical AC well pumps usually work at 6 gpm and up. These pumps are *not* suitable for PV-direct use—they require a battery bank, an inverter with high surge capacity,

Other PV-Direct Applications

Water pumping is certainly the most common PV-direct application, but there are others that are also a perfect fit.

Water aeration is used to oxygenate or prevent freezing in ponds. Some systems use water pumps and fountains; others use compressed air.

A simple air compressor on shore and diffuser system at the bottom of the pond, powered directly by a PV module, can be very effective at keeping the water from freezing. Rising air bubbles bring warmer water from the bottom up to the surface, and aquatic life in eutrophic ponds with insufficient dissolved oxygen levels can also benefit from aeration.

Sizing a PV-direct compressor/aeration system is very similar to sizing a water-pumping system. Instead of total dynamic head, you'll be calculating air pressure drop (from pump depth and air tubing size), and the flow per minute will be measured in cubic feet instead of gallons. Instead of a pump curve, you'll consult a compressor curve. But all the basic system design concepts remain the same, and purpose-built, efficient DC compressors are readily available. Water fountain aeration systems are sized using the same math as in other water-pumping applications.

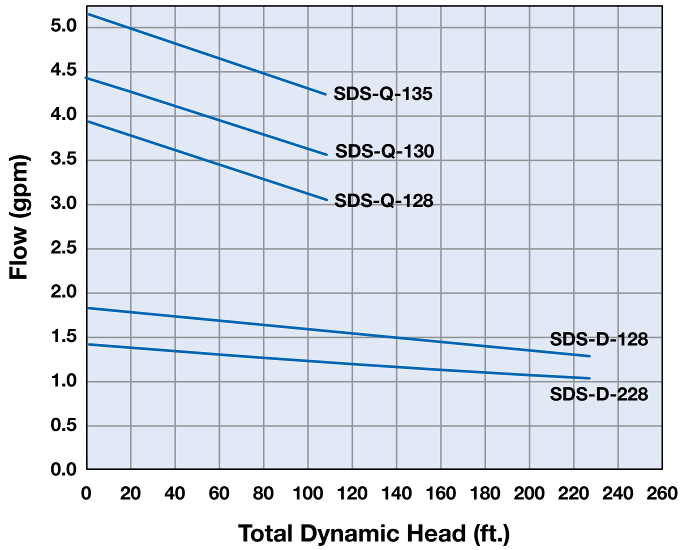
PV-direct water or air pumps can provide aeration and/or freeze protection.

PV-direct ventilation systems, such as greenhouse fans and attic fans, are also popular, and can be a very logical and cost-effective application—the more intense the sunlight, the more airflow is typically needed in an attic, greenhouse, or other structure. Systems retain the same similarities in design—the blower, controller, and PV array must all be matched to the duct size and pressure losses. Efficient, purpose-built PV-direct DC blowers are easy to find.

Courtesy SunPumps (2)

The stronger the sun shines, the more air this PV-direct ventilation fan exhausts.

Example Pump Specifications



and a larger PV array. If you already have one of these pumps in your well, you'll need to replace it to use PV-direct pumping. Most solar pump manufacturers provide graphs of specifications for their pumps, grouping model series on one graph to make selection easier.

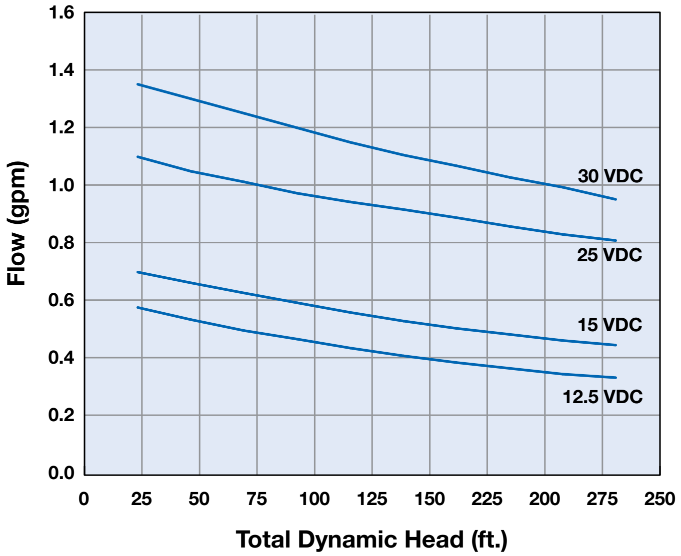
For example, let's say you need about 240 gallons of water per day for domestic, livestock, and irrigation use. From well draw-down level to the cistern, the water must be lifted 60 feet over a distance of 500 feet. You have 3/4-inch polyethylene pipe ready, and a sediment filter at the tank causes a pressure drop of 2.41 psi. The well refills at 3 gallons per minute. Your average daily insolation during the worst month of the year is 4 sun-hours, and you need enough water to ensure cloudy periods of up to 7 days.

Working backward with storage capacity, you'll need a 1,680-gallon water storage tank (240 gal./day × 7 days). The flow rate required would be about 1 gallon per minute [240 gal./day ÷ 240 min./sun-hours day (the number of minutes in 4 hours)]. Because the well refills at 3 gpm, there is no chance you'll run the pump dry.

Next, calculate total dynamic head (TDH). The total pipe length is 560 feet (500 ft. horizontal + 60 ft. vertical). The 2.41 psi pressure drop from the filter adds 1 foot of TDH, and pipe friction at 1 gpm adds another 1.55 feet, for a total of 62.55 feet of TDH. There are also unknown factors, such as the friction from pipe connectors and valves. A safe estimate is 70 feet of TDH—always oversize your system.

The lines on a pump manufacturer's graph (above) show the maximum output the pump can produce at a given head and flow. Find the intersection of 1 gpm flow and 70 feet of head on the graph. That spot sits nicely below the curve of the example SDS D-series pumps, and far below the more expensive SDS-Q series. In this example, then, the D-series would be a better investment.

PV / Pump Voltage Selection



Sizing the PV Array

The final piece of the puzzle is calculating the size of the PV array required to run the pump at the specified head and flow rate. Again, the pump manufacturer can provide the specs for you.

Most home-scale PV-direct applications require between 100 and 800 watts of PV, depending upon the site and the needs. You should always oversize the PV array by at least 20% to make up for electrical and mechanical losses in the system. If your calculations indicate a PV system larger than you can put in, you might save money with a smaller array and a pump with slower flow—but spending a little more on a larger water tank.

