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How Wood Heat Stacks Up

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Raising Green Home Design Standards (Again)

Feb. & Mar. 2014, Issue 159
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contents

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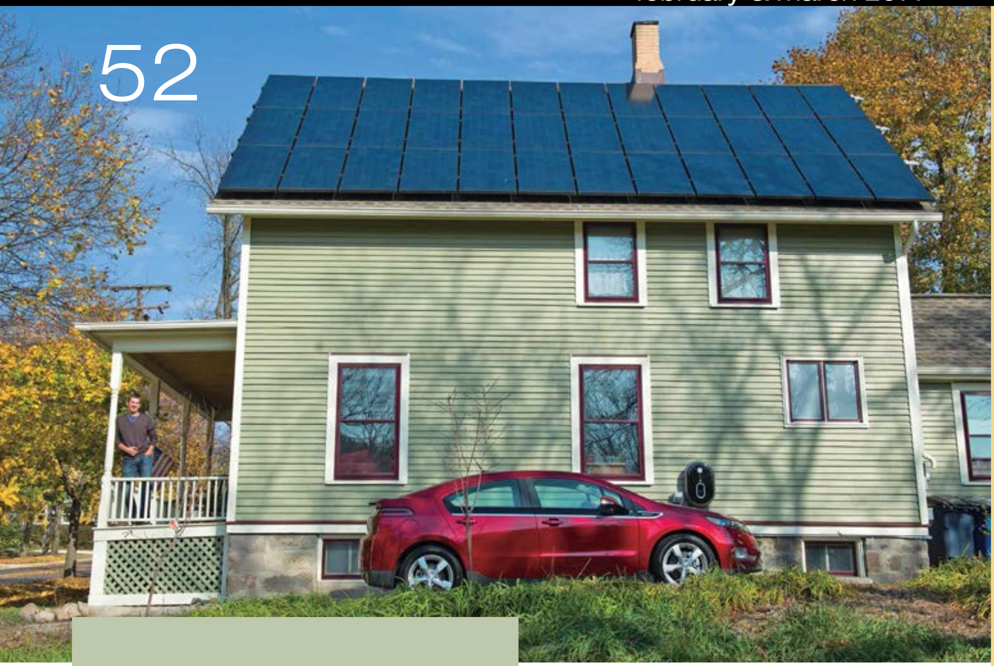
52



Main Features

Photos, left to right: Matt & Kelly Grocoff, Lopi, Willow-Witt Ranch, whattookyousolong.org for USAID, Salt River Project

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On the Cover

Off-grid renewable energy systems have provided this working ranch with most of its electricity for more than 20 years.

Photo: Shawn Schreiner

44

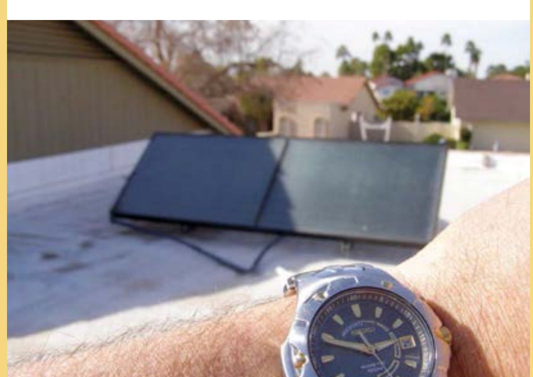
34

contents

Up Front

More Features

64



In Back

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What Are You Waiting For?

That's not a comment in the form of a question—we really want to know. Over the years, *Home Power* has tried to figure out what it would take for home-scale rooftop solar to "explode" into use—becoming so commonplace among homeowners that seeing PV modules would no longer result in pointing a finger at the rare rooftop array and saying, "Wow, how cool."

In the early '90s, we naively thought that point would be when PV modules reached $5 per watt. But some of us had the minds of early adopters, and I mistakenly believed that the general population would, like us, jump at the opportunity when solar would appear even remotely affordable.

We've been below that not-as-magical-as-we-thought $5 per watt point for awhile. In fact, *entire* installed systems—not just the PV modules themselves—are below that point in many cases. Assuming there is some perceived value in coolness and greenness, rooftop solar has been theoretically affordable for many years—even though it was costing a little more money than grid energy. But still no "explosion."

Grid parity has been reached in many markets throughout the Western world. For the home-scale solar market, grid parity is the point at which the cost of electricity from a rooftop PV system is equal to or cheaper than what you would pay for utility electricity. According to a recent report from Deutsche Bank, grid parity has been reached in 11 out of the 25 countries they analyzed (including several energy markets in the United States) and is very close in others.

Yet the explosion still has not happened. It turns out that even though nearly everyone likes rooftop solar, it takes more than low cost to decide to implement it. I still think that most important is the desire—how much you really want solar. With enough desire, nearly any impediment to PV can be overcome.

Of course, along with desire and cost is access to funds. Solar could be half the cost of utility service, yet many still feel they cannot afford the upfront cost of installation. It is a lot gentler on the wallet to pay a monthly utility bill than come up with several thousand dollars to install a PV system. But in nearly all cases, that should no longer be an obstruction. Financing is available through second mortgages or refinancing a home to get improvement money. Financing is available from many solar installation companies too. And for those who cannot qualify for financing, there are leasing programs offered by some installers that can put a company-owned system on your roof.

So back to the original question. Now that PV-generated electricity is, in many places, cheaper than grid energy; and now that financing is readily available; and since the coolness factor has not decreased, and environmental situations have *increased* the value of the green factor—please let us know what you are waiting for. And if you already have a PV system, we'd love to hear what it was that helped you decide to "go solar."

—Michael Welch, for the *Home Power* crew

Think About It...

"Git-R-Done."

—Larry the Cable Guy

contact us

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Reforms
for Small Utility-Scale Interconnections

New federal standards may make it easier than ever for distributed generation (DG) projects to connect to the grid.

Following nearly a year of public comment and stakeholder participation, the Federal Energy Regulatory Commission (FERC)—the agency responsible for regulating the high-voltage electricity grid—issued reforms to the interconnection rules for wholesale DG systems up to 20 megawatts in size and subject to FERC jurisdiction. The reforms target certain provisions of the "Standardization of Small Generator Interconnection Agreements and Procedures" or "Order No. 2006," which was established in 2005.

"FERC's rule changes are an important step forward for interconnection in the United States," says Jane Weissman, president and CEO of the Interstate Renewable Energy Council (IREC), which worked with FERC and other stakeholders to help develop the proposed changes.

Growing Distributed RE in the U.S.

According to the Interstate Renewable Energy Council, roughly 95,000 distributed grid-connected PV systems were installed in the United States in 2012 and nearly 300,000 total residential PV systems are now connected to the grid. More than 3,800 wind turbines were installed in 2012, and 69,000 systems are now grid-connected, according to the U.S. Department of Energy.

The new rule, which was finalized in November, makes it possible for more projects to avoid undergoing a full interconnection study and connect to the grid more quickly. The changes address the growing volume of interconnection applications and the number of circuits that are starting to include smaller-scale renewable generation sources.

Under the original rule, only projects 2 MW or smaller qualified for fast-track interconnection—all others had to carry out costly and time-consuming studies. One change revises fast-track eligibility for systems up to 5 MW, based upon individual system and resource characteristics. The new rule also creates a pre-application report process that enables generators to obtain available system information which will assist small generators in evaluating the potential costs and time frame associated with their project.

The FERC rule-making process began in February 2012 when Solar Energy Industries Association (SEIA) filed a petition against FERC. A key contention was that a project could not

continued on page 12


Courtesy Nextamp

Under the new FERC rules, PV systems less than 5 MW, like this 4.5 MW installation at Westford Solar Park in Westford, Massachusetts, may be eligible for fast-tracking.

be approved for fast-track interconnection unless it was less than 2 MW and the total DG was less than 15% of the line section's annual peak load. According to SEIA, the 15% rule excluded the majority of solar projects from the fast-track process, forcing them to perform interconnection studies and upgrade processes that often jeopardized project viability through higher costs and the length of time required to get approval.

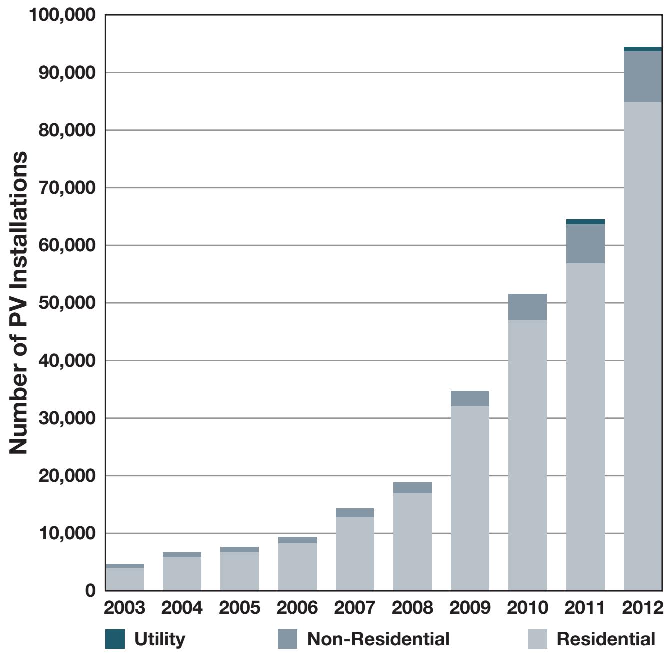
While FERC's jurisdiction is limited to large, interstate transmission lines utilized by wholesale energy generators, states tend to follow FERC's lead. The agency's 2005 standards—which established the first set of interconnection procedures for wholesale electricity generation projects under 20 MW in size—were adopted by many states and remain in place today.

With rare exceptions, the majority of smaller wholesale DG systems connect to the distribution grid via lower-voltage lines regulated at the state level. This is why it is important for state regulatory bodies to similarly update their interconnection rules.

"Many of the top solar states—those with high numbers of residential and net-metered systems—already have severe backlogs. These new procedures will benefit those states immediately. Other states may not have backlogs now, but DG is growing rapidly. Those states need to act fast to avoid lengthy interconnection queues," says Sky Stanfield, an attorney with Keyes, Fox & Wiedman who represented IREC interests in the rule-making process.

"The hope is that these new rules will trickle down to the state level. These changes will open up the markets for solar and wind across the country, and get these systems connected to the grid quickly," says Ted Ko, associate executive director of Clean Coalition, a California-based nonprofit organization working to accelerate the transition to local renewable energy sources.

Distributed PV Installations Since 2003



Source: Interstate Renewable Energy Council

While the rule change won't immediately affect the average homeowner or small business, it will likely have a far-reaching impact on DG and help spur community solar projects in the long run, according to Stanfield. Rhone Resch, president and CEO of SEIA, says the decision will help to reduce interconnection bottlenecks and bring PV systems online faster.

—Kelly Davidson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Fronius USA's Galvo

Courtesy Fronius USA

String Inverters

Fronius USA (fronius-usa.com) has four new residential string inverters. The Galvo inverter series includes models with rated power outputs of 1.5, 2.0, 2.5, and 3.1 kW. The 1.5-1 and 2.0-1 models have an MPPT range of 120 to 335 VDC. The MPPT range for the two higher-power units, the 2.5-1 and 3.1-1, is 165 to 440 VDC. All models can be connected to 208 or 240 VAC services.

The low-profile, 36.9-pound Galvo inverters feature an innovative SnapINverter hinge-mounting system for quick installation and serviceability, and an integrated DC disconnect. The high-frequency transformer topology allows for positive- and negative-grounded systems. Internal protective devices include a Type 1 arc-fault circuit interruptor (AFCI), ground-fault detector/interruptor (GFDI), and DC reverse-polarity protection. The Galvo series inverters include integrated WiFi and free data hosting for the life of the system on Fronius's SolarWeb monitoring portal.

—Joe Schwartz

OutBack Power's FLEXcoupled

AC-Coupling System

Courtesy Outback Power Systems

The FLEXcoupled system from OutBack Power (outbackpower.com) utilizes an AC-coupling center (GSLC 175-AC-120/240) to provide stable electromechanical coupling of grid-tied string and microinverters with OutBack's Radian GS8048 battery-based inverter. The solution is developed to be compatible with a wide range of string and microinverter products and array voltages of up to 600 VDC. The FLEXcoupled solution provides backup for grid-tied systems with up to 6 kW of PV input. Designed for both new and retrofit installations, the full AC-coupling includes the AC-coupling GS Load Center, Radian GS8048 inverter, MATE3 with mounting bracket, eight EnergyCell 200GH batteries, and an integrated two-shelf battery rack.

—Joe Schwartz

Appalachian Institute for RE

Developing the Southern Sun

In the fall of 2013, Highland United Methodist Church (HUMC) in Raleigh, North Carolina, flipped the switch on a 50-kilowatt rooftop PV system. Installed by Atlanta-based Inman Solar, the system was developed using a unique public-private partnership model organized by the Appalachian Institute for Renewable Energy (AIRE, aire-nc.org), a nonprofit group based in Boone.

With assistance from AIRE, the church's "green" committee sought congregation members willing to invest in the church's PV system. Nine members stepped up, each contributing $10,000 to $30,000 to the project. The investor group formed a limited liability corporation (LLC) to capitalize on tax credits and incentives that are designed to promote renewable energy development but restricted to businesses and high-income individuals.

"As a nonprofit, the church could not qualify for the tax credits that make PV systems an affordable option. AIRE showed us that there is another way to achieve our solar energy goals," says Carneal Downey, a congregation member who invested and helped organize the project.

The Highland United Methodist LLC members are leasing the system to the church, operating and managing the PV system for the next four years. During this time, the project investors will recoup their investment through accelerated depreciation, the federal investment tax credit, and the sale of produced electricity and renewable energy credits (RECs). Once the investors recover their investment, the LLC plans to donate the system to the church, generating a charitable tax deduction for the investor group. In the end, investors will walk away having recouped most, if not all, of their initial investment, and will have helped the Church protect against the rising cost of fossil fuel-based energy. While the investors could have profited from the investment, they chose to structure the deal to the church's advantage.

AIRE executive director Steve Owen founded the group in 2007 as an outgrowth of his work to end mountaintop removal for coal mining in Appalachia. His goal, he says, was to start the renewable energy conversation in Appalachia and illuminate the importance of community-scale projects in reducing fossil fuel dependence. Recognizing that the upfront costs of PV systems are a barrier for most nonprofit and community organizations, Owen began researching financing options. He found inspiration in the John Deere Corp., which takes out loans to help farmers finance multimillion-dollar wind turbines. As the initial tax-equity investor, the corporation covered the upfront cost of the systems and then used tax write-offs to make a return on their investments. For a typical five-windmill deal, selling the electricity can generate between $1 million and $1.5 million per year in revenue. The federal production tax credit is worth about another $500,000 annually. After 10 years, when Deere paid off the loan and recouped its investment, plus profit, the ownership structure flips, with the farmers becoming majority owners of the systems.

Continued on page 18

The AIRE-assisted array at Highland United Methodist Church in Raleigh, North Carolina.

Courtesy Highland United Methodist Church

Continued from page 16

Owen wondered if the model could work for nonprofits and community organizations. "Tax law is very complicated. The law allows a number of credits for companies and corporations, and for wealthier individuals who have a certain level of passive income from dividends and interest," says Bob Olsen, a CPA and tax attorney who consults on AIRE projects. "While the average person cannot benefit from these credits, a group of average people united in a legal structure, such as an LLC, can."

In 2009, Owen tested the model with a pilot project in downtown Boone: a 2.4-kilowatt PV system installed on the building where AIRE's office is located. He organized the project as an LLC, with five investors who covered the upfront cost of $8.34 per watt. In this case, the group made a modest return on their investment through federal and state tax incentives (including North Carolina's 35% income tax credit), and by selling the electricity produced under a power purchase agreement with the building's owner.

Since then, AIRE has assisted with the development of seven projects, and has 10 others planned for the coming year, including its largest project so far—a 1-megawatt ground-mounted PV system, plus a 50 kW solar carport (with two EV charging stations), at the Salisbury campus of Rowan-Cabarrus Community College. AIRE covers its administration costs by collecting developer fees—typically 10% to 20% of the project cost—from the project investors. When possible, AIRE waives their fees or secures grant funding to cover their costs.

AIRE is helping community solar find its place in North Carolina, but with the predominance of coal and nuclear energy, Owens says that the state faces an uphill challenge with renewable energy. "There's a lot of tension between the state's key stakeholders over our energy future and what ought to be, but we're getting there. While North Carolina may never be a California, Massachusetts, or New Jersey where renewables are concerned, we're making strong headway for a southern state," he says.

Helping drive the state's RE development is its renewable portfolio standard—the only mandatory one in the Southeast. In 2012, North Carolina installed 124 MW of solar-electric capacity, ranking fifth nationally, but the momentum might slow if the state's tax credit—equal to 35% of the cost of eligible RE systems—is not renewed in December 2015. Last spring, the legislature lowered marginal tax rates, making this credit less valuable to investors. Reductions in incentives—namely the expiration of the federal tax credit in 2016—could threaten the longevity of AIRE's model, but Owen remains confident that rising costs of fossil-fueled electricity, paired with declining PV prices and growing demand for RECs, will keep AIRE's approach viable for years to come.

—Kelly Davidson

Students, Science & Solar

Courtesy Bertschi School

Bertschi School Living Science Building (BSLSB), located in Seattle's Capitol Hill neighborhood, was one of the first projects in the world to pursue the Living Building Challenge (LBC) certification under its version 2.0 criteria—and the first to achieve it. This nonprofit elementary school science wing was designed with the input of the students.

BSLSB is a 1,425-square-foot building on a site that was previously a paved sport court. The school has a variety of outdoor student learning zones that provide everything from physical activity to quiet contemplation. The most important aspect of the project is that all sustainable features are visible and functional to students to learn ecological concepts that can become intrinsic values for future generations.

The advocacy for health was one of the drivers for Bertschi School to undertake the rigorous standards of the LBC. During the design phase, the team worked to create spaces that provided healthy air and daylight for occupants, and carefully chose building and finish materials that were as nontoxic as possible.

The building taps into the sun with a 20.4-kilowatt batteryless grid-tied PV system, which produces all of the building's electricity. The microinverter-based system allows students to participate in real-time monitoring of the solar power production through Enphase Energy's Enlighten website.

All of the water needed for the building is collected and treated on-site through a variety of methods, including cisterns for storage and a composting toilet to treat blackwater. The inclusion of the green wall of tropical plants to treat graywater (see "The Living Building Challenge" in this issue) has the added benefit of helping purify the air.

For the students of Bertschi School, the beauty of their LBC building is in the manifestation of their dreams. When the design team began the project, they started with the students, asking them what a "living building" meant to them. What did they dream about seeing in their classroom? How did they wish to see nature expressed? The students were inspiring and shifted the focus of what the designers thought was possible, requesting "a stream [that] could be running under the classroom" and "a greenhouse where something would be always growing." Out of these ideas developed some of the building's greatest design features that not only perform functions and met LBC imperatives, but inspire and illustrate the beauty of nature.

—Adapted from the BSLSB case study on the International Living Future Institute website (living-future.org)

Overview

Project name: Bertschi School Living Science Building

System type: Batteryless grid-tied PV

Installer: West Seattle Natural Energy

Date commissioned: August 23, 2010

City: Seattle, Washington

Latitude: 47.5°N

Average daily peak sun-hours: 3.8

System capacity: 20.4 kW STC

Average annual production: 23,600 kWh

Average annual utility bill offset: 100%

PV modules: 60 Schott 225 W; 30 SolarWorld 230 W

Inverters: 60 Enphase M190 microinverters; 30 Enphase M215

Inverter rated output: 60 at 190 W each; 30 at 215 W

Array installation: South-facing roof

Array azimuth: 180°

Tilt: 28°

Cargo Bicycles

Cargo bikes are the pickup truck of bicycles, and with an electric assist they can be a very effective car substitute. They can have a box in the front like the Dutch bakfiets (translation: box cycle), which are common in Amsterdam and Copenhagen, or have an extended rear frame with a large rack, like the long-tails. The box or rack makes it easy to carry kids, groceries, large boxes, or even surfboards. Adding an electric motor enables using a bike instead of a car, and the battery is also a good power source for a bright headlight.

There are also trikes being used as utility vehicles, but my narrower two-wheeled Bakfiets has been a better fit on the rural roads of Vermont, where I live. With light to moderate pedaling, my electric-assist bike is using an average of 13.2 watt-hours of electricity per mile (equivalent to 2,553 miles per gallon), at a cost of a quarter of a cent per mile. My traveling speed is usually 16 to 19 mph, with an overall average of 14.8 mph. My fastest speed has been 40.9 mph. Hills are much easier with the motor. The six-mile ride to the center of my town takes 21 minutes on the Bakfiets versus 13 minutes in a car, and the 17-mile ride to the food co-op is 56 minutes versus 29. An errand of 40 miles is feasible, even though I'm not in shape for that!

The tradeoffs are weather and speed. Temperature isn't as important, as dressing for the cold is standard procedure in Vermont, and riding along on an electric bike when it is hot is actually enjoyable. Precipitation is more of a problem, although loads in the cargo box stay dry. The slower speed has turned out to be not that much of a problem. Compared to a car, it works out to 10 to 20 minutes of extra time for most trips, which is acceptable.

In contrast to the many PV modules required to recharge an electric car, an electric bike can typically be charged with one PV module. I've added 60 watts of PV to my Bakfiets, which, on sunny days, provides a quarter of the energy needed and also recharges the battery when the bike is parked. Bikes participating in The Sun Trip tour carry enough solar-electric modules to fully power them. The original Sun Trip bike traveled 7,500 kilometers last summer from Savoie, France, to Astana, Kazakhstan (thesuntrip.com).

Bikes are an excellent fit with a renewable-energy-powered world. I would like to suggest publishing an article about electric-drive bikes and, in particular, cargo bikes for everyday utility use. There are 14 bakfiets and 15 long-tail bike companies that I know of. Plus, Smart Growth America's National Complete Streets Coalition is gaining some traction. I've also started a blog about my bike—MySolarElectricCargoBike.com—and would love to hear from others.

Karl Kemnitzer • Hartland, Vermont

Monetizing Sunshine

I enjoyed Andy Kerr's "Monetizing Sunshine" in *HP154.*

There is one very major factor that is not considered with solar as an "investment." If you have money to invest in solar, you then subtract utility costs from other investment returns you are considering. In other words, if you choose to invest in a mutual fund instead of solar electricity, you subtract your utility cost from your mutual fund returns. If a solar-electric array costs $15,000 out of pocket and returns $80,000 in savings—that's good. The same $15,000 invested in a mutual fund may return $100,000, but you've still paid the $80,000 in utility costs.

Now consider what you *do* with the savings. If you pay off your array in five years, and then *invest* the savings in an individual retirement account—well, now you're talking. Because—work with me now—to pay a $100 electric bill, you have to *earn* almost $150 in order to also cover taxes. Which means you can now save roughly 150% of your utility cost, tax-deferred. Your out-of-pocket is the same, but you are paying yourself $150 instead of $100 to utility and $50 to Uncle Sam.

R. Schorert via homepower.com

Wind Turbines & Property Values

In 2005, I presented at a public hearing to get approval to install a classic Jacobs Wind Electric wind turbine atop a 120-foot-tall tower in our backyard in Merton, Wisconsin. The opposition concern heard most often was over potential declining property values. It was only after five hearings that we finally received formal approval and installed the Jake in September 2006.

Afterward, I was determined to further prove that a residential small wind-electric system would, in fact, *not* cause a decline in neighborhood property values. I compared the prices of homes sold in the affected zone (our neighborhood) versus the entire town of Merton before and after the installation

Home values peaked in the United States and Merton in the second quarter of 2006. During the 12 years I looked at, the number of homes sold in a given year varied greatly.

I used various statistical tools to determine whether a wind genny affects residential property values. The conclusion that I drew was that a wind genny installation

Median Home Price Comparison

Year	Wind Genny Area	Town of Merton	Difference
2001	$247,500	$227,500	$20,000
2002	272,200	272,200	0
2003	320,000	272,000	48,000
2004	315,000	314,500	500
2005	344,250	319,500	24,750
2006	341,950	337,500	4,450
Wind genny installation in 2006, which coincided with the housing market crash			
2007	328,700	334,450	-5,750
2008	286,500	319,250	-32,750
2009	323,500	300,450	23,050
2010	320,750	312,500	8,250
2011	313,500	272,950	40,550
2012	336,000	328,000	8,000

continued on page 24

continued from page 22

has no effect on the median home sales prices in a residential neighborhood. It is my sincere wish that this study will help make the approval process a bit smoother for anyone else encountering similar opposition to installation of their own residential wind turbine.

Willi Hampel • Merton, Wisconsin

Automatic Energy Savings

Your "From the Crew" article in the recent issue of *Home Power* was great ("Energy Lessons in Action" in *HP158.*) I agree that showing your kids actual numbers is a very effective way for them to understand the concept of energy usage.

A very helpful energy-saver is an "occupancy sensor"—a replacement for a light switch. As the name implies, it has a motion detector that turns on the lights in a room when someone is present, and turns them off after the room is vacated. These are available at almost every hardware store around the country, and the cost range is $20 to $28 per switch. They are as easy to install as a new light switch. The nice thing about these switches is that it eliminates the need to constantly remind (both kids and adults) about conserving energy.

Jeff Siegel • via email

Courtesy Leviton

Heating Choices

I enjoyed reading the article entitled "Platinum PV" in *HP158.* It was interesting to see where the designers didn't agree with the LEED standards. I would like to take issue with another of the design decisions made in this house: the choice of an electric furnace instead of an air-source heat pump.

The article mentions that it was less expensive to add PV to cover the electricity of the electric heat than to install a heat pump. While this may certainly be the case, it doesn't take into account the actual electricity used to power the heat. Electricity is used in real time. The utility isn't storing our PV-produced power for us to use later. This electric heat unit will likely run mostly at night and during cloudy weather. This means that it will be using electricity largely produced by coal, nuclear, or natural gas—not PV-produced energy.

So with this design choice, you have a heating system that overall uses more electricity than a heat pump. And, this electricity is most likely coming from conventional energy sources. It seems that a Platinum-certified LEED house would strive to use less energy overall (even if offset by PV production) and certainly less from fossil fuels. Installing an air-source heat pump would have met both of these goals and provided air-conditioning for the home.

Matthew Huffman • Swoope, Virginia

Induction Cooking

Kathleen Jarschke-Schultze wrote about induction cooking in "Home & Heart" (*HP157*), and, like her, we've been thrilled with induction cooking. I recommend theinductionsite.com as a source for information on induction cooking, and comparative testing and evaluations of induction cooking appliances. That's where I found information on our Max Burton hotplate by Athena, which delivers 1.5 kW at its top setting (more than Kathleen's)—close to the maximum that a 15 A, 120 V household circuit can deliver. It boils a pot of water faster than on our gas stove, so in summer we haven't used the stove at all. The hotplate is also portable, so I use it to do canning outside, keeping the house cooler, and sometimes for camping or traveling.

I recommend that you never put an empty pot on the burner when it is on, nor one that is not round, or is larger than the induction area shown. Also, don't wear on your hands any jewelry that has so much iron in it that a magnet will stick to it. The magnetic field has a limited range of about a half an inch above the "burner" surface, so it is no threat to those with pacemakers, but anything mostly ferrous that spends much time in that magnetic field, like a spoon, for instance, will get blazing hot.

