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contents

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Photos, clockwise from upper left: SMA America, Fujitsu, Mark McDermott, Surrette Battery, Peter Harris/BuildingGreen, Chuck Marken

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On the Cover

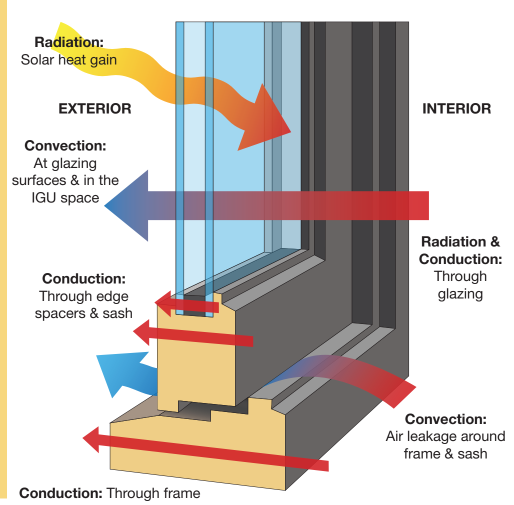
Wayne Robertson's home PV system (under construction in the photo) uses 4-volt, 1,270 Ah Trojan deep-cycle IND23-4V batteries. See page 74 for information on choosing the right battery for your RE system.

Photo courtesy Trojan Battery and Lisa Joyce Photography

contents

66

74



82

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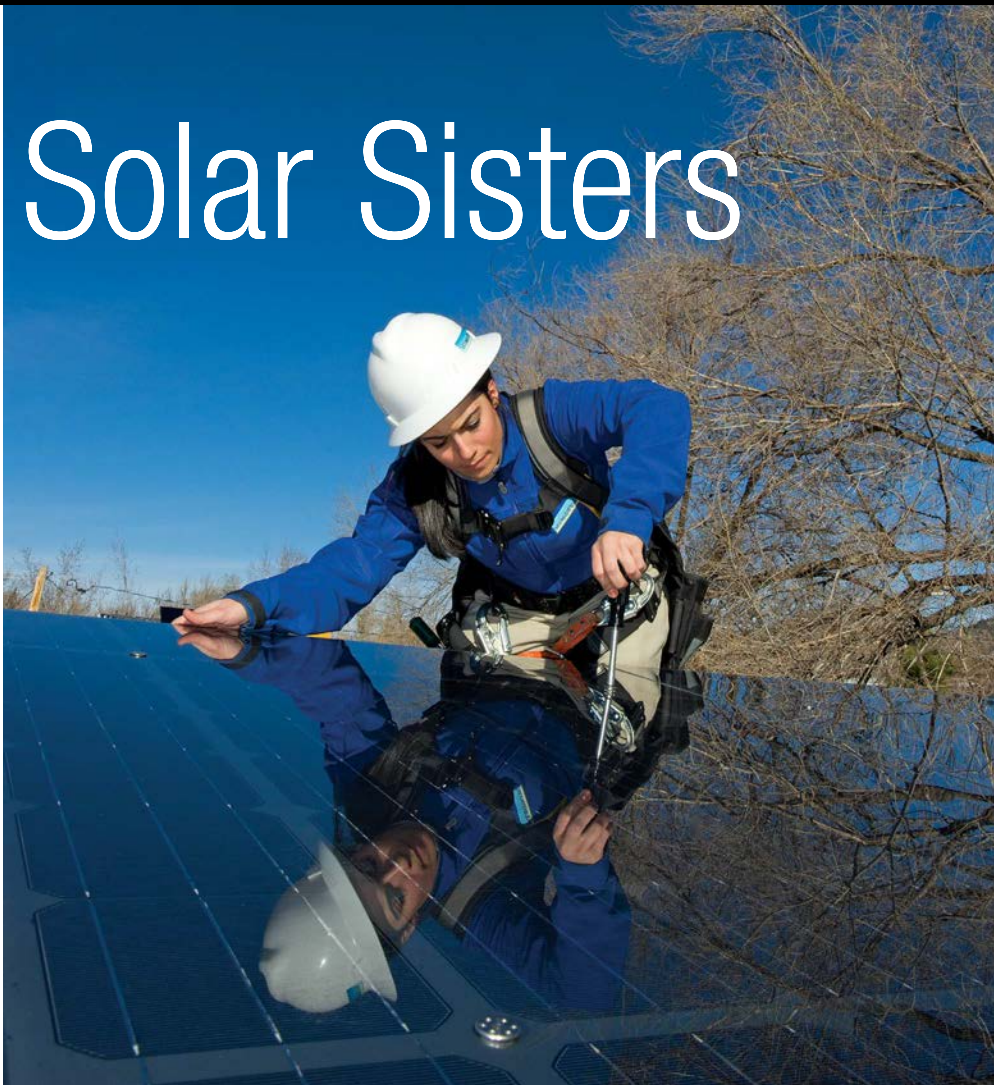

Topher Donahue

I've worked in the renewable energy industry for two decades. When I first started out in solar back in the '90s, very few women were working in the field. One of my goals was to encourage more women to join us. For 10 years, I helped teach a women's PV course for Solar Energy International and had the honor of meeting, teaching, and watching hundreds of women enter the industry.

Across the globe, I have seen our "solar sisters" take on and excel in a variety of roles—as installers, designers, crew leaders, engineers, instructors, project developers and managers, sales and marketing representatives, and educators. I am always excited to see and learn about their latest endeavors and accomplishments. Many of these smart, talented, and inspiring individuals are key players in continuing to move the solar industry forward.

As *Home Power's* senior technical editor, I attend major solar industry business-to-business events around the country. At each one, I excitedly step onto the conference floor and marvel at the aisles upon aisles of solar equipment. I look forward to seeing old friends, meeting new colleagues, and learning about recent equipment and innovation trends.

Unfortunately, one disappointing trend is the objectification of women that is increasingly apparent at these conferences. This "booth babe" culture is at odds with the progressive character and the integrity of the solar industry I joined two decades ago. And each year, it seems to get a little bit worse. An exhibitor at a recent event went as far as displaying women in a cage, dressed in torn catsuits with whips.

Scantily clad women hired by solar companies to draw attention to their products have no place in our industry. This isn't the 1950s. These marketing techniques are inappropriate and unprofessional. Not only does this type of display make me uncomfortable, it also deflates my enthusiasm and excitement for the event. In fact, once I know where the offending booths are, I tend to avoid those areas of the conference floor as much as possible.

As the mother of an 8-year-old girl who is already showing a keen interest in science, it's disheartening that, with the current "booth babe" culture, I wouldn't consider taking her to a solar conference. I am hopeful that event organizers will recognize the negative impact of these sexist marketing stunts, and will encourage a more professional atmosphere at solar industry events in the future.

—Justine Sanchez, for the *Home Power* crew

Think About It...

"There have been fantastic efforts over the years from various groups to promote the role of women in the industry, but it is time for the industry to make this effort formal, both to stop the 'booth babe' culture and to work hard to create compelling careers for women in solar energy."

—Kristen Nicole, Women in Solar Energy • solwomen.org

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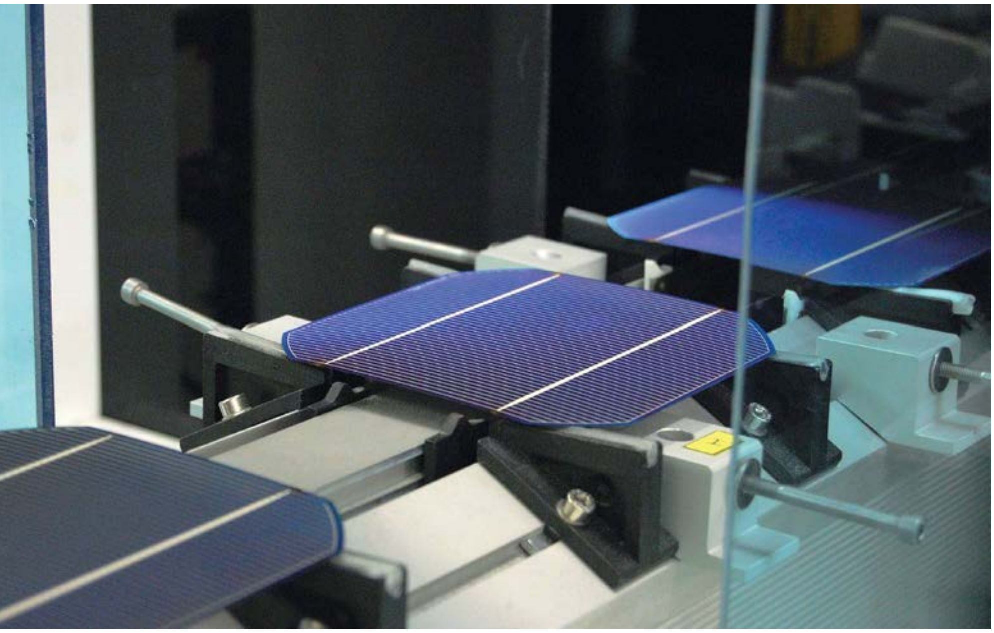
Greener Module Manufacturing

Following some critical reports about improper handling and disposal of toxic waste, the U.S. solar industry is feeling the heat. The flame is a February 2013 article published by The Associated Press (AP) that raised questions about the industry's "dirtier side."

In response to an AP records request for 41 California solar manufacturers, the California Department of Toxic Substances Control (CDTSC) provided data that showed 17 had reported waste, while the remaining did not. The article noted: "The state records show the 17 companies, which had 44 manufacturing facilities in California, produced 46.5 million pounds (23,250 tons) of sludge and contaminated water from 2007 through the first half of 2011. Roughly 97% of it was taken to hazardous waste facilities throughout the state, but more than 1.4 million pounds (700 tons) were transported to nine other states: Arkansas, Minnesota, Nebraska, Rhode Island, Nevada, Washington, Utah, New Mexico, and Arizona."

Courtesy Trina Solar



While the numbers may seem alarming at first glance, a second look reveals that there are more layers to this story. The AP would not share with *Home Power* the list of solar manufacturers that the article addressed, and a spokesperson for the CDTSC said that records requests are not saved and this exact dataset was no longer available.

Dr. Vasilis M. Fthenakis, an expert in PV technology credited with advancing lead-free soldering for PV applications and developing research in thin-film technologies, had the opportunity to examine the records referenced in the article earlier this year and found "the volumes of waste generated in California between 2007 and 2011 are not indicative of the amount of waste being generated by mature manufacturing operations today."

Fthenakis, a senior scientist at Brookhaven National Laboratory in Upton, New York, and the director of the Center for Life Cycle Analysis at Columbia University, found the article's interpretations to be "distorting of the facts." To start, he took issue with the obvious contradiction: The article vilifies U.S. PV manufacturers for following the rules—reporting and handling wastes in accordance with state and federal regulations, and transporting 3% of the waste to Environmental Protection Agency-approved handling facilities in other states.

The records, he says, showed "mostly dilute liquid solutions reflecting startup operations that have not optimized material utilization, and facilities that had not yet invested in liquid-solid separations and recycling processes to minimize the amount of hazardous waste generated."

"In mature operations," says Fthenakis, "hazardous compounds are precipitated and/or separated with ion-exchange processes and liquids are regenerated and/or recycled, to minimize the amount of hazardous waste that has to be disposed."

Dustin Mulvaney, the key source for the AP story, agrees with Fthenakis on this point. "A lot of the companies that are in those records are startups that were trying to perfect their recipe for solar panels during those years. Experimentation like that usually

continued on page 12

continued from page 10

creates more waste than a mature manufacturing facility that has refined its processes," Mulvaney says.

"Any form of energy production has a dirty side, and solar is no exception, but I do think we tend to hold solar manufacturers to higher standards," says Mulvaney. "Unlike conventional fossil-fueled technologies, solar power does not produce harmful greenhouse gases or other air pollutants during operation. The concerns with the chemicals are at the beginning and end of the module's life cycle."(For more information on how PV electricity compares to fossil-fuel produced electricity, see homepower.com/thebigpicture.)

Mulvaney does point out, however, that Germany-based SolarWorld, which has been making PV modules in the United States since 1975, topped the list—a fact the company does not defend or dispute. "It would be surprising if we weren't the largest waste producer in the state during those years, since we were the largest manufacturer in the state," says Ben Santarris, a SolarWorld spokesperson.

During those years, the company's Camarillo, California, plant produced as much as 150 megawatts of modules annually. SolarWorld purchased the Camarillo plant in 2006 from Shell Solar, and upgraded the facility to automate module assembly operations, but closed the plant in 2011 and consolidated all domestic manufacturing at its facility in Hillsboro, Oregon.

"The fact that the AP can do this article and look up public records about our practices is a good thing. It is all part of the robust system of checks and balances that supports our regulatory environment, and pushes American industry to achieve higher standards. We have nothing to hide," Santarris says. "You can't say the same about producers operating in China, where there is no transparency."

Sergio Vasquez, health, safety, and environment and facilities manager for SolarWorld America, says the issue boils down to economics. "We need to use certain chemicals, but chemicals are expensive. The fewer chemicals we use, the more money we save. The less we pollute, the less we pay to mitigate our waste and the less we pay for environmental control equipment. There is no motivation to be wasteful."

SVTC Steps In

It is no secret that solar manufacturing involves toxic chemicals and heavy metals—such as cadmium, copper, lead, and selenium. Like most industrial chemicals and metals, these materials require special handling and regulation to limit exposure to the environment and workers. Any hazardous byproducts and wastewater must be handled in accordance with local, state, and federal regulations.

The Silicon Valley Toxics Coalition (SVTC), a San Jose-based environmental watchdog organization, calls for the reduction and eventual elimination of these toxic chemicals. In 2009, the group released a white paper that documented the environmental and health hazards associated with solar modules. The report recognized that, although PV modules provide clean energy while in use and can help address global warming, a variety of factors during the manufacturing and disposal of the modules have the potential to damage the environment.

"Modules are designed to live on a roof, in a completely inhospitable environment. They can withstand heat and moisture, and they are pretty solid. The semiconductor material, where the chemicals are housed, is encapsulated. So long as the integrity of the module is not compromised to expose the actual semiconductor, then there's little risk of the chemicals escaping into the environment," says Mulvaney, coauthor of the paper, and the technical advisor for the SVTC's Just & Sustainable Solar Industry campaign.

Today's most common PV technology—crystalline silicon (c-Si)—is based on silicon semiconductors, and uses manufacturing processes and materials similar to those of the

continued on page 14

Abound Solar Spoils

Fueling the fire is coverage of the cleanup of defective or unsellable thin-film PV modules and other "hazardous waste" left behind by now-bankrupt Abound Solar at its four Colorado warehouses and manufacturing facilities.

Abound Solar filed for bankruptcy in June 2012, and since then, has been making headlines for violating state hazardous waste laws, including operating without proper hazardous waste handling permits. The Loveland, Colorado-based solar module manufacturer left behind nearly 100,000 defective and unused solar modules, along with 4,100 gallons of cadmium-tainted waste in drums and tanks, and building-wide cadmium dust contamination at two sites.

Abound's facilities included two manufacturing plants and two warehouses for storing finished and returned modules. The two warehouses had no contamination or wastes aside from pallets of modules, which were deemed hazardous waste by the Colorado Department of Public Health and Environment (CDPHE).

In documents and news reports, the modules were called "hazardous waste." However, what most media outlets did not clarify was the reasoning. "Once abandoned, the modules—whether intact or damaged—contain cadmium, and the abandonment constituted an illegal 'disposal,'" explains department spokesman Mark Salley. "Cadmium is not a particularly difficult contaminant to control. It is in a metallic form combined with another metal—tellurium."

The modules produced by Abound were based on a thin-film PV technology that applies a semiconductor layer of cadmium telluride atop a sheet of glass. A similar process is utilized by First Solar and other thin-film solar manufacturers.

As of July 2013, three of the four Abound sites had been "decontaminated" in accordance with a compliance order issued by the CDPHE in February. About 70,000 usable modules were purchased by Best Safety Glass in Singapore, and the remaining unsellable lot, some 22,000 defective or broken modules, were shipped to First Solar's thin-film recycling facility in Ohio, where up to 95% of the semiconductor material can be reclaimed for reuse in new modules. Other miscellaneous wastes were shipped to landfills and hazardous treatment facilities.

Courtesy First Solar

continued from page 12

microelectronics industry. As Mulvaney explains, there are three main chemicals of concern related to c-Si production: silicon tetrachloride, hydrofluoric acid, and lead. Silicon tetrachloride is a toxic byproduct of polysilicon production, but most companies have invested in the equipment to recover and reuse it in new silicon feedstock.

Hydrofluoric acid is used to etch and remove oxidation from semiconductors, and discharged into the wastewater. While the acid can be neutralized and the wastewater treated to remove the pollutants, the industry is exploring alternatives for hydrofluoric acid etching. "Other chemicals and thermal processes could be used, but they are more expensive and not commercially proven at this point. Companies have described efforts to reduce hydrofluoric acid and better treat wastewater containing it, but it remains an essential input for making silicon-based PV," Mulvaney says.

Lead is used to solder PV electrical components, but there has been an industry push to use lead-free or tin-lead alternatives, with lower toxicity levels. Some manufacturers—including SunPower, Mitsubishi Electric, and Trina Solar—offer lead-free or low-lead content modules.

A key concern is that photovoltaic manufacturing and production processes require large amounts of water that discharge different pollutants such as hydrogen fluorides, suspended solids, mixed acids, silicon dioxide, and high oxide particles. Demonstrating the need for chemical reduction plans, a study that appeared in the March edition of the *Desalination and Water Treatment Journal* explored wastewater treatment options for PV manufacturing, and noted that wastewaters produced by PV manufacturing are "highly toxic and contain high concentrations of fluoride."

Newer thin-film technologies use less semiconductor material, but there are also health and environmental concerns related to these technologies. The more-popular thin-film technologies—cadmium telluride (CdTe) and copper indium gallium selenide (CIGS) mainly used in large commercial PV installations—contain cadmium, a carcinogen that is considered highly toxic by the EPA and Occupational Safety and Health Administration (see "Abound Solar Spoils" sidebar).

Cadmium is banned by the European Parliament's Restriction of the Use of Certain Hazardous Substances (RoHS), which requires by law that certain hazardous substances, including lead, mercury, and cadmium, be replaced with safer alternatives in electrical and electronic equipment. CdTe thin-film PV modules are explicitly allowed by RoHS to contain unlimited cadmium, even though cadmium is restricted in all other electronics. This exemption is why thin-film companies like First Solar are able to sell their CdTe modules in Europe. Proving what is possible, Japan-based Solar Frontier has developed copper indium selenide (CIS) thin-film solar modules that are cadmium- and lead-free.

On the production side, there's also the energy used by solar manufacturing facilities to factor into the equation. While there is some PV manufacturing accomplished largely with solar power, the most energy-intensive processes—polysilicon manufacturing, for example—are often upstream and rarely powered by renewable energy, Mulvaney says.

Dealing with Waste

As of 2014, EU's Directive on Waste in Electrical and Electronic Equipment (WEEE) will also apply to PV modules, and require solar manufacturers to operate recycling and recovery programs for their products. Currently no such federal mandate exists in the United States.

Part of the problem, says Sheila Davis, executive director for the SVTC, is that the "universal waste" laws that govern hazardous waste disposal vary by state. "What is considered hazardous waste in one state may not be in another. That makes it difficult to regulate and ensure that *all* modules are being manufactured, and disposed of, safely," she says.

California's standards are known to be more strict than most states, and, in some cases, surpass the federal government's regulations. The state's standards are nearly identical to those at the federal level, but the state applies the standards to more wastes. Dry-cell alkaline batteries, for one, are considered hazardous waste in California, but not at the federal level.

While PV modules are not identified as hazardous waste at the federal level, they are regulated as hazardous waste in California—largely due to concentrations of cadmium and other toxic materials, and the potential that those materials might leach into the soil or water if not disposed of properly, according to Rick Braush, division chief for policy and program support with the CDTSC.

The problem with California's stricter enforcement is that complex cradle-to-grave protocols and manifests must be completed by the end user of the PV module. At the residential level, as the current hazardous waste management scheme for PV modules stands, that means the homeowner must complete all the paperwork as the end user. To streamline the process, the CDTSC is in the process of adopting a new regulation that would relieve some of the bureaucratic burden and make it easier for the average homeowner to recycle PV modules.

continued on page 16

continued from page 14

"Our concern is that the complexity of the process will encourage clandestine and illegal dumping," says Braush. "We are not so much concerned with the owners of large arrays, like utilities and large businesses, because they have the resources to handle these matters. We are more concerned with homeowners and smaller system owners. If they cannot dispose of the PV modules with ease, then we're worried people will abandon them on the roadside or wherever, or they'll end up tossing them in normal landfills where the materials could leach into our water and soil."

On the Horizon

In the absence of consistent state regulations to monitor solar manufacturing and end-of-life waste, SVTC created its Solar Scorecard to encourage greater accountability. According to Davis, survey response through the years has been lower than what would be expected of a green industry.

In August, the SVTC released its 2013 Solar Scorecard. Ten companies, representing 34.6% of the PV module market share, responded to the 2013 survey—a decline from 51.1% in 2012, due largely to the bankruptcy of several former participants and declining market shares of the remaining participants.

For the second year in a row, Trina Solar captured the scorecard's top spot for its environmental and social performance (see "Solar Scorecard Highlights"). Trina bumped SolarWorld from its No. 1 spot in 2012—the two have been vocal adversaries in the U.S.-China trade dispute in recent years. "The fact that two Chinese firms topped the list this year may motivate U.S. manufacturers to do better," Davis says.

Davis does, however, point out that Trina and Yingli are the exception among Chinese companies. "We're glad that they're participating and exhibiting a strong commitment to their environmental and labor practices, but most of their Chinese counterparts are at the bottom of the list because they did not respond to the survey and do not publicly share information about what they're doing," Davis says. "Moving forward, we want to push the bottom-dwellers to respond to the survey and take responsibility for their practices. At this point, every solar manufacturer should have a chemical reduction plan and a take-back program in place.

"Overall, the industry seems to be making strides in the right direction, and taking a different path than the microcomputer and electronics industries, which did not put enough thought into the manufacturing and disposal of their products, and ultimately created a global e-waste problem," says Davis, who fears that solar companies are becoming so pressed by competition that they are going to start cutting corners. "It could become a competitive disadvantage to be green," she says.

Additionally, Davis would like to see more support from the Solar Energy Industries Association in pushing its members to be more transparent. "This industry needs strong leadership to stay on the right course. Too many solar manufacturers are still unwilling to share their practices publicly, and that's not okay for any company in any industry," she says. "If they're truly as green as they claim to be, then a solar company should have no problem reporting their health, safety, and sustainability metrics on their websites and within annual reports."

—Kelly Davidson

Solar Scorecard Highlights

For the 2013 Solar Scorecard, SVTC augmented its research and scoring, including prior survey responses and additional sources such as interviews, news stories, and publicly available data and information. As a result of the more difficult and comprehensive methods, some companies may have scored lower than they did in years past. Here are some highlights from the 2013 Scorecard:

- Twelve PV manufacturers post annual hazardous chemical reduction targets on their websites or in sustainability reports.
- Nine companies—Yingli, Trina, SunPower, Upsolar, Axitec, Mitsubishi, Renesola, LDK, and Solar Frontier—manufacture PV modules with amounts of cadmium or lead below the world's most stringent regulatory thresholds set by the European Union. This means that the maximum concentration found in any homogenous material that makes up the PV modules made by these companies is less than 0.01% for cadmium and 0.10% or less for lead.
- Three PV manufacturers—REC, SolarWorld, and Yingli—do extensive chemical emissions disclosure and reporting. Fourteen companies report one or more categories of emissions (hazardous waste, heavy metals, air pollution, ozone depleting substances, and landfill disposal). The caveat is that some companies make everything from polysilicon to PV modules, and some companies only make PV modules. While a PV module manufacturer may appear to have lower emissions, this is because other companies do the more chemical-intensive aspects of production. For an apples-to-apples comparison, it is therefore important to ensure that a company's supply chains also participate in chemical reporting so the emissions data is complete.

For the complete results, check out the SVTC's Solar Scorecard at solarscorecard.com and examine the life cycle effects of photovoltaic products at svtc.org/solarlifecycle.

web extra

How Does PV Compare to Fossil Fuels?

According to the U.S. Energy Information Administration, nuclear, hydro, wind, and solar sources met 18% of total U.S. energy consumption, yet produced *none* of the country's energy-production-related carbon dioxide emissions. Conversely, coal accounted for 20% of the energy consumption, with 34% of the emissions; petroleum provided 36% of the energy consumption, with 42% of the emissions; and natural gas provided 26% of the energy consumed, with 24% of the emissions.

Read the full article at **homepower.com/thebigpicture**

SMA Sunny Boy

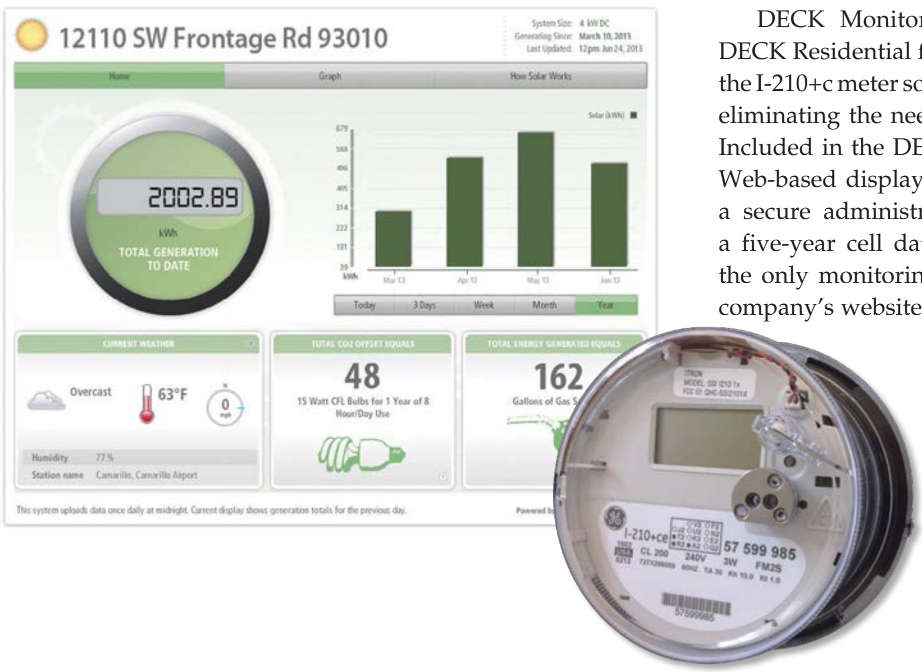
240-US Microinverter

Courtesy SMA America

SMA America (sma-america.com) released its Sunny Boy 240-US microinverter in August 2013. It can accept up to 250 watts from a photovoltaic module, with a maximum rated AC output of 240 W at 240 VAC, and a 96% CEC efficiency. The microinverter connects to the DC output of a module and its AC output is in turn connected in a daisy-chain to the next microinverter. Communications and final connection to the grid is through the Sunny Multigate, which accepts up to 12 microinverters and sends the aggregated power to a circuit breaker in the site's AC load center. The Multigate can be connected to an onsite Internet router, enabling module-level monitoring which can be viewed either by Sunny Explorer software on an onsite computer, or through SMA's Sunny Portal website.

—Justine Sanchez

DECK Residential Monitoring



Courtesy DECK Monitoring

DECK Monitoring (deckmonitoring.com) released the DECK Residential for online monitoring of PV systems using the I-210+c meter socket. The meter includes a cellular modem, eliminating the need for additional communications wiring. Included in the DECK monitoring package is the meter, the Web-based display (both a public "dashboard" display and a secure administration page for project developers), and a five-year cell data plan. Except for an on-board display, the only monitoring available for the DECK is through the company's website.

—Justine Sanchez

Networking Community Power

With support from the Community Power Network and the Capitol Hill Energy Cooperative, the Lutheran Church of the Reformation installed a 17-kilowatt PV system.

What began with one Washington, D.C. neighborhood has grown into a national network committed to building community renewable energy systems across the country.