In the example given, use the pump manufacturer's voltage and capacity chart (above) to size the PV array. In this example, 1 gpm at 70 feet TDH is too much to run PV-direct from a single 17-volt PV module—the spot where gpm and TDH cross is above the graph line. At 34 V module-direct, though, capacity is more than ample; the manufacturer calls for 72 W of PV. Two 50 W, 17 V modules in series would be ideal.

For some systems, using a tracker so the PV array follows the sun to increase the energy output may be worth considering, though it will add expense and more moving parts to the system. If most of your water-pumping needs occur during summer when trackers yield the most benefit, you can calculate how cost-effective tracking would be by using NREL's online insolation calculator and examine scenarios using single- or dual-axis trackers. Even without using a tracker, consider using a mount that can be adjusted seasonally.

Electrical Considerations

Depending on the pump and controller/LCB that you choose, different PV array wiring configurations may be possible. It's always better to use higher voltage at the array, as wire size and cost are decreased—array voltages of more than 150 volts are possible, combiner boxes may not be needed, and pump motors operate more efficiently at higher voltages. The LCB steps this down to something lower (usually 12 to 48 volts) near the pump. A high-voltage PV array is less costly to locate farther from the controller to give more choices for siting, and can be connected with smaller-gauge, less-expensive wire.

PV-direct systems can often be installed without a structure to house the equipment. Be sure that all electrical equipment is installed and wired with weatherproof, outdoor-rated boxes and connectors. Follow the manufacturer's recommendations for overcurrent protection for the pump and controller. PV-direct systems should be grounded to *National Electrical Code* specifications. That may entail two ground rods—one for the PV array frames, rack, and pole; one for the pump, controller, and electrical boxes—depending on distance and other factors. Grounding is a complicated issue, so be sure to consult with a system designer, electrician, or local electrical inspector.

Like any renewable energy investment, PV-direct systems require research and design before the first PV module and pump is purchased and installed. Because each component must be carefully matched to the others and to the load, proper planning is essential—so the results will be an efficient, reliable system that will be functioning for years to come.

Access

Author and educator **Dan Fink** (danfink@buckville.com) has lived 11 miles off the grid in the northern Colorado mountains since 1991. He teaches about off-grid systems and small wind power, and is the executive director of Buckville Energy Consulting, a NABCEP/IREC/ISPQ-accredited continuing education provider. Dan is the coauthor of *Homebrew Wind Power.*

Pump Manufacturers:

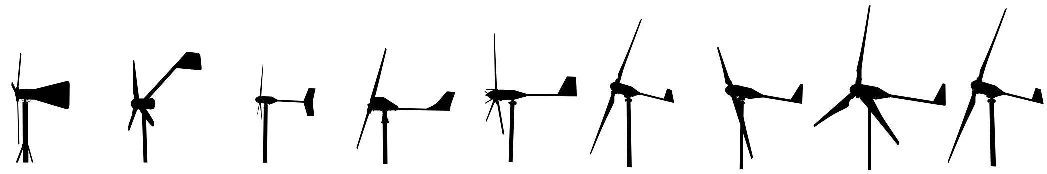
ACS-Solarsystems • www.acs-solarsystems.com/Solar_Pumps.htm
Aquatec • www.aquatec.com
Hartell • www.hartell.com
Innovative Solar (Dankoff Solar Pumps) • innovativesolar.com
Ivan Labs Inc. (El-Sid) • 561-747-5354
Laing • http://lainginc.itt.com
Lorentz • www.lorentz.de/
LVM • www.ittflowcontrol.com/alternative-energy/
March Pumps • www.marchpump.com
SHURflo •www.shurflo.com
Solar Converters Inc.• www.solarconverters.com
SunPumps Inc. • www.sunpumps.com

Solar Ventilation Fans:

Natural Light • www.solaratticfan.com
Snap Fan • www.snap-fan.com
SunRise Solar • www.sunrisesolar.net

Pump Controls/Linear Current Boosters:

AeroVironment • www.avinc.com
BZ Products • www.bzproducts.net
SunPumps Inc. • www.sunpumps.com

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Years
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DIY SOLAR AIR HEATER

by Stephen Hren

Stephen Hren

A build-it-yourself solar air heater can be a fairly simple project for motivated homeowners. These units can help offset or even eliminate the need for auxiliary heating, depending on the climate and the size of the space.

When most folks hear about solar power, the first thing that comes to mind is solar electricity. Solar electricity is amazing stuff, but for households on a budget or for individuals who love to tinker in the shop, it is not the most accessible or affordable solar technology.

Besides needing electricity, most homes, shops, or offices also need to be heated. Capturing solar energy for space heating is a straightforward and efficient way of bringing renewable energy into our lives. One of the most direct, easiest, and economical ways of doing this is with a solar air heater, used for supplemental heating.

More than any other solar technology, solar heaters are DIY-friendly, since they require only a basic knowledge of carpentry and electrical skills, can be made of easy-to-find materials, and can be installed on a south-facing wall rather than on a potentially dangerous roof. Solar air heaters are tolerant of less-than-exact construction details. A small air leak will only reduce the heater's overall efficiency, not leak fluid or potentially overheat or shock you if installed improperly. While care should be taken with any project, the consequences of potential mistakes are much less dire. For homeowners interested in the basics of renewable energy, building a solar air heater can be a great project.

Considerations

Before beginning, it's important to have access to the sun where and when you need it—or all of your hard work will be for naught. Make sure there is full sunlight on the south-facing wall in the winter months from about 10 a.m. to 2 p.m. The sun is at a low angle during the winter, so the number of potential obstructions increases. If you can't accurately assess the winter solar window within a few weeks of the winter solstice, use a solar analysis instrument such as a Solar Pathfinder or Solmetric's SunEye.

DIY solar heaters should be installed on south-facing walls and never on roofs. Homemade heaters tend to fare poorly in the extreme weather conditions that exist on roofs, and the produced heat tends to stay at the ceiling level. Hot air is likely to stratify into layers and stay stuck away from where residents want it—near the floor. Using a stronger blower might seem like it would solve this problem and help circulate the air, but it risks moving the air through the heater too quickly before it has time to heat up, and quickly moving air, regardless of temperature, has the effect of cooling the skin and making a room feel drafty.

Design Types

A solar air heater is basically a glazed, insulated black box with two vents. This simplicity allows a great variety of potential designs. Primary concerns are the design's efficiency, construction ease, and cost—and there's some trade-off between these goals. I decided on a simple design that blows air between a black metal absorber plate and polycarbonate glazing. A fan moves the air from the bottom of the collector to the top, transferring heat from the absorber to the air.