We figure induction cooking saves us cooking energy and house-cooling energy in summer—a win-win scenario. Though solar cookers can save even more energy in both areas, they require more advanced planning, so sometimes we use the induction cooking even when the solar cooker is also ready to go. It's nice to have so many good options!

Christina Snyder • via email

Thank you for your letter. I'm so happy you have found induction cooking such an excellent fit into your lifestyle. Your unit is clearly more powerful than mine. Actually, my favorite setting is a very low simmer—it's hard to burn the sauce that way. You don't say whether you are off grid or not. I would love to use mine for fall canning, but alas, that is when our energy production is at its lowest. In the winter when our hydro is up and running' I do not mind heating the house with my cooking. theinductionsite.com is a wealth of information—thanks for that.

Kathleen Jarschke-Schultze •
Home & Heart *column author*

High-Efficiency Home Heating

Compliments to "High-Efficiency Home Heating" (*HP157*) author Scott Gibson for the research, and for simplifying this topic down to useful information that we can use to compare apples to apples. I'd like to add some thoughts in addition to those in the article as to, "How do we define, and what do we consider to be true efficiency."

The most important aspect of a heating system is to "get the heat to the person without heating the rest of the house or the outdoors." That being said, the optimal system is not necessarily the one that has the highest efficiency rating, but rather a combination of unit efficiency, individual thermostatically controlled rooms, efficient distribution (ducts or individual room heat), a heat recovery ventilation (HRV) system, and ease of locating/installation. I believe that every new home should have an HRV system to save heat that would otherwise be lost due to required house ventilation. The tighter a house is, the more important whole-house ventilation is.

Now, we have to look at how to control the individual rooms so that we are heating the rooms where people are, instead of heating the whole house with a single

continued on page 26

continued from page 24

thermostat. The best way to do this is to use an individual heat source in each room. My preferred method is to use a electric radiant ceiling panel system.

With radiant heat you heat objects instead of the air. The occupant will instantly feel the warmth, just like stepping into the sunshine. It is also instant on/instant off. It can be controlled with a thermostat in each room as well as an on/off switch that can be turned off when leaving the room, and with a whole-house switch at the front door. Radiant heat from above is the best way to go in my opinion, and I have yet to see a more "efficient" system. True, it does use electricity, but I would recommend solar-electric modules on the roof and super-insulating the walls to have a true net zero-energy house.

Forrest Jones via homepower.com

Hi Forrest,

I think it is important to point out that electric radiant ceiling heat is still electric resistance heat, which is expensive energy for consumers in many parts of the country. When a homeowner is heating with radiant ceiling elements, there's no way to take advantage of off-peak rates. If you need heat during the day, when electricity is at its most expensive, you just have to turn the system on. The electrical thermal storage units described in the article also run on electric resistance heating, but the idea is to charge the systems when power can be purchased at off-peak rates.

Zoned heating is indeed more efficient because you can heat only those areas that are being used. But if each room in your house has its own radiant-ceiling heating element, you'll have to turn up the thermostat every time you move around.

Electric radiant systems embedded in the ceiling are more difficult to repair than many other types of heating appliances. And heat-recovery ventilators reduce the energy penalty of whole-house ventilation, but they are not related to how heat is produced or distributed.

In a well-insulated house that has very little air leakage, almost any type of heating system can be used at a relatively low cost, even electric resistance heat. That's the premise of the Passive House standard and it's why reducing heating and cooling loads is so important. But for many homeowners, who live in relatively leaky houses with too little insulation, electric heat is an expensive option.

Scott Gibson • Home Power *contributor*

write to:

mailbox@homepower.com

or Mailbox, c/o Home Power
PO Box 520, Ashland, OR 97520

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Battery Technology

Why Lead-Acid Batteries Are Still the Most Common Batteries Used in PV Systems

Balanced Battery Coverage

Home Power seems stuck in the old technology of the past, just like coal power plants, with articles on lead-acid batteries in almost every issue. Please at least balance your articles with some information on advanced lithium batteries, which are being used for many applications including utility power regulation and peak time-of-day storage.

"Understanding Batteries" in _HP157_ missed the mark in many ways. It did not mention the longest-lasting batteries that have been available for many years—nickel-iron—and didn't mention advanced lithium batteries.

Jim & Elaine, the Solar Stacks • via email

I appreciate your criticism of lead-acid (LA) batteries. Lead pollution from mining, smelting, and recycling accounts for a pervasive risk to human health (see "Exported Battery Recycling" in *HP145*).

In countries with few enforceable environmental regulations, battery manufacturing and recycling has a high impact on human health and the environment. By comparison, according to the U.S. Environmental Protection Agency, 96% of LA batteries in the United States are recycled. The risk of pollution in modern recycling plants is low because of strict environmental, health, and safety standards, emission monitoring, stack scrubbers, dust control, and waste treatment.

The issues are less with the fundamental technology, and more with global economic and social inequalities. As long as cars have LA batteries, these issues will persist.

More than 1 billion people worldwide lack access to reliable electricity. Most will never see a power line in their community. As cellphones have allowed people in less-developed countries to enjoy the benefits of microenterprise businesses, small, decentralized PV systems using LA batteries provide lighting, communication, and medical services that would otherwise be unobtainable

Lithium batteries are now being used all over the world, but primarily for consumer devices such as cell phones. They are only finding utility applications in some developed countries, and have achieved wide acceptance in none. They are not yet ready for wide acceptance in energy-storage applications for homes.

HP153 included a feature article on lithium-ion (Li-ion) batteries for off-grid systems. The article fairly presents their pros and cons for RE storage—in short, Li-ions are a highly promising technology not yet ready for widespread use: "At present, the lack of battery management system integration in residential RE power conversion equipment is the biggest hurdle."

Courtesy Gardner Engineering AES

This 48-volt lead-acid battery bank consists of eight 6 V batteries. Lead-acid is the most widely used battery type in home renewable energy systems.

Nickel-iron (NiFe) battery technology is more than 100 years old and indeed offers long life and more benign materials than LA. But before spending your money, look into their disadvantages—low charge and discharge efficiency, high self-discharge, and high cost. The only current source for NiFe batteries is China, and only MidNite Classic controllers have settings to accommodate their atypical charge-cycle performance. Common inverters lack settings to properly charge and maintain them.

Few NiFe suppliers serve North America, and these batteries can be up to four times the cost of comparable LA batteries. And, assuming 100% depth of discharge, an equivalent Li-ion pack is six to 10 times the price.

LA batteries have established themselves as the default choice for most applications because of a practical combination of predictable life, ease of maintenance and recycling, wide availability, and reasonable cost. *Home Power* focuses on today's practical solutions, warranted, supported, and affordable to as many people as possible.

Allan Sindelar • Positive Energy; positiveenergysolar.com

Installing an Earth Tube

Trench Depth & Pipe Insulation

Courtesy Jim Riggins

Earth Tube Questions

I've read, and reread your net-zero home article ("Net-Zero Performance" in *HP150*) many times. I am going to break ground on an earth tube system near Provo, Utah, modeled upon the one in the article, and I have some questions.

Is antimicrobial trade-name pipe better than stock pipe? What evidence exists showing bacterial overgrowth in well-designed earth tube systems, and mitigation with the more expensive product?

Costs depend greatly on trench depth. In rocky, boulder-strewn ground like mine, I'll have to strike a balance between trench depth and cost. How about placing polystyrene insulation on top of the pipe at a depth of 3 to 5 feet and then backfilling, instead of digging 10 feet deep?

Chris Anderson • via email

continued on page 32

continued from page 30

The system I used— the only one I found with an antimicrobial coating in the tubes—is Ecoair by Rehau. Their U.S. division is Amvic (amvicsystem.com).

I read about the issue of mold in a handful of articles by folks who installed earth tubes, but typically theirs were installed in more humid climates than my climate zone 5B in central Colorado. I found as much anecdotal evidence of systems that had no mold issues. While I'm not sure what all the differentiating factors are, I suspect:

- The use of smooth-walled tubing versus ribbed tubing minimizes the risk and increases airflow
- Specific microclimate characteristics
- Slope of the pipe (no low spots) and use of a condensate drain at the low point
- Number of hours of operation
- Degree of waterproof seals at tube joints

Still, I did not want to gamble with my family's health, so I went with the Ecoair. The systems are costly, though. For the roughly 4.5 kBtu per hour heating capacity we gain from the earth tube, we will have a very long payback time to recoup the $6,500 system cost, including trenching, labor, and parts. I knew this when we designed the house, but this was one of about four areas where my wife and I opted for the moral imperative of reducing our ecological footprint—we intentionally did not select the most cost-effective course of action.

As for trench depth, I believe you will be compromising the system's performance if you don't bury the pipe deep enough. In the Provo, Utah, area, at a depth of 3 to 5 feet, pipes will barely be below the frost line and ground temperature will fluctuate. At your latitude, the soil temperature will be 50°F to 52°F at approximately 8 feet of depth. By insulating above the pipe, you would reduce part of the surface area available for heat transfer. However, if trench depth is a insurmountable limitation, using insulation would be better than not using insulation. I would use R-10, 2-inch extruded polystyrene foam, and extend the foam 4 feet on either side of the tube. But overall, the deeper the tube, the better. Data from the geothermal heat-pump industry indicates that at depths of 6 meters and greater, the soil temperature equals the mean annual air temperature. At 4 meters below the surface, the soil temperatures vary approximately 3°F; at two meters, about 10°F.

Some installers run a cable the full length of the earth tube during construction, which is used to pull a cleaning rag or plug through the tube once per year. This seems like a good, low-tech way to reduce the risk of mold.

Jim Riggins • EnerSmart Energy Solutions; enersmartenergy.com

write to:

asktheexperts@homepower.com

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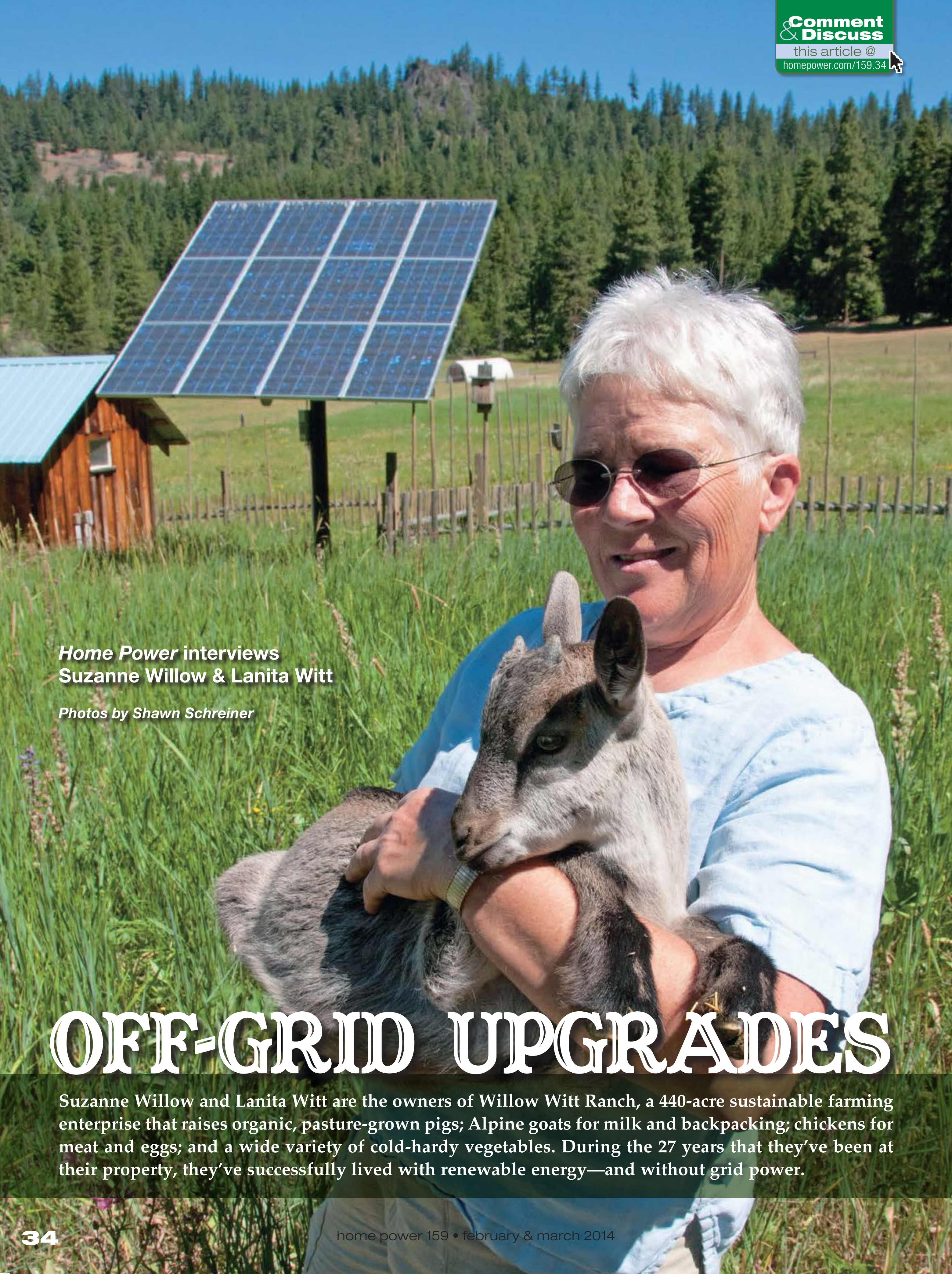


Home Power interviews
Suzanne Willow & Lanita Witt

Photos by Shawn Schreiner

OFF-GRID UPGRADES

Suzanne Willow and Lanita Witt are the owners of Willow Witt Ranch, a 440-acre sustainable farming enterprise that raises organic, pasture-grown pigs; Alpine goats for milk and backpacking; chickens for meat and eggs; and a wide variety of cold-hardy vegetables. During the 27 years that they've been at their property, they've successfully lived with renewable energy—and without grid power.

HOME POWER: In addition to your home's energy needs, you also have a goat dairy and meat operation. With potential large electrical draws such as refrigeration and water heating, did you ever consider connecting to the grid?

WILLOW-WITT: When we bought the property—27 years ago—we contacted the utility to see what the cost of bringing in grid electricity would be. We were four miles from the nearest power pole, and they quoted us a cost of more than $100,000.

HP: So how did you expect to meet your energy needs? How familiar were you with off-grid living?

WW: Suzanne had previously used solar energy at her rural home near Redway, California, from 1976 until 1983. The system powered a few lights, a radio, and a tape player.

Lanita had no experience with living off-grid or farming, although her family had farmed in Texas in the 1940s. She wished to return to a more rural life.

And that we did. In 1986, we moved from our house on 0.7 acres in Napa, California, to a 1920s farmhouse on 440 acres near Ashland, Oregon. We used kerosene lamps and had a propane cookstove and water heater. We heated the space with wood. As the old farmhouse was renovated, we put in wiring to handle either DC or AC, though we had neither at the time.

In 1987—after having been on the ranch for about a year—we decided to use Suzanne's original PV modules from her Redway home and a battery to power a radio phone. Six years later, however, we were ready for more electricity. We built a combination greenhouse, woodshed, and chicken house, and with a south-facing roof on one end, this structure housed our first complete PV system: four solar-electric modules and four Trojan L16 batteries. We installed electric lighting in the house. We also were required by the county to install a sand filter for the septic system. Since that required a pump, we connected a generator for backup.

The 1920s farmhouse has been subject to several electricity upgrades.

A central masonry fireplace provides efficient wood-fired heat all winter.

Where we live and how we live is both a choice and an adventure. It is an educational experience to share with those who visit us.

An evolution of off-grid cooking: vintage wood cookstove on the left and gas stove on the right.

Suzanne in her light and airy home office and greenhouse. This initial farmhouse addition held the first PV system on its roof.

HP: What differences did the PV system make in your lives?

WW: We got less sleep as electricity prolonged activity into the dark of the night! (Laughs.) The greatest joy was doing laundry at home instead of at the laundromat that was a 30-minute drive away.

HP: What other RE upgrades have you made since your initial foray into solar electricity?

WW: By 1996, we had paid off the land by doing salvage logging on mistletoe-infested white fir, and selective cutting of diseased and dying trees, so we took out a new loan to put in a water storage tank and piped water from the spring box to flow through a Pelton wheel as it fell into the tank. The tank is located just above the pond, so the overflow from the tank still keeps the pond full. The microhydro generator has a permanent-magnet alternator that outputs wild AC current then is transformed to 12 volts DC and sent to our house system's batteries. This provides a continuous trickle charge that is especially appreciated during the winter, when solar electricity production is low. We laid 4,000 feet of pipe to have ample water for our domestic use with 50 pounds of water pressure.

The upgraded house system consists of twelve 130 W Mitsubishi PV modules on an adjustable pole mount.

That year, we also upgraded our house system to twelve 51 W modules with eight Trojan L16 batteries and a more efficient inverter (from a Trace 2012 to a Trace SW2512).

HP: What other changes have you made since then?

WW: The home site sits along what used to be the main ranch road—on the northwest side of a large mountain—and that compromised our array's electricity production. So, in 2007, we relocated the house's PV array farther from the house so it could capture more solar energy—it now intercepts about 70% of the sun's path. This is not a tracked system, but pole-mounted. During this time, the system was upgraded from 12 V to 24 V, with twelve 130 W PV modules, a new inverter and new charge controller, and 12 Rolls Surrette S460 batteries. Seasonally, we adjust the array's tilt.

A 6 kW diesel generator provides backup, as well as battery equalization and recharging. In the winter, we use it about two hours daily—in the early morning and evening. Occasionally, we'll use it in the summer, depending on ranch visitors' electricity utilization, since most of them are not conservation-savvy.

In the house, we use standard AC Energy Star appliances, but still use propane for water heating, cooking, and drying clothes. We previously had a propane freezer and refrigerator, but have switched to electricity for these. These are also just typical, off-the-shelf brands. We time our "big" loads—like washing clothes and vacuuming—for when we have ample energy, that is, when the sun is shining and the batteries are fully charged.

Above: The OutBack Power VFX3524 inverter provides 3.5 kW on demand for the main house's PV system.

Left: Twelve Rolls Surrette S-460 batteries provide enough energy storage to keep the house supplied with electricity through Oregon's long winter nights.

HP: So what motivated you to upgrade your house system?

WW: Better-quality batteries were available when we needed to replace them and there had been inverter improvements as well. Plus, we were able to afford to move the modules to a better location. Propane costs had steadily gone up and it is difficult to find quality propane refrigerators. Propane freezers are expensive to buy and operate.

HP: Given your remote location, how were you able to support your ranch and rural lifestyle?

WW: In 2006, Suzanne retired from her career as a physician's assistant, and began running the ranch full time. Lanita continued (and continues) to work as a gynecologist in nearby Medford. We decided to try making the enterprises on our land be fully self-sustaining, including economically.

We manage the forested acres with restoration logging and replanting to obtain a sustainable timber harvest, but in the recent downturned economy, the cost of logging became greater than the income.

We always have had dairy goats and organically raised pigs for meat. We have expanded to breeding our own Berkshire pigs, and we have developed a raw goat-milk herd-share enterprise and milk 12 goats twice a day. We sell our three lines of specialty goat and pork sausage at farmers' markets and online, and have recently started community-supported agriculture (CSA) partnering with other local organic meat producers who contribute beef, lamb, rabbit, and chicken.

Twelve goats produce milk, which is distributed to customers using a herd-share model.

The strict regulations for a commercial dairy—milking machines, equipment washing and sterilization, and refrigeration—are all large energy consumers, which prompted the installation of a second PV system dedicated to this operation.

Left: The PV system on the barn has 21 Samsung 247 W PV modules for a total of 5,187 W. The system is mounted on a purpose-built power shed with a roof tilt equal to the site's latitude to optimize off-grid winter production.

Below: The OutBack Power Systems dual VFX3648 inverters provide 7.2 kW of power for farm operations.

We time our "big" loads, like washing clothes or vacuuming, for when we have ample energy.

Left: Four HuP Solar-One 12 V industrial batteries, wired for 48 VDC, provide 1,690 amp-hours of storage capacity.

Right: Even with a large PV array, the Northern Lights 6 kW generator still provides about 10% of the farm's energy needs.

In addition to raising livestock, we offer "farm stays" for folks who are interested in a sustainable getaway on a working ranch. We have a seasonal campground with tent camping, as well as wall tents for luxury and comfort. Both opportunities provide agritourism income and educational experiences—guests get to experience off-grid farm life, the animals, and quality, farm-fresh foods, as well as the natural beauty of the woodland and meadows.

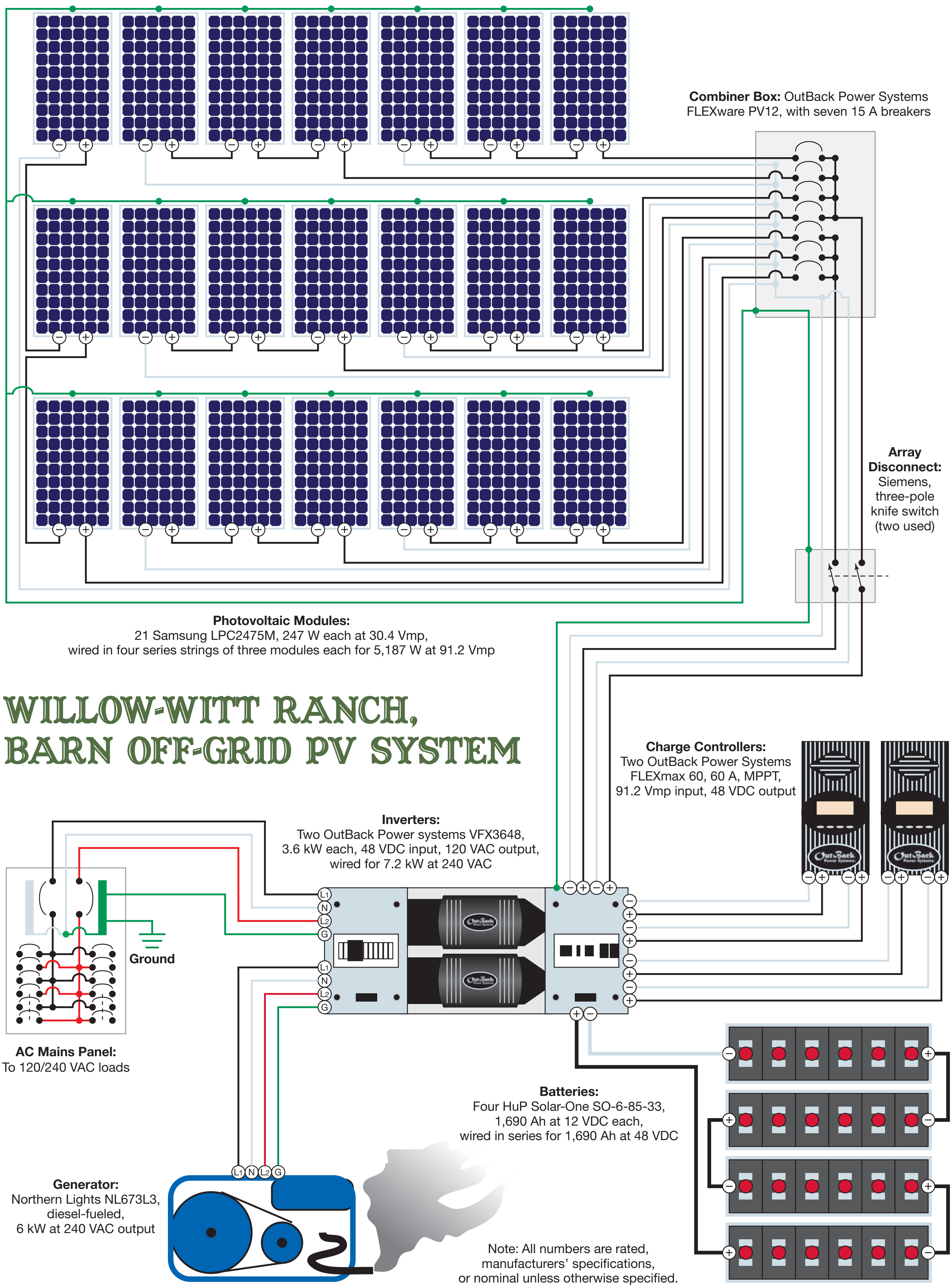
Where we live and how we live is both a choice and an adventure. It is an educational experience to share with those who visit us.

HP: What energy systems support your more recent ranch enterprises? How did you originally meet these needs? How did you design/size this system?

WW: We could not have expanded our meat production and the goat milk herd-share system without the energy upgrade, but we did use our house system and rely on the generator during the two years it took to get a grant and commercial system going.

In 2009, we obtained a U.S. Department of Agriculture Rural Energy for America Program (REAP) grant to develop a commercial PV system for our dairy and meat enterprises, which require a commercial dishwasher, milking machine, barn

WILLOW-WITT RANCH, BARN OFF-GRID PV SYSTEM



TECH SPECS

Overview

System types: Off-grid, battery-based solar- & hydro-electric

System location: Ashland, Oregon

Latitude: 42°

Solar resource: 4.9 average daily peak sun-hours

Main House System

Installer: Electron Connection

Date commissioned: 2007

Production: 134 AC kWh per month (estimated)

Modules: 12 Mitsubishi Electric, 130 W STC, 17.4 Vmp, 21.9 Voc, 7.5 Imp, 8.1 Isc

Array: Three four-module series strings, 1,560 W STC total, 69.6 Vmp, 87.6 Voc

Array installation: Pole mount; tilt is adjusted seasonally

Batteries: 12 Rolls Surrette S-460, 6 VDC nominal, 350 Ah at 20-hour rate, flooded lead-acid

Battery bank: 24 VDC nominal, 1,050 Ah total

Battery/inverter disconnect: 250 A breaker

Charge controller: OutBack Power MX-60, 60 A, MPPT, 48 VDC nominal input voltage, 24 V nominal output voltage

Inverter: OutBack Power VFX3524, 24 VDC nominal input, 120 VAC output

Barn System

Installer: Alternative Energy Systems

Date commissioned: August 2011

Production: 443 AC KWH per month (estimated)

Modules: 21 Samsung LPC247SM, 247 W STC, 30.4 Vmp, 37.6 Voc, 8.04 Imp, 8.47 Isc

Array: Seven three-module series strings, 5,187 W STC total, 91.2 Vmp, 112.8 Voc

Array combiner box: OutBack FLEXware PV12 with seven 15 A breakers

Array disconnect: Siemens, 60 A, three-pole knife switch

Array installation: Unirac Solarmount flat-top standoffs, with heavy-duty rail mounts installed on true south-facing roof, 45° tilt

Batteries: Four HuP Solar-One SO-6-85-33, 12 VDC nominal, 1,690 Ah at 20-hour rate, flooded lead-acid

Battery bank: 48 VDC nominal, 1,690 Ah total

Battery/inverter disconnect: Two 175 A breakers

Charge controllers: Two OutBack FLEXmax 60, 60 A, MPPT, 91.2 Vmp input voltage, 48 nominal output voltage

Inverters: Two OutBack Power Systems VFX3648, 48 VDC nominal input, 120 VAC output

System performance metering: OutBack Mate2

lights, and refrigeration. The best solar site was 400 feet into the wetland from our barns, but it took nine months to get approval from the county for the structure. This was a huge delay that pushed the project into the late fall and winter, so we could not start construction until the following summer.