In 2006, 12-year-old neighborhood pals Walter Lynn and Diego Arene-Morley attended a screening of Al Gore's *An Inconvenient Truth*—a documentary about climate change—with their parents. The two boys surfaced from the movie with an acute observation: "Why do so many grown-ups talk about climate change but don't do anything about it?"

The two boys then asked their parents, "Why don't we just put solar on our houses?" It was a seemingly simple question with a not-so-simple answer, recalls Walter's mom Anya Schoolman. "Back then, solar [electricity] was very expensive, installing for about $8 per watt. There were no locally or federally funded rebates available, and the District's policy did not encourage utilities to provide incentives," says Schoolman, who understood the complexities of energy policy having held high-level positions in the U.S. Department of the Interior. "I knew it would be a lot of work, jumping through the hoops and dealing with all the bureaucracy. Rather than do all that work for just one or two houses, we came up with the idea to do solar at the neighborhood scale."

The two boys, Schoolman, and Diego's father Jeff Morley hashed out a plan to bring rooftop PV systems to D.C.'s Mount Pleasant neighborhood. At Schoolman's kitchen table, about two miles from the White House, the Mount Pleasant Cooperative (MPC) was born. "We started with the idea of a bulk-purchase program, but we quickly discovered that we needed to first address the holes in the existing policy," Schoolman says.

Over the next couple of years, the MPC organized members and lobbied for new local energy policies. As a result of their efforts, the District passed landmark legislation that created rebates and incentives for RE systems, which made residential rooftop PV systems more affordable. With favorable policies in place, the MPC organized a series of bulk solar purchases, saving participating co-op members 20% or more on installation and equipment costs. Since then, nearly 100 row houses in the Mount Pleasant neighborhood have installed grid-tied PV systems.

As word spread about the MPC's success, Schoolman received requests from other D.C. neighborhoods interested in starting their own co-ops. By 2010, she had helped launch cooperatives in all eight wards of the District and formed a citywide umbrella organization called DC Solar United Neighborhoods (DC SUN), which lobbies for local RE policy change and provides support for neighborhood solar co-ops.

Before long, Schoolman was fielding calls and emails from people all over the country. In 2011, she founded the Community Power Network (CPN), a nonprofit group that serves as a platform for RE advocates to share their experiences about community RE projects. Supported by grants from foundations and other organizations, the CPN has grown into a national network of more than 90 independent community and nonprofit organizations across the country.

"We have a broad definition of what community power is," Schoolman says. "The projects come in all different shapes and sizes. It is not just the neighborhood cooperative. It can be a school or church that wants to go solar, a group of homeowners that want to build a solar garden, or a statewide group of citizens lobbying for policies that support community RE. The common thread is an interest in creating a decentralized RE system that benefits everyone."

Emily Stiever, CPN's program director, is one of four full-time staff. "We'll talk or meet with people interested in starting a project to help them figure out a strategic approach or organizational structure," says Stiever. "For instance, I recently spoke with a group in Missouri that wants to organize a neighborhood solar group purchase. I shared our experience organizing this type of project in D.C., and I suggested that they operate as a community organization rather than a business. I also suggested that they start with a pilot project before incorporating, since their approach and mission may change once they have some experience."

The CPN connects organizations via its membership directory, and uses its weekly newsletter, website, Listserv, and social media platforms to share information and ideas.

continued on page 22

continued from page 20

"Often our members will read about a project that another group is doing and contact us. We'll then put them in touch with one another, so they can share information or work together," Stiever adds.

"The CPN gave us great exposure. I've had great conversations with members, and I've made valuable connections," says Andreas Karelas, founder of San Francisco-based RE-volv. A member since July 2012, Karelas credits the lessons he learned from fellow members and the publicity he received through the CPN for helping RE-volv raise the funds to complete its first project this spring—a 10-kilowatt PV system for the nonprofit Shawl-Anderson Dance Center in Berkeley, California. In a little more than one year since its launch, RE-volv has gone from being virtually unknown to receiving national attention for its unique nonprofit model, which pools donations into a revolving "solar seed fund" to provide leases for community solar energy projects at schools, universities, hospitals, and places of worship.

"There are many community power groups out there—renewable energy groups, energy efficiency groups, energy conservation groups, and the like. These groups often share common goals but find themselves pitted against one another competing for local funding. The CPN is serving a critical need, helping these groups find allies and build successful coalitions," says Robert Robinson, an activist with DC SUN.

A key function of the CPN is helping member groups develop campaigns and strategies to advocate for local policy changes. This may include anything from hosting petitions and managing email lists of supporters to taking "an insider's baseball" approach, says Stiever.

Currently, Schoolman and her team are helping DC SUN activists lobby the District Council for net-metering legislation that would allow "virtual" access to PV systems for renters, condominium owners, and people whose rooftops aren't suitable for solar electric systems. They also helped launch SUN groups in Maryland and Virginia. Both groups are in the process of organizing solar bulk purchases in several neighborhoods throughout the region.

Schoolman says her best advice came from her son: "'You don't have to know what you're doing before you start. The key is just starting,' he told me," says Schoolman. "So much of our success has been a process of learning by doing."

—Kelly Davidson

Join CPN

To become a member, visit **communitypowernetwork.com**

Tracking PV in Washington State

Courtesy Brothers Electric Solar

"It doesn't have to go on your roof," I explained to homeowner Eric Lindgren of Bonney Lake, Washington, while Alex from Brothers Electric Solar was on the roof measuring for a new PV array. To take advantage of Washington's production incentive program, Lindgren was considering installing a 9-kilowatt solar-electric system, which would generate enough energy to recoup costs before the program expires in 2020. But the roof had its challenges: it was partially shaded and the shingles needed to be replaced. At a 5:12 pitch, it wasn't at an optimal angle for a flush-mounted PV array. Plus, there wasn't enough space on the roof to fit a PV system that would max out the yearly incentive payment. Lindgren's south-facing yard was huge, though—perfect for a ground-mounted array.

We measured the area for a 9.12 kW array. To capture the highest incentive rate, we needed to use Washington-made equipment, which meant using 38 Itek Energy 240 W modules and Altenergy Power System (APS) microinverters. The same modules installed on a dual-axis tracking mount, however, only needed to be 7.2 kW, since production increases by up to 28% with a tracked array at this location. We estimated that two rows of 15 modules each on Sedona Solar dual-axis frames could produce the kilowatt-hours needed to pay off the system within seven years.

Compared to the fixed system, installing a dual-axis tracking framework and controllers was less expensive, since there were eight fewer modules and inverters to purchase. An added bonus in Lindgren's case is that the two arrays fit perfectly around his garden.

The framework that holds the modules and tracking frames is mounted on eight 4-inch-diameter galvanized steel posts set in concrete. Two actuating arms control the array's elevation and another controls its azimuth. They are energized by the controller and position the array by calculating the sun's position based on the site's longitude, latitude, and local time.

Each module is wired to a microinverter. The inverters and wiring had to be carefully placed on the framework to avoid any contact with the rotating modules and rack. Module-level online monitoring is through the APS software, and a smartphone app (designed by Lauritzen Inc.) is available for remote operation of the system. Having remote control of the array allows the system owner or installer to reposition the modules for cleaning, maintenance, storm readiness, or even snow clearing—without having to open up the control box on each subarray. The smartphone app allows access to the controller's many parameters with a joystick-like interface.

—Dave Cozine

Overview

System type: Batteryless grid-tied

Owners: Elizabeth & Eric Lindgren

Installer: Brothers Electric Solar LLC

Date commissioned: April 2013

City: Bonney Lake, Washington

Latitude: 47°

Average daily peak sun-hours: 3.8 (4.9 with dual-axis tracking)

System capacity: 7.2 kW STC

Estimated PVWatts annual production: 9,600 kWh AC

Estimated annual utility bill offset: 75%

Equipment Specifications

Number of modules: 30

Manufacturer and model: Itek Energy 240

Module rating: 240 W STC

Inverters: 30 Altenergy Power System YC-200

Rated output: 225 W

Array installation: Dual-axis tracking

Mount manufacturer: Sedona Solar Technologies

Controllers: Lauritzen Inc.

Predicting SWH Performance with RETScreen

How much energy can you save with a solar water heating (SWH) system? Here's a modeling system that can help you estimate your system's performance.

While organizations such as the Solar Rating & Certification Corporation (SRCC) provide ratings for solar collectors and SWH systems, this data is best for comparing the performance of different types of solar equipment. The system performance estimates through these programs are only accurate for a particular project if that project shares similar characteristics with the testing protocols.

For example, the SRCC OG300 system ratings are based upon a household that sets the water heater temperature at 135°F, uses 64.3 gallons of hot water per day in a very specific pattern, and has an incoming cold water temperature of 58°F. These ratings assume a due-south orientation, but do not account for shading, variations in collector orientation, or a household that uses significantly more or less than 64.3 gallons per day.

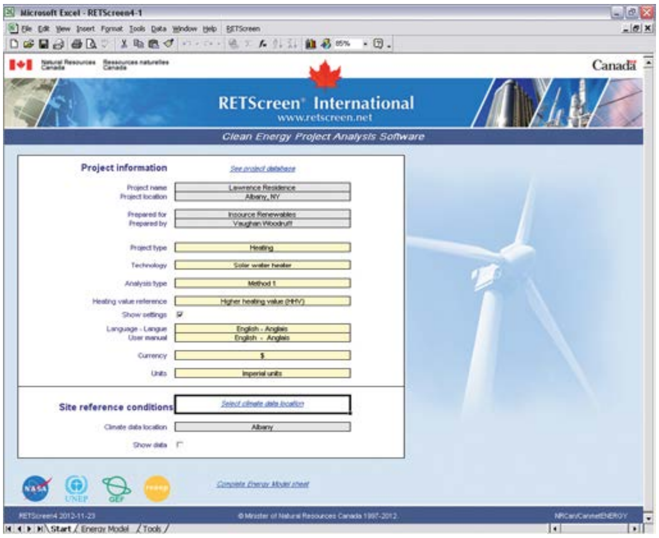
SWH professionals use a variety of modeling programs to predict the performance of a SWH project. These programs utilize climate data, including outdoor air temperatures and the amount of available solar radiation, to predict system performance. Some of them even account for the variations in incoming water temperature. Professionals input project-specific data, such as the location of the project, daily hot water consumption, collector orientation, and the type of SWH equipment.

One such modeling program is the RETScreen Clean Energy Project Analysis software developed by Natural Resources Canada. This free software is a Microsoft Excel-based spreadsheet that can be used for modeling a variety of systems, including simple solar water heating systems. The program uses several sheets within an Excel workbook to perform its analysis.

"Start" Worksheet

RETScreen can provide performance estimates for a number of renewable energy and energy-efficiency technologies. The Start worksheet is where the user specifies a domestic SWH project by selecting Heating as the "Project Type" and Solar water heater as the "Technology."

Language and units (like metric vs. imperial) are set in this first worksheet. The user must also retrieve the appropriate climate data for the project site by selecting a weather station in RETScreen's database.

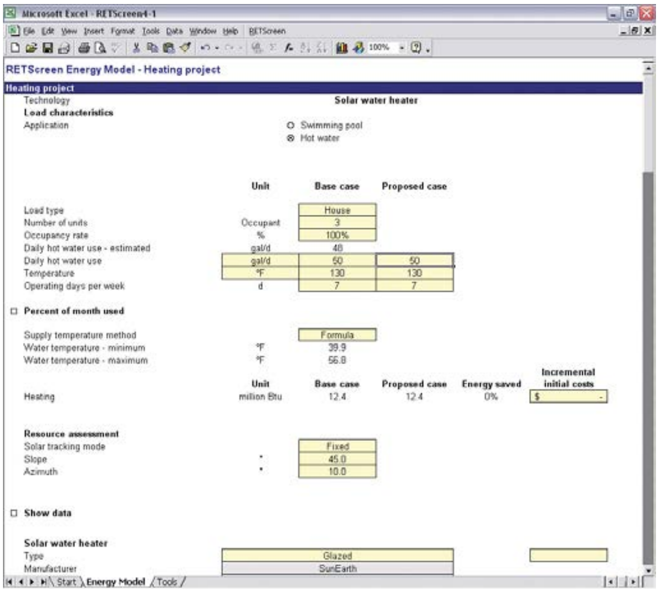


Energy Model Worksheet

Next, the user selects the Energy Model worksheet to enter information on the hot water use characteristics of the home, the orientation of the collector array, and the key system components. RETScreen uses an internal database that estimates the daily hot water load. This estimate is displayed based upon the number of occupants. The user may either enter this value or select a more precise value based upon the number of showers, loads of laundry, etc.

The collector's tilt and azimuth must be entered. The array azimuth is entered as a value relative to south. A value of 0° denotes true south.

continued on page 28



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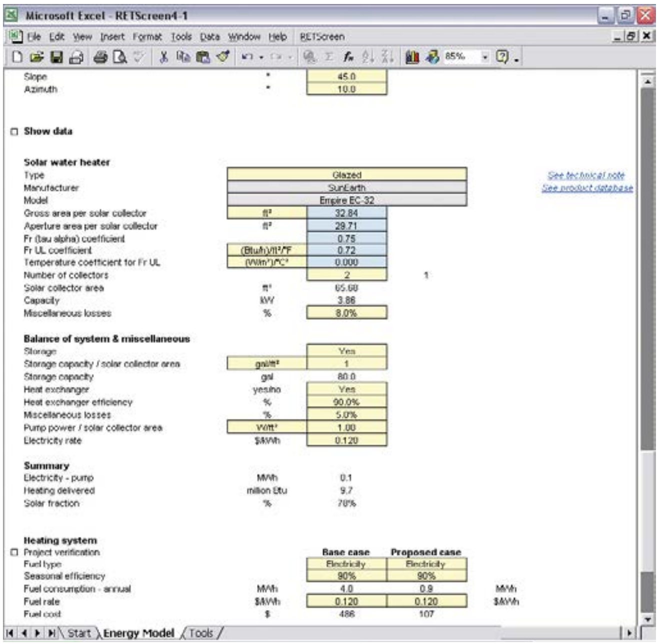

The specific collector used for the project can be selected from the internal database by clicking on the "See project database" link. If a collector is not in the database, the specifications can be entered manually from a rating sheet. (When you're entering this information, be sure that the units are consistent.)

If a shading analysis has been performed for the site, the effects of shading can be entered in the "Miscellaneous losses" field in the Solar Water Heater section of the Energy Model worksheet. Other information entered into the model includes storage tank size, heat exchanger efficiency, and the amount of energy required by the pump(s) to run the system.

Interpreting the Results

In the Summary section of the Energy Model sheet, the "Heat Delivered" estimate is displayed, as is the "Solar Fraction"—the percentage of total domestic hot water that is supplied by the SWH system. The user can enter information on the type of fuel, fuel cost, and efficiency of the heating appliance to estimate energy costs, with and without the SWH system to estimate energy savings. It is useful to compare the cost estimate for the "Base case" (without the SWH system) to current water heating costs to verify the accuracy of the results.

Since it is often difficult to quantify the daily hot water use, it can be a challenge to determine the energy costs attributed solely to water heating. It takes some finesse to ensure the results of any performance modeling software is within reason.

There is a steep learning curve when using RETScreen, even for those who are familiar with Microsoft Excel. With additional information, the program also provides economic estimates for a particular system. RETScreen has an extremely detailed user manual available online.

—Vaughan Woodruff


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Enough is Enough

On the shoulders of previous generations, women have made remarkable strides in gender equality, but we all know the fight is far from over. Around the country, gender politics are coming to a head. In state and federal legislatures, and in the U.S. military, women are on the front lines, battling for basic and fundamental human rights, equality, and dignity. Again this year, the global community has born witness to heinous crimes against women and girls in developing countries and in conflict zones. And in addition to these aggressive attacks, every day, every woman has to endure many difficult decisions not only regarding the kind of woman she is going to be, but the kind of person she is going to be and what values she is going to project to the world.

It seems like only a few years ago, our generation (and the mainstream media) had a very awkward time articulating gender issues, but feminism is not a clichéd concept from another era. In 2013, the gender context on issues of basic human rights, equality, respect, and dignity are real and very much alive, including in the solar industry and in the broader context of the clean energy revolution.

For those of us who have attended Solar Power International (SPI) and Intersolar, we (the solar industry) have definitely noticed (and mostly scoffed at) the ever-increasing "booth babe" culture. I don't think we need to draw a picture, but suffice it to say this culture encourages a certain image that portrays women as sex objects for marketing purposes (we get it: sex sells). This has occurred for years now, but increasingly, scantily clad women are becoming more scantily clad and are being featured at SPI after-parties and cocktail hours, impacting the entire conference culture. It has become impossible to ignore and is, frankly, a huge distraction.

At SPI last year in Orlando, Florida, this issue went too far. One of the largest solar manufacturing companies developed advertisements for a product line they called "nice rack." Further, folks outside the industry took notice. See the related write-up below:

> These ads not only diminish and trivialize women, but they discourage them from entering a field of work where they are already underrepresented. They also encourage men within the industry to continue to see women as outsiders—valuable only for their beauty and sexuality.
>
> When an influential company like [omit company name] throws a "Nice Rack" party—the self-proclaimed "biggest solar party of the year," which is taking place during one of the biggest industry weekends of the year (according to this site, last year's SPI event was attended by 24,000 professionals and more than 1,200 exhibitors)—they are implying some pretty shallow things about the professional people who will actually be attending said event.
>
> —Imran Siddiquee, "#NotBuyingIt: Solar Company Advertises 'Nice Rack' Party," missrepresentation.org

Aside from this example, the undertones of this culture are rampant and adding unnecessary negativity in our industry—and it is only getting worse. What's ironic is that the industry has real issues with gender diversity—it should be attracting more young girls to solar, and this culture is a huge deterrent. At the same SPI conference last year, the representation of female speakers on conference panels was fewer than 9%.

The solar industry has many awesome women, but this awesomeness does not reveal itself through our "nice racks." In fact, most of us women in the solar industry haven't gotten to where we are in life by being very "nice" at all—one could argue that most of us are 100% badass. The women who are drawn to the solar industry are unapologetic environmentalists, brilliant engineers and scientists, precise construction workers and project managers, ruthless financial and corporate cats, tough-jawed policy advocates, and relentless educators. Simultaneously, we are all working moms, wives, sisters and/or daughters who are trying to change this world for the better. Any woman or girl who is educating herself to purchase or support solar energy is a trailblazer, a true visionary. The industry should be nothing but proud of its women.

At solwomen.org, we have humble roots but we have been working to get greater organization, visibility, and participation for women in the solar industry. There have been fantastic efforts over the years from various groups to promote the role of women in the industry, but it is time for the industry to make this effort formal, both to stop the "booth babe" culture and to create compelling careers for women in solar energy.

We are asking our solar industry leaders to help get us back on track. Here are a few options:

- Support a culture of professionalism in the solar energy industry, within your own organizations and specifically at industry events.
- Make a concerted effort to support women in the solar industry through programs that help elevate more women of influence in the industry. This includes supporting solar-related education programs, women-in-solar workforce development, women-owned businesses, and international development efforts supporting solar, humanitarian causes, and women.
- Consider formally supporting further development of organizations like ours, which is promoting the involvement of women in advancing the solar industry.

The women of the solar industry are fully prepared to further drive these efforts, but we need your support and leadership to set an expectation of professionalism for the industry.

Kristen Nicole • Women in Solar Energy

Insulation Typo?

I read with interest the cover story in *HP156.* Everyone involved in that project is to be commended for doing the best for Mother Earth. One thing caught my attention, however. The cross-sectional drawing on page 39 shows the R-value of a nonbearing 2-by-4 wall filled with loose-fill cellulose as R-24. My best guess, or maybe my hope, is that this is simply an editing error.

As a charter subscriber to both *Home Power* and *Fine Homebuilding*, I have read many similar articles and researched cellulose insulation extensively for use in my own home. Cellulose increases in R-value as density goes up, to a point. To the best of my understanding, R-4 per inch is the highest value. So, with a 3.5-inch cavity, taking the absolute best-case scenario, you could maybe achieve R-14 (3.5 x 4 = 14). Loose-fill cellulose is more in the R-2.5 to R-3 range, and that is only achievable in an open cavity. Judging from the picture on page 40, I would say the stud spacing is 24 inches on center, and framing members bring down the overall R-value average, sometimes between 15% and 20%. I would be surprised if the 2-by-4 wall is R-10. If the author stands by the R-24 assertion, I would be interested to learn how that number was arrived at. Incidentally, the same drawing shows an 8.25-inch SIP wall at R-24 as well. I realize it's a different type of insulation, but this is far more plausible.

Steve Borgatti • via email

The wall assembly for this home is actually a 6 1/2-inch SIP panel (R-24)—not an 8 1/4-inch panel as depicted—with a 1 3/8-inch airspace. The 2-by-4 wall inside the panel is faced with 5/8-inch plasterboard, yielding an overall wall thickness of 12 inches. According to

continued on page 32

continued from page 30

your calculations, this would make the total nominal R-value 44. Using Oakridge National Testing Laboratory's whole-wall R-values (bit.ly/WallRValues), the 2-by-4 wall plus the airspace would yield R-19.88. With the SIP R-value of 22.04, that gives a whole-wall R-value of 41.92.

One of the features of this double-wall system is that the inner wall can be positioned to add as much space as you need to achieve your target R-value, using the insulation of your choice.

Patrick Sughrue • structuresnw.com

Happy EV User

I've been driving my 2011 Nissan Leaf electric vehicle for a couple of years now, and it is truly a remarkable car. So far, I have spent absolutely nothing on maintenance, and have saved a lot on fuel cost. It bears mentioning that with an EV, the owner often has more choices of where and how to "refuel." You can charge at home, and some charging stations are free. I have a solar-electric system installed on my home, which makes my electricity clean and very inexpensive.

When I ordered my Leaf in late 2010, it was really the only mass-production EV available. Fortunately, after a test drive, I was sold and pretty excited to own one. The range was advertised as 100 miles, but I knew this is only realistic under perfect conditions. A more realistic average range is more like 80 miles. The Leaf meets my needs just fine, since my typical daily commute is less than 40 miles. I own no other vehicle.

However, for anyone considering buying an EV, you need to realize that the car's battery pack is not just another "fuel" tank that just needs refilling. It is a sensitive, expensive, and critical component of an EV, and needs to be treated with care to get the most out of it. Some Leaf drivers I know are finding out that one of the consequences of not following Nissan's recommendations is sooner-than-expected reduced battery capacity. I really look forward to breakthroughs in battery electric vehicle technology.

The lineup of available EVs is growing. For me, there was never any question that I wanted a pure electric vehicle, and I was willing to adjust to living without the gas pump.

Marc Fontana • via homepower.com

In Support of All Solar Energy

I am writing in support of Steve Baer's letter to the editor entitled "Question Authority" in *HP155*. He is right to question the assumption that solar power is available only from the corporate-controlled grid. As an avid gardener, I have to remind visitors to our solar house that photosynthesis is also solar energy.

I had been reading Steve Baer's articles in issues of the *Co-Evolutionary Quarterly* and *Whole Earth Catalogs* back in the 1970s.

Maynard Kaufman • Bangor, Michigan

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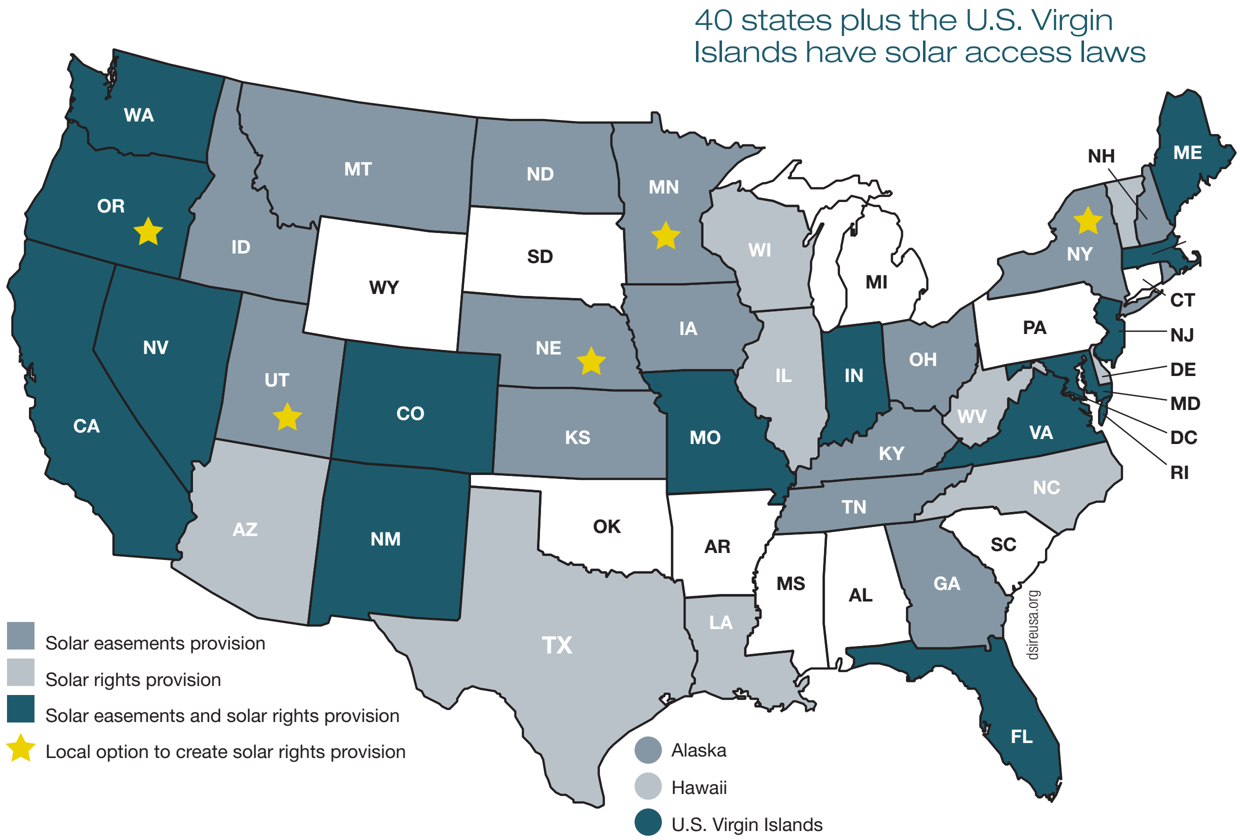

Who Owns My Sunlight?

Legal access to sunshine is an extremely important consideration, especially in a city or other densely populated area. Who owns your sunlight? Surprise! In many parts of the United States, you don't necessarily own your sunlight.

I did not get any easements, conveyable or otherwise, from my previous neighbors when I installed my 1.3 kW array in 1998. I had excellent solar access, which was one of the main reasons I bought a PV system. But in 2006, the house next door (14 feet away) was demolished and replaced with one that is five times larger and three times taller (it would have been four times taller if I had not complained loudly to the building department in a moment of unhappiness). Now, I have shade instead of sunlight and was told by city, county, and state officials that they sympathized, but I was out of luck. My only options were to sue (but I was told I would lose—wish I had tried anyway), or I could move my PV array at my expense. For a news story on my situation, see bit.ly/WinfieldNews.

Robert Winfield • via homepower.com

Robert's cautionary tale warns us to make sure that we have the right solar access before installing solar. Using solar can get caught in the tension between one person's rights infringing on another's. As for who owns their access to the sun, it depends on where they are.

Some areas guarantee solar access to property owners by limiting buildings and vegetation on adjacent properties. When I installed my first solar energy systems in Ashland, Oregon, I registered the locations of my solar hot water collectors and photovoltaic array with the city, which informed my neighbors that they could not plant any new vegetation that might eventually block my solar access.

For my home solar systems in Washington, D.C., my solar access was coincidentally protected, as I live in a designated historic district that prevents building taller structures. The townhouse to the south is the same height as mine.

Solar access can also be guaranteed by deed restriction or easement, similar to those for protecting ocean-view properties. Such legal instruments may have been placed by the original developer or later in private transactions with payment or other consideration.

If your home is at too much risk of losing solar access—or doesn't have it now—you may still be able to reap the benefits of solar energy. Legislation is pending in Congress that would allow homeowners to receive the 30% federal renewable energy tax credit for investing in community PV projects within 50 miles of their homes. For billing purposes, a utility would treat the electricity from your remote PV system as if it were on your house.

