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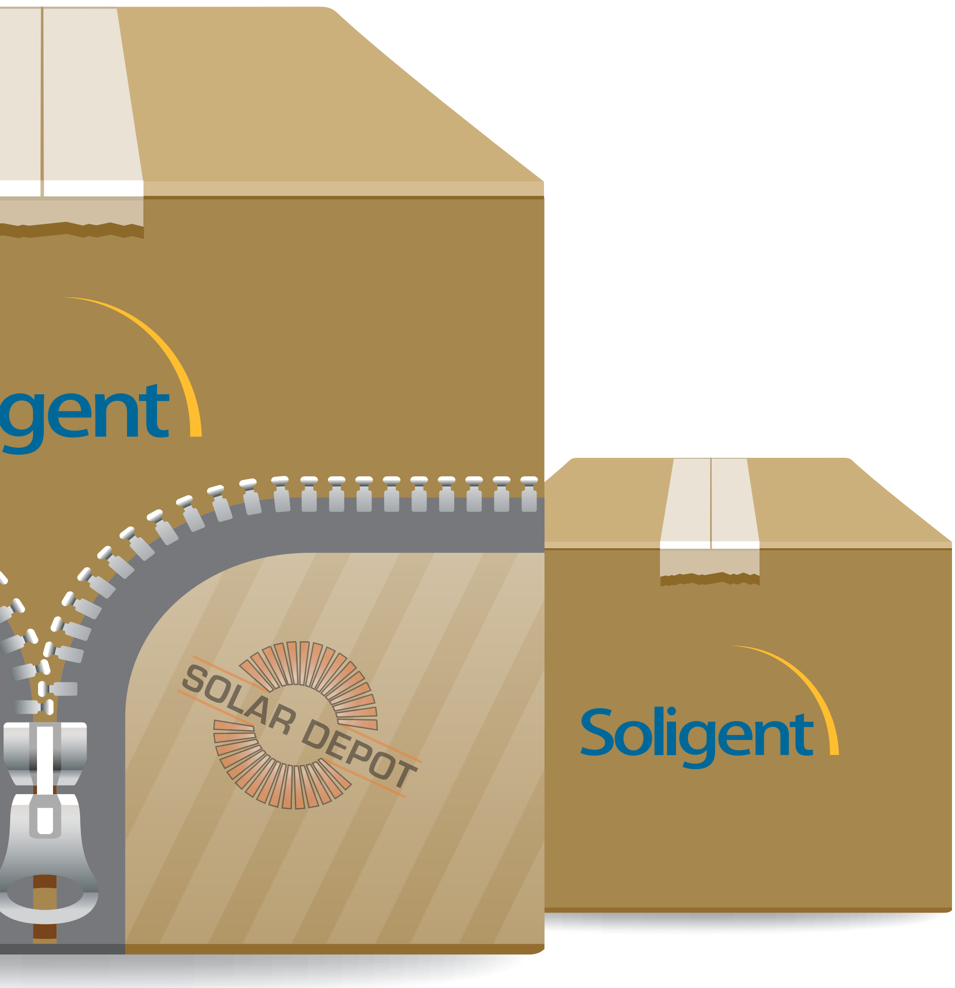

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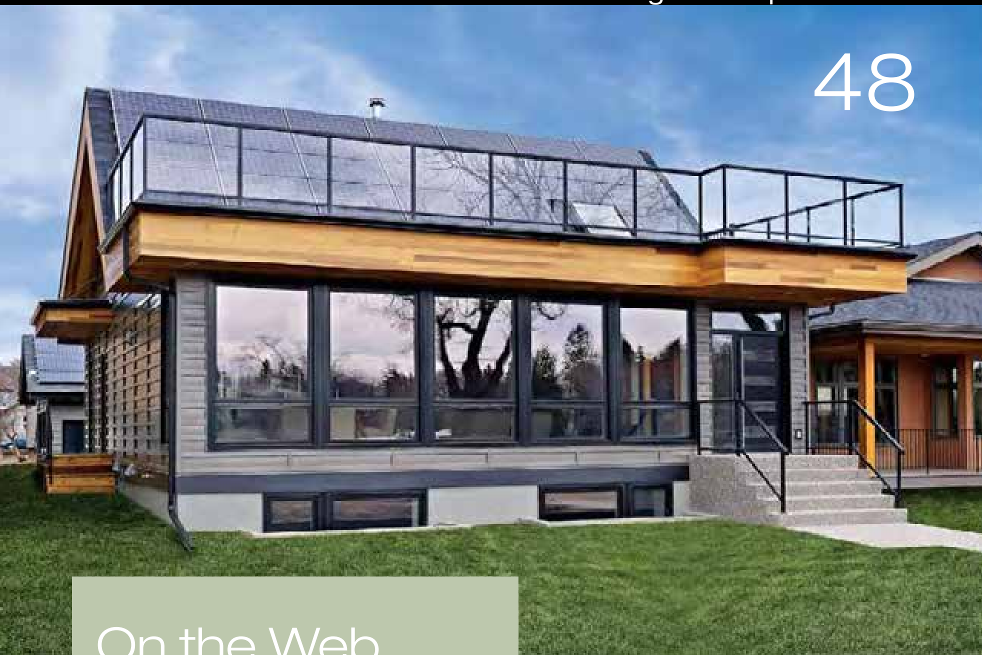

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Main Features

Photos, left to right: Merle Prosofsky Photography Ltd., Jim Riggins, Ted Dillard, Apricus, Intus Windows.

On the Cover

This Belgravia Green home in Edmonton, Alberta, Canada, was designed to produce as much electricity throughout the year as it consumes.

Merle Prosofsky Photography Ltd.

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In Back

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Measuring Our Footprint

I no longer own a car, and though I use cars and trucks when I choose to, I prefer moving about by bicycle for short and medium distances, combining them with buses, trains, and planes for longer jaunts. The other day while on my bike on the ferry to my island home, someone remarked that my carbon footprint "must be pretty small." I pleaded ignorance to the actual number, while predicting that based on the multiple airline trips I take each year for work and family, it might not be that low. And I added that I hold a certain skepticism about the carbon footprint measurement anyway.

I told my acquaintance that I'd hate to live in a low-carbon world with a lot of unhappy, angry, ignorant, or controlling people. I'd also not be too excited to live in a low-carbon world where I was disconnected from my far-flung family and friends, and my varied passions and interests, which range from Maine to Washington State to Costa Rica and beyond.

While *Home Power* is focused on renewable energy and sustainability, these are only one part of a life well lived. I want to enjoy communities full of love, laughter, music, culture, friendship, and innovation—and these are all values that are a bit harder to quantify than a carbon footprint.

Also, too often I think we focus on the benefits of whatever cause we are promoting without looking at its liabilities; or at the liabilities without quantifying the benefits. I remember watching a local "health and safety" bureaucracy hassle a couple for not following urban codes, when the couple lives more healthily, safely, and sustainably than the enforcement officers will ever hope to live. I wondered if anyone counted the environmental impact of the cars, buildings, and flood of paper that the agency generates. On the other side, a good friend and colleague regularly bemoans the fact that he must fly from Scotland to teach renewable energy for me in the northwestern United States, concerned about his carbon footprint. My point of view is that he improves the planet more by his instruction and inspiration than he'll ever damage it with the jet fuel used.

For me, the bottom line is that we all have different goals and standards, and in my experience it works better if I choose mine and enthusiastically apply them, leading by example, with a minimum of finger-wagging. I'm for a larger happiness footprint (with thanks to the fourth Dragon King of Bhutan, who coined the phrase "gross national happiness"). Renewable energy is a piece of that for me, and I find that living lower on the energy food chain not only "looks good on paper," but leaves me feeling more connected to nature, people, and the communities I'm involved in.

A small carbon footprint and a happy, productive, and fun life aren't mutually exclusive. That's what *Home Power* is here to show—maybe it's our main purpose. If we make conscious and smart choices about our energy sources and uses, we can have our happiness cake, and feel good about the energy that baked it, too.

—Ian Woofenden for the *Home Power* crew

Think About It...

Electrons have no edges, are not solid objects, pass through walls and our bodies, dance the edge between life and death, and nobody has ever seen one, yet they do my bidding.

—Zot Lynn Szurgot, solar electrician

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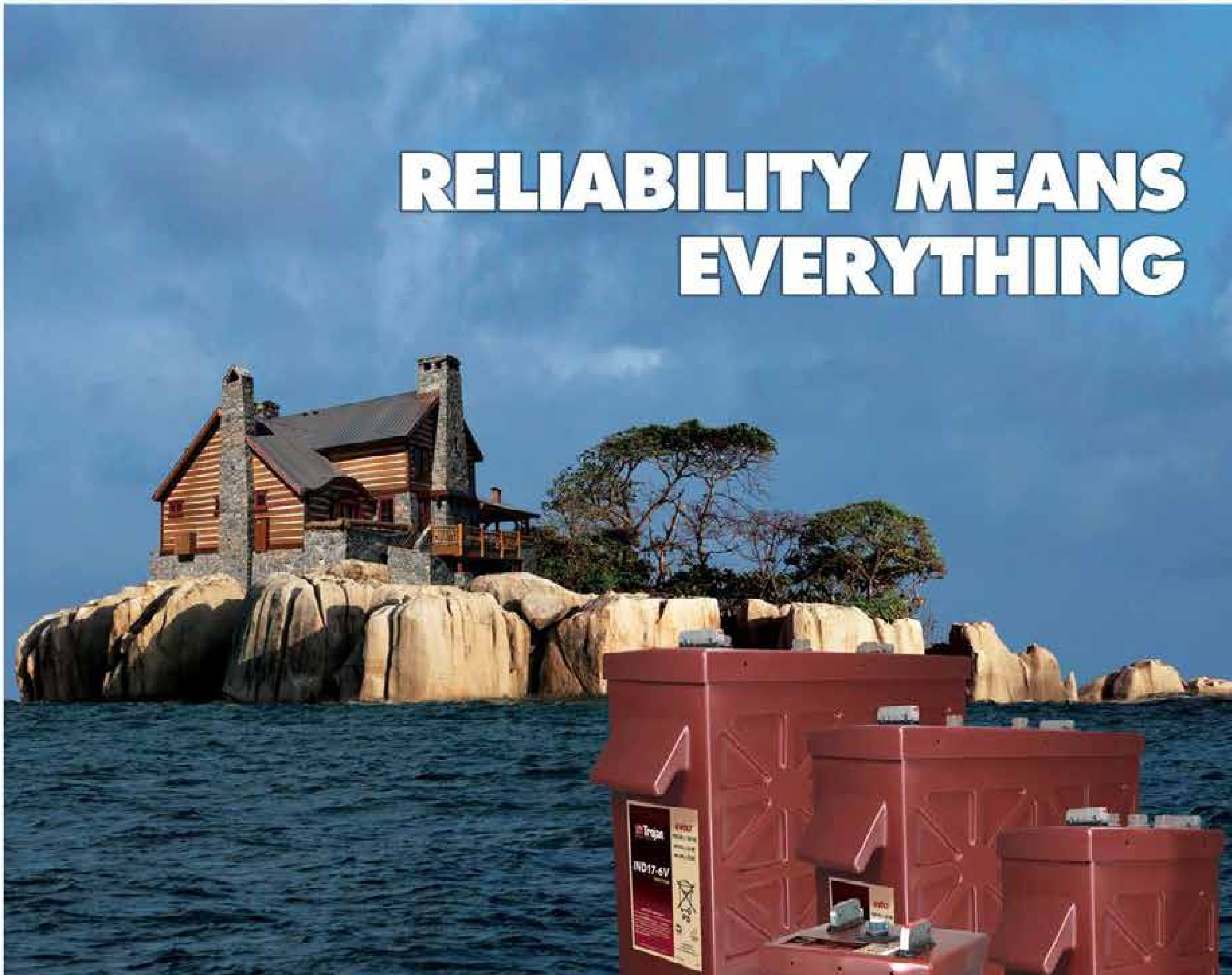

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IND13-6V	533	673	820	6 VOLT
IND17-6V	711	897	1090	6 VOLT
IND23-4V	977	1233	1500	4 VOLT
IND27-4V	1183	1457	1780	2 VOLT
IND29-4V	1245	1570	1910	4 VOLT
IND33-2V	1456	1794	2187	2 VOLT

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Choosing Sides

The U.S.–China Solar Trade Dispute

If you've been following the energy blogs or your favorite news site, chances are you've read about the U.S. Department of Commerce's preliminary decisions to levy taxes on solar products imported from China.

The DOC is investigating whether China-based PV manufacturers have violated fair trade practices by illegally "dumping" solar products in the United States that may have been unfairly subsidized by the Chinese government. The proceedings began last November after Oregon-based SolarWorld Industries America filed a complaint with the DOC against China-based manufacturers within the crystalline silicon solar industry—singling out Suntech Power Holdings and Trina Solar.

Thus far, the DOC rulings have sided with SolarWorld—though the company "does not believe the duties outlined so far cover the full extent of China's illegal trade practices." The case has divided the solar industry, with U.S. manufacturers dominating one side (CASM—Coalition of American Solar Manufacturing, led by SolarWorld) and China-based manufacturers supporting the other (CASE—Coalition for Affordable Solar Energy). Solar installers, project developers, and other related companies seem split on the issue (and the cross-section of both CASM and CASE membership includes many of these downstream players), but they generally share a common concern for the bottom line. Beyond the central issue of fair pricing, the case has prompted a larger discussion as to whether trade enforcement is good for the U.S. solar industry, and whether this action may bring retaliatory trade action from China.

Energy policy analysts Melanie Hart and Kate Gordon, with the D.C.-based think tank Center for American Progress, explain the central issue: "If the Chinese government—or any other foreign government—is indeed engaging in 'dumping' by using WTO-illegal methods to reduce export prices and drive foreign firms out of the market, the end result of those practices will be Chinese market dominance. If that dominance is due to natural market forces, it is not necessarily a bad thing. But if it is due to state subsidies, that is problematic, because that would mean state officials in China are determining which companies and technologies dominate this critical global market, and those officials may not choose well."

The Process

In October 2011, SolarWorld submitted a 3,000-plus-page petition, calling for the DOC to levy trade remedies—countervailing duties (to offset the subsidies from the Chinese government) and antidumping tariffs (to discourage dumping)—on Chinese-based manufacturers. Once the DOC determined that the petition satisfied all statutory guidelines, including criteria for industry support, the DOC formally initiated the investigation, asking Chinese exporters/producers to submit reports that detail their production costs. These reports were compared with information collected by the DOC as well as that provided by SolarWorld's original petition. That information was the basis for preliminary decisions released on March 20 and May 17, 2012. The rulings exclude thin-film PV products and non-PV technologies (solar thermal and concentrated solar).

The May decision requires Chinese producers/exporters to pay antidumping tariffs, as follows: Suntech, 31.22%; Trina Solar, 31.14%; 59 other named firms, 31.18%; and all other Chinese producers/exporters (those that did not provide info to DOC), 249.96%. These tariffs are in addition to the countervailing duties the DOC levied on Chinese producers/exporters in March, ranging between 2.9% and 4.73% (far below some analysts' expectations of 20% to 30%) to offset Chinese government subsidies. Both decisions pertain to Chinese-made crystalline silicon PV cells, modules, laminates, and building-integrated materials.

Definitions

Not sure what to make of all this talk of countervailing duties and antidumping tariffs? For the purpose of Department of Commerce investigations:

- "Dumping" occurs when a foreign company sells a product in the United States at less than fair value.
- "Countervailable subsidies" are financial assistance from foreign governments that benefit the production of goods from foreign companies and are limited to specific enterprises or industries, or are contingent either upon export performance or upon the use of domestic goods over imported goods.

For the next step, the DOC is working to verify the information reported by the Chinese exporters/producers. The final decision, expected in October, may uphold or modify the preliminary rulings. From there, the case moves to the International Trade Commission (ITC) to determine whether the U.S. solar market has indeed incurred "injury" and whether to support the DOC's ruling. For now, all duties and tariffs collected are held in reserve. Should the ITC reject the decision, then those monies would be returned to the respective Chinese exporters/producers. If upheld, Chinese exporters/producers can appeal through the Court of International Trade and/or the World Trade Organization.

The Debate

Both sides seem to agree that it took intense competition among manufacturers from many regions to drive mainstream solar market adoption. What they disagree on is if Chinese firms have priced their products fairly and have a legitimate cost advantage over U.S. firms. CASM's position is that China has used government subsidies and loans from state-owned banks to drive its solar industry "to massively overbuild and sell at dumped prices overseas in an anticompetitive export drive." The group maintains that China's unfair pricing caused 12 U.S. manufacturers of crystalline silicon solar cells and/or modules to undergo plant shutdowns, significant layoffs, and bankruptcy filings.

Chinese firms—Trina Solar, for one—say the purchase price of their solar products reflects that which the market sets. As a NYSE-listed company, the company stands by the transparency of its costs, affirming that selling price exceeds costs-per-unit-sold, even under the most conservative accounting definitions, a spokesperson explained.

Independent Analyst Shyam Mehta Weighs In

On strategy: "Contrary to what people might think, Chinese firms are not going to stand still, accept the tariff, and continue business as usual. The companies are likely going to reconfigure their supply chains to bypass the import tariffs. Since the tariff only applies to cells made in China and modules made with cells in China, Chinese firms are likely going to adopt one of two strategies: set up cell manufacturing outside China, or use tolling agreements with Taiwan-based suppliers to turn wafers into cells there and then assemble the modules in China. While reconfiguring their supply chain is certainly a hardship and will take some time, it is a manageable task and expense. We estimate that tolling cells to Taiwanese firms would increase costs by 6% to 12%, and at current profit margins, Chinese manufacturers would certainly have to raise U.S. prices to turn a profit. But the cost increase may only translate to a 5% to 10% increase on module prices because the companies will accept slightly lower profit margins. That price increase is not as alarming when you consider that the price of Chinese modules is, on average, about 30% lower than U.S.-made modules."

On system prices: "Even with the tariff in place, PV will still continue to get cheaper and cheaper. We look at all the factors when assessing the long-term impact. More efficient modules will be making their way onto the market. This means we will be able to pack more power onto a roof using fewer modules. Fewer modules will cut down on the labor time and cost of installation. There is a trend toward lower permitting fees, and the cost of other system components is likely to decline as well, helping temper any slight increase in module prices."

On U.S. manufacturing: "Even with the slightly increased prices, the Chinese firms should be able to price modules meaningfully below the levels sold by Western and Japanese competition. We don't think the tariff is going to signal a change in U.S. manufacturing in the long term. Just because the prices of Chinese modules may increase, that doesn't mean everyone is going to run out and buy U.S. modules. The modules industry is global and very competitive, and U.S. manufacturers still need to compete with manufacturers in other countries."

On U.S. solar employment: "You won't see a lot of new manufacturing jobs returning to the United States. The tariff might prompt some China-based companies to open a U.S. manufacturing plant, but those will be isolated cases. Most of the jobs created by Chinese companies in the United States are in sales and marketing. I don't think the tariff issue is going to have an effect on those jobs. Separate from that, there is downsizing going on in the industry at large due to the global oversupply environment we are in. With regard to existing jobs, I know that some installers are worried about potential price increases and lowered demand, which would impact their businesses. As a result, some have placed expansion plans and new hiring on hold. My view is that they are overestimating the impact these tariffs will have."

Central to the fair pricing discussion is China's 12th Five-Year Plan for the Solar Photovoltaic Industry (2011–2015). The plan lays out the country's goal to reduce the cost of PV modules to $1.11 per watt by 2015 and $0.79 per watt by 2020. CASM says that prices in the marketplace are already well below this level, suggesting that China is currently not selling at prices that cover its production costs and is benefiting from unfair government subsidies. Critics call China's plan irresponsible, reasoning that aggressive capacity targets will exacerbate the global oversupply and force more companies to close or scale back operations. Countering this position is the argument that strong companies will survive and low prices will help the industry grow. The People's Republic of China defends its solar energy strategy as "essential to guarantee energy supply, establish a low-carbon society, promote economic restructuring, and foster strategic emerging industries."

Another contentious point involves an October 2011 "Solar PV Manufacturing Cost Analysis" from the National Renewable Energy Laboratory. The study found that, without government subsidies, Chinese module producers have a 1% to 2% cost benefit; however, when shipping costs to the United States are factored in, they face a 5% cost disadvantage. Still, some analysts have poked holes in the study's approach and validity.

Some argue that China's solar manufacturers are winning because they're more competitive than their U.S. counterparts. Molly Castelazo, the director of ChinaGlobalTrade.com, sums up the general sentiment: "Blaming China takes the spotlight off U.S. manufacturers and U.S. policy makers—and what they can and should be doing to keep American solar manufacturers competitive in this global economy."

The Impact?

No one really knows. Both sides paint grim pictures, colored by their own interests. Regardless of which side you favor, there is no denying that the decision could have broad implications. In 2011, China exported $3.1 billion of solar cells to the United States, up from $640 million in 2009, according to the DOC. The total represents more than half of the U.S. market—not surprising since Chinese-made solar products are, on average, 30% cheaper than their U.S. competitors.

The question remains: How will these taxes affect the average consumer? "Consumers shouldn't be too alarmed," says Shyam Mehta, an analyst with GTM Research, an independent renewable energy market analysis firm based in Boston. "China-based firms cannot maintain their U.S. prices at tariff-free levels and still be profitable. If the China-based firms were to absorb the tariff, their costs would be close to that of many U.S.-based suppliers. For the short term, China-made module prices will increase slightly in the United States, but this increase won't have any real effect on demand and installation growth domestically." (See sidebar on preceding page for more from Mehta.)

—Kelly Davidson

IN THEIR WORDS

Whatever side you choose, it seems there may be no clear winner. We called on two of the leading voices in the debate—CASM and CASE—to make their cases.

CASM

CASM is a consortium of seven U.S. domestic producers of crystalline silicon solar technology, led by Oregon-based SolarWorld Industries America, a unit of Germany's SolarWorld AG. Key players also include Wisconsin-based Helios Solar Works and New Jersey-based MX Solar USA, a unit of Italy's MX Group. The four other companies remain anonymous (see americansolarmanufacturing.org).

CASM's position is that markets, not governments, should set prices, especially abroad. This principle is upheld in U.S. law and World Trade Organization agreements, which state that dumping goods (selling below cost) in another market and government subsidies are illegal when they injure a competing industry.

Says CASM: "By plowing billions of yuan in government subsidies and loans from state-owned banks into its industry, China's authoritarian policy apparatus has put its full might behind an illegal export campaign to wipe out foreign solar competitors. It is simply not reasonable to expect that China would continue to invest tens of billions of dollars in public funds to keep prices artificially low in foreign markets after it eliminates competition—China would raise prices. Manufacturing and installation jobs outside of China would stop growing. Investment in innovation would slow. Pressures for production efficiency would ease. Long term, everyone would lose. Any claim that prices will skyrocket [as a result of tariffs] overlooks the market reality of plenty of fierce competitors from other regions, including Taiwan, Japan, South Korea, and Europe. Enforcing our rights as an industry under U.S. trade law is not the same thing as causing a trade war."

CASE

CASE represents 177 member companies, including silicon and module manufacturers, project developers, financial and real estate services, and installers. Key players include Suntech Power and Trina Solar (see coalition4affordablesolar.org).

CASE says that "97% of solar jobs are outside of the sector that punitive tariffs would supposedly protect: silicon solar cell manufacturing. More than 52% of all solar jobs are in installation and maintenance—the high-paying, family-supporting, blue-collar jobs that the nation needs to recover from the recession. With punitive tariffs, homeowners, developers, commercial users, electrical utilities, and consumers will have to pay higher prices for solar energy, and many will have second thoughts about solar power. This year, as the use of solar energy continues to increase, the industry expects to develop almost $12 billion worth of projects and hire some 24,000 more workers. But higher costs could delay or even cancel these projects. According to a study conducted before the Department of Commerce's preliminary decision by the economic consulting firm The Brattle Group, steep tariffs on imported solar modules would result in the loss of almost 50,000 jobs by 2014. If the solar industry becomes the battleground in a trade war with China, the first casualties will be American workers, business people, and environmentally conscious consumers."

Shade: PV Effects Beyond Electricity

According to the research team Anthony Dominguez, Jan Kleissl, and Jeffrey C. Luvall at the University of California-San Diego's Jacobs School of Engineering, PV modules can do more than just generate electricity. They can also help reduce a building's annual cooling load.

In a first-of-its-kind study, published in *Solar Energy*, the official journal of the International Solar Energy Society, thermal imaging and temperature sensors were used to measure the effect of PV modules on roof and ceiling temperatures. Data for the study was gathered over three days on a university building equipped with both shallow-tilted (4.4°) and flush-mounted PV modules.

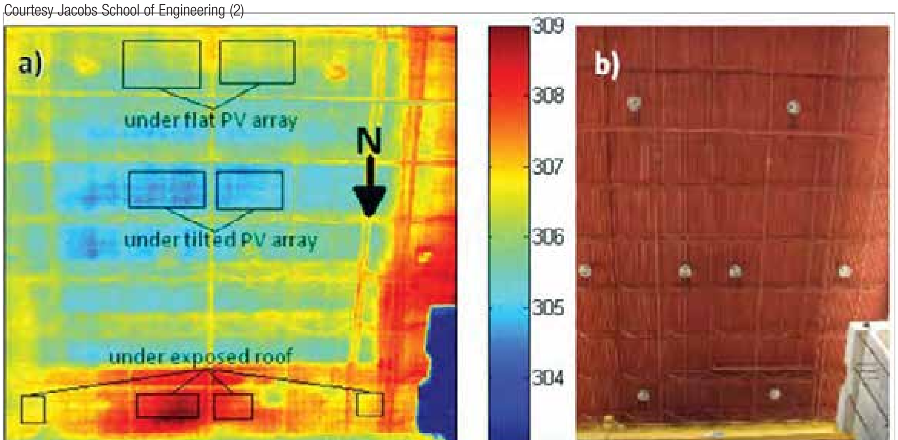
The study found that inside the building, the ceiling was up to 5°F cooler in areas under the tilted PV modules than under the exposed roof (and about 2.5°F cooler under the flush-mounted array). The team developed a model to extrapolate the findings and predict the cooling effects throughout the year. The reduction in total annual cooling load for the PV-covered roof was estimated to be 38%. They also determined that the cooling effect amounted to long-term savings in energy costs—the annual equivalent of increasing the PV array energy contribution by 4%.

Other findings include that the daily temperature swings for the roof under the array were about half that of the exposed roof, which can reduce overall thermal stress on the roof structure. In winter, the arrays can reduce the passive heating of the building, increasing heat load during the day. However, the extra "roof" layer reduces heat loss at night. Overall, the winter effects in daytime and nighttime cancel each other out. Consequently, the researchers concluded that a PV array (for the San Diego climate and building type) can reduce the annual cooling load, without increasing the annual heating load.

The actual impact of an array on a building's heating and cooling load will vary depending on building type, climate zone, and temperature preferences, as well as existing roof insulation and reflectance. Kleissl and his team hope to secure funding to create a tool that can calculate the effect, on a house-by-house basis.

—Kelly Davidson

Courtesy Jacobs School of Engineering (2)



Going the Distance

Having range anxiety with your EV? There's an app to solve that!

Courtesy Recargo

Knowing if your electric vehicle can go the distance is crucial. Fear not—smartphone apps are here to help ease your range anxiety and give you the peace of mind to hit the open road.

The lineup for mobile apps dedicated to EV charging stations is small, and those out there have some quirks, but here are a few promising ones to test drive. These services may save your day, and can get you from point A to point B (and even C and D) with their trip-planning features. Each integrates Google Maps with GPS technology to give you turn-by-turn directions to your charging station of choice.

ChargePoint • chargepointportal.net This app features a simple, smooth user interface and will point you to unoccupied, nearby charging stations that are part of the nationwide ChargePoint network. View the charging station configuration (voltage/current/connector), price to charge, and total cost of a charging session. Drivers aiming to go day-tripping will appreciate the trip mapping tool, which allows users to locate and reserve stations within five to 1,000 miles along a planned route. Available for Android, iPhone, and Blackberry.

CarStations • carstations.com A relative newcomer to the genre, this app is easy to navigate and will intuitively locate the nearest station within its growing network of charging stations—3,300 and counting, with new stations being added by the company and users regularly. Adding a station is an easy process that you can do from within the app. When in need of juice, filter your search by station type, and get real-time updates on a station's availability. What's more, share your tips and heed the advice of other app users, such as a charging station's exact location in a parking structure or good places to bide your time while your EV's batteries recharge. Available for Android and iPhone.

PlugShare • plugshare.com Unique to its counterparts, this app taps into the kindness of strangers. In addition to locating public charging stations, you can offer up your home charging station for emergency charges and, when all else fails, find a fellow EV driver willing to do the same for you. Simply create a user profile, upload info about your home charging station, and be willing to field inquiries. While this app is more basic than others, we appreciated its simplicity and ease of use. A straightforward map pools 4,500 public and private charging locations worldwide, and users can share photos, comments, and station specs. Available for iPhone and Android.

Recargo • recargo.com Even if this app had a cost, it would be worth every penny. The design is sleek, the features are well-integrated, and the usability is superior. This app stands out for its ability to toggle between street map and satellite views. We liked scrolling the two news feeds: one with the latest EV news from plugincars.com and one from other users sharing photos, tips, and station info. Search by plug type and charge network (ChargePoint, Blink, and unaffiliated); save locations for future trips; and see when the charge stations are in use, available, or off-line. Available for iPhone and Android.

—Kelly Davidson

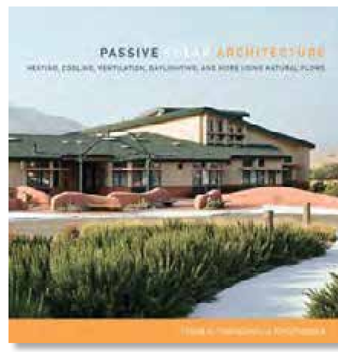
Plug In

Be sure to post your app reviews at either the Apple or Android marketplace. Developers use your feedback to make improvements. Remember, these apps serve a greater purpose than mere navigation: Until EV charging stations dot our highways and communities like gas stations, these services help build the consumer confidence necessary for mainstream EV adoption.

Passive Solar Architecture

***Passive Solar Architecture: Heating, Cooling, Ventilation, Daylighting, and More Using Natural Flows* by David A. Bainbridge and Ken Haggard**. 2011. Chelsea Green Publishing. 294 pp.

When many people think of solar design, photovoltaic modules come to mind. As marvelous as these high-tech wonders are, there is a whole other aspect to the subject—designing homes to capture the sun's energy to both heat and cool buildings *without* mechanical equipment.



Courtesy Chelsea Green Publishing

Ancient cultures knew the importance of siting their homes for good solar exposure, but much of this knowledge was lost with the discovery of cheap energy. The ancient Greek author Aeschylus observed that the first Barbarians "lacked the knowledge of houses turned to the sun." As do most American architects. The modern convenience of brute-force heating and cooling with fossil fuels has allowed several generations of architects to ignore the sun.

These authors want to bring passive solar back into the consciousness of architects, builders, and the general public with their new book, which sets forth in easy-to-understand text and useful images their vast knowledge gained from two lifetimes of professional work in harnessing the sun's free energy. As the book's subtitle suggests, it covers more than just passive solar design—including integrated sustainable design that considers the local site, local materials, and both ancient and modern building designs, as well as integrating modern technological devices and systems. Besides PV and solar hot water systems, one can install rainwater collection and greywater systems.

Full-color photos, drawings, maps, graphs, and tables allow the reader to wade in as deeply or as lightly as they want. References and recommendations for further inquiry abound. If you are a homeowner pondering creating your own more sustainable home, a designer, or an architect, you'll get a lot of value from this book.

—Andy Kerr

Schletter 2.5 kW Ground Mount Kit


Courtesy Schletter

Schletter (schletter.us) has introduced its 2.5 kW ground mount kit, designed to accommodate 10 modules (two rows of five modules, in portrait orientation). The mount includes integrated grounding that is ETL-classified to UL standards 2703 and 1703. This kit contains posts, rails, module clamps, and all necessary mounting hardware. Two concrete foundations are required (poured around the supplied posts). The mount is designed to withstand 95 mph winds and 35 pounds per square foot (psf) of snow loading (with an alternate rating of 105 mph wind load and 30 psf snow load). Optional add-on hardware is available to increase these wind- and snow-load ratings. Also included is an engineer-stamped permit package to meet International Building Code 2006/2009 requirements (for most states).