The 21 Samsung 247-watt PV modules are mounted on the roof of a new power shed, while the interior houses the rest of the system. It includes a Northern Lights 6 kW 120/240 VAC diesel generator and a diesel storage tank. But the PV system supplies about 90% of our commercial energy needs, providing electricity for three Energy Star-rated freezers, two commercial refrigerators, a commercial dishwasher/sanitizer with internal water-temperature booster, the vacuum pump for the milking machine and milking machine itself, and exhaust fans, as well as some lighting and smaller loads.

This system cost $85,000. The grant offset $20,000 of the cost, and we also took advantage of state and federal tax credits, which shaved more off the bottom line, although the balance was a ding to our pension fund and would not be fully recovered for a long time. That said, it has been worth all of the effort.

A Harris Hydro generator generates power from a spring located near the farmhouse.

HP: What kind of involvement do the systems require?

WW: We have scheduled maintenance that we do every two weeks to check the battery electrolyte levels, the filters on the diesel generator, and the generator fluids, with oil changes based on the generator's run time. Battery equalization is done monthly.

HP: What are the challenges in relying on this system for your business and home? How much do you rely on the backup generator?

WW: The technology is so advanced that we rely on the professionals who installed the systems for troubleshooting. This makes us less "independent," but they are much more knowledgeable.

We will always need to rely on generator backup, as our refrigeration needs are significant. Milking, however, can (and sometimes does) take place by headlamp or battery-powered lanterns. Batteries are the main periodic expense and technology improves the quality of the inverters, so when we are looking for improved efficiency and can afford to upgrade, we will do so.

HP: Knowing what you know now, what, if anything, would you do differently from the start?

WW: Getting started, we mounted our renewable energy systems on existing structures, which resulted in less-than-optimal siting and, of course, lower energy production from our systems. Given a bigger budget, we would have installed our current system where it is now for both our home and our commercial electricity production.

HP: What accommodations have you made for living with an off-grid system?

WW: We have lived this way for so long that it's normal—we don't feel like we're making concessions. We have flashlights for backup lighting and use rechargeable batteries and phones that are plugged in to recharge during the day, while our PV system is providing lots of electricity.

Access

Willow Witt Ranch • 541-890-1998 • info@willowwittranch.com • willowwittranch.com

Efficient Heating with Wood

by Stephen Hren

Courtesy Harmon

Is burning wood for heat an efficient and renewable way to keep our homes warm—or a dirty relic that pollutes air and ruins habitat?

Wood straddles the line between being a renewable and a fossil fuel. It is a store of solar energy and atmospheric carbon that can be consumed at a pace similar to the rate at which it is produced—in which case it is renewable. Or it can be burned more quickly, acting more like a fossil fuel. Unlike with vehicles or other complex energy systems, pollution from wood heat remains largely unregulated, and there's a high potential for misuse. That's reason to become better informed about the technology and how—and when—to use it most efficiently.

Pros & Cons

There are many reasons why burning with wood can be appealing. First, trees can regenerate or be replanted, making wood a potentially renewable fuel. Trees also consume carbon dioxide (CO_2) so, over time, heating with wood has the potential to be carbon-neutral. In places where there is little solar gain to be had in winter, wood offers an opportunity to use stored solar energy to provide heat.

Wood warms you three times—once when you cut it; once when you split and stack it; and once when you burn it.

istockphoto/xalanx

Heating with wood can make you more energy-aware. Even if you have already-split wood delivered, using wood and turning it into energy requires forethought and effort—carrying, splitting kindling, and stacking. This is very different than simply adjusting the thermostat and writing a check to the utility once a month. Also, if the appliance is thoughtfully placed to heat commonly occupied spaces, wood heat can reduce the overall amount of energy consumed for space heating compared to a typical furnace system, which supplies heat to all of the rooms in the house, all the time.

For those on a budget, wood heat has the potential to save money compared with other fuel systems. And wood heat often means independence—both from power outages and the vagaries of the market, especially if you can harvest wood from your property. If wood is purchased locally, it can also help keep dollars in the community.

But the way we've burned wood for most of human history—in open hearths—is dangerous, inefficient, and polluting. And even efficient modern wood heaters have drawbacks, so they need to be used responsibly and appropriately. For instance, harvesting trees for firewood can turn into decimating forests if it's done on too large of a scale. Estimates by wood heat advocates are that an acre of healthy forest can produce a half-cord (64 cubic feet) of split wood each year. Obtaining wood from smaller companies that get most of their wood from tree-trimming or forest management can provide a sustainable source. Source your wood (whether pellet or cordwood) from a company that is not engaged in clear-cutting or shipping wood long distances, which consumes lots of fossil fuel.

Burning wood can produce a large quantity of airborne pollution, especially if done inefficiently. According to the U.S. Environmental Protection Agency (EPA), burning improperly cured wood is the biggest contributor to airborne pollutants from wood-burning heaters. Properly cured wood has a moisture level of less than 20%. Typically, this is achieved by air-drying rain-protected split wood for at least six warm months. Properly seasoned wood has more than four times the heat value of green (uncured) wood, since, when burned, not as much energy has to be used to remove moisture. Then there's the efficiency of the fire, which needs to get hot enough (around 1,000°F) to completely combust the material. This requires advanced wood heater technology, which most modern wood heaters have.

istockphoto/SimplyCreativePhotography

Besides being less efficient at heating a home, a poorly burning fire contributes to local air pollution, emitting particulate matter.

Wood Heater Particulate Emissions & Efficiency

Type	Particulate Emission Rate (Grams/Hr.)	Combustion Efficiency
Conventional fireplace[1]	20 – 50	75%
Outdoor wood boiler, single-stage[1]	10 – 40	30 – 40%
Metal wood heater (pre-1990)[1]	10 – 20	30 – 50%
Noncatalytic metal wood heater (post-1990)[2]	< 7.5	60 – 75%
Catalytic metal wood heater (post-1990)[2]	< 4.1	65 – 82%
Pellet heater, EPA-certified[3]	2 – 4	70 – 80%
Advanced Danish wood heater[3]	1 – 3	75 – 85%
Advanced wood boiler, two-stage gasification[4]	1	80%
Masonry heater[5]	1 – 2	75 – 80%

Sources: 1) epa.gov; 2) burningissues.org; 3) hearth.com; 4) 4cleanair.com; 5) Masonry Heater Assoc.

What Type, Where & When?

Fires in open hearths, and in older wood stoves and fireplace inserts (generally pre-1991) that do not employ advanced stove technology are not able to reach sufficient temperatures to combust the gases and soot that burning wood creates. This means they are inefficient, letting much of the potential fuel "go up in smoke," and they are polluting, because that smoke permeates the air in the surrounding neighborhood (and with open hearth fires, in your home), potentially contributing to health problems such as asthma and lung disease.

But even well-cured wood burned in an efficient wood heater produces pollution. Most smoke from a well-built fire is CO_2 mixed with carbon monoxide (CO), but trace amounts of potentially lung-damaging particulates such as dioxins and volatile organic compounds, and heavy metals such as arsenic are found in wood smoke. Like car exhaust, the key to reducing any potential harm from the results of this combustion is dispersal. Some regions have atmospheric inversions in winter that can trap pollutants at ground level for days. Population density also has a dramatic effect on particulate pollution from wood heating. Where burning wood displaces direct combustion of fossil fuels—like with oil- or natural gas furnaces—the pollution level increases substantially, often 100-fold or more. There is a trade-off between burning wood, a potentially renewable fuel that creates more particulate but less CO_2 pollution, versus burning a fossil fuel-based system that creates fewer particulates, but more CO_2 pollution.

So when is heating with wood an appropriate solution, both economically and environmentally? Four factors come into play:

- Ability to obtain local, sustainably produced fuel (firewood or pellets)
- Room for storage and/or drying firewood
- No atmospheric inversion problems
- Low population density
- Ability to source and install a high-efficiency wood- or biomass-burning heater

Although heaters are rated on their output (in Btu per hour), the range can be quite large and depends on several factors, including the species of wood, the moisture content in the wood, and how the heater is operated. An "average" U.S. home can require 25 to 30 Btu per square foot per hour to maintain comfortable temperatures, says *Consumer Reports* magazine, but there's really no "average." Your home's size, layout, and insulation determine how easy (or difficult) it is to heat. A better way to "size" a wood heater is to figure out your home's heating requirements, either through analyzing previous heating bills or performing a heating-load calculation. Speaking with a nearby dealer (who heats his or her home with wood) is usually the best way to get a properly sized, quality wood heater.

Once you've determined you want to heat with wood, there are several types of wood-burning appliances to consider. Your choice will depend on your home's specific heating needs.

Metal heaters (aka wood stoves). Technological improvements in metal-constructed wood-burning heaters include insulated fireboxes; a means for secondary combustion; and catalytic converters, though not all heaters will have all three. An insulated firebox, usually insulated with rock wool and/or insulating firebrick, is the first strategy toward an improved burn since it can contain the heat better, raising the fire's

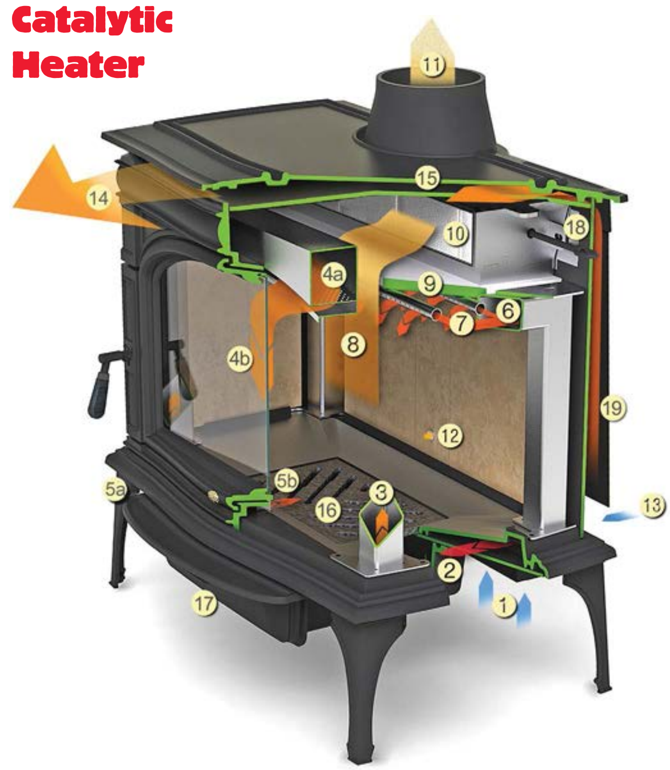
This catalytic wood heater marries modern technology with a traditional aesthetic.

Courtesy Lopi (2)

Courtesy Rais

Wood heaters are available in a variety of styles, from traditional cast-iron models to conventional welded-plate steel versions.

Catalytic Heater



1. Combustion air/outside air; **2.** Preheating chamber; **3.** Vertical air-wash channels; **4a.** Horizontal air-wash channel; **4b.** Air-wash; **5a.** Air control; **5b.** Primary combustion air; **6.** Secondary air manifold; **7.** Secondary air tubes; **8.** Secondary combustion zone; **9.** Stainless-steel baffle; **10.** Catalytic combustor; **11.** 6-inch flue; **12.** Electric igniter system; **13.** Room air; **14.** Heated room air; **15.** Top convection chamber; **16.** Grate; **17.** Ash-pan; **18.** Bypass damper; **19.** Rear heat shield.

temperature. The hotter the fire is, the more complete the combustion will be, resulting in higher efficiency and lower emissions. Improved sealing and insulation of the firebox (usually with high-temperature silicone) will be reflected in the metal heater's efficiency numbers.

The second improvement is a metal channel adjacent to the firebox that heats secondary combustion air and feeds this preheated air into the top of the fire, providing fresh oxygen without reducing the fire's temperature. This allows for volatile gases and particulates to be further combusted in the top of the firebox.

The third innovation is the catalytic converter, a metal honeycombed chamber that allows the wood smoke to combust at about half the temperature—about 500°F. The catalyst itself often reaches temperatures of 1,500°F. Catalytic converters work great when new (as they are when tested) but the catalytic element degrades with use. Ironically, by the time the catalyst is due for replacement, emissions are a lot higher than 7.5 grams per hour limit set for noncatalytic wood heaters, according to WoodHeat.org. An additional technological improvement, coming out of Northern Europe and especially Denmark, are stoves that regulate secondary air intake using oxygen sensors, which results in a reliably hot, and thus more efficient and low-emission, fire. The sensors work in conjunction with regulating the airflow. If the oxygen is low, more air is admitted, and vice versa.

The firebox size and the heater's efficiency determine how often it will need to be stoked, known as its burn time. Because they are low-mass, these types of wood-heating appliances have a high heating efficiency—they rapidly transfer heat produced by the fire to the room, creating a very hot space around them. They also cool fairly quickly when not in use. Depending on your heating needs, this may be an advantage or disadvantage. It may be difficult to regulate the heat output so that it is comfortable, but restricting the air supply to regulate heat output reduces combustion efficiency, creating more emissions.

Some metal stoves may have enough horizontal surface to serve as a cooking surface. If the power goes out, you'll still have space heating—and a place to cook meals.

Pellet heaters. Instead of using logs, pellet heaters burn little compressed nuggets of sawdust or wood shavings. Because their emissions are lower, wood pellet heaters may be a better choice in places where population densities are higher, such as in suburban areas, which average between 1,000 and 3,000 people per square mile. Because pellets burn hotter than cordwood and more completely, they produce fewer particulate emissions. The regularity of the shape of the pellets and their high surface area compared to cordwood lends to their burning more evenly.

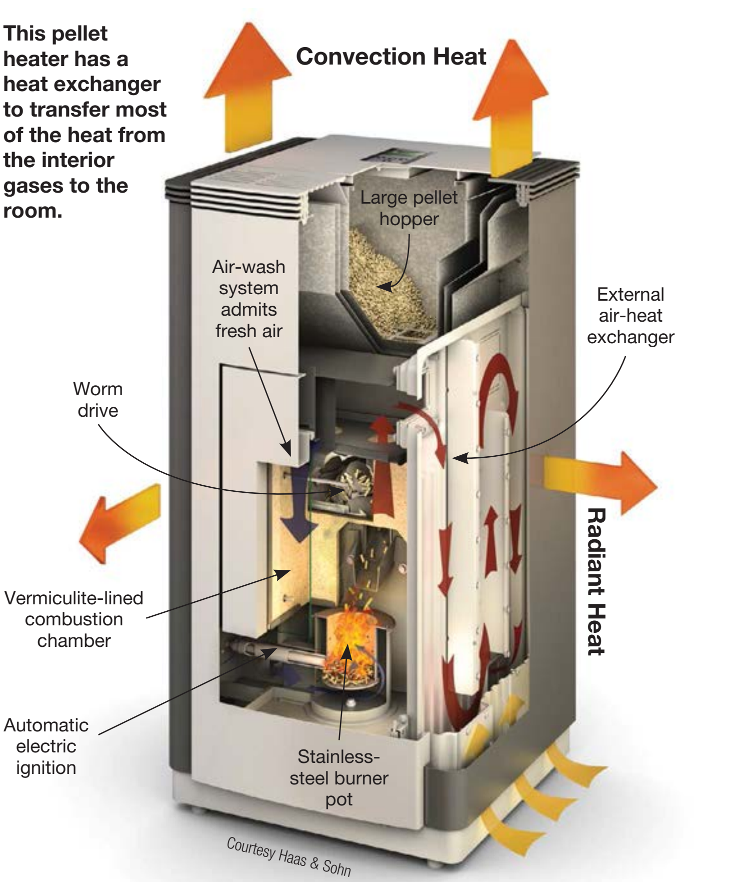
Pellets are first loaded into a hopper and an electrically powered auger conveys them into the firebox, where they are burned. One fan moves air through the firebox to combust the pellets, and another fan blows heated air into the room. Compared to a typical wood heater, a pellet heater is easier to operate. It also burns longer without attention and burns more efficiently.

Courtesy Harmon

Exhaust gases from some pellet stoves may be cool enough that hidden, through-wall flues, instead of interior stovepipe, can be used.

Pellet Heater

This pellet heater has a heat exchanger to transfer most of the heat from the interior gases to the room.



While pellet heaters cost more, this expense can often be recouped in lower installation costs since these heaters can often be vented through a sidewall instead of through the roof, although this is subject to model type and local building codes. Pellet heaters require annual maintenance, which tends to be more costly than wood heater maintenance because of their increased complexity, but require less-frequent ash removal during the heating season. If you want to have a secure source of heat during power outages, you'll need a generator or battery backup for your pellet heater, since it relies on an electric screw conveyor and blower.

In many suburban areas, pellets are readily available. While obtaining pellets is usually not difficult in forested areas where there is a wood products industry, the sustainability of these products can be somewhat questionable, since they take energy to manufacture and transport. In some areas, Forest Stewardship Council-certified wood pellets may be available. If not, inquire from the retailer about their origin.

Wood boilers. Wood boilers don't provide direct heating, but instead heat water for distribution through a hydronic heating system. There are generally two types—outdoor single-stage models (one of the most polluting ways to burn wood—avoid these) or high-efficiency two-stage gasification models that are usually installed in the basement.

Two-stage gasification units use oxygen sensors and electronic controls for an almost fully automated burn with a calibrated fuel/air mix. First, wood is heated in an oxygen-poor chamber to draw out combustible gases. These gases are then burned at a high temperature in a separate, second chamber. The heat is stored in water, generally in large tanks up to 1,000 gallons, and circulated through the house either through radiators or hydronic tubing in the floor. Boilers provide domestic hot water and have the potential to be used in conjunction with solar water heating systems. Econoburn is a U.S. manufacturer of two-stage boilers. HS Tarm is a highly regarded European model that also is available in North America.

Wood Boiler

A wood boiler uses cordwood fuel to heat water for distribution through a hydronic heating system.

Wood boilers, combined with the water storage, can take up a sizable chunk of space—50 square feet or more. Plan on spending close to $10,000 (or more) for their purchase and installation (and potentially much more if you also need to have a hydronic distribution system installed). Wood boiler advantages include their efficiency and low emissions, single-loading (one burn per day), and the production of household hot water. Their main disadvantages are their required size and cost, and that they remove the fire as a centerpiece of the home.

Extensive channels inside a masonry heater expose heated gases to the heater's thermal mass, which absorbs and slowly radiates the heat into the room.

High-efficiency masonry heaters. These site-assembled cordwood-burning stoves use many of the same principles of advanced wood-heater technology—a well-insulated firebox, preheated secondary air intake, and proper firebox shape—to create high-temperature fires capable of achieving the same or better efficiencies of wood or pellet heaters. Built with high-heat bricks, which make up the inner portions of the heater, and sometimes faced with soapstone, these high-mass heaters absorb heat from the burning flue gases and then

Masonry stoves are also available as kit assemblies from companies like Tulikivi. Starting at about $5,000 (plus delivery), this can be a less expensive option compared to a custom-built heater.

A serpentine flue path and high thermal mass capture a high percentage of the fire's heat for gradual release into the living space.

Courtesy Tulikivi (2)

Wood Heater Emissions & Combustion Efficiency

If you're purchasing a new stove, look for one certified by the U.S. Environmental Protection Agency (EPA) or a European model (their standards are more stringent). Scandinavian heaters that carry the Nordic Ecolabel are particularly good, since most have incorporated mechanical air-regulation devices to keep the fuel/air mix at optimal levels for improved efficiency and reduced emissions.

Wood heaters that carry the EPA certification will bear a paper sticker on the front of the appliance and a metal plate attached to the back or side that lists *self-reported* numbers for both emissions and combustion efficiency. To be certified, catalytic wood heaters cannot produce more than 4.1 grams of particulates per hour; noncatalytic models cannot produce more than 7.5 grams per hour. (In Washington state, these limits are lower: 2.5 grams per hour and 4.5 grams per hour, respectively.)

While the emission rate published by the EPA can be used to compare one model to another, combustion efficiency test methods have not been standardized and regulated. Independent, reliable data on wood-heater combustion efficiency—the ability to burn a given fuel completely and without pollutants—is difficult to find. When a piece of wood is burned, about 30% of the heat generated comes from the solids; 70% is contained in the gases. If the gases are not fully burned, waste heat and smoke (particulates) can result. Manufacturers self-report these numbers, and only a handful of wood heaters have third-party certification. Combustion efficiency numbers assume well-seasoned wood burning at maximum heat, with the air-inlet damper fully open. Damping down a wood heater can substantially reduce fire temperature and efficiency, while increasing particulate pollution.

However, in the next year or two, all wood heaters may be required to have third-party verification. Until then, there are five companies that have, at their own expense, obtained third-party verification for their wood heaters' efficiency and combustion emissions (see "Wood Heater Particulate Emissions & Efficiency" table). Find a complete list of all wood heaters and their self-reported efficiency and emissions numbers at bit.ly/EPAWoodHeat.

Wood: Which Way?

The way that the logs are oriented in the firebox can have a big effect on how they burn and on how much heat the stove can put out over an extended burn.

A stove with a firebox that is deeper than it is wide has more heating capacity, since its full volume can be used. There's also no danger of logs falling against the glass door (if there is one). This orientation usually provides better combustion as well, since more air can be drawn over the length of, and between, the logs.

A stove with a firebox that is wider than it is deep has less heating capacity, since only about 50% of its firebox volume can be used. If it's loaded too full, logs can fall against the glass door, preventing further stoking and/or creating a hazard since the live coals can easily tumble out.

gradually release it. In passive solar homes, depending on their placement, these heaters can also collect solar gain.

When wood burns in the firebox, the burning flue gases are forced into an upper combustion chamber. From this location, the fire gases are directed downward, into side channels. By forcing the gases to follow a long path to the chimney (known as "contraflow"), the heat can be absorbed by the masonry. Masonry heaters are engineered to generate quick, hot fires in their fireboxes. When the fire is out, the damper is shut, stopping the draft that would otherwise cool the heater. A hot fire means improved combustion efficiency, and masonry heaters boast some of the highest efficiencies among wood-heating appliances.

Burning Details

An improperly installed heater has the potential to burn down your house and endanger your family. Even when done properly, wood heating requires more effort and maintenance than most other heating options. Installation, if possible, should be done with the assistance of an experienced installer (see Resources).

A masonry heater, as defined by the Masonry Heater Association of North America, must have a mass of at least 1,760 pounds; tight-fitting doors that are closed during the burn cycle; and an overall wall thickness not exceeding 10 inches. The gas path through the internal heat-exchange channels must include at least one 180° change in flow direction (usually downward), before entering the chimney. The length of the shortest single path from the firebox exit to the chimney entrance must be at least twice as long as the firebox's longest dimension.

Unlike a steel or cast-iron heater, in which the fire may need to be regularly stoked to maintain comfortable room temperatures, masonry heaters are typically only fired once in an 18- to 24-hour period. For example, a "large" (6,292-pound) Tulikivi reaches its peak approximately six hours after its fire is started; it has released half of its heat output 18 hours later, and about 75% 31 hours later.

Masonry heaters work best in a home with an open floor plan, and their placement needs to be well-considered. Since these heaters tip the scales at several tons, it's recommended that they have an extensive footing. Because of this, they may be difficult to retrofit into an existing structure without considerable expense.

Although most masonry stoves are individually crafted and high-dollar items ($10,000 or so), they are often works of art that become a home's centerpiece. Lower-cost alternatives are prefabricated masonry stoves or masonry stove kits, such as Tulikivi and Temp-Cast, that can be assembled by someone with masonry skills.

Access

Stephen Hren (stephenhren@riseup.net) is the author of, most recently, *Tales from the Sustainable Underground: A Wild Journey with People Who Care More About the Planet than the Law.*

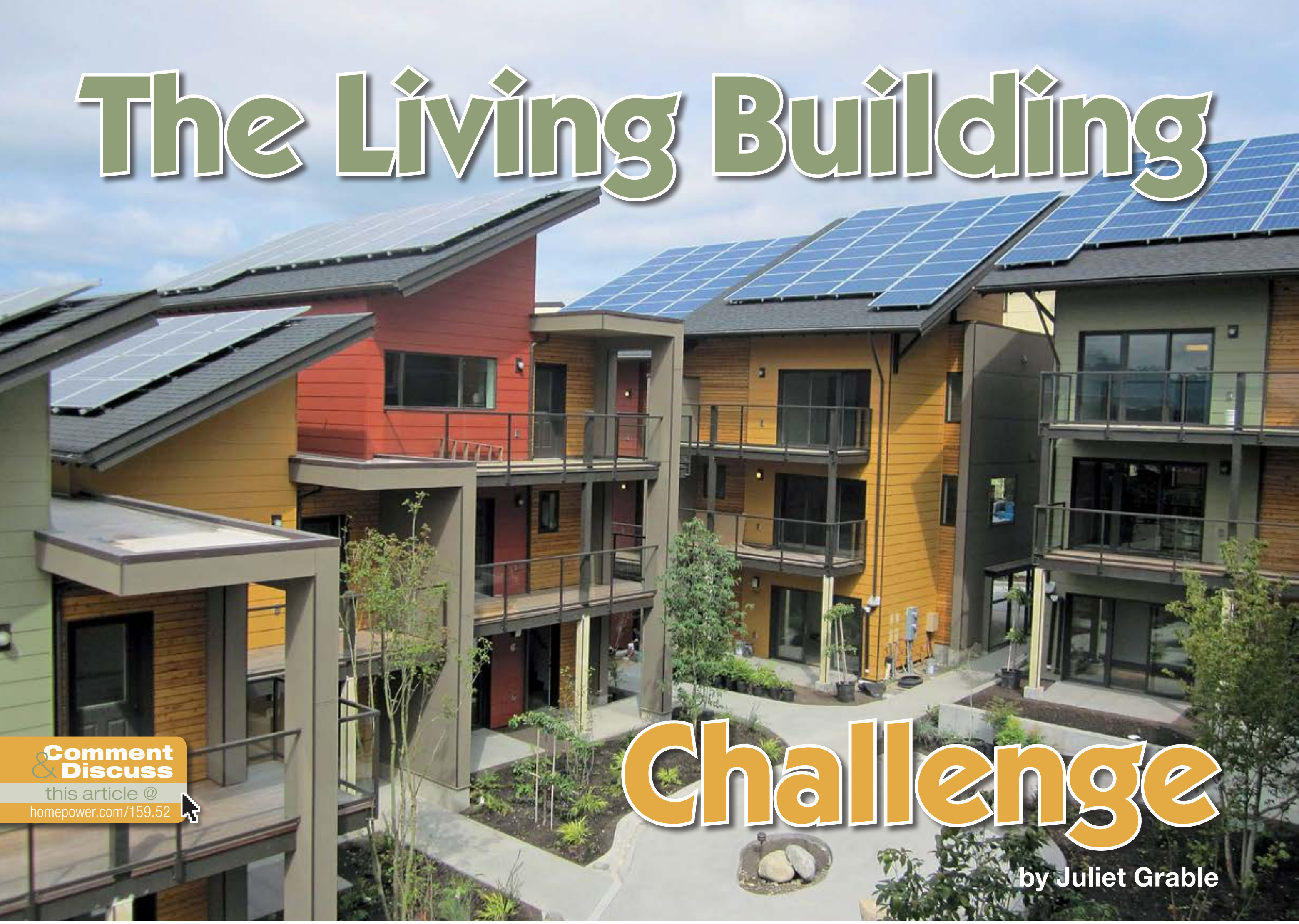
Wood heater recommendations • forgreenheat.org

Wood & pellet heater reviews • wiseheat.com

Chimney Safety Institute of America • csia.org • Installer search engine

The Living Building Challenge

by Juliet Grable



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Courtesy zHome

The zHome project, a 10-unit townhouse development in Issaquah, Washington, is designed to achieve net-zero energy, among other Living Building Challenge imperatives.