For complete listings of solar access, easement, and rights laws and regulations, see dsireusa.org.

Andy Kerr • andykerr.net

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Courtesy Bob Owens

Right: Bob and Barbara Owens' solar-heated hot tub was featured in *HP104*. Heated water from the roof-mounted collector is piped directly into the tub. The SWH system pump and controller are housed in the box that also serves as a step.

Solar Hot Tubbing

Aloha! I want to build a solar-powered hot tub, and wonder how to keep the water at a constant temperature of about 103°F? Years ago, I made my own domestic solar hot water system. It worked well, but there was a wide variation in temperature depending on the sun conditions and the level of hot water usage.

Karim Wingedheart • via email

I assume from your greeting that you are from Hawaii. The combination of plentiful sunshine and the highest energy costs in the United States would make investing in a solar water heating (SWH) system for your hot tub a smart idea.

But don't expect the SWH system to do it all. In *HP104*, Floridian Bob Owens describes his solar-heated hot tub, which needs help from the electric heater at times. Hot tubs are known to lose heat quickly when the jets are on, which is why many tubs are heated with a hardwired 240-volt, 50-amp dedicated circuit. (A 120 VAC resistance tub heater with a 20 A circuit has only 25% of the heating capability of the 240 VAC heater.)

The Owens' single-collector SWH system heats his 360-gallon hot tub to 104°F just as an AC heater does, but it won't keep up with the heat loss when the jets are on—losing 0.5°F to 1°F per minute. A 360-gallon tub losing 1°F per minute needs about 3,000 Btu of heat added per minute to overcome this loss and keep the tub temperature above 100°F. The heat loss will vary with the ambient temperature.

Any solar energy system capable of meeting this intermittent load would be so large that its size and cost would be prohibitive. The only solution is storage. In the case of a SWH system similar to the one described in *HP104*, a larger storage tank and more collector surface area would be required. A possible alternative is a grid-tied PV system—with the grid "supplying" the "storage." In any case, the heat loss, size of the tub, and amount of time used per day are needed to know how to design an effective system.

If we stick with the 360-gallon hot tub and assume a loss of 1°F a minute for an average of 30 minutes a day, we have a daily loss of 90,000 Btu per day, or an electrical equivalent of 26.4 kWh per day. In Hawaii, an SWH system would require about three 4- by 8-foot collectors and a 120-gallon tank to keep up with the load. The tank water would be heated daily to 140°F to 160°F. To keep up with the heat loss, a pump of about 10 to 15 gpm (a medium-head pump) would be needed to transfer the heat from the storage tank to the tub.

In Hawaii, a batteryless grid-tied PV system that could supply the 26.4 kWh per day would need to be about 6 kW (DC). At an installed cost of $5 per watt, this system would cost approximately $30,000 (prior to incentives). The SWH system would cost about half that. This would change depending on applicable tax incentives and does not address the significantly reduced energy required to maintain the hot tub temperature with its cover on.

Please keep in mind this is a hypothetical scenario. Changes in heat loss, usage per day, installation location, and time of the year will all affect system size and performance. For example, an outdoor tub installation in Phoenix on a summer day won't have any heat loss, while the same tub in November in Seattle will.

Chuck Marken • *Home Power* solar heating editor

write to:

asktheexperts@homepower.com

Published letters are edited for content and length. Due to mail volume, we regret that unpublished letters may not receive a reply.

Courtesy: O2 Energies

Solar Equipment Innovations

by Rebekah Hren

Along with a growing demand for PV systems comes pressure for lower-cost and higher-efficiency equipment, safer operation, and faster installations. Manufacturers of PV equipment—inverters, modules, racks, and other balance-of-system components—respond with innovative devices, drawing upon feedback from installers and designers.

Above: While a little more difficult to handle because of its physical size, a larger PV module can mean less installation time and expense.

Comment & Discuss this article @ homepower.com/157.38

PV Module Innovations

Changes in PV modules happen in two areas. First, manufacturers make incremental improvements that result in efficiency—and power—gains. Second, major design changes happen, like increases in the size or number of cells in a module, different frames or mounting methods, and different materials used for the front and back protection.

Higher Power

The PV industry experiences a seemingly inevitable march toward more powerful, larger modules: In 2000, 75-watt modules were commonplace; in 2009, 200 W modules were plentiful; in 2012, 250 W modules were becoming the norm. Today, there are more than 1,000 different models of 300 W or greater modules on the market and manufacturers continue to expand the selection in this size range.

Larger modules mean more power installed more quickly—15 years ago, a 3,000-watt array would have meant racking and wiring 40 modules. Today, that can be accomplished with 10 modules. Fewer wired connections mean savings for both the system owner and the manufacturer. For framed modules, the ratio of aluminum frame material to the module footprint decreases with wattage increases, which lowers costs for manufacturers and reduces mount costs.

Most higher-wattage modules, in the range of 300 to 445 W, are designed with 72 (or 96) cells in series, rather than 60 cells, which was the standard for many years. Six-inch-diameter cells have replaced 5-inch cells—a 44% increase in surface area, and more area means more current per module.

Because all those cells are wired in series, higher voltage is produced as well. The open-circuit voltage on 72-cell modules can exceed 45 volts (60 V on 96-cell modules). Higher-voltage

The Benefit of Higher Voltage

Higher DC voltages means lower cost. Connecting fewer modules in series (a PV source circuit) means fewer conductors and connections, reduced voltage drop, fewer fuses or breakers, and fewer or smaller combiner boxes. Higher voltage also means lower current for the same amount of power, which allows using smaller-gauge wire that costs less.

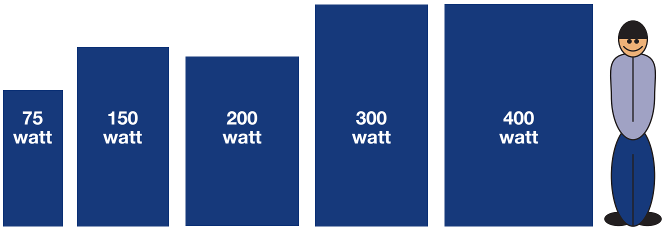
modules can limit design options for arrays connected to step-down charge controllers or string inverters. Higher voltages equate to bigger "building blocks" and means fewer choices for PV string sizing. Depending on the equipment's voltage window, it may be impossible to specify the right number of 72- or 96-cell modules that won't exceed the equipment's high-voltage limit on the coldest days, nor drop below its low-voltage window on hot days. This is especially true for climates that experience wide temperature swings.

Higher-wattage modules can sometimes limit the overall array size. For example, if a string inverter has a voltage input window of 300 to 600 VDC, in many locations when temperatures are hot at least 10 of the 72-cell (300-watt) modules need to be in series to keep the inverter humming. This translates to a (minimum) 3,000 W array—with only one string. Furthermore, with average 72-cell module specifications, if the expected low temperature is 14ºF (-10ºC) or less, then the maximum number of modules in series would be 11. This results in a very narrow range of system size options: 3.0, 3.3, 6.0, 6.6 kW, etc.

One solution is to use an inverter with a wider maximum power point tracking (MPPT) window (such as the PowerOne Aurora PVI models, which have a window of 200 to 530 VDC). This could allow as few as six or seven modules in series. AC modules or microinverters (see below) are another option for high-wattage modules.

Higher-wattage modules also have a larger footprint. For example, while 72-cell modules are generally about the same width (about 39 inches) as 60-cell modules in the 180 W to 260 W range (six cells wide), they are 12 cells high instead of 10—about 12 inches taller and 8 pounds heavier. This increases the load on the rack attachment points, with the same amount of rail holding more module weight. Also, more caution is needed when moving larger modules—typically it requires that two people carry each module.

Evolution of Common PV Sizes



Some glass-on-glass modules allow light to pass through or between cells, creating a pleasant ambience beneath and the possibility of collecting more light reflecting up from below.

Frameless & Glass-on-Glass Modules

The 2012 *International Building Code*, while still not yet widely adopted in the United States, requires that rooftop rack-mounted PV systems have the same fire classification as required of the roof assembly—Class A, B, or C depending on the building type and location. Class A roofing materials or assemblies have a greater ability to resist fire spreading and to resist burning embers. While residential roofs have not generally been required to be Class A, some areas with high fire hazards are moving in that direction for new construction or significant reroofing projects. For example, Colorado Springs, Colorado, and many cities in California have local

This glass-on-glass module from Trina Solar offers a Class A fire rating.

agency ordinance requirements for residential Class A roofs. Some roofing materials are considered Class A, like slate, clay, concrete roof tiles, and steel, although they must be installed correctly (for example, eliminating gaps between the roof covering and decking where birds could build nests) to earn this rating. Class A fiberglass-reinforced asphalt composition shingles are also available, while other types of asphalt or wood shingles will typically have a lower Class B or C rating.

Most glass-front, plastic-backed modules have a Class C fire rating, but modules with glass on both sides may meet higher Class A rating requirements. Trina's TSM PDG5 and Silicon Energy's Cascade Series are both fire Class A-certified, glass-front and glass-backed modules.

Besides their improved fire resistance rating, some glass-on-glass modules have the benefit of allowing dappled light to pass through for structurally integrated arrays like patio or walkway covers. Looking up at the back of a module that is letting light into an atrium and seeing the PV cells instead of an opaque plastic backsheet is considered by many people an aesthetic improvement and architecturally interesting. Another advantage of glass-on-glass modules is superior protection for the back of the module as compared to plastic, and enhanced resistance to sheer stresses.

Frameless versions of glass-on-glass modules are available (including many thin-film modules) that have no metal frames to ground, so the labor and material costs of grounding module frames to racking are eliminated. (Note that the rails still have to be grounded.)


Courtesy SolarWorld USA

SolarWorld's Sunmodule Protect glass-on-glass module offers improved reliability (it's less prone to water intrusion and cell breakage) and a 30-year linear performance guarantee.

Courtesy Enphase Energy

Courtesy Power-One

Microinverters offer module-level multiple power point tracking, monitoring, and simplified array design.

AC Modules & Microinverters

The benefits of AC module and microinverter systems include simplified array design with no string sizing necessary and MPPT for every module, rather than a whole array or string. Unlike with a string inverter, one module or inverter failure does not affect the whole system. In addition, module-level data monitoring capabilities allow easy troubleshooting of an underperforming array or module, and arrays are more easily scalable, as modules can be added without dealing with the constraints of series strings.

Both system types are extremely safe to install and operate, compared to systems with string inverters, because DC voltages are kept to a one-module maximum; all equipment connectors are touch-safe; and DC voltages will generally stay below the 50 V limit associated with shock hazards. Shutting off the main service AC disconnect or PV system disconnect also immediately deenergizes all the PV system conductors except module leads, as the inverters shut off immediately without the presence of grid voltage. One of the benefits of AC modules includes even-quicker installation, since the inverter is preinstalled—there is no DC field wiring, and no DC arc-fault protection necessary. (Metal module frames and any other metal equipment like junction boxes or racks still need equipment grounding.)

AC modules and microinverters share many characteristics, but they are different from both an *National Electrical Code*

Courtesy SunPower

AC modules have microinverters pre-attached, providing the same benefits as microinverter installations, but reducing installation time and complexity.

(*NEC*) and an installation perspective. Microinverters are field-installed, one inverter per module, while AC modules have factory-integrated inverters and have one warranty for the complete assembly. AC modules are listed to both UL standard 1741 (for inverters) and UL 1703 (for PV modules). AC modules generally have a standard 25-year performance warranty, like PV modules, while microinverter warranties vary from 10 to 25 years.

There are only a few microinverters currently available in the United States. Those include Enecsys' Gen 240/300-60-MP, in 240 and 300 W AC output power versions, that can be paired with 60-cell modules; Enphase Energy's M215 and M250 models, producing 215 W or 250 W AC output power, which are also compatible with 60-cell modules; PowerOne's Aurora microinverter (250 W or 300 W versions, which accommodate 60-, 72-, and 96-cell modules); and SMA America's Sunny Boy 240-US (used with 60-cell modules; see "Gear" in this issue).

AC modules are available from Canadian Solar, ET Solar, Mage Solar, SunPower, Talesun, and Westinghouse Solar. The microinverter that is part of an AC module is usually made by a third party (like SolarBridge Technologies) but is typically sold under the module manufacturer's label. For information about AC modules and the *NEC*, see "Code Corner" in this issue.

Inverter Innovations

Higher-Efficiency Inverters

Grid-tied string inverters are more efficient than ever. Go Solar California's eligible equipment list (gosolarcalifornia.org) includes more than 30 models with a weighted efficiency value of 98% or greater. Inverters operate more or less efficiently at different power output levels, so weighted efficiency is an average across a range of power, with estimated percentage of time spent in a given power range factored into the equation. Model specification sheets list "peak efficiency" as a higher value than weighted efficiency, as peak efficiency is the *highest* efficiency an inverter can reach, regardless of power output.

One technological development that helps increase efficiencies is the move to transformerless inverters (also called nonisolated inverters). Instead of relying on an iron-core or high-efficiency transformer, transformerless inverters convert DC to AC through rapid electronic switching, with no isolation between the DC and AC conductors. These inverters are not only more efficient, but weigh less and feature superior ground-fault protection that detects faults more reliably and at lower current levels. Some can be enabled to check the insulation resistance of DC conductors each day before beginning operation—helping reduce the potential of fires due to undetected ground faults. Some, including SMA America's transformerless inverters, include DC arc-fault protection, as required in the 2011 *NEC*.

Many inverter manufacturers are offering these inverters, often distinguished by "TL" in the model number. Although neither current-carrying conductor on the DC side is bonded to ground (there's no DC system ground or DC grounding electrode conductor necessary), they still must have all of the equipment grounding required of any PV array (see "Ungrounded PV Systems" in *HP150*). The fourth-generation Enphase M250 is an ungrounded microinverter and does not require a DC-grounding electrode conductor.

Topher Donahue & Namasté Solar

Transformerless inverters offer more safety features, as well as higher efficiency and lower weight.

Courtesy SMA America

SMA America's Sunny Boy TL series with Secure Power Supply is the first grid-tied inverter that can provide limited PV-direct power during a grid outage—without battery backup.

Daytime Solar Backup

SMA America's new Secure Power Supply (SPS) feature is available on SB 3000, 4000, and 5000 TL-US inverters. In the past, capturing power from a utility-interactive array during a power outage was only possible if the system had a battery bank and inverter with stand-alone capabilities. While SMA's SPS-enabled inverters are primarily utility-interactive, each includes a manually switched outlet that allows stand-alone daytime power during utility outages. When the sun is shining at a high-enough irradiance level, the inverter can provide up to 1,500 watts through the outlet. The power supply can be used for small appliances or to charge cellphones or computers, but there is no energy storage for use at night or during cloudy weather. The amount of power available will fluctuate based on the sun's intensity on the array.

Charge Controller Innovations

Modern modules come in a wide range of voltages that rarely match nominal battery bank voltages, so higher-voltage charge controllers make designing battery-based systems much simpler. These MPPT controllers include a voltage-step down capability to convert higher array voltage into lower battery-bank voltage. The controller input is at a higher voltage and lower current; the output is at a lower voltage with a higher current. For example, a 240 W module may have a maximum power voltage of 30 V and a maximum power current of 8 amps. With the module operating at maximum power and charging a 12 V nominal battery, a step-down charge controller would output around 17.5 A to a battery at 13.5 V.

Schneider Electric—and, expected in late 2013, Morningstar—makes controllers to handle PV arrays up to 600 V maximum. One of Schneider's Conext MPPT controllers can handle a 2,560 W array connected to a 24 V battery bank, or a 4,800 W array at 48 V. (The output is current-limited, so a higher-voltage battery bank allows more array watts to pass through the controller.) MidNite Solar offers controllers that can handle maximum voltages of 150, 200, or up to 250 volts from the array, depending on the model. OutBack Power's Flexmax charge controllers can be connected to a 150 V array, and are available in 60- or 80-amp models. Morningstar also offers the TriStar MPPT controller that can output 45 or 60 A and accommodate arrays up to 150 V.

High-voltage charge controllers enable the use of smaller-diameter wire from the array to the controller, and the ability to use a wider range of higher-voltage modules in the system.

Courtesy MidNite Solar

Rack Innovations

Auto-Grounding

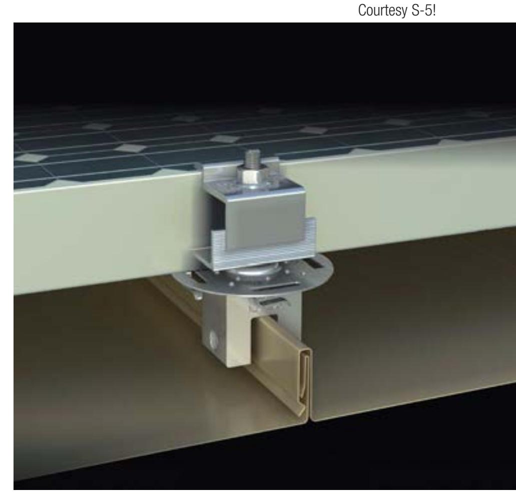
Racks may be the fastest-evolving section of the PV industry, as there is lots of room for innovation. One of the biggest rack innovations is making it easier to ground the metal module frames to the equipment-grounding conductor or rail. Manufacturers including PanelClaw, S-5!, Schletter, Zep Solar, and others have had their racks tested to Underwriters Laboratories (UL) standard 2703, which includes testing the integrity, continuity, and longevity of metal parts bonded during the construction process, and allows them to offer clips and/or bolts to integrate grounding. This means that modules are bonded to the metal rack as part of the mechanical installation and do not need any other grounding device. Other manufacturers like Daetwyler and Zilla are using mounting hardware listed to UL standard 467 for grounding to accomplish the same result (see "Code Corner: Grounding & Bonding PV Systems" in *HP153*.)

Railless Mounting

Several rack manufacturers offer pitched-roof mounts designed to reduce installation time by eliminating the traditional module support rails. Proprietary designs by Westinghouse Solar, Silicon Energy's Cascade Series, Zilla, DynoRaxx, and Zep Solar-compatible modules enable module connection directly to mounting feet. PMC Industries' AceClamp Solar Kit and the S-5-PV Kit offer module clamps for standing-seam metal roofs that attach directly to the roof.

Courtesy Zep Solar

Courtesy S-5!



Railless mounting decreases the time, materials, and cost of mounting PV arrays, as do auto-ground solutions like the dimpled disk (at right), which scratches through the anodization on the aluminum module frame to electrically bond it to the adjacent module via the disk.

Innovations for Safer Systems

Dealing with DC Arc-Faults

Section 690.11 of the 2011 *NEC* added a requirement for direct current arc-fault circuit protection from faults resulting from the failure in continuity of a wire, connection, or other piece of equipment in a system. This can occur when there is a loose connection—for example, when modules' touch-safe connectors are not properly latched together, or when a DC conductor is connected under a screw that is not properly torqued. These high-resistance connections can cause an arc-fault, resulting in temperatures greater than 5,000°F. Arc-faults can quickly burn through conductor insulation, plastic connectors, module back sheets, and even metal conduit and electrical boxes. They can also lead to ground-faults. For example, when a current-carrying conductor behind a module burns through, one energized end may fall onto the metal rack, allowing fault current to flow through the grounded metal until detected by the ground-fault protection device.

The arc-fault protection requirement only applies to DC circuits on or entering a building, with a maximum system voltage at or above 80 V. The system must be able to detect and interrupt series arc faults as described above (a failure in conductor continuity) and disconnect inverters or charge controllers connected to the fault (or system components within the arcing circuit). In addition, the equipment must not automatically restart after a fault and have a visual indicator that a fault has occurred. Opening the circuit stops the arc immediately, so this technology decreases fire potential.

Some inverters, such as this Fronius IG Plus, now provide arc-fault protection, as required by the 2011 *NEC*.

Courtesy Fronius

While there are still very few choices of equipment available to meet these requirements, more are appearing. In the spring of 2012, SMA America was the first inverter manufacturer to provide arc-fault detection in its inverters. Fronius now offers its IG Plus Advanced inverters with built-in arc-fault detection. Microinverter and AC module systems less than 80 VDC are exempt from this requirement, as are ground- and pole-mounted systems that have no DC circuits inside a building. Arc-fault protection that is integrated into charge controllers is available, as well as breaker-like units that can be integrated into a combiner box.

Keeping Out Critters

Whether battling squirrels that chew on module wiring, or birds and rats that build nests under arrays, keeping critters away is an ongoing battle that, if lost, can result in electrical faults and decreased electric production. There's now PV array pest-deterrent hardware available. Clips from Heyco (Sunscreen) and Spiffy Solar hold screening against the frames of modules, preventing animal access under the array. SnapNrack's Edge Screen kit is available for its pitched-roof racks. Future building or electrical codes may require this; in the meantime, installers can save themselves a lot of headaches, callbacks, and liability by keeping the vermin at bay.

Wire Management

Another critical step in keeping PV arrays operating safely is keeping module wires, PV source circuits, and wiring for microinverters reliably secured and supported so the insulation isn't damaged. Stainless steel and plastic clips for securing module wiring to frames are available from multiple manufacturers, including Arlington's SC100, Burndy's Acme, HellermannTyton's E-Clips, Heyco's Heyclip Sunrunner, and Thomas & Betts' Ty-Rap. Heyco also offers a vinyl-jacketed stainless-steel cable tie—the Sunbundler—for PV wire management. Rack manufacturers SnapNrack, Schletter, and Legrand, and module manufacturers Lumos Solar and Silicon Energy, make racks with integrated wire management. On larger systems, cable tray, or similar products from manufacturers like SnakeTray, are making quality wire management easier than ever.

Courtesy HellermannTyton

Courtesy Thomas & Betts

Proper wire management is key to professional-looking installations, and helps ensure that wiring stays safe and secure.

Courtesy SnapNrack

Screening or mesh that keeps critters out from underneath an array provides an additional measure of system protection.

Access

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High-Efficiency Home Heating

Courtesy Fujitsu

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by Scott Gibson

Heating accounts for 29% of all energy used in the average American home, according to the U.S. Department of Energy, so it makes perfect sense to choose the most energy-efficient heating system possible. Ductless minisplit heat pumps, wood and pellet appliances, electric thermal storage devices, ground- and air-source heat pumps, and gas-burning furnaces and boilers are potential choices. But there is no single solution that covers all situations. Climate, utility costs, labor rates, and the fuel all should figure into a decision on which heating appliance to buy.

Start with A Tight Envelope

Houses with minimal air leaks, lots of insulation, and multipane windows require less energy to remain comfortable in cold weather than older houses or those built to code minimums. In high-performance houses like these, heating equipment can be of lower capacity, and therefore less expensive to install and operate.

Passive solar design is another way of lowering heating bills. Orienting the house with its long axis east to west—so windows on the south face can capture the sun—and choosing windows with low U-values and the correct solar heat gain coefficients for the climate are among the steps that can reduce the need for fuel-fired space heating.

Keeping heating loads at a minimum pays big dividends, not just when buying a heating system initially but also in keeping operating costs down. For example, consider a house that's been certified under the Passive House standard, a building method that originated in Germany and is now relatively common in Europe. It sets tough benchmarks for airtightness, total energy use, and energy use for heating and cooling, and houses built to these standards far exceed the performance of conventionally built houses in the United States. Passive House Institute US estimates a house meeting its standard would use as little as 10% of the heat energy of a conventionally built home.

Before you invest in a new space-heating system, be sure to weatherize your home.

Finally, whether the house is old or new, make sure your heating contractor calculates heat loss so the equipment can be sized correctly. Buying oversized equipment, which contractors sometimes recommend just to be safe, is a waste of energy and money.

Heater System Comparison

Heating System	Needs Electricity For	Fuel Notes	Provides Domestic Hot Water	Also Provides Cooling	Pros	Cons
Ductless minisplit	Compressor, fans, pumps	No on-site combustion	No	Yes	Ideal for houses with low heat loads. No central ductwork required. Makes zoning simple.	Interior wall-mounted fan unit. Equipment more expensive than air-source heat pumps.
Modulating gas furnace	Fans to distribute heat	Natural gas cheaper than most other fuels	No	No	Very efficient. Central ducts can be used for air conditioning & humidification.	Forced-air systems are noisier than some options. Ducts difficult to install in retrofit.
High-efficiency boilers	Circulation pumps	Natural gas is best choice if available	Yes	No	Quiet, especially with hydronic. Good source of DHW when paired with indirect tank heater.	More expensive than forced-air systems.
Ground-source heat pump	Circulation pumps, compressor	No on-site combustion	Yes	Yes, with forced-air distribution	Forced-air or hydronic heat distribution. Very quiet with hydronic. Can be operated by on-site renewable energy.	High initial cost. Requires deep wells or significant open land.
Pellet (biomass)	Circulation pumps or distribution fans, pellet auger	Limited availability of bulk pellets	Yes, for boilers	No	Some clean automatically. Low fuel cost. From a renewable source. No fossil fuels.	High initial cost. Load by hand where bulk pellet distribution not available.
Electric thermal storage	High current draw for resistance heaters	No on-site fossil fuel consumption	Yes, but not all models	No	Air or hydronic distribution. Best for low off-peak electric rates. Can store RE. No heater core maintenance.	Higher operating costs than natural gas or biomass. May require wiring upgrades.

Minisplits

One of the most intriguing heating options available, especially for tight, well-insulated houses, is a type of air-source heat pump—a ductless minisplit. Just like conventional air-source heat pumps, minisplits have inside and outside components. The outdoor compressor pumps refrigerant to an indoor evaporator/fan coil, which blows hot (or cold) air to individual rooms. As many as eight indoor fan units can be connected to a single outdoor compressor, although most systems have fewer than that. Airtight houses can be heated with just a few wall-mounted heads, and because the indoor fan units are operated individually, these systems make it easy to zone a house for heating and cooling.

Inside and outside components are connected by a small refrigerant line, a power supply, and a condensate drain. In new construction, these lines can be hidden in an exterior wall; in a retrofit, installers bore a hole (3 inches or less) through an exterior wall to connect the equipment. A cover on the outside of the house hides the supply lines.

Conventional air-source heat pumps operate most efficiently in ambient temperatures of 40°F or higher. Below that, electrical resistance heat or some other supplemental heat source has to kick in, lowering overall efficiency. For this reason, air-source heat pumps are much less common in the northern tier of the country where winter design temperatures are typically well below 40°F. Minisplits, however, operate efficiently in much lower temperatures, some of them down to -13°F. They allow fans and compressors to run by variable speed motors—a more efficient option than the on–off cycling of conventional heat pumps. Fujitsu, a minisplit manufacturer, says that less than 1% of standard air-source heat pumps use variable speed motors while 75% of minisplits use them. Ductless minisplits do not have supplemental sources of heat. You'll have to install a backup unit—wood, natural gas, or even electric (in a high-performance house)—if your ambient temperature is too low.

Heat pump efficiency is described by the coefficient of performance (COP), which is the ratio of energy consumed to heat delivered. If a heat pump has a COP of 5 it means it produces five units of heat for every unit of energy it uses. The National Renewable Energy Laboratory found COPs for minisplits it tested ranged from a 2 or less at -5°F to 7 when the outdoor temperature was 55°F.

Ductless minisplits also eliminate the heat losses of a ducted system, which, according to the U.S. Department of Energy, can waste 30% of the heat that otherwise would be circulated in the house. Heat losses are especially high when ducts pass through uninsulated crawl spaces or attics. Insulated refrigerant lines in minisplits are much smaller and incur losses between 1% and 5%.

Manufacturers say minisplits are often less expensive to install than conventional ducted systems. Although the equipment itself tends to be more expensive, there's less labor because there are no ducts to build and install.

Minisplit indoor distribution units (below) can be installed on exterior walls anywhere that can be reached by electrical source circuits and the plumbing from the outdoor unit (right).