Because this design uses a fan, it is an **active** solar air heater—there are moving parts that require electricity. A **passive** solar air heater moves air by convection only—as the air inside a passive heater warms, it expands and becomes lighter, moving upward until an unassisted flow called a *thermosiphon* develops. Active heaters are roughly 200% more efficient than passive heaters, but with additional complexity and cost. Passive heaters tend to become overheated and reradiate much of the heat trapped in the collector back to the outside before it warms the air flowing through into the building.

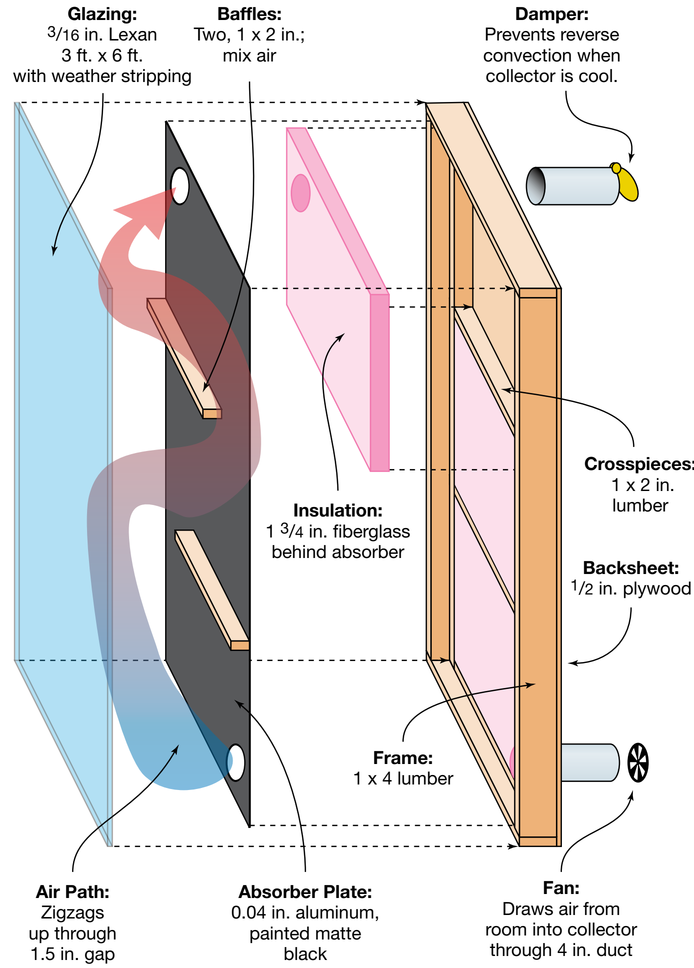
Besides the difference between active and passive, there are four heater design considerations based on time, skill level, and available materials. The one we built is an **empty box collector**—air is heated by passing through an empty glazed box facing the sun.

An improvement on the empty box collector design is the **screen collector**, which uses either a dark metal screen, lathe, soffit vent, or some other metal material with lots of holes, placed between the metal absorber plate and the glazing to cause air disruption. Creating turbulence in the air inside the heater allows more air to come in contact with the absorber plate to increase heat transfer.

One problem with empty box and screen collectors is that dust and dirt accumulating in the heater and on the interior of the glazing can reduce efficiency. Other designs can eliminate the problem by isolating the air from the glazing. A **can collector** consists of aluminum cans (painted black) with their tops and bottoms removed. Stacked end-to-end, they form channels within the collector through which air passes. Other metal tubing, such as gutter downspouts, can also be used. The dead air between the glazing and the metal channels creates a layer of insulation, reducing heat loss through the glazing and raising the collector's overall efficiency.

A **backpass collector** uses the same principle as the can collector, but instead of air traveling through channels, it travels behind the black metal absorber plate. This is common with pre-manufactured solar air heaters. For information on a variety of solar heater designs, see Gary Reysa's website, www.builditsolar.com.

Solar Air Heater Anatomy



Making the Heater Active

Using an electric fan adds complexity to the collector design, but, in addition to increasing efficiency, allows the possibility of automation. Automating the fan with a thermostat (essentially a programmable switch) and temperature sensors (called thermistors) make the heater come on only when there is useful heat to be gained. But a simpler method would be to switch on the fan manually. I was interested in maximizing understanding of renewable energy, while at the same time keeping the design most useful and the construction as easy as possible. It made sense to use a small PV module to directly power a DC fan. A PV module placed where it gets the same solar exposure as the heater adds operational elegance: The fan only works when the sun shines on the collector and PV module, and the stronger the sun is, the faster the fan blows air through the heater. A manual DC switch allows users to turn off the heater when it's not needed.

CONSTRUCTION

The box is constructed using 1/2-inch plywood, and 1 by 4s are attached to the perimeter using wood glue and exterior-grade screws. Weight is a concern, especially for full-sized 4- by 8-foot heaters. This heater is only 3 by 6 feet. Most of the materials came in dimensions that would have worked for a 4-by-8 heater, so the expense for the larger heater would not be much more. Airtight construction is important; wood glue helps greatly.

Before insulating, the perimeter is lined with 1 by 2s to support the sheet metal. Across the back, 1-by-2 crosspieces are placed approximately one-third of the way in from both of the ends to support the baffles. Gluing and then screwing into the crosspieces from the back of the plywood adds strength to the box.

Fiberglass batts are placed in the box. Planning ahead will save you some cutting.

Once the fiberglass insulation is installed, cut a hole for the 4-inch vent pipe. The exact positioning will depend on the room where you are installing the heater. Make sure it can go through the wall between the wall studs.

Courtesy Katherine Walker (6)

The absorber plate is a prepainted piece of 4- by 10-foot aluminum, typically available from metal roofing suppliers. Prepainted steel is cheaper, but the aluminum transfers heat to the air more readily. Use gloves and eye protection when fabricating and handling metal parts, as the edges are sharp.

Cut the dimension of the metal about 1/4 inch less than the interior dimension of the 1 by 4s around the edges, so that there is room for expansion. Fit the metal into the box. If it comes with a plastic film, leave that in place for now to prevent scratching the metal.

Once the absorber plate is fit, cut the vent pipe holes. Cover the edge of the vent pipe with pencil graphite, then put the absorber in place, pressing it to the pipe to leave pencil outlines where the holes are to be cut. Now you're ready to cut out the hole in the metal. Use a large bit to drill a pilot hole, and then use tin snips to carefully follow the marked circle on the metal.

Place the metal into the box and mark the center of the 1 by 2s that will support the baffles. All visible wood, including the baffles, will need to be painted with black, heat-resistant paint.