—Justine Sanchez

Courtesy Advanced Energy

Advanced Energy

Transformerless String Inverters

Advanced Energy's (advanced-energy.com) transformerless inverters have a 97% CEC weighted efficiency, and are offered in 3.8, 5.0, 6.0, and 7.0 kW models. All units include an integrated four-string, fused combiner box, as well as AC and DC disconnects. The minimum MPPT voltage varies from 225 VDC for the 3.8 kW unit to 200 VDC for the three larger models; all models have a maximum input voltage of 600 VDC. Data communication is offered as a ZigBee wireless configuration, which is standard for all models. All units are field-configurable for output voltages of 208, 240, or 277 VAC. Inverter weight ranges from 87 to 102 pounds and lifting handles are integrated into the case. Like all transformerless inverters, these units must be installed with ungrounded PV arrays, and installations must meet specific *NEC* requirements for ungrounded systems (see "Ungrounded PV Systems" in this issue). The inverters come with a 10-year warranty (extendable to 20 years).

—Justine Sanchez

One Person, One Community

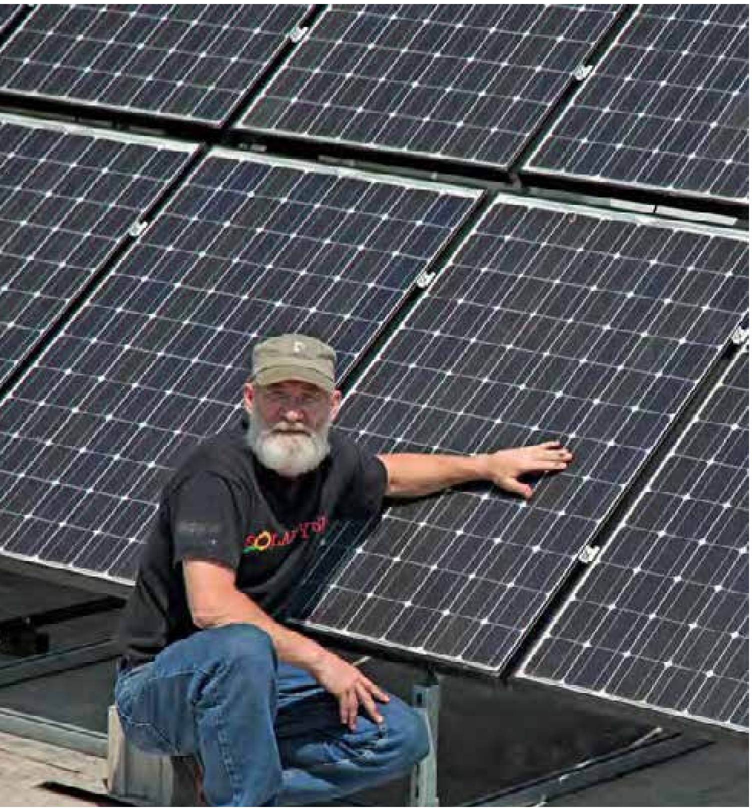
Making a Difference

If you're looking for proof that one person can make a difference, look no further than the community of Ypsilanti (ips-ill-ANN-tee) in southeast Michigan, just outside of Detroit. Commonly called "Ypsi" for short, the town is on its way to becoming a Midwest solar destination, thanks in large part to the dialogue started by Dave Strenski.

When he's not at his day job as a computer systems engineer, chances are Dave can be found atop a roof somewhere in town or giving a talk on solar energy. He is the brains and brawn behind a local community group that is helping the town "think solar."

SolarYpsi, as Dave and his like-minded band of helpers are known, is run through the local food co-op, and is really nothing more than a website and some "solar geeks" who come together to work on projects. So far, the group has installed four small-scale PV systems in town, and Dave's signature solar presentations have empowered a number of area businesses, schools, and homeowners to initiate solar projects independent of SolarYpsi. But that's just the beginning, if Dave has his way.

Courtesy SolarYpsi



"Ypsi is a typical small Michigan town that has been devastated by the collapse of American manufacturing. It is economically depressed, so there is not a lot of money flowing for solar projects, but we're making progress," Dave says. "My hope is that we can attract more progressive-thinking people and rebuild the town around solar, renewable energy, and other technologies of the future."

Cooperative Solar

While Dave is modest about his efforts and always speaks in "we" when referring to SolarYpsi, those in town, even the mayor, seem to agree: "It's all Dave." It all began in 2004 with a rooftop PV installation at the Ypsi Food Co-op, the member-owned grocery store where Dave volunteered as a handyman. The store's manager, Corinne Sikorski, encouraged Dave to research whether solar power would work for the co-op. "With his typical energy and enthusiasm, Dave ran with the idea," Sikorski says. "He must have read everything he could find on solar power and explored every financing angle out there."

With advanced degrees in civil and mechanical engineering, Dave—who admits his interest in solar comes from being "more of a geek than an environmentalist"—picked up the nuances of solar electricity and installation rather quickly. He surprised even himself when his amateur grant-writing skills won a $6,000 state grant to fund a 760-watt demonstration system for the food co-op.

As a condition of the grant, Dave had to create an educational presentation on solar energy. He started showing the slides and speaking around town to anyone who would listen—church groups, school children, farmers, and business owners. One thing led to another, and as word spread of Dave's newfound expertise in solar, people began coming to him with questions and project ideas.

Solar City Hall

The growing interest in his solar talks inspired Dave to do more, and it was on his commute to work in 2007 when he realized the next step: City Hall.

"Every day I would be stopped at the traffic light on the corner of South Huron and Michigan Avenue, and be staring at the back of City Hall," Dave says. "After several weeks of staring at this big blank wall facing south with no shadows, I decided to call the mayor and see what he thought about putting PV modules up on the wall. I thought it would be a perfect place, for both its solar and public exposure."

With sketches in hand, Dave met with Ypsilanti Mayor Paul Schreiber. The mayor liked the idea, but there was one catch: The project needed approval from the Ypsilanti Historic District Commission (YHDC). Since the installation was the first solar project within the town's historic district and would set a precedent for future projects, it took more than three years for the YHDC and the City Council to create the necessary guidelines and approve a final design.

"When there was no one else, long before there were other solar companies in this area, Dave was our go-to guy for solar. He spread the word and made people think about solar," says Schreiber. "Perhaps his most impressive accomplishment is that he stood up for the City Hall project. He believed in the importance of the project and saw it through to the end, and thanks to his efforts, the door is now open for other solar projects to move into the historic district."

The turning point for the City Hall project came in 2008 when Dave won two additional state grants, totaling $80,000. The grant funds—which were administered by Sikorski through the food co-op, since SolarYpsi is not a formal entity—fully funded the City Hall project. The remaining funds provided an additional 1.3 kilowatts in modules for the co-op, along with a 6-kilowatt PV system for the River Street Bakery, which sits next door to, and is owned by, the food co-op.

In 2010, once all the roadblocks had been cleared, Dave organized more than a dozen volunteers, mainly skilled tradespeople from town and members of the food co-op, to work with a licensed electrician to install the 2.5-kilowatt system at City Hall. The final design called for 12 PV modules running in one row along the upper portion of the four-story brick wall. While Dave had hoped to fill the whole wall, he is happy enough with the one row for now. "It's a good start," he says.

Educational Monitoring

Dave also designed and built a monitoring system to measure the output of the PV systems. In speaking with an engineer at the utility company, he learned that he could tap into data available from the utility meters.

To access the data, Dave enlisted Nik Estep, then an undergraduate student at Eastern Michigan University, to build and maintain the SolarYpsi website, which posts the monitoring data in "near real-time." The site features monitoring data for the systems at City Hall, the food co-op, and the bakery, as well as basic information for several other installations in town that were completed independent of SolarYpsi (see "Solutions" in this issue).

In keeping with the food co-op's mission to serve as a demonstration system, Dave set up small, flat-screen monitors inside the store. Each displays graphs of PV system output and other information (such as energy purchased from the utility) as it appears on the website—and the response has been positive from day one, according to Sikorski.

"Putting up the PV modules on City Hall and here at the co-op has had a ripple effect throughout the community," she says. "People come in and ask questions all the time, and more and more systems are popping up around town."

Today Ypsi is home to more than 50 kilowatts of small-scale solar projects—including an 18-kilowatt system installed in late 2011 at the Corner Brewery, located in the historic district. While the town's solar progress may be slow compared to other communities, Ypsilanti has come a long way for a small town in the heart of the nation's automotive capital. "We are in one of the worst places for solar, but we're getting there. I like to say that if we can make solar work in Michigan, it can work anywhere in the United States," Dave says.

Dave continues to push solar education and is doing what he can to get a couple of systems installed each year. Next up is a 6-kilowatt demonstration system that will be temporarily installed at the park for the Ypsilanti Heritage Festival in August and then moved to a local homeowner's backyard for permanent installation. This summer, he also plans to organize a crew to install an additional 18 modules on the co-op's roof—made possible by a $0.78-per-watt closeout sale on Evergreen Solar modules through a local distributor.

At every step, Dave is adding more resources to the website, in hopes of reaching a wider audience. What keeps him motivated? "Coal, gas, and oil are all 'fixed' resources. We can argue about whether we will run out tomorrow, next week, next year, or 10 years from now, but we are going to run out sometime. Renewable energies, like solar, are just that—renewable; they never run out. We need to switch now."

To learn more and experience Dave's signature solar presentation, see solarypsi.org.

—Kelly Davidson

More Online

For more about Dave Strenski and SolarYpsi, check out these Web videos:

The Solar Generation USA Road Trip chronicles a film crew traveling cross-country, touring solar installations and manufacturing sites, and interviewing workers and solar clients. Along the way, the crew stopped in Ypsilanti: bit.ly/TheSolarGen.

YouTube and Google feature Dave in "Search Stories:" bit.ly/SolarYpsi.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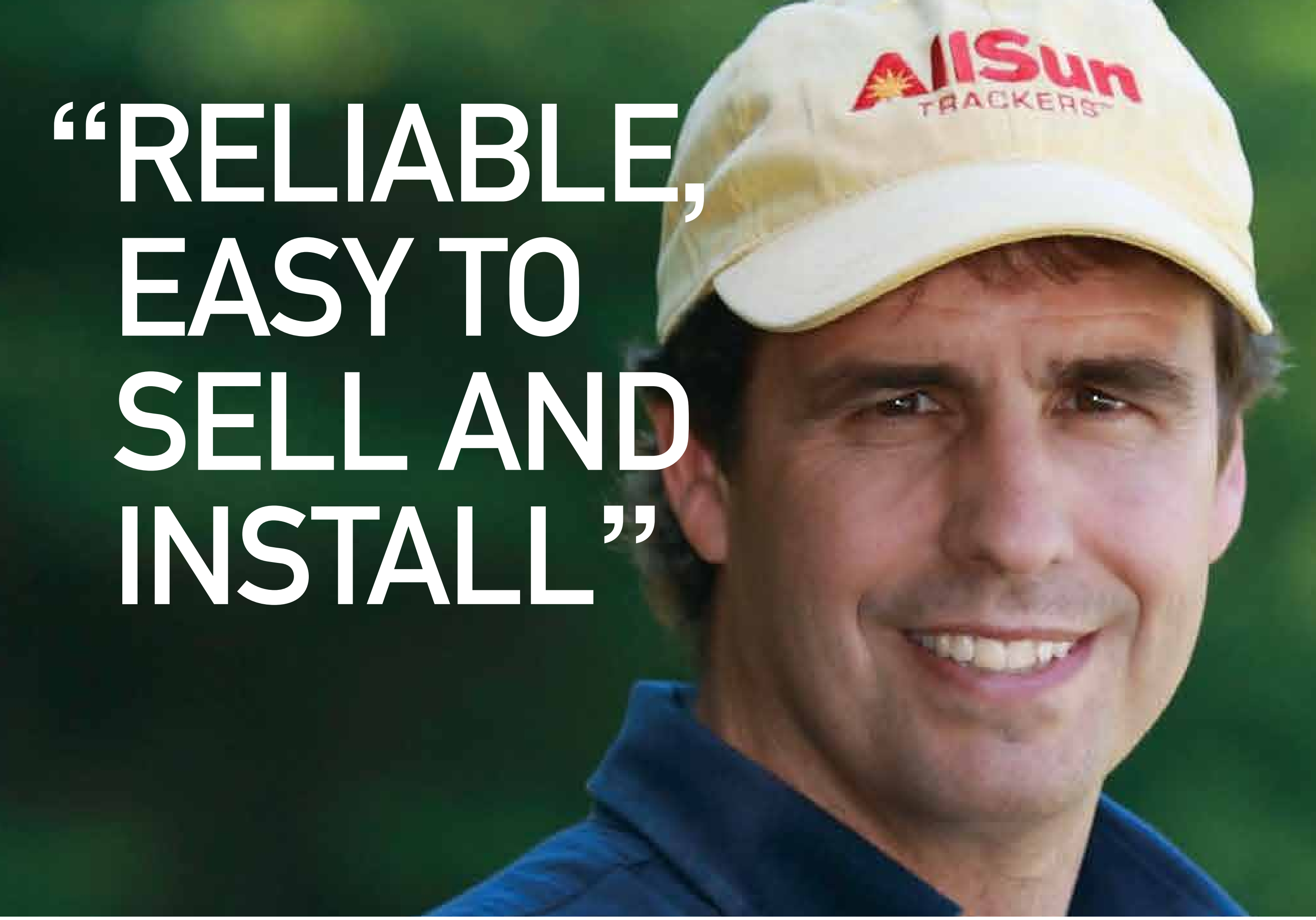

Phil Coupe – co-founder of ReVision Energy, an AllSun Tracker installation partner

ReVision Energy is another member of a growing team of installation partners who have discovered the AllSun Tracker advantage for installations large and small. "Dual-axis AllSun Trackers are complete, pre-engineered solutions that simply work – for me and for my customers. My customers love them because they perform beautifully, producing up to 45% more energy than fixed solar. My team loves them because they're surprisingly easy to sell and install. Plus, they've enabled us to help customers who simply don't have the right roof."

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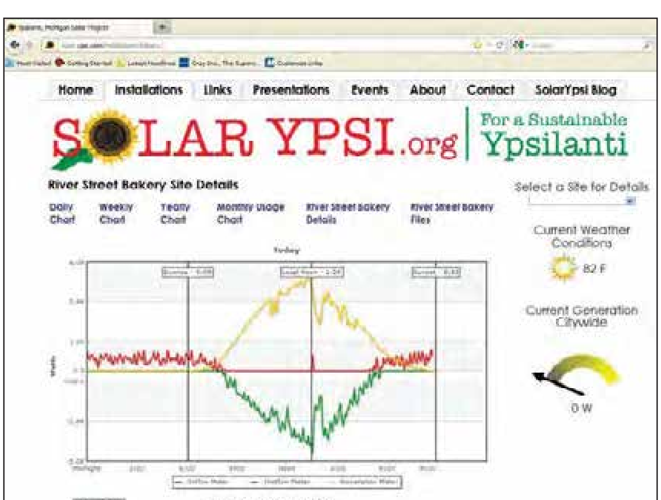
SolarYpsi Data Monitoring

SolarYpsi is a group of volunteers in Ypsilanti, Michigan, who design and install photovoltaic projects around town (see "Returns" in this issue) and who have invented an inexpensive way to monitor electrical energy—including PV power and utility import and export power—for five Ypsilanti solar installations. The monitoring system also tracks daily, weekly, monthly, and annual energy (kWh) production and consumption.

Information is Key

SolarYpsi wanted a method to compare multiple solar installations uniformly. It made sense to simply figure out how to read the utility meters directly rather than relying on inverter- and fee-based monitoring systems. An added benefit of monitoring through the utility meters is that energy consumption problems could be spotted. For example, during the first week of monitoring at the Ypsi Food Co-op, it was noted that the power consumption did not drop as expected one night. It was discovered that the lights had been left on overnight, and actions were taken to educate employees on energy conservation.

One of the systems, the River Street Bakery, was awarded a $44,620 grant to make the bakery 100% solar-powered. The design process started by reviewing the electrical utility records for an entire year. Using this data and the information from the National Renewable Energy Laboratory's solar radiation data (1.usa.gov/NRELmap), SolarYpsi calculated that the bakery would need a 6 kW PV array to turn their meager four hours of peak sun into enough electrical energy to run the bread-dough mixer, lights, and refrigerators. With a limited amount of roof space, 17.2% efficiency Sanyo HIT 200-watt modules were selected.



Overview

Project name: River Street Bakery

System type: Batteryless grid-tied PV

Installers: SolarYpsi volunteers

Commissioned: September 2010

City: Ypsilanti, Michigan

Latitude: 42° north

Solar resource: 4 average daily peak sun-hours

System capacity: 6 kW

Average annual production: 6,465 kWh

Utility electricity offset annually: Approx. 100%

Equipment Specifications

Number of modules: 19

Manufacturer & model: Sanyo HIT HIP-200BA19

Module rating: 200 W STC

Inverter: SMA America SB7000-US

Array installation: Flat roof with galvanized UniStrut rack

Array azimuth: 180°

Tilt angle: 38°

Share the Power

To help showcase SolarYpsi's solar efforts to the public, a method was developed to directly read utility meters at installed PV systems with a laptop computer. With the help of an engineer at the utility, DTE Energy, SolarYpsi learned about "KYZ pulse output"—the means by which some digital utility meters are able to count energy use.

The local utility agreed to install these types of digital meters, which gave three data wires to use. The data wires are connected to a relay in the utility meters, and the other end is connected to the parallel port of a laptop. Every pulse detected in the wire means a specific amount of energy went through the meter. By counting these pulses with specially developed meter-reading software and sending the information to the software on SolarYpsi's web server, real-time system information (array output, building consumption, and energy exported to the utility) can be tracked and recorded with the same accuracy the utility company uses for billing. The open-source software is available on the SolarYpsi website for free, along with information on how to use it (see solarypsi.org).

—Dave Strenski

Leveling & Squaring Your PV Array

A square and level array begins with a good layout on the roof. Taking the time to do this in the beginning will make the entire process go more smoothly.

Sketch the basic layout on the roof with either a nonpermanent marker (for metal roofs) or chalk (for rough surfaces), starting with the array outline from your design. In addition to the array outline, mark where the rails will be located. To avoid confusing your lines, use one color for the array outline and another for rail lines. With the system lined out, then install your roof attachments, which may be L-brackets or standoff posts—just be certain to use flashing to meet building codes and prevent leaks.

Level the Rails

First, determine that the array lies in a single plane. This process is easiest when you work with at least one other person—and with a rack system that has quick and easy leveling features. Otherwise, this step can be a huge time sink.

Install your rails onto the previously installed roof attachments. Leave the rail hardware loose to allow the rails to rest low on their mounts.

The rails are fairly rigid and tend to lay straight, but from rail to rail there is no connectivity. To line up the installed rails, place an extra rail or other straight-edge perpendicular to the installed rails. Another option is to use a string line or laser level—although the laser level may be difficult to see in the sunlight.

Tighten the bolts on the top and bottom rails; then use the straight-edge to level the rails in between. If the middle of the roof sags, the rails in between will be adjusted higher. If the middle of the roof is raised, then the top and bottom rows will need to be raised.

Watch for "potato chipping," which is caused by the top rail not sitting in the same plane as the bottom rail. This is easily observed, so get your eye down to the plane of the rail tops to look for any variations. Check that the top and bottom rails are in the same plane before working on the rails in between. Site from both ends of the array. It is often helpful to also inspect the rails from ground level, where they'll be seen the most.

It is tempting to use a bubble level to check that the rails are plumb. But roofs aren't necessarily level. If you want the array to look good, it's more important that it match the roof lines.

Next, square the rails as preparation for installing and squaring the modules. To verify that a rectangle is square, measure diagonally—from the top corner of each side to the opposite bottom corner. The two lengths of the "X" should be equal. (Note: On most installations, the rails do not need to be perfectly square. It is more important that they *look* square when comparing them to the roof and building.)

When you are done squaring and leveling the rails, tighten every fastener to its torque specification *before* access is limited by the modules.

Courtesy SnapNrack

Install & Square the Modules

Roofs are rarely square, so as you install the modules, make them square to the lines of the structure that will be most visible from the ground. As a result, modules may not be perfectly lined up to the rails, which is usually fine. It's difficult to spot minor discrepancies in rail alignment relative to module alignment, but if the modules are not aligned to the prominent edges of the structure, it will be very visible.

A common practice is to start with the bottom row of modules, since the bottom roof edge is often the most critical visually. A string line can help with lining up the bottom row and will help you catch "module creep" early. Make sure any string lines used are taut, so they won't blow in the wind or sag.

Generally, PV modules have very square edges, which make line-of-sight an excellent way to confirm alignment as the installation progresses. However, don't assume that all PV modules are perfectly square—the module frame itself can get slightly out of square during shipping and handling.

Once the first row of modules is in place, the other rows usually install quickly as they are spaced uniformly adjacent to the first row. Occasionally, one side of the array may be more visible from the ground or even from a second-story window—so you may want to do visual inspections from various vantage points as you attach the PV modules to the rails. Continue using your tape measure, string line, and a discerning pair of eyes to make certain the array looks good from every angle.

Finally, verify that all of the module clip bolts are tightened to their recommended specifications.

—Greg McPheeters & Tim Vaughn

He’s not taking any chances with roof leaks. Are you?

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Roads Scholar

Kathleen Jarschke-Schultze's most recent *Home & Heart* was great ("Roads Scholar" in *HP149*)! Thanks from those of us who live that life. Michele and I live 3.1 miles from the paved highway on "Mail Box Road." A neighbor has a tractor—but we hate to always depend on him. Several years ago, the community pooled its resources and bought a 1912 mule-pulled road grader (now pulled by a surplus Army truck). Still, the road has to become almost impassable before we all pitch in and do repairs. Once we do, there is a fantastic sense of community, but between those times, we just live with the rough road.

I'd like to add that "base course"—a mixture of gravel and fines (dirt)—is better than gravel. It is usually a product of the crusher at the gravel pit. But it can be mined as-is. As Kathleen mentioned, "round" rock tends to move; the crushed gravel has sharp edges and tends to hold together. The gravel in base course lends stability; the fines in it bind the gravel together. Stretches of road where we've added base course years ago are still holding up. Another option is "DOT base course," which has added lime to further stabilize the road and aid in water shedding.

As Kathleen says, rising fuel prices have skyrocketed the cost of delivery, while the cost of material is not that high. And many drivers do not want to drive on our roads—they are glad to deliver to the top of the road at the highway. If they have to drive very far on our road before dumping, they will often only deliver once. Plus, there is a large disparity in the drivers' abilities to spread the gravel. Some are great, but many end up spreading the gravel in lumps. More than a few refuse to even try—they just dump their load in one pile, which requires either the tractor or a lot of wheelbarrow loads. (Once, it took eight hours for Michele and I to move 13 tons dropped in the middle of the road.)

Another key to road maintenance is "drainage! drainage! drainage!" Culverts, water diversions, and doming our roads are critical. Thank you for your article, Kathleen. I always enjoy reading your column.

Grey Chisholm • via email

In these parts, what you call "base course," we call "pit run." It can be really good stuff or it can have a bunch of larger (tennis- to softball-sized) rocks in it, which makes it a real pain to smooth unless you are putting down 6 inches or more. Who has that kind of dough? What you describe—and we get if we're buying gravel—is hereabouts called "3/4 minus." Same thing as your base course, except it has no dirt—just lots of fines from the crush.

Works great for potholes, but as you point out, it migrates. If I have the time and it's handy to do so, I like to mix in a little native dirt with the gravel to bind it. Makes it stay in the potholes better.

Of course, timing is everything. If the moisture content of the road is just right, it's easy to grade and you can get pretty good results. Too wet or too dry and you are wasting your time, except for filling potholes. Even if you time it right, a bunch of late rain can trash it again. I also tend to mound up the filling a little and let it get compressed by the vehicles' tires.

We hear you about the cost of trucking—yikes! When we buy gravel, we always get a full transfer truck and *trailer, rather than just a dump truck. You get a little less weight per load, but then there are two loads. The cost of the material is about 20% of the cost of the haul!*

As I'm a bit of a tool freak, I bought a good used backhoe/loader a few years back, so I'm always on the lookout for a good gravel pit in the neighborhood. It's kind of like hunting for gold—there are small pockets of good, decomposing rock here and there that you can mine. Last year, we acquired a two-axle dump trailer. We use it mostly for hauling manure and firewood (it can hold a cord and a half of wood or seven yards of dry horse manure), but it works pretty good for moving gravel around, too.

You are lucky to have neighbors who pitch in. We don't have much help. Since 99% of the road work falls to us, tooling up is just about the only way we can keep the road reasonably passable. Since roadwork is also a springtime chore—along with all the other springtime chores—keeping the time spent on it to a minimum is also important.

Bob-O Schultze &
Kathleen Jarschke-Schultze

Rainwater Legalities

I thoroughly enjoyed Stephen Hren's informative and detailed article about rainwater harvesting in *HP149*. But here in my home state of Colorado, collecting rainwater counts as theft of property from downstream water-rights owners, and can result in fines of $500 every day that the rainwater collection system is in operation. Even placing a bucket under your shower to gather the first couple of gallons of cold water before it heats up and you jump in, and then watering your outdoor garden with it, is often illegal—no matter where the water comes from. As they say 'round these parts, "Whiskey's for drinkin' and water's for fightin'."

In 2009, Colorado eased up a bit on the law after a study revealed that 97% of rooftop rainwater never makes it into streams or aquifers anyway, but rainwater harvesting is still not legal for most Coloradoans. If water service is available from a utility, no matter the distance or cost to run it to your home, you can't use rainwater or snowmelt from your roof, driveway, or yard—for anything. If you own more than 35 acres and have a special well permit, you might be allowed to use rooftop rainwater outside your home for a very few, specific uses. If your rural property is less than 35 acres and you don't have city water service, you are now allowed to use roof-harvested rainwater inside the home, but not outside for a hot tub, vegetable or flower garden, greenhouse, aquaculture, trees, or animals.

And in all cases under the new law, a permit from the state Division of Water Resources is required for any rainwater harvesting. Even composting toilets and water storage for fire protection are tricky legal areas; composting toilets don't put wastewater back into the ground, and fire-protection cisterns may have to be locked so that only firefighters can draw water from them.

Of course, it's unlikely that your grandmother in Denver will be fined or jailed for watering her petunias and tomatoes from the rain barrel under her downspout. State regulators claim to focus on violators who try to store large amounts of rainwater for irrigation and livestock. And Colorado's water-rights laws are not some new bureaucratic affront to our personal freedoms, but rather date from the era of presidents Abraham Lincoln through Ulysses S. Grant—before Colorado was even a state. In any case, though, tell grandma to watch her back. For more information, see www.ext.colostate.edu/sam/rainwaterbills.pdf.

Dan Fink • Buckville Energy Consulting

write to:

mailbox@homepower.com

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PO Box 520, Ashland, OR 97520

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

Dust on Solar Modules

I am doing a science fair project about dust buildup on solar-electric modules. I tested my modules and found that, on average, they lose 0.0332606% in efficiency per day due to soiling. Is there a graph showing efficiency losses due to dust in a more controlled setting?

Laura Ratliff • La Canada, California

Your letter made my day. It's great to see a young person committed to science, interested in renewable energy, and using accuracies to that many decimal places!

We've touched on efficiency reductions due to dust dirt (called "soiling") on PV modules a few times in *Home Power* articles—see the *HP143* article by Justine Sanchez, which estimates an average of 5% loss per year due to soiling, and an *HP127* article by Jeremy Taylor, which says that, in some especially dirty environments, modules can experience 25% losses per year!

If I take your per-day value and multiply it by 365 days per year, I get an annual loss of 12% (which doesn't account for rainfall or array washing). That's about halfway between the average and "especially dirty." Lots of things might affect the amount of dirt on a PV array, such as living near a dirt road, factory, desert, or ocean; rainfall frequency; and array tilt, which can influence how much dirt sticks and how easily rain washes it off.

The value you obtained sounds plausible. Actually, if your scientific method is proper, and your experiment is set up right, then I would have to believe your numbers, at least for your specific location. Did you use two PV modules in your test: one that gets washed (called a "control"), and one that is allowed to collect dust?

You could extrapolate your numbers to create a sloping, but relatively straight, graph that would show that in a place that's twice as dusty, there would be twice as much "negative" effect on power output, and vice versa.

Seventh grader Laura Ratliff investigated the effects of soiling on PV module power production and showcased her results at the California State Science Fair.

Courtesy Laura Ratliff

See the "Back Page Basics" article by Erika Weliczko in *HP131*. The graph in the upper right column shows how PV module power (voltage × current) is influenced by the amount of sunlight hitting it (1,000 watts per square meter is considered normal, bright sun on a clear day). That means that 800 watts per square meter is 80% the light of a bright day. You could also consider that to be 20% dirty—it's the same thing. Zero watts per square meter could be a pitch-black night, or it could be so much dirt that no light gets through at all.

Electrical current is affected in a very linear way relative to the amount of sunshine (irradiance, or measured over time, insolation). But voltage changes very little with irradiance. That means if you graphed irradiance on one axis and power (voltage times current) on the other axis, the line would be a pretty straight slope.

If you graph the data that you gathered from your experiment (at an average of 0.033% per day), it would start at 100% clean (100% irradiance) on one axis and 100% PV power on the other axis. The line would be plotted at the 0.033% per day rate for the number of days in your experiment, but could be extrapolated for many more days (the days between significant rainfall or array washing)—even though you don't have the actual data. That continuation would be your scientific prediction.

You can compare your results to a 2006 study that measured efficiency losses between 46 large grid-connected PV systems in California and the desert Southwest. It was found that PV system efficiency declines by approximately 0.16% per day between significant rainfall events for systems located in urban, highway, or airport settings. The study concluded that annual energy loss was between 2.5% and 6% depending on the system location (see graph).

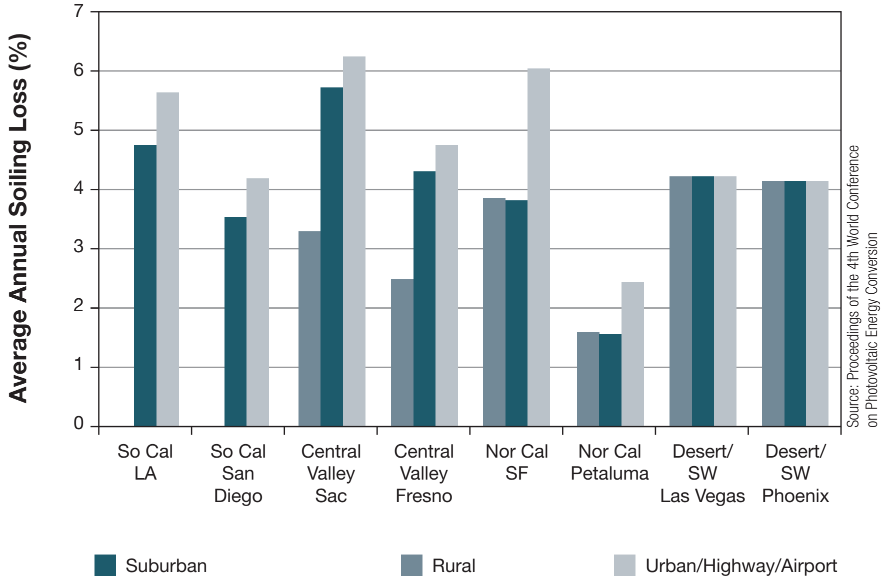
You are asking good questions and thinking about good ideas, so I hope this is interesting and useful for you. Let us know how your science fair project turns out!

Ben Root • *Home Power*

I got third place in physics at my school and third place in Engineering Research at the Los Angeles County Science Fair. I was in the Alternative Energy category at the California State Science Fair (see photo), and while I didn't win anything at State, it was a great experience. I appreciated the help from your magazine, and it is really exciting that you want to publish my letter.

Laura Ratliff • via email

Average Soiling Loss By Region and Environment



Wire Management & Fire Prevention

With the generous PV incentive program currently available in Louisiana, there has been a rush of unqualified installation companies into our local market. We have seen examples of poor workmanship throughout our coverage area. Please see the attached photograph for one such example of poor rooftop wire management.