Courtesy Fujitsu (2)

Ground-Source Heat Pumps

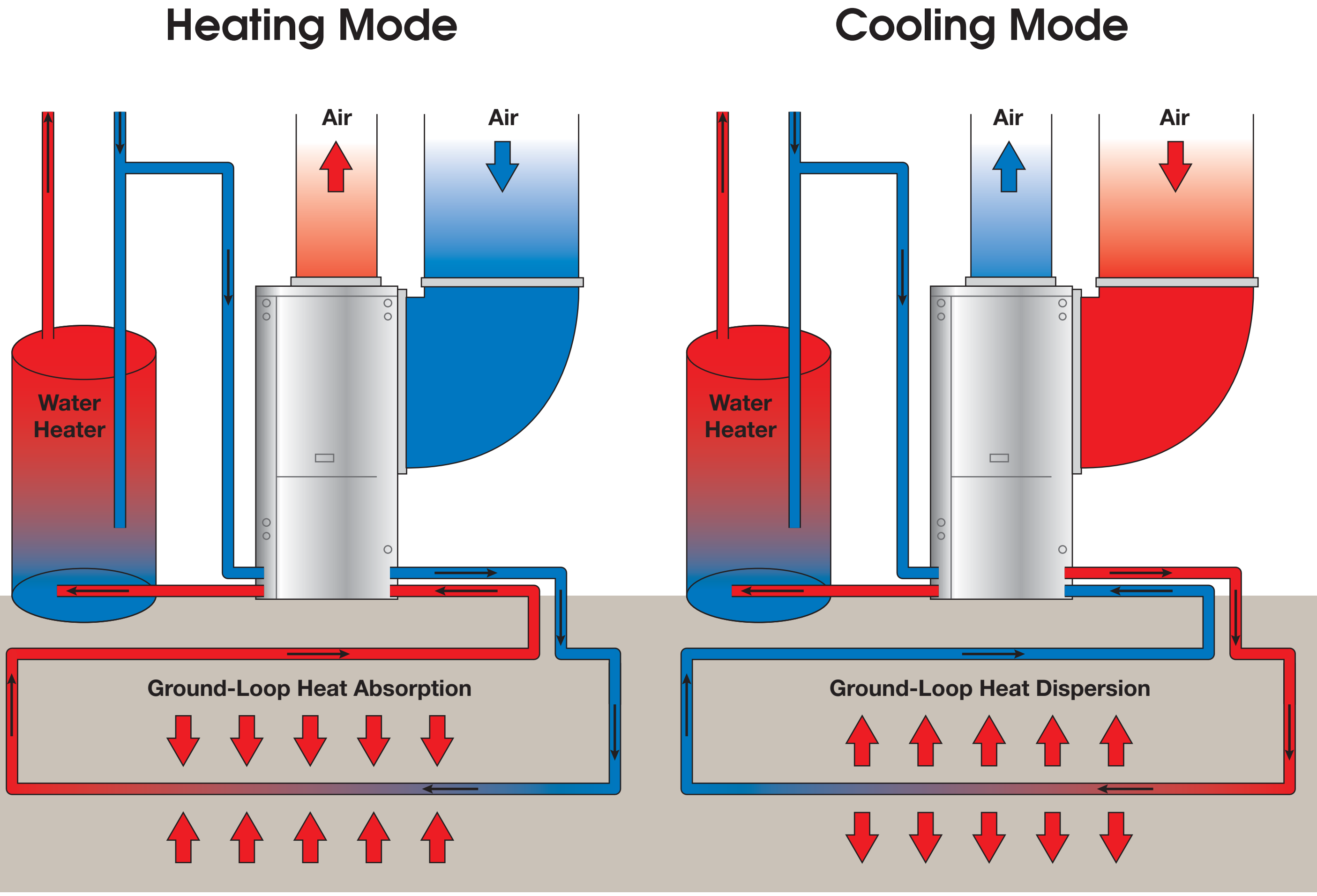
Just like air-source heat pumps, ground-source heat pumps move heat from one place to another. The system includes a compressor, a closed loop of refrigerant, and an air or water distribution system—just like an air-source appliance. Water-to-air systems also have a heat exchanger and a forced-air distribution system. Instead of capturing latent heat in the air, a ground-source heat pump uses a ground loop that runs in horizontal trenches or deep vertical wells. An add-on component (called a desuperheater) can also produce domestic hot water. Ground-source systems can distribute heat via water or air. Most are forced-air systems, using ducts.

Ground-source heat pumps run on electricity. When combined with a renewable electricity system, they can make an extremely attractive heating and cooling package.

Manufacturers claim COPs as high as 5, making these systems very efficient. But there is a catch: Published COPs do not include the electricity needed to run the pumps that circulate water through the ground loops, so actual COPs are less—probably closer to 3. The initial expense can top $40,000 for a residential system, including excavation or well-drilling expenses and the heat-pump equipment.

Courtesy Water Furnace (2)

Typical forced-air, ground-source heat pump equipment. In this case, the system includes a desuperheater to provide domestic hot water, which is stored in the tank on the right.



Modulating-Condensing Furnaces

In the United States, forced-air furnaces are installed in nearly 60% of all new single-family homes. Federal regulations require them to have a minimum annual fuel utilization efficiency (AFUE) of 78%, but a new generation of modulating-condensing furnaces tops out at more than 95%—a significant improvement.

In a conventional furnace, the burner and blower kick on when the thermostat calls for heat. When the room reaches the set temperature, the furnace shuts off. Modulating-condensing furnaces, or "mod-cons" as they're sometimes called, have several ways of increasing efficiency.

First, a modulating gas valve varies the amount of fuel the furnace burns depending on how much heat is required. Second, models with variable-speed fans can run faster or slower to regulate the amount of heat delivered to the house much more precisely.

Third, the "condensing" part refers to a heat exchanger that captures residual heat in combustion gases leaving the unit. In old-style furnaces, this energy goes right out the flue. Because flue gases are cooled as energy is extracted from them, a masonry chimney or double-walled stovepipe is not needed to vent a mod-con. Plastic (PVC) pipe will suffice, which reduces installation costs compared to a conventional furnace. An additional benefit to mod-cons is their size—some models are small enough to be hung on the wall of a mechanical room.

These furnaces are sealed-combustion units, which means they draw in outside air for combustion rather than using air from inside the house. This eliminates the potential for backdrafting, a dangerous condition in which lowered indoor air pressure, from a bathroom fan, for example, draws combustion gases into the house. It also decreases the infiltration of unconditioned outside air needed to replace combusted air.

Variable-speed motors for fans use less energy than single-speed units. The American Council for an Energy-Efficient Economy warns that some furnaces can use more than 1,200 kWh of electricity per year. The most efficient Energy Star models use roughly 150 kWh per year.

Courtesy Rheem

A typical modulating-condensing furnace.

High-efficiency furnaces can be twice the cost of conventional units, according to the National Association of Home Builders' Home Innovation Research Labs. For example, the labs said a complete Rheem modulating heating system with an AFUE of 94%, including ducts, could cost $4,000, compared with a Rheem conventional system with an 80% AFUE furnace at about $2,200. (Prices can differ sharply in different areas and with different manufacturers.)

According to the American Council for an Energy-Efficient Economy, it's possible to calculate how much money you'll save by replacing an older heating system with a more efficient one. For example, if you replaced a 65% efficient gas furnace with a 90% efficient model, you'd save $27 per $100 of your existing fuel bill, the ACEEE says. If your annual fuel bill is $1,300, the savings would be $351 per year. A chart for calculating these savings for a wide range of heating efficiencies is available at the ACEEE's website (bit.ly/HeatSavingsCalc).

Site vs. Source Energy

Getting the full story on the energy efficiency of a particular heating system requires understanding the difference between "site energy" and "source energy." Site energy is the amount of energy that's used at the house. As defined by the U.S. Environmental Protection Agency, source energy represents the total amount of raw fuel that's used, including transmission, delivery, and production losses.

Because of the inefficiencies of generating electricity by burning coal or gas, along with some transmission losses, it takes about 3 units of source energy to produce 1 unit of site energy. In other words, utility grid power is about 33% efficient. When fossil fuels are burned on-site, conversion losses are much lower. The site-to-source conversion factor for natural gas is 1.092 (1.092 units of source energy for every 1 unit of site energy). The ratio is 1.158 for fuel oil and 1.151 for propane.

Let's compare the real efficiencies of electric baseboard heat and a run-of-the-mill gas furnace with an annual fuel utilization efficiency (AFUE) of 78%. When the site–source ratio of 1.092 is applied, the 78% AFUE furnace is 70% efficient on a source basis, meaning that for every 100 Btu of energy potential in the raw fuel, 70 Btu are delivered in the form of heat.

On a site basis, electricity is roughly 100% efficient because virtually all of the site energy is converted into heat. But on a source basis, gas is more than twice as efficient, roughly 70% compared to 30%.

Comparing site and source energy gives a better picture of heating efficiency, and a more accurate measure of the environmental impact of using different types of fuel.

Automated Pellet Boilers

Federal emissions regulations have resulted in a cleaner, more efficient generation of wood heaters, and the evolution continues in this area with “biomass” boilers and furnaces that use compressed wood pellets for fuel.

Pellet boilers are more common in Europe than the United States, but in parts of the country where pellets can be delivered in bulk, these heating systems are no more trouble to use than a gas- or oil-fired boiler and can offer substantial fuel savings.

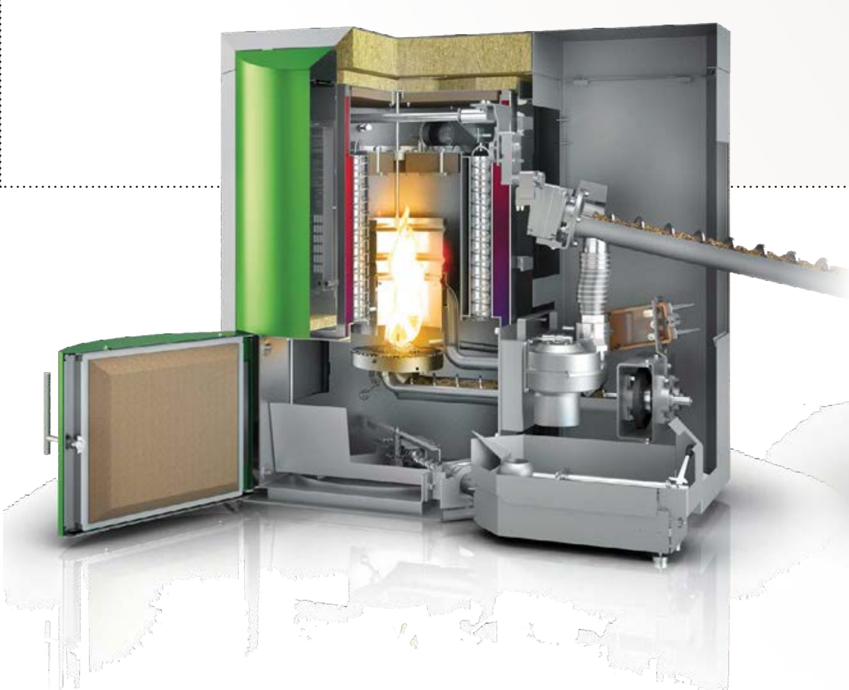
Advanced pellet boilers, like those offered by Maine Energy Systems or Greenwood Clean Energy, feature automatic pellet loading and automatic ash removal. Maine Energy models also clean their heat exchangers automatically and burn with an efficiency greater than 87%, not including the “source energy” it takes to make and transport the pellets. Pellet boilers can also provide domestic hot water and can distribute heat via air ducts or hydronically, such as with a radiant-floor system. In the Northeast, where bulk pellets are available, a delivery truck offloads into a storage bin, much like fuel oil or propane would be delivered. The homeowner never touches the fuel. Ash is collected and compressed in a container that needs to be emptied only four times a year, according to Maine Energy Systems. In other parts of the country, homeowners have to resupply a pellet bin manually. Some biomass heaters, like those from MagnuM, also can burn corn.

Depending on what type of conventional fuel they replace, pellets can lower heating costs significantly. For an estimate, check the U.S. Energy Information Administration’s interactive calculator at bit.ly/CalcTheHeat. Using June 2013 national averages for various heating fuels, the calculator shows the fuel cost per million Btu with a 78% efficiency pellet room heater is $19.43. Under current fuel pricing, pellets produce heat much less expensively than #2 fuel oil ($28.95 per million Btu), electricity ($34.22) or propane ($26.68). The calculator allows adjustments in appliance efficiency as well as fuel costs to better reflect local prices for more accurate comparison.

The heaters, however, aren’t cheap. Maine Energy Systems’ smallest boiler costs more than $11,000, not including installation or pellet storage. Pellets also take up more room than other kinds of fuel, except firewood, because they’re not as energy-dense.

Yet, according to John Shelly of the University of California at Berkeley, there are several advantages to using biomass fuel: It’s a nonfood, renewable resource; it can reduce wildfire hazards when the wood is sourced from forests and wildland-urban interface zones; and biomass can be considered a “carbon-neutral” fuel.

Compared to wood heaters, pellet heaters (and, especially, pellet boilers) require much less work on the part of the homeowner. There’s less cleaning, since pellets produce much less residual ash. And while pellets have a higher embodied energy (energy used to manufacture and transport a product), the sweat energy is far less compared to cordwood, since there’s no cutting, hauling, splitting, or stacking required. The disadvantage to pellet heaters is that you’re at the mercy of purchasing your fuel and some models with electric blowers and electric augers won’t work if there’s a power outage.



Courtesy Maine Energy Systems (2)

This automatic pellet boiler manufactured by Maine Energy Systems includes an auger that moves pellets from a nearby storage bin to a self-cleaning combustion chamber.

Electrical Thermal Storage

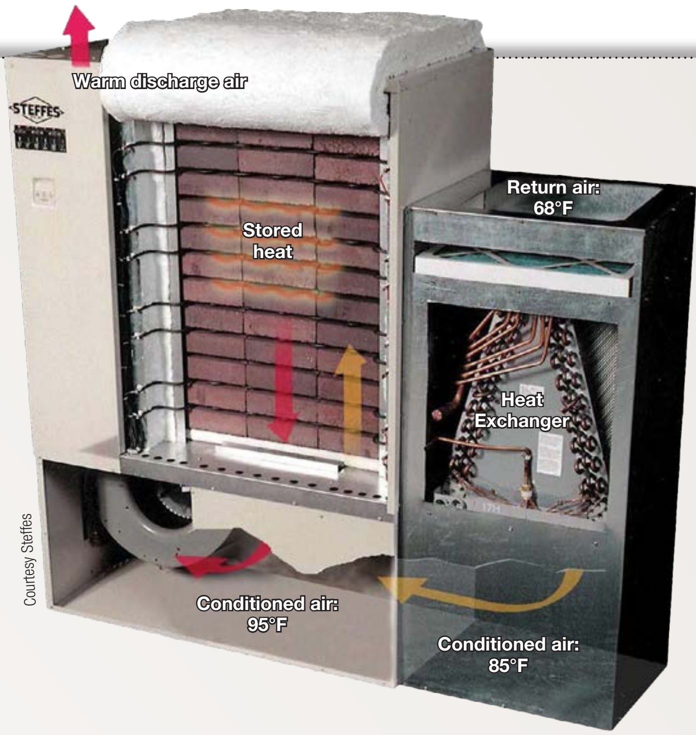
Electric resistance heaters are 100% efficient, but the relatively high cost of utility energy usually makes electricity a poor choice for space heating. Electric thermal storage (ETS) heaters are one way of getting around that problem. They draw energy during off-peak hours when supply is plentiful and rates are relatively low. An ETS system contains electric heating elements within dense ceramic bricks, which store heat.

ETS heaters are available as stand-alone room heaters, much like a wood heater, but also as whole-house forced-air or hydronic systems. They can be incorporated into an existing heating system as a backup for an electric furnace or to supplement a heat pump, but also work as a principal source of heat.

Local electricity rates and rate structures are a key consideration in purchasing an ETS heater, since these units use a lot of electricity. Room-size heaters draw 1.32 to 10.8 kW, with outputs from 46,602 to 136,480 Btu. The smallest Steffes central-air heater draws 14 kW. An ETS heater may require wiring upgrades to handle the current. The run-time for the units depends on the size of the heater, the size of the heated space, the heating load, and how much stored energy was used during the previous heating cycle.

Off-peak rates, which are lower than during high-usage times, are usually available at night or on weekends—when utility system demand is the lowest. Take, for example, the residential rate structure offered by Portland (Oregon) General Electric. Its on-peak rate is $0.1327 per kWh, its mid-peak rate is $0.075 per kWh, and the off-peak rate is $0.0442 per kWh—one-third of the peak rate. The biggest advantage for the utility is the avoided cost of not having to build new power plants to meet spikes in demand during peak hours.

ETS heaters probably can't beat natural gas at current fuel prices, but they can save money for consumers who currently use propane or No. 2 fuel oil. The ability of these appliances to balance the load on the grid by storing energy is a key advantage, says Paul Steffes, CEO of Steffes Corp. a manufacturer of ETS systems.



An electric thermal storage unit. Note that the side insulation has been rolled back to reveal the ceramic bricks inside the unit.

Manual J for Heat Loss

Oversized heating equipment costs more initially and will not operate as efficiently as a correctly sized appliance. Equipment that's too small won't provide adequate heating. So the goal should be to be to install equipment that's chosen carefully on the basis of actual heating loads rather than guesswork.

The standard for many years has been "Manual J," published by the Air Conditioning Contractors of America, which allows HVAC contractors to do the necessary heat load calculations and recommend the right heating system. A corresponding set of calculations in "Manual D" is for sizing ductwork in houses with forced-air heating and cooling systems.

Contractors once filled out the worksheets by hand, but there are now a number of computer programs that do the work. A variety of factors are plugged in, including type and amount of insulation, window type, lighting, what appliances will be in the house, and how much air leakage there is.

A Manual J calculation (or an approved equivalent) is now required in new construction by the International Residential Code. But there is ample anecdotal evidence that many HVAC contractors don't use Manual J, sizing the system on the square footage of the house instead. Homeowners investing in new heating equipment should insist the calculations be performed.

High-Efficiency Boilers


Courtesy Lennox

A typical high-efficiency boiler.

Boilers heat water, which distributes heat via radiators or radiant-floor tubing. Alternately, boilers can supply a forced-air distribution system if it has a hot-water heat exchanger. Heating systems that use water or steam to transfer heat are much less common than forced-air systems, accounting for only about 2% of the U.S. total in single-family homes built in 2012.

No matter how the heat is distributed, you'll find improved efficiency in modern boilers. Government regulations require boilers to have a minimum AFUE of 80%, but some are available with efficiencies greater than 95%. Natural gas is the most common fuel, but high-efficiency models that burn No. 2 fuel oil are also available.

Condensing boilers use the same technology as condensing furnaces to capture waste heat. Combustion gases are routed through a stainless steel heat exchanger where water vapor condenses and releases more heat.

Boilers can produce domestic hot water, but can't provide air conditioning or dehumidification. That probably makes boilers with hydronic distribution a better bet in regions where air conditioning and dehumidification aren't top priorities.

Access

Scott Gibson writes about green building design and energy efficiency for a number of publications and blogs, including *Fine Homebuilding* magazine and GreenBuildingAdvisor.com. He and his wife live in southern Maine.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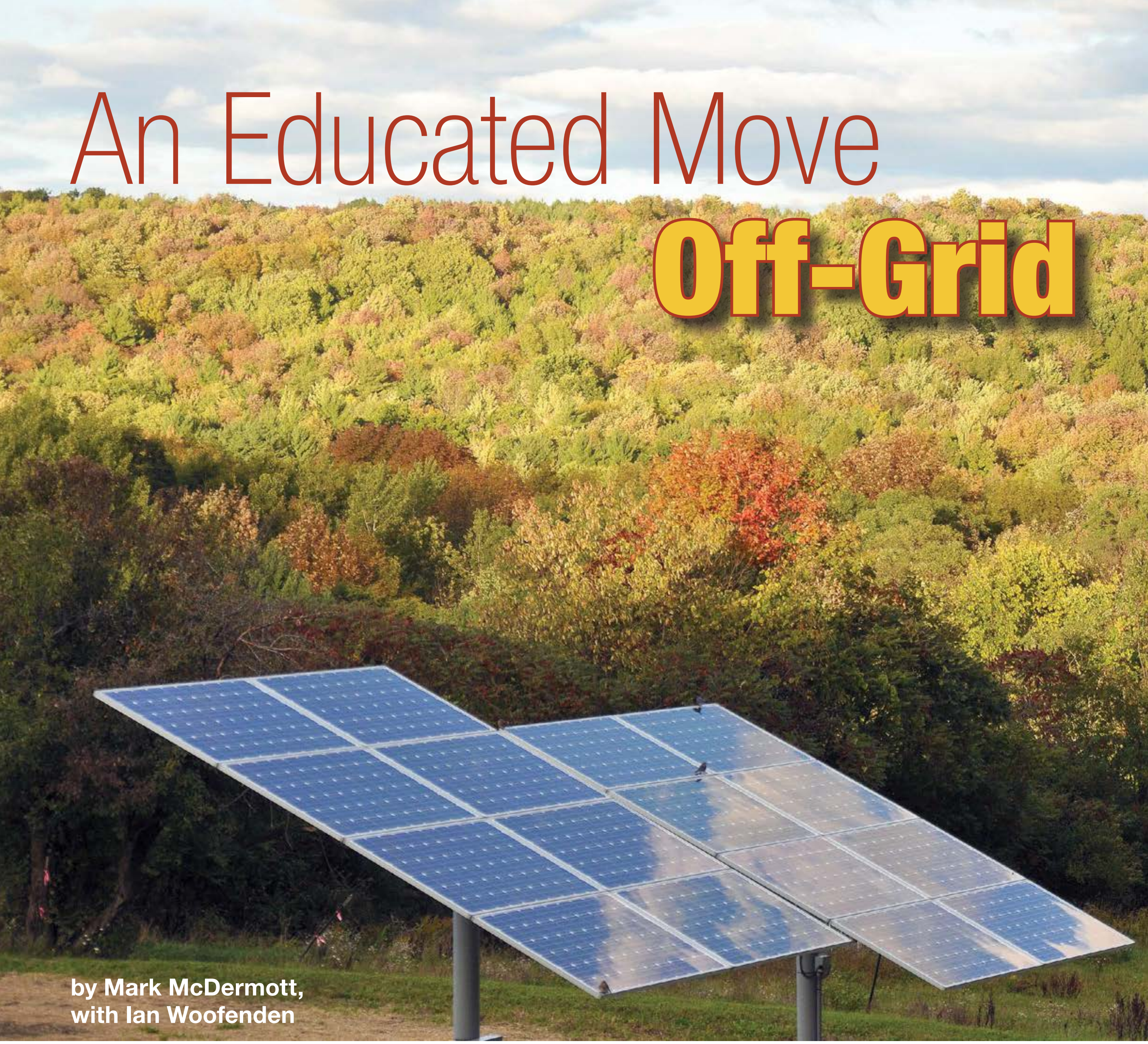
An Educated Move Off-Grid

by Mark McDermott, with Ian Woofenden



My wife Teresa and I had talked for some time about moving to the country, and in late 2011 we started getting serious about it. But we were not going to move to just "anywhere" in the country. I wanted some land where I could hunt and practice with my firearms, since I am an avid hunter and enjoy competing in local shooting matches. Teresa was interested in raising farm animals and keeping honeybees—and not having a neighbor right next door. We used the Internet to search for properties and contacted a real estate agent to assist us.

After months of searching, a couple of things became apparent. The first was that locals here in the southern tier of New York, near the Pennsylvania border, believe there is natural gas under their land and wanted top dollar—or would not give up their mineral rights. The second thing was that it was going to take a bit of luck to find a property where everything we wanted would meet what we could afford.

Prime Property?

When our home came up on the radar, we knew it had what we were looking for and it was a great deal, but it was a little farther away from work than we wanted. On the 60-acre property was a six-bedroom home with a large separate workshop/store, two big barns, a cabin in the woods, and a sizable pond. An additional 100 acres were also available. We had looked at properties with less land and smaller houses with no outbuildings that were double this property's asking price. The description in the real estate listing was a little vague and seemed too good to be true.

After talking to the agent, it became immediately clear why the property was priced so low. The house belonged to and was built by an Amish family—there was no electricity in the house and no indoor plumbing. We made arrangements to see the place, located in rural Steuben County, southern New York, during one of the only snowstorms in the winter of 2011. Perched atop a hill, the house and property sit in a windy area, near several wind farms.

Away From the Rat Race

We met the family and toured the house and some of the property. The home was beautiful and the land was exactly what we were looking for, but there were no modern conveniences. Instead, there was a hand pump for water, an outhouse, and no central heat. There was a Hitzer gravity-fed coal heater and a wood-burning cookstove. When we left that day, we were pretty sure that it wasn't the place for us, although we were completely intrigued by the Amish lifestyle.

But the more we talked and thought about it, the more the idea of getting away from the "rat race" appealed to us. Our kids had been spending most of their time watching TV, playing video games, or surfing the 'Net. Teresa and I were no better, with a lot of our free time being wasted in front of the computer or TV. So we talked to the kids and, surprisingly, they were all for it.

I could write another article about the hurdles we encountered getting financing and insurance on a home with no electricity, no plumbing, and no central heat, but the important part is that we decided to buy this home and land. We put in a purchase offer with a couple of contingencies in case we ran into problems and needed an out. The seed for living off-grid was planted.

Mark McDermott (2)

New meets old: A high-tech off-grid system now provides electricity for this twentieth-century farmhouse. Originally built by an Amish family, it was formerly electricity- and plumbing-free.

Going to RE School

We wanted to have electricity, and I learned a lot from online searching. The first advice I got (from many sources) was "Don't do it—If you can, connect to the grid!" The per-kilowatt-hour cost of utility-provided electricity is often much lower than the per kWh cost of making your own off-grid electricity and the payback is very long—so I looked into extending the grid to our house. But our experience with the utility was not encouraging, and the cost and red tape were beyond our means and patience. The grid ended 0.5 mile in either direction from our home. On the southern side, we would need to obtain permission from one neighbor and we would need to remove (or have removed) all of the trees that were within 30 feet of the road. The estimate from the electric company was $50,000 to $75,000 for setting the poles and lines. Coming in from the north, there were two neighbors who we would need to get permission from, but most of the land coming from that side was open field. The electric company estimated the cost to be $35,000 to $45,000 to run the lines and poles there. We actually considered this option but unfortunately (or fortunately) neither of the neighbors was willing to grant us permission. And both cost estimates were minimums and we were warned that it could be much more. So I was relieved when we finally made the decision to keep the home off-grid.


Mark McDermott

Energy-efficient appliances play a critical role in reducing the electrical loads in an off-grid system.

System Design

Before we designed the off-grid system, we set a rough budget for the house, with two major considerations: We needed to wire the house so that we could use whatever electricity our system would make and we needed a septic system so that we could have indoor plumbing.

Early in the process, I decided on a solar-only system. There was no hydropower source on the property, and while wind electricity is widely used in the area, I just didn't have the funds to do a hybrid system, nor did I want to go with just a wind system. Once I focused on a solar-only system, I began the critical process of sizing it.

We used about 1,000 kWh per month at our grid-tied home. That works out to be about 33 kWh of electricity a day used (or, mostly, wasted). I had never examined our electricity usage before. All I saw and complained about was the monthly bill.

Defining the Load

The first step in system design is to figure out how many kWh a day are needed. That seems simple enough, but it is very difficult to arrive at an accurate number. I bought a Kill A Watt meter and measured the energy use of the toaster, computer, TV, dryer, washing machine, and everything else in our existing house that plugged into a 120 VAC outlet. I recorded all of the watts and watt-hours used for everything in the house on a spreadsheet.

Some of our appliances were very energy-efficient and other older ones were energy hogs. But knowing how much energy everything used was crucial. Next, I needed to estimate how many kWh we would need per day in our new house. That sounds easy, but it is also quite difficult. How many lights would we use during the evenings and how long would they be on? The same question applied to everything electrical in the house. Going off-grid forces you to be very aware of how you use your energy.

The trick to off-grid living is conservation and efficiency. After looking at many different scenarios, I came up with an estimated minimum of 6 kWh per day. After getting real data from our appliances and deciding that we would be able to change some of our electrical usage habits, I targeted a 3 to 4 kW system. (Since the system was installed, we've loosened our conservation belts a little this summer and have used as much as 6 to 7 kWh per day on a couple of occasions.)

Once your average daily electricity use is estimated, the size of the battery bank can be calculated, based on a specific depth of discharge and the number of days of autonomy (no sun) you expect.