Ask Living Building Challenge (LBC) creator Jason McLennan about buildings and he'll likely start talking about flowers. "Both are literally and figuratively rooted in place," says the author and architect. "Unfortunately, [right now] that's where the metaphor ends—but I don't think it should."

As McLennan points out, a flower gets all of its energy from the sun. It gets all the water it needs from the precipitation immediately surrounding it. It doesn't pollute. It creates habitat—and it's beautiful.

McLennan believes architecture should be judged by the same metrics, and has translated his vision into the LBC, one of the most ambitious green-building certification programs in the world. He has developed unique terminology for his program's parameters. LBC projects must address seven performance areas, or "petals"—site, energy, water, health, materials, equity, and beauty. Each petal is further subdivided into a total of 20 "imperatives."

Several of the petals match categories found in the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program. And, like LEED, LBC projects are divided into types, including renovation, landscape or infrastructure, building, and neighborhood.

Right: LBC creator Jason McLennan.

Below: LBC Ambassadors-in-training at a Portland, Oregon, workshop.

But the LBC goes beyond LEED. At a minimum, a project must not consume more energy than it produces, and must harvest all of its water and treat all of its wastewater on site. Building materials must be sourced "appropriately" and locally, if possible, and cannot contain any chemicals on the "Red List," a list of 14 known toxins, carcinogens, and endocrine disrupters. In addition, LBC certification is based on actual, rather than anticipated, performance. Unlike LEED, projects don't earn points in each category; instead, the project team must demonstrate how it has met each imperative through a combination of essays and other documents, and audits. After 12 consecutive months, the International Living Future Institute (ILFI)—the LBC's umbrella organization—sends an auditor to conduct a final audit. Because it's not prescriptive, the LBC encourages creative, local solutions unique to each project.

"The LBC is really the 'what'—the guiding vision," says Matt Grocoff, an LBC ambassador and net-zero energy consultant. "Other programs have the 'how.'"

Siting Right

Restoring a healthy coexistence with nature.

To justify the LBC's first imperative, Limits to Growth, McLennan says, "No new sites; we've developed enough." This imperative sets the uncompromising tone of the LBC, instructing people to work with what they already have rather than developing more raw land. Projects must occur on "previously developed sites," which the LBC defines as sites that were altered from a greenfield before December 31, 2007. The exception is grayfields and brownfields that aren't sensitive habitat or prime farmland. According to the LBC, setting limits should restrict our collective footprint and foster connected, compact communities.

The other three Site imperatives support this idea. Habitat Exchange acknowledges that each project causes disturbance and displaces native plants and animals. To mitigate this, project owners must set aside land away from the site—a minimum of 1 acre for every acre of project—through an official land trust organization.

The Car-Free Living imperative encourages movement away from individual car ownership through the creation of dense, mixed-use neighborhoods. To achieve this, residential projects cannot decrease the overall density of either the site or neighborhood (within a 0.6-mile radius of the project site).

Siting Petal Imperatives

	Limits to Growth	Urban Agriculture	Habitat Exchange	Car-Free Living
Renovation	Imperative	Optional	Scale Jumping Possible	Optional
Landscape & Infrastructure	Imperative	Optional	Scale Jumping Possible	Optional
Building	Imperative	Scale Jumping Possible	Scale Jumping Possible	Imperative
Neighborhood	Imperative	Scale Jumping Possible	Scale Jumping Possible	Imperative

Imperative; Scale Jumping Possible; Optional

Courtesy Benjamin Benschneider

The LBC-certified Bertschi Living Building Science Wing in Seattle, Washington, met its Site petal, in part, by building on a former grayfield—a paved sport court.

The Urban Agriculture imperative encourages self-sufficiency by declaring minimum percentages of the site area to be set aside for "opportunities for agriculture," which could mean gardens, crops, orchards, or animal husbandry. The percentage of land that needs to be devoted to this imperative varies depending on the project's density. That is, a country house on 5 acres must devote a higher percentage of land to agriculture compared to an urban home on a tiny city lot.

There are exceptions. These last two imperatives are optional for renovation projects, since the owners can't change the characteristics of the original site. And projects in rural agricultural areas don't have to meet the density requirements for Car-Free Living, since greater density in agricultural areas isn't necessarily desirable.

Energy Net Producer

Relying only on current solar income.

The Energy petal's Net-Zero Energy imperative is simple: 100% of a project's energy must come from renewable, on-site sources. These include PV and solar thermal arrays, geothermal systems, wind turbines, microhydro generators, and hydrogen-powered fuel cells (so long as the fuel is generated by renewable energy). Systems may or may not be grid-tied, and the determination is made on a net-annual basis. What isn't specified is how to achieve this goal—there are no minimum R-values for insulation or blower-door test requirements, for instance—but the implicit assumption is that projects will complement RE systems with energy-efficient design and construction.

There are a few rules. No nuclear energy is allowed. With very few exceptions, no combustion is allowed either, not

To meet the LBC's Energy imperative, the Bullitt Center in Seattle, Washington, includes a large rooftop PV array.

even wood heaters, as LBC projects should not contribute to pollution or carbon-dioxide emissions. The Net-Zero Energy imperative, along with several others, does allow for something called "scale-jumping" when cost and/or environmental impact make it smart for a project to take part in a larger system. For example, several households might share a PV array or a water cistern, so long as the project doesn't move too far away from functioning as its own utility.

Documentation requires a short narrative describing the system, photos of the components, and 12 months of energy bills and meter readings. Though challenging, achieving the Energy petal is not as daunting as the Water and Materials petals. Examples of net-zero energy buildings of all scales already exist, and the increasing popularity of programs like LEED and Passivhaus have raised the building industry's collective IQ around energy performance. Incentives and leasing programs have put renewable energy within more people's grasp, and there are few, if any code barriers.

Energy Petal Imperatives

	Net-Zero Energy
Renovation	⊕
Landscape & Infrastructure	⊕
Building	⊕
Neighborhood	⊕

⊕ Scale Jumping Possible

Making & Saving Water

Creating water-independent sites, buildings & communities.

The Water petal's two imperatives direct projects to declare independence from systems that bring water to the site from afar and carry it away once it's "used." The Net-Zero Water imperative states that a project must supply all of its water on-site. Residential projects may rely on wells, and rainwater harvesting systems and cisterns, but no chemical treatment is allowed. Instead, systems must use physical or biological filters and/or UV treatment.

As with Energy, the language is not prescriptive; composting toilets are not mandatory, though many LBC projects choose them. At the Eco-Sense residence, an LBC project near Victoria, British Columbia, the owners originally planned to use groundwater for irrigation and captured rainwater for everything else. In the end, it made more sense to use groundwater for household needs, in part because it didn't require filters and UV treatment, as rainwater does.

While the climate in a given project area may guide system design—the size of cistern, say, or the roof area needed for rainwater collection—state and local codes also have an impact. Many states have not yet adopted graywater codes, for instance, making such systems illegal. Even greater barriers exist to processing "blackwater" (from toilets) on-site. This means a person renovating a rural home with an existing well and septic is going to have an easier time than a person building a new house on an urban lot. But the LBC was designed to be an agent for change, not just a certification program. If a project team runs into code barriers, it must appeal to the appropriate agency, hopefully starting a dialogue that leads to the eventual removal of the barrier.

Homeowners Barbara Scott and Tom Elliott scored a huge victory when the city government approved their graywater system for Desert Rain, their LBC project near the heart of downtown Bend, Oregon. Because Oregon's graywater code is relatively new, most municipalities don't have experience

A composting toilet, 10,000-gallon rainwater storage cistern, and graywater recycling help the Eco-Sense house in Victoria, British Columbia, meet its Water petal imperatives.

Water Petal Imperatives

	Net-Zero Water	Ecological Water Flow
Renovation	Scale Jumping Possible	Optional
Landscape & Infrastructure	Scale Jumping Possible	Scale Jumping Possible
Building	Scale Jumping Possible	Scale Jumping Possible
Neighborhood	Scale Jumping Possible	Scale Jumping Possible

Scale Jumping Possible; Optional

with the systems. Three-plus years of meetings and redesigns finally led to approval of Desert Rain's "Tier II" system, which incorporates a 600-square-foot constructed wetland for filtering graywater. It's the first of its kind in the state.

The Ecological Water Flow imperative, according to ML Vidas, architect and sustainability consultant for the Desert Rain project, says that "when you're done with the water, you put it back." This does not mean sending stormwater and "used" water to municipal storm drains and sewers, but rather managing it on-site with landscaping, graywater systems, bioswales, or constructed wetlands—anything that captures nutrients and encourages infiltration. Water can be sent to adjacent sites to feed agriculture or recharge groundwater there. The documentation process is similar as for the Energy petal; "scale-jumping" solutions are also allowed.

Health

Maximizing physical & psychological health & well-being.

The Healthy Air imperative promotes healthy indoor environments: systems at entryways that prevent tracking in dirt and other particles; ventilation systems for kitchens and bathrooms; and mandated air-quality testing. The Civilized Environment imperative mandates operable windows for every occupiable indoor space. But the Biophilia requirement takes the notion of health a step further, examining how a building can "connect with nature and culture," says Amanda Sturgeon, architect and LBC vice president, "and how it can function as part of an ecological system."

Six biophilic design elements are recognized, including environmental features, natural shapes and forms, and light and space. Environmental features could include anything from natural materials and colors to methods of admitting natural light and fresh air into a building; natural shapes mimic those of plants and animals. The arcing Miro Wall in the Desert Rain project is a good example. The earth-toned wall begins outside Desert Rain's west face and threads through it, literally connecting the building with the outside environment and creating a natural separation between the home's public space and the more private, contemplative areas. Each of these elements must be represented for every 2,000 square meters of the project, and the architect or designer must submit a two-page narrative describing the project's biophilic design.

Red List

An LBC project cannot use products containing asbestos; cadmium; chlorinated polyethylene and chlorosulfonated polyethylene; chlorofluorocarbons (CFCs); chloroprene (Neoprene); formaldehyde (added); halogenated flame retardants; hydrochlorofluorocarbons (HCFCs); lead (added); mercury; petrochemical fertilizers and pesticides; phthalates; polyvinyl chloride (PVC); or wood treatments containing creosote, arsenic, or pentachlorophenol.

The Red List imperative considers not only the health of the people who may be exposed to toxins while occupying the project, but of those involved with a material at every stage of its life, from extraction, manufacture, transportation, installation, and disposal. Formaldehyde is used as an adhesive in sheet products (plywood and particleboard) and PVC is used in products from piping to siding to carpet backing, and neoprene is used in weather-stripping and expansion-joint filler—products that enhance a building's energy performance.

The ILFI allows several specific temporary exceptions, including lead in grid-tied solar battery systems and phenol formaldehyde in glue-laminated beams. There's also a "small component" exception for "complex products made from more than 10 constituent parts," so long as the Red List ingredient is contained, discrete from other materials, and doesn't make up more than 10% percent of the product by weight or volume.

For the Energy Lab at the Hawaii Preparatory Academy, one of four projects to achieve full LBC certification, the project team was able to find acceptable substitutes for some items. For example, instead of Trex, a plastic-wood fiber composite material that contains PVC, they chose FSC-certified wood decking, and eschewed mercury-filled exit lights for bioluminescent, nonelectrical fixtures. In other cases, the team had to compromise; for instance, the formaldehyde-free foam ceiling insulation contains flame retardants, as was required by code.

The team not only had to apply to the ILFI for a temporary exception, someone also had to write a letter to the manufacturer urging the company to consider replacing the Red List material with something less toxic. These exceptions are understood to be temporary, until the time when materials without Red List components are widely available.

Health Petal Imperatives

	Civilized Environment	Healthy Air	Biophilia
Renovation	Imperative	Imperative	Imperative
Landscape & Infrastructure	Optional	Optional	Imperative
Building	Imperative	Imperative	Imperative
Neighborhood	Imperative	Imperative	Imperative

Imperative; Optional

Matthew Millman Photography, courtesy of Flansburgh Architects

With few native building materials to choose from, the distance radius and density threshold limits for red-list compliant materials posed a challenge for the Hawaii Preparatory Academy's Energy Lab. Project managers had to exercise their ingenuity and creativity to meet the Materials petal imperatives.

Material Transparency

One of the most challenging tasks for LBC project teams is sourcing materials, and finding the documentation to show that those materials meet the program's stringent requirements. The International Living Future Institute (ILFI) launched its Declare initiative to facilitate this process, touting it as a "nutritional label" for building products. To qualify for the Declare label, a company must state what its product is made of, where its component materials come from, and where it will end up after its useful life—and pay a license fee.

"Sometimes it's difficult to get information from a manufacturer," says Vidas, who has kept meticulous materials records for the Desert Rain project. Although companies must create material safety data sheets for their products, they're only required to disclose hazardous materials. "And sometimes a percentage of a product will be made up of proprietary materials," she says. "We're trying to encourage transparency."

Encourage—and reward. As the LBC grows, so will demand for Declare products, which should create a positive feedback loop by giving participating companies an edge. The program includes three tiers:

1) LBC Red List-Free products have disclosed all of their ingredients, and contain none of the chemicals or materials on the LBC's Red List.

2) Products that are LBC Compliant meet the requirements of the Red List imperative due to a temporary exception. For example, low-mercury fluorescent lighting is a product that qualifies as LBC Compliant.

3) Declared products may contain Red List ingredients but have voluntarily self-disclosed at least 99% of their ingredients. Although Declared products can't be used on LBC projects, they still contribute toward increased transparency.

Declare was created to directly support the LBC, but anyone can access the database (declareproducts.com). While the list of products is still short, comprising mostly American companies, there are also Declare products from Portugal, Australia, and the Netherlands.

In the fall of 2013, the ILFI launched a second label protocol called Just, which asks for in-depth information on 20 aspects of workplace equity and justice. These include pay-scale equity, gender pay equity, employer-provided health insurance, and worker safety.

Courtesy International Living Future Institute

Material World

Endorsing products & processes that are safe for all species through time.

Programs like LEED put a lot of emphasis on materials sources and types. The LBC does too—there are five imperatives under the Materials petal—but the program takes acquisition to another level, considering a material's embodied energy (which includes manufacture and transport), as well as its chemical makeup. The Appropriate Sourcing imperative lays this out in chart form, identifying seven zones for different categories of materials and the maximum allowable distance of the manufacturing facility to the project site.

"In general, materials that weigh a lot should come from nearby," says Vidas. "Lighter materials and components essential to water and energy performance can come from farther away." For example, high-performance windows, which should help the project attain the Energy petal, can come from 5,000 kilometers away, while "heavy or high-density materials" like stone and concrete must come from within 500 kilometers. This imperative addresses the high energy cost of transportation and encourages the development of local and regional economies.

Locating materials that meet appropriate sourcing criteria and don't contain Red List components (see "Red List" sidebar) can be one of the most difficult tasks on an LBC project. If no option exists, protocol does allow a "next-best" substitute, but a project team member must write a letter to the manufacturer stating they are using the product reluctantly because no other choice exists. The letter must urge the company to change its manufacturing process and/or collaborate with companies that are closer to the project site.

Direct pressure on the manufacturer can make a difference, and LBC Projects Coordinator James Connelly cites a compelling example. The super-efficient, triple-pane windows sourced for the Bullitt Center—a commercial LBC project in Seattle, Washington—included a unique venting mechanism, but they were manufactured by Schüco, a German company located far beyond the allowable radius for heavy materials. The Bullitt Center Team worked with Schüco to bring manufacturing equipment and expertise to Goldfinch Brothers, a local window company outside Seattle. Goldfinch now provides super-efficient windows to other cutting-edge green projects, including two pursuing LBC certification. In this way, the LBC helps stimulate innovation and local business.

The Responsible Industry imperative encourages LBC projects to support fair labor and sustainable extraction via third-party certification programs. All lumber used in a project (unless it's recycled or harvested on-site) must be Forest Stewardship Council (FSC) certified, but for industries that don't yet have such certification programs, the project team must write letters encouraging their development.

Project teams must also create a Material Conservation management plan, with the goal of reducing or eliminating waste during the building's construction, life, and end of life. The embodied carbon from construction must be estimated and offset with a one-time carbon credit purchase that supports a new RE project.

Materials Petal Imperatives

	Red List	Embodied Carbon Footprint	Responsible Industry	Appropriate Sourcing	Conservation & Reuse
Renovation	●	●	●	●	●
Landscape & Infrastructure	●	●	●	●	●
Building	●	⊕	●	●	●
Neighborhood	●	⊕	●	●	●

● Imperative; ⊕ Scale Jumping Possible

Equity

Supporting a just, equitable world.

One of the most striking ways the LBC departs from LEED is the inclusion of Equity and Beauty parameters on par with Materials and Energy. In the United States, the Americans with Disabilities Act (ADA) requirements address one facet of the Equity petal—all primary transportation, roads, and non-building infrastructure considered externally focused must be equally accessible to all members of the public—but there's a philosophical component, too, says Vidas.

"An LBC house wouldn't be built in a gated community, for example," she says. The equity imperative functions to discourage, if not forbid, exclusivity, by stipulating that the "project may not block access to, nor diminish the quality of fresh air, sunlight, and natural waterways." In other words, no cordoned-off beaches or homes that tower over neighboring ones.

continued on page 62

Equity Petal Imperatives

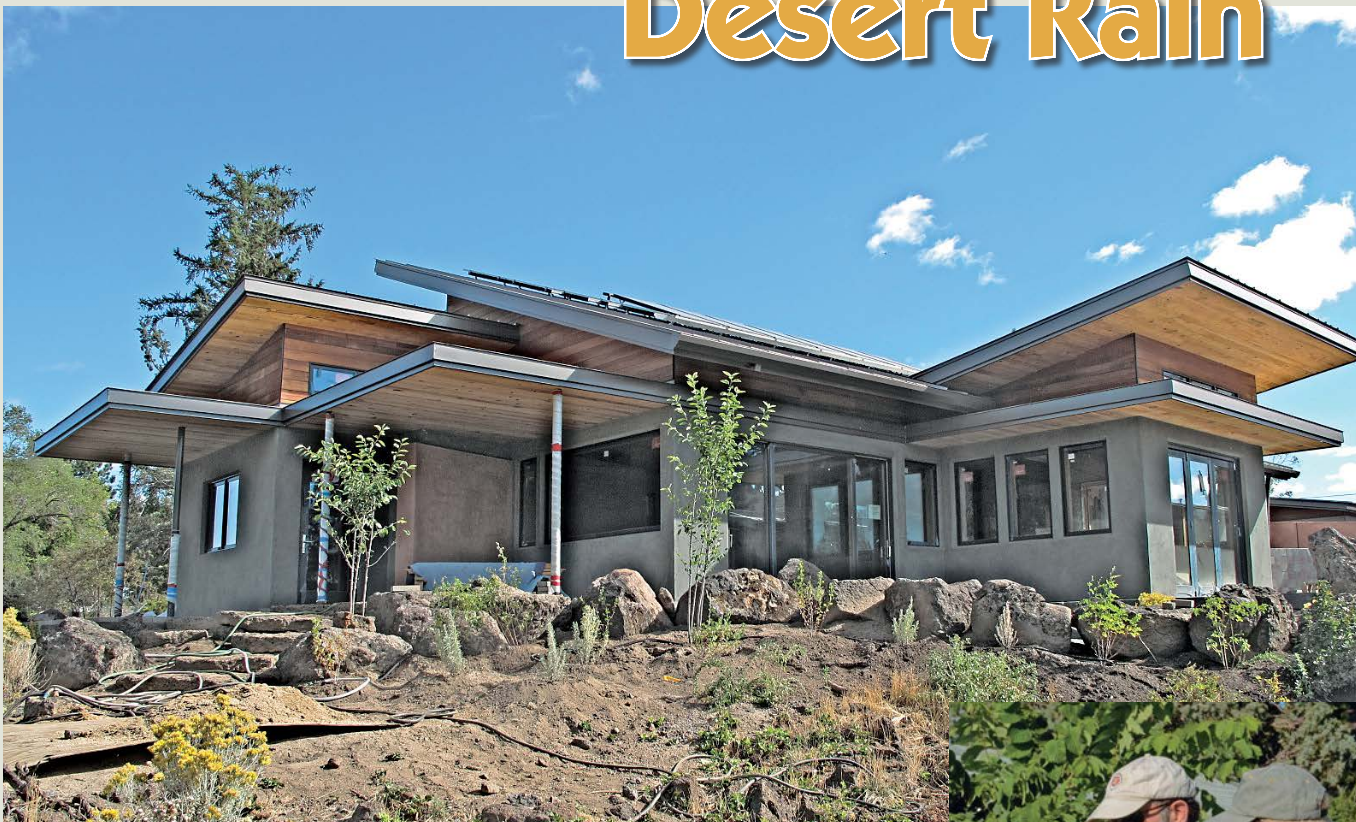
	Human Scale & Humane Places	Embodied Carbon Footprint	Rights to Nature
Renovation	⊖	●	●
Landscape & Infrastructure	⊖	●	●
Building	●	●	●
Neighborhood	●	●	●

● Imperative; ⊖ Optional

Careful material selection, reuse, and restoration were part of this home's path to earning its LBC petals.

Courtesy Matt & Kelly Grocoff (2)

Desert Rain



Courtesy Barbara Scott & Tom Elliott (4)

Tom Elliott and Barbara Scott achieved the Living Building Challenge's imperatives with their green dream home.

Homeowners Barbara Scott and Tom Elliott were so taken by McLennan's vision after hearing him on a National Public Radio broadcast that they returned to the drawing board with their building project, which was initially planned to be LEED-certified. Motivated by cost concerns, they also downsized the house by one-third.

Their home, Desert Rain, was designed to LBC standards from the ground up. The main residence went from two stories to one, in part to expand the roof area for rainwater collection, and the project evolved into an ambitious "residential compound" with a main house and two accessory dwellings.

For their designer, Al Tozer, who'd been practicing sustainable design for nearly 20 years, it was the opportunity of a lifetime. "Instead of picking one or few design tools," says Tozer, "it was like dumping the toolbox upside-down on the floor and saying, 'We're going to use all of these.'"

The masonry wall and newly planted tree memorialize a Ponderosa pine that was sacrificed for the project.

A constructed wetland helps process the home's graywater.

A batteryless grid-tied 14.8 kW PV system provides abundant electricity to meet the home and accessory dwelling unit's needs.

The main house design includes staggered-stud 2-by-4 double walls that were insulated with spray-foam, for 8- to 12-inch-thick walls insulated to R-36 to R-47. A concrete floor provides thermal mass to store passive solar gain. In the summer, deep overhangs prevent direct sunlight from heating the space; well-placed windows provide good cross-ventilation for passive cooling. The arid climate—Bend's average annual precipitation is 9 inches—drove parts of the design, including the large roof area for rainwater collection, constructed wetland, graywater storage cistern, and 35,000-gallon potable water cistern, which is housed under the two-car garage.

The couple has enjoyed the collaboration among team members and says the LBC has challenged many of their subcontractors. For instance, when the stucco contractor couldn't source exterior plaster that complied with Red List and Appropriate Sourcing criteria, he created a new product from local materials.

Scott and Elliott have embraced the Beauty petal's second imperative: education and inspiration. Early on, the couple reached out to the local paper, the *Bend Bulletin*, which has been publishing a series of articles following the home's construction. The couple hosts about four tours a month, and plans to use the property as an educational venue.

Courtesy Barbara Scott & Tom Elliott (2)

An eight-collector solar water heating system (not pictured) provides hot water for the hydronic floors.

Overview

Dwellings: Primary home (2,236 ft.^{2}) with two-car garage; accessory dwelling (489 ft.^{2}); Desert Lookout (second dwelling; 850 ft.^{2})

Location: Bend, Oregon

The Team

Owners: Tom Elliott & Barbara Scott

Designer: Tozer Design

Builder: Timberline Construction

Landscape architect: Heart Springs Landscape Design

Water system: Whole Water Systems

Sustainability consultant: ML Vidas, AIA LEED

Energy

Passive solar: Main home's long facade oriented east-west; 4-in. concrete slab for thermal mass; 1-in. plasterboard for added thermal mass. Minimal windows on north side. Eaves shade windows from direct summer sun but allow winter gain.

Renewable energy systems: 14.8 kW batteryless grid-tied PV system; eight solar thermal collectors in drainback system

Wall assembly: Staggered-stud wood framing for thermal breaks; walls vary from 8 to 12 in. (thickest walls on north side)

Water & space heating: Domestic water & radiant floor heating supplied by SWH system; backup heating provided by air-source heat pump

Cooling: Natural ventilation through operable windows; overhangs keep out direct summer sun

Envelope: Met Passive House standards (0.6 ACH) before plasterboard was installed

Insulation: Closed-cell spray foam (R-36 to R-47 in walls; R-70 in ceiling; R-43 in floor)

Windows: Triple-glazed, argon-filled, U-0.21 (ave.)

Lighting: LEDs only

Water

Water harvesting & treatment: 5,020 ft.^{2} of steel roof feeds rainwater into 35,000 gal. tank via a gravel filter; water then purified via two 20-micron filters and a UV system

Graywater: Collects from sinks, laundry & showers; pumped through a 1,500 gal. tank & constructed wetland first & then into a 1,000 gal. treated water tank; 5,000 gal. storage tank for irrigation & water features

Blackwater: Seeking approval for system that brings all blackwater to a central composting unit. A solar hot air device will evaporate liquids, including dishwasher wastewater.