INSTALLATION

Stephen Hren

The installation begins. The sheet of metal has been removed from the box and placed on the wall to locate our two vent holes. Make sure the collector is positioned to avoid cutting any electrical wires in the wall. Studs also need to be avoided. In homes with exterior siding, you can determine stud position from the nailing pattern.

Courtesy Katherine Walker (3)

We positioned the fan at floor level to draw cooler air into the heater and promote overall mixing of air within the room. Forcing air upward into the heater works in tandem with the natural thermosiphon effect to create a steady flow through the heater. It also helps circulate air within in the room by drawing warmer air gradually toward floor level, where it's wanted.

Once the holes are marked on the wall, drill a large pilot hole for the reciprocating saw blade and cut out the circle.

Nail a temporary board to support the heater while you position it. Shim it to the right spot (check by putting the vent pipes through the heater and into the office).

Stephen Hren

This wall had plywood sheathing and 1-inch-thick wood siding, so we felt comfortable using 3-inch lag screws and not worrying about penetrating the studs. If you have any doubt, however, go to the extra trouble of screwing into the studs. We put two lag screws near the top and two near the bottom.

After placing the fiberglass insulation, we installed the metal absorber plate. We sealed it to the frame with a heat-resistant, high-grade silicone caulk to prevent air leakage.

Courtesy Katherine Walker (3)

INSTALLATION, CONT.

After the sheet metal was installed, rubber-gasketed weather-stripping was stapled around the perimeter and on top of the baffles.

Next, the vent pipe was cut to length, measuring from the inside of the wall to the outside of the heater and leaving an inch extra to cut into tabs. We siliconed around these tabs and pressed them into place.

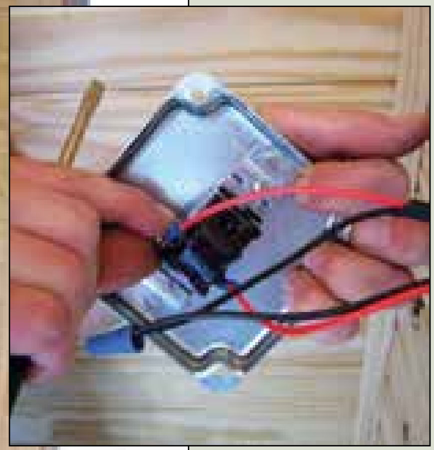
The heater is mounted on the wall, with vent pipes installed, baffles in place, and weather-stripping ready to receive the polycarbonate glazing.

Courtesy Katherine Walker (5)

The polycarbonate glazing is tough, easy to install, and has low thermal mass. We predrilled the polycarbonate every 8 to 10 inches and attached it to the frame using metal roofing screws with neoprene washers.

A 30 W 12-volt nominal PV module used to power the fan was mounted on the exterior wall next to the heater. The fan and the PV module should be the same voltage, typically 12 VDC. The fan will have a power rating, labeled in watts. The fan we chose is an 8 W unit. At a minimum, the wattage of the PV module should be twice the wattage of the fan.

Stephen Hren



Stephen Hren (2)

Here's the setup inside the room:

Even without the fan, air can flow through the heater by thermosiphon, causing unwanted cooling or heating. A back-draft damper keeps the system closed when the fan is not operating. We used a 4-inch dryer vent assembly, modifying it for aesthetics.

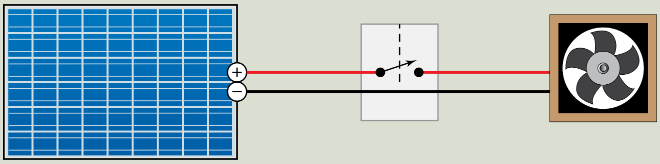
The DC fan moves about 100 cfm, doing well for this 18-square-foot heater. For a 4-by-8 heater (32 ft.^{2}), 200 cfm would be appropriate. Size your PV module accordingly—the higher the air volume, the more power it will draw. A wood box provides nice finish detail around the fan.

The DC switch shuts off electricity from PV module to fan when heating is not needed.

PVC conduit and fittings were used since we didn't have access to the wall interior for running the wiring for the switch, fan, and PV module.

For wiring the DC switch, the black (negative) wires are joined together with a wire nut, then taped. The red (positive) wire coming from the PV module goes to one side of the switch, the red (positive) going to the fan is wired onto the other side of the switch. Crimped-on ring terminals provide a secure connection. During all of the wiring, make sure the system isn't live by covering the PV module with a piece of cardboard.

Wiring the Solar Fan



Performance

Using an infrared temperature gun, we were able to determine that the air in the heater was heated by about 60°F at midday (from 60°F to 120°F on the day of the installation). Earlier in the morning and later in the afternoon, the added heat was around 40°F. After two winters, the heater is consistently capable of raising the temperature inside the building 15°F on a sunny winter day.

Some rough calculations of the amount of heat captured, based on a conservative efficiency of 50%, show that the 18-square-foot heater generates about 2,800 Btu per hour when in full sun (solar energy is about 317 Btu/ft.^{2}). In the six hours the fan runs in the middle of winter (from about 9:30 a.m. to 3:30 p.m.), this adds up to 17,000 Btu, comparable to the heat energy of a pound of coal burned every three hours or a gallon of propane burned every five and a half days. Keep in mind that the size of our heater was confined by space and it would not have been much more money or trouble to make a 4- by 8-foot collector and almost double the heat output, assuming the fan and PV module were likewise upgraded.

Payback for this heater will take longer as well, because of its smaller size and the relatively short winters here in North Carolina. Even so, it will save about a gallon of propane each week over our four-month heating season, saving roughly