Battery Sizing

Since the solar energy is stored in a battery bank, its capacity has to be enough to provide the energy you need without overdischarging your batteries. The battery bank feeds the inverter that converts the DC to AC electricity used by standard household appliances.

Estimated System Loads

Item	Qty.	Watts	Hrs. / Day	Days / Wk.	Avg. Daily Wh
Fridge	1	114	10	7	1,140
TV	1	300	3	7	900
Fans	2	36	9	7	648
Microwave	1	1,200	0.5	7	600
Laptop	2	78	2	7	312
Computer	1	228	2	4	261
White noise machine	3	9	9	7	243
Toaster	1	960	0.25	7	240
Vacuum cleaner	1	1,380	1	1	197
Gaming console	1	216	2	3	185
Compact fluorescent lighting	2	30	3	7	180
Clock radio	2	3	24	7	144
Compact fluorescent lighting	3	16	3	7	144
Clothes dryer (propane)	1	312	3	1	134
TV	1	60	2	7	120
Hair dryer	1	1,200	0.08	6	82
Washing machine	1	180	3	1	77
Night light	1	8	9	7	72
Ventilator	1	7	9	7	63
Various chargers	3	8	3	5	51
Small tabletop fan	1	59	4	1	34
				Total	5,827

Determining the size of your array and battery bank is a bit of a balancing act. An array that's too small will struggle to keep your batteries charged. An array that's too large will cost more up-front. I gathered all my data, calculations, and best guesses and came up with a target system: a 48-volt, 400- to 600-amp-hour battery bank and a 3 kW solar-electric array.

We knew that heating anything significant with electricity was going to be too big a burden on our PV system. We kept the two Hitzer gravity-fed coal stoves, and decided to use propane for backup space heating, water heating, cooking, drying clothes, and to run the backup generator. But we would be reducing our electricity usage by nearly 80%—going from 33 kWh a day to relying on a system that in the depths of winter would produce only 6 to 7 kWh. Our grid-tied house used natural gas for space heating, water heating, and clothes drying. We had a very large chest freezer, electric convection oven, two refrigerators, five TVs, three DVR/cable boxes, a large gaming computer, two printers (one inkjet; one laser), incandescent lights, and a bevy of other little electronics. A pellet stove ran 24/7 all winter. Everything was plugged in and powered most all times. Every night, there were fans and other electronics running. I made some drastic assumptions to reduce our electricity usage. That worried me. What if I had made a wrong calculation? And what if I could not install the system in time for our first winter? With those fears, I decided to hire a professional to help design and install our system.

Going with a Pro

I contacted several different NABCEP-certified solar installers. I had a good idea of what the complete system would look like and what equipment was available, so this was kind of a test for the two I sought bids from.

I hired Four Winds Renewable Energy (FWRE) out of Arkport, New York, which was only a few minutes' drive from our property. Not only had owner/installer Roy Butler been installing off-grid PV systems for decades, but he also lived off-grid. After Roy did a site survey, we took his proposal and tweaked it a little bit to arrive at our system design: a 4 kW PV system with a 740 Ah battery bank and a 6 kW backup generator. FWRE would order and install the equipment (see the cost table) for about $30,000. New York state does not offer any rebates or tax incentives for off-grid systems, although we did qualify for the 30% federal tax credit.

Two 48 V strings of Trojan L-16-RE batteries provide energy storage for the McDermott home.

Mark McDermott

Site Prep & Installation

To keep costs down, I took responsibility for hiring an excavator for the pole holes and the wiring trenches, repairing the yard after the trenching was finished, preparing the basement wall for mounting the balance-of-system components, and the rough AC wiring between the generator and the inverter. I was also responsible for selecting and installing the generator and its fuel supply—a propane Generac 6 kW EcoGen, which is the only generator designed and warranted for off-grid use with a renewable energy system.

We started the installation the first week of September. It probably would have taken less time to install if I hadn't been there, but it was important to me to watch and learn as much as I could about the installation and how all of the components worked together.

Setting the two 6-inch, 21-foot-long steel poles for the pole-mounted system was a critical step. They had to be lifted into place with the backhoe and set in 24-inch, 6-foot-long concrete form tubes. Since the arrays presented a large surface area for wind loads, plenty of ballast was needed to keep them in place.

While the concrete was curing around the poles, we installed the BOS equipment. The inverter, charge controllers, battery box, and batteries were all wired, connections torqued, and parts labeled.

The Generac EcoGen 6 kW propane generator is designed and warranted for off-grid use with an RE system.

The balance-of-system components include an OutBack inverter and two MidNite Solar charge controllers.

Mark McDermott (3)

Tech Specs

Overview

System type: Battery-based, off-grid solar-electric

System location: Prattsburgh, New York

Solar resource: 4.2 average daily peak sun-hours

Daily production (ave.): Fewer than 3 kWh (winter); 3 to 5 kWh (spring); 9 to 10 kWh (summer)

Photovoltaics

Modules: 16, SolarWorld Sunmodule Plus SW 255, 255 W STC, 31.1 Vmp, 37.8 Voc, 8.15 A Imp, 8.66 A Isc

Array: Four, four-module series strings, 4,080 W STC total; each string: 125.6 Vmp, 151.2 Voc

Array combiner box: MidNite Solar MNPV 12-250 with 15 A breakers

Array disconnect: Two 60 A breakers

Array installation: Two DP&W adjustable tilt top-of-pole mounts

Energy Storage

Batteries: 16 Trojan L16-RE series, 6 VDC nominal, 370 Ah at 20-hour rate, (flooded lead-acid)

Battery bank: 48 VDC nominal, 740 Ah total; 35,520 Wh

Battery/inverter disconnect: 175 A breaker

Battery monitors: OutBack FNDC

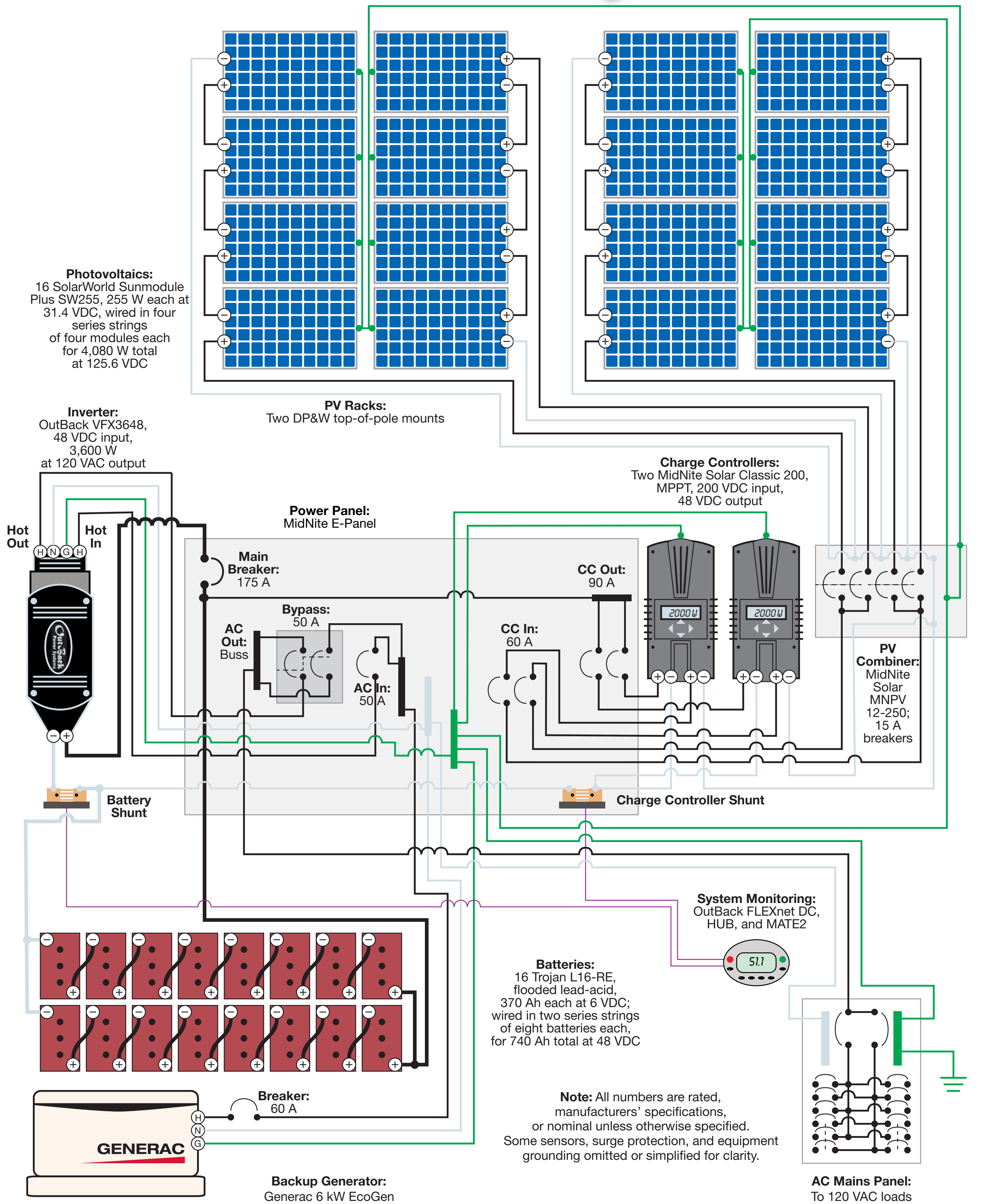
Balance of System

Charge controllers: Two MidNite Solar Classic 200, 65 A, MPPT, 200 VDC nominal input voltage, 48 VDC nominal output voltage

Inverter: OutBack VFX3648, 48 VDC nominal input, 120 VAC output; MidNite Solar 175 E-Panel

System performance metering: OutBack MATE & HUB4

McDermott Off-Grid PV System



Mark McDermott (2)

Much of the 21-foot lengths of the mounting poles are encased in concrete to handle the wind loads on the large arrays.

Strong, Silent Energy

A couple of days later, the first array was installed and was charging the batteries. Our new system sounded like nothing—it was dead silent. No generator noise, just a dull hum from the battery box fan. A day or two later, the second array was online. The backup generator was delivered, and we installed that and wired it into the system for those stretches of little to no sun, and for enough energy to occasionally equalize the batteries (an intentional overcharging of the battery bank to remove imbalances between individual batteries).

The first thing we did was plug in our refrigerator. It's funny how some things get taken for granted, like having a refrigerator instead of buying ice every day and living out of an ice chest, as we did before installing the PV system. I remember my wife saying that if all we could ever supply electricity to was the refrigerator, it would be OK with her.

By the last week in September, our new system was complete. There was still much to learn and do—understanding the technical and practical details of a whole new electrical supply system, tweaking the charge parameters to properly charge the batteries, and reminding the kids to turn off the lights! I pay special attention to the batteries, since they are the heart of the system and its most vulnerable part. To date, there have not been any major issues or problems. The array tilt was adjusted to an optimum angle for the winter and left there. I adjusted the array for the summer angle on April 1, and will readjust it again this fall.

Embracing Off-Grid Living

Our system is well-balanced, and our family is well-matched to it. I ran the generator only a handful of times last winter, and only when the batteries were in the 70% state of charge (SOC) range. On the weekdays, we typically use between 2 and 3 kWh. On weekend days, our use climbs to 4 or 5 kWh. However, since last winter was our first winter with the system, we were very conservative with our usage. But none of us feel like we have had to make huge sacrifices to keep our usage low. We currently have a spring-fed cistern that we use for our water supply. We may need to drill a well, which will require a different pump and more electricity. We are and will be using more energy as our comfort level with living off-grid increases. My thinking now is, use it or lose it—"it" being the solar energy available.

Did we give up any modern conveniences? Yes and no, according to how you define modern conveniences. We "gave up" everybody having a TV in each of their bedrooms. We gave up having multiple cable boxes, DVRs, and a large surround-sound system. We gave up having a huge chest freezer filled with who knows what and a large side-by-side refrigerator. We gave up having every light in the house on all the time. We gave up having all of our electrical devices plugged in and ready to go.

We currently have two energy-efficient TVs—we added a 24-inch LED TV that uses 60 W. We made the decision to use an over-the-air antenna and not get a dish, so we "gave up" 200+ channels. All of the appliances with phantom loads—

Above: The McDermotts' off-grid life also includes this Olde English Babydoll lamb. Right: Teresa inspects her beehives and checks for honey. Notice the solar-powered electric fence used to keep out pesky black bears.

TVs, gaming console, computer, and printers—are plugged into power strips that are turned off when not in use. We let the kids have limited use of the gaming console and TV (most of the time they limit themselves). We have family TV time in the evenings—when we decide to watch TV. We brought in a fiber-optic phone line to the house, since there was no cell or Internet service. The modem is powered all the time. All of our lights are energy-efficient and only one or two are on at a time most nights. Overcoming our bad energy practices has actually been a little easier than I thought it would be.

Off-grid family Mark and Teresa McDermott with their son Dylan and daughter Laura.

Mark McDermott (3)

We all work together to conserve electricity, which is really astonishing to me, since conservation was not even in our vocabulary a year ago.

Going off-grid has taught me many things. First was the importance of tracking the energy usage of all of your electrical appliances—clocks, chargers, *everything*—it all adds up. Do not depend on the sticker that gives the amperage on the back of an appliance—they are not accurate enough. Second, every dollar spent on conservation will save you more than that on the cost of your PV system. Energy efficiency in your lifestyle and appliances is a must. If you hire an installer, check references and go see at least one of their installations. Ask questions.

If you look at changing to off-grid living strictly as a financial problem, it may or may not pencil out, since the cost of electricity from the grid is usually cheaper than from an off-grid system. In our case, the costs of bringing in the grid and installing an off-grid system were about the same if considered over 10 years. It may even have been cheaper if we had gone the grid route. But being on our own and telling the electric utility to take a hike…well, that is priceless!

As we moved into our first spring off-grid, the system was really coming into its own. We have embraced living off the grid. I think our family and friends thought we were crazy to buy a home with no electricity or plumbing. But now all we hear is how lucky we are and how beautiful it is out here. We love it and would definitely do it all again.

Access

Born in Elmira, New York, Mark McDermott (mcdermotma@gmail.com) has worked at Corning for 28 years. He currently serves as a development engineer there, working on optical fiber and photonic components.

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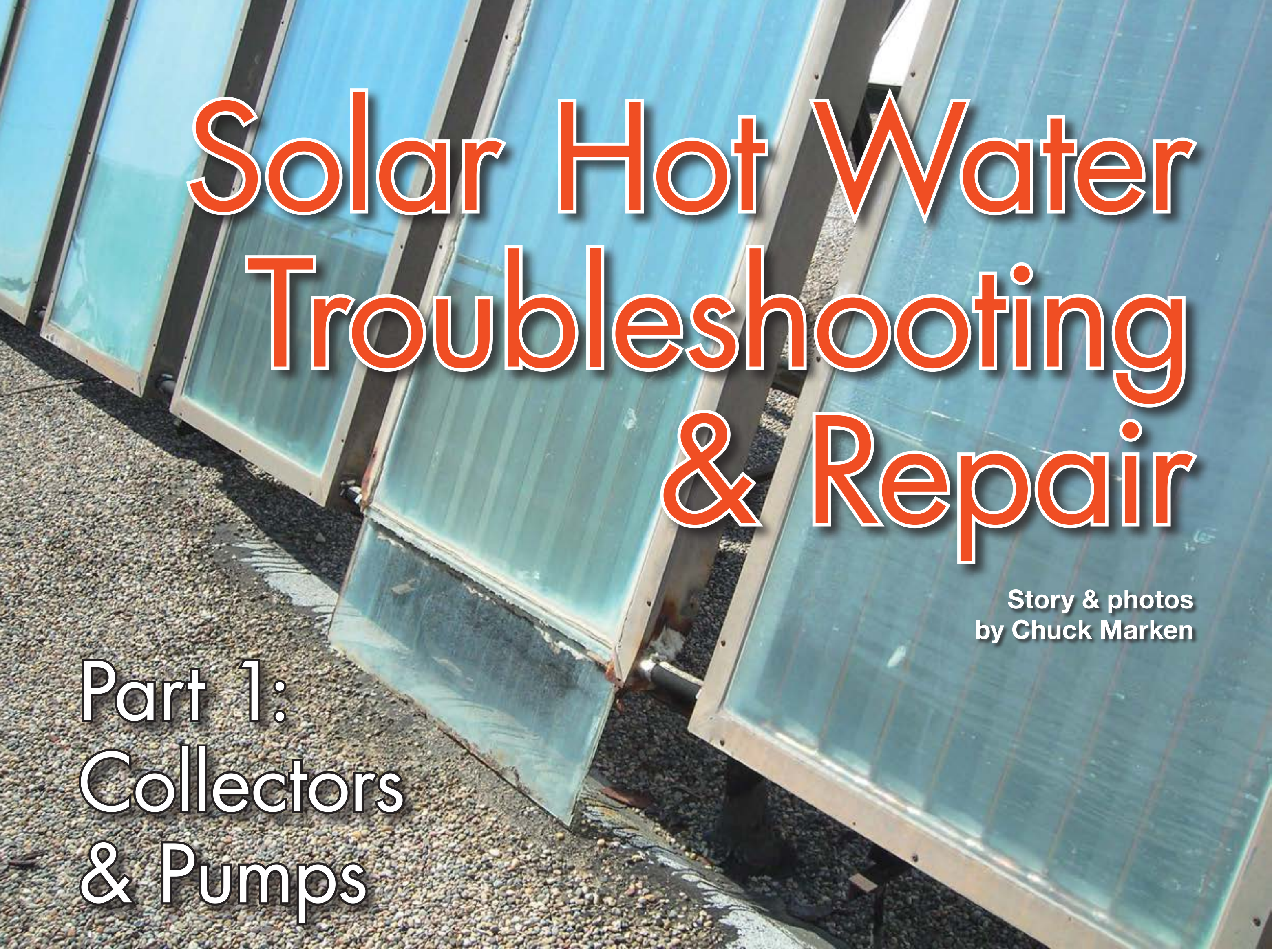
Solar Hot Water Troubleshooting & Repair

Story & photos
by Chuck Marken

Part 1: Collectors & Pumps



Physical problems with collectors are sometimes quite apparent to the naked eye.

Modern, high-quality solar hot water (SHW) systems are reliable and long-lasting if designed and installed properly. Many systems installed more than 30 years ago are still going strong. However, most systems this old and older have needed repairs and component replacement from normal wear and tear. In some cases, repairs or alterations are needed because of design and/or installation flaws.

Whole-System Checks

SHW systems are fairly simple appliances—not as straightforward as a tank-style water heater but nowhere near the complexity of a car. Seeing, hearing, smelling, and touching components (carefully) can assist in diagnosing problems before any troubleshooting equipment and tools are used. Experienced technicians use their senses to determine the status of a solar water heater. Unusual, high-pitched noises and burning odors are associated with bearing wear from the pumps. Burning smells can also indicate electrical problems, such as burned motor windings, loose connections, or damage from excessive voltage or current. Visual inspection can reveal controller malfunction, leaks, and fluid levels.

SHW Troubleshooting & Repair Tools

- Multimeter
- Glycol test kit (litmus paper or pH meter, propylene glycol tester)
- Probe HVAC & infrared digital thermometers
- Tape measure for sizing glass
- Wet/dry shop vacuum
- Glycol charging equipment
- Pipe wrenches, adjustable wrenches, adjustable pliers, all sizes of screwdrivers & nut drivers
- Cordless drill/driver
- Hammer
- Ladders
- Sweat-soldering equipment

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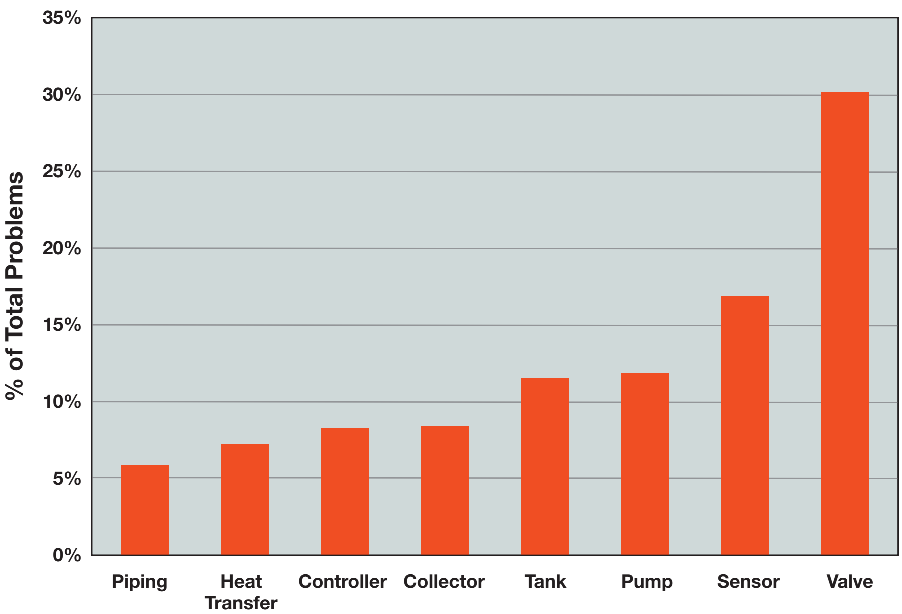
Pumped SHW Component Failure



Source: "Assembly and Comparison of Available Solar Hot Water System Reliability Databases"

If all appears normal after a quick inspection and the sun is out with the pump(s) energized, measuring the temperatures of the collector loop supply and return can provide valuable information. If pipe temperatures allow it, feel the two pipes, with one hand on each pipe. If pipes are too hot to touch (above about 120°F), measure their temperature with an infrared thermometer. A noticeable difference in temperature between the two pipes indicates that the collectors are adding heat—the system is working.

Cold supply and return pipes are a symptom of no flow—check the pump(s) or controller first. Both pipes being hot and at the same temperature is likely only to occur in a system with an external heat exchanger. This indicates that the collector loop pump is operating and the controllers have turned it on but that the heat is not being exchanged to the home's potable water. A malfunction in the domestic hot water (DHW) pump or an obstruction on the DHW side of the heat exchanger is indicated. More detailed symptoms are component-specific.

What goes wrong and why depends on the SHW system, the climate, and the water conditions. Dave Menicucci, an ex-Sandia National Laboratories engineer, compiled the surveyed results of hundreds of systems that had experienced failures and needed service calls in the past three decades (see "Assembly and Comparison of Available Solar Hot Water System Reliability Databases," bit.ly/SHWreliability). The survey indicated that most problems resulted from component failures. Failures due to installation and maintenance were in the minority.

The fact that valves accounted for the highest percentage of reported problems can perhaps be attributed to hard water and open-loop thermosyphon and direct forced-circulation (DFC) systems. The relatively high problem rates of valves also include a significant number of freeze-protection valves, which are used only in very mild climates, in lieu of true freeze protection, which is accomplished by drainback and antifreeze-based systems.

My company's experience was that controllers and sensors were the major component problem, and pumps were second. Valves were not as much of an issue, but that's likely due to freeze-protection valves being eliminated in most local installations after the late 1980s. The rest of the component problems listed, which fall in the 6% to 16% range, jibe with our field experience.

Conducting a visual inspection of your solar hot water system's components is the first step in troubleshooting.

Collectors

Modern flat-plate collectors are fairly simple appliances, and durable especially if they are certified by the Solar Rating & Certification Corporation. They experience lifetimes exceeding three decades and can probably last 60 years or more if not abused. That said, these are some problems that can be encountered with collectors.

Flat-Plate Collectors

Broken glass. Glass breakage is the problem that most often arises with flat-plate (and evacuated-tube) collectors. While the glass can be replaced by removing the collector trim, finding a source of low-iron tempered (LIT) glass can be difficult. If you can't purchase it locally, shipping a single piece of glass can be expensive—sometimes more than the glass itself. Because of this, most people opt for common tempered glass. Any metro area will usually have at least one tempering plant that supplies local dealers with tempered glass for commercial windows, and patio and shower doors.

Carefully measure the glass before ordering, since tempered glass cannot be re-cut. Broken glass should be replaced quickly or additional damage to the collector can result from wind and rain. The fragments from a 4- by 8-foot tempered glass pane will fill a 5-gallon plastic bucket; a wet/dry vacuum cleaner is a handy cleanup tool. The gasket around the glass can most often be reused. If it is defective, fill in with a contractor-grade silicone sealant.

Heavy condensation buildup usually indicates a leak or standing water within the collector.

Condensate buildup. All collectors will exhibit some condensate on the glass intermittently, but if it is present all the time, standing water may be accumulating in the bottom of the collector. The remedy for this is drilling 1/8-inch weep holes in the bottom corners of the collector. The holes must be placed in the back of the collector and away from the glass front, since a drill will fracture tempered glass, and care should be taken to avoid drilling into any tubes.

Right: Once the glass face is broken, other elements within the collector corrode and degrade rapidly.

Below: A damaged frame allows moisture to infiltrate, increasing the component breakdown within the collector.

High-temperature black paint can serve as a DIY approach to refurbishing absorber coatings, although it won't be as effective as the original selective surface coating.

Absorber coating deterioration. If copper or aluminum is showing through the absorber's paint or coating, it should be repainted. The original coating may have been a selective surface like black chrome but that will be impossible to replicate in the field. Semi-selective paints like Solkoat are available online but difficult to apply without experience. Painting absorbers with a spray can of flat black paint won't have the same properties as a selective or semiselective coating, but is much better than bare or partially bare metal. Use high-heat stove, barbecue, or engine paint to refurbish absorber coatings. Roughing the absorber surface with sand cloth from a soldering kit can help the new paint adhere to the metal.

High collector glass temperature may be due to failed solder joints or a low flow rate through the collector, which could be caused by several things. Some collectors used a lower-temperature solder to bond the copper tubes to the absorber plate. After years of enduring repeated heating and cooling cycles, these joints can separate, reducing efficiency significantly. A collector with a debonded absorber will be very hot, and the temperature difference between the supply and return lines will be small. Much of the heat in a collector with a debonded absorber will be reradiated through the glass and can be detected with an infrared thermometer. Absorbers that have debonded need to be replaced if you can find a manufacturer that will supply them—ask if they make custom absorber plates. If a replacement absorber can't be found, the entire collector will need to be replaced.

Unlike a debonded absorber, low flow rates will show as a high temperature difference between supply and return piping. Ideally, a collector loop will have a difference between 10°F and 30°F from inlet to outlet. Differences greater than 50°F marginally affect efficiency, but differences above 70°F indicate that the system is operating at a significantly lower efficiency, since heat loss through the glass is increased.

Lower flow rates could be caused by installation design flaws, an undersized pump, a partial pump failure, or a restriction in the piping, heat exchanger, or collector tubes. Partial pump failures can be due to hidden impeller damage. In hard water areas, reduced flow rates may be caused by scale buildup from dissolved minerals in open-loop, direct forced-circulation, and thermosyphon systems. First look for installation design flaws like the tubing being too small or too many collectors for the size of tubing. The pump problems (in particular, impeller damage) may require pump removal and inspection.

Leaks in collectors are mostly due to freezing—usually the result of gizmo freeze-protection like freeze valves. Freeze breaks in the absorber tubing should be repaired by brazing or silver soldering. The silver solder process is easier than normal soft soldering used on pipe joints and the copper tubes don't require a bright fluxed finish to seal the leak. Soft soldering inside collectors is not suitable due to the lower melting point of the solder.

Automotive radiator additives, like Alum-A-Seal, a powder that accumulates to plug leaks, can be used to stop pinhole leaks caused by slightly corrosive fluids like overheated antifreeze, but this is a temporary repair. As it does in car radiators, the conditioner can give an old collector a few extra years of life. However, this strategy should only be used in systems with double-wall heat exchangers due to the uncertainty of the chemical contents in additives. This is definitely not considered a "best practice."