Materials

Wood: FSC-certified or salvaged/reclaimed

Roof: Standing-seam metal

Interior wall finish: American Clay plasters

Exterior wall finish: Lime plaster, all local/regional materials

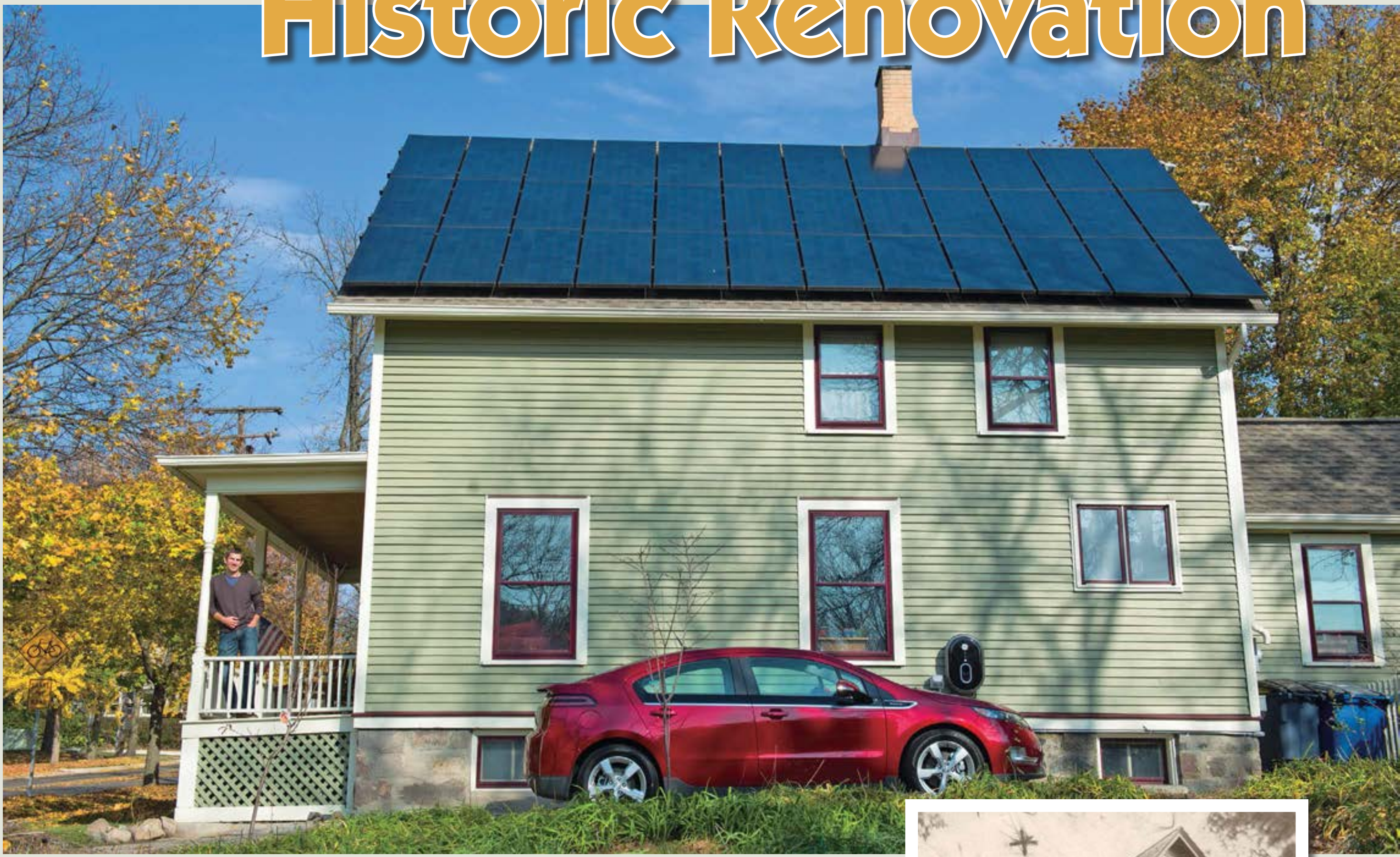
Miscellaneous: Recycled glass tile

Waste & Recycling

Site preparation: Two buildings on property were deconstructed and recycled or donated to Habitat for Humanity

Waste management: Builder claims project has generated less than 1,000 pounds of waste

Historic Renovation



The Grocoffs are restoring their Victorian home one LBC petal at a time.

Matt and Kelly Grocoff are renovating a 112-year-old Victorian in Ann Arbor, Michigan, to LBC standards. They bought the house in 2006, detecting "good bones" under the layers of carpet, linoleum, and asbestos siding. They also recognized that the home's pitched roof was well-suited for solar collection.

Matt, who runs a net-zero consulting firm, began the project before the LBC was announced, focusing first on energy. They added cellulose wall insulation where there was none and insulated the ceiling with spray foam and finished it with plasterboard. They replaced all of the lighting with compact fluorescent bulbs—and later, with LEDs—and installed occupancy lighting sensors in every room.

Upgrading the home's single-pane wood windows presented a special problem. Because the house lies within Ann Arbor's Historic District, they couldn't replace the original windows and still qualify for a historic preservation tax credit. Then Matt met Lorri Sipes of the Wood Window Repair Company, who showed the couple how they could make their old windows more efficient by reglazing them, repairing sashes, and installing weather-stripping and adding low-e storm windows. Blower door tests showed a 70% reduction in air leakage.

A geothermal heating system and an 8.1 kW PV system should take the house to net-zero energy. Starting in July 2013, the Grocoffs began monitoring their energy usage and PV system production.

Kelly Grocoff reveals the hardwood floors prior to their restoration.

Courtesy Matt & Kelly Grocoff (3)

Maintaining the home's character, while improving its energy efficiency, was an important goal.

The Grocoffs are tackling the LBC one petal at a time. "You can add petals as you go," says Matt, who hopes to achieve the Energy petal by summer 2014. Though they intend to pursue full LBC certification, the Materials petal may elude them, in part because they started renovating seven years ago and didn't document everything.

They're taking on the Water petal next, and have recruited the University of Michigan's BLUElab for help. Devki Desai, a doctoral candidate in civil engineering, is leading the project team.

Added insulation boosts the home's thermal comfort and its overall energy performance.

"There are many parts to this, from rainwater catchment analysis and purification to piping and pavement design," says Desai. Many LBC projects rely on well water, but this one can't. A toxic plume of industrial solvent moves under much of West Ann Arbor, the legacy of former local industries. Consequently, the home must rely solely on rainwater, which means coming up with innovative ways to expand roof collection area.

"It's about half the size it needs to be," says Desai. "We're looking at expandable and retractable surfaces that can be pulled out of view when not in use."

Processing wastewater on site presents a different challenge. The Grocoffs will be seeking a code variance from the city since code doesn't allow on-site gray- or blackwater treatment, or composting toilets. "A lot of times, we discover that a sustainability strategy is 'illegal,'" says Matt, but adds that one of the functions of the LBC is to identify obstacles and instigate change.

Courtesy Matt & Kelly Grocoff (2)

Instead of being replaced, the home's original windows were reglazed and repaired. In the winter, low-e storm windows are installed to reduce heat loss.

Overview

General description: 112-year-old, three-bedroom, two-bath Victorian in historic neighborhood (1,300 ft.^{2})

Location: Ann Arbor, Michigan

The Team

Owners: Matt & Kelly Grocoff

General contractor: Matt Grocoff, greenovation.tv

Energy performance contractor: Meadowlark Construction

Water systems: BLUELab, University of Michigan

Energy

Renewable energy system: 8.1 kW batteryless grid-tied PV system

Wall assembly: 2 x 4 stick-frame construction

Water & space heating/cooling: Geothermal, 3-ton Envision Water Furnace

Envelope: Added insulation to walls, ceiling & floor joists; brought attic into building envelope

Insulation: Spray foam at rim joists; dense-packed cellulose (R-13) in walls; R-30 in ceiling

Windows: Original wood windows salvaged by the Wood Window Repair Co.; air leakage reduced by 70%; Trapp low-e storm windows installed in winter

Lighting: Replaced all bulbs with CFLs, then LEDs; Wattstopper occupancy sensor switches installed in every room

Water

Water conservation: Caroma dual-flush toilets; Caroma 1.28 gpm showerheads; Bricor aerators. Owners currently use about 70 gallons per day

Graywater, blackwater & stormwater: Rain barrels for now; working with the University of Michigan BLUElab to design system for recycling graywater, & harvesting, treating & storing rainwater

Materials

Wood: Salvaged doors from ReStore; some wood salvaged from Urban Wood; restored original wainscoting, beadboard, siding & windows

Flooring: Restored original hardwood floors throughout; installed wool carpet (G&K Flooring) on stair runners.

Finishes: Zero-VOC paints (Benjamin Moore Aura, AFM Safecoat, Sherwin-Williams Harmony); Bioshield Hard Oil #9 floor finish; Hock natural shellac molding finish

Petal Imperatives

Inspiration & Education; Beauty & Spirit: Matt produces instructional videos and articles for Greenovation.tv; the couple hosted wood window repair workshop on-site; regularly hosts tours

The Grocoffs feel they achieved this imperative after restoring the home's original features.

Healthy Air, Civilized Environment, Biophilia: Nontoxic paints, finishes used throughout; Ultimate Air ERV; restored windows are operable; natural materials, especially wood, used throughout

Equity: Renovated house in scale with rest of historic neighborhood; owners worked within building's original footprint

continued from page 57

Beauty Petal Imperatives

	Beauty & Spirit	Inspiration & Education
Renovation	●	●
Landscape & Infrastructure	●	●
Building	●	●
Neighborhood	●	●

● Imperative

Beauty is an important imperative of the LBC. The EcoHouse, with a wall full of tropical plants that treat the building's graywater, was inspired by students who wanted "a greenhouse where something would always be growing."

Courtesy Benjamin Benschneider

Beauty

Celebrating design that creates transformative change.

As for the Beauty petal, the LBC believes that people are more inclined to care for places they find beautiful, and their hope is that beautiful buildings will inspire people to extend this care to the natural world. "It's not intended to be a objective analysis," says Sturgeon. "It's more about what beauty means to [the inhabitants]." For Matt and Kelly Grocoff, who are renovating a 112-year-old Victorian home in Ann Arbor, Michigan, under the LBC guidelines, this meant restoring the home's original features and connecting with the home's history by learning about its original owners. For Scott and Elliott in Bend, Oregon, it meant pairing natural materials with a contemporary design (see "LBC Case Studies"). As for documentation, both the project designer and the owners must write essays (at least four and two pages long, respectively) describing how the project fulfills the imperative.

On the Leading Edge

With its varied, stringent requirements, the LBC program is only for the very determined—and those with the resources to pull it off. Although the ILFI offers support through its website, case studies, and network of project teams and ambassadors, there is much that project teams must figure out on their own. However, these first "pioneer projects" show what's possible and are crucial to breaking barriers, whether technological, legal, or one of public perception.

LBC offers two alternatives to full certification: Net-Zero Energy Building certification and Petal Recognition, which requires "earning" at least three petals, one of which must be Materials, Energy, or Water. While only four projects have achieved full certification, three others have earned Petal Recognition, and 12 others are complete and somewhere in the 12-month documentation process as of September 2013. There are more than 150 registered projects around the world, including Australia, Romania, New Zealand, and Mexico. In North America, many are in Oregon, Washington, British Columbia, and Alaska. Google recently announced plans to build a 1 million-square-foot "Living Campus"—a solid sign that the word is getting out.

Access

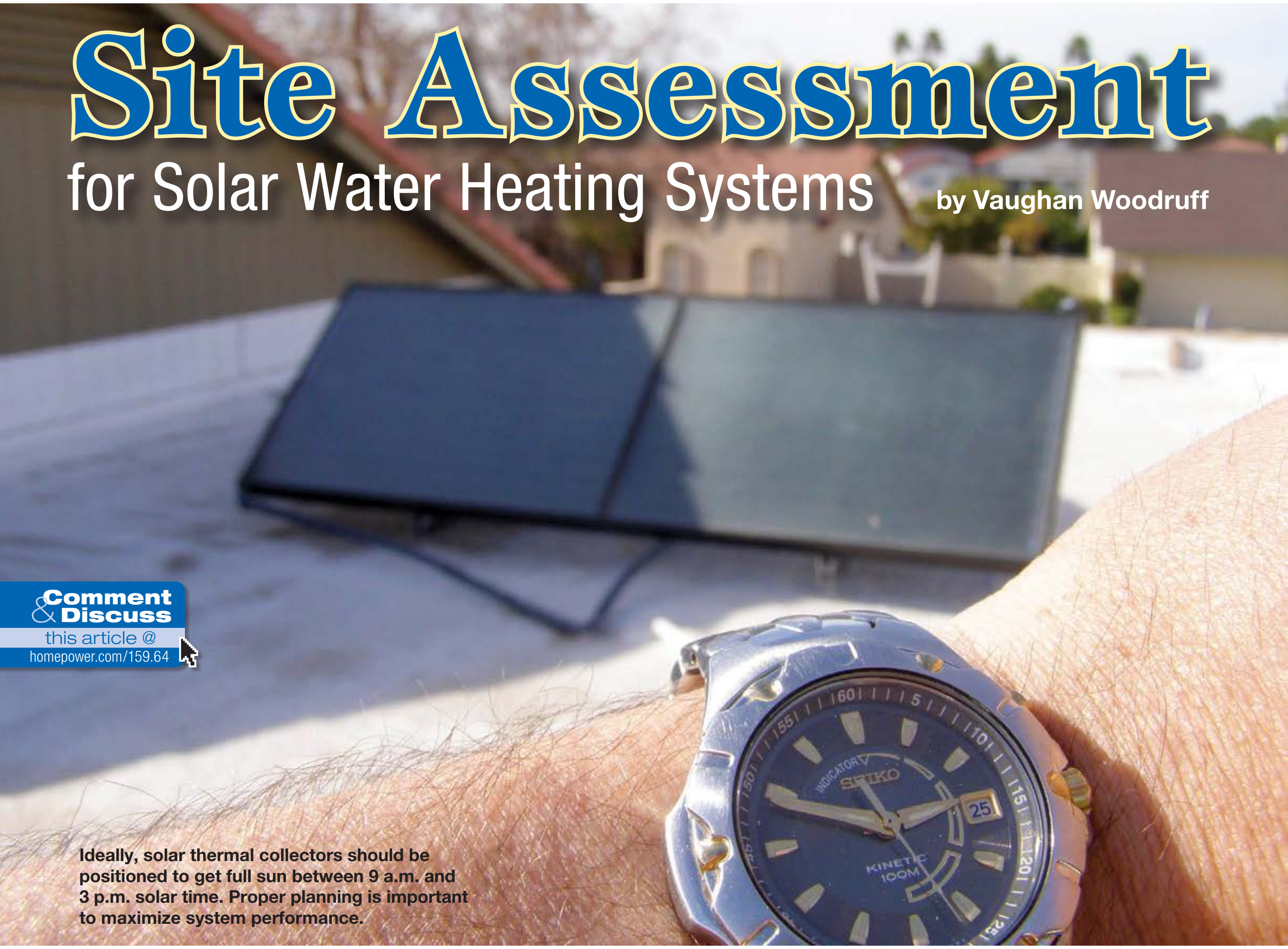
Freelancer **Juliet Grable** (julietgrable@yahoo.com) frequently writes about green building and renewable energy. She lives on a beautiful, south-facing slope in Oregon's Southern Cascades.

Living Building Challenge • living-future.org

Site Assessment

for Solar Water Heating Systems

by Vaughan Woodruff



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Ideally, solar thermal collectors should be positioned to get full sun between 9 a.m. and 3 p.m. solar time. Proper planning is important to maximize system performance.

Courtesy Salt River Project

Without a proper site assessment, you may be putting your solar thermal system at risk for poor performance.

It is a fairly common occurrence for a solar professional to hear from a potential client, "We get tons of sun," or "Our roof faces due south," and then discover that the site is not nearly as ideal as the homeowner's optimistic assessment.

Several years ago, a general contractor contacted me about a project that was nearing completion. His company had gutted a home and was finishing the retrofit designed by a local architect. Our meeting contained a bit of immediacy on his part. I then proceeded to make a decision that betrayed every lick of common sense I had—I committed to the job, site unseen.

I ordered the equipment specified in the design plans and planned two days at the end of July to complete the job. After a stop at the supply house and a long drive, my crew and I arrived at the job site around 10 a.m. As soon as I stepped out of the truck, I began to regret taking the job.

I peered up at the south-facing roof—and noticed nothing but shadows. Several 70-foot-tall trees were shading the roof. To make matters worse, the trees were on the neighbors' property.

Initial Info Gathering

Given that solar water heating (SWH) collectors provide heat for domestic hot water and sometimes for space heating, it is vital that they are appropriately positioned. And part of that is assessing any shading impacts that might occur during the service life of the system.

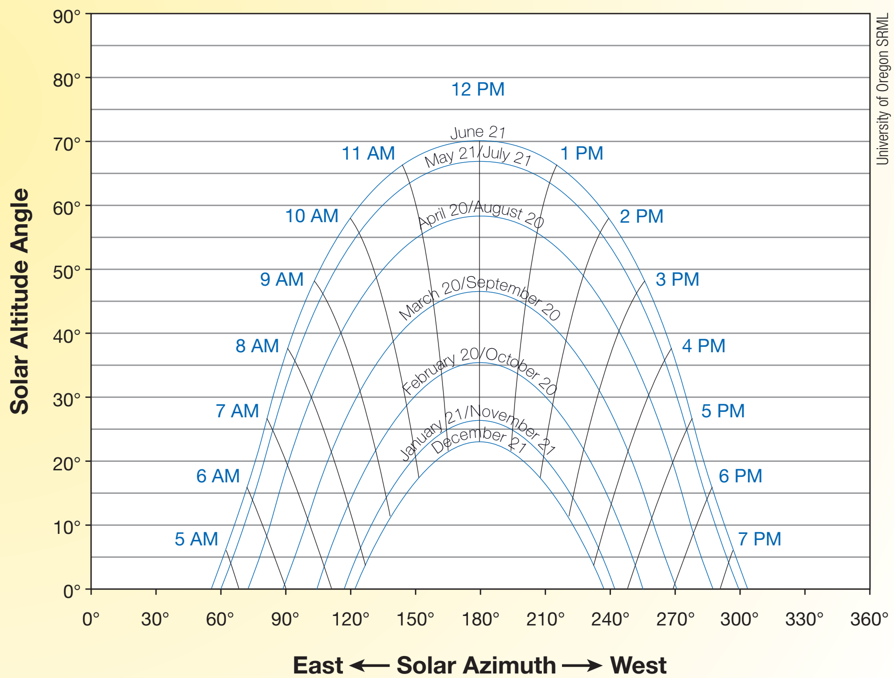
A thorough site assessment helps identify any site deficiencies, such as a sagging roof or plumbing code violations, and is used to determine how to integrate the SWH system with existing water heating appliances. Homeowners putting in their own system can observe the site over long periods. A solar professional typically has less than an hour to get it right.

The Solar Window

Sun Path for Portland, Maine; Latitude 43.7°N

The area of sky open to sunlight for a site is called the "solar window." The upper limit of the solar window is the sun's path on the summer solstice—the day of the highest arc that the sun will make. Assuming no obstructions, the path of the sun on the winter solstice is the lower limit of the solar window.

The east and west edges of the solar window are not defined by the horizons, as one might expect. While the sun travels through the width of the sky, the amount of radiation that reaches the earth during early morning and late afternoon is limited due to the increased thickness of atmosphere that it must pass through. Instead, the edges of the solar window are typically considered 9 a.m. to 3 p.m., solar time. This six-hour window contains a majority of a site's solar radiation. It is preferable to have no shading within the solar window, since shading during this time will most adversely affect system production.



A solar heating system site assessment typically begins long before an installer or salesperson sets foot at a prospective job site. This process begins during the first communication, when a solar professional asks for information:

What type of project is the customer considering? It is important to determine whether the system is for heating domestic water, supplementing the customer's space-heating system, or heating a swimming pool.

What are the primary reasons for this project? Customers inquire about SWH systems for a variety of reasons. Perhaps they want to reduce their energy costs, gain greater energy independence, or reduce their household's carbon emissions. Professionals assess these motivations to determine the best approach to take with their prospective clients.

Where is the prospective site? Determining the exact location of the site helps a solar professional make preliminary assessments on particular design challenges, such as nearby obstructions that may cause shading.

Is there shading that might affect siting or require tree removal? It is good to have a discussion about the impacts of or possible remedies for trees or adjacent buildings that will have a significant impact on system performance. At times, this can be a deal-breaker.

How will the building's orientation and architecture impact collector placement? Some buildings are perfectly situated for a roof-mounted collector array. Others may require a wall- or ground-mounted array. These approaches may affect system cost and performance.

How is the water currently heated? Almost all SWH systems are integrated with water heaters powered by electricity, propane, natural gas, or oil. The type of auxiliary heat used with the SWH system will have a significant impact on the type of tank that is appropriate.

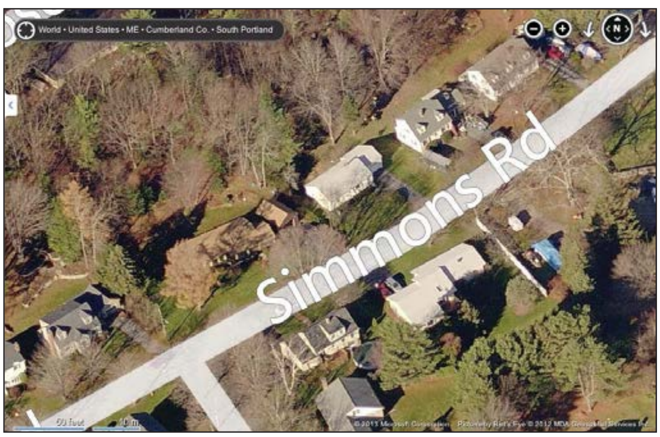
How many people live at the home? Since the production of a SWH system is dependent upon household hot water consumption, it is important to gauge whether the household uses enough hot water to justify the expense.

How much money is currently being spent for water heating? Throughout its history, the solar industry has been driven by competing energy costs. If a system has the potential to save its owner a bunch of money, this is a huge benefit. By determining the costs of water heating, a professional can also more precisely estimate the average hot water use for the household.

Some prospective clients have done their homework, identified the system type that best fits their desires, and have a good sense of the system costs. Others might


Courtesy Google Maps

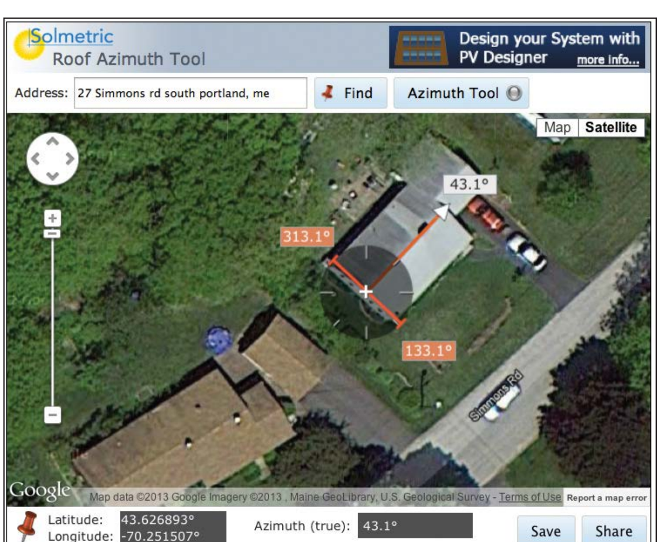
Street-level views can assist with identifying site-specific characteristics, such as roof type and roof slope, and potential shading issues.



Courtesy Bing Maps

Aerial photos from online maps can also be used to spot potential shading issues. In addition, they can help the assessor determine the building's orientation.

Solmetric's free online Roof Azimuth Tool can calculate a roof's orientation angle with two clicks of a mouse.



Courtesy Solmetric

simply be interested in "going green," becoming more self-sufficient, or reducing their energy costs. In all cases, the professional should visit the site to verify the conditions before proceeding. If any homeowner interested in self-install has doubts, they would be wise to hire a pro to perform an initial assessment.

Powerful online tools are huge assets to the solar professional during this preliminary phase. Aerial maps and satellite photos from common online providers allow remote site observation. The building's orientation, large trees or other obstructions that might cause shading, and roof space that might be appropriate can be identified. Street-level and isometric views provide greater detail for gathering as much information as is practical before visiting the site.

A site assessor can use these tools to observe barriers for installation. Had I checked remotely on the project mentioned earlier, I would have seen that the neighboring trees were a significant problem and been able to address this issue during the planning process, instead of after arriving on-site.

On-Site Assessment

Key details must be confirmed before selecting equipment and determining the system design. Some of these include:

How will the system be integrated with the existing heating system? The type of heating fuel is critical, as it affects tank selection and controls. If the existing heater is old or inefficient, it may make sense to replace it.

Will the SWH system also provide space heating? A system that provides space heating also increases complexity. Information is needed about the type of distribution (i.e., baseboard, radiant tubing, ducts, etc.), the efficiency of the building envelope, and the configuration of the current heating system.

Where will the equipment be located? The collector location can often be approximated without a site visit. Details such as the location of storage tanks, controls, piping, expansion tanks, and other components often require a site visit.

Will the storage tank fit? It is important to verify that a preferred tank will actually fit. In addition to checking that there is sufficient clearance, door widths are checked to ensure the tank can be maneuvered into place.

Will changes to existing systems be required? Existing plumbing or electrical code violations should be addressed before the new system is installed.

Are there any red flags? Some issues don't lend themselves to remote observation. For instance, is the roof sound enough to hold a system for 25 to 30 years? Are there major code violations or safety concerns with the existing water heating system? Will there be significant extra costs due to the need for electrical upgrades or complicated piping runs?


Courtesy Chuck Marken

Fitting additional solar equipment into an existing utility room can be a challenge and may affect system design.


Courtesy Insource Renewables

Since an SWH system is designed to function for at least 20 years, it may be best to replace damaged or old roofing material prior to the system's installation.

Shading Assessment Tools

Another key detail that can be observed during a site visit is the impact of shading. A shading assessment may be required for local incentives such as state tax credits or utility rebates.

Handheld digital devices and smartphones can use apps such as Solmetric's iPV (for iPhone; $39.99) and Comoving Magnetic's Solar Shading (for Android; $16) to measure the amount of shading at a site. They can provide a reasonable shade profile for homeowners who don't need a professional shading assessment tool for a single installation.

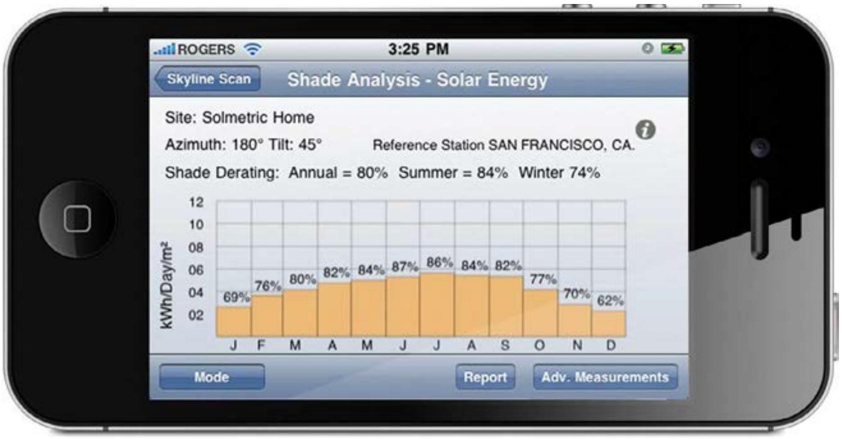
When I went out to the tree-shaded site mentioned above, all I had with me was iPV. After using it for a few minutes on the roof, I returned to the ground with a shading profile of the site. For 80% of the year, the roof received no sun. The architect arrived, and I attempted to tactfully address the situation. After introductions and a couple of clarifying questions about why I had requested her presence, I explained that the trees on the neighbor's property were going to be an issue.

I discussed sun angles and the performance of shaded collectors while trying to restrain my inner-Mainer, who occasionally defaults to an unhealthy dose of sarcasm. The architect was initially skeptical of my assessment, until I pulled the iPhone out of my pocket and showed her the results.

Designed primarily for assessing PV sites, the Solmetric SunEye 210 ($1,995) is a handheld device that includes a fish-eye camera and a touch screen for operation. The site

Solmetric's iPV app allows users to trace obstructions on-screen to determine the site's effective skyline.

Solmetric's iPV app offers a sample shade analysis for a site in San Francisco showing a 20% annual loss due to shade.