To promote better overall installation practices, we are trying to gather information and evidence related to rooftop fire hazards. In particular:

- **How can loose (unmanaged) wires spark a rooftop fire? What might initiate an arcing event?**
- **How susceptible are shingles to fires caused by electrical arcing? Are there any documented cases of a connection between a rooftop fire and improper wire management? Any feedback you can offer is appreciated.**

Corey Shalanski, Joule Energy • New Orleans, Louisiana

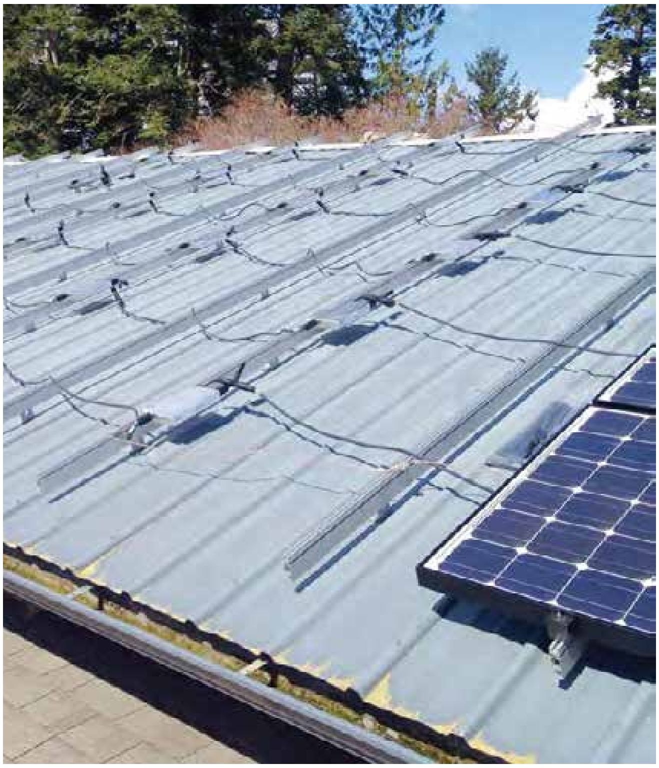
Courtesy Corey Shalanski

Unmanaged PV wiring can lead to damaged conductor insulation, increasing the potential for a DC arc to occur on the roof.

In the days before maximum power point tracking (MPPT) charge controllers (see "Buyer's Guide to Charge Controllers" in *HP146*) and direct grid-tied inverters, PV arrays operated at "nominal" battery bank voltages of 48 volts DC or below. At such low voltages, fire hazards from rooftop PV arrays were minimal. MPPT technology has since revolutionized PV system design, allowing high-voltage PV arrays of up to 600 VDC, smaller and more economical wire sizes, and much greater overall system efficiency.

While roof fires directly related to PV arrays remain rare thanks to updated electrical codes for DC circuits and installer certification programs such as NABCEP, the downside of higher PV array voltage is increased fire hazard from arcing, which is directly related to poor rooftop wire-management practices.

Another case of poor planning and unmanaged array wiring: Here, rail alignment does not allow for PV wiring to be secured or supported by the racking system.



Courtesy Ian Woofenden

No roofing material can withstand the 3,600°C (6,512°F) temperature from a DC arc for very long. Worse, such arcs can energize unexpected and dangerous current paths in metal roofing, and flashing and conduit, posing an electrocution hazard to both firefighters and electricians called to the scene to repair the system.

New products are being introduced to the PV marketplace that can reduce the risk of DC arcs, such as transformerless inverters (see "Ungrounded PV Systems" in this issue) and DC arc-fault circuit interrupters (AFCIs). AFCIs are now required by *National Electrical Code* Article 690.11 on any DC circuit of more than 80 volts. They may be located in inverters, PV module-mounted electronics, DC-to-DC converters, or combiner boxes.

While these new PV products will help reduce the risk of fire, damage to PV conductors and/or modules still needs to be avoided. Common causes of physical damage include accumulated snow, ice, leaves, and conifer needles under an array that is not inspected and maintained regularly.

PV array wiring is also vulnerable to wildlife damage, and to more gradual wear from the movement of rooftop wires from wind, and the natural expansion and contraction of metal conduit and array racking due to temperature changes.

Modern PV modules now also employ preattached, outdoor-rated wire leads instead of old-school screw terminal junction boxes that required watertight flexible conduit between the modules. These interconnection systems have drastically reduced PV array installation time and cost, but have also left many installers wondering how to safely and neatly manage the jumble of wires and connectors hanging from the back of a typical installation.

Taking care to avoid pinched or nicked wires during installation and liberally using S-clips and zip ties to avoid damaged wires after installation will mitigate most of the hazards posed by modern, high-voltage PV arrays. Be sure to research the newer PV racking systems that include integrated and protected raceways for DC conductors. And remember, just like back in the day—regular system inspection and maintenance will catch most potential problems before they can turn into disasters!

Dan Fink • Buckville Energy Consulting

Home Electricity Monitoring

I've been a subscriber to this wonderful magazine longer than dirt. But, unless I missed it, you have never done an article, or a review, about different types of home electricity monitors.

I've done "everything" in the way of renewable energy over the last 35 years or so, but now I'm interested in reducing wasted energy by figuring out where all the electricity I use is going. I did a primitive monitoring of a fridge and freezer, by randomly noting when each was running and when they weren't. From this, I determined the percent run time, multiplied this number by the rated power consumption in watts, and voilà—I determined how many kilowatt-hours per day were being used by each of these appliances.

It turned out that the old fridge was running about 25% of the time, and the older freezer was running about 75% of the time, so bye, bye, freezer. The new one not only draws less power, but it's running only about 15% of the time.

But now I'd like to monitor *everything*. I'm told that a "smart meter" is capable of figuring this out, but I don't want a smart meter, at least not one that can be hacked into, as that seems to be an open invitation to hackers/burglars so prevalent around here (well, not now, but maybe after we all get on smart meters).

I have perused what's for sale, and have decided that *Home Power* folks are way better at figuring out stuff like this than I am, so how about an article or two? Besides, I am certain that there are others besides me who would find an article on this helpful. Thanks in advance, *Home Power* folk—you are rad!

Malcolm Drake • Grants Pass, Oregon

There's a range of electric power monitoring tools, starting with the simple Kill A Watt and Watts Up? meters that simply plug into an outlet. These devices are ideal for evaluating the power draw and energy consumption of individual, 120 VAC appliances. Then there are whole-house systems and smart meters. "Beyond Your Utility Meter" (*HP138*) reviews a variety of metering systems.

If your utility does not yet offer smart meters, whole-house energy monitoring systems, such as those made by The Energy Detective (theenergydetective.com), are available for $200 to $300. The much more complex and expensive systems, such as the eMonitor from Powerhouse Dynamics (powerhousedynamics.com), allow you to monitor every circuit in your home separately. Its price ranges from about $500 to $900, depending on the number of circuits you choose to monitor. Both systems have monitors that install in the main breaker panel to show detailed information on various devices from a small wireless display to your computer or your smartphone.

Courtesy Claire Anderson

Home energy monitoring systems allow homeowners to keep tabs on their electricity consumption details—and change their energy-use habits accordingly.

Smart meters provide you with detailed power draw and energy consumption information in near real-time via a Web portal, and save you the several hundred dollars that a whole-home monitoring system costs. While smart meters have been hacked, the only purpose for hacking one would be to cheat the utility company. Not all smart meters are hackable, however, and those that are require physical access to the meter. So far, there have been no known incidents of malicious hacking.

Power monitoring systems create a pathway for saving energy by increasing your consumption awareness. Many people have reported significant energy use reduction after installing energy monitors. There is an anecdotal story about a woman who installed an energy monitor that she could access from her smartphone. She looked at it on her way to work and noticed her energy consumption was 1,000 W higher than it should be, and returned home to check it out. She found that she had left the toaster oven on and that it was turning brown and beginning to melt. So you never know, maybe an energy monitor will also save you from burning down your house!

Guy Marsden, Energy Maven • arttec.net

Array Sizing for Best Battery Charging

I am working with a customer in southern Oregon who has an existing stand-alone solar-electric system, and is considering adding an additional array and charge controller to help get the battery bank fully charged.

The existing system consists of a 0.5 kW 24-volt array, an older Trace C30A+ charge controller (from a previous system), an OutBack VFX3524 inverter/charger, a 24-volt, 850 Ah battery bank and an 8 kW Northern Lights generator. He is concerned that the array is not sufficient to fully charge the batteries and that the generator is running too often.

The existing array is partially shaded and I am not convinced that adding another array is a good solution. The owners are aware of what they can (and cannot) run on the batteries alone, and use the generator whenever they feel they would be overtaxing the batteries.

With a given amount of solar exposure and energy usage, what size array would be sufficient to charge the battery bank? Or would it be better to upgrade to a newer controller that uses MPPT technology, such as an OutBack FlexMax 60, instead?

Tom McDowell • via email

You have brought up several issues with your questions. First, the system you have described may best be labeled as a "generator-based system with PV assist," because the generator, charging through the inverter, is the only source capable of fully charging the batteries. Some basic calculations will explain this. The ratio of battery capacity (in rated Ah) to the rate of charge or discharge (in amperes, or A) is called the C-rate. This ratio is used to quantify charge and discharge rates. For example, a common golf-cart battery has a capacity of 220 Ah. If a 22 A load is placed on the battery, it is being discharged at a C/10 rate (220 ÷ 22 = 10). If the battery is then recharged by a PV array producing 11 A, it's being charged at a C/20 rate. A 1,000 Ah battery would need to be charged at 50 A to achieve the same C/20 rate.

A PV charge rate of C/20 or better is generally considered the minimum needed for good battery care. For the 850 Ah battery at 24 V, this would be 42 A (plus enough to meet the household loads)—or a PV array rated at more than 1,400 watts. This OutBack inverter/charger is capable of charging at 85 A continuously, according to published specifications. Assuming that the generator is properly set up to deliver its full AC current to the inverter at 120 VAC, this is a C/10 rate (850 Ah ÷ 85 A), which is adequate for proper charging and equalizing. The existing PV array can supply at best about 15 A to the batteries, less any energy used to run household loads while charging. This is about a C/56 charge rate (850 Ah ÷ 15 A)—too low to even overcome the batteries' internal resistance, much less equalize the batteries.

In the earlier years of off-grid residential system design, PV modules were expensive and batteries were relatively inexpensive, and systems were designed accordingly. Extreme electrical energy efficiency was essential to live within the capacities of a home's PV system. All of that has changed in recent years: Batteries have doubled in price and PV module prices have dropped to one-third of what they were 15 years ago. To add to this, homeowners now expect continuous performance from their systems—seldom do modern inverters go to sleep at night. While a 1 kW array was common and sufficient to supply a well-planned off-grid home's needs 10 years ago, 2 kW and 3 kW arrays are more common today, and are affordable as well.

Today, it's common, at least in relatively sunny climates, to design a system to provide only one to two days of autonomy. Arrays are usually sized to recover 100% of the average daily winter load in a single day. This approach tends to keep the batteries full throughout most of the year, leading to less generator run time, longer battery life, and better overall system performance. (For RE professionals reading this, see Christopher Freitas' article "High-Capacity Battery Banks" in *SolarPro 5.2* for more on this subject.)

This is the antithesis of your customer's current system. I would suggest both adding to the array and upgrading to a modern MPPT charge controller and proper safety disconnects. Not only will a modern controller increase efficiency, but it will allow the array to be wired at higher nominal voltage: up to 60 V (up to 72 V in milder climates) with an OutBack FlexMax, and even higher with a MidNite Classic. This would allow locating the new array farther from the batteries, if there is a place with less shading.

Once that is done, keep the C30A on the old array, but keep an eye on it. The C30A has been out of production for 15 years, is quite unsophisticated, and had a reputation for failure (of the internal fuse holder and relay). It also lacks temperature compensation. Set it to regulate at around 29.5 V as a sort of trickle charger; the new controller will compensate. Lower its regulation voltage only if your customer has to add water more often than every few months (assuming that the batteries are not near the end of their life, when water loss increases). If and when the C30A fails, replace it with a simple, modern controller; the 15% to 20% increase in output provided by MPPT is hard to justify against its increased cost with a 500 W array.

Allan Sindelar • Positive Energy Inc.

Combination Water Heating

I have a combined bath and utility room of about 180 square feet that sits inside a larger, unheated barn space. The floor slab has not been poured yet and I would like to use radiant floor heating for those two rooms. My plumber suggested using a conventional tank-style water heater to provide both domestic hot water and heat for the radiant floor pipes. He said he could rig up a heat exchanger on a conventional water heater but I thought it would be better to go with a product that is designed for that purpose. The problem is that virtually every combination water heater I can find is gas-fired. I would prefer using electricity because I already have a 4.5 kW PV system that can meet some of that load. Do you have any suggestions? In the future, I might consider adding a solar thermal system to preheat water.

Dennis Favello • Union Dale, Pennsylvania

Many people use conventional water heaters with radiant floor heat delivery systems. Numerous solar companies offer tanks with an integrated heat exchanger and electric element backups (see "Solar Hot Water Storage: Residential Tanks with Integrated Heat Exchangers" in *HP131*).

Consider the amount of heat that's delivered for each type of fuel. Gas and propane heaters usually have 35,000 to 50,000 Btu burners and can normally heat a reasonably well-insulated area of 1,200 square feet, perhaps more. An element for an electric water heater is usually 4,500 watts, although 5,500-watt elements are available. There are about 3,412 Btu in 1 kWh, so a 4,500-watt element will produce a little more than 15,000 Btu per hour.

Even when a tank has two elements, they are never on at the same time, so the total heat output is limited to one element. For your application, this is plenty of heat—*if* the room is insulated. The electric water heater is a better environmental option if you have any excess winter production from your PV system or a significant part of your electricity is generated with renewables.

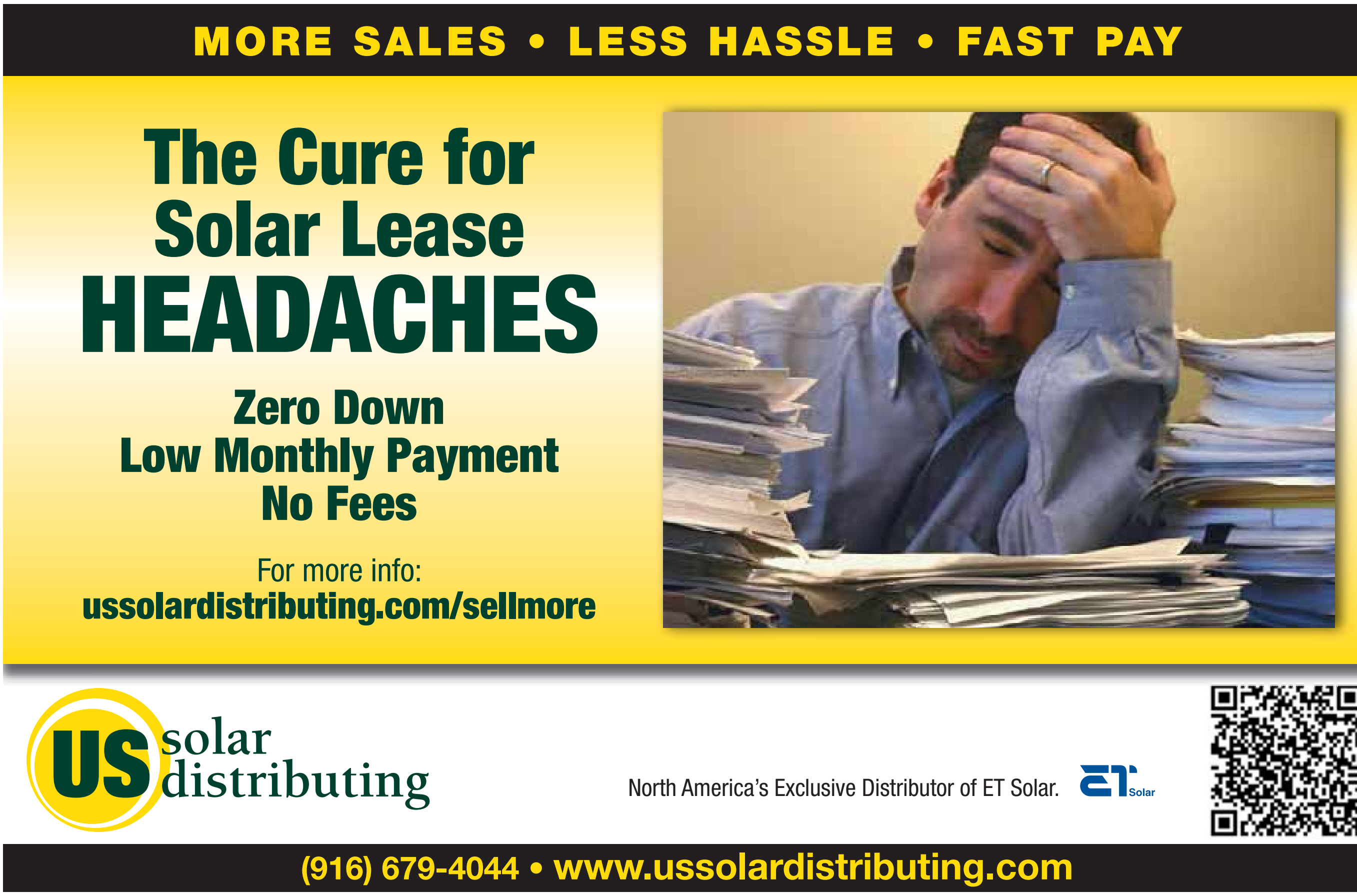
An external heat exchanger option suggested by your plumber is a good idea with either gas or electric heaters, but will require two circulator pumps. External plate-type stainless steel heat exchangers are very efficient, though, and, in some cases, more effective than integrated heat exchangers. The electric heater is also a better option for a backup for solar collectors, since electric heaters have fewer standby losses because they don't need a flue pipe, which is normally needed to vent gas and propane water heaters.

Chuck Marken • *Home Power* thermal 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.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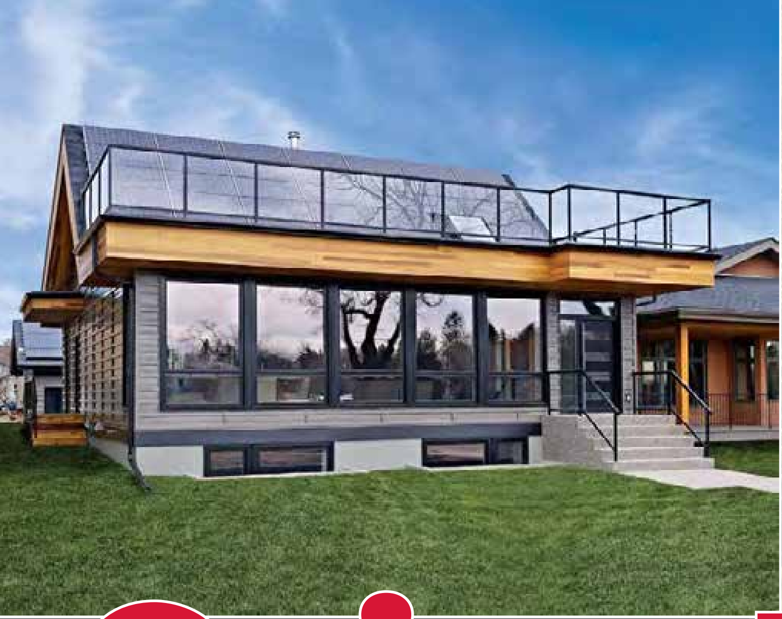


Going to Zero

Excerpted from *Home Sweet Zero Energy Home* by Barry Rehfeld

The future of building is not about any radical change in the way houses and other buildings look. It goes deeper, to the way they work, and here the change is nothing short of revolutionary.

Photos, clockwise from upper left: Merle Prosofsky Photography Ltd.; Courtesy Steve Johnson; AJ Mallory/Bright House Images; Courtesy Bob Heath

Put simply, these are houses that will produce as much energy as they use. This balance is summed up in the name they are known by: zero energy or net-zero energy homes. It doesn't stop there, though. The spirit, if not the letter, of zero energy homes requires that the energy produced must be from completely natural renewable energy sources—typically solar, but possibly wind too—converted into electricity on the property. What isn't used at the time is fed into the local utility grid. Any energy consumed when the sun isn't shining or the wind blowing is also electricity, supplied to the home by traditional, often fossil fuel-burning power plants. Eventually, however, those plants will be replaced by solar, wind, geothermal, hydroelectric, and ocean-wave power facilities—as they have been in a few communities to some degree today—when coal, oil, propane, and natural gas supplies start running out or become more expensive than the renewable sources (and nuclear facilities become untenable).

Beyond Balancing Consumption & Production

A zero energy home consumes very little energy. The amount should be at least two-thirds, and hopefully as much as 90%, less than what's consumed by a standard house of the same size. Smaller houses trump larger, too—the better to reduce the amount of energy used.

Inside the house, it's mostly a story about the many ways—small, unseen, out of the way, or uncommon—that make up the structure and components of the house that will separate the future from the present and the past.

However, everything it takes to build the house of tomorrow is for sale today, bought off the shelf or off the Internet. Some of the features and ways of doing things will be new to most homes, though much of what makes up a zero energy house will just be more efficient versions of what's already in them.

In the package of features that make up a zero energy home there can be heat or energy recovery ventilator systems, tankless water heaters, heat pumps, fiberglass doors, low-flow showerheads, Energy Star top-freezer refrigerators, front-loading clothes washers, LED lighting, and cellulose and foam insulation, as well as triple-pane, gas-filled windows and solar-electric modules.

As important as its components is its affordability: a zero energy home must be priced within the means of the average home buyer. Ideally, zero energy homeowners would wind up paying nothing for the electricity they consumed over the course of the year. For the owners of a typical American house, eliminating the entire energy cost in an all-electric zero energy home could be a savings of about $2,200 annually (2009 figures). It can also mean more money in the pocket later, when the house is sold. In a study appearing in *The Appraisal Journal*, a home's value was said to increase an average of $20 for each $1 decrease in the annual utility bill.

A net-zero energy home starts with using as little energy as possible. High insulation values in the walls and the roof help keep heating and cooling loads low.

Besides dollar savings, a higher quality of life—by a number of different measures—is another advantage of living in a zero energy home. These homes are quieter, maintain temperature settings better, allow more natural light, have better air quality, and may stand up to storms better than traditional homes.

But as welcome as these advantages are, they don't speak to the reason why zero energy homes are—many people would say *must be*—the housing of the future. In the United States, buildings, both residential and commercial, account for roughly 40% of energy use and carbon emissions—more than either of the other two main sectors of the economy, industry and transportation. Throw in construction and demolition, and it increases to 50%.

(continued on page 58)

Courtesy AJ Mallory/Bright House Images

With renewable electricity as the main energy source, heating and cooling with it make sense. In most cases, a heat pump can serve as a source of efficient heating and cooling.

Net-Zero Energy Profiles

Home Power put out the word that we were looking for some net-zero energy homes to showcase, and we found some good examples from across the continent. Each takes a different approach that relates to its individual climate and specific project goals—the Pacific Northwest home was designed for moderate temperatures; the Tennessee home, for humid, sultry weather and wider temperature swings; and the Canadian homes, for the long, cold months of winter. In other ways, they all adhere to some common principles and technologies. Check out the similarities and differences on the following pages.

If you're interested in how a net-zero home might measure up, turn to "Net-Zero Performance: Year 1," which details the performance of a Colorado net-zero energy home that was featured in our pages last year for its design plans ("Heading for Zero: Smart Strategies for Home Design" in *HP141*).

Belgravia Green

This profile details one of two homes in Edmonton, Alberta, Canada's Belgravia district. The home was built as a show home by Effect Home Builders (EHB; effecthomes.ca), an Edmonton company known for its energy-efficient houses. Flanking it are two privately owned custom homes—and all are designed to approach or achieve net-zero energy status.

A 12.5 kW PV system produces a yearly net surplus of electricity.

According to Les Wold, EHB's managing partner, "One of the big things we've learned is that there are multiple ways to approach building energy-efficient homes—that's what we really like about this project. There are three different homes and they are all reaching toward the same goal, but approaching it with different considerations and different technologies."

Central to the homes' efficiency is the building envelope—an important factor in any energy-efficient design. All three houses achieve a high level of airtightness, and HRV systems are used to exchange stale indoor air with fresh outdoor air, while retaining most of the heat in the air.

SIP construction makes a tight and well-insulated building envelope.

A heat recovery ventilator (top) keeps the air fresh without undue heat loss.

This air-source heat pump provides a means of efficiently heating and cooling the homes.

Merle Prosofsky Photography Ltd. (8)

EHB's Les Wold poses with the grid-tied PV array, which features microinverters.

Vital Statistics

Name/owner	Les Wold
Contractor	Effect Home Builders
Designer	Howell Mayhew Engineering
System installers	Great Canadian Solar & DayStar RE
Occupied date	None; currently for sale
Location	Edmonton, Alberta, Canada
Total cost: Systems & house	$575,000
Square footage	1,540

Building

Orientation	South-facing
Walls	Nascor Energard wall system with polystyrene insulation, R-42; basement built with insulated concrete forms, plus 5 in. of polystyrene insulation
Ceiling or roof	R-80
Floor	Slab: 4 in. polystyrene insulation underneath, R-16; main floor: 4 in. thick structural concrete with steel joists
Windows	Triple-pane, argon-filled, low-E, SHGC = 0.521, U-factor = 0.130; 217 sq. ft. of south-facing windows
Other contributions to passive solar design	Black concrete countertops & clay interior wall finishes contribute to thermal mass

Energy

Annual energy consumption (kWh)	14,600
Annual energy production (kWh)	15,400
Energy software	Building: HOT 2000; PV: RETScreen, plus Solmetric PV Designer
Renewable electricity	Grid-tied PV system on house roof & detached garage
Rated power (kW)	12.5
Heating degree days (F)	9,382
Cooling degree days (F)	104
Cooling system	None
Heating system	Trane XR15 air-source heat pump & fan-coil forced-air distribution
Solar hot water	None
Water heating	Electric on-demand
Lighting	LED & compact fluorescent
Additional features that help achieve net-zero energy	HRV with 0.58 air changes/hr. at 50 pa; energy- & water-efficient appliances

Bonus

Green transportation	Six-minute walk to light-rail transit & two blocks from public buses
Other green features	Polished concrete floors, no-VOC paint, programmable thermostat, dual-flush toilets, electric induction range, no natural gas use, grey-water ready

A net-metered, grid-tied PV system meets all of the show home's energy use over the year. The other two homes are PV-ready, with a conduit run from the mechanical room to the roof. Although solar generation is only one part of the additional cost incurred when building net zero, Wold estimates that the cost of building net-zero ready is only about 7% to 8% more than a standard house.

Above right: A wood stove provides supplemental heating, if needed.

Right: South-facing windows and a thermal mass floor are archetypes of passive solar design.

The Ballard house's 6.4 kW PV system was planned for future expansion, which would provide power for an electric vehicle.

Rainwater collection reduces the load on storm drains and provides some water storage.

Courtesy Eric Thomas (3)

Ballard Zero Energy House

This single-family home was the first net-zero energy house in Seattle, Washington. Owners Eric Thomas and Alexandra Salmon built it in part as a platform for sharing what they've learned. They help organize public tours of homes in the area, and started a series of free green-building talks that bring in experts to speak at green-built or green-retrofitted homes in the neighborhood. Their blog—zerohouse.wordpress.com—documents the building process of their home, as well as provides information on local green home talks and tours.

Recently married and on a tight budget, Eric and Alexandra demonstrate that net-zero energy building doesn't have to be the domain of the wealthy. By using stock plans, avoiding costly additions (like granite counters), and keeping focused on net-zero energy, they kept building costs to $124 per square foot (including the PV system)—much less than Seattle's average of $200 per square foot.

Absent from their home is a heat recovery ventilator (HRV). In Seattle's mild climate, the amount of heat recovered by an HRV is outweighed by the electricity needed to run it. HRVs are essential to serious efforts to conserve energy

Courtesy Marcus Pearson

Left: Eric and Alexandra make the commitment to net-zero energy.

An air-to-water heat pump sends energy to the hydronic in-floor heating system, seen here before the concrete slab was poured.

Courtesy Eric Thomas (2)

Structural insulated panels make for a quick-to-assemble, well-insulated envelope.

AJ Mallory, Bright House Images

in very cold climates—they just don't make sense in the maritime region of the Pacific Northwest. In this house, adequate air exchange is provided by exhaust fans.

Similarly, in this climate it was cheaper to add more PV capacity to heat water electrically with a heat pump than to add a SHW system. And the extra room on the roof may one day be used to PV-power an electric car.

Even with 100% electric heat (no natural gas, wood, or other fuels used), the grid-tied PV system is producing surplus energy.

Vital Statistics

Name/owner	Eric Thomas & Alexandra Salmon
Contractor	TC Legend Homes, Bellingham, WA
Designer	Zero-Energy Plans, LLC (zero-energyplans.com)
System installers	Sunergy Systems, Seattle, WA
Occupied date	September 2011
Location	Seattle, WA
Total cost: Systems & house	$237,000
Square footage	1,915

Building

Orientation	South-facing
Walls	$6\frac{1}{2}$ in. thick SIPs, R-26, including siding & drywall
Ceiling or roof	$10\frac{1}{4}$ in. SIPs, R-42, including roofing & drywall
Floor	Dark-stained concrete slab, closed-cell foam underneath, R-20; R-10 vertical rigid insulation to perimeter footing
Windows	Vinyltek vinyl frame, triple-pane; U-factors from 0.15 to 0.20
Other contributions to passive solar design	Roof eaves let in winter sun & provide summer shade

Energy

Annual energy consumption (kWh)	6,064
Annual energy production (kWh)	6,778
Energy modeling software	Design: WSU Component Performance Worksheet, then REM/Rate (HERS rating)
Renewable electricity	Grid-tied PV system
Rated power (kW)	6.4
Heating degree days	4,615
Cooling degree days	35
Cooling system	Exhaust & ceiling fans
Heating system	Air-to-water heat pump; Unico 3-ton electric UniChiller
Solar hot water	None
Water heating	100°F preheating with air-to-water heat pump; electric to 120°F
Lighting	LED & compact fluorescent
Additional features that help achieve net-zero energy	Passive solar; low-flow showerheads; efficient appliances; super air sealing (exceeded Passivhaus standards))

Bonus

Green transportation	Car-free household; close to public transportation & shopping; stacking bike rack
Other green features	Rain garden, reclaimed fir floors, recycled fixtures, zero-VOC paint, low-waste engineering, clothesline, room for additional PV modules to power an electric car 5,000+ miles per year

Two of the subarrays of this 7.6 kW PV system do double-duty—providing renewable electricity and shading windows.

Heath Net Zero

Bob Heath's home is another net-zero energy home located in the Belgravia area of Edmonton, Alberta, Canada. This house is a direct result of the Canada Mortgage and Housing Corporation's EQuilibrium Sustainable Housing Demonstration Initiative. Habitat Studio & Workshop (HS&W; habitat-studio.com)—the Heath home's contractor—was one of 12 selected by CMHC to build energy-efficient demonstration houses.

Bob's home, the third net-zero energy house built by HS&W, takes advantage of the main lesson learned from the first two houses—keep it simple. It has no solar thermal system—a 30-gallon electric hot water tank provides domestic water heating. Electric baseboard heaters provide backup space heating. A ground-source heat pump was rejected as too expensive for the small amount of space heating required.

Adjustable PV awnings optimize electricity production and control solar heat gain simultaneously.

Large south-facing windows admit an abundance of natural light, significantly reducing or even eliminating the need to rely on electrical lighting during the day.

Courtesy Bob Heath (6)

Vital Statistics

Name/owner	Bob Heath
Contractor	Peter Amerongen, Habitat Studio & Workshop
Designer	Owner & contractor
System installers	Owner & contractor
Occupied date	November 2011
Location	Edmonton, Alberta, Canada
Total cost: Systems & house	$550,000
Square footage	1,900

Building

Orientation	South-facing
Walls	Double 2-by-4 stud wall, 16 in. thick; cellufibre insulation, R-56
Ceiling or roof	26 in. of cellufibre; R-90
Floor	Basement slab: 5 in. of polystyrene underneath, R-20; thermal mass: $2\frac{1}{2}$ in. thick concrete floors
Windows	Fiberglass frame, triple-pane; south windows (12% of floor area): SHGC = 0.6, U-factor = 0.2; others: SHGC = 0.37, U-factor = 0.15

Energy

Annual energy consumption (kWh)	9,000
Annual energy production (kWh)	9,500
Energy modeling software	Building: HOT2000
Renewable electricity	Grid-tied PV system, on adjustable awning
Rated power (kW)	7.6
Heating degree days (F)	9,382
Cooling degree days (F)	104
Cooling system	None
Heating system	Electric baseboard; 8 kW total
Solar hot water	None
Water heating	Electric tank in R-36 insulated box to reduce standby losses by 75%
Lighting	LED & compact fluorescent
Additional features that help achieve net-zero energy	Energy-efficient appliances, including an induction range

Bonus

Green transportation	$\frac{1}{2}$ block from light-rail transit station; have small vehicle, but walk & cycle extensively
Other green features	Roof rainwater catchment for flush toilets

An unusual feature of the house is the adjustable awnings on which 24 of the 36 PV modules are installed. The awnings are adjusted in the summer to completely shade the south-facing windows. This also orients the PV modules more perpendicular to the sun. In winter, the awnings are readjusted to allow the low-angled winter sun to enter the windows. This also puts the modules at a more favorable orientation to the low-angled winter sun and facilitates snow-shedding. These seasonal tilt adjustments yield a 15% higher energy production. The awning design won 2011 Product of the Year at the Net-Zero Energy Home Coalition awards.