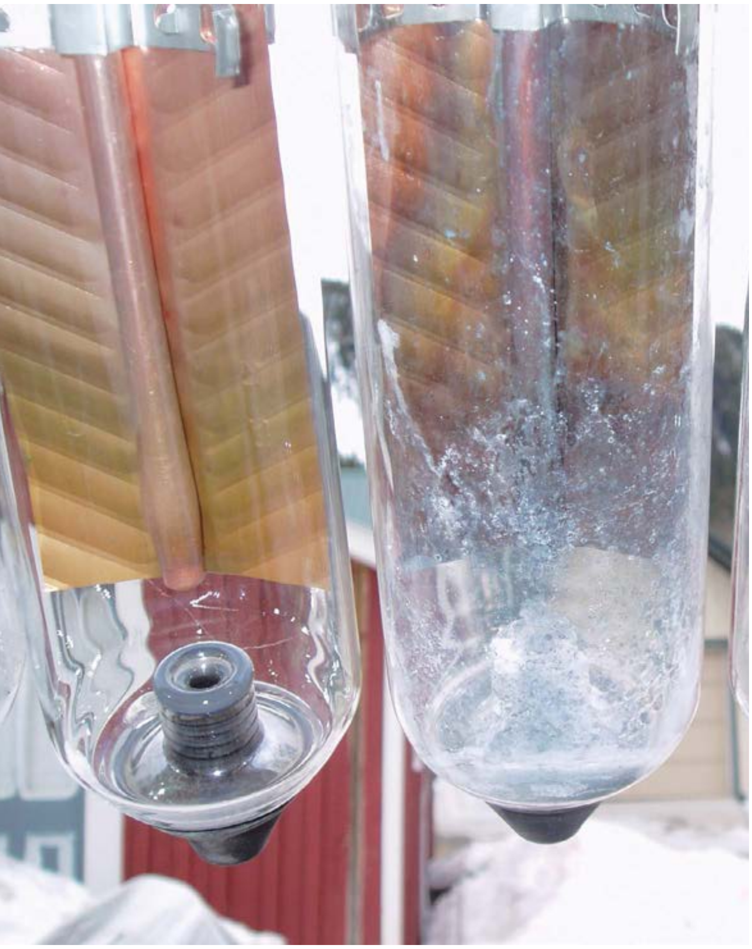
Evaluating Evacuated-Tube Collectors

Evacuated-tube collectors are most often used in antifreeze systems. Although the tubes have been in the marketplace for more than three decades, due to higher costs than flat plates they have been popular mostly in cold, cloudy climates like northern Europe and Canada. The superior insulation of the vacuum in the tubes makes them most applicable in harsher climates with reduced solar resources.

Broken glass. Evacuated-tube manufactures use borosilicate glass or soda lime glass in the collectors. The glass is not tempered, so breaks into shards that can be more dangerous than the small pieces from tempered glass breakage. Consequently, evacuated-tube collectors are more fragile than flat plates, as glass strength is proportional to its thickness. Broken glass in a twin-tube-type collector can often be replaced separately from the absorber/heat pipe components. The vacuum in twin-tube collectors is between the two pieces of glass much like a thermos bottle. The heat pipe in twin-tube models slips into the tube on installation and can be removed and reinserted into a new glass tube. In single-glass collectors, the heat pipe is factory-installed.

Double-wall evacuated tubes have replaceable glass.

The tube on the right has lost its vacuum, and will feel very hot to the touch. Its single-wall design means that the whole tube or entire collector will need to be replaced.



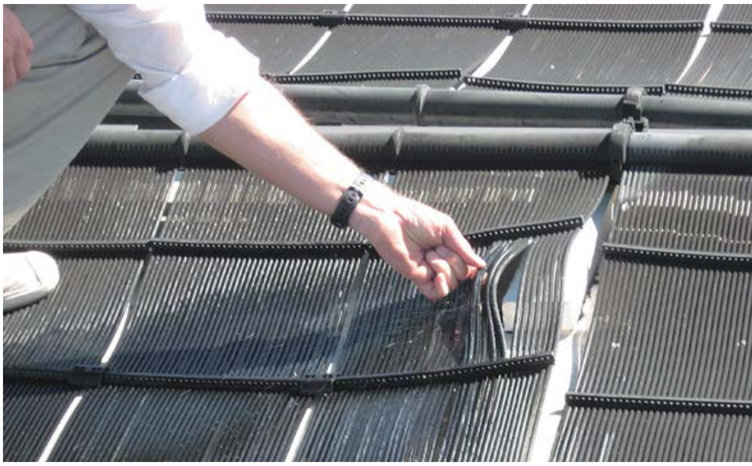
Jay Posner/Nunatak Alternative Energy

Vacuum loss. Evacuated tubes have life spans of about 15 years but this varies depending on the type of tube and manufacturer. Vacuum loss, through glass breakage or through the connections, is the most common failure with tubes. Once the vacuum is gone, there is little insulation left to retain the collected heat. The collectors can lose their vacuum in other ways (seals and connections) depending on the type of tube, but exactly how the loss occurs isn't well understood, since it normally occurs over a few years. There is little evidence left as to how the vacuum was lost in most cases unless glass breakage is evident.

Swimming Pool Collectors

If they're not abused, most swimming pool collectors, made of UV-inhibited polypropylene, have life spans of 20 years or more. However, polypropylene is a high-temperature plastic (polymer) to which normal sealants and glues will not adhere. This makes fixing pinhole leaks that may appear in the collector's later life difficult unless factory plugs are used. The repair process requires cutting the leaking tube at both ends near the large header pipes and inserting the correct-size rubber plugs into the tube. This repair isolates the leaking tube but is often a stopgap repair, since these types of leaks indicate that plastic tubes are deteriorating and the collector is likely near the end of its useful life.

Pinholes in pool collectors usually indicate that the whole collector is reaching the end of its life.



Potential Pump Problems

SHW circulation pumps have no suction lift and must be primed (be below the source water) at all times to function. They normally have life spans of 10 to 20 years and are made to withstand fluid temperatures up to 240°F.

Alternating current (AC) solar pumps are lubricated only by the circulating fluid. Many direct current (DC) pumps powered by PV modules and a few AC pumps use a magnetic drive. The magnet is an interface between the motor and the spinning impeller. These also usually lack provisions for periodic lubrication.

Always replace pumps with ones made of the same materials and close to the same head and flow specifications. Replacement pumps don't need to be from the same manufacturer.

Pump stations are factory-assembled with most of the components needed for an antifreeze system and save installation time. A caution with the stations is that some have pumps with a check valve in the pump impeller housing. Pumps used in a drainback system cannot include a check valve, so be sure that you use the correct one for your system.

Bearing failure. The most common problem with pumps is bearing failure, which becomes more likely to occur if the pump is installed incorrectly. The shaft of the pump should be oriented horizontally. A pump with the impeller housing on the top or bottom has the shaft in a vertical orientation, which can increase lateral pressure on the bearings.

A continuous screeching noise is a sign of bearings that are about to fail. If the pump impeller is locked up (not movable by hand), the bearings are frozen and the pump needs to be replaced. Pumps mounted with the shaft vertical can also have air trapped in the housing, stopping the circulation.

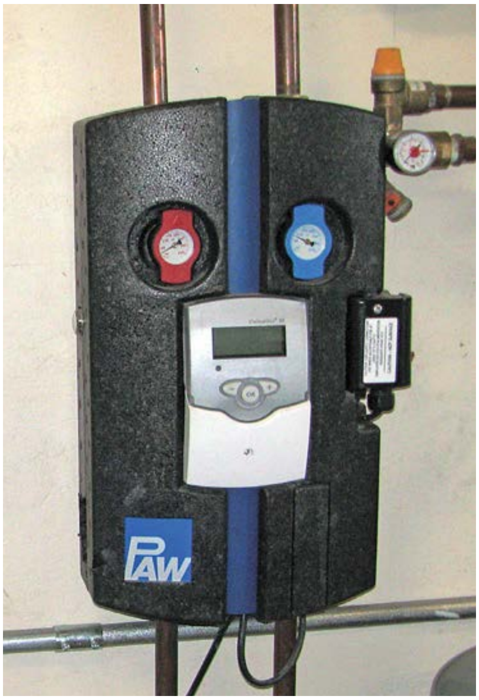
A vertically oriented pump shaft (shown above) will increase wear and tear on the bearings. Pumps should always be mounted with the motor axis horizontal.

Damaged motor windings. Although less common, motor windings can also fail. If the impeller spins and the capacitor checks out OK, the windings are probably the problem. Winding failure is usually accompanied by a strong burned smell, so you should test this only after you've ruled out

Which Pump is Right?

Bronze pumps can cost many times more than iron pumps, but bronze (or stainless steel) pumps should always be used in any application containing potable water. Iron pumps that are used on freeze-protected closed loops will corrode quickly in open loops.

A drainback system requires a pump with sufficient head to pump from the tank water level to the top of the collectors. Both of these pumps have the impeller shaft horizontal, as it should be when installed.



Some modern pumps have integrated check valves (pump stations). If the pump serves as the collector-loop pump in a drainback system, check the impeller housing and remove this check valve.

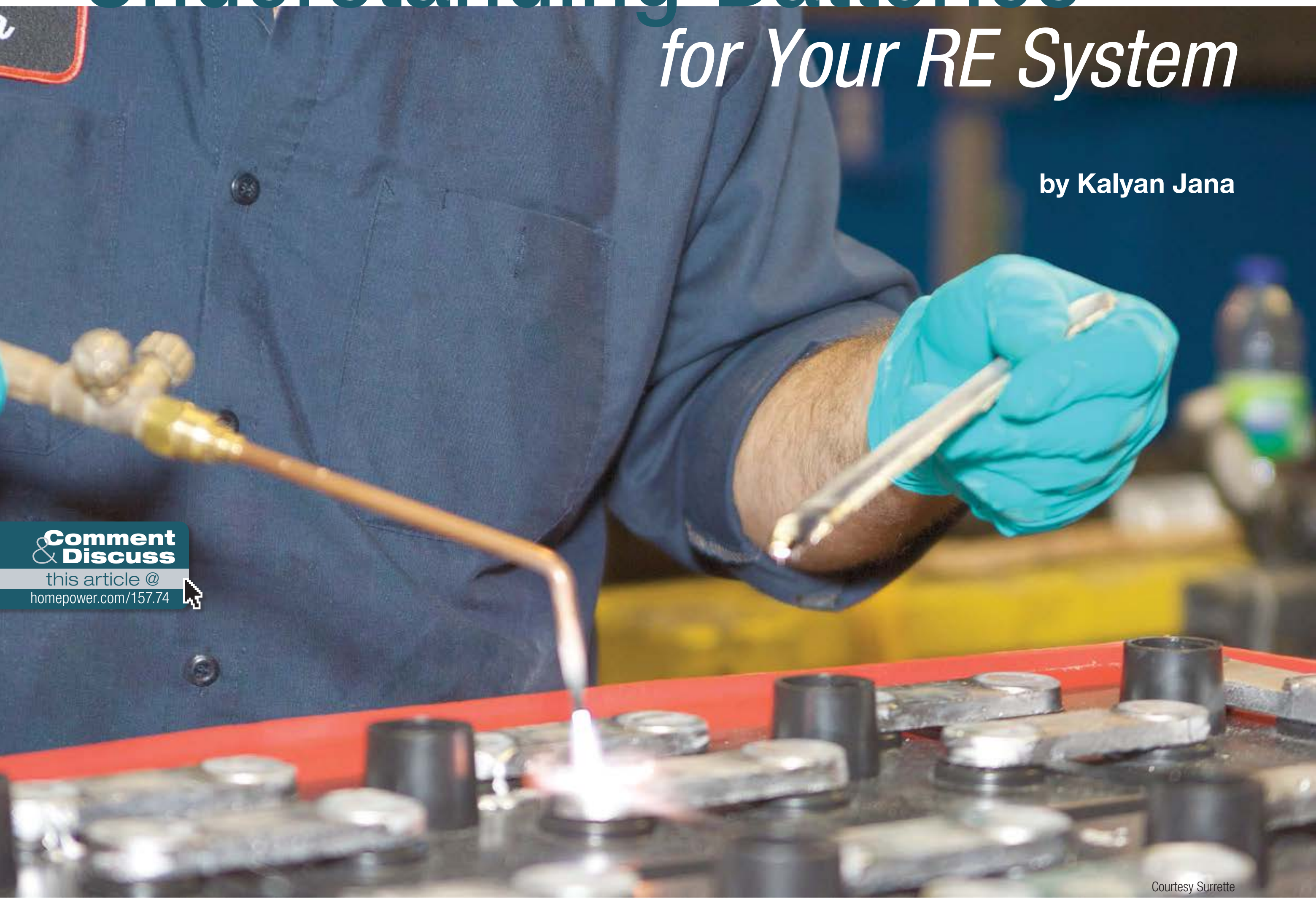
bearing failure. AC-powered pumps often use a capacitor to start the pump. The housing on AC pumps where the wire or conduit enters the pump contains the capacitor. A capacitor must be removed to be tested, and the wire connections should be marked to put it back together correctly. A multimeter on a low resistance measuring scale is used to charge and discharge the capacitor by alternating the meter leads on the two capacitor wires. If the meter exhibits a burst of resistance when charged and then falls back to open (discharged), the capacitor is good. If the capacitor doesn't cycle through this simple charge/discharge test, replace it. A new capacitor costs less than $20; a new bronze high-head pump can cost a few hundred, so it is worth the time to rule out the capacitor first.

Access

Chuck Marken is a *Home Power* contributing editor, and a licensed electrician, plumber/gasfitter, and HVAC contractor. He has been installing, repairing, and servicing SHW and pool systems since 1979. He has taught SHW classes and workshops throughout the United States for Sandia National Laboratories, Solar Energy International, and many other schools and nonprofit organizations.

Understanding Batteries
for Your RE System

by Kalyan Jana



Courtesy Surrette

When shopping for batteries for a renewable energy (RE) system, it is important to choose a battery designed for deep-cycling, and one with a track record of long-term reliability and performance. Make sure to evaluate both the battery manufacturer's reputation for using quality components, as well as the manufacturing process employed to assemble a deep-cycle battery.

While buying cheap batteries may seem a good idea at first, it can cost you much more down the road. Cheap batteries will not withstand the rigorous deep-cycling that is inherent in RE applications. Over time, these batteries will fail and need to be replaced more often than quality deep-cycle batteries, costing you more money in the long run. Lower overall cost of ownership and reducing the need to constantly replace batteries should be the determining factors, not just the initial purchase price.

Battery Types

A battery uses an electrochemical reaction to store energy. Unlike primary batteries that cannot be recharged, secondary batteries can be recharged many times before they reach the end of their life. Several types of secondary batteries are available in sizes appropriate for an RE system, including lead-acid, lithium ion, nickel-cadmium, and nickel-iron. However, lead-acid, deep-cycle batteries, specifically designed to be deeply discharged to 50% to 80% of capacity, are most often used due to their relative low cost and wide availability.

Flooded lead-acid (FLA) and valve-regulated lead-acid (VRLA, or "sealed") are two types of lead-acid batteries. FLA batteries lose electrolyte as the electrolyte is converted from a liquid to a gas during charging, so the individual cells must be periodically topped off with distilled water to avoid permanent damage. VRLA batteries can be either absorbed glass mat (AGM) or gel and are maintenance-free—they cannot accept the addition of water. AGM batteries feature individual cells that contain positive and negative plates separated by a glass mat separator (see "When to Use VRLAs" sidebar).

Batteries to Suit Your System

Lead-acid batteries are made for specific discharge duty cycles. For example, a starting-lighting-ignition (SLI) battery (used to start vehicles) is designed to deliver high amperage for short durations, and then be recharged quickly. Similarly, a lead-acid battery that is part of an uninterruptible power system (UPS) may need to provide energy for just a few minutes when the utility experiences a grid anomaly or outage—usually only a few amp-hours are taken out of the battery. In contrast, a battery in an RE application must run various electrical loads for long durations, and possibly over several days. So for an RE application, choose a battery designed for a marathon, not a sprint.

Charging characteristics also influence battery choice. A SLI battery is designed to charge for a few hours at most (via the vehicle's alternator) before the next engine-cranking event. Since a UPS battery has to be ready for discharge at any time, it is on a trickle ("float") charge whenever the source is available. A deep-cycling RE battery will experience constant charging and discharging over several years. Because of this, the ideal battery for an RE application must be capable of delivering many cycles over a longer time than SLI, and can have some charging flexibility—either more slowly from an RE source or more quickly from a backup generator.

Details Make a Difference

Although all battery manufacturers use the same general processes, all batteries are not created equal. There are significant differences in the battery components used during the manufacturing process as well as the quality control processes each battery manufacturer implements within their facilities. Evaluating these differences is key in determining a battery's longevity and performance, and this information can usually be found on a deep-cycle battery manufacturer's website. If not, ask your sales rep or the battery manufacturer directly about specific manufacturing processes.

The working components of lead-acid batteries are their plates, which are made of lead. To harden the lead for use in a battery, it is combined with other metals (calcium, in VRLA batteries; antimony, in flooded batteries).

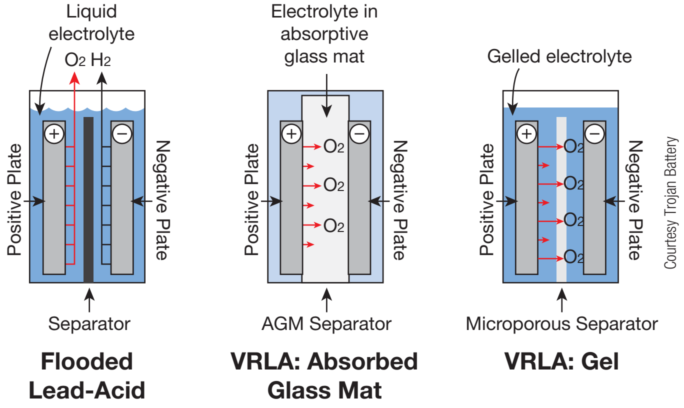
Lead oxide is used to produce the pastes, which include the positive active material (PAM) or negative active material (NAM) that is applied to a grid of lead that becomes the battery's positive and negative plates. The chemical compositions of PAM and NAM are proprietary. Deep-cycle batteries have PAM and NAM recipes tailored for applications such as RE, propulsion (in EVs), or equipment like electric forklifts. Therefore, it's important that a user understand what they want to achieve from their batteries—long float life or long cycle life. A battery's design and paste formulations are customized for one or the other.

When to Use VRLAs

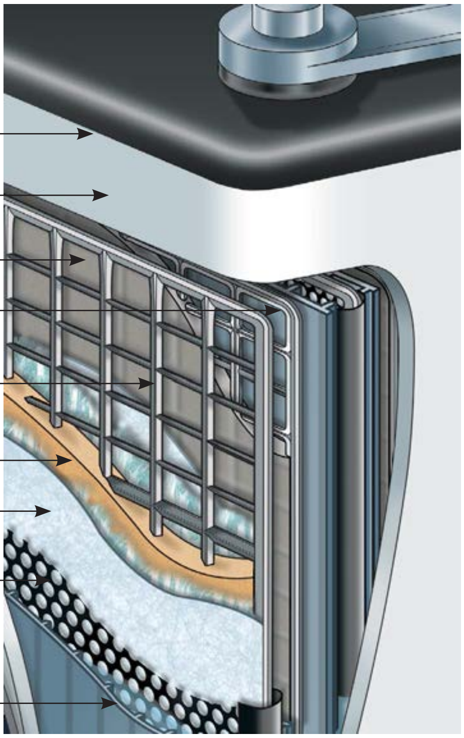
Valve-regulated lead-acid (VRLA) batteries, which include absorbed glass mat (AGM) and gel types, are ideal for use in applications where one or more of the following apply:

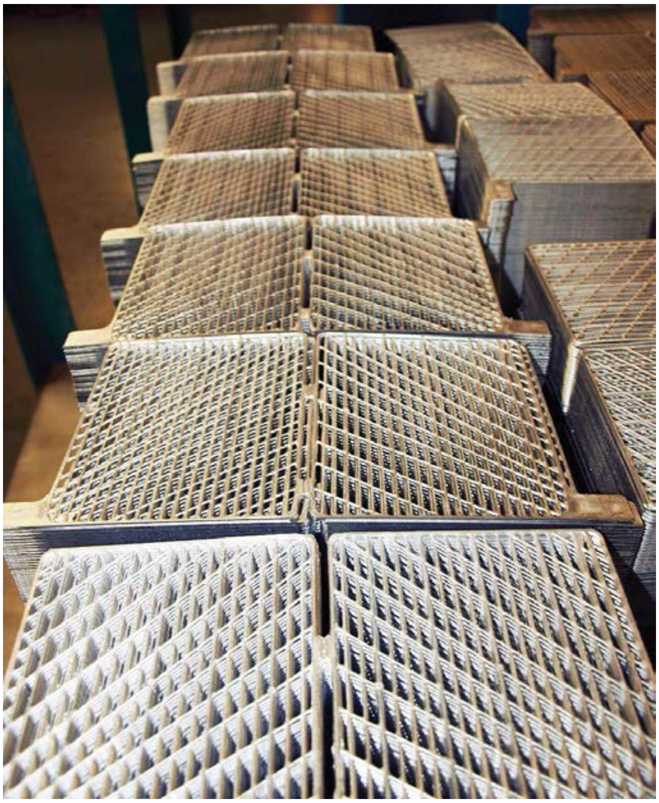
- Regular battery maintenance is difficult. This may be due to the system's remote location or the fact that maintenance labor is too expensive.
- Local ordinances prohibit the use of flooded batteries due to environmental concerns about possible acid spills.
- A spill containment system may not be feasible for an installation.
- In places where heavy hydrogen off-gassing may pose a hazard.
- An installation where the batteries must lay on their sides.
- If batteries must be shipped, VRLAs can usually be classified as nonhazardous cargo. Shipping these batteries is usually less expensive than shipping flooded lead-acid batteries.
- AGM batteries are better suited for very cold temperatures: the battery's internal resistance is lower and the charge acceptance is better than FLA and gel-type batteries. Also, the specific gravity of an AGM battery's electrolyte is higher, so is less subject to freezing.
- In applications that require very high discharge rates, such as UPS backup power, AGM technology is a good fit because of their lower internal resistance (compared to flooded batteries of equal capacity). Not all AGM batteries are designed for high power rates. Only those batteries designed to work within high-energy demands of deep-cycle applications are best for RE applications.

Battery Types



Components of a Battery





Plates are cast from lead and shaped to provide adequate surface area to hold the paste, where the chemical reactions occur.

The battery's lead grids are designed to hold the active materials (PAM and NAM). The grids also provide an electrically conductive path that enables the electrons to move in and out of the battery. Positive and negative grids are cast from molten lead alloys, and the patterns used in the design of grids vary from manufacturer to manufacturer. Grid designs and configurations help the current flow through the grid network, enhancing overall battery performance.

Once the positive and negative grids are pasted with PAM or NAM, they undergo curing, in which the paste is dried slowly. During this process, a bond is created between the paste and metallic grid, to develop an electrochemically active mass. Curing must be accomplished under precisely controlled temperature and humidity to produce a high-quality battery. The curing time can take as long as 72 hours to fortify the interlocking crystal structure of the PAM and NAM.

After curing, the plates are arranged in groups, alternating positive and negative. A separator is placed between each plate that prevents them from touching and shorting. The separator material's quality and design are important factors in determining the battery's service life. High-quality batteries use glass mat or rubber separators that reduce the chance of stratification, which is a typical mode of battery failure in renewable energy systems. Stratification is the process in which the acid concentration at the bottom of the battery becomes greater than the concentration at the top. If not addressed, stratification will destroy a battery.

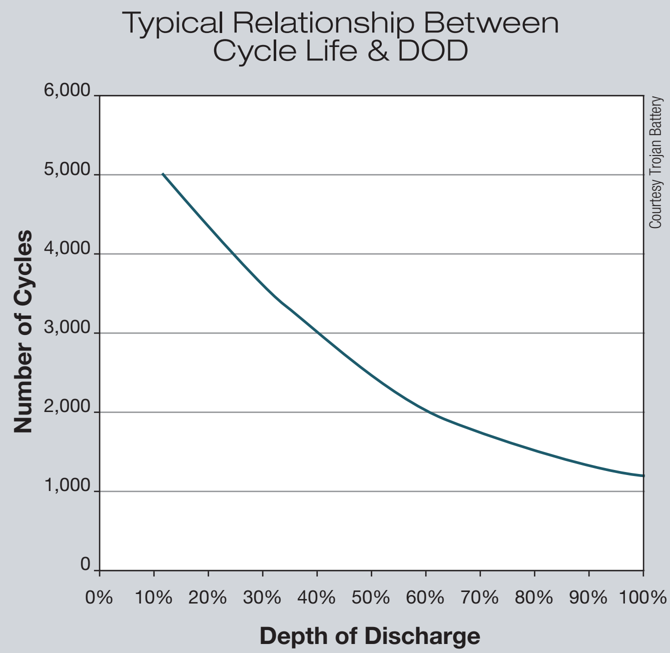
Plate Construction

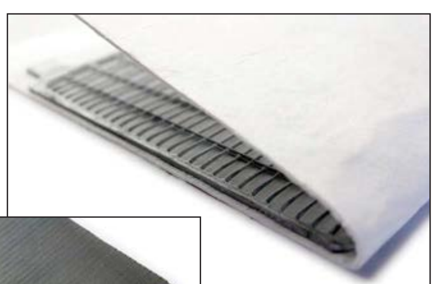
Life Expectancy Ratings

A single battery cycle consists of bringing the battery up to a full (100%) state of charge (SOC) from particular end-of-discharge voltage. Partial cycles will affect a battery's longevity, especially if the batteries are not fully recharged after each discharge. Batteries are capable of only a certain number of cycles before capacity loss becomes noticeable and the battery reaches the end of its life. Proper charging is critical to ensuring a battery reaches it fully rated life capacity.

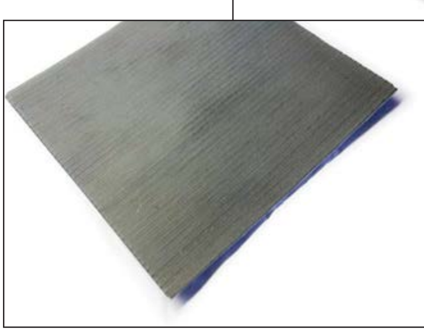
There are two ways in which a battery is used—floating or cycling. A battery designed for backup will spend most of its time in float mode, which means it is under a constant, small charge to stay full and ready. Its life expectancy at a specific temperature (usually 77°F) is expressed in years. A deep-cycle battery used in off-grid RE applications, on the other hand, will have its life expectancy expressed in the number of cycles delivered to a specific depth of discharge (DOD). If a 100 Ah battery delivers 50 Ah on each cycle, it is discharged to a 50% DOD.

The graph shows a typical battery's expected cycle life under various DODs. At 20% DOD, the battery will deliver 5,000 cycles; at 50% DOD, the same battery can deliver only 2,750 cycles before reaching the end of its life. A battery is considered to have reached its end of life when it fails to support the load for at least 50% of the designed time.





The glass mat envelops the plate to enhance electrical conductivity.



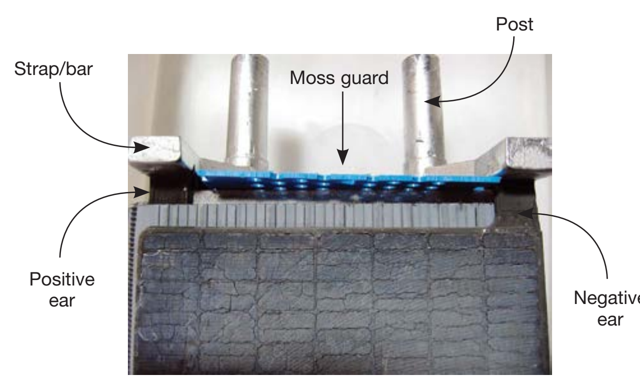
A rubber separator keeps acid channels open longer, enhancing electrochemical processing while reducing the risk of stratification.