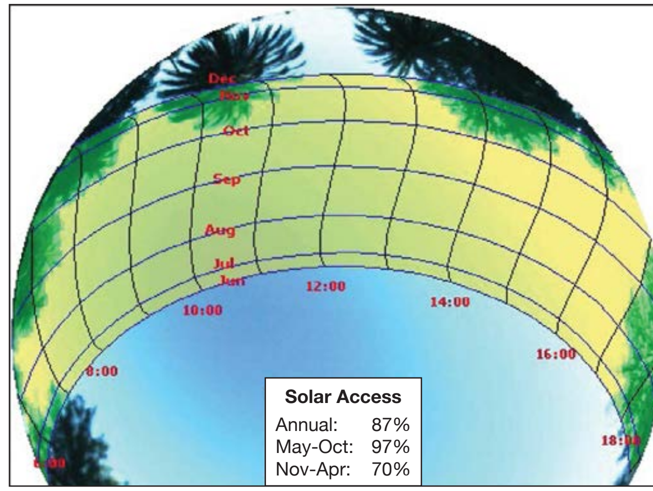
Courtesy Solmetric (2)

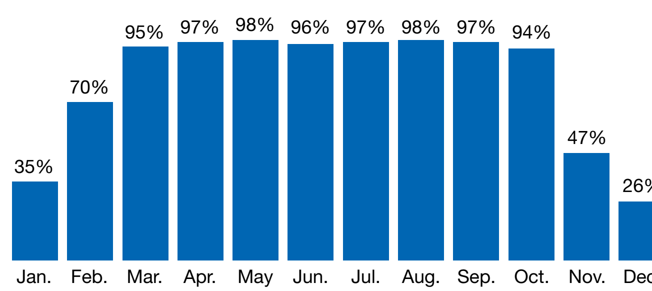
Courtesy Solmetric (2)

Solmetric's SunEye is a digital interface that provides detailed information about a site's solar access, expressing it as a monthly, biannual, and annual percentage (right).

Example SunEye Site Data

Sky04 – 11/5/2010 15:53 – SW corner
Panel Orientation: Tilt=26° – Azimuth=169° – Skyline Heading=180°
GPS Location: Latitude=38.40332° N – Longitude=122.81831° W
Solar Access: Annual: 87% – Summer (May-Oct.); 97% – Winter (Nov.-Apr.): 70%
TSRF: 94% – TOF: 99%



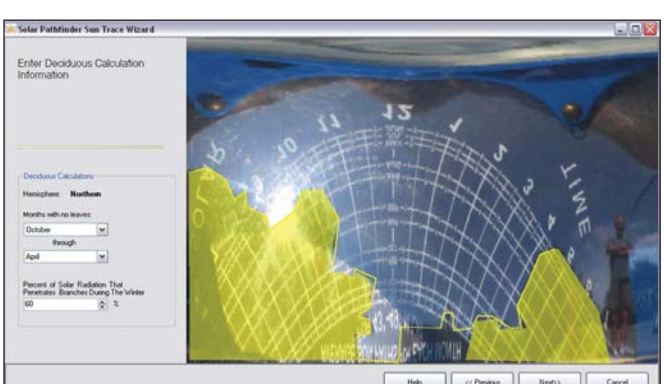


assessor can input information about the project, such as the collector's tilt and azimuth and the site's coordinates. Once this information is entered, the touch screen displays a view through the fish-eye lens, a digital compass, and a digital level. While the SunEye is level and oriented to true south, the operator captures the fish-eye image. The device then compiles the data, overlaying a silhouette of the obstructions on a diagram that illustrates the sun's position in the sky throughout the year.

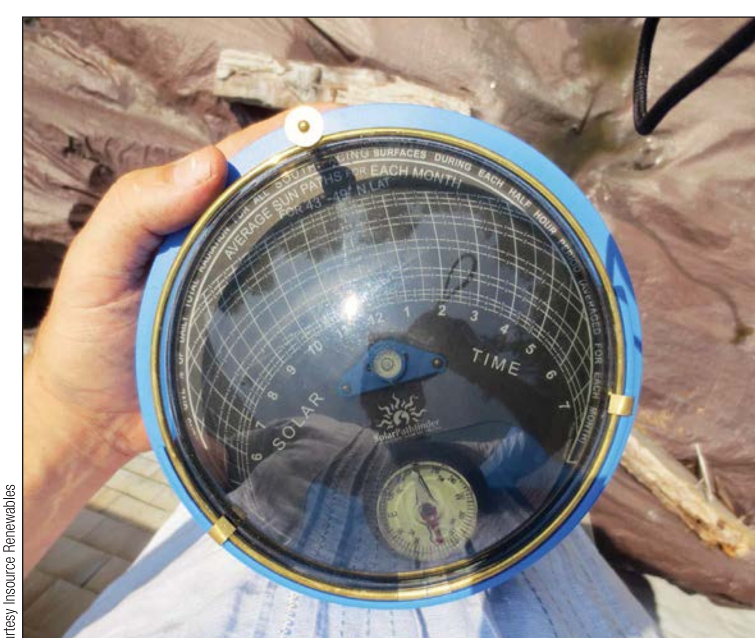
From this, the SunEye calculates the percentage of available solar radiation at the site during each month and over the course of the year. The calculations are presented almost

The Solar Pathfinder solar assessment tool can be used manually (users trace the outline of obstructions reflected on the plastic dome onto the black sun path diagram) or an image can be imported into software for automated calculations.

The Solar Pathfinder's Sun Trace Wizard allows users to trace the shadows of obstructions from a digital photo, and then calculates monthly solar access.



Vaughan Woodruff



Courtesy Insource Renewables

Which South?

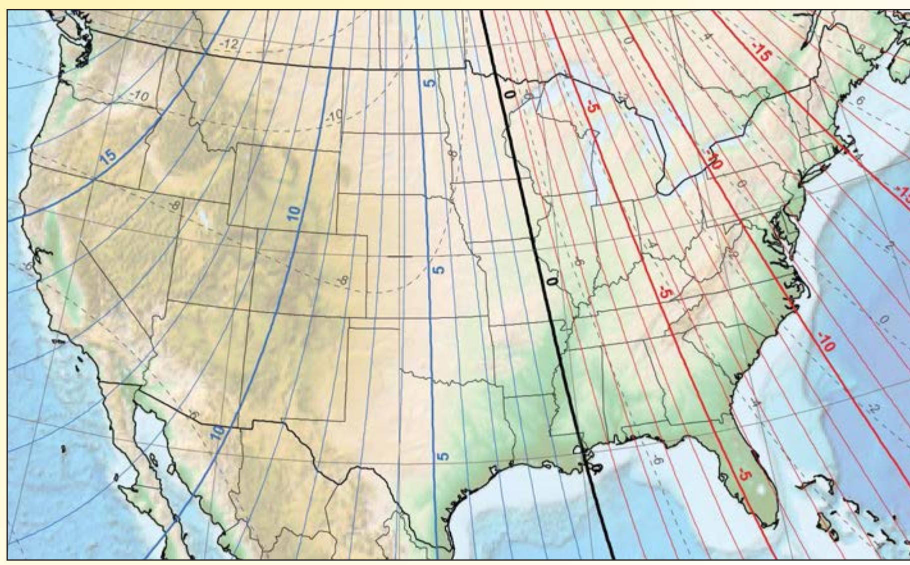
Unless you live where true north and magnetic north are nearly identical, magnetic declination keeps a compass from displaying solar (true) south. Magnetic declination describes the difference between true north and magnetic north for a particular site. At a location with a magnetic declination of 10°E, the magnetic north pole is 10° east of the actual north pole. For accuracy, solar assessment tools must account for this difference.

In the United States, sites east of the Mississippi River Valley have a western declination; sites west of the Mississippi River Valley have an eastern declination. For example, the magnetic declination in Baltimore, Maryland, is approximately 11°W. If you were trying to determine solar south in Baltimore with a compass, you would find magnetic south, then rotate 11° to the west.

Magnetic declination changes over time. The variation is slight for locations in the central United States—for instance, the declination in New Orleans will change by 1° in eight years. But in Fairbanks, Alaska, the declination is currently changing by 1° every three years. The National Geophysical Data Center's declination calculator provides current data on a site's magnetic declination (bit.ly/DeclCalc). Aerial maps are aligned with true north and true south.

Magnetic declination values vary depending on location. To face true south, arrays planned at sites with a western declination will need to be oriented west of magnetic south, and conversely sites with an eastern declination will have to be adjusted to the east.

Courtesy National Geophysical



Courtesy NOAA National Geophysical Data Center/Google

instantaneously and can help an installer make decisions on the fly. For instance, the site assessor can modify the graphic by erasing trees to determine how tree removal would affect shading. Solmetric offers PV Designer software that syncs with the SunEye data to aid in solar-electric system design, but does not offer a comparable program for SWH systems. Instead, the data must be entered into separate solar heating modeling software, such as RETScreen, F-Chart, T-Sol, Polysun, or the Solar Pathfinder Assistant (SPA; see below).

The Solar Pathfinder (starting at $260) is a simpler device consisting of a plastic dome that overlays a sun-path template appropriate for the site. Once the device is leveled and oriented true south, the reflection of objects on the dome can be traced on the template with a grease pencil. Alternately, the Pathfinder can be aligned with magnetic south, and a photo of the reflection can be imported into the SPA modeling software. The software will automatically account for the site's magnetic declination.

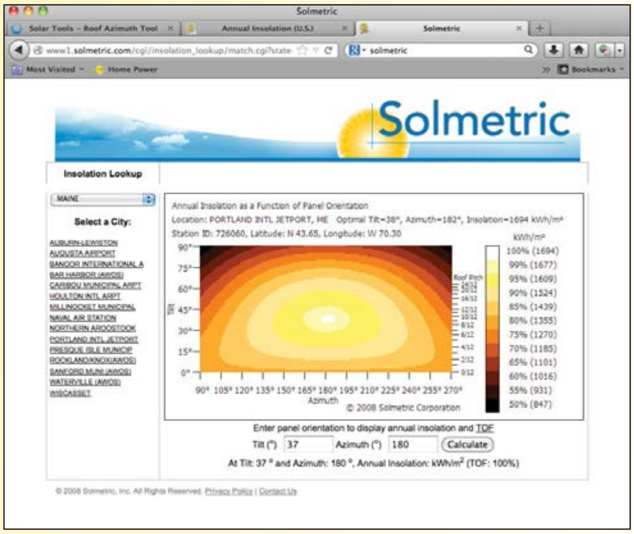
At the site, the assessor can manually calculate the shade derating each month by counting the shaded numbers on the template. Each sun-path on the template shows a number for each half-hour increment of the day. The numbers are the percentage of the day's total solar radiation occurring during that half-hour window. During the middle of the day, when solar radiation passes through less atmosphere, it is more intense and the percentages are higher. In the early morning and late afternoon, the percentages are much smaller. The procedure is less precise and more arduous than with the SunEye, but gives the site assessor a fairly solid idea of the site's potential.

Many solar professionals will qualitatively observe the reflections on the diagrams of the Solar Pathfinder to compare the shading at various locations around the same site. For accurate assessment, the site assessor will take a digital photo and import it into the Solar Pathfinder Thermal Assistant Software ($189), which allows users to input various details about the proposed system (number of collectors, collector

The Effects of Tilt & Azimuth on Collector Performance

Solmetric offers its free online Annual Insolation chart, which illustrates the effects of an array's tilt angle and azimuth (deviation from true south) on the amount of annual solar radiation that strikes it. Data is available for more than 1,000 sites across the United States. This program is directly applicable to grid-tied PV systems, in which maximizing the amount of energy produced by a system is desirable. Since net-metered systems do not need to store energy and often provide the greatest benefit by maximizing their annual production, PV installers can refer to these charts to determine how a particular roof pitch or building orientation might affect array production.

While this tool can provide some general comparisons between different orientations of solar heating systems, caution must be exercised. Unlike net-metered PV systems, the energy value produced by a SWH system often depends upon storage and always depends upon the quantity of hot water used in the building. Trying to maximize annual production in an SWH system can lead to system overheating in the summer and minimal production in the winter because the amount of energy that strikes a surface is maximized by favoring the time of year when the most solar radiation is available. Instead, SWH system design seeks to match system production with hot water consumption. A standard residential SWH system is quite similar to an off-grid PV system—the match between production and storage is crucial.



Courtesy Solmetric

Solmetric's Annual Insolation tool illustrates the amount of annual solar radiation that strikes a flat surface for selected sites. The tool has some limited applicability for SWH systems.

An important lesson that can be learned from the chart is that minor deviations from a true south azimuth and tilt set at the location's latitude have minimal effects on the amount of solar energy that strikes the array. Constructing elaborate designs to orient a collector array to true south or at an "optimal" tilt angle is often not worth the expense or aesthetic sacrifice.

model, collector tilt and azimuth, size of storage tank, etc.) and the hot water use in the home (i.e., average daily hot water use, delivery temperature) to estimate the system's monthly and annual production.

Many states' incentive programs require the use of the Solar Pathfinder or SunEye to verify that a project is properly situated and worthy of funding. Most solar heating professionals use one of these two tools for meeting these requirements and for quantifying the benefit of an SWH system.

Thinking Like a Pro

As you plan, you can take an approach similar to the pros. Start by using aerial maps and other online tools to get an idea of the site's overall suitability. If you want more accuracy, consider investing in a solar siting tool. (Local organizations may have the shade-assessment tools available for the public to borrow or rent.)

If you are planning to install the system yourself and have limited knowledge of SWH, you will do well to use an engineered system that has received OG-300 Certification through the Solar Rating & Certification Corporation (SRCC) or the International Association of Plumbing and Mechanical Officials (IAPMO).

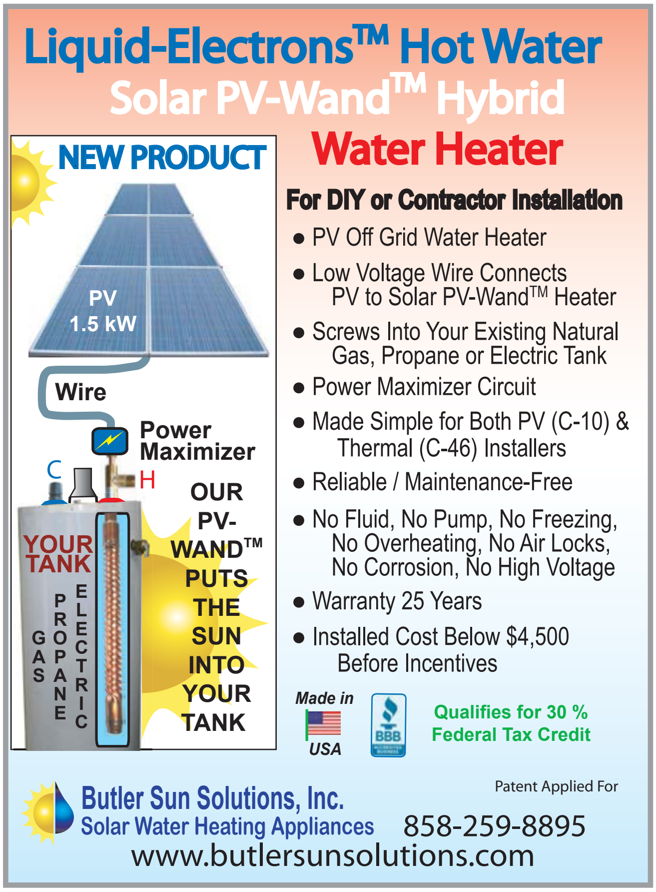
These systems have been reviewed and approved by a third party in accordance with national standards and are required to have thorough installation and operation manuals, alleviating some of the challenges that arise with installing and also integrating a new SWH system with your existing water heating system. Specifications for system equipment are included, which will help you determine where this equipment can be placed—or whether it will fit at all.

Finally, you could use the shading assessment to estimate the system output. You could make an investment in a Solar Pathfinder and Solar Pathfinder Thermal Assistant software, purchase another solar heating modeling software, or use free resources for estimating system performance (see "Methods" in *HP157*).

These approaches are valuable for solar professionals, whose success depends upon providing productive systems for their clients and minimizing trips to the job site. For do-it-yourself projects, these approaches help prevent very unpleasant surprises and maximize the production of a solar heating system.

Access

Vaughan Woodruff (vwoodruff@insourcerenewables.com) is a contractor, engineer, and educator. He owns Insource Renewables, a design/build and consulting firm in his hometown of Pittsfield, Maine.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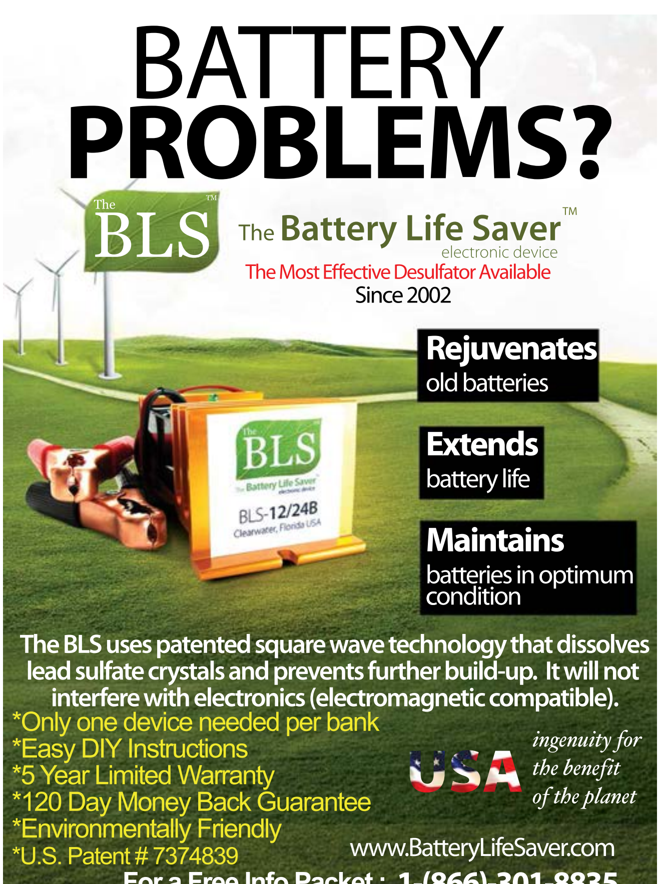
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BACKUP POWER WITHOUT BATTERIES

Story & photos by Orion Thornton

"Will we be able to use the energy from our grid-tied PV system when the grid power is off?"

The typical answer is no—unless you have a battery backup system, which is more expensive than a batteryless grid-tied system and requires routine maintenance. During a grid failure, most inverters made for batteryless systems shut down, making energy from the PV array inaccessible. But a new inverter from SMA America can feed a load—without batteries.

SMA America's new batteryless grid-tied inverter allows users to access up to 1.5 kW from their PV array—even when the grid is down.

When Jeff and Kathy Ball wanted a PV system that would offset all of their home's electricity usage, backup power was one main point of interest. The Balls don't experience frequent grid outages or have critical loads that absolutely must run during a loss of utility power, but they were interested in fully utilizing their potential solar-electric system. They considered battery backup, but the added cost of batteries and a battery-based inverter was approximately $5,000 more (about $24,475 installed cost) than a batteryless grid-tied system (about $19,000).

The decreased energy yield due to lower system efficiencies of a battery-based system was also a deterrent. The weighted efficiency of a typical grid-direct inverter ranges from 94% to 97%, while a battery-based inverter's efficiency is lower—91% to 93%. A standard charge controller, which is also needed for a battery backup system, incurs another 1% to 2% loss, making the battery backup system even less efficient. Over a year, the losses would add up to about 340 kilowatt-hours for the Balls' proposed 5-kilowatt solar array.

While the Balls weighed the pros and cons of a battery backup system, another option became available: beta-testing SMA America's Sunny Boy TL-US inverter. During a grid outage during the day, this inverter can supply up to 1,500 watts (at 120 VAC) from the PV array to a dedicated wall-mounted, switched outlet—without batteries.

Inverter Innovations

From time to time, there are small technological advancements that have a large impact on the solar industry. The new TL-US inverter feels like one of those small but significant advancements.

This inverter has all the latest features—a wide DC voltage input range, which allows for more flexibility when considering array-to-inverter matching; transformerless construction, leading to higher conversion efficiencies compared to transformer-based inverters, along with a decrease in overall weight, making for an easier and safer installation. The inverter's dual MPPT inputs allow array strings to be separated, reducing the potential for shading and module-mismatch inefficiencies and increasing flexibility in array placement. But what sets this inverter (and its series models: 3, 3.8, 4, and 5 kW) apart is its "secure power supply" (SPS) function. Given the impact of the SPS function, it will be no surprise if other inverter manufacturers introduce similar features in their own future models.

Code Considerations

No specific *National Electrical Code (NEC)* requirements apply to the secure power supply (SPS) technology in inverters. The inverter is not isolated, so all ungrounded system *Code* requirements need to be followed (see "Ungrounded PV Systems" in *HP150*), along with other standard *NEC* requirements for running AC wiring in a home. Even though there are currently no labeling and marking requirements for the SPS circuit, it is appropriate to identify this circuit as such with a placard at its location, along with operational instructions.

The TL-US inverter model is similar to a Japanese model that was developed after the nuclear power plant failures at Fukushima to provide a small amount of standby power in the event of a grid outage. The SPS inverter was designed specifically for charging small electronics, like cell phones and laptops. The TL-US series and TL-JP model debuted within months of each other, with the Japanese version being first to market.

Even though the technology that allows the SPS to function is integrated into the inverter, the actual electrical outlet circuit is not—it must be installed exterior to the inverter. This includes a wall-mounted receptacle, a switch, and all associated wiring. Additional labor and material costs are a consideration when integrating the SPS circuit, and depend greatly on the desired location of the SPS outlet in relation to the inverter. There is no limitation as to how far away from the inverter the SPS outlet is installed, although voltage drop will need to be considered. If the SPS circuit is located a significant distance from the inverter, wire size may need to be increased due to voltage drop..

In the Balls' system, the SPS outlet was installed in the mechanical room, which is centrally located within the home, but about 50 feet from the inverter. The additional cost for the SPS circuit was $400, including all labor and materials. The inverter was installed in an upstairs open storage area since the mechanical room was not big enough. In many instances, however, the SPS outlet and inverter can be installed within a few feet of each other, reducing the overall labor and material costs.

The retail cost of the inverter itself is actually slightly lower than its counterpart, the 5000US, which helps to cover some of the additional costs of adding the SPS circuit. Along with a higher reported efficiency (96.5% in comparison to 95.5%), the TL-US inverter is a clear choice over the standard transformer-based model.

Tech Specs

Overview

Project name: Ball residence

System type: Batteryless, grid-tied solar-electric

Installer: Onsite Energy

Date commissioned: April 1, 2013

Location: Bozeman, Montana

Latitude: 45°N

Solar resource: 4.7 average daily peak sun-hours

Record low temperature: -43°F

Average high temperature: 83°F

Average monthly production: 497 AC kWh

Utility electricity offset annually: 110%

Photovoltaic System Components

Modules: 20 REC 250PE, 250 W STC, 30.2 Vmp, 8.3 Imp, 37.4 Voc, 8.86 Isc

Array: Two series strings, 10 modules per string, 5,000 W STC total, 302 Vmp, 8.3 Imp, 374 Voc, 8.86 Isc—Imp and Isc are per each of two separate MPPT PV inputs

Array installation: SnapNrack S100 with DPW Easy Feet standoffs on south-facing roof, 33.7° tilt

Inverter: SMA Sunny Boy 5000TL-US, 5,000 W rated output, 600 VDC maximum input, 175 – 480 VDC MPPT operating range, dual inputs, 240 VAC output

System performance metering: SMA Sunny Webbox

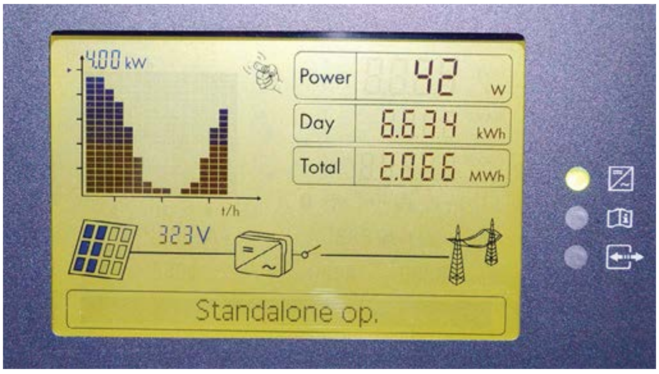
How It Works

Unlike a typical grid-tied battery backup system, which automatically switches on the backed-up loads during a grid outage, the SPS circuit must be manually operated. Once the inverter receives a signal from the SPS switch, it initiates a 45-second SPS startup process, which includes an arc-fault circuit interrupter (AFCI) self-test. After the startup process is complete, the inverter displays that it is in stand-alone operation, which indicates that it is isolated from the grid and the SPS circuit is live. The inverter then displays the amount of power the SPS loads are consuming.

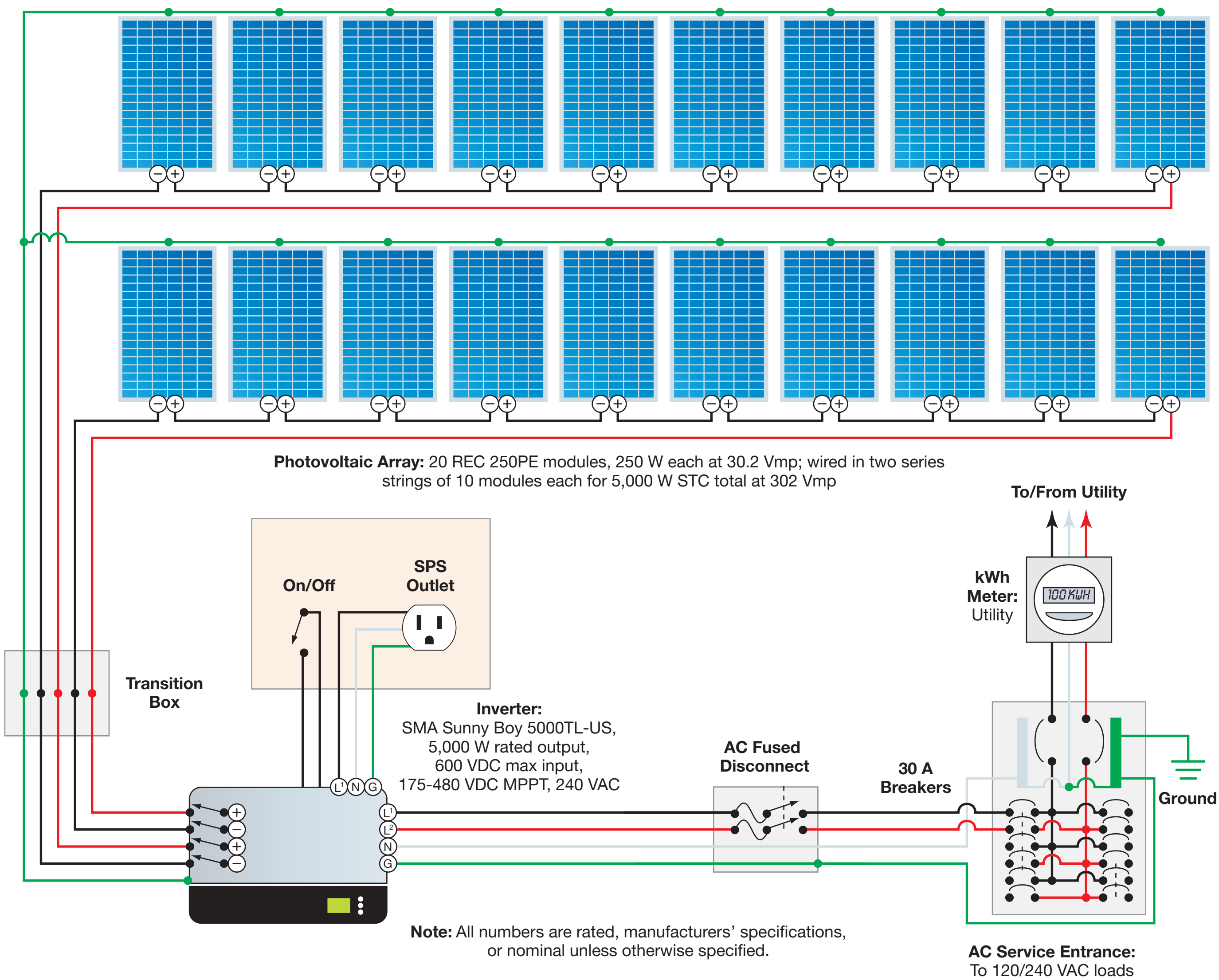
The inverter uses its capacitor bank to throttle PV array current, varying its internal resistance and acting as a current-controlling device to provide a stable voltage. Changes in insolation will cause the array output to fluctuate, which will influence how much power will be available to the SPS circuit. If the loads on the SPS circuit exceed 1,500 W or what the array can supply, the inverter will disconnect from the SPS and then try to reconnect every 20 seconds until the load size is appropriate.