Once filled with cellulose, these 16-inch-thick double-stud walls will provide an R-56 insulation value.

One of two grid-tied inverters, which process PV power and send excess energy to the utility grid.

A standard tank-style electric water heater is housed in its own insulated closet to reduce standby heat loss.

Johnson Residence

Although this Nashville, Tennessee, all-electric home does not "officially" qualify as net-zero energy, homeowners Steve Johnson and his family show a *financial* surplus on their utility bill at the end of the year. The grid-tied PV system was designed with net-billing in mind, so that the annual cost of their energy zeroes out each year. Under TVA's Generation Partners program, the system generates surplus credit ($480 for 2011). Last year, the Johnsons bought an electric Nissan Leaf, and now they are saving an additional $1,750 on gasoline while recharging the Leaf with solar electricity.

A 6.9 kW PV system provides enough electricity for the house and electric car.

The house's grid-tied inverter.

Courtesy Steve Johnson (7)

In addition to the home's grid-tied PV system, the Johnsons use PV technology in other places: on a golf cart (690 W); on their barn (510 W off-grid system); and for a solar-pumped fish pond. A 20-watt PV module powers LED trail lights. They also use a 30-year-old Elec-Trak lawn tractor and employ the simple technology of two 10-watt solar attic fans to help keep the attic (and, therefore, the home) cool.

Vital Statistics

Name/owner	Steve Johnson
Contractor	LightWave Solar
Designer	Steve Johnson
System installers	LightWave Solar
Occupied date	June 1990
Location	Nashville, TN
Total cost: Systems & house	$300,000
Square footage	3,000

Building

Orientation	South-facing
Walls	2 by 6 in. exterior studs, R-19
Ceiling or roof	Blown-in cellulose, R-38
Floor	Power-vented crawl space with 10-mil vapor barrier; joists & floor are sealed with spray foam; insulated, stained concrete slab in sun room
Windows	Large, south-facing (but original 1986 double-pane units); large clerestory
Contributions to passive solar design	Two-story, 12 ft. wide stone fireplace for winter heat retention; windows shaded by eave overhang & solar shades

Energy

Annual energy consumption (kWh)	16,000
Annual energy production (kWh)	9,157 $400 net; feed-in tariff incentive
Energy modeling software	None, designed to cover 100% of billed energy costs
Renewable electricity	Grid-tied PV system
Rated power (kW)	6.9
Heating degree days	3,729
Cooling degree days	1,616
Cooling system	Two ground-source heat pumps; 150 ft. vertical bores
Heating system	WaterFurnace Envision heat pump; central heating with variable-speed fans; wood heater with thermostatically controlled blower
Solar hot water	None
Water heating	Heat pump with electric tank
Lighting	Compact fluorescent
Additional features that help achieve net-zero energy	Surplus is financial due to billing incentives; other RE systems on site

Bonus

Green transportation	Nissan Leaf EV, with home charging station; Hybrid-electric Toyota Prius; golf cart & an Elec-Trak electric tractor/mower
Other green features	Rain barrels, composting, clothesline

A stand-alone (off-grid) PV system provides electricity for the horse barn.

The large stone hearth provides thermal mass, absorbing passive solar gain and storing heat from the wood stove.

The house's ground-source heat pump uses PV electricity to gather heat from the earth.

Steve Johnson charges his family's Nissan Leaf with electricity from the grid-tied PV system.

AJ Mallory/Bright House Images

In all of the houses profiled, one or more grid-tied inverters bank excess solar electricity on the grid, with a goal of yearly net-zero (or better).

Courtesy Steve Johnson

Marketable Pricing

In the words of the U.S. Department of Energy (DOE), "marketable zero energy homes"—the kind of zero energy homes that the average American home buyer could shop for on Sunday outings as they would for any other home—were needed. It became the job of DOE's Building America program, established in 1995, to make that idea a reality by 2020 and there were soon a few concrete signs. Within five to 10 years, a number of private homes that looked much like any other, but that were far more energy efficient and that had solar installations on their roofs, were built under the program. By the end of the first decade of the 21st century, the various initiatives appeared to be having some impact. Builders scattered about the country began showing an interest in developing the kind of zero energy-rated production homes that might serve as models for large-scale development.

The challenge of developing a zero energy home at the same cost as a conventional house remains and, in fact, has become even more challenging. The world's love of all things that run on electricity has only grown with time. In the first half of electricity's first century in American homes, lighting, radios, and refrigerators were the only significant users. In the post-war era, there has been an explosion of electric appliances and gadgetry. Televisions, clothes washers and dryers, dishwashers, air-conditioning, ranges, microwaves, computers, video game sets, DVD players, cell phones, and innumerable electric gadgets, including electric blankets, toothbrushes, hair dryers, can openers, exercise equipment, chargers, iPods, and e-books are fixtures in the homes of developed nations. Many are always on, sucking "phantom" energy as if through a straw.

Energy Growth

It's no wonder then that residential electricity use had grown from 67 billion kilowatt-hours annually in 1949 to 1,379 billion kilowatt-hours annually in 2008, according to the Energy Information Administration (EIA), far outstripping the growth of the population. (That increase is virtually the same for commercial electricity consumption.) In recent decades, the rate of growth has slowed considerably, but the outlook for cutting back on our energy use isn't encouraging. Whatever timelines governments may impose, the EIA doesn't see any reduction in residential energy use—nor in commercial, transportation, or industrial energy use—out to 2035. Still, that doesn't mean there can't be a dramatic drop in residential energy use.

Evidence suggests that incentives are an important engine for change. Solar electric use, for example, is highest in those states that have incentives and lowest in those that don't. Six of the top 10 solar markets listed by the Interstate Renewable Energy Council have among the best financial incentives, including No. 1 California, which also has abundant sunshine. Out of the remaining top nine markets, four are western states with plenty of the latter and space for utilities to develop large-scale solar arrays.

Lew Pratsch, a former zero energy homes project manager in the Building America program, thinks it's just a matter of moving enough money around. "If you increase the cost of utilities, then used these revenues to provide financial incentives so that homeowners could see it, then it would work," he says. In short, the cost-effectiveness of efficiency and solar production would be obvious and irresistible should the government wield financial carrots and sticks.

Yet, even if zero energy homes remain a major challenge for large-scale development, they will increasingly become the standard by which housing is measured in the developed world. It's a standard whose meaning is clear virtually everywhere. There's no living up to the spirit of a "green," "efficient," "sustainable," or "eco-friendly" home, since there's no one standard or benchmark for any of these. Builders toss "green" around with impunity for adding a few good features, like Energy Star appliances, that modestly improve a home's efficiency.

But as ideas travel around the world, zero energy homes will become increasingly accessible to builders and homeowners committed to developing and living in one. In fact, with the passage of time they will be proven to be cheaper than traditional homes. That's because owners who stay in them over the length of a typical mortgage will get a return on their investment through energy savings far greater than with any other housing.

At this stage in the history of zero energy, prospective developers are pioneers. Although there are a handful of courses and programs available, for the most part, builders will be self-taught and home buyers will have to take on the role of general contractor. This in itself is not an unusual role for homebuyers to be in. Enough information is available so that there need be no mystery to developing a house that is extremely efficient and produces as much energy as needed at a price middle-class buyers can afford. Production information, builders, and even designs are a click away. Attics loaded with insulation are readily obtained. Low-flow plumbing fixtures' time has come. The advantages of buying the most efficient type of mass-produced refrigerator should be indisputable. More than a few tasks should be routine, cost effective, and supremely satisfying. It will take some adjustments. Size will likely have to be scaled back.

Compromises in layouts may be needed, though moving exposure to sunlight up the wish list should be easy to accept. Behavior may also need to be modified. The neighbors will probably have more electronic gadgetry. Zero energy will need to be seen as "cool"—the way giving up smoking became a goal worthy of the effort. This will come, many behavioral scientists and economists think, when enough Joneses live in zero energy homes and many others have to strive to keep up with them.

Not that the homeowner or buyer has to go all the way all at once—or ever. While the aim is to hit zero, anyone taking on the job can pull up short, or pick and choose what they want to do knowing that no more than a handful of builders have even gotten halfway there. Given the low risk of failing to beat the pack, there's no better place to start than the beginning with nothing, or rather zero, to lose.

Usually, a net-zero energy approach leads to using other resource-saving strategies, too. Here, an integrated handwashing sink drains to the toilet bowl, where the water can be used one more time.

AJ Mallory/Bright House Images

Access

Barry Rehfeld has been a journalist for more than 30 years and is the editor of ZeroEnergyIntelligence.com, where he writes about everything you need to know to build, buy, or renovate a home that produces as much energy as it uses. This article was excerpted with permission from *Home Sweet Zero Energy Home* (2011, New Society Publishers).

Net-Zero Perfor

In the February 2011 article "Heading for Zero—Smart Strategies for Home Design" (*HP141*), I described the design and computer-modeling processes for our passive solar, net-zero energy home. The design followed the German Passivhaus philosophy. Now, after a year of performance data logging, we can see how close the house came to our design goals and modeling.

Year 1

rmance

Story & photos by Jim Riggins

Above: The Riggins family is net-zero energy, ...including their car.

We have two adults and two children in the household. Our home, called Heliospiti (Greek for "sun house"), is an all-electric house of 3,180 square feet, with a slab-on-grade foundation, and is located at an elevation of 7,000 in Monument, Colorado. According to the Western Regional Climate Center (wrcc.dri.edu), this area averages 6,324 heating degree-days and 149 cooling degree-days per year—a heating-dominated climate. The shell consists of R-49 double-stud walls, an R-67 roof, and an R-21 insulated concrete slab main floor for thermal mass.

The Accurate Dorwin windows are triple-pane, argon-filled. On the south side, we specified windows with a high solar heat gain and low U-factor; north windows have a very low U-factor; and there are no windows on the east or west sides. The house is oriented with its long axis east–west to maximize solar gain on the south face. To take the house from simply being a high-efficiency passive home to a net-zero energy home, we installed a 4.5-kilowatt grid-tied photovoltaic (PV) system and a solar hot water (SHW) system with three 40-square-foot collectors.

The passive solar design meets all of our space-heating needs, using a 4-inch-thick polished concrete floor and 1 1/4-inch-thick gypsum walls as the primary thermal mass. A passive solar wall based on "Build a Solar Heater…for $350" (*HP109*) heats the thermally isolated wood shop and garage. A single Mitsubishi Mr. Slim variable-compression minisplit air-source heat pump provides backup space heating. An UltimateAir RecoupAerator energy recovery ventilator (ERV) provides balanced, efficient ventilation. The incoming air for the ERV is passively preheated by a 100-foot-long, 10-foot-deep Rehau earth tube.

Heliospiti Design Goals

- Produce as much (or more) total energy than is consumed over the course of a year.
- Reduce the cooling loads to zero and the heating consumption to less than 10 million Btu per year, through passive means.
- Minimize electricity consumption by using efficient appliances, lighting, and well pump, and by eliminating phantom loads.
- Maintain very high indoor air quality.
- Minimize our environmental impact through sustainable construction practices and building materials.
- Build a home that showcases cost-effective, ultra-energy-efficient design and construction techniques for the local community.
- Produce enough extra electricity to power an electric vehicle.

A solar hot-air collector, built from plans in ***Home Power*** **(*HP109*), heats the garage space passively.**

Overall Performance

Our home's energy performance is monitored through a variety of devices. Mountain View Electric Association, our electric utility, provides a net meter that displays the home's net energy consumption (or production). Internet-based software from Enphase Energy provides detailed production data for individual PV modules. I installed a four-channel Onset Hobo data logger to track the temperatures of outdoor and indoor air, the concrete slab, and the earth tube air as it enters the house. Internet-based software from Nissan tracks the daily and total recharging energy required for our Leaf electric vehicle (EV).

So how did the house perform overall? For the 314 days before the EV's first recharge, the house produced an excess of 2,981 kilowatt-hours (kWh), averaging 9.5 kWh excess per day. The large surplus was intentional—our long-range goal was to produce enough additional electricity to charge an EV and still remain net-zero. While it is premature to say if we met that goal, the initial numbers look promising. During its first 61 days, the Leaf consumed an average of 6 kWh per day. When subtracted from our average excess production, this still resulted in a surplus of 3.5 kWh per day. So far, our goal of net-zero was exceeded, even including EV charging.

Air Tightness

The physics behind modern building science clearly shows the large impact of building tightness on energy efficiency. This has led to the extremely low air leakage allowance by the Passive House Institute. Through meticulous attention to sealing during construction, our house tested at 0.40 air changes per hour at 50 Pascals pressure difference between the inside and outside (ACH50)—33% tighter than the 0.60 ACH50 Passive House limit. And with an effective leakage area (ELA) of 15.4 square inches, it was 20% better than the ELA design goal of 19.3 square inches that we had initially set for construction.

Using closed-cell spray foam (usually intended mainly for its insulating properties) on the inside face of all wall and roof sheathing also played a big part in the home's airtightness. Every wall bottom plate was sealed with a double bead of caulk and a thick rubberized sealer was used between the sill plates and concrete. Every door and window rough opening, and every electrical and plumbing penetration, was sealed with spray foam or caulk. After a 3-inch-thick layer of spray

Low U-factor, high SHGC windows on the south side admit the sun's energy, which is absorbed by the concrete slab floor.

The wood heater has proven more useful for setting ambiance than as necessary for auxiliary heating.

Closed-cell spray-on polyurethane foam was used on all inside sheathing faces for an airtight, high R-value insulation.

A water-to-air heat exchanger connected to the earth tube outlet isn't needed, and was never connected to the solar thermal system.

From the earth tube, air passes through an ERV, which transfers energy (and humidity) from outgoing to incoming air.

foam was applied to the walls, and before installing the 9 inches of blown fiberglass and the drywall, I conducted a blower door test and used a thermal camera to locate and repair any air leaks. Finally, other than the energy recovery ventilator, there are no fans that vent to the outside—no clothes dryer ducting, or range hood or bathroom vents.

Space Heating

The graph on the following page tracks a particularly cold week in December when the highs and lows for the week were below long-term averages. It shows data for outside, inside, earth tube air, and slab temperatures, in two-hour increments.

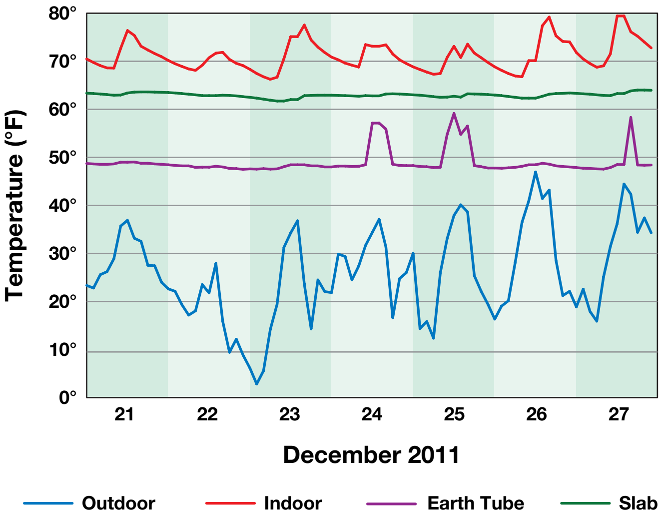
Mechanical Heating. After compensating for the passive solar contribution, Energy-10's predicted annual requirement for mechanical heating was 5,954 kBtu (thousand British thermal units). But we never turned on the minisplit heat pump, and burned only 1.9 cubic feet (0.015 cords) of hardwood molding scraps in a 63% efficient wood heater, which provided 187 kBtu. However, these five one-hour fires were lit for ambiance, not comfort, and we had to open windows to avoid overheating the house.

Earth Tube. Perhaps the most positive surprise is the performance of the 100-foot-long, 8-inch-diameter earth tube, which preheats incoming ERV air in winter and pre-cools the air in summer. This ECOAIR earth tube system has an antimicrobial interior coating, and sealed joints to prevent moisture and radon infiltration.

During design, we had no data on the thermal transfer rate from the ground to the tube air, and the Energy-10 computer model did not include earth tube energy input. So to err on the safe side, I simply ignored the contribution of the earth tube during initial modeling. But the temperature graph shows a fairly significant earth tube contribution. Even with low outside temperatures in the single digits, the incoming tube air maintained a fairly constant 48°F to 49°F. The three

The 100-foot-long earth tube was placed in a 10-foot-deep trench. The earth tube tempers incoming air—cooling it in the summer, and warming it in the winter.

Cold-Weather System Temperatures



temperature spikes on the earth tube air line were due to turning off the ERV and opening some windows to moderate interior temperatures before we installed window coverings. With the ERV turned off, the air in the tube at the temperature sensor begins to rise to interior air temperatures.

Taking one data point in late December, the outside air temperature was 14.8°F, the air temperature in the tube at the house inlet was 48.3°F, and the measured airflow through the 8-inch-diameter tube was 64 cubic feet per minute (cfm). Using the heat delivery rate equation, we estimate the earth tube was producing 2.3 kBtu per hour:

Btu/hr. = △T (°F) × 1.08 (Btu/(hr. × cfm × °F)) × airflow (cfm)

Btu/hr. = 33.5 × 1.08 × 64 = 2,316 Btu/hr. (2.3 kBtu/hr.)

The Energy-10 model predicted a peak heating load of 4.5 kBtu per hour with passive solar gains included. This indicates that, for temperatures in the teens, the earth tube provided approximately 50% of the predicted peak heating load (although the peak load occurs at the design temperature of 5°F).

Another indication of the passive solar contribution to the heating demand was that, with no mechanical backup heating and temperatures as low as -4°F, the coldest interior temperature through the winter was 63°F on two mornings, just before sunrise. By 10 a.m. on those mornings, the temperature was above 68°F.

Solar Hot Water Heat Coil Loop. The original plan was to tap excess heat capacity from the solar hot water storage tank to heat ERV supply air through a water-to-air heat exchanger in the ERV supply duct. We purchased all of the components and installed the heat exchanger, but did not connect it when it became clear that the house was meeting all of its heating load with just passive gain.

Above and right: A minisplit heat exchanger was installed as a backup space heating system, but has never proven necessary.

Space Cooling

Chimney Effect. The Colorado climate provides cool, dry nights through the summer, so we had no trouble meeting 100% of our cooling load through passive means, even with a week of record-high temperatures (in the mid-90s). The house includes a central open staircase that serves as a thermal chimney. At night, we open three small lower-floor windows on the north and south faces, and two windows at the highest point at the top of the stairwell. The convective chimney effect, plus north-south prevailing winds, pull cool air across the concrete floor and exhaust hot air through the upper windows. If we properly time closing the windows in the morning, the house does not get hotter than 76°F, since the thermal mass floor moderates the temperature. On the couple of occasions that we delayed closing the windows until mid-morning, temperatures reached 80°F inside. With the low humidity and the occasional use of an Energy Star-rated ceiling fan, however, even these temperatures feel very comfortable.

Energy Recovery Ventilator. The RecoupAerator ERV has an "econo-cool" mode that shuts off energy transfer between incoming and exhaust air. Combined with the earth tube inlet, the ERV supplied comfortable, cool air during days that were too hot to ventilate the home via the windows.

Overhangs. Roof overhangs were designed to block most of the high summer sun, but allow maximum heat gain in the winter. We were in the second week of August before the sun started to appear on the windowsills, and into September before the sun reached the concrete floor at midday.

The home's "solar side": Passive space heating, solar water heating, solar electricity, solar clothes drying, and solar cooking (with a portable solar oven). Garage air heater not shown.

Domestic Hot Water

The goal of producing 100% of our hot water demand year-round with SHW was met. The backup electric element has not been used. The 120-gallon Vaughn storage tank with three SunEarth EC-40 collectors kept the water at an average temperature of 165°F in the winter, peaking at 170°+ in January and February. The average summer temperature was between 140°F and 150°F due to collector high-temperature limits. The lowest temperature at the top of the tank was 128°F during a rare three-day period of cloud cover and fog.

The SHW system is an unpressurized, indirect drainback design with distilled water as the heat-transfer fluid. Three roof-mounted (39° pitch) SunEarth collectors form the heart of the system. A 15-gallon drainback tank sits in a conditioned attic, 10 feet below the top of the collectors. A Vaughn 120-gallon, dual-heat exchanger tank provides storage and backup electric water heating. A Caleffi iSolar Plus controls the system.

Hot water production is only one side of the efficiency equation—distribution and demand is the other. Every inch of hot water line in the house is insulated with 3/8-inch-thick foam pipe insulation, and we installed high-efficiency water appliances and plumbing fixtures (see "Water Conservation" sidebar).

Water Conservation

We felt a moral imperative to avoid contributing to diminishing water supplies in our high desert region. And when you have to pump, it means that water equals energy—so minimizing consumption became a big part of our net-zero plan. We use:

Zero outdoor irrigation. Landscaping incorporates native, drought-tolerant grasses and trees. We harvest all the rainwater from our roof by diverting it into two 9-inch-deep rain gardens.

WaterSense fixtures. All shower heads and faucets are U.S. EPA WaterSense certified.

Ultra low-flow toilets. The Coroma toilets are WaterSense-certified dual-flush units with 0.8 and 1.2 gallons per flush. An integrated hand-washing sink sends hand-wash "greywater" into the tank for the next flush.

Highest-tier Energy Star dishwasher and washing machine. These appliances consume 20% to 30% less water than standard appliances. Our Bosch clothes dryer is a condensing style that does not vent to the outside but rather condenses water from the clothes. We collect this water for indoor plants.

Hot water recirculation. We installed an ACT D'Mand whole-house hot water recirculation system and a dedicated hot water loop to and from the solar storage tank. When hot water is needed for showers or dishwashing, a push-button starts the circulation pump, which continues to circulate until the water in the return loop reaches 120°F. This process takes two to three minutes and prevents water from running down the drain while waiting for it to warm up.

Thermal Tech Specs

Overview

System type: Indirect, unpressurized drainback solar hot water

Location: Monument, Colorado

Solar resource: 5.48 average daily peak sun-hours

Production: Rated 2,836 kBtu per month (average)

Climate: SRCC Category D, Cool Climate

Percentage of hot water produced annually: 100%

Equipment

Collectors: Three SunEarth, EC-40, 40.9 ft.^{2}

Collector installation: Roof-mounted with 190° orientation; 39.8° tilt

Heat-transfer fluid: Distilled water

Drainback tank: Solar Hot S-T-15SSDB, 15 gal.

Circulation pump: Taco 008-SF6

Pump controller: Caleffi iSolar Plus

Storage

Tank: Vaughn, S120SRW202TB45, 120 gal., dual heat exchanger

Heat exchangers: Two Vaughn copper, removable, submerged finned exchangers

Backup DHW: 4,500 W heating element in solar storage tank

System Performance Metering

Thermometer: Four Winters T174-SW, plus two thermocouple connections to Caleffi controller

Flow meter: Blue-White Industries, F-450

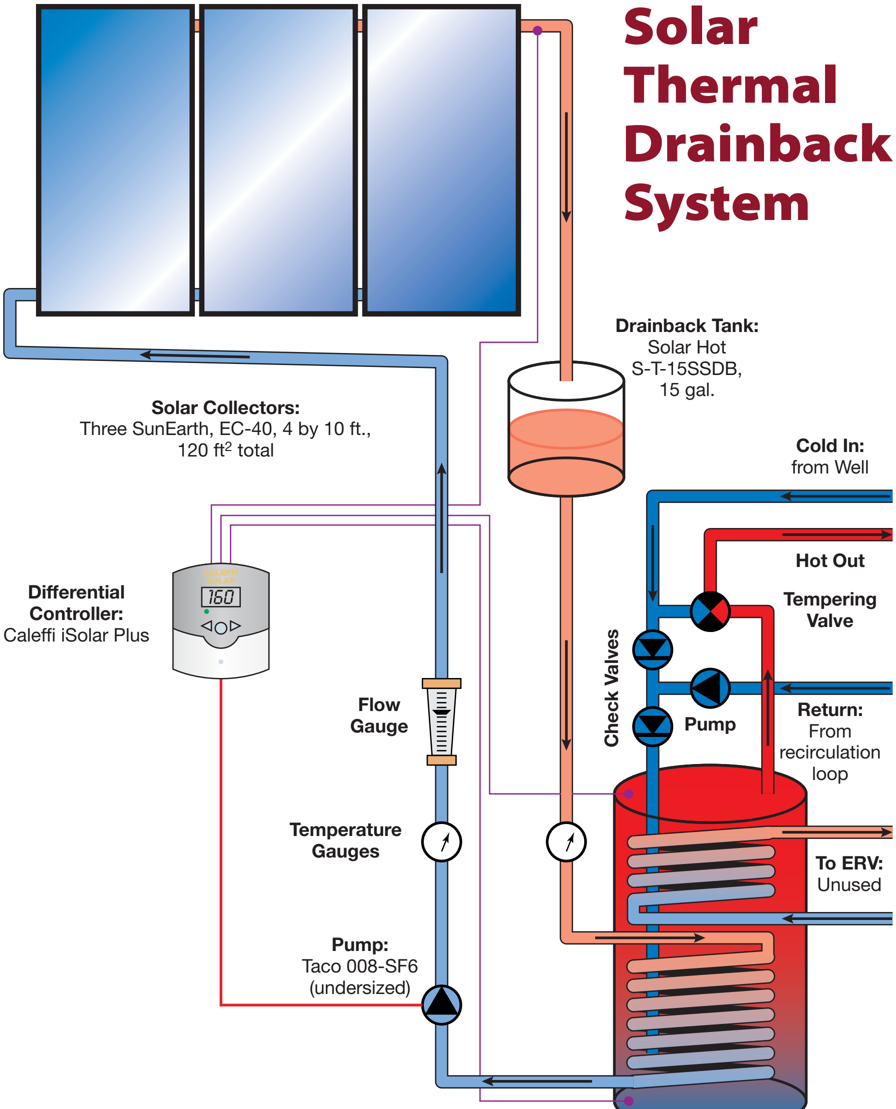
System Cost

Initial Cost: $12,440

Less Incentives, Rebates & Tax Credits: $3,732 (federal tax credit); $3,000 ("Recharge Colorado" rebate)

Final installed cost: $5,708

Solar Thermal Drainback System



Above: A 15-gallon drainback tank sits in the conditioned attic space.

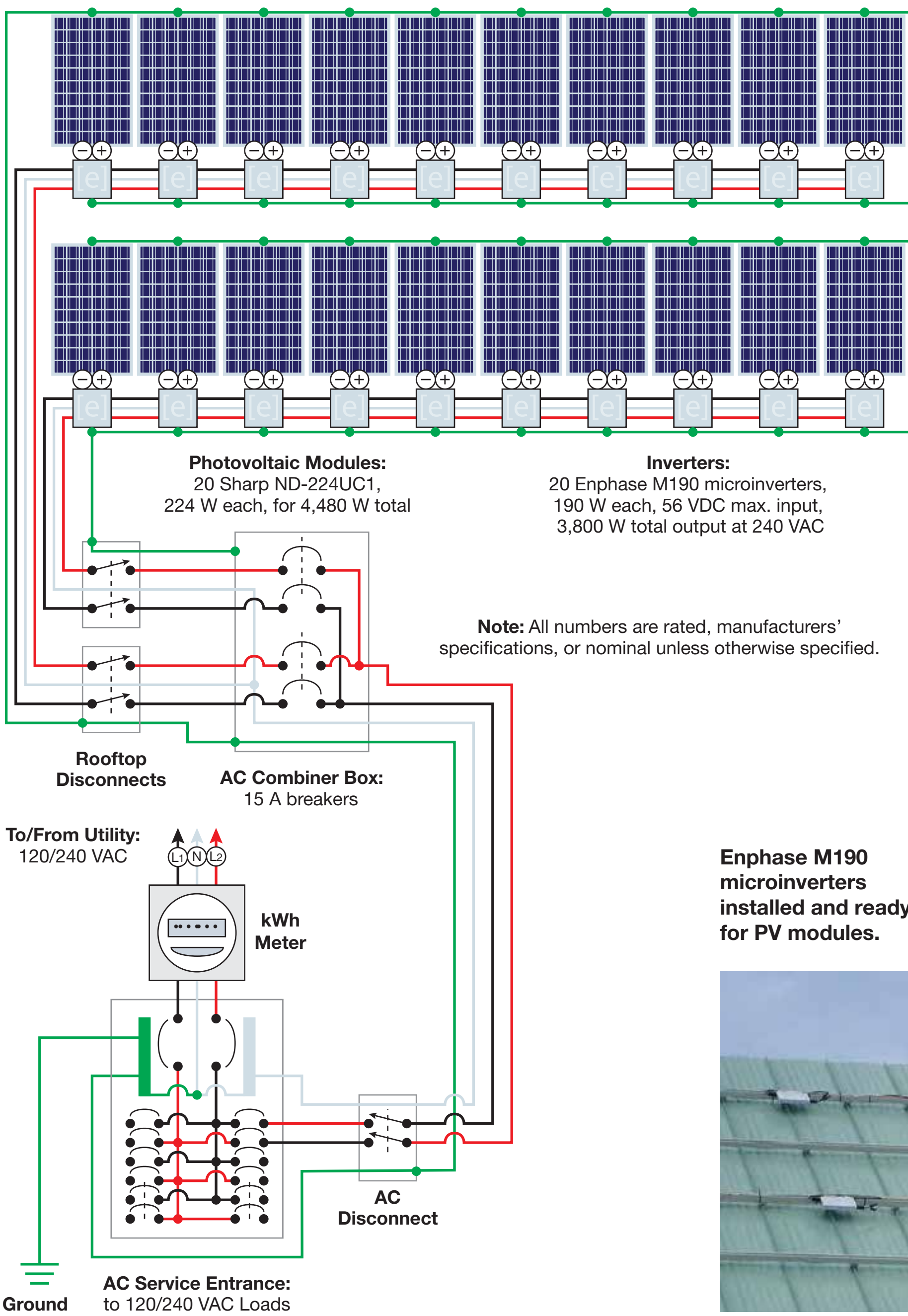
Right: A 120-gallon, dual heat-exchanger storage tank with a backup electrical element.

Solar Electricity

The grid-tied PV system has 20 Sharp 224-watt modules, with each connected to an Enphase 190-watt microinverter. Total rated output, given the nominal limits (see below) of the microinverters, is 3.8 kW. We mounted the modules on our standing-seam metal roof using nonpenetrating SolarMount S5! clamps to secure the rails.

A key element in the design process was to estimate the system's energy production. The graph on the following page shows the system's month-by-month predicted production (generated by NREL's PVWatts program) and actual production to date. I used a 0.82 total DC-to-AC derate factor instead of the default 0.77 derate, due to the better efficiency of the microinverters compared to a central inverter. With the exception of October 2011, the actual energy production exceeded the predicted values. October's lower production values were due to a failed roof-mounted disconnect switch, which took out 10 modules' production over 10 days.

Grid-Tied Photovoltaic System



Enphase M190 microinverters installed and ready for PV modules.

Photovoltaic Tech Specs

Overview

System type: Batteryless, grid-tied solar-electric

Location: Monument, Colorado

Solar resource: 5.48 average daily peak sun-hours

Record low temperature: -27°F

Average high temperature: 82°F

Average monthly production: 632 AC kWh (Measured)

Utility electricity offset annually: 118%

PV System Components

Modules: 20 Sharp ND-224UC1, 224 W STC, 29.3 Vmp, 7.66 Imp, 36.6 Voc, 8.33 Isc

Array: Two, 10-module parallel strings, 4,480 W STC total, 240 VAC, 16 A (AC) nominal output

Array installation: S5! metal roof clamps and Prosolar rails on south-facing roof, 39.8° tilt

Inverters: 20 Enphase M190 microinverters, 190 W rated output, 56 VDC maximum input, 22–40 VDC MPPT operating range, 240 VAC output

System performance metering: Enphase Envoy Communications Gateway plus Enphase Enlighten Web-based software

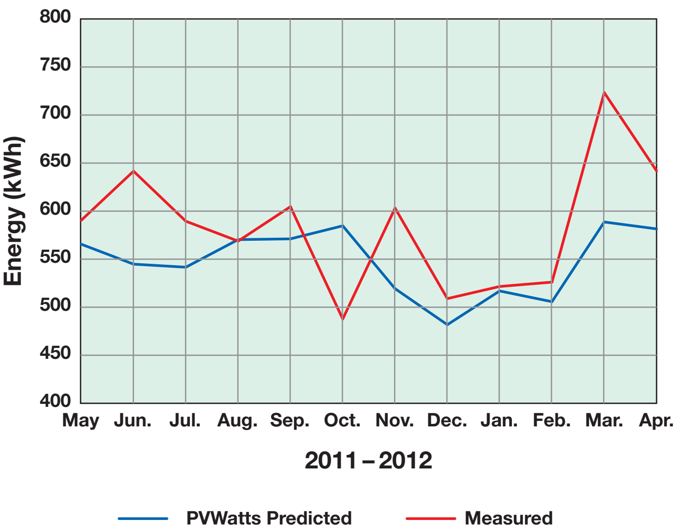
System Costs

Initial Cost: $23,805

Less Incentives, Rebates & Tax Credits: $7,141 (federal tax credit); $4,500 ("Recharge Colorado" rebate)

Final installed cost: $12,163

PV Production: Predicted & Actual



The Nissan Leaf's average daily electricity consumption is falling within the available excess PV production.