Stephen Hren

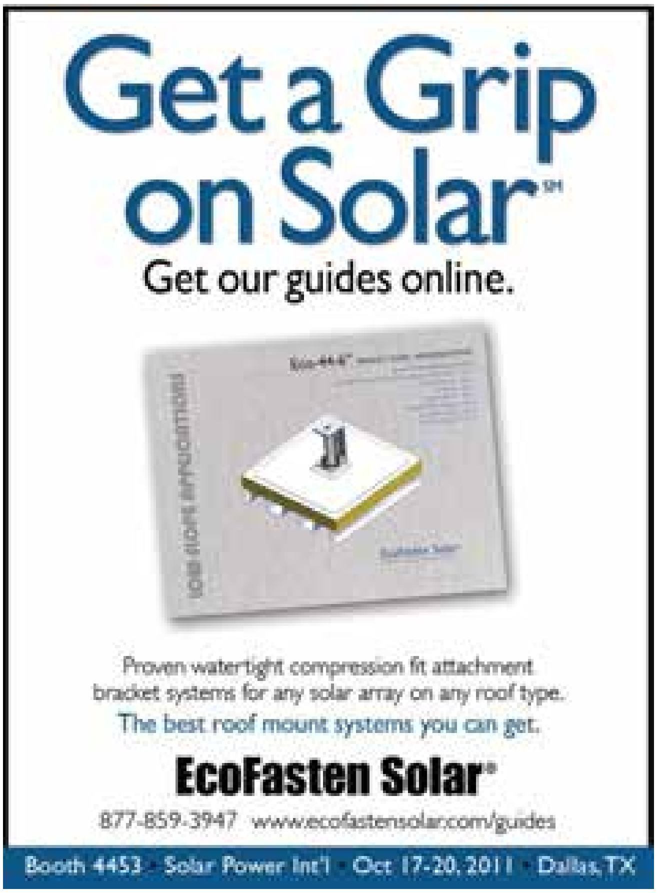
Solar Air Heater

Air box materials	$300
Fan	20
Collector plate	90
Miscellaneous electrical	50
PV module, 30 W (used)	150
Total Solar Air Heater Cost	$610

$60 each year and paying back its $600 price (relatively high because we used new materials) in about 10 years. Since it is well-protected from the rain and out of the sun during the summer, we expect at least a 20-year lifespan of producing clean renewable, homemade energy.

Access

Stephen Hren (stephenhren@gmail.com) is a builder, teacher, and author focusing on sustainable design. He is the author of the upcoming book *Tales from the Sustainable Underground* and coauthor of *The Solar Buyer's Guide for the Home and Office* and *The Carbon-Free Home.*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Sorting Out the *Code*

by Ryan Mayfield

The previous *Code Corner* introduced the 2011 *National Electrical Code (NEC)*, its purpose, its fundamental requirements, and also included a few key phrases as defined in Article 100. This time, we'll explore a few more important definitions.

As you read through materials that reference the *NEC*, pull out your *Code* book and open to the specific sections. It is one thing to read the distilled information presented in a magazine article, but to truly grasp it, you need to absorb it firsthand. Not all the definitions presented here are the full text—and shouldn't be used as a replacement. Some definitions in the *Code* include informational notes that will help you even further, and if nothing else, paging through the book is an exercise that will help you navigate it better in the future.

Defining Code

To begin, I'll lump three definitions together:

Identified (as applied to equipment). Recognizable as suitable for the specific purpose, function, use, environment, application, and so forth, where described in a particular *Code* requirement.

Labeled. Equipment or materials which have a label, symbol, or other identifying mark of an organization that is acceptable to the authority having jurisdiction (AHJ) and is concerned with product evaluation; that maintains periodic inspection of the production of labeled equipment or materials; and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

Listed. Equipment, materials, or services included in a list published by an organization that is acceptable to the AHJ and that is concerned with evaluation of products or services; that maintains periodic inspection of the production of listed equipment or materials or periodic evaluation of services; and whose listing states that either the equipment, material, or service meets appropriate, designated standards, or has been tested and found suitable for a specified purpose.

When you first read these, the definitions seem similar, but there are some subtle differences. Product identification is required when the *Code* is concerned with very specific applications. Labeling and listing can be more general and typically are handled by nationally recognized testing laboratories (NRTLs) that test and verify product suitability. NRTLs are required to work from the same standards to make sure all products within a certain classification will behave the same when installed in the field. These repeatable and documentable tests are outlined in different product standards. For example, utility-interactive inverters are tested to UL 1741, while enclosed switches are tested to UL 98. The product standard can be used by a number of NRTLs such as CSA, ETL, or UL to perform identical tests and properly list the inverter, disconnect, or whatever piece of equipment is being tested.

The key for these three definitions lies in AHJ acceptance. Multiple times in the *Code*, you'll see the requirement that the equipment be "identified and listed"—Section 690.4(D) is one example. However, the identification and listing associated with products don't automatically mean they are acceptable and approved. For a refresher, go back to the definition of "approved" in Article 100.

In nearly all situations, if a product carries a listing and is properly labeled as such, that product will be approved by the AHJ. You will need to verify that the product is identified for the installation—just because a utility-interactive inverter is listed to UL 1741 does not mean it is appropriate for your installation. If you plan to install the inverter outside, for example, you need to make sure it is properly identified for an outdoor location. There have been cases when an inverter was properly identified, listed, and labeled, but the installation did not pass inspection because the AHJ did not approve that equipment based on the listing NRTL. This is an extreme example that hasn't been a common problem in the PV industry but one that can occur and further illustrates the role and power of the AHJ.

Moving further into the definitions:

In Sight From (Within Sight From, Within Sight). Where the *Code* specifies that one piece of equipment shall be "in sight from," "within sight from," or "within sight of," and so forth, another equipment, the specified equipment, is to be visible and not more than 50 feet from the other.

There will be numerous times you run into a requirement that one piece of equipment needs to be installed "in sight from" another piece of equipment. Without this definition, the interpretations would be endless, but with the definition, we have a maximum distance value as well as the visual requirement. This definition is especially important when dealing with disconnecting means. For example 690.14(D) allows utility-interactive inverters to be installed in not-readily accessible locations, as long as a DC PV disconnecting means is mounted within sight of the inverter. In some cases, 690 has additional requirements, such as labeling based on equipment location.

Two more definitions you need to have down pat:

Interactive System. An electric power production system that is operating in parallel with and capable of delivering energy to an electric primary source supply system.

Utility-Interactive Inverter. An inverter intended for use in parallel with an electric utility to supply common loads that may deliver power to the utility.

The majority of PV systems installed today are interactive systems. And while this is definitely on the decline, in some scenarios, you may be required to explain the PV system's functionality to the AHJ. The way the PV system interacts with and isolates itself from the utility in a grid disturbance (anti-islanding) is not universally understood and needs clarification at times. This definition becomes critical when you get into the methods allowed for interconnecting a PV system with a utility-interactive inverter to the primary energy source—the utility grid.

The final definition must be addressed because there is a requirement called out in Section 690.4(E) based on this definition:

Qualified Person. One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved.

In most of the United States, only properly licensed individuals—generally considered "qualified persons"—can install electrical equipment. Since PV installations are relatively new, some states and jurisdictions don't have formal policies for the licensing requirements for PV systems. In some cases, only licensed electricians are legally allowed to work on PV systems, even if they haven't received any PV-specific training. Most tradespeople will recognize their limitations and won't work with equipment they don't understand, but occasionally the opposite will happen, with potentially dangerous consequences. If there is any doubt as to what constitutes a "qualified person" in your location, consult with the state's electrical licensing division and make that clarification.