At a limited output of 1,500 W, the loads that can run will most likely be relegated to communications (cell phones, routers, etc.) or lighting. That said, if adequate power is available during the day, the SPS circuit could potentially be used for larger loads, as long as the 1,500 W limit is not exceeded. That means, during daylight hours, you may be able to keep a small refrigerator operating or run a TV and

SMA's Sunny Webbox performance meter displays when the system is in stand-alone operation. Here, the system is supplying 42 W to the SPS load.



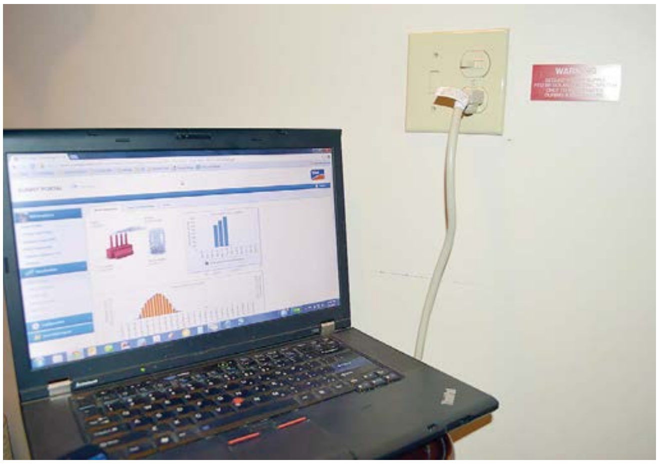
SECURE POWER SUPPLY (SPS) BACKUP



entertainment system. There are, of course, many loads that would exceed the inverter's 1,500 W capability, including space heating, power tools, and electric water heaters. With the manual nature of the SPS circuit, it's imperative that system owners know the limitations of the SPS circuit. It may be helpful to produce a list of appliances that can be operated during stand-alone operation and post it next to the SPS outlet.

Once grid power is restored, the SPS switch must be manually turned off for the inverter to restart its grid-tied operation. Otherwise, the SPS circuit will keep the inverter in "stand-alone op" mode, preventing grid-tied operation, and therefore preventing the rest of the array's solar electricity from being used in the home or any of it from being fed to the grid.

Here, the SPS powers a router and a laptop, which displays the PV system's cumulative data.



Thanks to the inverter's two separate MPPT circuits, shading on one string of the array will not compromise the performance of the other string.

SYSTEM DESIGN CONSIDERATIONS

On the Balls' property, a large ash tree partially shades the eastern slope of the roof from September through March, resulting in an estimated 7% annual decrease in solar energy production. Because of this shading issue, the PV array was divided into east and west arrays, taking advantage of the inverter's two separate MPP tracking inputs. Pruning enough to significantly reduce the array shading would have affected the tree's health, so the Balls decided to leave it alone. Instead, they increased the array size to make up for the loss in energy production—and enjoy the tree's summer shade on their south-facing porch.

The inverter displays the individual power output of each of the two MPP inputs, providing easily accessible interpretations of how the individual strings are performing. In the Balls' case, having this information is helpful in comparing the energy production of the unshaded west array to the partially shaded east array. This function also helps users identify underperforming strings, particularly when shading is not a factor. The information provided by the dual MPPT inputs could also help the Balls determine if it might be worth pruning the tree in the future.

Once the PV array placement was set, the inverter location needed to be finalized. The Balls had planned for adding a living area in their home's second floor. However, the space was not converted and instead was used for storage. This large, open area, closer to the PV output circuits, was the best location for the Sunny Boy inverter. If adequate space had been available in the mechanical room, this would have also been a good option, and would have allowed the inverter to be closer to the SPS outlet, but in turn would have increased the wire run distance from the solar array to the inverter.

If beta-testing the TL inverter had not been an option, but the Balls still wanted a backup power source, the location of the inverter/power system may have been reconsidered. Due to the potential exposure to hazardous gases, installing a battery bank in a living space is not advised. In addition, the floor joists on the second level of most homes are usually not designed to accommodate a battery bank's weight. Determining proper equipment placement is an added complexity of grid-tied battery backup systems. But less consideration is needed when determining the location of the SMA TL inverter and its associated SPS circuit.

The next design consideration was how and where to integrate the SPS circuit. A typical grid-tied battery backup system's critical loads are hard-wired into a dedicated load panel, while the SPS circuit is a wall-mounted outlet into which the homeowners can plug a variety of appliances. For the Balls, who wanted to supply electricity to their computers, cellphone chargers, lamps, or, when solar conditions are right, even a 900 W refrigerator, having the SPS circuit centrally located was key. The mechanical room, which lies at the center of the home, was the best location. From there, the Balls can run a properly sized extension cord to their home office or kitchen.

The Balls' TL inverter was commissioned in April 2013 and has operated flawlessly. Since the system startup, there has been only one grid outage. Since it occurred during the night, power to the SPS circuit was not available since there was no solar input from the array. This is an obvious limitation of the SPS circuit—it will only operate when there is sufficient solar power available. In the case of the Balls' system, even a fairly overcast day will have enough available solar radiation to supply 1,500 watts to the SPS circuit, as the total output of the array is 5,000 watts. But at night, of course, the solar potential goes to zero and the SPS circuit is unusable.

Beyond the use of the SPS circuit, the Balls' system has produced more than 4 MWh of energy and their system has accumulated 1,800 kWh of net-metered credits. In addition, knowing they have the ability to use some of the sun's energy during a future grid outage, the Balls feel their investment is well-justified compared to a typical batteryless grid-tied solar-electric system.

Is the SPS Right for You?

Even though the SPS technology has limited applications in comparison to a battery-based grid-tied system, the ease and low cost of adding it to a grid-tied design, including the cost of the SMA inverter and the associated wiring, makes it hard to imagine why anyone wouldn't want the added benefit of accessing otherwise unused solar power during a grid outage.

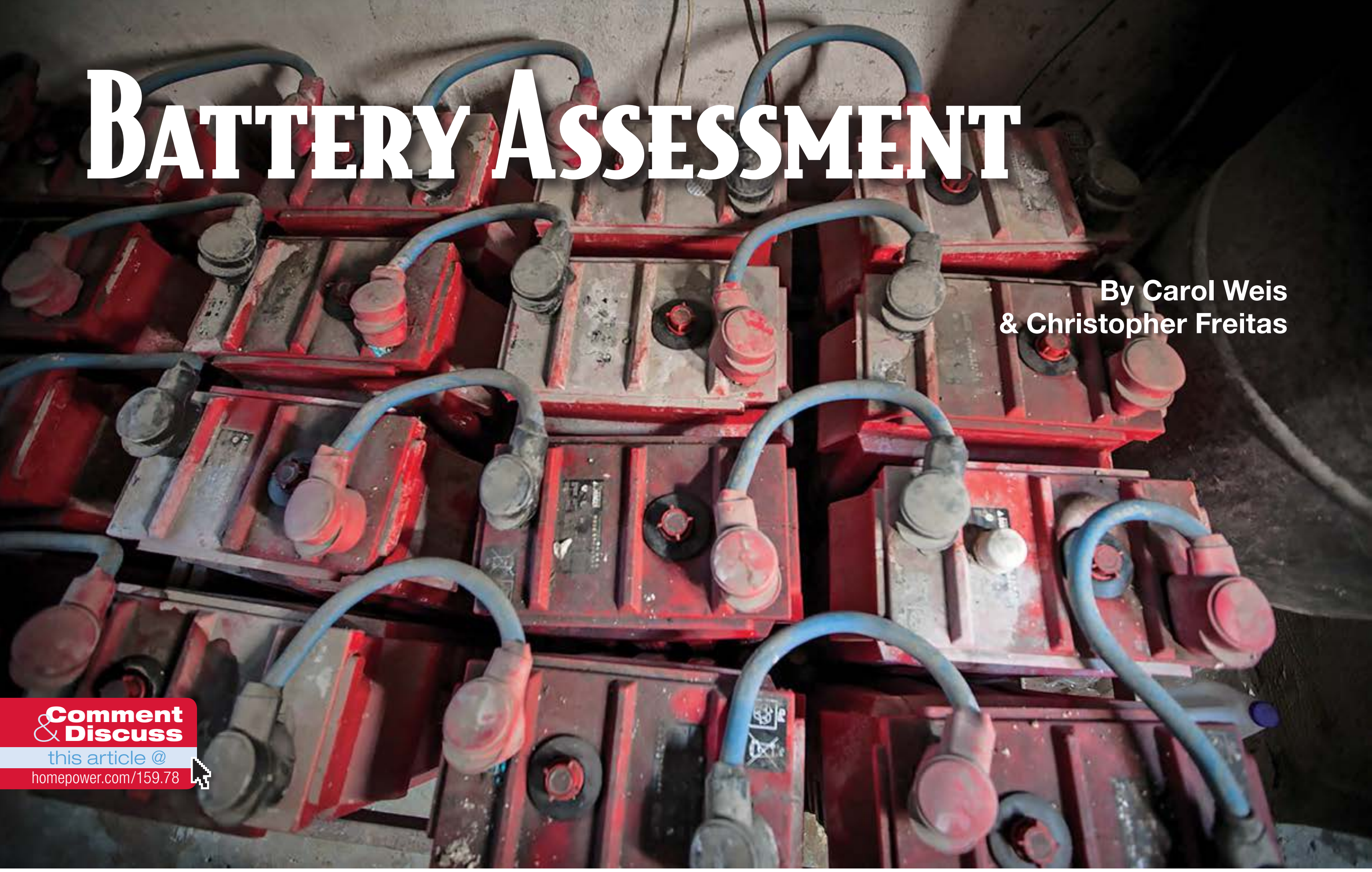
Deciding whether or not the SPS suits your needs as a backup power source is another question. Because the Balls don't have critical loads that need to run during a grid outage, or frequent power losses associated with their utility service, the SPS circuit is adequate for their needs. On the other hand, the SPS circuit may be too limited for those who want a backup power system that can run at any hour of the day and is not limited by the solar irradiance available at the time of the grid outage. For those who already have a grid-tied PV system, but have always lamented over not being able to use their solar energy during a grid outage, it may be possible to upgrade their system by replacing their current inverter with the new TL model. The feasibility of this upgrade will depend on the system capacity, array configuration, and, of course, cost considerations.

Whether it's the 3, 3.8, 4, or 5 kW model, each TL inverter can redirect 1,500 W of solar power. If a system owner wants more backup capacity, they may want to consider dividing their array into subarrays and using separate TL inverters. The Balls' 5 kW array is wired into two strings of 10 PV modules. Instead of installing one 5 kW TL inverter, with each string feeding a separate MPP input, each series string of 10 modules could have been tied into a separate 3 kW TL inverter, giving them two 1.5 kW SPS circuits. Of course, the cost of installing two 3 kW inverters would be more than the cost of one 5 kW inverter, but, given the right circumstances, it is a design option worth considering.

Access

Orion Thornton is the owner of Onsite Energy, a Montana-based solar-electric design and installation company. He is a NABCEP-certified PV installation professional and a contracted instructor for Solar Energy International (SEI). Orion lives in a net-zero energy home powered by solar electricity, solar thermal, and wood heat.

Battery Assessment



By Carol Weis
& Christopher Freitas

Courtesy whattookyousolong.org for USAID (2)

This article outlines the steps to evaluate a battery bank's health, which starts with a visual inspection of the battery bank's location, its enclosure, and the condition of the batteries themselves. Next, specific measurements are made, including testing battery voltages and checking the electrolyte in each cell for its level, specific gravity, temperature, and color.

The information collected during a battery assessment can be used to track the changes in a battery over time; analyze the impact of charging setpoint adjustments; or review the performance of a battery with the manufacturer or supplier. This data is particularly useful when replacement is necessary, and when you need to determine what changes should be made in the system's settings and operation to achieve better performance and longer battery life.

Using a battery room for storage can lead to poor accessibility to the batteries for maintenance, and can be a safety hazard.

Visual Inspection

The first step of a visual inspection involves making general observations about the battery bank and its enclosure or room. This includes checking if the batteries are protected from the weather; if there is good airflow to keep the batteries cool and to dissipate hydrogen gases; and verifying that necessary safety equipment is accessible. Each battery must be checked for problems such as bulging cases, cracks, leaks, and corrosion. Next, the system's setpoints need to be reviewed and recorded. Finally, the condition of the charging system's battery temperature sensor is evaluated.

Battery bank location is important, as it can affect the amount of ventilation available to dissipate heat and hydrogen/fumes produced by the battery. The location should also provide protection from weather extremes—such as shading from the sun or insulation from cold. The bank also needs to be isolated from any sources of flame or spark (such as a gas-fired water heater), which could ignite hydrogen produced by the batteries.

Coming Up...

The second article in this series—"Battery System Maintenance & Repair"—focuses on what regular maintenance needs to be done to promote battery health.

Courtesy whattookyousolong.org for USAID (2)

Besides eye protection, acid-proof gloves, baking soda, and distilled water, a Class C fire extinguisher and an eyewash station are important to have near the batteries.

Workspace clearances and safety. There needs to be easy and safe access for maintenance. Live parts of the battery (terminal posts and cable connections) should be guarded against accidental contact. Clearance and equipment accessibility are important to safe system maintenance and are required by the *NEC* (see "Code Corner" in *HP156*). The battery room should not be used as a storage space—impeded access to the battery bank can discourage maintenance and can also affect airflow.

Adequate safety gear should be available for maintenance and repair. This includes goggles, chemical-rated gloves, insulated tools, and a nonmetallic flashlight. A supply of baking soda and distilled water should be kept with the batteries. A Class C-rated fire extinguisher should also be located at the entrance of the room in case of an emergency.

The condition of the battery enclosure and rack needs to be evaluated, since corrosion from a metal enclosure or rack to a battery terminal can result in ground faults or shock hazard. The enclosure or rack should include spill containment trays or liners to handle spills from overfilling or leaks. There should be air vents in a battery enclosure (bottom and top) to allow air to enter and exit. All metal enclosures or racking should also be connected to the grounding system.

Assess the battery's overall condition. Bulging battery cases may be caused by swollen plates, which have been damaged from overcharging. Dirt- or debris-covered battery tops can increase the battery's self-discharge and result in contamination

Battery Bank Evaluation Checklist

Battery Bank Location

- [ ] Protected from weather extremes, heat sources, and direct sunlight; insulated from cold
- [ ] Separated from sources of flame or sparks

Workspace Clearances & Safety

- [ ] Adequate workspace in front and on the sides of bank to comply with *National Electrical Code (NEC)* and to allow maintenance
- [ ] Battery bank does not block access to other equipment mounted above it, complying with the *NEC*
- [ ] Adequate safety gear provided (i.e., goggles, chemical-rated gloves, insulated tools, and nonmetallic flashlight)
- [ ] Baking soda, distilled water, Class C fire extinguisher, and eye-wash station in the room

Battery Enclosure/Rack Conditions

- [ ] Battery enclosure/room locked to prevent access to unauthorized personnel
- [ ] Battery enclosure and rack free from corrosion and degradation
- [ ] Spill-containment tray or liner provided in the battery enclosure
- [ ] Air-entry vents provided at the bottom of the battery enclosure
- [ ] Air ventilation to dissipate heat and hydrogen/fumes
- [ ] Metal enclosure or rack connected to the grounding system

Battery Condition

- [ ] Free from cracks, bulges, or leaks
- [ ] Tops of the batteries clean from dirt, dust, or other debris
- [ ] Terminals free from corrosion
- [ ] Terminals in good condition (none melted or show damage from arcing)
- [ ] At least 1/2 inch of space between each battery to allow heat dissipation
- [ ] All batteries are the same model, from the same manufacturer

Temperature Sensor

- [ ] Well-attached/adhered to the side of the battery
- [ ] Located in the middle of a battery bank and two-thirds up on the side of a battery
- [ ] Wiring intact, and free from breaks, kinks, and nicks

Note: An additional checklist reviewing cables, cable lugs, and terminal hardware will be included in an upcoming article in this series.

Carol Weis

Battery terminal corrosion can lead to poor system performance and/or reduced battery life.

of the electrolyte. Melted battery terminals may be evidence of arcing from loose connections, or from a direct short-circuit during maintenance. Corrosion on the terminals can reduce performance and lead to imbalanced charging between paralleled strings of batteries. The battery makes and models must all be the same and the same age; mixing different battery manufacturers or models will result in uneven charging and reduce the batteries' performance and life.

The battery temperature sensor is critical to ensuring proper charging. The sensor needs to be well-attached to the side of the battery, about two-thirds of the way up from the bottom. It should be located toward the middle of the battery bank—not on the end or sides, where it would have more airflow or be influenced by other heat sources. Check the sensor wiring for damage, such as breaks or nicks in the insulation.

Only properly installed temperature sensors can adjust the charge regime correctly. This one should have been installed two-thirds of the way up on the side of the battery, and between two batteries.

Courtesy whattookyousolong.org for USAID

Battery Measurements

Once the visual inspection is complete, move on to taking measurements—the only way to really ascertain what's truly happening inside of a battery. First, sketch out the battery bank layout and assign a label to each battery and each cell.

In the "Labeling Batteries for Consistent Data" illustration, four 6-volt batteries are wired in two series strings for 24 volts and the two strings are wired in parallel. Each battery is made up of three 2-volt cells with a cap on each cell, which allows individual electrolyte inspection and measurement. Permanently marking each cell of the battery with an identification number or letter is very useful for future reference and comparison.

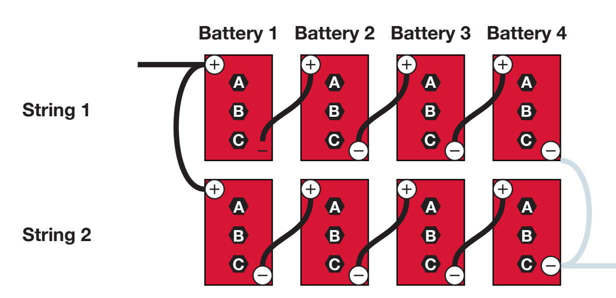
Voltage

Voltage is the easiest measurement to make, since it only requires a digital voltmeter to be connected to the terminals of each battery. Measure and record each battery's voltage in a table similar to the example. Some batteries allow measurement of each individual 2-volt cell, while others with multiple cells in one case allow access only to groups of cells—such is the case with nearly all 6-volt and 12-volt batteries.

The battery should be kept in an open-circuit condition while making these measurements—this is accomplished by disconnecting all charging sources and all loads. Allow the battery to rest for 30 minutes, and then make all of the measurements in as short of a time period as possible. To get accurate state-of-charge measurements, many battery manufacturers suggest waiting six or even 24 hours for the battery voltage to stabilize. However, this can be difficult at sites where the battery system is the only power source. When voltage is used to compare one battery to another, a shorter time period can be used.

The voltage variations between the individual batteries provide valuable information on the batteries' overall condition. Low-voltage readings can reveal weak or failed batteries, and wide variations can indicate the need for an equalization charge, an intentional overcharging of the battery bank to bring the weakest cells up to their full charge. Equalization also mixes the electrolyte to eliminate stratification of the acid and helps remove any sulfation on the lead plates. This can help to balance capacity differences between cells and allow the battery bank to be charged to its maximum potential. This will be discussed more in the second part of this three-part series.

Labeling Batteries for Consistent Data

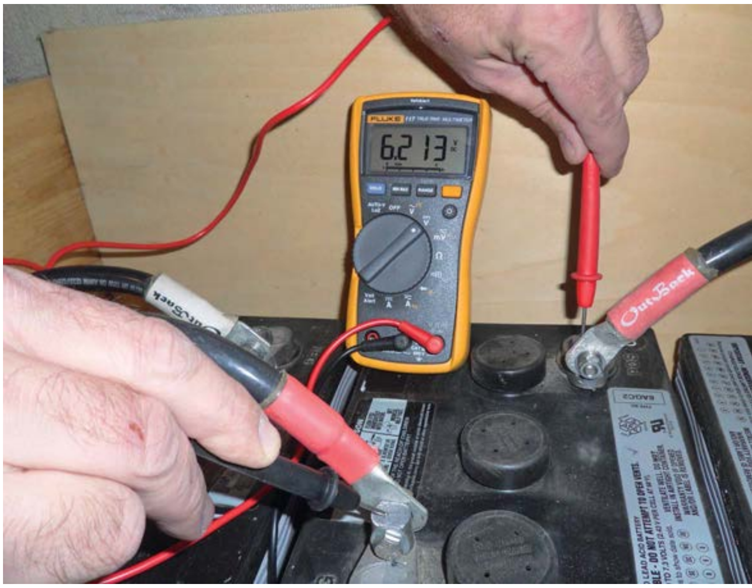


Load-Testing

All batteries have a higher voltage when no loads are connected. Once a load is connected, the battery's voltage decreases. The amount that the voltage drops is a good indicator of the battery's health and can be used to compare each battery in a bank to find poorly performing batteries or cells.

A battery load tester applies a large momentary load on a battery. Common automotive-type load testers are rated for up to 500 amps. They include a built-in load and an analog-type volt meter. On most testers, the current rating is only for 12 VDC batteries; when used with a 6 V battery, a 500 A load tester will only draw about 125 A. On a 2 V battery, it will only draw about 30 A. Specially made units can be bought for 6 V or 2 V batteries that will draw higher amperages at these lower voltages, but they are more expensive and harder to find.

Christopher Freitas



Testing the voltage of each battery is a quick way to identify a weak or failing cell.

Sample Battery-Test Table

24 V System: Two Strings of 6 V Batteries

		Cell	Battery Voltage	Electrolyte Level[1]	Electrolyte Color[2]	Specific Gravity	Cell Temp. (°F)
String 1	Battery 1	A					
		B					
		C					
	Battery 2	A					
		B					
		C					
	Battery 3	A					
		B					
		C					
	Battery 4	A					
		B					
		C					
String 2	Battery 5	A					
		B					
		C					
	Battery 6	A					
		B					
		C					
	Battery 7	A					
		B					
		C					
	Battery 8	A					
		B					
		C					

[1]High = Full • Medium = Needs water, but plates not exposed • Low = Plates exposed

[2]Clear • Dark gray or brown • Milky white

To load-test a battery, securely attach the two cable clamps of the tester to the battery's terminals. It is also useful to connect a quality digital voltmeter to the battery being tested as the load-tester's built-in voltmeter is usually not very accurate. Press the "test" button for approximately three seconds, read the display on the separate digital voltmeter before releasing the button, and record the value. Repeat this test on each of the individual batteries with the load applied for the same amount of time. All of the batteries should indicate similar voltages when a load is applied. Any significant variation would suggest an unequal charging or a damaged battery or cell.

A "capacity test," which estimates the amount of energy a battery is able to store, is another useful load test. This test involves significantly discharging the battery with a constant load over a five- to eight-hour period. At remote sites, this can be challenging, as the power drawn by normal system loads varies and the battery will need to be recharged afterward. Typically, this test is only done after verifying that the batteries are fully charged and all maintenance procedures are complete.

Electrolyte Level & Color

For systems using flooded lead-acid batteries, ensuring that the electrolyte levels in each cell remain above the battery plates by regularly adding distilled water is critical to the batteries' health.

A one-time check of the electrolyte levels on an unfamiliar battery bank can be misleading, since you'll be unable to determine if the plates had previously been exposed, the cell had been overfilled, or if water was just recently added. Regardless, checking and recording each cell's current electrolyte level will give you a reference point for future inspections.

Allowing the electrolyte level to drop below the plates can substantially reduce a battery's capacity, since the area of the battery's plates that was left exposed to air loses the

Carol Weis

The electrolyte level in this battery is very low, exposing the plates to air, which causes permanent damage.

ability to react with the electrolyte. Overfilling a battery and losing sulfuric acid out through the vent cap can result in the electrolyte becoming diluted, which will also reduce the battery's capacity and shorten its life.

While you're checking cell electrolyte levels, note the color of the electrolyte in each cell and any residue on the inside of the battery vent cap. Sulfuric acid in a healthy lead-acid battery should be clear and colorless and you should be able to easily see the plates. The inside of the battery vent cap should have only a clear, colorless liquid residue on its surface.

As a battery ages and is charged and discharged, the color of the electrolyte and residue in the vent cap provide clues about what is occurring within the battery. If the electrolyte liquid is dark gray or brown, this typically indicates significant overcharging or excessive temperatures. The dark color results from particles of the lead plate coming off and mixing with the acid. A milky or cloudy light-gray electrolyte typically indicates excessive sulfation of the plates, which occurs when the battery is routinely left in an undercharged condition for long periods of time.

When working with batteries and their electrolyte, be sure to put on goggles and chemical-rated gloves, but first remove all jewelry and/or watches, which could accidentally come into contact with battery terminals and cause arcing. A good flashlight is usually needed to see the level of the electrolyte inside of the battery—but be sure its housing is not metal, either.

The electrolyte on a properly filled battery should be approximately 1/4 inch below the fill tube. If the battery is overfilled, the electrolyte can flow out of the vent caps when the battery is charged, as bubbles of hydrogen and oxygen that are produced cause the electrolyte's level to increase.

Sometimes, battery cables or other obstructions can make maintenance of one particular cell, battery, or even an entire battery string, difficult. Pay attention to these types of problems and correct them, as seemingly small improvements can have a dramatic effect on the frequency of future maintenance and battery longevity.

Specific Gravity

While a voltage measurement provides a quick side-by-side comparison (identifying potentially weak batteries or cells), the overall battery voltage fluctuates significantly depending on if the battery is being charged, discharged, or if it has been at rest. For flooded batteries, specific gravity (SG) readings show the actual concentration of sulfuric acid in the electrolyte and thus are a much better indicator of the battery's state of charge (SOC) for each cell and the entire battery. SG can only be measured on nonsealed, flooded-type batteries.