Courtesy Trojan Battery (2)

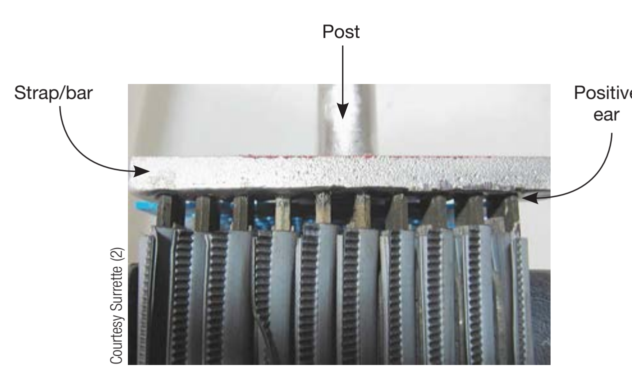
After the appropriate number of positive and negative plates are stacked, they are placed into a plastic case, which contains one cavity for a 2 V cell, three for a 6 V battery, or six for a 12 V battery. The number of plates depends on the specific capacity of the battery being built, i.e., the greater the amp-hour capacity, the larger the number of plates. The positive plates are then welded together at the top, as are the negative plates, forming a single cell assembly. In multiple-cell batteries, each cell assembly is welded in series or in parallel to determine the battery's voltage.

Group Construction

Side View



Front View



Courtesy Surrette (2)

Courtesy Trojan Battery

Trojan's Industrial line of batteries is engineered specifically to support renewable energy systems with large daily loads, where the batteries are cycled regularly.

A cover is then heat-sealed to the case. The quality of this seal is important—if poorly done, the seal's integrity can be compromised, leading to future problems such as breakage and/or separation of the lid from the battery case.

Once battery assembly is complete, the battery goes through "formation." The formation process involves filling the battery with a solution of sulfuric acid and distilled water. The battery is then given an initial charge, which preps the battery plates for operation. Formation usually takes several days to complete; the greater the battery capacity, the longer the formation period.

When the formation process is complete, the battery is tested to confirm it meets the manufacturer's specifications. This is called "end of line" testing, which ensures all electrical connections are working properly and there are no obvious defects. The battery is then cleaned of any residual acid on its external surfaces, labeled to be in compliance with all necessary regulations, and prepared for shipping.

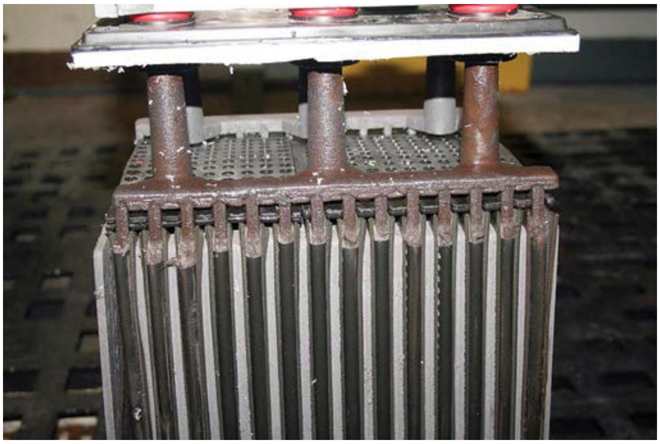
Quality Control

The differences in the manufacturing processes for a deep-cycle battery can have a profound effect on its performance and life, as seen in the images that show high- and lower-quality batteries.

Both had the same rated capacity, were the same age, and experienced identical service under controlled conditions. However, the battery on the left has aged far more gracefully than the one on the right. Why? The battery cell on the left has a moss shield on the top of the plates, which prevents the plates from expanding and shorting out at the top of the cell. The absence of a top shield on the other battery eventually caused short-circuiting, leading to lower capacity and a shorter life span. The battery on the left also featured a paste formulation specifically designed to optimize use of the battery's active material, resulting in sustained battery performance over a longer period of time.

Besides the presence of a moss plate, the design and use of a battery's grid and separators are equally important. Corrosion can quickly kill a battery, and the thicker a battery's grid structure, the greater its resistance to corrosion. It also is important to ensure that the grids are cast, rather than stamped. Cast grids have no hairline fractures, which can cause the battery to fail prematurely.

In addition, separators between the battery plates should feature wide channels to increase the flow of acid, which enables optimum battery performance. Batteries that feature separators with wide-channel designs will also offer greater resistance to stratification.



Courtesy Trojan Battery (2)

The internal battery images above illustrate the difference installing a moss shield makes to the life of a battery. The two batteries shown are the same type, age, and duty cycle. However, the one on the left (manufactured by Trojan) used a moss shield, which successfully protected the plates from shorting to the cell strap.

A Battery's Chemical Reaction

The conversion of chemical energy to electrical energy enables a battery to operate and use the stored energy or electricity. When the positive and negative plates of a battery are immersed in electrolyte (sulfuric acid and water), a chemical reaction is created and the sulfur ions move in and out of the solution. This produces a battery's energy or charge. During discharge, some sulfuric acid turns into water and some lead oxide to lead sulfate. When charged, the water is converted back to sulfuric acid and the lead sulfate is converted back to spongy lead.

The chemical reaction shown below is reversible, as indicated by the double stacked arrows. During a discharge, the reaction proceeds from left to right; during a charge, the reaction proceeds from right to left.

A battery's capacity is the amount of energy (measured in amp-hours) that the battery can provide to the load (equipment) under a specific set of conditions (discharge rate, temperature, age, etc.).

Also, batteries have different "starting" and "fully charged" specific gravity measurements based on battery design, function, application, and the operational environment. Understanding and monitoring specific gravity readings of deep-cycle batteries is critical to ensuring reliable charge performance and achieving optimum battery life.

$$Pb + PbO_2 + 2\,H_2SO4 \underset{\text{Charge}\ +2e}{\overset{\text{Discharge}\ -2e}{\rightleftarrows}} 2\,PbSO_4 + 2\,H_2O$$

Pb=Lead; PbO_2=Lead Oxide; H_2SO_4=Sulfuric Acid
$PbSO_4$=Lead Sulfate

Outside Parameters

An essential component of determining the quality of a deep-cycle battery is the manufacturer's investment in independent third-party testing. This data provides valuable information on product performance, and validates a manufacturer's product claims. Independent, third-party data obtained from testing batteries per industry-recognized standards, such as by the International Electrotechnical Commission (IEC), allows consumers to compare products from different manufacturers, and can be found on some battery manufacturers' websites.

For an RE application, the two parameters of critical importance are amp-hour capacity (commonly at the 20-hour rate) and the number of cycles the battery can deliver to a given depth of discharge (DOD)—for example, 3,000 cycles at 50% DOD.

Once the short list of possible battery options has been created, the next task should be to ensure the battery manufacturer has not only a proven track record, but also builds quality into each battery it ships.

The type of battery you choose and the vendor you purchase from can have a significant impact on the performance, durability, and total cost of a renewable energy system. The battery bank in an RE system typically represents the largest equipment cost over the life of the system, so proper understanding of deep-cycle batteries is important to maximize the return on your investment.

Access

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Off-Grid & Grid-Tied
Solar / Hydro / Wind
Solar Water Pumping
Educational Toys
Homestead Supplies
Books
Wholesale Available
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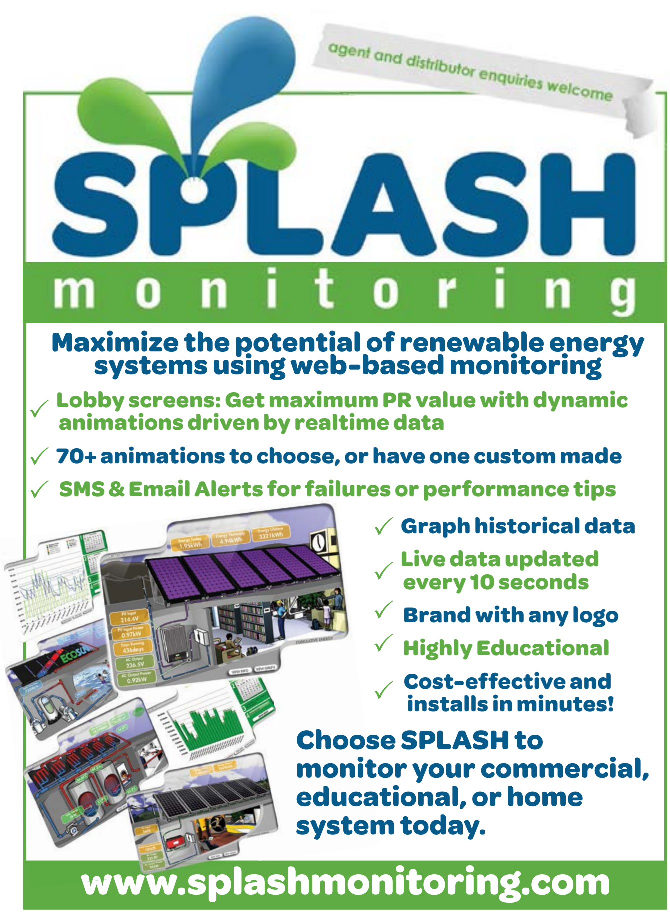
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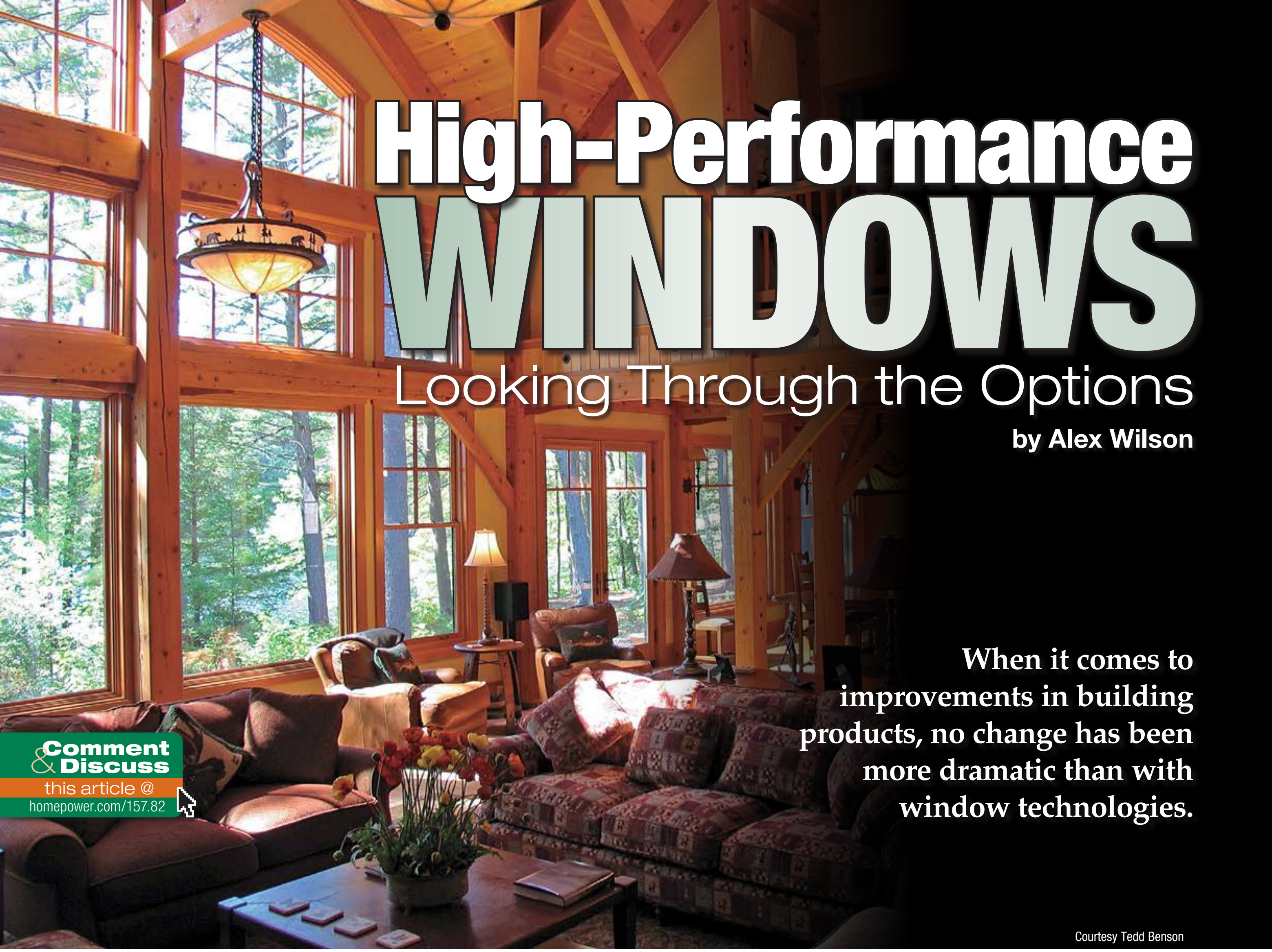
High-Performance WINDOWS

Looking Through the Options

by Alex Wilson



When it comes to improvements in building products, no change has been more dramatic than with window technologies.

Courtesy Tedd Benson

High-performance windows are multipurpose—including providing an inside view of the outside world, while contributing to a home's overall energy efficiency.

Prior to the 1970s energy crisis, most windows were a single layer of glass (single-glazed), with energy performance (a measly R-1 or so) mostly derived from the air film next to the glass (a layer of relatively still air forms along any material). Some windows were double-glazed, roughly doubling the performance (to R-2), but that was about it.

It is far different today. I recently installed windows in our Vermont home with an R-12.2 at the center of the glass. These fiberglass-framed windows have four layers of glazing (two panes of glass and two suspended films), three low-emissivity coatings, and krypton gas between the panes—and they admit enough solar energy to help passive solar heating in our cold climate.

As windows have improved, they have gotten a lot more complicated. Choosing windows is no longer a matter of deciding on double-hung versus casement and whether to get divided lites. This article examines the technologies that have revolutionized window performance over the past several decades and provides guidance on how to select windows that are best for your particular application.

What We Ask of Windows

To understand why certain windows and window technologies make sense for particular applications, it's important to understand the very different—and important—roles that windows play:

- Delivering natural light into a home
- Providing views to the outdoors
- Adding aesthetic appeal to a home
- Slowing heat loss
- Slowing unwanted solar heat gain
- Admitting passive solar heat—sometimes even serving as a home's primary heating system
- Preventing condensation
- Contributing to home security

In some parts of the country, blocking solar heat gain is more important than bringing that solar heat into the home. While a really high R-value may make sense in cold and snowy Vermont, it may not in mild, temperate coastal California. These differences may even apply within the same house—installing windows with different capabilities on the east and west sides of the house than on the south, for example. Balancing these needs can be challenging, but is a lot easier if we understand how windows work.

Understanding Heat Flow

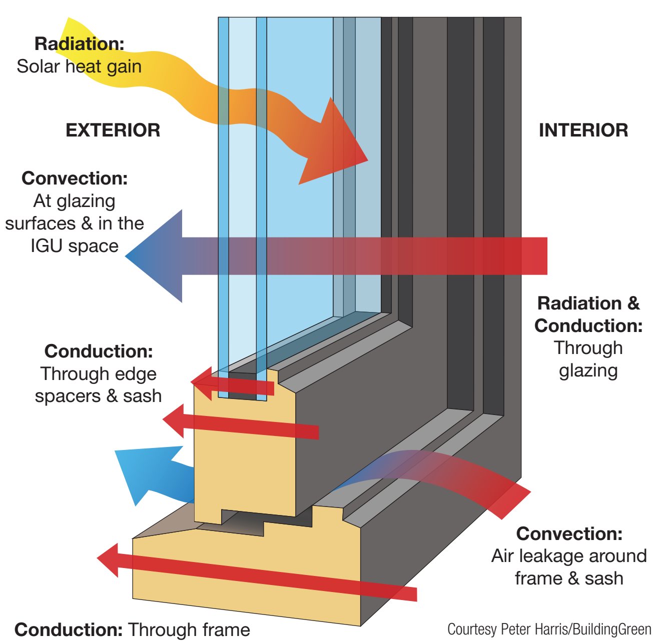
A window's energy performance comes down to physics. There are three modes of energy transfer—radiation, conduction, and convection—and all three play an important role with windows.

Radiation is the transfer of energy via electromagnetic waves or charged particles that travel in waves. Sunlight, a form of short-wavelength radiation, is readily transmitted through most glazing; while most glazing blocks long-wavelength heat radiation. As sunlight travels through a window and is absorbed by surfaces in a room, those surfaces warm up and begin emitting longer-wavelength heat radiation.

Conduction is the flow of heat through a material by contact. It is why the handle of a cast-iron skillet that's been on the stove is hot. While we usually think of heat conduction occurring through solid materials, it also occurs through liquids and gases. Differences between the thermal conductivities of air, argon, and krypton (used in the spaces between panes) affect the speed at which heat conducts through multipane windows.

This triple-glazed, low-e window from German company Unilux offers excellent insulation performance, yet transmits enough sunlight to be effective for passive solar heating.

Heat Transfer Through a Window



Convection is the flow of heat that occurs when warm molecules (gas or liquid) physically move. Warm air rises and cool air sinks; this process happens in an insulating glass unit (IGU; a sealed glazing assembly with at least two layers of glass separated by an air- or gas-filled space). Inside an IGU that's warm on one side and cold on the other, convection loops may form, increasing the convective heat transfer.

Advances in Energy Performance

Layers of glass. Among the oldest approaches for boosting window energy performance is adding a second layer of glazing. Thomas Jefferson added storm windows to Monticello and doubled the R-value of those windows (though the term "R-value" hadn't been introduced yet). Most glass energy performance comes from the air films on both sides of it. When there are multiple layers of glass, there is a relatively still layer of air that lies between each glass layer. The earliest IGUs relied on welded-glass edges, rather than modern butyl rubber and silicone sealants, so they sealed extremely well—better than today's IGUs.

Additional layers of glazing further boost the R-value. Nearly all windows in Sweden have been triple-glazed since the mid-1970s, when the country was very seriously affected by oil embargoes. Most of the largest U.S. manufacturers are finally offering triple glazing, including Andersen, Marvin, and Pella.

Alex Wilson

Well-placed windows can provide ample daylighting and ventilation to interior spaces.

More glazing means more weight, which means the hardware has to be sturdier (and is more expensive). To reduce the overall weight with triple-glazed windows and open up the option to add even more layers, a few manufacturers are instead using suspended plastic (polyester) films between the layers of glass. Alpen High Performance Products is the technology leader among window manufacturers using suspended films, and the company made the quad-glazed windows that I just installed. Several other window manufacturers, including Hurd and Marvin, offer suspended films.

Old single-pane windows are a constant household energy drain and compromise a home's overall thermal comfort.

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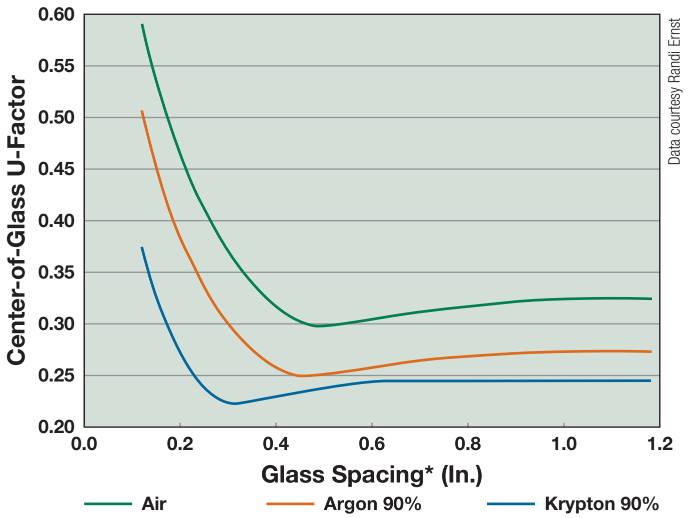
Spacing between layers. Increasing the airspace in an IGU offers a significant energy performance boost. In the 1980s, the standard was about 1/4 inch. Increasing the airspace to 1/2 inch boosts the center-of-glass R-value in an IGU without low-emissivity coatings (see "Thermal Effects of IGU Spacing" graph) from 1.75 to 2.04—a 17% improvement. Window performance is often reported as U-factor (the inverse of R-value). In this case, the U-factor drops from 0.57 to 0.49. Optimizing that air space thickness is an easy, inexpensive way to improve energy performance, and most window manufacturers have done that.

Thermal Effects of IGU Spacing



*Double-glazed low-e

Data courtesy Randi Ernst

Low-e coatings. The most important advance in window performance in recent decades has been the development of low-emissivity (low-e) coatings, microscopically thin, transparent metallic coatings that transmit short-wavelength light very well, but absorb and slow the transmission of long-wavelength heat radiation.

There have been two types of low-e coatings. Soft-coat, "sputtered" low-e has the lowest emissivity, but this type of coating is delicate and must be protected (facing the airspace) within the IGU, because weather or abrasion can damage it. Sputtered coatings are usually layers of silver, each layer just a few angstroms thick (there are 245 million angstroms in 1 inch). There can be one, or even two or three, layers of silver—leading to the common designation low-e^2 (low-e squared) or low-e^3 (low-e cubed).

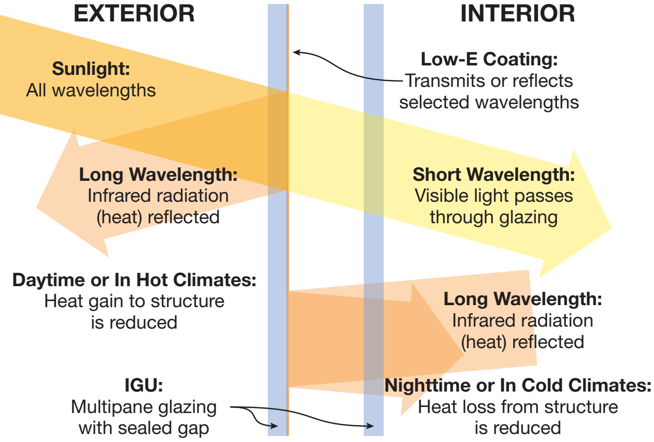
Pyrolytic coatings, typically made from indium tin-oxide, are melted into the glass while the glass is still molten. This durable "hard-coat" can be used in a single-glazing application such as a storm window. Smaller-scale window manufacturers often use this type because it can be handled more easily. Pyrolytic low-e coatings tend to tint the window more than sputtered silver coatings, and they also have a rougher surface that is harder to clean.

Alpen HPP can manufacture windows that have up to five glazing layers (three suspended films between two layers of glass), resulting in lightweight high-performance units that weigh only a little more than standard double-pane windows.

Courtesy Alpen HPP

A recent development produces a sputtered, hard-coat low-e that is durable enough to be applied on the outside of the pane of glass that faces a room. Made of indium tin-oxide, like traditional hard-coat low-e, it isn't melted into the glass, so the glass is much smoother, easier to clean, and less visible. This coating can be installed on the "warm side" (the face exposed to the room) in combination with a conventional sputtered soft-coat low-e within the IGU to achieve energy performance that was previously only available with triple glazing—a unit R-value as high as R-5 or a U-factor (the inverse of R-value) as low as 0.20.

Low-E Coating Performance



Window Gas Properties

Gas or mixture	Atomic Symbol	Molecular Weight	Specific Gravity[2]	Thermal Conductivity[3] Btu/(Ft. Hr.·°F)
Air	N_2O_2[1]	28.97	1.000	0.0139
Argon	Ar	39.95	1.380	0.0092
Krypton	Kr	83.80	2.890	0.0051
Xenon	Xe	131.30	4.530	0.0029

[1] Nitrogen: 78.1%; oxygen: 20.9%; argon: 0.9%; carbon dioxide, methane & inert gases: 0.1%
[2] Density relative to air
[3] At 77°F

Data courtesy theengineeringtoolbox.com

Low-conductivity gas-fill. Different gases have different conductivity. Argon, a common gas, has significantly lower conductivity than air, so filling the inner spaces with argon improves the R-value significantly. Argon is an unreactive "noble" gas, which accounts for about 1% of air. Other noble gases, krypton and xenon, have even lower conductivities than argon, but because they are more rare, they are much more expensive. The impact of different low-conductivity gases on energy performance is shown in the "Window Gas Properties" table.

Most manufacturers assume that 1% of the gas leaks out per year, but Randi Ernst of FDR Design, a fabricator of gas-filling and testing equipment, has done informal testing showing that the leakage rate is closer to 0.6% per year. At that rate, an IGU that starts out with 95% argon will still have 79% of the argon after 30 years and 70% after 50 years—though as organic glazing seals deteriorate over decades, that leakage rate could increase. As the low-conductivity gas leaks out, the window R-value will drop over time.

Some gas-filled windows, such as this one from Alpen HPP, are shipped with bladders to equalize pressure fluctuations in transit. They are removed during installation.

Alex Wilson

Courtesy Bieber

Frame options include wood with aluminum cladding (left), vinyl with polyurethane foam fill, (right), and uninsulated vinyl (below right).

Courtesy Alpen HPP

Glazing spacer. As the performance of IGUs has improved, addressing heat loss at the edges of the IGUs and the window frames has become more important. After the welded-glass IGUs disappeared, the most common method for separating the glass layers was to use aluminum channel and butyl sealants. However, highly conductive aluminum causes significant thermal bridging, leading to condensation and cold interior temperatures at the edges of windows.

Most modern IGU manufacturers now use stainless steel spacers, which have two advantages over aluminum: it's stronger, so the material can be thinner (less cross-sectional area for heat loss), and it is significantly less conductive. Other options include butyl rubber with a corrugated metal reinforcement strip and silicone glazing spacers, both of which have very low conductivity. Such spacers are often referred to as *warm-edge* spacers. The silicone Super Spacer from Quanex Building Products is the highest-performance glazing spacer available today.

Frame material. Early residential window sash and frames were made of wood, but polyvinylchloride (PVC) has increasingly gained market share to become more common than wood. In terms of energy performance, wood and vinyl are relatively similar, though if the hollow vinyl extrusions are filled with foam insulation the energy performance can exceed that of wood.

Metal windows—aluminum or steel—have lost popularity in residential applications due to their significant thermal conductivity. They remain common in commercial windows, due to their strength (particularly in large dimensions) and durability.

The highest-performance American-made windows have fiberglass frames. Fiberglass (usually a fiberglass-reinforced polyester plastic) has much lower expansion and contraction rates as it warms and cools than does PVC. This stability improves the window life and helps maintain air tightness. Like vinyl, fiberglass window frames are hollow and can be insulated with polyurethane.

Operability & window seals. Operable windows work either by sliding in a track (double-hung, single-hung, or horizontal-sliding) or by being hinge-mounted (casement and awning windows). The latter tends to have less air leakage, because compression gaskets can be used—as the window is closed, a gasket pushes against the frame for an excellent air seal.

Double-hung windows have a lower sash that can be raised with an upper sash that can be lowered, and are the most popular windows in the United States. Single-hung windows typically have a fixed upper sash and an operable lower sash—with roughly half the crack, airtightness is improved. Improvements in design and better weatherstripping make today's double- and single-hung windows much better than they used to be—and, in some cases, almost as good as the best casement or awning windows.

Courtesy Unilux

Casement windows manufactured in the United States typically open outward, while European casement windows more commonly open inward. The "tilt-turn" designs on high-end European windows (and some U.S.-made products) can open inward with side-mounted hinges or can tilt down with bottom-mounted hinges. Most have multiple closure catches for excellent air sealing. Whether casement windows open inward or outward affects the type of window accessories that can be used, such as interior insulating blinds or exterior roller shades.

Tinted glass. For hot climates, tinted glass can help block solar heat gain to reduce air conditioning loads. Tinted glass, though, can significantly darken the view, and in some cases block out as much as 90% of the sunlight. My preference for hot climates is to specify relatively clear glass (high visible transmittance), but with a solar heat gain coefficient (SHGC; the amount of solar radiation that passes through a window) of less than 0.3.

Dynamic glazing. A high-tech (and higher-cost) option to tinted glass is variable-tint or dynamic glass. This glass can be changed from clear to tinted with the flip of a switch to reduce heat gain or glare, and some products offer variable levels of tinting. Sage Electrochromics and View (formerly Soladigm) manufacture dynamic glass, though this option is only available with certain window lines—and costs a lot (on the order of $50 to $100 per square foot). These products are used primarily in commercial applications. Both require a small amount of current to maintain the tinting, but the energy use is minimal compared to the energy saved by reducing air-conditioning demands.

Vacuum glazing. While not commercially available yet, vacuum glazing may improve energy performance dramatically, and with very thin windows. Prototypes have been produced by Guardian Industries and several other manufacturers. The space between the layers of glass can be as thin as 250 microns (a quarter-millimeter), and the panes of glass have to be held apart with tiny beads or pillars (which are barely visible).