Electrical Consumption

The table below shows the house's predicted and actual electrical usage. As part of the design, we measured appliance energy consumption using a Watts Up? Pro energy meter, used Energy Star specifications for the appliances we expected to install, and estimated lighting consumption based on the number of fixtures and our expected usage. We estimated consumption for the well pump, solar hot water circulation pump, and the ERV based on component specifications and national consumption averages.

After eliminating backup space and water heating, the remaining actual electrical load was close to our predictions. However, some specific estimates were off by quite a bit. We underestimated SHW circulation pump consumption by 183 kWh per year. We overestimated the well pump consumption, having based it on a water consumption of 120 gallons per day—our actual average is about 36 gallons per day. We also overestimated the electric clothes dryer's consumption because we are using a "solar dryer" (outdoor clothesline) much more than anticipated. Our total electrical consumption, excluding the EV, averages 338 kWh per month. The EV has raised this average to 521 kWh per month, which is still much less than the average U.S. home's 920 kWh per month.

Predicted vs. Actual Annual Electrical Consumption

	Annual Energy (kWh)	
Load	Predicted	Actual
Backup space heating	1,550	0
Backup water heating	680	0
Appliances, lighting, pumps	4,030	4,053
Total Household	6,260	4,053
Electric Vehicle	10,512	2,190
Grand Total	16,772	6,243

EV Energy

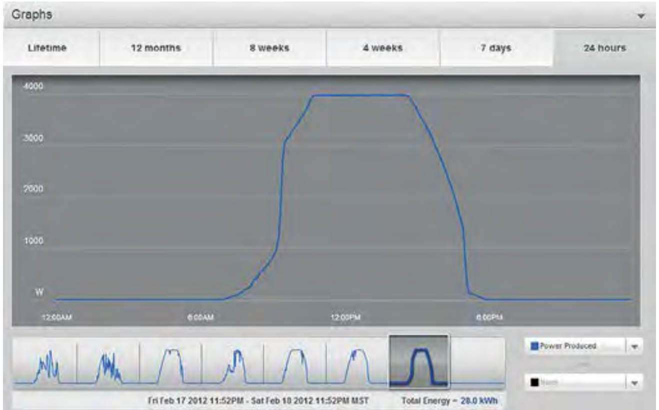
The energy our EV would consume was the most critical, yet most difficult, amount to predict. It would be the household's largest energy consumer. We did not know which vehicle we would purchase or what our driving patterns would be, and there was precious little manufacturer data on recharging consumption. Our prediction was based on published Chevy Volt charger specs and an assumption that the EV would require a full charge every night. Charging consumption from empty to full is higher for our Nissan Leaf compared to the Volt specifications, but it is consuming less than predicted, since full discharges are rare.

During its first 61 days with us, the Leaf consumed 366 kWh for an average of 6 kWh per day. We are eager to see how this will play out over the course of a year. Of course, with only two months of EV data under our belts, it is difficult at this point to make a long-term consumption prediction.

Challenges

Solar Hot Water. Even though the system met all of our hot water demand, the Taco pump is undersized. The low flow rate causes the collector to overheat, which in turn shuts down the system daily, except during cloudy weather. The other sign that the pump is undersized is the 55°F temperature difference between the collector inlet and outlet. Ideally, there would be only a 20°F difference. The installed pump should be able to provide a 6 gallon per minute (gpm) flow rate (2 gpm per collector) with the 10-foot head from the drainback tank to the top of the collector, but only provides 2.5 gpm. I suspect that the 12 or so 90° elbows are introducing excessive pipe friction, which is creating the 15-foot effective head—and low flow.

However, provided that the system continues to meet 100% of our demand, and we do not need the SHW system for backup space heating, it's unlikely we will replace the pump, since the pump that meets the 15-foot head requirement uses twice as much energy as the current pump.



The Enphase Envoy online metering shows an example of PV output clipping from the microinverters' 199-watt limit.

Solar Electricity. For 10 days in October and five in January, we lost 10 modules' worth of PV production (about 11.0 and 8.8 kWh per day, respectively). The fault was finally traced to a failed 240 VAC rooftop disconnect. After switching to an air-conditioner-type heavy-duty disconnect, the problem was eliminated.

There was another inverter-related problem we were aware of during the system's design. At the time of installation, the Enphase M210 microinverter was not available, so we used the M190s that Enphase specified for our Sharp 224-watt modules. These inverters (rated at 190 watts) have a maximum output power of 199 watts, which means that, under ideal conditions, module output would be clipped at 199 watts rather than 224 watts. Our high elevation and low temperatures may be contributing to more clipping than expected—it happens three to four days per week.

Finally, a minor issue is snowfall that sticks to the modules longer than anticipated. Even with their 39° tilt, the modules don't shed snow for at least two days if snowfall is greater than 2 inches—and they are too high to be swept. One advantage of microinverters, however, is that as the snow melts unevenly, individual modules start producing electricity rather than an entire string remaining shut down until all of the snow melts.

Space Heating. In hindsight, our 10 kBtu per hour Mitsubishi minisplit heat pump was probably overkill as backup—although staying warm was a key design area where we did not want to come up short. Any future backup heating needs (they were zero for this first year) could have been handled by a small 1,500 W to 2,000 W electric heating element in the supply trunk of the ERV, and cost much less.

Conclusions

Energy design by computer modeling is only an approximation and can never completely account for variations in occupant behavior and lifestyle. Still, our Energy-10 modeling predictions came very close to reality. There is still much to be learned as we monitor the house's performance over the long term. We can safely say, however, that we demonstrated that the Passivhaus philosophy works well, and that builders

Approaching Sustainability

Construction recycling. We did not meet our goal of a "zero-waste" job site, but came very close. All metal, plastic, glass, cardboard, and paper waste was recycled. All untreated lumber and drywall scraps (the largest element by volume) were ground up and plowed into the soil. Ceramic tile scraps were broken and used as aggregate in the earthen rain garden dams. What ended up in the landfill was treated lumber and plywood scraps, Styrofoam packing, and some cork flooring scraps.

Recycled content. We attempted to use recycled or reused content throughout the house. The bathroom and sunroom tile floors were built from Habitat for Humanity ReStore recycled tile. The wood heater's granite hearth and backdrop are a mosaic of counter scraps diverted from the landfill through an afternoon of Dumpster diving. The kitchen and bathroom concrete countertops used 650 pounds of recycled glass bottle pieces. The shop's passive solar heating wall uses perforated aluminum sheets from a local demolition project.

No- or low VOC finishes. Excellent indoor air quality was a crucial requirement, as was the sustainability of materials. To ensure no off-gassing of formaldehyde or volatile organic compounds (VOCs), we built all our own cabinets using solid hardwood and certified "no added formaldehyde" (NAF) plywood. All are finished with water-based dye, shellac, and soy urethane. Interior doors are solid core and NAF-rated. The concrete floor is finished with water-based stain and polyurethane. The cork flooring is solid cork, with no engineered wood core, and attached with a zero-VOC glue. All interior paint and wood dyes are also zero-VOC.

Kitchen and bath countertops used 650 pounds of recycled glass.

Cost Comparison

Our general contractor had very consistent cost data for his conventional homes that were built to the energy code, which made a cost comparison fairly simple: Our house cost 10.1% more to build than a conventional house (after solar tax credits and state incentives, the cost was 7.8% higher than conventional building costs). Excluding the PV and SHW systems, the cost was only 2.2% greater. Also, if you exclude the earth tube, the cost was only 0.7% higher for our efficient, tight, passive-solar house.

This low final cost points out a basic premise of incorporating passive efficiency in new construction: It's more about *how* to build than it is about costly new equipment or products. In some cases—such as incorporating advanced framing techniques—framing labor and material costs are actually lower than with standard framed construction. Caulk and spray foam are extremely cheap compared to the cost of not building a tight house. And some of the highest-rated toilets, showerheads, and faucets cost the same or less than their high-consumption counterparts.

Properly sized window overhangs help prevent summer overheating. A mix of good passive design and high-quality active systems make a net-zero success story.

can achieve tremendous energy-efficiency improvement with just a change in techniques and a modest increase in cost (see "Cost Comparison" sidebar).

Comfort and safety are very important, too. A home like ours is not for a "hands-off" family that insists on the narrow 68°F to 72°F comfort range that Americans have grown accustomed to since the widespread use of air conditioning. A passive solar home requires getting used to slightly wider temperature swings, and requires hands-on participation to occasionally open and close shades and windows to maintain comfort.

We also were pleased that humidity problems did not occur. Because of our dry climate, we purposely used an ERV for ventilation, rather than a heat recovery ventilator, because an ERV also transfers humidity between incoming and exhaust air. This worked extremely well—throughout the winter, the house remained between 25% and 35% relative humidity, the heart of the comfort zone in cold weather.

The challenges of detailed design and frustrations during construction began fading the moment we watched the electric meter run backward—and at the first of many 0 kWh electricity bills—and the first time the outside temperature dipped below 0°F, but we could sit in a 72°F house, with no heater turned on. It has been a fun and worthwhile adventure!

Access

Jim Riggins (info@enersmartenergy.com) is the owner and principal analyst of EnerSmart Energy Solutions (enersmartenergy.com), a Building Performance Institute (BPI) building analyst, EPA WaterSense home inspector, and a Residential Energy Services Network (RESNET) certified home energy rater. Jim and his wife Elise showcased Heliospiti in the 2011 Pikes Peak Tour of Sustainable Buildings to show the benefits of affordable energy-efficient construction to the Monument and Colorado Springs, Colorado, communities.

Products & Companies:

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ACT • gothotwater.com • D'Mand hot water recirculator

Enphase Energy • enphase.com • Microinverters

Habitat for Humanity ReStores • habitat.org/restores • Recycled building materials

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High-Performance Windows

by Stephen Hren

Windows can be called a home's "eyes on the world," but it would be just as accurate to call them a home's "holes into the world." So crucial are natural light and outside views to making a home livable that people once put up with what would otherwise be unthinkable—dedicating large amounts of wall area to openings that allowed in unwanted cold, heat, rain, noise, neighbors' stares, and bugs.

Courtesy Optiwin Windows

Modern high-performance windows—like this triple-pane unit from Optiwin that achieved the German Passivhaus certification—combine excellent sealing, thermal breaks in the frame, and specialized coatings.

Courtesy SeriousWindows

High-tech windows are an integral part of an efficient building envelope, with casings and glazings working with other architectural features to improve building performance.

From literal holes in the wall, Romans began substituting glass to help keep out the unwanted. For the next two thousand years, window technology improved little. While advances were made in how to open and close windows—such as the development of casement and double-hung windows—the barrier between the inside and outside remained a single sheet of glass. Operable windows had their own issue—because they never closed perfectly, air could seep in.

Over the last hundred years, huge strides in building science have been made. Many advances have centered on improvements in insulation—and windows have not been an exception. Now, double-, triple-, and even quadruple-pane windows are available. Reflective coatings that minimize heat transfer are common, and sashes that seal well when the window is closed are standard.

The result is a bewildering array of window options that require explanation. So whether you're settled in an older home that could use an energy-efficiency upgrade or building your passive solar dream home, here's a guide to choosing the best windows for your situation.

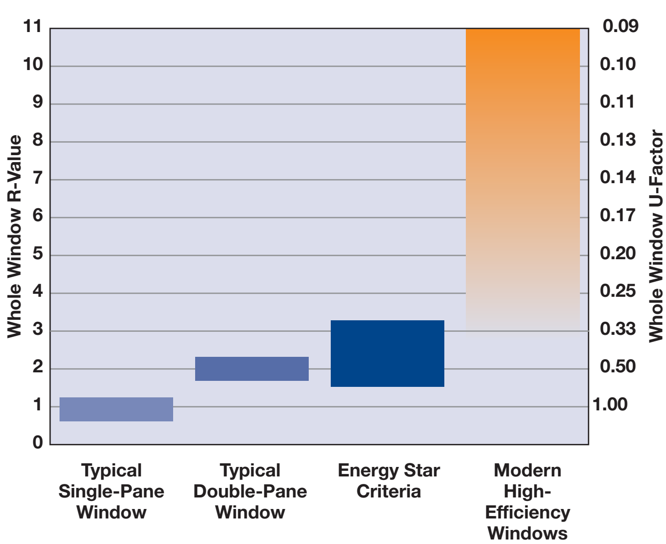
Modern Window Performance

Window energy efficiency is denoted by a U-factor, which indicates the rate of heat transfer. A U-factor is the inverse of R-value—for example, a U-factor of 0.25 equals an R-value of 4. The lower the U-factor, the better. Because windows are complicated and transfer heat by different methods (especially the radiation through the glazing and the draftiness of opening windows), U-factor is more comprehensive than R-value, which indicates resistance to heat flow.

A window's U-factor accounts for the whole window system and how it performs to block the transfer of energy between the interior and exterior. It encompasses the glass's insulating properties, as well as the frame material and leakiness. What it doesn't take into account is how well a unit is installed: poor installation can be a big energy drain (see "Installation Makes a Difference" sidebar).

Higher quality double-pane windows commonly achieve U-factors in the 0.20 to 0.35 range, or about R-5 to R-3. Triple-pane windows typically have U-factors below 0.20, with some top-of-the-line models (typically German brands) coming in as low as 0.10. Not surprisingly, efforts to reduce heat flow often decrease the amount of sun coming through, something measured by the solar heat gain coefficient (SHGC), represented on a scale of 0 to 1—the higher the value, the more sun that comes through. If you're interested in using your window for passive solar heat gain, it can be a challenge to find a highly insulating window that also allows for substantial heat gain, which would correspond to a SHGC of at least 0.50.

New Levels of Performance



Triple glazing provides some of the lowest window U-factors, but frame features affect overall performance, too. Intus Windows' Eforte aluminum- and wood-framed window combines interior aesthetics and exterior durability for excellent efficiency.

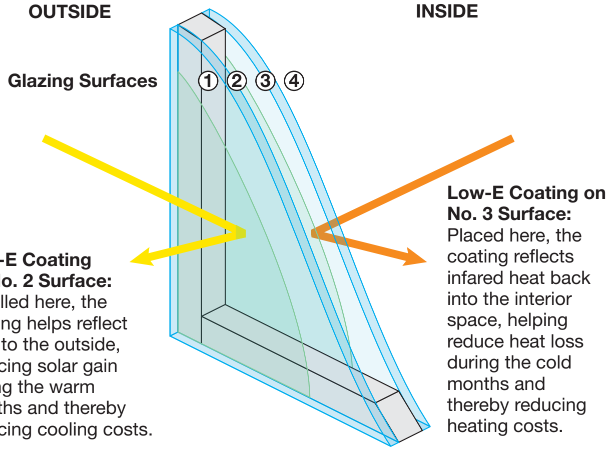

Courtesy SeriousWindows

SeriousWindows' suspended-film technology matches or exceeds the performance of triple-glazed windows, while minimizing weight and cost.

In quality windows, the glazing is sealed and the space between is filled with clear, inert low-conductive gas such as argon and/or krypton, the latter being more insulating, but pricier. The gas between the glazing acts like any trapped air, but these two gases are thicker and move more slowly than air, conducting heat less rapidly.

Window heat loss is most substantial through the glazing. In multi-pane windows, it occurs through convection inside the panes and by radiation, from a warmer pane to a cooler pane. Low-emissivity (low-e) coatings, microscopically thin and transparent layers of metal or a metallic oxide applied to one of the panes, are used to slow radiation between panes—reflecting or absorbing radiated energy. A pyrolytic low-e coating, applied while the glass is still hot, results in a baked-on, "hard" coating that is very scratch-resistant. It is also used in single-pane applications like storm windows. Sputtered low-e coatings are applied in a series of sprays after the glazing has cooled. It is considered a "soft" application and almost always must be on a side of the glazing that faces toward one of the other panes so it does not get scratched. Some companies use a "solar-selective" low-e coating that provides a low solar heat gain coefficient to enhance comfort in warm climates.

Low-E Coatings & Performance



Window Components

The options in modern windows relate to how each component is designed and manufactured. The most familiar part of the window is the sash—the frame that holds the glazing. Sashes often have two and, occasionally, three or four layers of glazing, referred to as double-, triple-, or quadruple-paned windows.

Frames hold the sash in the wall. They can be made of different materials, which vary in their thermal conductivity. Metal window frames, typically aluminum, are great conductors, and generally a poor choice for energy-efficient windows. Metal frames can be improved by having a thermal break within the frame to slow conduction. Wood frames have better thermal performance. They can be challenging to maintain, however, since condensation and rain can cause rot and peeling paint. Vinyl windows are rot-resistant, but need to be insulated to be energy efficient. Fiberglass and composite windows offer low maintenance combined with high strength and good insulating properties, but with additional cost.

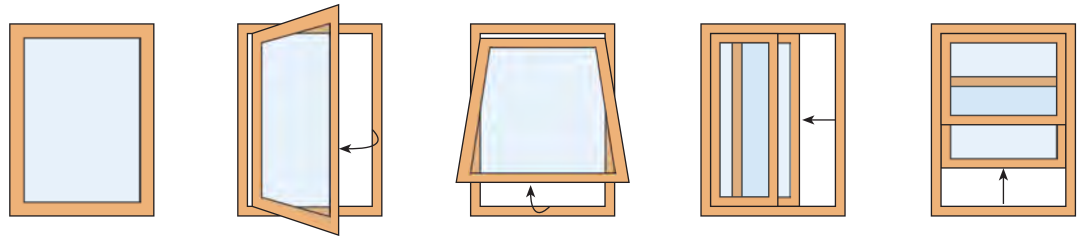
Operating type describes how the sash is opened to allow ventilation. The two most commonly available varieties are double-hung and casement windows. Double-hung windows have two sashes, one at the top and one at the bottom, that slide up and down, with the screen on the outside. Casement windows are hinged on one side and generally crank outward, with a screen on the inside. From an energy efficiency standpoint, casement windows are superior. When open, they allow much more airflow, since the entire area of the sash is open compared to only about half in a sliding window like a double-hung. Casement windows seal better than sliding windows—when they are closed (and locked in place) the entire sash is pulled against the weather stripping. In sliding windows, the sides remain relatively loose. Keep in mind that not all windows need to open, however, and that a fixed window can be less expensive and more energy efficient than an operable window.

Sash/Frame Performance

Material	U-Factor*
Aluminum (no thermal break)	1.9 - 2.2
Aluminum (with thermal break)	1.0
Aluminum-clad wood	0.4 - 0.6
Wood	0.3 - 0.5
Vinyl	0.3 - 0.5
Fiberglass	0.2 - 0.3

*Sash/Frame only

Operation Types



Performance	Fixed	Casement	Awning	Horizontal Slider	Single/Double Hung
Air Seal	Best	Good	Good	Fair	Fair
Ventilation	None	Best	Good	Fair	Fair

Installation Makes a Difference

Installing high-performance windows correctly is critical, since improper installation can create thermal bridges and drafts. To preserve a high-performance window's efficiency in conventional construction, window openings must be framed square and plumb and to the exact dimensions required by the rough opening for each specific window. Otherwise, drafts are a concern, and so is water infiltration. House wraps should be folded out rather than in to keep water from rolling into the house along the head jamb, since some water always finds its way behind siding. Redundancy in flashing is important—the house wrap provides an initial layer of water protection, but additional layers of metal or vinyl flashing do the bulk of the work. Metal flashing can be a thermal bridge, so weaving flashing through the entire rough opening should be avoided. Butyl tape is a must for creating an effective seal. Follow this by caulking before finishing with the window casing and installing siding.

European installation typically involves bringing exterior insulation onto the face of the window frame rather than bumping up against the casing as is typical in American construction. The casing is then applied on top of this extra insulation, allowing for an effective seal that can greatly increase the window's overall U-factor. This is rarely done in the United States (except with some Passive House construction), but is worth examining to see if it might work for your project.

Courtesy SeriousWindows

Other styles of windows are oriented differently but behave in a similar fashion to casement or double-hung. For instance, a slider has two sashes that slide horizontally and performs like a double-hung, and an awning window is hinged at the top but otherwise performs like a casement window. A tilt-turn, which can hinge on either the side or the base, is becoming an increasingly popular style.

Holding up all of those panes of glass in such a small area is not easy, and the first generation of windows mostly accomplished this by using aluminum spacers to hold the glazing in place. But aluminum is a great conductor and this thermal bridge wicked away large amounts of heat, negating much of the benefit of multiple panes. Another problem was condensation resulting from the differences in temperature across the window unit. Spacers made of composite materials or stainless steel, along with thermal breaks in the spacers, have greatly reduced these problems. The latest windows have also made improvements in the seals that lock in the argon or krypton gas between the panes, meaning much greater sash longevity, which previously had been prone to eventual leakage.

Casement windows capture the most air for ventilation when opened and seal tighter than other types of operable windows.

Courtesy SeriousWindows

The NFRC & Energy Star Labels

Don't buy any window that doesn't have a National Fenestration Rating Council (NFRC) label. The NFRC tests windows for performance, measuring five parameters. Access the NFRC's Certified Products Directory at nfrc.org.

Choose windows that have a **U-factor** of 0.35 or less. The lower the number, the better the window will be at keeping heat in.

Visible transmittance (VT) measures how much light is transmitted through a window. Higher numbers mean the windows provide more light. A value below 0.40 means the window will let in little light and should be considered tinted glass.

Condensation resistance (CR) measures how well a window resists condensation. Rated on a scale from 1 to 100, the higher the CR, the better a window performs. CR is also an optional rating to report.

Courtesy SeriousWindows

SHGC measures how well a window blocks solar gain, expressed by a number between 0 and 1. The lower the SHGC, the less solar gain. Generally, choose windows with a low SHGC for east, west, and north windows. If you have a passive solar home, your south-facing glazing should have the highest SHGC numbers possible, while having a low U-factor.

Air leakage (AL) measures the infiltration through the window. The lower the AL, the tighter a unit is. New windows should have an air leakage rating of less than 0.3. AL is an optional rating, and manufacturers don't always include it on their labels.

Unfortunately, the **Energy Star** logo is not very useful for making buying decisions when it comes to windows. It makes general assumptions about windows without regard to house orientation. For instance, it allows inefficient windows to qualify for southern states with high cooling loads (windows only have to have a U-factor less than 0.6) and doesn't specify high SHGCs for the south-facing windows of passive solar homes. The right window choice may not meet Energy Star criteria because it has too high of a SHGC, for example. So stick with the NFRC label when you're window shopping.

Windows for Passive Solar Homes

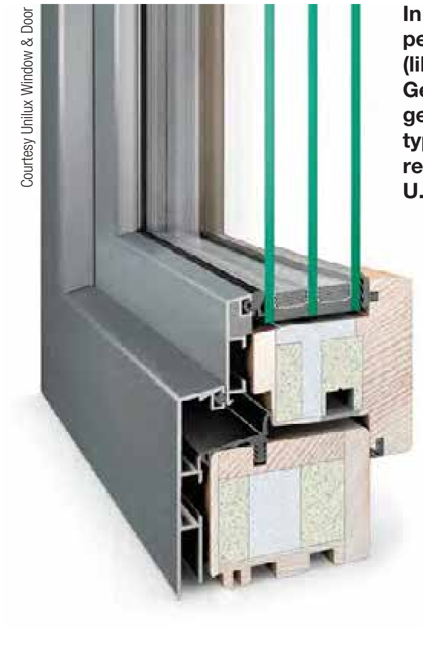
Passive solar design captures solar gain, admitted through south-facing windows, to help with winter heating. Every window, however, replaces insulated wall space with an area that is much less insulated. In a well-built home with walls reaching R-21, adding even a triple-glazed window will make the wall space that contains the window only about a quarter as effective at stopping heat transfer.

In the past, passive solar design meant lots of south-facing glazing coupled with lots of thermal mass to absorb the solar energy. Insulating shades were often part of the design to reduce heat loss at night. Newer designs tend to be less aggressive in their glazing applications. The reason for this is simple—windows (in addition to being costly) can lose many times as much heat per given amount of wall space as an insulated wall.

Modern, high-tech vinyl-framed windows like this one from SeriousWindows offer good thermal performance, low maintenance, and longevity—at a lower cost than other frame materials.

For new construction, a solar site assessment that considers winter irradiance is crucial in deciding the amount of windows. If, say, only an hour or two of winter sun is available, that means heat is escaping the other 22 or 23 hours of the day. A net heating gain from lots of south-facing windows will be close to impossible. There's going to be some windows on your south-facing wall no matter what, and it's a shame not to take advantage of the gain that does come through them.

Probably the best windows for passive solar gain come from Germany, where building codes require higher-performance techniques than in the United States, and where the Passivhaus movement—which focuses on eliminating mechanical heating and cooling systems—is strong. Some reputable manufacturers are Internorm, Optiwin, Pazen EnerSign, and Unilux. These manufacturers offer triple-pane windows with U-factors in the 0.10 to 0.15 range combined with SHGC above 0.50. These units are expensive, however, at upwards of $100 per square foot of window space (not including shipping). What is available depends on what dealers are nearby. Remember that you only need low U-value,



In the past, high-performance windows (like this Unilux from Germany) were difficult to get stateside. Today, these types of windows are more readily available through U.S. distributors.

What Windows Where

A few general rules can be applied based on your home's orientation. In most climates, south-facing windows should allow as much winter sun in as possible and have a high SHGC paired with the lowest U-factor you can find. Properly sized overhangs or adjustable exterior awnings, shutters, or other structures help mitigate summer heat gain. Insulated shades can also reduce cooling loads, although they aren't as effective as blocking the sun before it enters the house.

In general, east- and west-facing windows should block as much sun as possible, so you'll be shopping for the windows with relatively low SHGCs and U-factors, although windows with SHGC less than 0.35 may appear too dark. In places with high summer cooling loads, east, west, and even north windows would ideally also block as much sun as possible, as early morning and late afternoon solar gain can be substantial in mid-summer. In most climates, northern windows should be limited and as insulating as possible (lowest U-factors).

The guidelines for installing highly efficient windows (such as triple-pane units) are the same as installing insulation elsewhere in your home. If you live in a climate with high heating and/or cooling loads, then the purchase will pay back quickly in reduced energy costs. For many locations, investing in additional insulation is the best way to reduce carbon emissions compared with other renewable energy purchases, but also to yield the highest annual financial return for your investment. Knowing your climate's total degree days (TDD), a combination of heating and cooling degree days (HDD and CDD) is essential. Homeowners who live in climates with TDDs above 4,000 should invest in the windows with the lowest U-value possible.

Courtesy SeriousWindows

Windows on the north, east, and west walls should be minimized to achieve maximum thermal performance.

Courtesy Intus Windows

Right: Huge expanses of south-facing glass can result in too much nighttime heat loss. Instead, a well-placed area of low U-factor and high SHGC glazing does the job.

Windows for Historic Homes

Green building and historic restoration are sometimes at odds, but never do they conflict so much as with windows. Preservationists are hard-pressed to replace a wavy piece of historic glass with a new energy-efficient window. Likewise, leaving any part of a building leaky and uninsulated is anathema to most green builders. Even in less historically significant homes, the cost of replacing all or even some of the home's windows can be a major expense.

Storm windows offer a great compromise between cost, energy efficiency, and historic considerations. Improvements in storm windows are comparable to those made in new windows, and include reflective coatings and improvements in sealing—these are not the junky aluminum pieces of yesteryear.

While the air space between the original single-pane window and the storm window has not been shown to have much insulating benefit, the great reduction in air leakage (and outside noise) along with cutting back radiant heat transfer can effectively double the R-value of older windows. (Granted, this amount is only from about R-1 to R-2 once storm windows are added.) Especially for historic homes, interior storm windows add a green upgrade while preserving the home's exterior character and beauty.

Interior storm windows improve the efficiency of old windows without sacrificing the historical aesthetic.

Courtesy SeriousWindows (2)

The online window selection tool at the Energy Efficient Windows Collaborative website is a great place to start comparison shopping.

high SHGC windows for the south side of your home if you are building a passive solar home, so it may make sense to use a combination of windows from different manufacturers to keep costs reasonable. German manufacturers benefit from having ready access to low-iron glass (almost all iron oxide has been removed for clarity), developed primarily for that country's booming PV market.

North American windows can be half the price of European ones, and shipping and lead times are substantially reduced, although design, operation, and energy efficiency are generally reported to be a notch below their German counterparts, according to NFRC certifications. There are dozens of window manufacturers, so a comprehensive review isn't within the scope of this article. Accurate Dorwin, Duxton, Fibertech, Inline Fiberglass, and SeriousWindows are reputable North American manufacturers. U-values typically range from 0.15 to 0.30 for higher-quality windows.

So, where to begin? If you're interested in highly energy-efficient windows, you probably won't find them at your big-box hardware store, although acquainting yourself with the prices of average windows will give you a starting point. The best place to start is the Window Selection Tool on the Energy Efficient Windows Collaborative website. This is a location-specific tool that will generate a window availability list based on criteria such as triple-pane or a high SHGC. Your window purchase can rival buying a car in cost and complexity, and the more legwork you do for your specific project and location, the better off you'll be.

Access

Stephen Hren (stephenhren@gmail.com) is a builder and writer. He is the author of *Tales from the Sustainable Underground* and coauthor of *A Solar Buyer's Guide for the Home and Office* (see www.earthonaut.net).

Energy Efficient Windows Collaborative • efficientwindows.org • Window industry info

Passivhaus windows • bit.ly/HPwindows • Sourcing low U-value, high SHGC windows

National Fenestration Rating Council • nfrc.org • List of window manufacturers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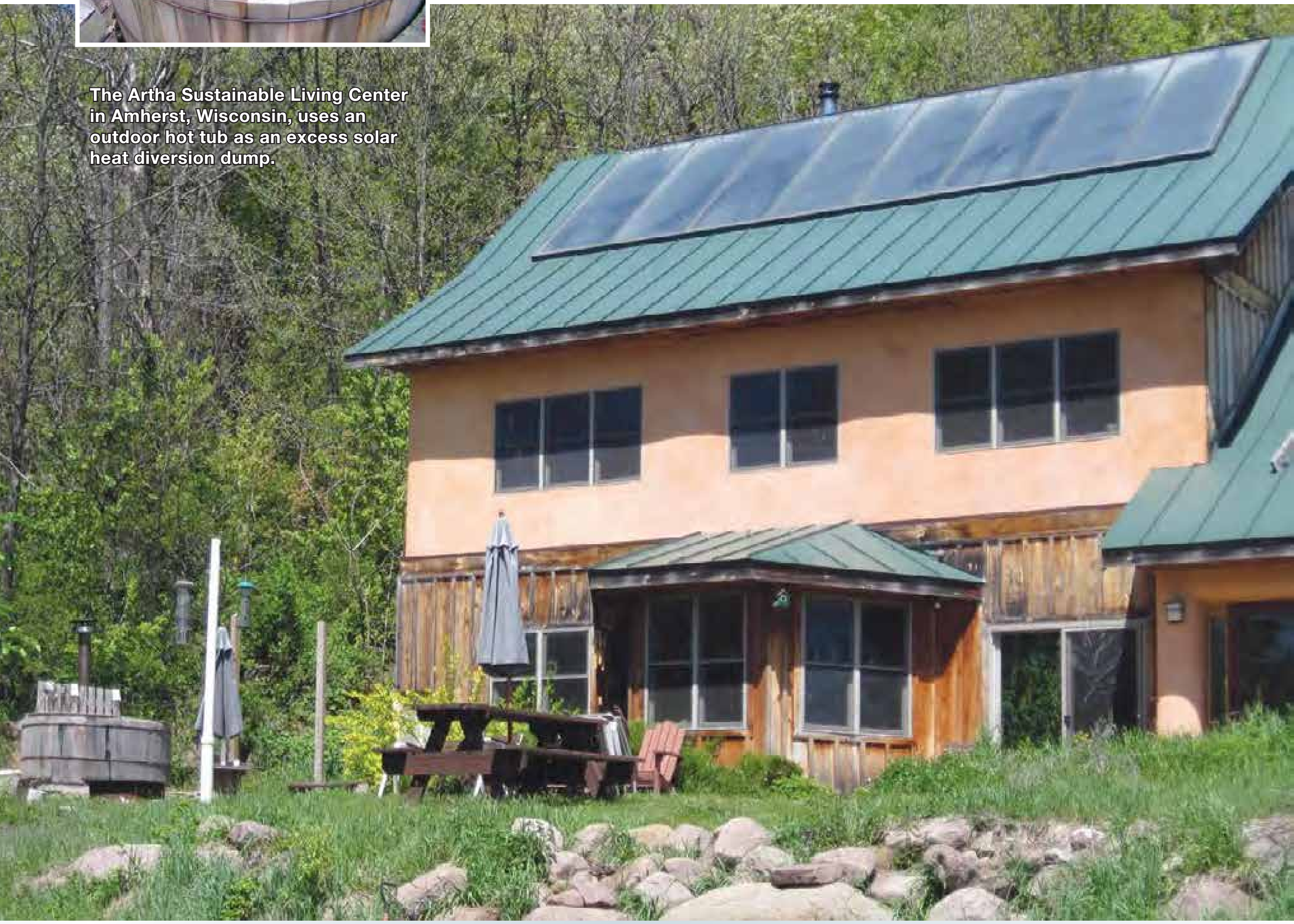
Getting Hot

But Not Too Hot

by Bob Ramlow

A solar hot water system can be sized to meet all of your hot water needs, year round. But what can you do with the excess heat that will inevitably be generated during the hottest, brightest days of the year? Put it to work, heating a hot tub or pool.