Generally Speaking

Next up in the *Code* is Article 110, Requirements for Electrical Installations. This article sets the basic requirements for all electrical installations. This Article has direct implications on your PV installations, so walking through it and highlighting applicable sections is well worth your time.

In section 110.3(A), the *Code* lists items to consider when examining equipment. These items are intended to make sure the installed equipment is appropriate for its location and doesn't pose a hazard to anyone who might come into contact with it. Section 110.3(B) is another, often-quoted section of the *Code.* This section requires that all equipment be installed per the manufacturers' instructions. If the manufacturers' instructions are not followed completely, this blanket statement can make an entire electrical installation in violation of the *NEC*.

I have seen installations that have passed inspection, even though a manufacturer's instructions weren't followed to a "T." Some inspectors will allow such variations if they feel the installation is safe and meets the purpose and intent of *Code.* Generally speaking, inspectors realize that not all instructions are perfectly clear and in some cases, mistakes are found within the instructions.

Article 110 has many more requirements and sections, which I'll discuss in the next *Code Corner*. Until then, crack open that *Code* and start studying!

Access

Ryan Mayfield (ryan@renewableassociates.com) is the principal at a design, consulting and educational firm with a focus on PV systems in Corvallis, Oregon. He is a NABCEP-certified PV installer, an ISPQ Affiliated Master Trainer, and is proud to welcome his newest little achiever home.


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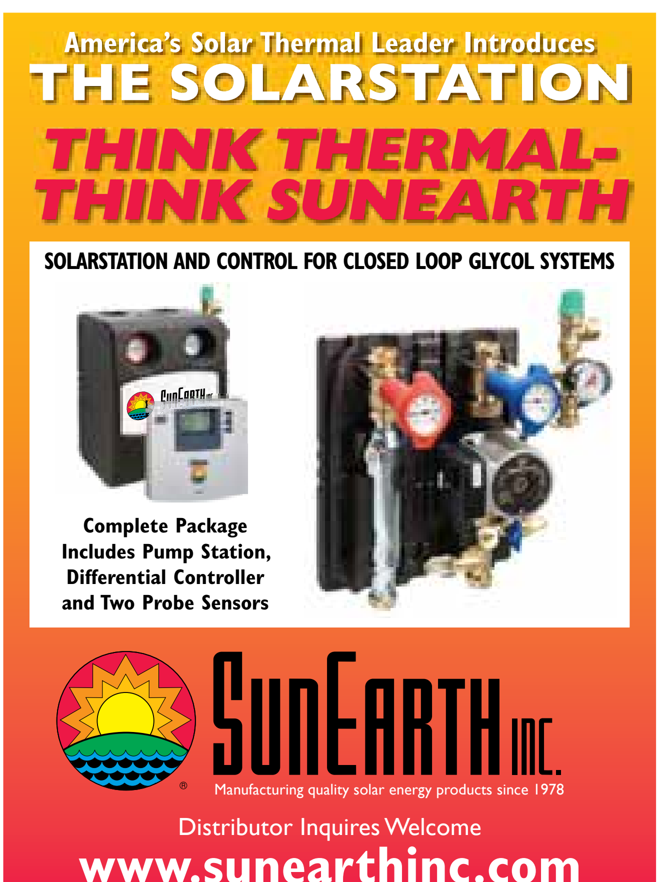
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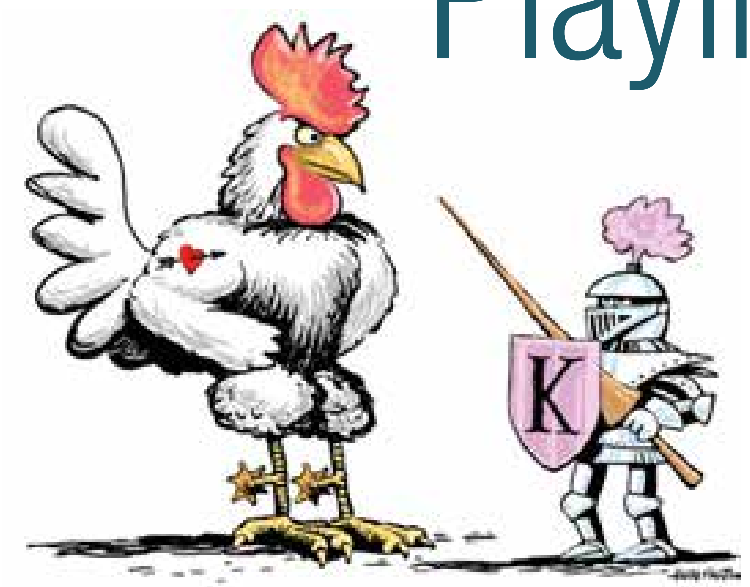
Playing Chicken

by Kathleen Jarschke-Schultze



My cousin Carrie once said, "In our family, there are two phrases that will immediately stop and change the direction of any conversation." They are, "Oooh, shiny!" and "Look, a chicken!" It is too true. We are magpies, attracted to glittery objects; and we love poultry.

In recent years, there has been a resurgence of small backyard flocks of chickens. This phenomenon has come about because people want to be more self-reliant, and the cost of food continues to rise as do the reports of unsafe, unhealthy food being sold to the public.

Chickens take up only a small amount of space and are easily kept in a backyard. They eat food scraps and reward you with wonderfully bright-yellow-yolk eggs. Most towns will let you keep chickens within the city limits, although some have restrictions against keeping roosters. Roosters can be loud and obnoxious, especially just before dawn. However, if you are going to have a free-ranging flock, I highly recommend a rooster. Roosters will take care of the hens and break up fights. They also find succulent bugs and call the hens over to feast. Many a rooster has given up his life in defense of his hens. And, face it, they are just pretty to look at.

Chicken Attrition

I was recently given the most beautiful rooster I had seen in a long time. Unfortunately, it is a grim tale, and I'll start at the beginning.

While on our annual vacation, our house sitter neglected to close the chicken coop one night. We were between dogs at the time and that was all it took. I was suddenly left with only one hen, having lost the other eight hens and a wonderful rooster, Ned, to what I later determined was a family of raccoons. I gave the survivor to my sister Tamra and took a break from raising poultry.

Then my husband Bob-O found an ad on our local Craigslist for pullets (young hens just about to start laying eggs for the first time) for $5 apiece. The woman lived nearby, so I loaded up my animal transport cages into my truck and off we went. On the way I told Bob-O, "I'll get six hens."

A couple of miles down the road, I amended that. "I'll get eight," I said. We arrived to find a motley crew of mixed-breed hens running loose. It was up to us to catch them, so six was sounding better again. They were sprightly and healthy-looking. Then the woman selling the hens came out with a couple of fishing nets and her two teenagers to help.