Heat conduction and convection in vacuum glazing are largely eliminated because most of the air molecules have been eliminated from the airspace. A moderate vacuum is created in these glazings (about 10^{-4} torr—compare this to a thermos bottle, which has a much "harder" vacuum of about 10^{-6} torr). This leaves radiant heat transfer as the primary mechanism for heat loss through glazing.

However, without a low-e coating, there is relatively little to be gained by the vacuum, because radiant flow is not effectively blocked. With standard hard-coat low-e, Guardian's prototype vacuum window would only achieve R-2 to R-3, while a standard sputtered soft-coat low-e double-glazed unit with the vacuum glass would yield about R-7. The best triple-layer (low-e^3) could achieve as much as R-12. (Note: Values are center-of-glass measurements.) The greatest challenge with vacuum glazing is how to seal the edges and maintain the seals over many years.

Measuring Window Performance

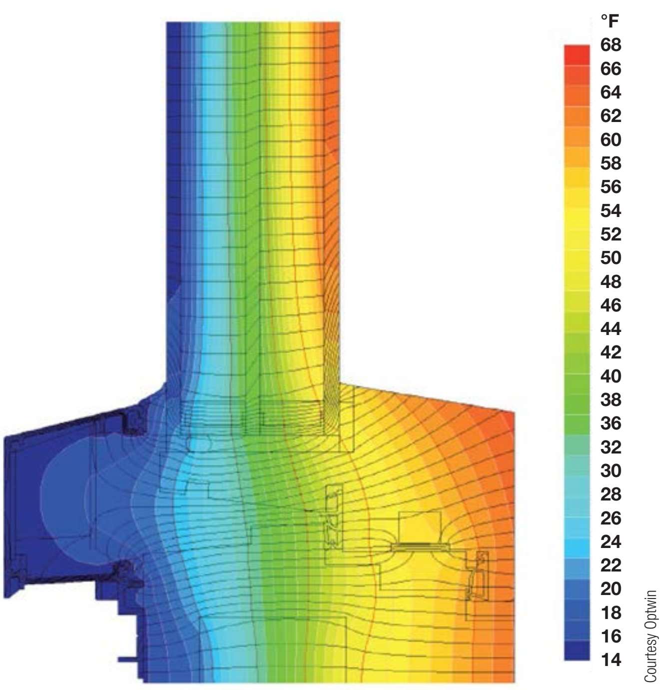
The most important measures of window performance are insulating value, visible light transmission, and solar heat gain.

U-factor. Insulating performance is expressed as U-factor, the number of Btu moving through a square foot of window in an hour with a 1°F difference in temperature across the window. U-factor is the inverse of R-value (U = 1/R); a better-insulating window has a lower U-factor and a higher R-value.

This insulating performance can be for the center of glass or the entire unit, which factors in the effect of the IGU's edges and the window frame. The National Fenestration Rating Council (NFRC) U-factors are for the whole unit, rather than center-of-glass. As IGUs have gotten better (lower U-factors), the effect of window edges and frames has become relatively more significant, so the difference between center-of-glass and unit values has increased. The high-performance windows on my house have a center-of-glass insulating value of R-12.2 (U-0.082) and a whole-unit value of R-8.2 (U-0.12).

Visible light transmittance (VT) is a value between 0 and 1 that corresponds to how much total visible light can pass through the glazing relative to a 1/8-inch-thick piece of clear glass. The higher the value, the more light is admitted. This is the light you want for daylighting, and it determines how clear the windows appear. Most people favor windows with high VT.

Whole-Window Heat Transfer



This image shows how heat moves through a high-performance window cross-section. Yellow and red areas indicate higher temperatures than green or blue areas. Standard windows have greater thermal bridging (greater heat loss through the higher-conductivity portions of the window).

Alex Wilson

NFRC window labels include U-factor, solar gain, transmittance, and optionally, air leakage and condensation resistance.

The solar heat gain coefficient (SHGC) is also a value between 0 and 1, and measures how much solar heat makes it through the window. The SHGC includes portions of the electromagnetic spectrum that are invisible—infrared and ultraviolet. These spectra don't provide visible light, but they contribute to heat gain. A window can have a fairly high VT and low SHGC because of the selective transmittance properties of advanced low-e coatings. It's part of the "magic" of modern windows.

Air leakage measures how tightly windows close and the effectiveness of weatherstripping or gaskets. In the United States, air leakage is typically measured in cubic feet per minute (cfm) per square foot of window area, assuming a 75 pascal difference in pressure across the window (based on a standard test method).

Finally, **condensation** resistance measures how likely condensation is to occur at the window perimeter. Even in high-performance windows, condensation may occur at the window edges, because greater heat loss occurs there and the glass temperature is lower—causing condensation to form on the inner surface. NFRC has a test method for determining condensation resistance, with the resultant number between 1 and 100—the greatest resistance.

Successful Window Shopping

Choose durable frame materials. Rotting window frames and sashes is a common cause of window failure. To maximize the life of windows, avoid exposed wood on the exterior. If wood windows are being used, select clad windows, which have protective exterior cladding of aluminum, vinyl, or fiberglass. With non-wood windows, avoid metal (steel or aluminum) because of their high conductive heat loss. Windows with frames made from extruded vinyl or pultruded fiberglass allow insulation (usually polyurethane) in the hollow frames, though not all vinyl or fiberglass windows *are* insulated—you'll need to verify. In general, the most durable, high-performance windows have fiberglass frames.

Model energy performance. Installing too many windows in a house can introduce too much solar gain, causing overheating, which may force the air conditioner to work harder (particularly if those windows are east- or west-facing). Too many windows can also create excessive heat loss, depending on the U-factor of the windows. To determine how the windows will affect the home's energy performance, nothing beats energy modeling. There are excellent software tools for modeling performance, including REM/Design ($347) and EnergyPlus (free)—though these programs take some training or experience to use effectively. Using these tools during a home's design can influence the placement and size of the windows—leading to lower energy bills and also greater thermal comfort.

Look to the NFRC labels. When shopping for windows, make sure you're comparing apples to apples. Use NFRC labels to compare different products' U-factors, visible transmittance, and solar heat gain. Some NFRC labels also include numbers for air leakage and condensation resistance. The Efficient Windows Collaborative (efficientwindows.org) has an excellent online tool for help with window selection.

Define energy performance targets. This depends on both the climate and the location of the windows in the house. Given the many glazing options to choose from, it increasingly makes sense to "tune" windows by orientation—in other words, specify a certain type of glazing depending on the window's location. With this approach, the primary variables are U-factor and SHGC.

If you want passive solar heating, especially in northern climates, specifying high-SHGC windows for the south makes sense, even if it means a sacrifice in the U-factor. For windows located on east and west walls, glazing with lower SHGCs will help limit unwanted solar gain. For north-facing windows, the SHGC value doesn't matter much; a low U-factor window is more important. For practical reasons, it usually makes sense to specify one type of glazing for south-facing windows, and another type for all of the other windows. Some designers and builders like to design the south windows to be slightly different dimensions to ensure that they aren't mixed up with windows slated for other walls (see the "Tuning Windows for Orientation & Climate" table).

continued on page 90

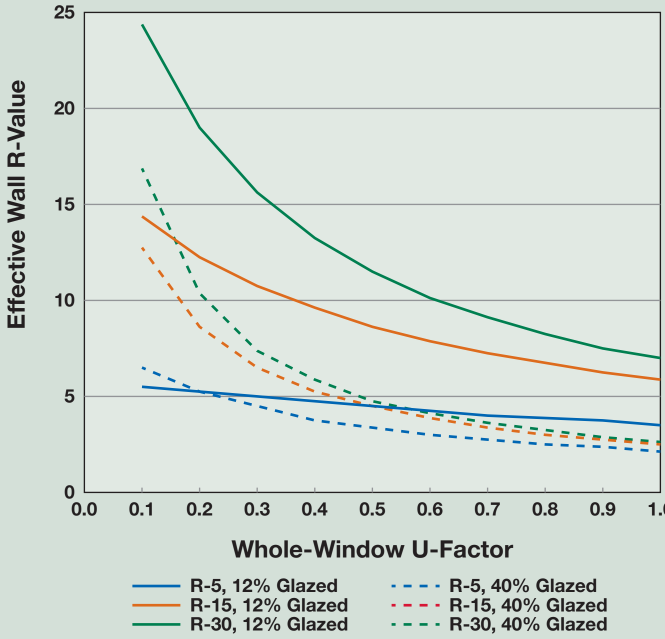
Tuning Windows for Orientation & Climate

			SHGC	
Climate	Number of Glazings	U-Factor (NFRC)	Non-South or Non-Passive Solar	South or Passive Solar
Hot	Double	0.25 – 0.39 (Lower is better)	0.20 – 0.30 (Lower is better)	0.36 – 0.63 (Location-dependent)
Cold	Double	0.20 – 0.30 (Lower is better)	0.30– 0.55	0.50 – 0.75 (Higher is better)
	Triple	0.10 – 0.26 (Lower is better)	0.30 – 0.49	0.42 – 0.63 (Higher is better)

Checklist for Window Selection & Installation

- ☐ "Tune" windows by orientation. In most situations, use low-SHGC glass for windows on east and west walls. On the north walls, solar gain isn't a problem, so maximize thermal resistance while retaining reasonable visible light transmission. High-SHGC windows on south walls should be shaded during summer months with overhangs or other exterior shading devices.
- ☐ Match windows to the functions of the space, importance of views, and location of building. If daylighting is important, ensure high visible light transmission. If views and a lot of glass are important, use high-performance glazing to minimize the energy penalties.
- ☐ Don't rely solely on windows to control solar gain. Consider exterior shading to manage direct sunlight, so the glass doesn't have to filter out more light than necessary. For fixed shading, overhangs on the south are the best, while on the east and west, operable exterior shade screens or plantings will do a better job blocking low-angle sun.
- ☐ Invest in windows with the best U-factor you can afford, allowing for appropriate solar gain, solar control, and visible light transmission. High-performance windows cost more, but they make the space near them more comfortable and may pay for themselves with the savings that result from reduced heating and cooling loads (and the ability to install smaller and less expensive heating and cooling systems).
- ☐ Ensure proper installation. Make sure proper flashing details are used. Follow manufacturers' instructions. You can test for water leakage with a hose following installation.
- ☐ Make sure hinges and closures are rugged enough to handle the extra weight of operable windows.
- ☐ Rely on objective performance data, such as that found on NFRC labels and through Passive House certification. Two U.S. manufacturers have attained (or are about to attain) Passive House certification for their highest-performance windows: Alpen High Performance Products and Marvin. Using certified windows is not required for Passive House projects, but the performance standard is so stringent that high-performance windows make a huge difference.
- ☐ Don't include more windows than necessary. Windows lose more heat than insulated wall sections, and too much solar gain causes overheating. This point is clearly illustrated in the "Effects of Whole-Window U-Factor on Wall R-Value" graph, which shows how windows significantly reduce a wall's average R-value. For a wall with R-30 insulation, for example, standard double-glazed, low-e argon windows (U-0.35) taking up 12% of the wall reduces the effective R-value for the whole wall to about R-14.
- ☐ Use larger panes to minimize edge losses. Applied or internal grilles, if desired, can mimic the appearance of many small panes without compromising thermal performance as significantly.
- ☐ Gang windows together to reduce framing—and corresponding thermal bridging—from multiple rough openings. Make sure the head flashing is continuous and lapped properly with a weather barrier.
- ☐ For windows tuned by orientation, make sure they are labeled clearly or otherwise differentiated to ensure that they get installed in the correct spot. Some designers plan south-facing windows to be a slightly different size to ensure the correct windows are used for the orientation they are specified for.

Effects of Whole-Window U-Factor on Wall R-Value



This graph shows the impact that windows have on whole-wall R-value. Just 12% glazing (with U=0.30 windows) can reduce a wall's overall insulation value by almost half.

- ☐ When the design permits, choose hinged windows (casements and awnings) that have tight-sealing compression gaskets, instead of sliding-sash windows (double-hung, horizontal sliders).
- ☐ Evaluate which windows need to be operable. Better energy performance comes from fixed-glass windows, due mainly to air leakage. Rather than double-hung windows, consider single-hung windows with fixed upper sashes to cut the leakage area by half.
- ☐ Avoid all-wood windows unless the wood is well-protected from the elements. Cladding makes sense for wood windows. To keep rain off the window, consider deep roof overhangs. As an alternative to wood frames, consider fiberglass, which will expand and contract less than vinyl.
- ☐ Replace existing windows if they fail or are in poor shape, or if you are working to achieve a level of home energy performance that only new windows can provide. Conditions for replacement include rotted wooden frames or sills; lead paint on surfaces that are subject to friction when windows are operated; inoperable sashes or out-of-square metal or vinyl sashes; or condensation or fogging between panes of an insulating glass unit (which indicates failed seals).
- ☐ When considering replacing windows that are in good condition, evaluate whether performance-enhancing window attachments, such as storm windows, interior window panels, or interior insulating blinds, may offer a more cost-effective solution.

continued from page 88

Egress considerations. Certain windows must be designed for getting out if there's a fire. These windows have to be a specified minimum size, and they should be readily operable—usually without separate storm windows or window attachments that require opening. In general, egress is easier with casement than double-hung windows. A building official will be able to advise on egress requirements in your area.

Warranties. Warranties make an important difference. Many have 20-year warranties or 20/10 warranties (20 years for the glass and 10 years for the non-glass components). Labor to replace failed windows is often covered for a much shorter period of time. Some manufacturers offer "limited lifetime" warranties, though understanding the fine print on "lifetime" tends to be an art form.

Access

Alex Wilson is the founder and executive editor at BuildingGreen, which publishes *Environmental Building News.* He also is president of the nonprofit Resilient Design Institute, which works to advance measures to improve the resilience of our buildings and communities.

Efficient Windows Collaborative • efficientwindows.org

National Fenestration Rating Council (NFRC) • nfrc.org

Manufacturers:

Alpen High Performance Products • alpenhpp.com

Cardinal Glass Industries • cardinalcorp.com

Guardian Industries • guardian.com

Hurd Windows and Doors • hurd.com

Marvin Windows and Doors • marvin.com

Pilkington Glass • pilkington.com

Quanex Building Products (Super Spacer) • quanex.com

Sage Electrochromics • sageglass.com • Dynamic glass

View • viewglass.com • Dynamic glass

AC Modules

by Ryan Mayfield

Section 690.6 of the *National Electrical Code* covers AC modules—those that output AC current to tie directly to the grid. These modules are a fairly new technological development. Although this section does not cover all of the *Code*-related rules, there are some key points that designers and installers need to be aware of.

As with many sections within the *Code*, it is worthwhile to read the definitions. Section 690.2 defines an AC module as "a complete, environmentally protected unit consisting of solar cells, optics, inverter and other components, exclusive of tracker, designed to generate AC power when exposed to light."

There are some products that look a lot like an AC module, but they are actually a microinverter connected to a PV module. This only can lead to confusion and misapplication of the *Code*. A true AC module is one with the inverter integrated into the module design at the factory—not added after the fact. Some industry people even contend that a true AC module will not have any exposed DC wiring; that the only wiring external to the module is the inverter's output conductors (since there is nothing in the definition that prohibits exposed DC conductors, this is not an absolute requirement). But the presence of exposed DC conductors opens up parts of these *NEC* sections to interpretation. There are listed AC modules that have exposed DC wires. Since these are listed as an AC module by a nationally recognized testing laboratory (NRTL), my opinion is that the DC wiring can and should be considered internal to the listed product. In contrast, some AC modules integrate the inverter within the module's junction box, keeping all DC conductors concealed.

Conductors & Overcurrent Protection

Section 690.6 (A) states that, since any DC circuits are considered internal wiring, the requirements for PV source-circuit conductors do not apply to AC modules.

DC conductor sizing and maximum voltage calculations are not required by Section 690.6(A), since they are provided by the AC module manufacturer and are covered in the module's listing. According to the *NEC*'s second subsection in this section, the output from an AC module is considered an inverter output circuit and as such must follow those rules for circuit sizing and current calculations in 690.8. This results in calculations and conductor sizing that is the same as for any other inverter output circuit used in grid-tied PV systems.

Courtesy SunPower Corporation

This AC module has a maximum continuous output current of 0.94 A at 240 VAC (for a maximum output rating of 225 W AC) and comes with a 25-year warranty.

Read the 690.8 subsection titles carefully, as the requirements set within vary based on the circuit you are considering. For example, 690.8(A)(3) applies to AC module circuits, but the other three current definitions within 690.8(A) do not. The maximum inverter output circuit current is defined as the continuous output current rating. To properly size the conductors and overcurrent protection, refer to 690.8(B)(1) and (2). This process is similar to the conductor and sizing calculations used for string inverters, as the *Code* does not differentiate between inverter technologies. You should also follow the manufacturer's listing instructions for this portion of the installation, which may provide important details like the maximum number of AC modules per branch circuit and maximum ampacity of the overcurrent devices.

Section 690.6(E) provides allowances for overcurrent protection per 240.5(B)(2). This section deals with the ampacity and allowable overcurrent protection for fixture wiring, the factory-supplied conductors connected to the AC module. This section deals specifically with the fixture wire but does not specifically address the size of the branch-circuit conductor. Designers and installers do not have control over the conductors attached to the modules but are responsible for the branch circuits from the point of interconnection to the PV installation. When sizing conductors and overcurrent protection for these circuits, use the established methods outlined in 690.8(A) and (B).

Disconnecting Means

AC modules also have requirements for disconnecting, which are detailed in 690.6(C). A single disconnecting means for one or more AC modules can be used when in accordance to 690.15 and 690.17. 690.6(C) stipulates that each AC module in the system must have its own disconnecting means. This can be the module connector that is used to connect multiple AC modules together.

In many situations, the module wiring output connector *qualifies as* the disconnect required in 690.17, so this will meet the *Code* requirements. Although adding a rooftop disconnect at the array location is not a *Code* requirement for AC modules, some installers prefer to include one. This additional disconnect can provide an easier location to disconnect the array without having to access conductors under modules and can provide a good visual indication that the conductors have been disconnected.

Since the circuit is carrying AC, there are numerous options for disconnects that can be integrated into the installation. The challenge will be to make sure you install a disconnecting means appropriate for the NEMA ratings of the enclosure.

Grounding & Bonding

Grounding and bonding is considered one of the most contentious topics for PV installations. For listed AC PV modules, grounding and bonding is a little bit easier. When attempting to provide the proper grounding and bonding for an AC module array, the first place to begin is with the manufacturer's installation instructions. Not only is this a requirement per Section 110.3(B), but the manufacturer will likely have the best understanding of the proper way to install their product within the scope of the *NEC*. You can then use these guidelines and recommendations to reference the *Code* and make the final determinations.

Under Section 690.6(D), which covers the ground-fault detection for AC modules, the *Code* allows for a single detection device and removal of AC power to the system. The *Code* language here is permissive, rather than establishing requirements. At this time, the most commonly used method to provide the protection is to use the circuit breaker in an AC distribution panel. This breaker will protect the conductors in the event of line-to-line or line-to-ground faults.

Courtesy SolarBridge

This AC module solution has the DC source cabling exposed.

One aspect of the AC module installation not covered in 690.6 is the grounding and bonding requirements. As for equipment grounding, a method for bonding all of the equipment together and providing a low-impedance connection for ground-fault detection is necessary. The AC module manufacturer may supply an equipment grounding conductor (EGC) within the cable assembly used in conjunction with the modules. All of the modules and racks still need to be bonded together using grounding lugs and a separate EGC or using grounding clips that bond the modules and rails together. If an EGC is not included in the AC module's wiring harness, you will need to bond all the PV and racking components together and continue that conductor through a disconnect or transition wiring box to the electrical distribution equipment. This conductor is not required to be unspliced and will be sized based on parameters set forth in 690.45.

System grounding for AC modules occurs at the service entrance. The DC conductors are considered internal to the AC module and therefore a grounding electrode conductor (GEC) is not required for AC modules. The requirements set in 690.47(A) dictate the grounding electrode system installation for AC modules, referencing 250.50 through 250.60—all of which deal specifically with the installation of a grounding electrode system and grounding electrode conductor. Since an AC module system is connected to an electrical distribution system, the grounding electrode is already part of the electrical system. You may need to examine and bring this portion of the electrical system up to *Code*, but, generally, you will not be required to bring an additional GEC from the PV array to the existing grounding electrode. For this portion of the installation, it becomes very important to refer to the manufacturer's installation instructions. If the manufacturer does indicate that a GEC is required, you will need to follow those instructions and meet their requirements. And as with any installation, it is a good idea to bring your authority having jurisdiction into the conversation early for this portion of the installation.

Access

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Inductee

by Kathleen Jarschke-Schultze

Living off-grid with three different seasonal renewable energy sources (wind, water, and sun) means our energy production ebbs and flows. It ranges from very high (for us) to a thriftier trickle as the weather runs its course. Bottom line: During times of bountiful power, if I'm not using the electricity our systems produce, then it is wasted.

Abundance

When the wind blows, the water flows, and the sky is blue, our batteries rarely get below 100% charge. My husband Bob-O has installed a shunt to take the extra electricity our system produces and, through an electric element, this excess heats the water in our water tank.

This works so well that sometimes the water coming out of our faucet is 150°F. That's okay—we are used to it and are careful. When you take a shower at our house, you first turn on the hot water all the way and then use the cold water to regulate the temperature. And there's absolutely no toilet-flushing allowed when someone is showering.

The hot water is great, but we only need so much. It seems like whatever I do to use excess electricity also uses water. I can wash laundry in my water-efficient front loader or wash dishes in my water-efficient dishwasher. That is all well and good during the seasons in which we have an abundance of water. But there are times when the creek is so low we can't run the hydro turbine, and the spring that feeds our domestic water system slows to a trickle. The sun and wind inputs are at full bore, so in the daytime there is a lot of electricity. That's when I need an appliance that uses electricity, but not water. I could use my microwave oven to use that electricity, but I mainly use it for reheating food—I don't really like the idea of cooking my meals in it.

Inducing Heat

For years I have been curious about induction cooking. What would it be like to cook with electricity? I've always cooked on natural gas or propane stoves. Using electricity to make heat or cold usually uses a lot of electricity. That is why off-grid homes use gas to cook with, and solar or gas for heating water (unless you have a shunt setup like ours), and use a gas clothes dryer. In arid locations like ours, air conditioners are abandoned in favor of more energy-efficient evaporative coolers.

While it uses electricity, induction cooking is different from cooking on electric elements. Induction does not involve an electrical element heating a pot or pan—it makes the cooking vessel itself the generator of the cooking heat.

I'm not going to go all nerdy here—I'll let Wikipedia do it: "An induction cooker transfers electrical energy by induction from a coil of wire into a metal vessel that must be ferromagnetic. The coil is mounted under the cooking surface, and a large alternating current is passed through it. The current creates a changing magnetic field. When an electrically conductive pot is brought close to the cooking surface, the magnetic field induces an electrical current, called an 'eddy current,' in the pot. The eddy current, flowing through the electrical resistance, produces heat; the pot gets hot and heats its contents by conduction."

Just the pot gets hot and that's what cooks the food inside. I've really wanted to try this for some time, but the cost was prohibitive. I saw one for sale on Craigslist and the price was reasonable. I went online, looked up the model and started reading user reviews. That particular single "burner" model did not get ecstatic reviews, so I researched other models. I found what I wanted—the Sunpentown Mr. Induction Cooktop—read the reviews, looked for the best price ($59), and ordered it.

The single-burner unit draws 100 to 1,300 watts, depending on the setting. The temperature range is 100°F to 390°F. With seven cook (wattage) levels and 13 temperature settings, this gives me a huge amount of control.

Since the cookware must be a ferrous material, I had to check my pots and pans to see if they were compatible. This is very simple to do, using a small magnet for testing—if the magnet stuck, the pan or pot could be used on the induction cooker. All of my cast-iron pans were shoo-ins. I had an old enameled cast-iron casserole I was looking forward to using. The magnet stuck, but the bottom was not smooth and flat. There was a raised, round ridge on the bottom, and that put it out of the running. I tested everything—my countertops were littered with every pot I owned. I even dug into my camping gear. I ended up with a small array of workable cookware.

The first thing I tried was to boil water. It took two minutes on 700 watts (23.3 Wh) to bring two cups of water to a boil. Next, I made homemade corn tortillas and cooked them on my round cast-iron griddle. Wonderful! Then I cooked a big pot of beans in one of my enameled cast-iron camp pots. This worked quite well, although I was surprised to return after two hours to stir the beans and find that the unit was off. Apparently, as a safety measure, if you do not set the timer (one minute to eight hours), the unit will shut itself off in two hours. I turned it back on and set the timer.

Another safety feature is the "lock" button. To turn the unit on, the lock button must be pressed. If no other button is pressed within 30 seconds, the unit will turn itself off. It also turns off automatically when the cooking pot is removed.

Victory is Tasty

I know from my solar cooking education that food pasteurization begins at about 160°F. So I can set my cooktop to that temperature and feel confident to leave food safely simmering at that temperature for an extended period of time (say, more than two hours).

Of course, not all of my induction cooking is done for extended periods of time. I mostly use the cooktop during the daylight hours—when our solar and wind power sources are peaking. I have gotten into the habit of cooking things like rice, lentils, or potatoes during the day to use later as part of our dinner. The cooktop also works great for cooking breakfast grains (Bob-O calls them all "gruel") or for pancakes and eggs. Even though the batteries aren't completely full in the morning, they soon will be, and I'm careful to first check the battery meter on our wall, so I can see the battery bank's state of charge. This kind of cooking does not take a lot of time, so it takes less energy.

I feel very good about this purchase. I now have a method to cook food using our surplus renewable energy. It is one of the puzzle pieces that fit in to make our renewable energy system even more efficient.

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is looking into landrace vegetable farming to adapt varieties to the microclimate at her off-grid home in northernmost California.


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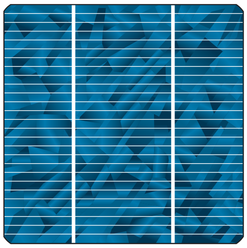

What is PV?

A photovoltaic (PV) cell directly converts light energy into electrical energy. It is *light* from the sun—not heat—that is used; crystalline photovoltaic cells are actually more effective when cool.

Each cell develops about half a volt of DC electrical potential. The maximum amperage of the cell is proportional to its surface area. While series strings of about 36 cells put together to charge a 12-volt system were the norm, series strings of 60 cells (or more) are now common. We call these organized strings of cells "modules."

The PV effect was first discovered in the 1800s, when scientists noticed that light shining on crystalline selenium produced an electrical current. Later, researchers found that silicon was more effective as a base material. In our present-day PV modules, the silicon is doped with boron, phosphorous, gallium, arsenic, or other materials. This creates loosely bound electrons, easily liberated by incoming photons (energized light particles). It also forms the "p-n junction," a region that naturally pushes those freed electrons one direction through an electrical circuit to do useful work.

The PV cell is overlaid with a grid of conductive wires that are connected together. When the photons bump the electrons, they are free to follow the rest of the circuit set up by the wires. Renewable energy expert Hugh Piggott says PV technology is "the energy shortcut—from the source to the ultimate goal in one conversion." There are no moving parts in this system. Only the photons and electrons move, and there are plenty of them to go around.

One of my favorite demonstrations of this technology is the pump in the bucket. Connect a small PV module to a bilge pump that's in the bottom of a bucket filled with water. Put the PV modules in the sun and watch the pump run. I've enjoyed seeing young children, scientific folk, and even my local backhoe operator become excited about solar electricity's potential after seeing this simple demonstration.

One closing note on the word: While we in the industry are very comfortable saying "photovoltaic" and "PV," the terms seem mysterious to many people. I think it's often better to say "solar-electric" when speaking to the uninitiated. When we say "solar panels," lots of people think of solar *thermal* panels, an entirely different technology that gathers the sun's energy in the form of heat. "Solar-electric" is a much easier phrase for most people to understand, and it clearly distinguishes the two different technologies.

—Ian Woofenden

Michael Welch

The magic of PV: Children learn about the energy of the sun when they see this solar-electric module powering a pump, which stops when the module is shaded.