The Artha Sustainable Living Center in Amherst, Wisconsin, uses an outdoor hot tub as an excess solar heat diversion dump.

Courtesy Bob Ramlow (2)

The first step in sizing a solar water heating system is to identify the load—how much hot water the household uses per day. Then we can calculate how large of a solar water heating system will be needed to produce that much hot water. The variables include the consistency of the load and the consistency of the solar resource. Hot water use varies some from day to day but is usually fairly consistent over the whole year. The solar resource changes seasonally, producing more hot water per day during summer and less in winter.

It would be great to have a solar water heater that provides all of your domestic hot water all year long. Unfortunately, that is not economical or practical for most—if we design the solar water heater to provide 100% of the hot water load on the worst solar day of the year, then every other day of the year we would have more hot water than we need. Another limitation is that a sunny day will provide most or all of that day's hot water—but if it's cloudy the next day we will run out of solar-heated water. If we size our system so that one sunny day provides two days' worth of hot water supply, then two sunny days in a row would result in the solar water heater generating excess heat on the second day.

Courtesy Caleffi

Caleffi StarMax V collectors are built with sloped internal headers, negating the need for mounting collectors at an angle.

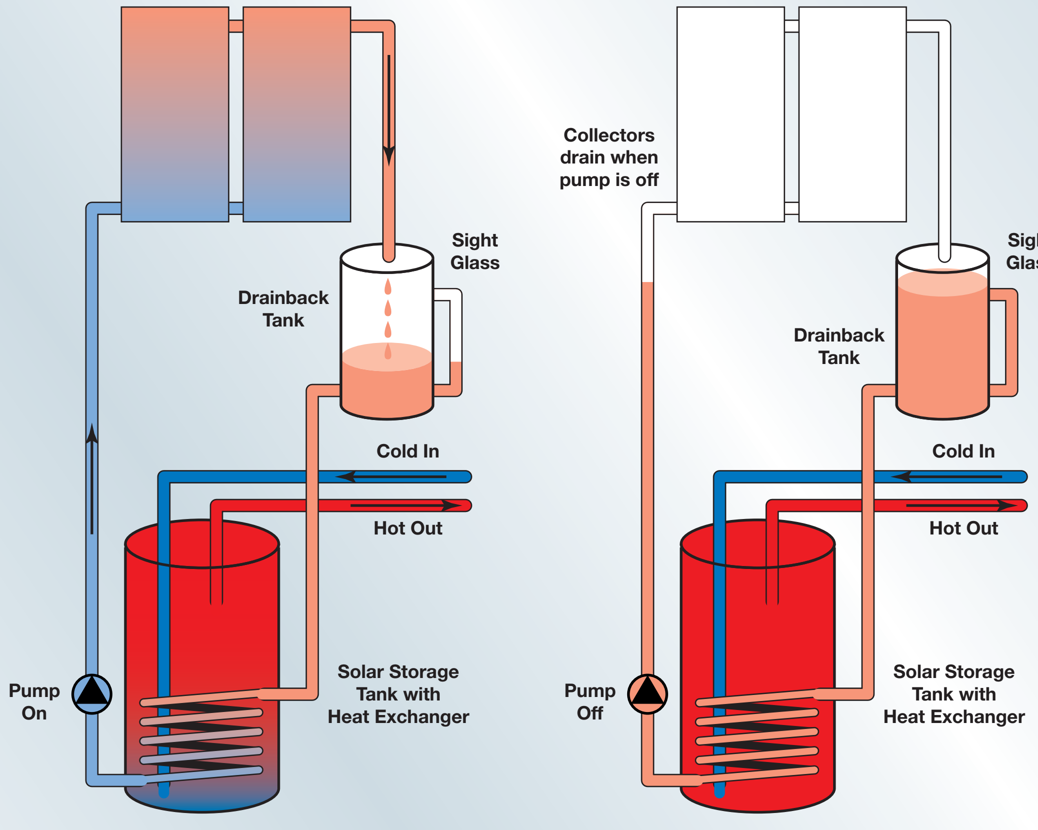
To many, the economics are not as important as avoiding using conventional, backup water heating. But then, what about the excess heat that system will produce? Another scenario that can get us into the same predicament is when a home with solar water heating is vacant for periods of time, especially during the summer.

Too Cold or Too Hot?

In most locations in the United States, a solar hot water system requires some kind of freeze protection. There are two types of freeze-protected systems that are used—drainback and pressurized—and both use a differential temperature controller to turn the system on and off at appropriate times. Whenever it is warmer in the collector than it is in the water storage tank, the controller turns the system on; the system stays on until the collectors are no longer warmer than the water storage tank.

Drainback systems offer both freeze protection and overheating protection by simply shutting down, allowing all of the fluid to drain out of the collector and pipes. Controllers appropriate for drainback systems turn off the system when a set high temperature limit is reached in the storage tank. In some homes, it is not possible to install the piping in such a way that guarantees complete drainage, so sometimes a drainback system is not an option.

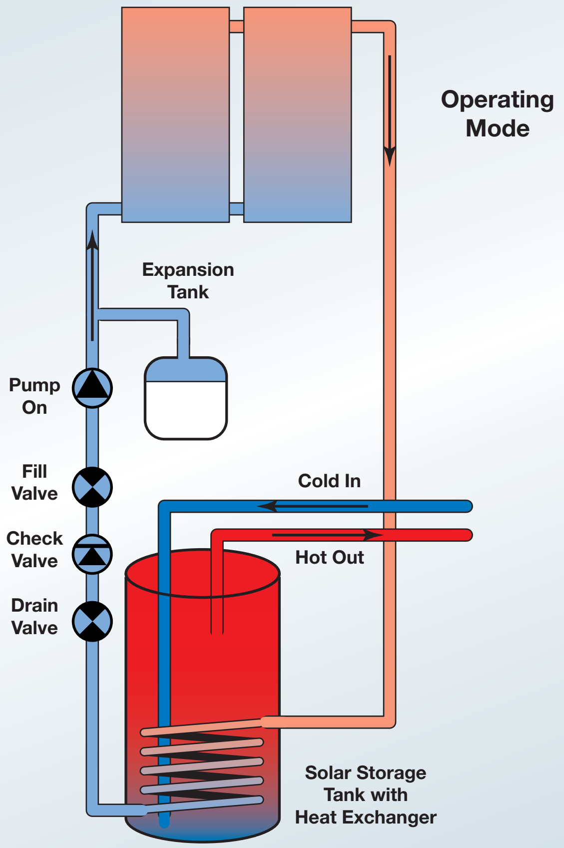
Typical Drainback System

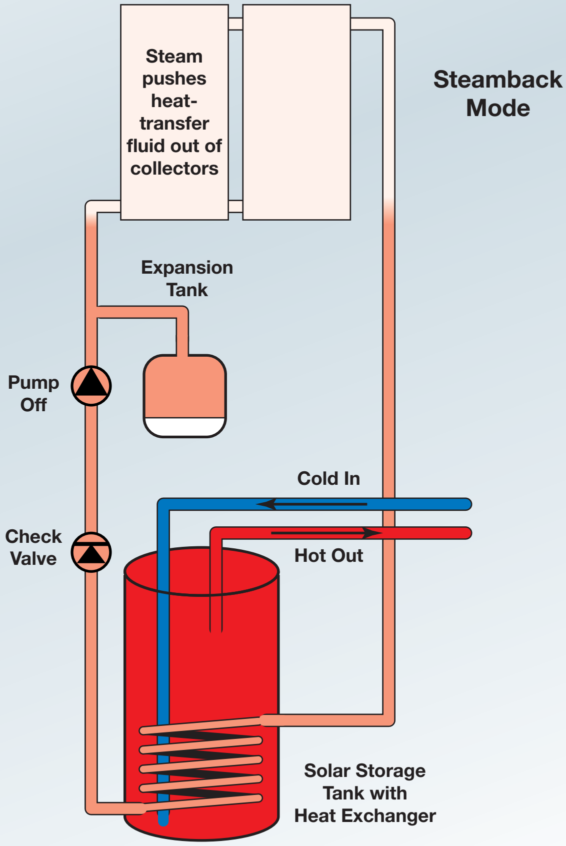


Drainback systems require sloping the collectors and all piping, which allows them to drain by gravity when the pump is shut off.

Courtesy Chuck Marken

Typical Steamback System





In that case, a pressurized system is called for. They don't drain and instead use a nontoxic heat-transfer fluid—which is also an antifreeze, and remains in the collectors and piping at all times. Pressurized systems allow more piping and installation options than drainback systems.

The potential overheating problem in pressurized systems is due to the heat-transfer/antifreeze solution used—almost exclusively it's propylene glycol mixed with water. Glycols are rated for various operating temperature ranges. But temperatures produced by flat-plate and evacuated-tube collectors can exceed glycol's highest operating range, resulting in thermal breakdown of the fluid, which causes collector and pipe corrosion.

When drainback systems reach their high-temperature limit, they turn off the pump, the system is drained, and no more heat is collected. If we employ the same strategy with pressurized systems and turn off the circulating pump when the storage tank reaches a high limit, the heat-transfer fluid will stop circulating but it will stay in the collector. If the sun is still shining on the collector when the circulation stops, the collector temperature and heat-transfer fluid temperature will rapidly rise. The temperatures in flat-plate collectors can reach more than 300°F—and the temperature of evacuated-tube collectors can be even higher.

Steamback

If a pressurized system is properly designed, there is no problem if the system reaches its high limit and the circulating pump turns off. The temperature in the collectors rises rapidly above the boiling point, creating steam. It takes about a thimbleful of water to make enough steam to completely fill a large flat-plate collector and even less to fill the manifold in an evacuated-tube collector, so very little water actually boils. This steam quickly expands to fill the

Steamback Specifics

For a SHW system to rely on an expansion tank for overheating protection, the expansion tank must be large enough to hold the volume of heat-transfer fluid from all of the collectors, plus the expansion of all the fluid in the solar loop. Additionally, the expansion tank must be located on the collector feed leg of the solar pipe loop—not isolated from the collectors by the check valve (see illustration). A design problem with many pressurized systems has been undersized expansion tanks. Sizing expansion tanks is a complex undertaking that involves calculating the thermal expansion of the solar fluid, adding the collector volume, and determining how much expanded fluid an expansion tank can accept. It is best to use a larger tank than take a risk with one that is too small.

It is also important to make sure the collector being used can withstand dry stagnation (empty under full-sun conditions) and/or empty properly. These are the same requirements placed on collectors used in drainback systems. All collectors certified by the performance-rating nonprofit Solar Rating and Certification Corporation are subjected to a 30-day stagnation test prior to performance testing.

Courtesy Bob Ramlow

With the correct positioning of an expansion tank, a pressurized glycol system can use "steamback" as a way to empty the collectors and prevent overheating.

collector and pushes the remaining heat-transfer fluid down to the expansion tank.

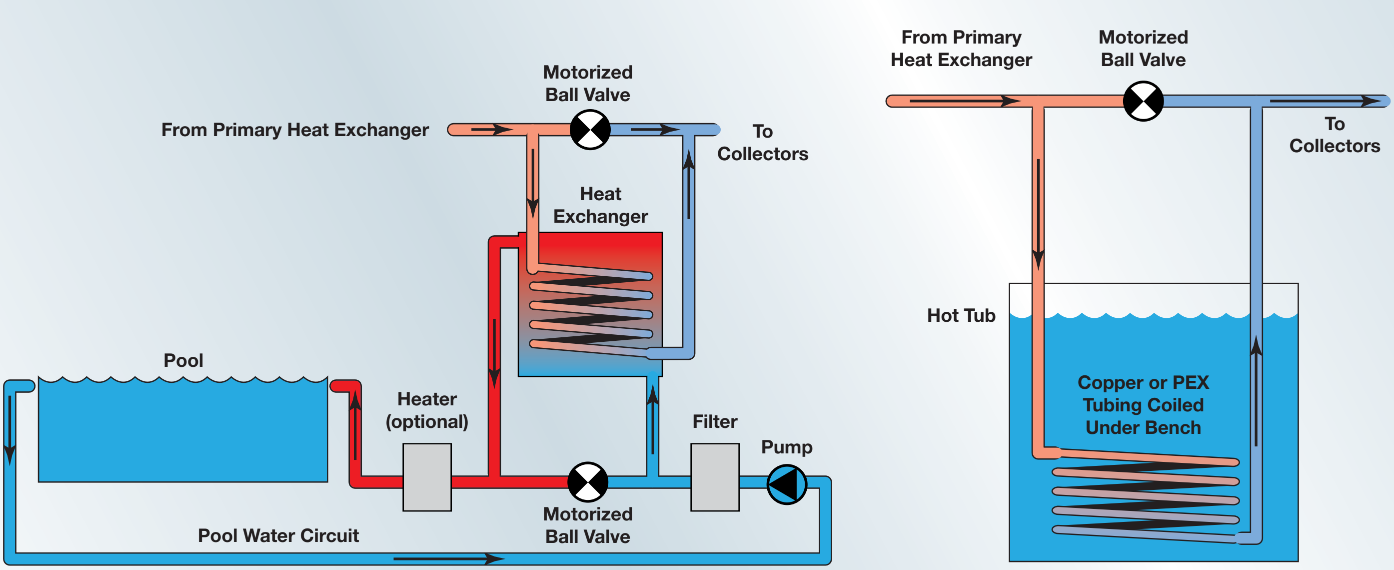
At this point, there is no fluid in the collectors, so the glycol is protected from thermal breakdown. When the collectors cool at the end of the day, the steam condenses, the pressure drops, and the heat-transfer fluid refills the collector. This "steamback" process is perfectly safe in a properly designed pressurized system. The key to success with this method is the size and location of the expansion tank within the solar loop (see "Steamback Specifics" sidebar).

Drainback and properly designed pressurized systems should not have overheating problems. However, there may be instances when systems reach their high limit and stop collecting heat while the solar resource is still available. This can occur during times when hot water is not regularly being drawn from the storage tank (for instance, if homeowners are away on vacation, especially during the summer) or with combination domestic water and space-heating systems, where there are lots of collectors for winter space heating that have no job to do during the summer. Wouldn't it be great if we could use that heat while still making sure our collector fluid never suffers from thermal breakdown?

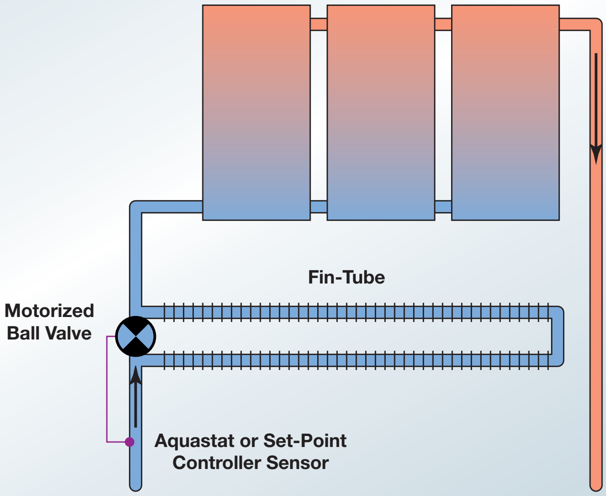
Enter the Pool

A great use for this excess heat is to divert it to seasonal swimming pools or outdoor hot tubs. Since excess solar heat production occurs mostly during summer, it offers perfect timing for providing heat to a seasonal pool. It is easy to divert heat to a pool or a hot tub by rerouting it through an alternate heat exchanger. Most swimming pools and many hot tubs use a chlorine or salt disinfectant in the water and both chemicals are extremely corrosive to most metals, so a special type of heat exchanger is required that will resist the chemicals' corrosive effects. Titanium exchangers will last the longest, but marine-grade stainless steel or cupronickel (copper/nickel alloys) may work, too.

Typical Pool or Hot Tub Diversion System



Typical Fin-Tube Heat Dump



Courtesy Apricus

The Apricus HD25 water-to-air radiator is a purpose-built dissipator for excess heat.

IMC Instruments' Solar Eagle 2 is a dual-relay differential controller capable of operating valves or pumps on diversion-load loops.

Courtesy IMC Instruments

When the solar storage tank reaches its high-limit temperature, the solar fluid is diverted from the tank's heat exchanger to the pool's heat exchanger. A controller that includes this option is required, like IMC Instruments' Eagle 2 dual-relay differential temperature controller with a built-in pump relay. When the solar storage tank temperature reaches the adjustable high limit, the solar circulating pump stays on and the second relay energizes a motorized ball valve or a circulation pump that diverts the solar fluid to the pool's heat exchanger or diversion loop, and away from the solar storage heat exchanger.

Sometimes, a second circulating pump is required to overcome any additional pipe and exchanger friction; in some other cases, a second circulating pump is used instead of a motorized ball valve. The first priority of the controller is the domestic hot water, so if the solar storage tank cools because of hot water use in the home, the controller turns off the second relay and the solar heating goes back to the domestic water until the high-limit setting is reached again.

When heating a pool with a SHW system, the pool pump and filtering system must be on at the same time. This ensures that the pool/spa water is flowing through the solar heat exchanger so it can absorb the solar heat from the hot solar fluid. The easiest way to make sure the pool filter pump is on when the solar energy may be diverted to pool heating is to set the pool pump timer to operate during daylight hours. Pools normally need filtering six to eight hours each day—and the timer energizing the pool pump is set to coincide with the system's solar day.

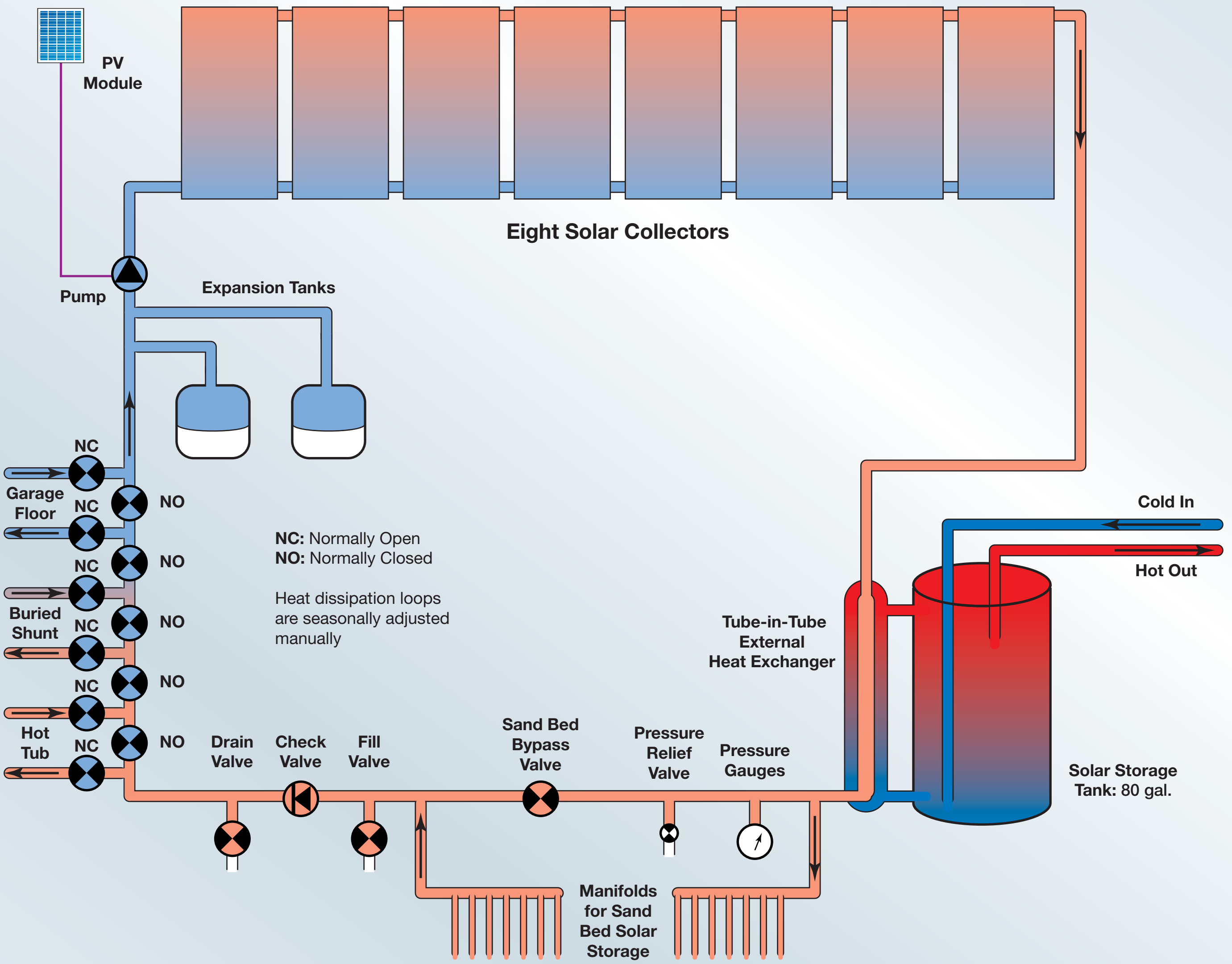
One of the solar heating systems at the Artha Sustainable Living Center in Amherst, Wisconsin, uses an outdoor hot tub as the excess heat diversion dump. That hot tub holds about 600 gallons of water, and it has no filtering system or filter pump. No chlorine or salt is used, so soft copper tubing is used as the heat exchanger. When the solar fluid is diverted to the tub, it simply travels through the copper tubing, transferring the heat to the tub water. If chemicals are used in a hot tub, PEX tubing can be used instead of copper, but the loop must be three times longer because the heat transfer capability of PEX is one-third that of copper.

Fin-Tube Heat Sink

There can be times when there is no way to use the excess heat produced, like in a pool or hot tub, but it still needs to be dissipated with an automatically controlled heat dump. These systems usually use copper fin-tube to shed heat to the atmosphere. The method is simple, economical, and effective. The recommended fin-tube is the core of baseboard heaters—a readily available product from hydronic-heating suppliers. There are commercial water-to-air heat dumps available as well.

The fin-tube is installed behind the solar collectors and the solar fluid is diverted through the fin-tube before it enters the collectors. One way to divert hot solar fluid through the fin-tube is to use the same control method mentioned above with a dual-relay controller. When the storage tank reaches a preset temperature, the main circulator stays on and the second relay also turns on. In this case, the relay energizes a

Artha Sustainable Living Center
Rooftop Solar Thermal Combisystem



Tech Specs

Overview

System type: Pressurized solar water and space-heating system
Location: Amherst, Wisconsin
Solar resource: 4.2 average daily peak sun-hours
Production: 7.2 kBtu per month (average)
Climate: 8,500 heating degree days
Percentage of hot water produced annually: More than 80%
Percentage of space heating produced annually: More than 75%

Equipment

Collectors: 320 sq. ft. of custom-made flat plate collectors
Collector installation: Roof-mounted, facing south at a 50° tilt
Heat-transfer fluid: Wausau Chemical Co. “HT” propylene glycol, 50% dilution
Circulation pump: March 809 HS, 12 VDC
Pump controller: PV-direct (no controller)

Storage

Tank: 80 gal. domestic water storage
Heat exchanger: AAA Solar Quad-Rod, 5 ft. thermosyphon
Backup DHW: Quietside dual-core condensing boiler
Other: 2,100 cubic feet of sand bed space-heating storage

Large, wintertime-weighted—or space-heating combisystems—often produce excess heat in the summer, but a properly designed system will include measures for mitigating overheating. The author's pressurized system is 30 years old and still has the original propylene glycol in it—a testament to good design.

motorized valve to divert the solar fluid to the fin-tube before it flows back to the collector array.

Another way to control the fluid flow is to use an additional set-point thermostat or an aquastat to operate a motorized valve that diverts the flow of the solar fluid. If the solar fluid reaches a preset temperature as it travels to the collectors, the flow is diverted through the fin-tube, where it cools. This fluid does not need to be cooled to ambient temperature; it only needs to be kept below 200°F.

There are several strategies you can use to keep your SHW fluid from overheating, and the best solution will depend on the climate and system specifics. A pool or hot tub can be an excellent choice and add to the enjoyment of living with solar. If properly designed and installed, SHW systems can provide decades of service—and hot-tubbing or pool heating.

Access

Bob Ramlow (artha@wi-net.com) has been active in the solar thermal industry for more than 40 years as an installer, consultant, manufacturer, and teacher. He is an ISPQ-certified solar thermal independent master trainer and a NABCEP-certified solar thermal installer. He is the co-author of *Solar Water Heating: A Comprehensive Guide to Solar Water and Space Heating Systems*. He teaches about solar heating and is a consultant to the industry (see arthaonline.com).

Resources

IMC Instruments • solar.imcinstruments.com • Solar thermal controllers


Nature provides us with the gift of energy through the sun, but unfortunately, nature's wrath may not be all that friendly to your PV system under stressful conditions. Snow, wind, extreme heat or cold, and seismic activities can wreak havoc on underengineered, underdesigned and insufficiently tested racking structures. Only UNIRAC solar structures have been engineered and third-party tested to withstand the harshest of elements and events for a long and enduring service life. Complies with IBC, IRC, ASCE-7-05, ADM, AISI, AISC, NEC and UL. For the highest level of engineering and construction with the lowest cost of ownership in the business, Unirac is the 24/365 solution for performance in and out of the sun. Visit unirac.com for more information.
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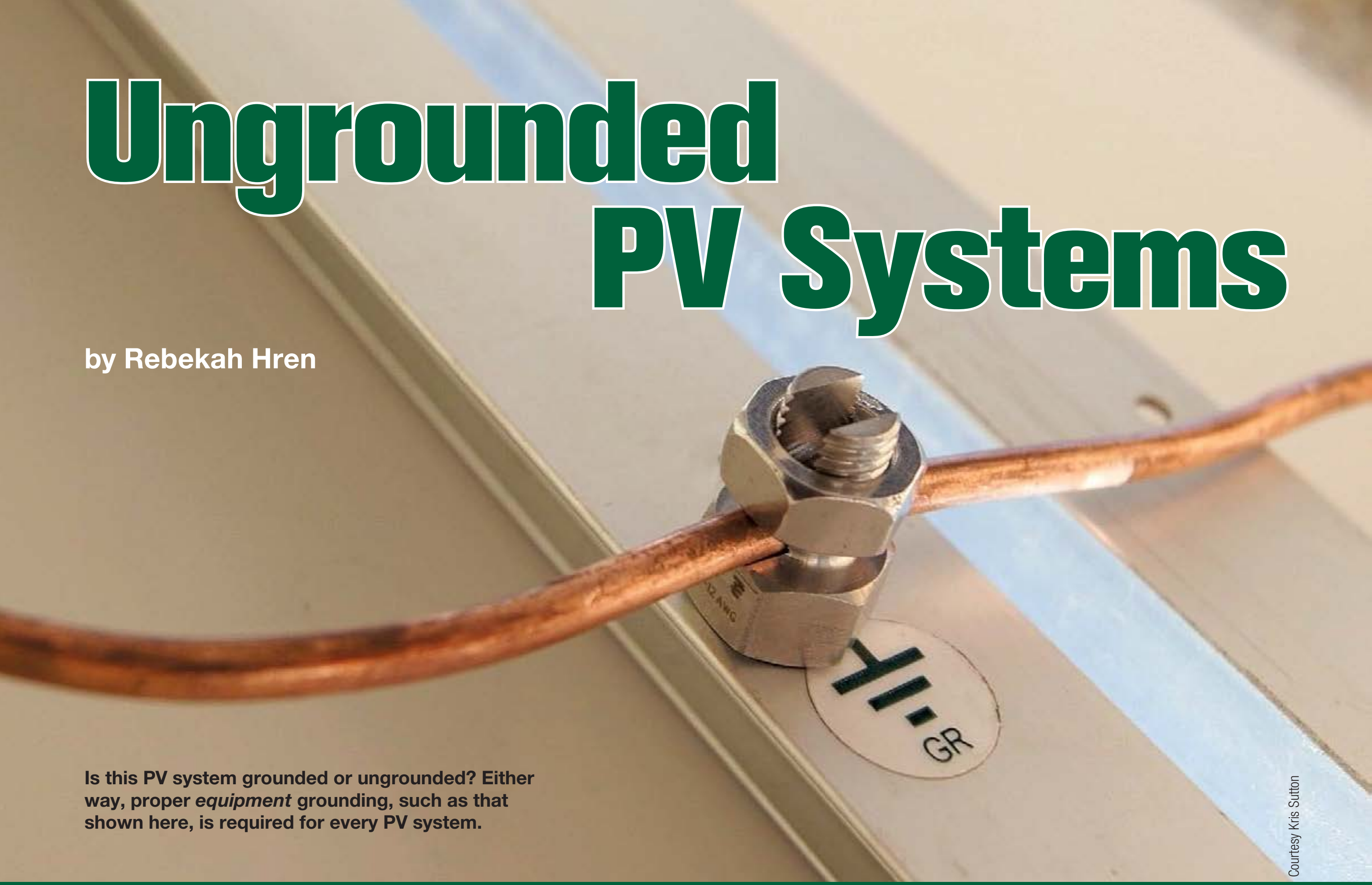
Ungrounded PV Systems

by Rebekah Hren



Is this PV system grounded or ungrounded? Either way, proper *equipment* grounding, such as that shown here, is required for every PV system.

Courtesy Kris Sutton

Manufacturers are rapidly bringing to market lighter weight, more efficient, and space-saving transformerless inverters for use with ungrounded PV power systems. And when these systems are properly installed, their safety is equal or superior to grounded PV systems.

Transformerless inverters—inverters that must be installed with ungrounded PV power systems—are becoming more common in the United States. The differences between ungrounded and grounded systems need to be clearly defined and understood for two important reasons: first, because the *National Electrical Code (NEC)* sets installation requirements that vary depending upon whether a system is grounded or not; and second, so that the safe functionality of ungrounded systems is not in doubt.

A common misconception about ungrounded PV systems is that they lack all grounding, including equipment grounding—the bonding to ground of exposed metal that could become energized in a fault situation. But all *Code*-compliant and well-installed PV systems must still have equipment grounding—the bare copper or green-insulated grounding conductors that bond the metal boxes, the metal conduit, the metal rails that hold modules, and the metal frames of the PV modules. This keeps the electrical potential of the metal at zero volts, facilitates the operation of overcurrent protection devices, and helps keep systems and people safe.

A "grounded" PV power source has either the positive or negative DC-carrying conductor connected to ground (called the "DC system ground"). An "ungrounded" PV system has *neither* the positive nor negative DC current-carrying conductor connected to ground. However, just like the grounded system, it still has equipment grounding. While "ungrounded" is the terminology used in the *NEC*, many in the solar industry call these arrays "floating," because of the confusion that can ensue over the variety of PV terminology containing the word "ground." Floating means that neither the positive nor negative conductors on the DC side of the system have a direct connection to ground.

System Grounding

NEC Article 690.41 mandates system grounding for PV sources greater than 50 volts. However, since 2005, Article 690.35 (listed as an exception to Article 690.41) allows PV power systems above 50 volts to be ungrounded—provided they comply with the requirements discussed below.