I was an oak. I looked the woman right in the eye and said, "I'll take 14, please."

We quickly chased them up and down and filled my cages with 14 assorted hens.

Since I wanted them to range free, I wanted to find a rooster for my newfound flock. I was at the local "feed and seed" getting some garden supplies when the woman there said, "If you want chicks this year, now is the time to order them." I explained I already had 14 pullets and what I needed was a good rooster. She smiled widely. "Why, a woman who left just before you got here put a notice on my board offering to give away a rooster," she said.

I got the number off the board and called the woman on my cell phone. Yes, she had the rooster; did I have a cage? No, I was hoping she had a cardboard box, so I could just get him home. I got the directions and drove to her house.

Raucous Rooster

There was a huge rooster, completely covered in glossy black plumage. He was sitting in a really nice, large dog cage. I told her I would bring the cage back but it would be a week or so. She didn't want the cage back. I was smiling as I drove off. I figured it was a double score for me, a big beautiful rooster and a nice big animal transport cage.

I named the rooster Simon. My hens took to him right away. He took to the hens right away, which is what I expected.

What I didn't expect was how mean he was. I could not turn my back on him. None of my previous roosters were so aggressive. The first time he got me I was walking down to the garden. He ran up behind, leapt in the air and spurred the back of my thigh, drawing blood right through my jeans. I whirled around in pain and surprise, and he pegged the front of my leg, again drawing blood. I kicked him away and went back to the house.

I got on www.backyardchickens.com and searched for "mean rooster." The advice I found was mostly: "Eat 'em." One person gave me a methodology to deal with Simon.

Whenever he attacked I was to catch him, hold him down on the ground with his belly exposed, hold his beak, look him right in the eye and tell him I was the bigger, stronger rooster, and that he was not the alpha of the flock.

I followed this advice for a couple of weeks, which meant that, several times a day, I was the alpha rooster. I still could not turn my back on Simon. I wrapped duct tape around his spurs to make them a little less dangerous. He seemed to have a learning disability.

An Ignoble End

The last straw was a sneak attack, when he jumped me from behind while I was walking to our shop. I was able to kick him back a few feet, but he flew at me again. The only weapon I could find to defend myself from his repeated attacks was a weatherworn, splintery 2 by 4 leaning against the garden fence. I parried his attacks for 10 minutes, getting splinters in my hands and losing any goodwill I had for the beast. I landed a pretty good hit that got him to move off far enough for me to back up all the way to the house. I waited till after dark to go close the coop that night. I told Bob-O that I had changed Simon's name to Terry, short for Teriyaki. Tomorrow I vowed I would end his life.

Bob-O let the chickens out to range the next morning. I cleaned the kindling axe and hung a cord across a low branch in the apple tree with slip loops on the ends. Donning a heavy jacket and leather gloves, I was ready to take care of Simon's antisocial problem. Bob-O went with me to find the chickens. He found them first and purposely turned his back on Simon. Simon flew at him, spurs up, but Bob-O whirled back around and caught the rooster in mid-air.

Off with his head and into a bucket to bleed out. Hung in the tree by his legs, I made quick work of my problem rooster. As our hydro turbine was churning out plenty of electricity, I was indeed able to use my slow cooker to make chicken teriyaki that day. While not a great rooster, Simon proved to be a tasty dinner that evening here at our homestead.

A couple of weeks later, when I celebrated my dad's 94th birthday with my family, my sister gave me two Old English Bantam roosters, the Dos Amigos, hatched in her flock. They are wonderful with the hens and courteous to me. When I know them better, I will name them.

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is thoroughly enjoying her new Airedale dog-daughter, Josie, at her off-grid home in northernmost California.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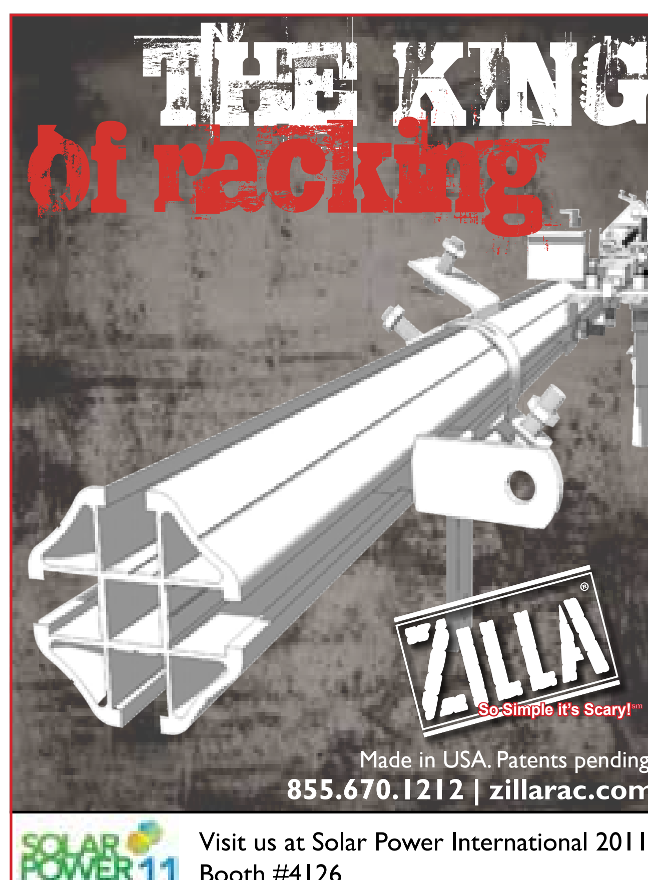
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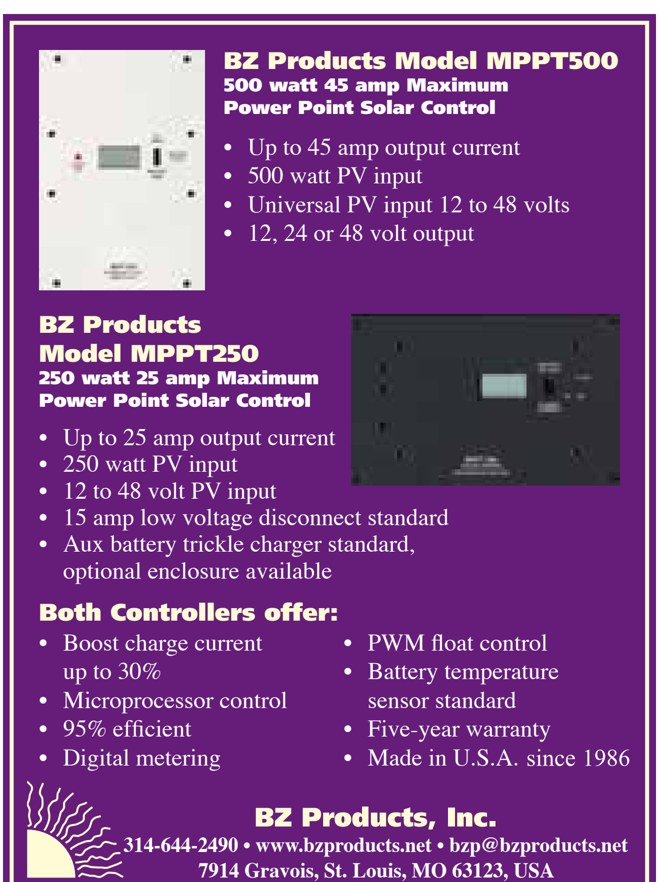
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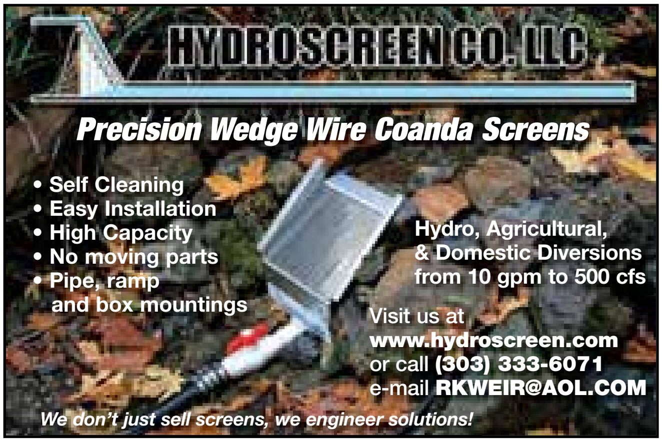