In PV arrays, both the positive and negative conductors are current-carrying. In an AC electrical system, such as a 120/240 VAC residential service, both the hot and neutral conductors are current-carrying, but the neutral conductor is the grounded conductor, meaning that at one point (and *only* one point) in the system, the neutral is bonded to the grounding system (usually at the main disconnect or in the main service panel). This grounding connection creates a potential of zero volts for the neutral conductor relative to ground—the same as all of the metal components in the system that are also connected to ground by equipment grounding.

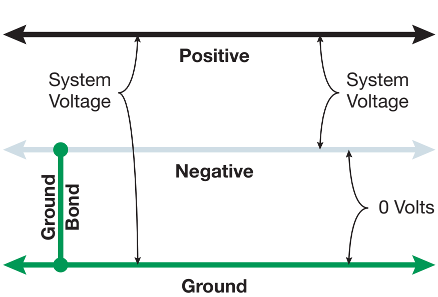
Potential difference is another way to say voltage, which is analogous to the potential electrical force existing between two points. Remember, it always takes two points to measure this potential. The two "hot" conductors in a 120/240 VAC residential service are the ungrounded conductors, referred to as Line 1 and Line 2. Voltage readings between an ungrounded conductor and either neutral or ground in an AC residential system will result in the same measurement, approximately 120 VAC, since neutral and ground are connected.

Voltage in a PV array is variable, changing with temperature and operating conditions. There is voltage between the positive and negative PV conductors, regardless of whether one conductor is connected to ground (a system ground). If the negative PV conductor is connected to ground at one point (a negative-grounded system), it will have zero voltage potential to ground, but its potential relative to the positive conductor will still be the array voltage. If instead the positive conductor were to be connected to ground (a positive-grounded system), it would have zero voltage potential to ground, but the potential to negative would still be the array voltage.

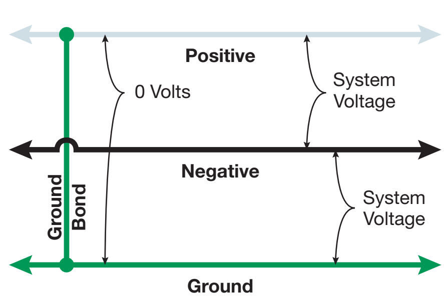
If, however, neither the positive nor the negative conductor is connected to ground, both should measure approximately zero volts relative to ground. Because there is not a low-resistance path for current to return to the modules via grounding conductors, there will be little or no electrical potential from the system to ground. Essentially, the PV array is unaware that "ground" exists. However, the voltage measured between positive and negative stays the same—at array voltage—regardless of DC system grounding, or lack thereof. PV systems can be installed and function whether they are positive-grounded, negative-grounded, or ungrounded. The choice of how and whether to ground a system comes down to equipment choices. Some module manufacturers, such as SunPower, may require positive-grounded systems when using their modules, because of possible system efficiencies related to the equipment's electrical design. Some applications, such as telecom systems, may also require positive-grounded systems. Historically, most PV systems in the United States have been negative-grounded. However, depending on the type of inverter used, an ungrounded PV system may be required.

While it resembles its transformer-based counterparts, this SMA America 8000TL-US inverter is a transformerless model and requires that the PV array be ungrounded.

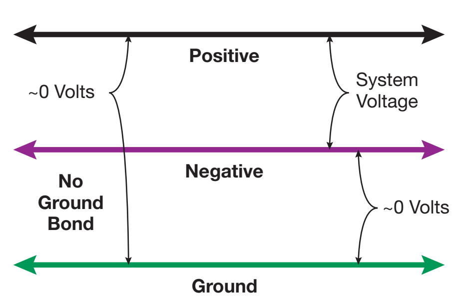
Negative DC System Ground



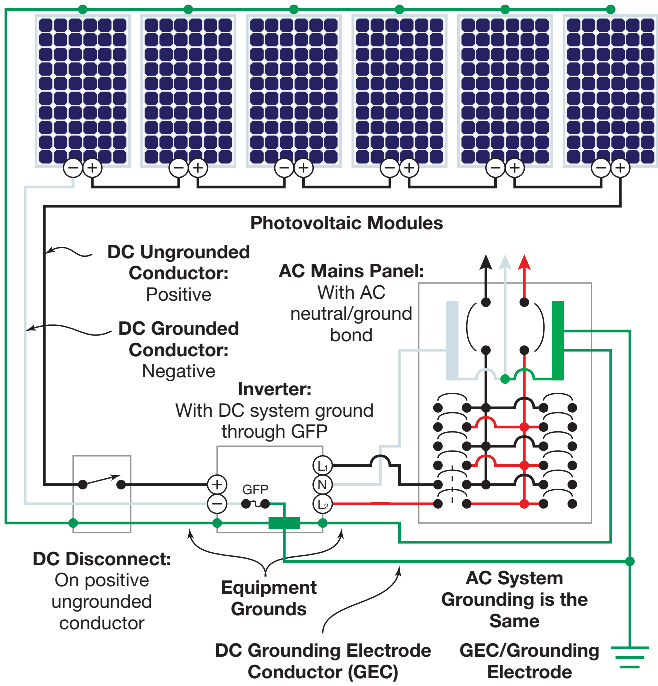
Positive DC System Ground



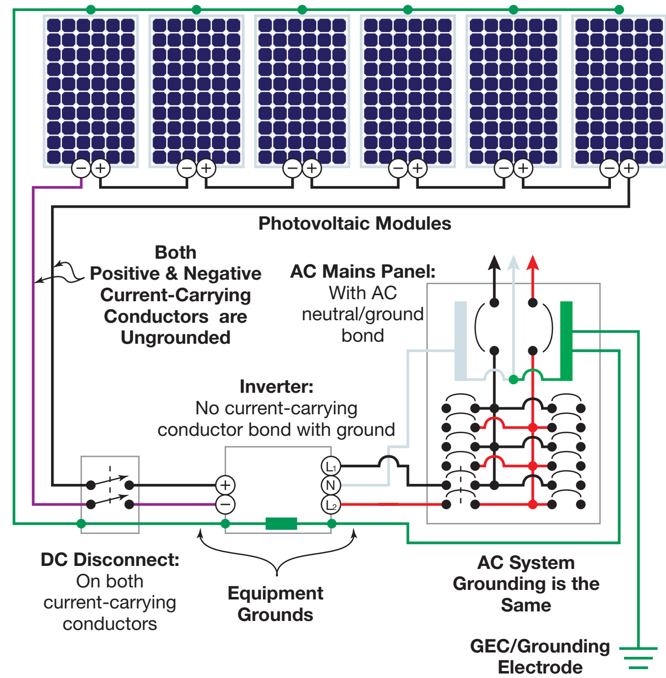
Ungrounded DC System



Negative-Grounded DC System



Ungrounded DC System



Ungrounded Systems & the Code

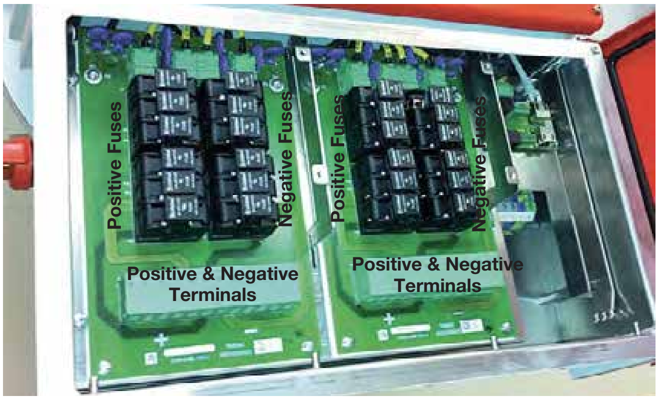
Because neither DC conductor is grounded in ungrounded PV systems, *NEC* requirements for ungrounded conductors must be followed. These include overcurrent protection (fusing) requirements per *NEC* 240.15, color-marking requirements, and disconnecting requirements.

In an ungrounded system, per *NEC* 690.35(B), each positive and negative conductor must be protected by an overcurrent device. Note that there is an exception in *NEC* 690.9(A) that doesn't require overcurrent protection for PV source circuits with limited sources of current that don't exceed the conductors' ampacity. An example is one or two paralleled source circuits connected to an inverter that can't back-feed current. Both positive and negative must be marked with a color other than white or gray, and green or bare—per *NEC* 200.6 and 250.119, those colors are reserved for grounded and grounding conductors.

For ungrounded DC systems, some PV installers use red to mark positive and black to mark negative, although these colors are also the convention for 120/240 VAC systems and 12 VDC automotive systems. While *Code*-compliant, using red and black could cause confusion during installation, or make troubleshooting harder if AC and DC conductors are in the same raceway. Other colors that might better be used for marking the positive and negative conductors include yellow, blue, purple, or brown. Also, while the same color could be used for both positive and negative conductors and still be *Code*-compliant, it is not a good idea. This could lead to polarity mistakes during installation, as well as make future troubleshooting difficult. When trying to determine the system type, a helpful distinction is that a grounded PV array will always have white or gray conductors (for the grounded conductor) on the DC side; an ungrounded array will have no white or gray conductors.

In an ungrounded system, a disconnecting means (a manually operable switch or circuit breaker) must be provided for both the positive and negative conductors, following the disconnecting requirements of *NEC* 690, Section III (see "Code Corner" in *HP119*). In addition, the module leads (PV source circuits) and exposed-wire home runs in ungrounded systems must be listed and identified as "PV wire," which has thicker insulation on the conductors, making it extremely durable and UV resistant. Many modules now come with PV wire leads. But some have leads that are listed only as USE-2/RHW-2, and the *NEC* prohibits those modules from being used in ungrounded systems. Furthermore, a transformerless inverter cannot usually be retrofitted into a PV system that has modules without PV wire leads—replacing factory-installed module leads will void the module warranty.

This REFUsol transformerless inverter/fused combiner, which has inputs for up to 12 source circuits, shows both positive and negative fusing.



Courtesy REFUsol

Ungrounded Benefits

Ungrounded arrays can be just as safe—or safer—than grounded arrays. If installed correctly, with proper equipment grounding, ungrounded arrays may provide the safest installation possible: The ungrounded system inverters include an enhanced ability to detect ground faults, and there is reduced possibility of shock to personnel installing or servicing the system.

Without a connection to ground on the DC side, the largest shock potential is directly from positive to negative, with very little shock potential from either ungrounded conductor to ground (or anything bonded to ground, such as a metallic enclosure). To understand why this is beneficial, imagine an installer working on a roof with a negative-grounded system, positioning an energized, positive PV source circuit home run in a metal junction box. If the installer's hand grazes against the metal box, the box completes the circuit between the positive and negative, which creates a serious shock hazard. (Safe working procedures should prevent this, but these procedures—such as not connecting any power sources until all conductors are wired at each termination—are not always followed.) If the system was ungrounded, the potential between the positive conductor and the metal junction box would have been close to zero volts—a high-resistance circuit with little shock potential. While no installer should work on energized conductors, ungrounded systems provide an additional level of safety. Homeowner safety is increased by enhanced ground-fault protection (see the "Ground-Fault Protection" sidebar).

Ungrounded System Installation Checklist

- ✔ Are the PV module leads listed as PV wire?
- ✔ Are both the positive and negative DC conductors color-marked other than white, gray, green, or bare?
- ✔ Do both positive and negative DC conductors have overcurrent protection if there are current sources that exceed module or conductor ampacity?
- ✔ Do both positive and negative DC conductors have disconnecting means?
- ✔ Is the inverter listed for use in ungrounded system applications?
- ✔ Is the system installed with proper equipment grounding?
- ✔ Are there warning labels on all DC junction and combiner boxes, disconnects, and other devices where energized circuits may be exposed during service that read:

Warning: Electric shock hazard.
The DC conductors of this
photovoltaic system are ungrounded
and may be energized.

Left: This SMA America inverter has a transformer mounted behind the circuit board. One conductor of the PV system must be grounded and fusing is only on the ungrounded conductor.

Middle: A transformerless inverter combiner box, with positive and negative fusing.

Right: A transformerless (TL) SMA America inverter. This inverter requires an ungrounded array, and uses the combiner to provide fusing on both the positive and negative conductors.

Courtesy SMA America

Ground-Fault Protection

NEC Article 690.5 requires DC ground-fault protection (GFP) for nearly every type of PV array installation, primarily for reducing fire hazards. GFP is built into all new grid-tied inverters, including transformerless inverters for ungrounded systems. Some older grid-tied inverters may not have integrated ground-fault protection, but GFP has been an *NEC* requirement since the 1984 *Code* cycle.

Ground faults happen when a current-carrying conductor makes inadvertent contact with an equipment grounding conductor, or any piece of metal that is grounded. This can occur through damaged conductor insulation or with improper installation. This is a potentially dangerous situation, and inverters are intended to detect these faults. For grounded arrays, the GFP device in the inverter is the point of connection between the grounded conductor and ground—the DC system ground—which is established through a fuse in the inverter. Transformer-based grid-tied inverters use the fuse or breaker as both the point of system ground on the DC side and as the GFP device. Smaller inverters (less than 10 kW) generally use a low-amperage fuse (typically 1 A); larger inverters use larger current devices (up to 5 A). This GFP device is meant to protect against fires—not against shock, like household GFCI receptacles—because the threshold for harmful shocks is much lower, around 10 milliamps.

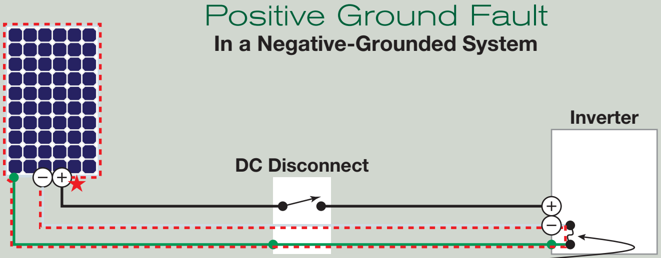
The GFP device is designed to detect current on the grounding system (i.e., a ground fault), which will blow the fuse and open the circuit. To understand this process, consider a negative-grounded system, wherein the negative conductor is connected to all of the grounded parts of an array (through the GFP fuse). If there is a fault (for example, from a positive wire pinched against a mounting rail), the current will try to flow from the fault on the grounded rail, through the fuse, and back through the negative conductor to complete the circuit, because that is a path of lower resistance than through the inverter electronics. Once the fuse's current rating is exceeded, the fuse will blow, opening the system ground (and thus stopping any short-circuit arc between the positive wire and the rail). The inverter will turn on a light to indicate a ground fault, and will be triggered to simultaneously open the ungrounded circuit conductors and cease supplying output power, effectively shutting off the system. Although the source of the fault is not fixed, nor its location known, the system is shut down to await repair.

With a transformerless inverter, since there is no isolation, a DC fault could affect the AC side of the system. In this case, it is just as critical (if not more so) to provide protection. Transformerless inverters have an entirely different type of ground-fault detection. Before the inverter starts operating, resistance to ground from the DC current-carrying conductors is checked. If there is low resistance to ground (an indication of a ground fault), the inverter will not start operating. Once operational, a differential current sensor continually monitors the current on both the positive and negative conductors. If there is no fault, the current should be identical. If a fault occurs, such that some portion of the current flows through a grounding conductor or grounded metal, the inverter detects the current difference, and thus the fault, shuts off, and indicates a ground fault. The fault threshold is much lower than a fused device, usually 300 milliamps, which is one reason ungrounded arrays can be safer than grounded systems.

A second reason the differential current-sensing GFP devices in transformerless inverters are considered safer than fused GFP devices is that they are equally good at detecting faults on both positive and negative conductors. A negative-grounded array may have a ground fault from negative to ground that never causes enough current to flow through the GFP fuse to trip the device. It's only when another, possibly catastrophic, positive-to-ground-fault occurs that the GFP fuse will blow. At this point, it may be too late to stop a fire from happening at the point of the initial or secondary fault.

Positive Ground Fault

In a Negative-Grounded System



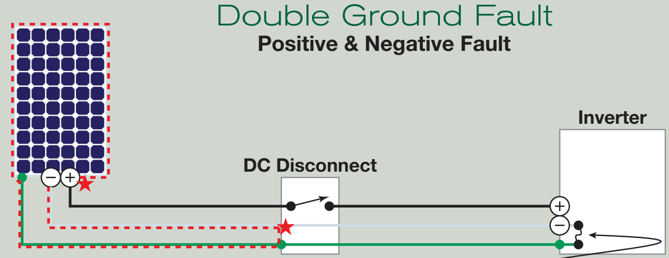
★ **Ground Fault:** Positive to module frame

---- **Fault Current Path**

GFP: Fuse blows when fault current is greater than fuse rating, opening the circuit so there is no return path for fault current

Double Ground Fault

Positive & Negative Fault



★ **Ground Faults:** Positive to module frame; negative to metal box

---- **Fault Current Path**

GFP: First fault (negative) doesn't blow the fuse; second fault (positive) may blow the fuse, but a looping fault current path still exists

Grounded vs. Ungrounded

Reasons why U.S. PV systems have typically been grounded include a long history of grounded electrical systems in the United States; the topology of the majority of grid-tied inverters available for the U.S. market; the way integrated ground-fault protection detection devices work (see sidebar); and the past difficulties of meeting *NEC* 690.35 requirements for PV wire, since few modules were manufactured with it.

The majority of inverters on the U.S. market are transformer-based. A transformer is a heavy component, made of wire wound around iron or steel cores, used to match the inverter voltage with the AC voltage of the utility grid. A transformer has primary and secondary side windings, and the transformation occurs as current is induced from one side to the other. The conductors on either side aren't touching, which means that a fault on the DC side of the system doesn't transmit to the AC side (a situation that would be termed "DC injection"). There is no physical connection between conductors on the two sides.

A transformerless inverter, on the other hand, uses a higher-efficiency process of electronic switching in which the conductors are not isolated between the DC and the AC sides. If DC positive or negative in a transformerless inverter system was to become grounded, the ground-fault protection device wouldn't allow the inverter to operate (see sidebar). Transformerless inverters are therefore installed with ungrounded PV arrays—those with no DC system ground, but always with equipment grounding.

Transformerless inverters generally weigh less, are more compact, and are slightly more efficient than transformer-based inverters. Many are now available in the United States (see the "2012 Grid-Tied Inverter Buyer's Guide" in *HP147*). Manufacturers offering residential-sized transformerless inverters include Exeltech, Ingeteam, Kaco, OPTI-Solar, Power-One, REFUsol, SMA America, and SolarEdge. These inverters offer a range of DC voltage windows similar to transformer-based inverters, and most come with integrated fusing and DC disconnect options (for both the positive and negative DC conductors). If external fusing and disconnecting means are necessary, then special equipment, such as combiner boxes and disconnects with separate fusing, and disconnecting means for both the positive and negative conductors will be required. Battery-based systems could also be ungrounded, but *Code*-compliant GFP equipment for ungrounded charge controllers isn't currently available.

There is no doubt that the number of ungrounded PV systems will continue to grow, claiming space on U.S. roofs and solar fields. While Europe may have paved the way for ungrounded systems, they are here to stay in the United States.

Access

Rebekah Hren (rebekah.hren@gmail.com) is a licensed electrical contractor, NABCEP-certified PV installer, and ISPQ-certified PV instructor for Solar Energy International. She lives off-grid and has experience installing and designing PV systems ranging from 10 watts to 4 megawatts. Rebekah works for North Carolina solar project developer O2energies.

Ungrounded System Inverter Manufacturers:

Exeltech • exeltech.com

Ingeteam • ingeteam.com

Kaco • kaco-newenergy.com

OPTI-Solar • opti-solar.com

Power-One • power-one.com

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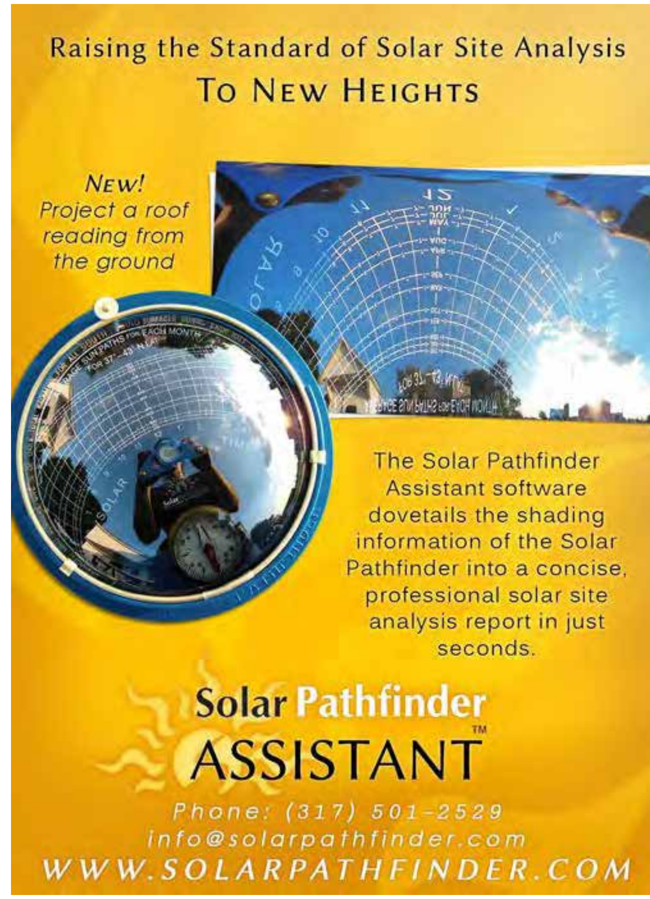
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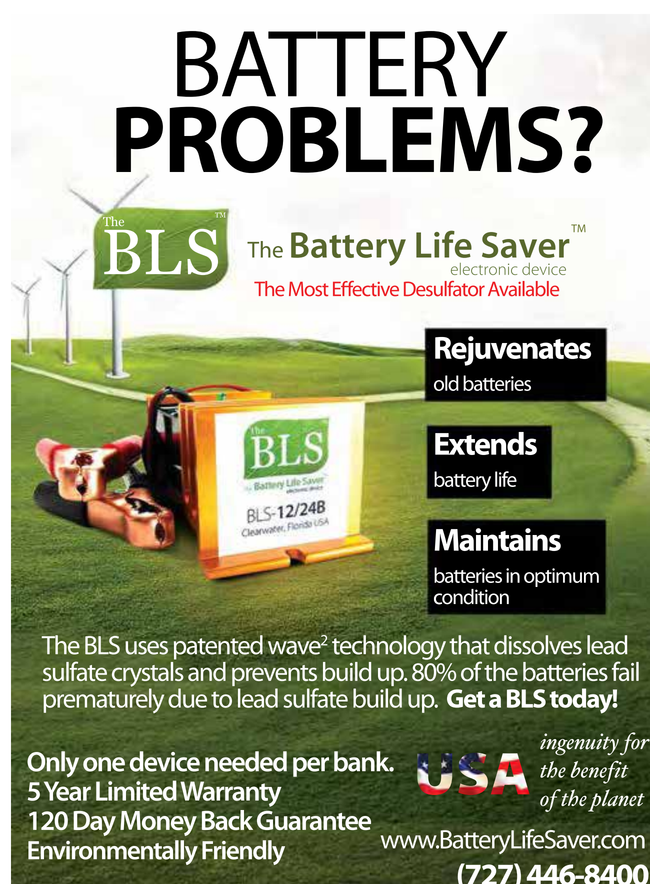
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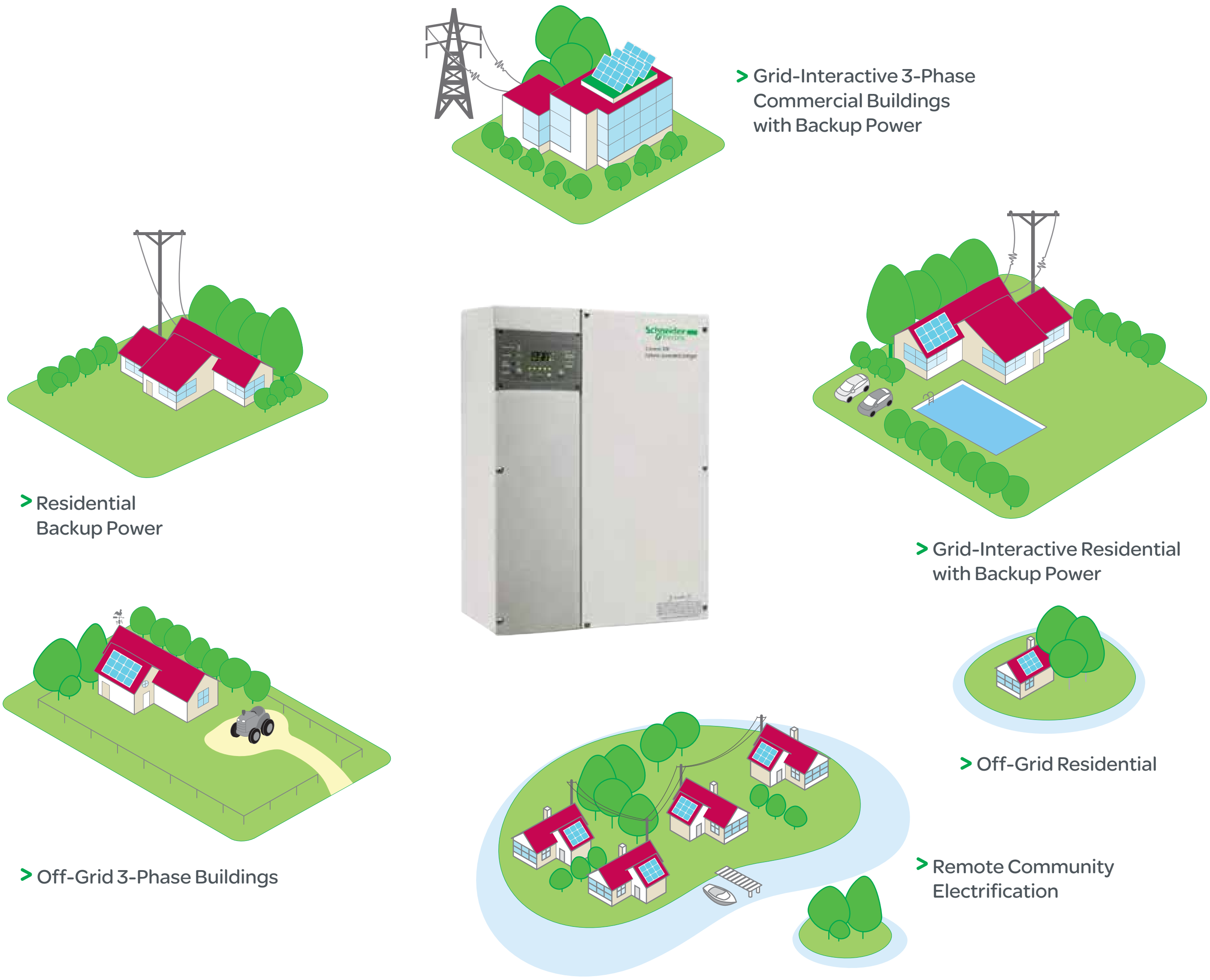

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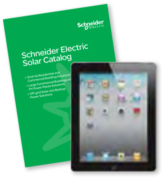

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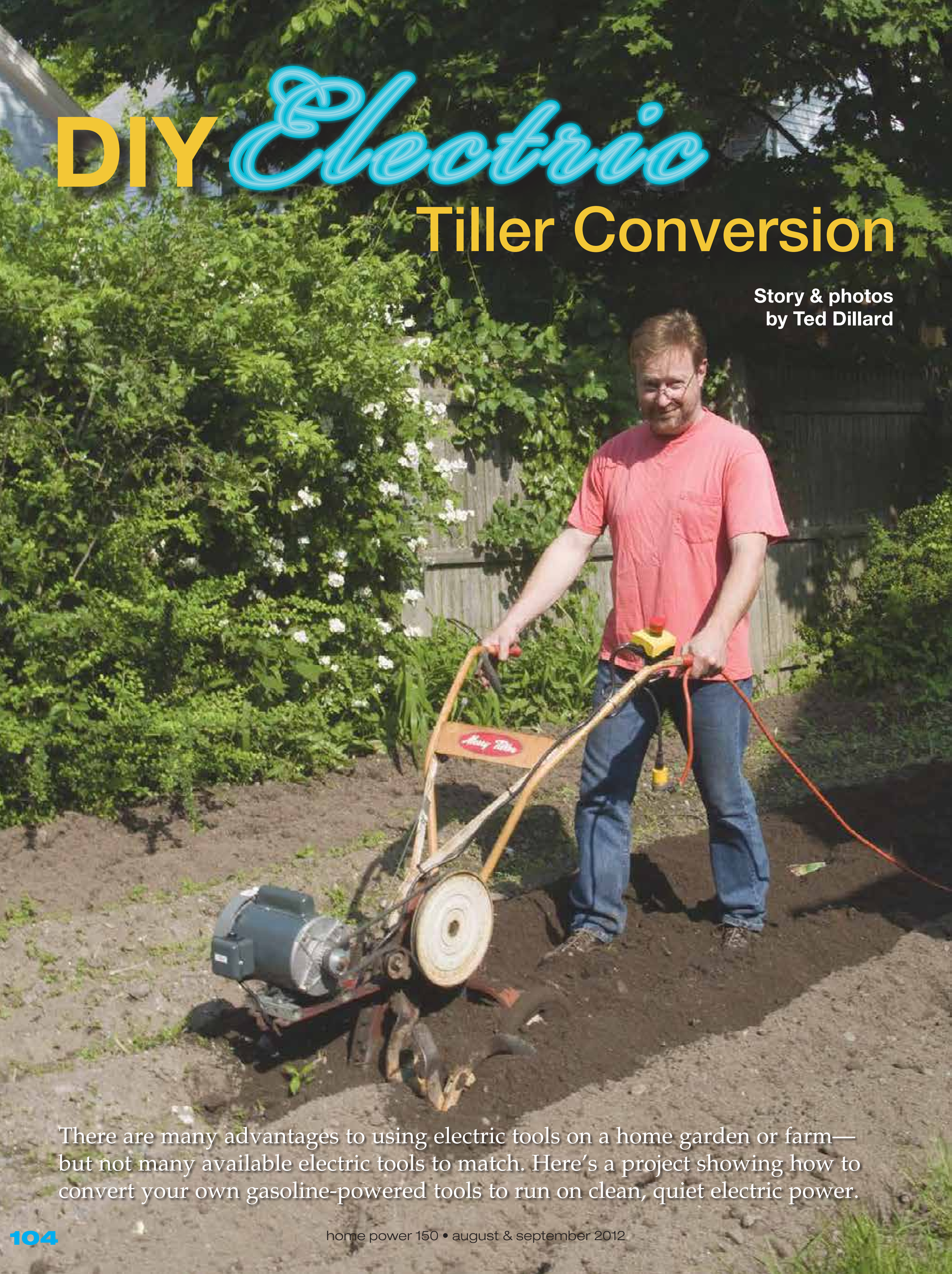
DIY Electric Tiller Conversion

Story & photos
by Ted Dillard



There are many advantages to using electric tools on a home garden or farm—but not many available electric tools to match. Here's a project showing how to convert your own gasoline-powered tools to run on clean, quiet electric power.

Electric tools don't need tune-ups, they need less lubrication, and they take less time to start, run, and put away for the season. And pollutants? Most small gasoline engines have little or no emissions controls, and contribute a large amount of pollutants to the surroundings—including acids (such as nitrates and sulfates), organic chemicals, metals, and harmful particulates which can end up in the soil—and our lungs.

The noise coming from an electric motor is insignificant compared to a gasoline motor with a typical muffler. At maximum power, a 1 hp AC motor is whisper-quiet at about 40 to 50 decibels. A 5 hp four-stroke gasoline engine with a stock muffler is about 80 decibels—loud enough to require ear protection, wake the neighbors, and scare off all the birds and wildlife. In a suburban environment, this becomes very important, especially if you're the type of gardener who likes to start working early on a weekend morning, rather than having another cup of coffee while you wait for the neighbors to wake up.

As we saw in the "Electric Gardener" (*HP148*), there is a growing selection of heavy-duty electric farm and garden products on the market—but in many cases they're expensive and hard to find. There are, however, many used, nonfunctioning, or broken tools on the secondhand market, some with engines that are ready to be replaced.

The Tiller Project

This project swaps out a small gasoline engine with a 120 VAC power-tool motor to make a corded AC tiller for use close to the house or barn. Look for a donor tiller that is robust and capable. We'll be using the converted tiller to open up new garden patches, turn the compost pile, and for occasional cultivating throughout the season.

Searching through online classified sources can yield a selection of out-of-commission tillers. Because they are typically used fairly heavily—but briefly—once or twice a year, then put away with relatively little "mothballing," they often fall prey to maintenance-related failures. If they're showing some age, it often seems easier to give them away or sell them rather than repairing them. You can find out-of-service tillers for $100 or less.

We were able to find a true classic: a 1960s vintage MacKissic Suburban Merry Tiller in running condition. Because this little tiller is almost legendary, we thought it was worth the premium $100 price tag. Plus, we'll be able to sell the working Briggs & Stratton 5 hp motor for a good price (if I can keep my teenager from putting it on a go-kart).

There's a throttle control on the handle, along with a spring-loaded clutch lever that operates a tensioning pulley to engage the belt drive. Converting the tiller to run on electricity is a matter of unbolting the gasoline engine, removing the throttle cable, and mounting the electric motor in place with an appropriate safety switch.

The Motor

The motor is a 1 hp, 120 VAC general-duty motor with a capacitor start and overheating protection, and has a cord with a switch. We found it on a surplus supply website for less than $100. There's one feature of this motor that's particularly important: It can be reversed with a simple change of wiring. Steer clear of a nonreversible motor, because most gasoline engines run in a counterclockwise direction (viewed from the output shaft end) and AC motors are set up to run in a clockwise direction. There's no practical way to reverse the direction of a nonreversible AC motor.

These motors have a standard mounting base, which works well for our tiller, and a commonly found 5/8-inch

The donor tiller, in its former incarnation.

This 1 hp, 120 VAC single-phase motor is perfect for the tiller, and inexpensive, too.

Tiller Project Costs

Item	Cost
Used Merry Tiller, 5 hp	$100
Electric motor, 1 hp	100
Extension cord, #10 100 ft.	85
Emergency cutoff switch	40
Misc. hardware	10
Pulley, 5/8 in. shaft	5
Sale of 5 hp gas motor	-50
Total	**$290**

Left: The cleaned mounting rails after the original engine was removed.

Right: Detail of how the new motor is mounted to the rails.

output shaft, so pulleys are readily available. This motor runs at about 3,000 rpm, so it's a good replacement for a 5 hp Briggs & Stratton gasoline engine running at full throttle. One hp—since it's measured as continuous horsepower versus the "peak" rating of 5 hp for the gasoline engine—seems to be in the ballpark.

To align the pulleys, we had to move the motor a little off-center. This shifts the tiller balance a little to one side, but only a fraction of an inch. We offset the motor using a square channel, to allow bolting to the frame through the bottom, then bolted the motor (about a 3/4-inch offset) to the top. Completing the power train was a matter of getting the same size pulley for the 5/8-inch shaft.

At this point, the tiller was operable—but not yet safe. The power switch is at the far front of the machine, making an emergency cutoff switch necessary. We found one at an industrial supplier. It's a simple wiring job—just put it

If the motor had been mounted directly the original rails, the belt would not have lined up properly, as shown in this photo.

Gasoline vs. Electric Motor Power

Choosing an electric motor to replace a gasoline engine can be confusing because they deliver power in very different ways. A gas engine has a peak output related for its rpm, torque, and resulting horsepower. An electric motor is more of a moving target, since it generates more torque as it's loaded, and draws more current as needed. The rating standards are considerably different, making it difficult to translate between the two types.

Our tiller's plug-in AC motor runs on standard 120 VAC, and most household circuits have a 15 A breaker. If we overload the motor, it will draw more current, and eventually trip the breaker. After a trip down a long extension cord and topping out at 15 A, 120 VAC probably gives about 1,200 W at the motor (including inefficiencies and voltage drop). That converts to about 1.5 hp—the maximum *actual* horsepower delivered.

If you can't deliver more than 1.5 hp to the tool, it's pointless to use a motor rated any higher than that. If you need a larger motor, run a 240 VAC motor and electrical circuit.

The emergency power cutoff switch will stop the motor and tines nearly instantly.

The Merry Tiller

The Merry Tiller is a remarkably simple machine, which accounts for its popularity. It has a basic two-rail angle-iron frame that the motor attaches to with four bolts. The transmission is an enclosed chain-drive with a very narrow profile, which is one of the secrets of this tiller's performance. Other tillers have a geared axle, which results in a much broader transmission enclosure and limits the depth at which the tiller can dig. The narrow Merry design allows the tiller to bury its tines, tilling to a full 12-inch soil depth.

The author with his newly electrified Merry Tiller, not missing the noise or exhaust fumes of its predecessor.

The new motor gets a new pulley. The belt is loose around the pulleys until the idler pulley (right side of photo) tightens the belt against the pulleys.

inline with one power lead to the motor. Solidly mounted to the tiller's handle with aluminum angle stock, you have a safe, big, red, push-button kill switch. Since it's not rated for continuous use, the switch is only for emergencies. You could eliminate this by moving the main switch to the bars, but it's nice to have that red kill button, much like other shop tools.

The tiller's operation lived up to every expectation. The motor makes a quiet "whoosh," and you hear an occasional clank of the tines or transmission bumping around. Because of its quiet operation, it can be run at virtually any time of day, regardless of the proximity to neighbors or your sleeping family. It produced one of the best-prepared beds we've seen —with no grease, oil, smoke, or noise.

Power Cord

Managing the extension cord is similar to working with a corded lawn mower, except with a tiller you're covering less ground and moving slower. Lay the cord out from your starting point, and always turn the tool away from the cord source. This keeps the cord behind and to the side of the business end of the tool.

Pay attention to the gauge and length of the extension cord you use. Extension cords are rated to handle only a certain amount of amperage—for example, a 16 AWG cord is rated up to 13 A, while a 10 AWG cord is rated up to 30 A. Excessive voltage drop can damage motors, so the cord's length must also be considered. Make sure you use an outdoor-rated cord of the appropriate gauge, and consult voltage drop tables to make sure you limit voltage drop to no more than 5%.

Access

Ted Dillard (ted@evmc2.com) has been an avid gardener since childhood and is an evangelist for all things electric. He writes "The Electric Chronicles" (devoted to two-wheeled electric vehicles), and is the author of *...from Fossils to Flux*, a basic guide to building an electric motorcycle. When he's not in his garden or in his shop working on his next electric project, he can be found at evmc2.com.

Making the Supply Side Connection: Article 705

by Brian Mehalic

Article 705 of the 2011 *National Electrical Code (NEC)*, "Interconnected Power Production Sources," provides requirements for any system producing electricity and operating in parallel with the utility grid. That means Article 705 applies to more than just utility-interactive PV systems (Article 690)—it's also applicable to small wind electric systems (Article 694, new in the 2011 *NEC*), fuel cell systems (Article 692), and generators (Article 445).

Sections of 705 cover disconnecting means, overcurrent protection, requirements for when the primary (utility) power source goes down, conductor sizing for inverter output circuits, and more. Some of these sections, such as Section 705.100, "Unbalanced Interconnections," were duplicated in the 2008 *NEC* in Articles 690 and 705. In 2011 several of these duplicative sections have been removed from 690, as they apply to any type of parallel power production system, not only PV.

A major change in the 2011 *NEC* was the removal of Section 690.64 which, in the 2008 *NEC*, was essentially duplicated in Section 705.12. Harmonizing the requirements for grid-connected systems makes sense, and allows the articles that cover the specific types (PV, wind, etc.) to be more streamlined. Expect more of this in future revisions—for example utility-interactive inverter output conductor sizing requirements are still duplicated in 690 and 705, and may end up residing only in Section 705 with a note indicating such in 690.

This "Code Corner" (and part 2 on load side connections in the next issue) will primarily focus on Section 705.12, "Point of Connection." This section governs how the output of grid-tied with battery backup, batteryless grid-tied, or other types of systems operating in parallel with the grid.

Types of Interconnections

The differences in how systems are interconnected are primarily dictated by system size (based on AC output current), the requirements of the local utility and authority having jurisdiction (AHJ), and rebate and incentive program requirements. Many residential and small commercial systems are net-metered, and connected on the load side (typically a back-fed circuit breaker in an AC panel) of existing service equipment. Larger systems, and systems that receive feed-in-tariff payments, may be interconnected directly to the utility through a meter or on the utility side of a building's main service disconnect (the supply side).

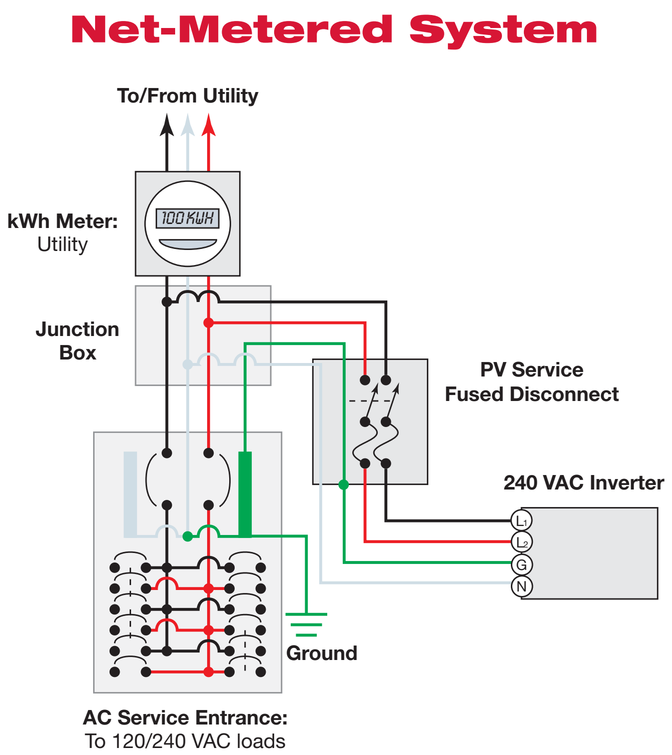
Supply Side Connections

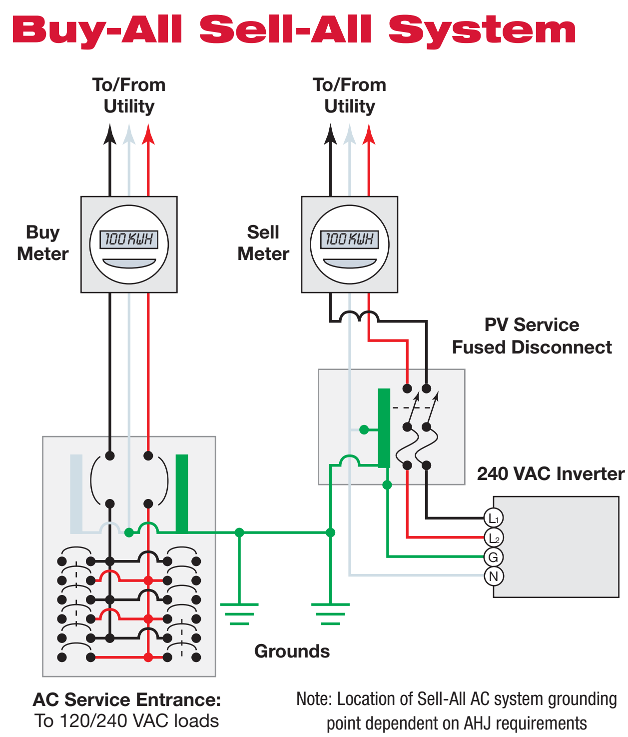
Section 705.12(A) permits connection on the supply side of the AC service disconnecting means, and refers to Section 230.82(6), which covers the various types of equipment that can be connected on the supply side. There are essentially two types of supply side connections. In areas with net metering and where system size does not allow it to be connected on the load side, they occur between the existing utility meter and main AC service disconnecting means.

On the other hand, "buy-all sell-all" type systems are connected directly to the utility through what is essentially a new AC service and a second meter—this is common in areas where feed-in-tariffs are offered, and all energy generated by the system is "sold" to the utility, while all energy used at the site is "bought." Large, multi-megawatt systems are connected in a similar manner, since there typically is no building or existing electrical service, and the size of the interconnection is beyond what would have existed.

There are numerous ways to make a supply side connection. In order to comply with OSHA requirements and NFPA 70E *Standard for Electrical Safety in the Workplace*, work should not be performed on energized conductors and proper personal protective equipment must be used. Careful coordination with the local utility and the AHJ is required, as power will have to be shut off from the existing service so that the new equipment can be installed and to ensure that the disruption to electrical service is minimized. Typically this involves the utility dropping the power, the work being performed, the AHJ inspecting the new work, and then the utility reconnecting power.

A supply side connection can be made by splicing into existing utility feeder conductors, tapping into bus bars on the utility side of the existing service disconnect, or double-lugging terminals (connecting a second set of conductors) either on the customer (load) side of the utility meter or the main AC disconnect. However, some of these methods can be difficult to accomplish in a code-compliant and practical manner—many residential and commercial load centers do not have means for connecting on the supply side without violating their listing requirements For example, bus bars often are not allowed to have additional holes tapped into them, and frequently connection points are not rated for more than one conductor. It is recommended to contact the





manufacturer of the existing equipment before proceeding, as additional equipment may be available or required, such as connectors that allow two conductors to be landed on each pole of a meter base.

Insulated piercing connectors allow a new conductor to be "spliced" to an existing conductor without having to cut or disconnect the existing conductor. While the temptation is to install them without shutting off utility power at the site, NFPA 70E is specific that working on energized conductors is allowed only in very limited circumstances.

More common in commercial applications is cutting into conduit or raceways between the meter and the main AC service disconnect to install an additional junction box inline. The box provides an access point where the service conductors can be cut to use Polaris-style insulated connectors for making connections. Piercing or Polaris-style connectors can also be used in residential and commercial applications if the conductors are accessible in the main AC service panel. Be sure to verify that this will not violate the listing of the equipment (if the conductors are insulated bus bars then this likely will not be allowed) as they can't be tapped and Polaris connectors cannot be used.

The requirements of *NEC* Article 230, "Services," must be followed. A service-rated fused disconnect—the minimum

Courtesy Positive Energy

Piercing-style connectors were used for the supply side connection for Line 1 and Line 2 in this 120/240 VAC residential service. The neutral conductor was landed on a terminal on the neutral bus bar.

A supply side connection on the bus bars of this large, three-phase service (note the black-, red-, and blue-marked conductors near the top).

Courtesy Sun Light & Power

size is 60 amps per Section 230.79(D)—is typically installed for supply side connections (using breakers can result in the panel needing to be oversized, for reasons that will be discussed in part 2 on load-side connections). The load side of the disconnect is connected to the PV system, and the line side to the utility. If the supply side connection is occurring between the main disconnect and the meter, then the new disconnect will count towards the maximum of six switches or breakers allowed per Section 230.71. However, Section 230.2(A) allows for additional services for parallel power production systems—the new meter and disconnecting means for a buy-all sell-all type interconnection should count as a separate service, but this will depend on the interpretation of the AHJ.

Section 230.91 dictates overcurrent protection device (OCPD) requirements, stating that the OCPD must either be integrated with or immediately adjacent to the disconnecting means. The current interrupting capability (AIC, not the "size") of the fuses in the new disconnect must be sufficient to comply with Sections 110.9 and 110.10, typically meaning it must at least match the AIC rating of the existing AC service disconnect.

Sections 230.23(B) and 230.31(B) require a minimum conductor size of 8 AWG copper or 6 AWG aluminum between the point of connection and the fused disconnect. Remember that these conductors are exposed to the full current potential of the grid—keeping them as short as possible, protecting them from physical damage, and oversizing them is recommended. However, be aware of the limitations of the terminals in the new, fused disconnect—a maximum size of 2 AWG is common for 60-amp rated switches.

Especially on residential systems, the overcurrent protection device size for the inverter output circuit required by Section 690.8 will be less than 60 amps, The rating of the fused disconnect must still be 60 amps, but fuse holders that allow smaller fuses to be inserted can be used so that, for example, a smaller 40 A fuse can be installed.

A supply side, buy-all sell-all connection in progress. The existing service entrance and meter are on the left; the PV production meter and fused disconnect are on the right.

Courtesy Rebekah Hren

Courtesy David Del Vecchio

New conductors were spliced onto the utility conductors in the box on the left for this supply-side-connected commercial PV system. The existing service equipment, including the original meter, is in the center; the meter for the PV system production and the fused disconnect are on the right.

Some utilities may require a second, lockable disconnect near the point of interconnection. If required, it can be installed between the new, fused disconnect and the inverter, and thus overcurrent protection is not required in this additional "utility" disconnect. It can simply be a switch, ideally located immediately adjacent to the fused disconnect and labeled per utility requirements.

Depending on the AHJ, for buy-all sell-all connections an equipment-grounding conductor (EGC) may or may not be installed between the new meter base and the service disconnecting means, depending on where the AC system ground (the connection between neutral and ground) is formed.

Previously, the size limit for a supply side connection was not specified in the *NEC*. As of 2011, the *Code* takes a common sense approach, stating in Section 705.12(A) that the sum of the ratings of all overcurrent protection devices connected to the power production sources cannot be more than the rating of the service. For example, if the required inverter output circuit OCPD—which would typically be a fused disconnect sized per Sections 705.60 and 690.8—for a PV system is 200 amps, the existing AC service would have to be at least 200 amps in order to connect the PV system on the supply side. If this isn't the case, the existing service, service entrance conductors, and possibly the utility transformer, may have to be upgraded.

Access

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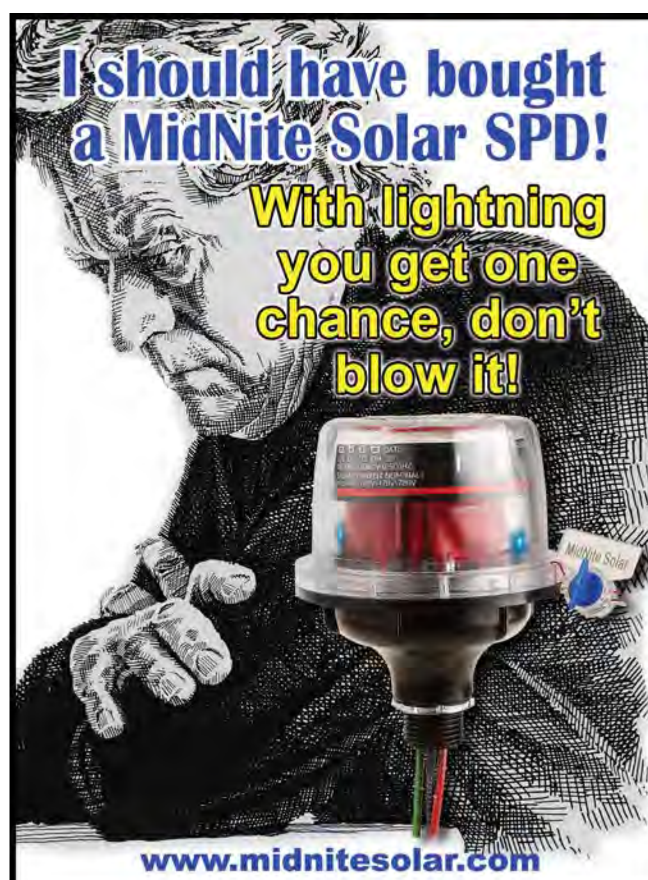
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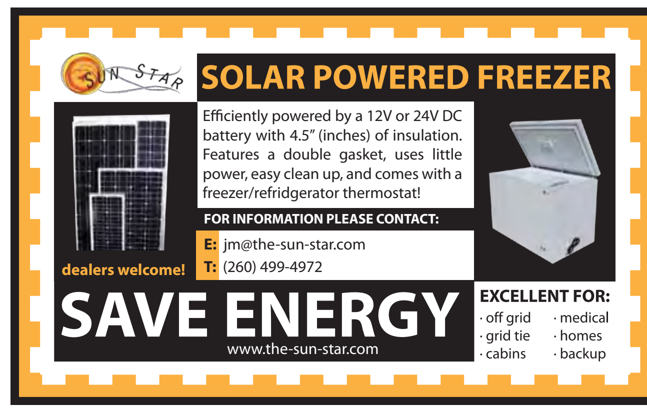
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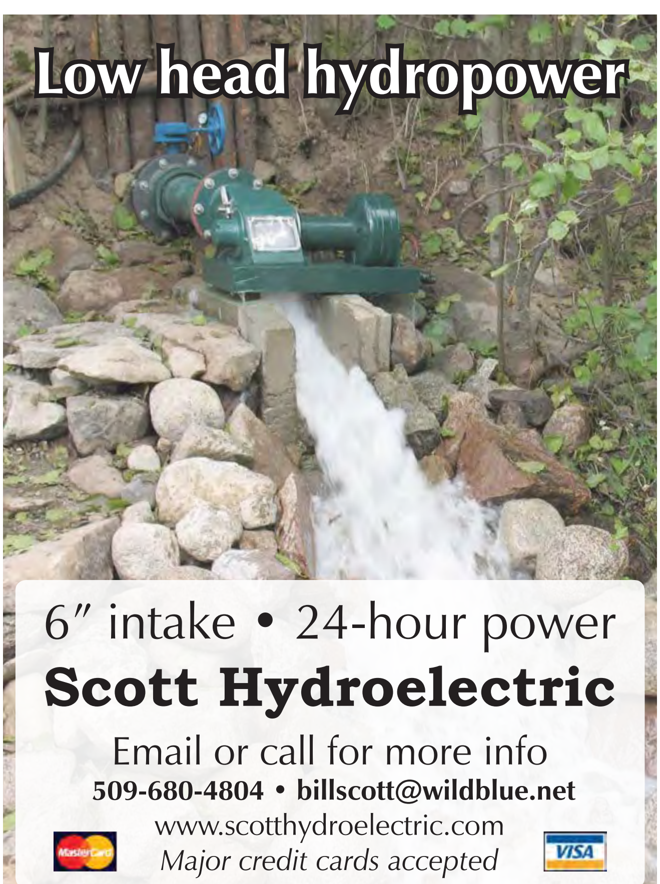
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The Code of the West

by Kathleen Jarschke-Schultze

While perusing my county's official website, I came upon a small e-book just 17 pages long. It is full of practical and (to me) amusing information for those people who move to our remote and unpopulated county to enjoy the country life.

Realities of Rural Living

The western author Zane Grey first wrote about the "code of the West." It's an unwritten code of conduct that bound the people who came to this part of the country during the westward expansion. In the booklet, the term is used to acquaint the urban newcomer to the realities of rural life.

Our county elevation ranges from 520 to 14,162 ft. and takes up about 6,300 square miles. That is more than 4 million acres, of which only about 12,000 acres are urban. With a population of 44,900, that comes to about seven people per square mile. Add that we enjoy all four seasons here in the mountains and you can see why newcomers might need a reality check.

The booklet goes on to describe the different geographical areas of the county—the history, activities, and attractions of each are outlined. I had to laugh when I got to one historical description. "Sawyers Bar boasts the oldest Catholic Church north of San Francisco. Built in 1855 and still in use, the church sits atop an estimated $200,000 in placer gold, surrounded by huge hydraulic cuts and preserved from undermining by the tiny historic cemetery adjoining it."

Several years ago, Bob-O and I went to a wedding at that church. When we were all seated in the old, shaky pews looking at the slightly tilting walls, the groom gave instructions. Starting with, "In the unlikely event of a water landing..." and ending with, "So, if the person next to you starts to drop through the floor, grab them firmly and quietly by the shoulders and hold on till the end of the ceremony." Good times. The last I heard, a priest from the valley comes over one Sunday a month for mass and to hear confession on the tailgate of his pickup.

Self Reliance

In rural life, you are responsible for many things that are covered by other entities in urban living. Clean water, sanitation, and access are your responsibility. As the whole county is open range, we have the right to fence out the ranging livestock. If that livestock tears down your fence and eats your tomatoes, you have the right to rebuild your fence and replant those tomatoes.

We have a "Right to Farm" ordinance here in paradise. Basically, this means if you move next to a farm, logging operation, cattle ranch, or just a neighbor with goats and chickens, you don't get to complain about the noise, smells, or view.

Water, the Real Gold

Mark Twain was supposed to have said, "Whiskey's for drinking, water's for fighting over." Without water, you can't live. Water is in short supply here and drought is common. You have to be realistic in your expectations of your water source.

While a well producing five gallons per minute is enough to support a couple with a small lawn and garden, it will not accommodate a family of six with a horse pasture and large garden without a water storage tank. All of our plantings, orchard, and vineyards are on drip, soaker, or low-flow mini-sprinklers and timers to utilize all the water available to us in the dry months.

Septic

There is a quite informative section on sanitation. Out in the country, we all have an ISDS (individual sewage disposal system). "The urbanite expects whatever they flush to go away. Locals expect the flush to end up underground in the back yard." Care and feeding of said septic system is covered fully.

My Road, Your Road

In the chapter about access to your property, the most useful advice is "Do not accept the word of a seller or agent, especially when they say you can't be kept off your property." From personal experience, I can tell you it makes for bad neighbor relations when someone falsely believes they have or control a property's access.

A four-wheel-drive or all-wheel-drive vehicle is recommended. "You may get along without one, but that ensures there may be times when you won't get out and won't get back for a few days." Yes, I can personally attest to this. It once took me two days to get back home because of a blizzard, and I was driving an all-wheel-drive Subaru. The only thing I can add is that if you come to a gate and have a right to pass through that gate, leave it how you found it—opened or closed. It was left that way for a reason.

A Fistful of Caveats

Property boundaries, mineral rights, homeowner associations, land use changes, buildability vs. livability, and construction are all touched upon briefly. The main theme is that it is up to you to educate yourself on these points as they pertain to your plans. There will be no one to come crying to if you are taken by surprise.

Utilities

The section on utilities reads like a prepper's handbook. Basically, there are utilities, but they can be unreliable. So, stock 72 hours' to a week's supply of non-perishable food, and get a generator if you need to run a pump for water or keep your freezer cold. Again, it is up to you to make sure your needs will be met.

I found two statements in this section very amusing. "Cell phone reception may be non-existent on the wild frontier." Hallelujah! Also, "Note: Salmon River Country has no commercial power available." Across the county on the Salmon River is where I married Bob-O 26 years ago. Starveout, the mining claim we lived on, was my first off-grid home. Except for buying less than 10 gallons of fuel a year for the backup generator, I haven't seen a utility bill in those 26 years.

Oh, Deer!

Nature has provided neighbors for you that have been here for thousands of years—deer, elk, bear, mountain lions, bobcats, coyotes, beavers, otters, raccoons, skunks, trout, hummingbirds, squirrels, et al. They were here first, some are protected, and some must be endured. A regional wildlife writer described a poodle on a deck as a "meatloaf with fur." We do have a county trapper provided to help get rid of nuisance animals. But he doesn't come until after Rover is somebody's dinner.

Wildfire

Wildfire is always a concern. Good advice is given on clearing a defensible perimeter. "The 'Darn Fool Clause' says it is OK if you burn your own house down. But if your house sets the woods on fire, and the neighbors are threatened or burned out, you are responsible."

Emergency Services

When we were on the Salmon River, Bob-O and I became emergency medical technicians (EMTs) with a volunteer rescue group. The rural reality here is that in many places in our county there is no "Golden Hour"—that time within which if you can get a severely injured person to a hospital, the odds are in their favor. When a tree fell on Bob-O and broke his leg open on a remote mountainside, it was four hours before a doctor saw him. That was with the volunteer rescue assisting and a helicopter ride.

Reality Checked ✓

Other information about which services you are responsible for and which the county provides are briefly discussed also. Another theme that runs throughout is the fact that where you live is your choice, and once you move there, your neighbors and the county are not going to change anything to suit your preferences. I truly appreciate the forethought that went into publishing "The Code of the West." I think anyone moving from an urban to a rural area should read and take heed. This tome of truths ends with, "It is not our intent to dissuade you, only inform you."

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is more than marginally mountain at her off-grid home in northernmost California.

The Code of the West...The Realities of Rural Living • bit.ly/CodeOfWest

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Power Factor

"Charges" (electrons in wires) are the energy carriers in an electrical circuit. Charges are part of the material of the conductor, the atomic structure of the copper or aluminum wire. Charges don't leave the circuit, and they aren't used up. They move from one atom to the next, with another charge filling the "hole" just vacated.

In a direct current (DC) circuit, they move in one direction. In an alternating current (AC) circuit, they move back and forth. In AC circuits, the direction of charge flow reverses many times a second. The voltage (electrical pressure) and amperage (rate of charge flow) go from zero to maximum in one direction ("positive"), back to zero, to the maximum in the other direction ("negative"), and then back to zero. We call this a "cycle," and in the United States, AC is 60 cycles per second (Hertz or Hz for short). When the voltage and amperage peak and then go to zero at the same time, we say that they are "in phase" (see diagram). This is what happens in circuits that have only resistance.

But many AC circuits also have a couple of other electrical properties—inductance (storing energy in an electromagnetic field, opposing a change in amperage) and capacitance (storing energy in an electrostatic field, opposing a change in voltage). These push the voltage and amperage out of phase with each other, so that they peak at different times. In these "reactive" circuits, some of the energy is bounced back at the source in a delayed reaction, due to the characteristics of inductance and capacitance. Reactive loads include motors, fluorescent light ballasts, and many electronic devices.

Power, the rate of energy flow, can be calculated by multiplying voltage and amperage (electrical pressure and charge flow rate). So in a purely resistive circuit, if source voltage is 120 and amperage is 10, the power is 1,200 watts.

In a reactive circuit, because the voltage and amperage are not in phase, less power is available to the load. Some of the charges are just moving energy back and forth unnecessarily, and this creates an illusion of power, known as "reactive power."

We call the product of volts times amps in a reactive circuit "apparent power" (also called "volt-amps", and abbreviated "VA"). We call the power that is usable to the load "true power" (watts, abbreviated "W"). The ratio of true power to apparent power is called "power factor" (PF). A power factor of 1—when the apparent and true power are the same—is ideal.

W ÷ VA = PF

If we take the same 120 volts and 10 amps from the example above, but the load in the circuit has a PF of 0.8, the power available to the load will be only 960 watts. To make up the difference, higher amperage is needed in the circuit. Since losses in a circuit are tied directly to the charge flow rate (amperage), raising the amperage (to compensate for low PF) in a given size of wire means that the voltage losses in the wire will increase. So a circuit with bad (low) PF will need larger wires to keep the voltage losses at the same level as a circuit with good (high) PF.

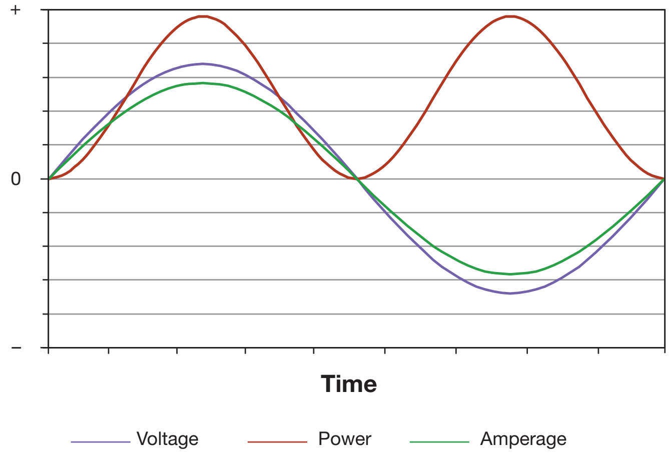
Devices that purport to save you lots of money by correcting power factor are largely a scam. While avoiding poor PF or correcting it is not a bad idea, the reality is that utilities do not usually charge residential consumers for VA-hours, but for watt-hours. These devices (if they do correct for PF) may help the utility, but won't help you much in most cases.

"Watts" are a measure of the energy flow from the generating source to the load. "Volt-amps" are a measure of the theoretical maximum energy flow, including the illusory reactive energy that is bounced back to the generating source. The practical lessons are that high PF devices are always going to be easier on your generating sources—they will increase efficiency in your systems. And wire sizing must take into account the full apparent power that the load needs, even though some of it is recycled by the circuit.

—Ian Woofenden

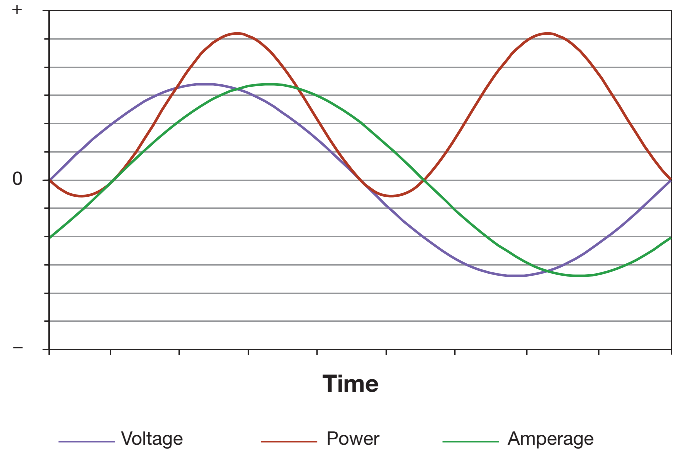
Resistive Load

(PF = 1.0, V & A In Phase)



Reactive Load

(PF = 0.8, V & A Out of Phase)

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