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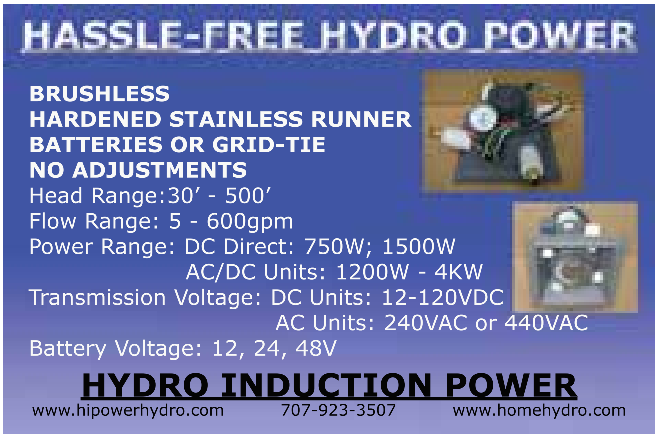

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PV Arrays & Galvanic Corrosion

Galvanic corrosion can cause failure of mechanical and electrical components.

Courtesy John Wiles

Galvanic corrosion can have a significant impact on array structures—causing visible cosmetic corrosion to the far-more-serious structural component failure. Finding ways to minimize its effects are critical to ensure a long-lived system.

For galvanic corrosion to take place, four things are required simultaneously: an anode, a cathode, an electrolyte, and a conductive path between two pieces of metal. A galvanic circuit is created when, with the assistance of an electrolyte, the anode loses electrons to the cathode. The galvanic cell created by two dissimilar metals and the presence of the electrolyte operates only in one direction. Consequently, the anode eventually disintegrates.

In PV installations, the anode and cathode are metals, such as stainless steel, copper, or aluminum. Water commonly serves as the electrolyte. Whether galvanic corrosion is a serious problem depends on the potential failure point of the metal. For a PV installation, the long-term effects of corrosion can range from unsightly finishes to rack or fastener failure.

The more dissimilar the metals, as designated by a "1" in the table, the greater the corrosion potential. For example, contact between copper and aluminum has a high potential for galvanic corrosion, but contact between aluminum and stainless steel does not.

The local environment also influences the reaction. Generally, as humidity increases, so does the rate of corrosion. Atmospheric contaminants, such as chloride (in marine environments) and sulfur dioxide and nitrous oxides (in industrial locations), also increase corrosion rates. This is why PV systems installed in desert climates are less prone to galvanic corrosion than those located in coastal, humid, or industrial environments.

Since PV arrays are sited in nearly all environments, installers must find practical ways to reduce galvanic corrosion. Methods include:

- Choosing metals that have a low potential for galvanic action (such as using stainless steel fasteners with aluminum racking);
- Selecting the appropriate protective coatings (such as paint, electroplating, or hot-dip galvanizing) to protect against environmental conditions; and
- Physically isolating dissimilar metals with nonconductive, nonporous materials, such as rubber washers with galvanized screws and painted steel; or stainless steel washers with an EPDM gasket already adhered. Certain plastics may also be suitable if they are rated for outdoor conditions.

When it comes to PV system installation, problems with galvanic corrosion can stem from fastening hardware. Since much corrosion takes place at a bolted connection, the integrity of each connection is a concern. The fastener selected should not be anodic in relation to the metals being secured or held in place. In PV applications, 18/8 grade stainless fasteners meet this requirement. While stainless steel has become commonplace in PV hardware assemblies, Mudge Fasteners' Dura-Con line uses coatings that reportedly meet or exceed the performance of stainless steel. Another area of concern with galvanic corrosion is with module grounding techniques. See *Code Corner* in *HP137* for more information.

Consult with equipment manufacturers about best practices that consider the climate, and with material trade associations, such as the American Galvanizers Association, that can offer guidance and summaries of research related to galvanic corrosion (www.galvanizeit.org).

—Erika Weliczko • REPower Solutions

Galvanic Corrosion Potential Between Common Construction Metals

	Aluminum	Brass	Bronze	Copper	Galvanized Steel	Iron/Steel	Lead	Stainless Steel	Zinc
Aluminum	—	1	1	1	3	2	2	3	3
Copper	1	2	2	—	2	1	2	1	1
Galvanized steel (zinc)	3	2	2	2	3	3	3	2	3
Lead	2	2	2	2	3	3	—	2	3
Stainless steel	3	1	1	1	2	2	2	—	1
Zinc	3	1	1	1	3	1	3	1	—

1. Galvanic action will occur with direct contact; 2. Galvanic action may occur; 3. Galvanic action is insignificant between these metals.
Source: Steel Tube Institute of North America