Measure and record each cell's SG with a hydrometer or refractometer, using all the same protective equipment as you've used for checking the electrolyte levels (see "Methods" in this issue). To correlate an SG value to the SOC level, check the SG graph or table from the battery manufacturer's specifications. For example, a typical SG reading for a battery at 100% SOC is 1.265. If the difference in SG between any two cells is greater than 0.025, the battery bank needs to be equalized to ensure that all cells receive a full charge.

Courtesy whattookyousolong.org for USAID (2)

The specific gravity of the electrolyte can be tested with a hydrometer (above) or a refractometer (right).

Typical Specific Gravity & State of Charge

Specific Gravity	% Full
1.255 – 1.275	100%
1.215 – 1.235	75%
1.180 – 1.200	50%
1.155 – 1.165	25%
1.110 – 1.130	0%

Cell temperatures that are too high can impact the number of available cycles.

Courtesy whattookyousolong.org for USAID (2)

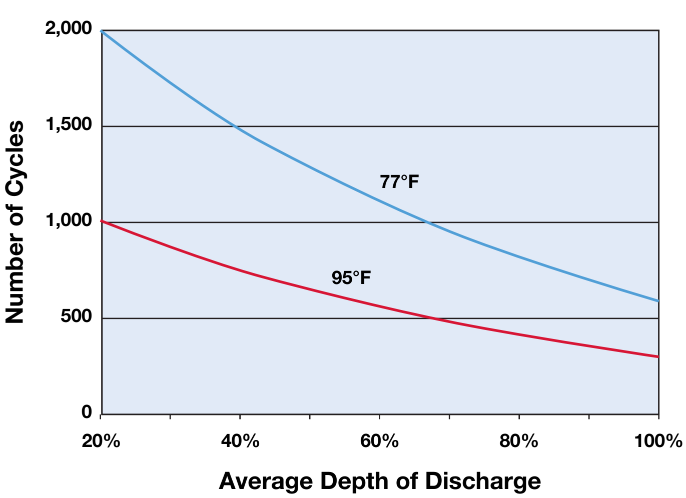
The BTS communicates the battery cell temperature to the inverter/charger and the charge controller to adjust the charging setpoints.

Cell Temperature

Battery capacity and cycle life are typically provided for a battery at a temperature of 77°F (25°C). If the battery is colder or warmer, the specification and performance will vary. At lower temperatures, the battery's available capacity (measured in amp-hours) will be decreased. At higher temperatures, the battery's life (number of cycles) will be diminished.

The "Typical Life Cycles vs. Average Depth of Discharge" graph shows the number of charge/discharge cycles versus the depth of discharge (DOD) for a typical flooded lead-acid (FLA) battery at 77°F and 95°F. Most FLA batteries will be able to supply only half as many cycles when the battery temperature is increased by 10°C (18°F). For example, at 25°C (77°F), a battery may be rated at 2,000 cycles at a 20% DOD. But when operated at the higher temperature of 35°C (95°F), it will only provide 1,000 cycles under the same cycling conditions.

Typical Life Cycles vs. Average Depth of Discharge



Factors like lack of ventilation, heat or sunlight exposure, and high charging voltages and currents can also increase a battery's internal temperature. Operation at consistently high internal temperatures can significantly reduce a battery's life.

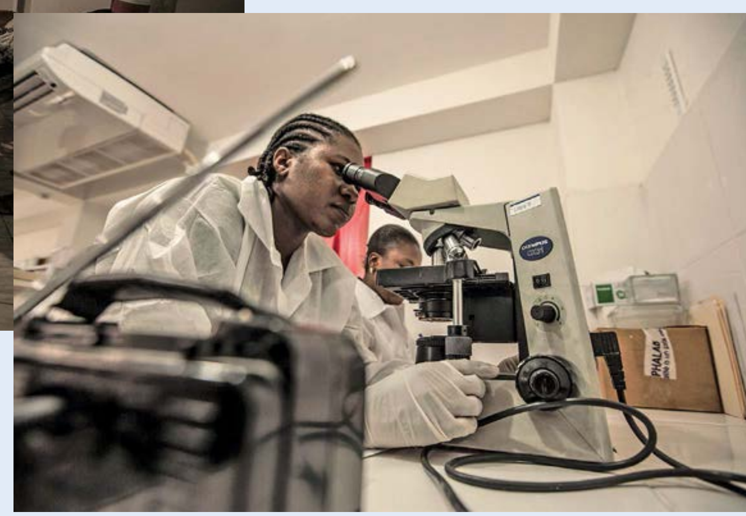
Some components, like charge controllers and system monitors, can display the battery's temperature by using a battery temperature sensor (BTS) mounted on the case of one of the batteries. The BTS's cable is plugged in to the inverter/charger or charge controller and automatically adjusts the charging voltages in relationship to the battery's temperature. As the battery temperature increases above 77°F, the charging voltage is automatically lowered. At lower temperatures, the charging voltage is automatically increased.

Positioning and adhesion of the BTS to the battery's case is important as the BTS will determine the battery's charging voltage levels based on the battery temperature. If a BTS reads a lower temperature than the actual battery temperature, the charge controller or inverter/charger will overcharge the battery, leading to excessive gassing, increased water usage, and excessive battery temperatures, substantially decreasing the battery life. Note that a BTS may not work well on batteries with steel or plastic double cases. In these cases, the installer will need to consult the manufacturer and may need to make provisions to attach the BTS to the inner battery case.

During a battery assessment, a more accurate measurement of each cell's temperature can be accomplished by inserting a glass thermometer directly into the electrolyte of each cell. Measuring each cell's temperature also allows for an interbattery comparison to determine if some cells are operating at higher temperatures than others. The resulting average temperature can then be compared to the reading from the BTS to determine its accuracy.

continued on page 86

Case-Study
Battery Backup Systems in Haiti



A battery backup system provides much-needed power for lights in a maternity ward (left) and for laboratory test equipment (below) in a Haitian hospital.

Courtesy whattookyousolong.org for USAID (2)

The Caribbean country of Haiti has electricity available to less than 25% of the population. Even in areas with utility-provided electricity, power outages are frequent and typically last for many hours. Operating health-care facilities under these conditions is difficult. Most hospitals have backup diesel generators, but fuel shortages, poor power quality, and breakdowns are common.

Reliable electricity is essential for the medical testing laboratories. Voltage surges can damage sensitive equipment and poor power quality can result in inaccurate medical test results. In rural areas, transporting fuel for the generators can be impossible during the rainy season due to impassable roads, limiting the number of hours generators can operate before they run out of fuel. Some hospitals have PV arrays, but their high initial cost has kept the systems small. They are mostly used to power specific loads, such as vaccine refrigerators.

As part of the U.S. Agency for International Development's (USAID) Improving Health Facilities Infrastructure (IHFI) program, 20 hospitals have been equipped with updated inverter-battery systems. Each uses diesel generators or grid power (where available) to charge batteries to provide high-quality inverter power to the laboratory and other essential loads 24 hours a day. An assessment of these systems was completed as a follow-up to an ongoing training and support program for the hospitals.

The systems were evaluated using several different methods to solicit feedback from the hospital staff about how well the systems were working, and also included inspections and testing of the backup power systems—which included a full battery assessment.

Assessment Results

Although the majority of the systems include a battery temperature sensor (BTS), most systems had problems with them that compromised their accuracy. At one site, the BTS was plugged into the secondary (slave) inverter instead of the primary (master) inverter, with the result that no temperature adjustment occurred. At other sites, the BTS was installed incorrectly—either lying on top of the battery lid or at the end of a battery bank, which also reduced its accuracy. At many sites, the adhesive on the BTS failed.

The team corrected the failed peel-and-stick adhesive used on the sensors by wedging soft packing foam between two batteries, forcing the temperature sensor against the side of one of the batteries. Though rudimentary, this mechanical fix can also be used as a redundant measure instead of relying only on the sensor's adhesive. It also insulates the sensor from the ambient airflow, making the measurement of the battery electrolyte's temperature more accurate and less affected by other heat sources.

The highest electrolyte temperatures, which ranged from 26°C to 38°C, were found in battery banks installed on the south side of a building without shade, in rooms with little ventilation, or in systems with battery chargers set at a high charging current. Batteries that operate at high temperatures on a regular basis will have reduced cycle life.

Christopher Freitas

A thorough inspection of installation practices can identify problems like this poorly crimped cable lug, which was pulled apart by the assessor after noticing the crimping methods.

Carol Weis

In hot climates, this rat-chewed battery temperature sensor cable will cause erroneous temperature readings and result in overcharged batteries.

System Charging Setpoints

It was determined that most of the batteries were being regularly overcharged, causing them to operate at higher-than-normal temperatures. The inverter/charger battery setpoints were adjusted to reduce the amount of internal battery heating and to reduce gassing. Changes were made to the absorb, float, and equalization voltage setpoints.

The total charging rate for the systems was also reduced for the same reasons. The original design was calculated to charge the battery at a C/6 rate, which means that the battery would go from a completely discharged level to a fully charged level in six hours. In this case, the battery manufacturer suggested changing to a C/10 rate to reduce the heat generated during charging from a generator or the grid.

On the inverter/chargers that were used in these systems, the setpoint controlling the maximum charge rate is programmed in AC amps:

$$\text{AC Charge Amps} = \frac{\text{Capacity (Ah)}}{\text{10 hrs. (C-Rate)}} \times \frac{\text{48 VDC}}{\text{0.85 (effic.)} \times \text{120 VAC} \times \text{\# of Inverters}}$$

It was also important to ensure the charging rate was appropriate for the existing battery bank. At one hospital, the system was originally installed with three paralleled strings of eight 6-volt batteries. In the interim, as individual batteries failed, they had reduced the battery system to two strings, and then one string in an attempt to delay the inevitable replacement of the batteries. However, when the number of batteries was reduced, the charger's maximum output setpoints were not adjusted. Battery electrolyte temperatures measured 50°C (the highest reading that the glass thermometer could indicate). Once the AC charging amps setpoint was reduced from 18 A to 6 A AC per inverter, the battery's electrolyte temperature dropped to 35°C—still hot, but not as dangerous or as damaging.

Haiti Hospital Inverter Charge Settings

Setting	Original	Proposed
Bulk/absorb voltage	58.8	57.6
Float voltage	53.2	52.5
Equalization voltage	63.2	60.0
AC charging amps	20.0	Varied

Summary

For systems operating in hot climates like Haiti's, high battery temperatures can be a big problem. The following list of measures is highly recommended:

- Properly locate the BTS. It should be placed on the side of a battery, two-thirds up the side of one battery and on a battery that's located toward the middle of the pack. The BTS should not be adhered to the battery top.
- Putting some insulating foam material over the sensor makes the sensor reading more accurate and less affected by ambient air temperature changes or other heat sources. This can also keep the BTS in position if the adhesive fails. Additional protective sleeving may be needed to prevent rodent damage to the BTS wiring.
- Verify that the BTS is functioning correctly during the system commissioning and during annual maintenance/inspections.
- A charging rate that is too high can result in overheating the battery. Calculate the maximum charge rate and consult with the manufacturer to verify the C-rate recommended for your temperature range.
- For backup systems that are connected to high-power charging sources, consider using slightly lower charging-voltage setpoints. This may reduce battery temperatures, eliminate excessive gassing, and minimize the frequency that water needs to be added to the batteries.
- Keep batteries in a shaded, cool area with good airflow, and keep them spaced apart to reduce the temperatures of the batteries in the middle of the pack.

continued from page 83

Setpoints

It is important to also check and record all of the inverter and charge controller settings, such as the charging voltages (bulk, float, and equalize); charging time (hours); and charging rate (charge amps). These values dictate how the battery will be charged: at what voltage; for what duration; and at what amperage. These parameters must be set for the specific battery type and size used (see the "Case Study" sidebar for a detailed example).

Depending on the application, other setpoints may also need to be evaluated to see how the battery is being managed on a daily and monthly basis. Understanding how settings for the low-voltage disconnect (LVD), load shedding, alarms, and backup charging sources impact the operation of the battery is often also required when completing a detailed battery assessment.

Data Logging

Performing an assessment several years after a system has been installed can be easier if the system has a data logger that has been recording information. If there is no online data logging system, then the data will need to be downloaded from the system's components using memory cards or via a connected laptop computer. Some system monitors can provide the daily minimum and maximum battery SOC and voltages, and some can tell you how long it has been since the battery was equalized. This information can be helpful in understanding how a system has been operated and also can be used to estimate the remaining life of the battery based on the number of DOD cycles or the cumulative amp-hours that have been removed from the battery over the system's life.

The data collected and its format varies between manufacturers. Assistance of the inverter and controller manufacturers is usually required to analyze and draw conclusions from the collected data.

If the system does not include a data logger, the manually written operator logs are sometimes available. They may reveal how often the battery was watered, when the generator was run, or how frequently the battery was equalized. This information can be useful in developing recommendations for the system's future management.

Access

Carol Weis (cweis@sunepi.org) is a NABCEP-certified PV installer and ISPQ Master PV trainer. She writes curricula and teaches national and international PV classes to technicians and end users. She has worked as a licensed electrician and solar installer in Colorado, and was part of Solar Energy International's PV technical team for 15 years.

Christopher Freitas (cfreitas@sunepi.org) is an engineer and project manager for international RE projects. He was a cofounder of OutBack Power Systems and was the director of engineering at Trace Engineering.

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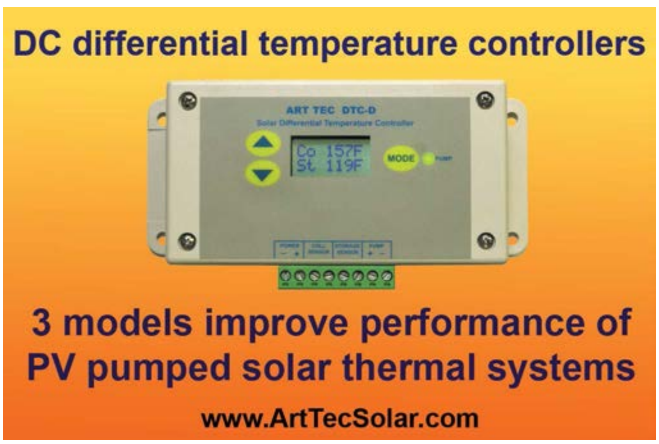
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PV Circuit Sizing
& Current Calculations

by Ryan Mayfield

Section 690.8 of the *National Electrical Code (NEC)* deals with PV circuit sizing and current calculations, and defines how to calculate four maximum circuit current values. These maximum circuit currents are used in additional calculations in sections 690.8(B). But before jumping into calculations, a few *NEC* definitions will be helpful, since the rules for correction factors and overcurrent requirements can change based on the specific circuit. Working from the array to the inverter, we have:

PV source circuits are conductors between the modules, and from modules to a common point of connection, typically a junction box or combiner box. In industry terms, these are often called the "home runs" from the individual strings.

PV output circuits are conductors between the PV source circuits and the inverter or DC utilization equipment. These are the circuit conductors after a combiner box to the inverter or charge controller.

Inverter input circuits, in a battery-based system, are the conductors between the inverter and the battery bank. In a grid-tied system, they are the conductors between the inverter and PV output circuits. Typically, these are the conductors between the inverter's integrated DC disconnect and the inverter's DC input connection.

Inverter output circuits are the AC conductors from the inverter to the ultimate connection to the AC distribution system for either stand-alone or utility-interactive systems.

Calculations

The first calculation, from 690.8(A)(1), results in the maximum PV source-circuit current. The rated short-circuit current (Isc) is multiplied by 125%. For example, if a PV module has an Isc of 8.8 amps, this calculation is: 8.8 A × 1.25 = 11 A.

Section 690.8(A)(2) covers the maximum current for PV output circuits. For output circuits, multiply the Isc by the number of circuits in parallel, and then by 125%. A common installation method is to keep the source circuits separate until they reach the inverter's integrated DC combiner and disconnect. In that case, there are no output circuits to consider because the source circuits are not placed in parallel outside of the inverter.

Section 690.8(A)(3) defines the maximum current for the inverter's output circuit. For utility-interactive inverters, there isn't a calculation required, since the maximum current is defined as the inverter's continuous output rating.

Section 690.8(A)(4) shows the calculation for the highest input current of a stand-alone inverter. This value helps determine the conductor size and overcurrent protection device (OCPD) rating between the batteries and the inverter. Divide the inverter's continuous power output rating by its lowest DC operating voltage, and then multiply by the inverter's rated efficiency under those conditions.

Part 5 of 690.8(A), added to the 2014 *Code*, defines the maximum output current of DC-to-DC converters as the rated output per the manufacturer's specifications. No additional calculations are required.

In the 2014 *NEC*, 690.8(B), which outlines the rules for calculating minimum conductor sizes in PV circuits, is titled "Conductor Ampacity." The OCPD section has been relocated to 690.9. The method for conductor sizing has not changed, although the 2014 sections incorporate some clarifications.

In 690.8(B)—690.8(B)(2) in the 2011 edition—two calculations must be run; the circuit conductor size must be based on the larger of the two values calculated. The first calculation is in 690.8(B)(1)—690.8(B)(2)(a) in the 2011 edition. Because PV system currents are considered continuous, the maximum currents calculated in 690.8(A) must be multiplied by 125% to calculate the minimum conductor size. This calculation ensures that the conductors do not carry more than 80% of the continuous current value (0.8 is the inverse of 1.25), a standard procedure in earlier *Code* articles. In the PV industry, the result of this calculation is commonly referred to as the "156% factor." When this rule is applied, the module's rated Isc has been multiplied by 156% (125% × 125% = 156%). However, don't just multiply everything by 156%. Inverter output circuits were not multiplied by 125% originally, so the 156% factor doesn't apply to them. This calculation is done before applying any adjustment and correction factors, commonly referred to as "conditions of use," which include corrections for conductors exposed to temperatures in excess of 30°C or more than three current-carrying conductors within a conduit. The ampacity of the conductor, at a minimum, then, needs to be greater than or equal to the maximum current in 690.8(A) × 1.25.

The second calculation and comparison is outlined in 690.8(B)(2)—690.8(B)(2)(b) in the 2011 version. Here, after conditions of use have been applied, we compare the conductor's ampacity to the maximum current as calculated in 690.8(A). This section does not require multiplying by 125% a second time.

Let's examine these calculations with an example three-string batteryless grid-tied PV system in Sacramento, California. The source circuits run in EMT from a rooftop junction box and down to the inverter. To begin, we consider the type of conductor used: THWN-2, which is rated at 90°C and for use in wet or dry environments. Use the ampacity values in the 90°C column of Table 310.15(B)(16) when adjusting the conductor's ampacity.

The temperature limitation of the conductor's terminals must also be considered. Although the direct reference to 110.14(C), which states that the conductor's ampacity rating needs to correlate with the terminal's rating, has been removed in the 2014 *NEC*, that *Code* section is still necessary. If the terminal is rated for 75°C (common for terminals in PV junction boxes), the ampacity of the conductor at the terminal is considered to be that of a conductor with the 75°C rating, as long as the actual conductor rating is 75°C or more.

To start sizing the conductor, first consider 690.8(B)(1) from the 2014 *NEC*. The source circuit's maximum current is 8.8 A × 1.25 = 11 A. The conductor must have an ampacity of 11 A × 1.25 = 13.75 A. Referring to Table 310.15(B)(16), in the 75°C column (because of the terminal limitations), 14 AWG is the smallest conductor listed with an ampacity greater than 13.75 A.

For 690.8(B)(2), the effects of temperature and the number of conductors in a conduit are considered. The 90°C rating for the conductors can be used. We need to know the local ambient temperature, the number of current-carrying conductors in the conduit or raceway, and whether any additional conditions apply. In this system, the EMT is installed 4 inches above the roof and runs 12 feet before going down to the inverter. Therefore, the correction factors in Table 310.15(B)(3)(c) need to be applied to determine the temperature imposed on the conductors. Looking at our correction factors:

- ASHRAE 2% ambient temperature: 38°C. The ASHRAE data is referenced in an Informational Note to Table 310.15(B)(3)(c). (See bit.ly/SolarABCmap.)
- For a raceway that lies 4 inches above the rooftop and is exposed to sunlight, add 17°C to the ambient temperature for correction-factor calculations:

    310.15(B)(3)(c)
    38°C + 17°C = 55°C

    Temperature correction factor for conductors rated at 90°C in 55°C environment:

    0.76 – 310.15(B)(2)(a)

- With three source circuits, there are six current-carrying conductors in the raceway.

    Table 310.15(B)(3)(a) correction factor is 80%

- To compare the 14 AWG conductor found in 690.8(B)(1), use the ampacity of 14 AWG from the 90°C column and apply conditions of use:

    25 A × 0.76 × 0.8 = 15.2 A

    This ampacity must be greater than the maximum current calculated in 690.8(A): 15.2 A > 11 A, so the 14 AWG fits for this calculation.

To complete the conductor sizing, verify that the conductors are properly protected by any OCPD in the circuit (refer to 690.9 in the 2014 *NEC* or 690.8(B)(1) in the 2011 version for the OCPD requirements).

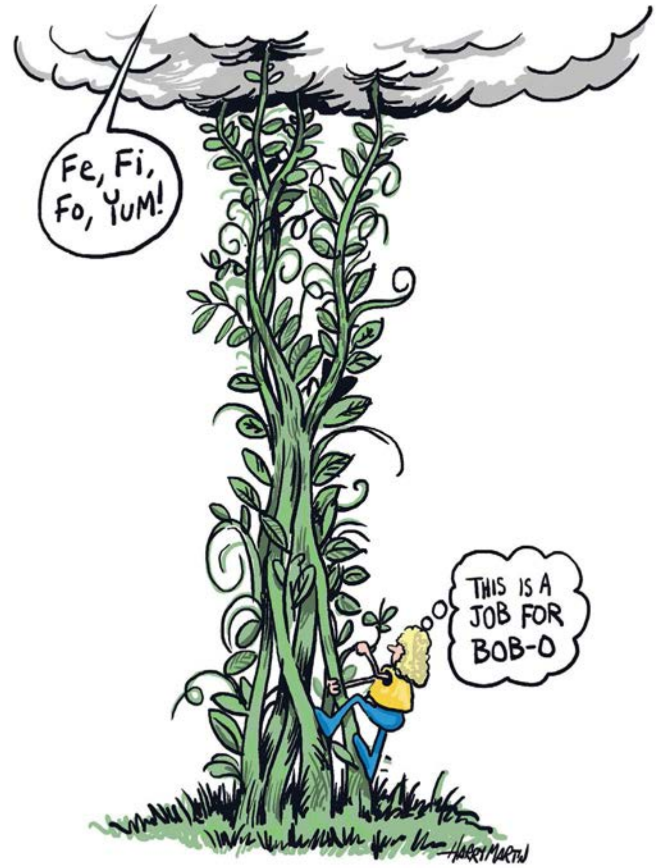
Access

Ryan Mayfield (ryan@renewableassociates.com) is the principal at Renewable Energy Associates, a design, consulting, and educational firm in Corvallis, Oregon, with a focus on PV systems.

Hill of Beans

by Kathleen Jarschke-Schultze

In our ongoing hands-on homestead experiment in self-sufficiency, my husband Bob-O and I tend to expand our garden, both in size and vegetable varieties. This past season, we tried several different vegetables with great success. But our main earnest effort was what he called "The Grand Dried Bean Experiment."



String Theory

More than 20 years ago, my gardening neighbor gave me a collapsible garden trellis. This structure enables me to hang vegetable netting or chicken wire to support climbing plants. A few years ago, I started looping garden twine over the top bar and dangling each end into a pole bean plant. This worked wonderfully well. Once the beans found the string, they grew lushly all the way to the top—8 feet on my trellis. At the end of the season, I just cut the twine and composted the dried vines and twine together.

Every year, I grew several neat-sounding pole varieties: Rattlesnake, Hidatsa Shield Figure, Good Mother Stallard, and a very large, white mystery bean given to me by the people we bought our dog from. I can never keep up with picking the fresh beans, so I let some dry out every year, getting about a half gallon of a mixed dried-bean medley. This provided us five or so meals made with our own beans.

Grand Beans

This past spring, we were ready to try growing a crop that would fill our dried bean needs for at least a year. However, one thing we've found in our years of gardening is that you can't always count on a good harvest. Some plants grow well each year—and some don't. I save seed from the plants that do very well, but even these can have lackluster yields at times.

We sampled several different kinds of dried beans, looking for one we liked enough to eat year-round. We only tried bush-variety beans, as making trellis for as many plants as we planned would have been daunting.

We chose the Vermont Cranberry bush bean, liking its flavor and creamy texture. A New England open-pollinated heirloom, this bean has a reputation for reliable harvests. A lot of its popularity comes from its ability to produce very well in areas with short summers. Dried, the variety stores exceptionally well. The maroon-colored beans are mottled with darker red markings. The Vermont Cranberry beans can be eaten at any stage of development, but we were interested in drying them as a staple.

Bean There, Done That

As is usual in our house, we planned early for this project. Bob-O tilled and made hills in five long rows in our lower garden. I laid out hose with a 1 gallon-per-hour dripper every foot. I had about 130 planting spots.

Mail-order prices for organic open-pollinated heirloom Vermont Cranberry seed were high, so I bought a couple of pounds of these dried beans from my local organic food store's bulk bins. I brought them home, put a handful in a pint jar, and rinsed them a couple of times a day. About four or five days later, they were all sprouting. I took those out to my greenhouse and potted them, along with some others I had soaked overnight. I still only had enough plants to fill half of the rows.

When the plants were 4 inches high and the ground was warming up, I planted each seedling under a dripper. But five days later we had a killing frost. It killed every tiny bunch of grapes in the vineyard and on the trellis. Any plants I had introduced to the garden early, hoping for fair weather, were killed outright—including the beans.

I soaked more beans and replanted the whole bed without waiting for the seed to sprout, since I was running out of time. Although we have a fairly long summer, we have a short watering year, and the earlier crops ripen, the better.

This time, the beans came up—and kept growing. They seemed slow at first, but then we left for a weeklong PV installation in July. When we came back home, we couldn't believe how much they'd grown in that week. The bed looked like a ruffled sea of green.

We weeded the bed a couple of times, usually after a rain. The nice thing about growing beans for drying is you can let them go without a lot of fussing—just keep them watered.

Aw, Shucks!

When some of the pods started drying out on the bushes, we picked the brittle pods and hand-shucked the beans into a big steel bowl that I stirred several times a day. More pods dried and soon I was shucking half of a bucketful every couple of days. I have to say that shucking beans is very meditative and Zen. It was so pleasing to pop the dried pod along its seam and thumb out the line of beans into the bowl.

Every so often, I'd encounter beans that were cranberry red—a fun surprise. Since intermittent reward is the greatest behavior modifier (that's why gambling is addictive), I told myself I would just shell beans until I hit a pod of the cranberry-colored ones. This was easy to fudge on because some pods had both colors of beans, so it had to be a pod of completely red beans.

Soon there were too many beans to shell by hand. Bob-O and I picked bucketfuls of dry, rattling pods. We put them into an old pillowcase, rolled the open end shut and secured the roll with clothespins. Bob-O then danced on top of the pillowcase with his socks on. The pods crunched loudly underfoot. Bob-O poured the contents of the pillowcase into a big steel bowl.

We separated the beans from the pods with wind power. While our down-slope, down-canyon breeze was blowing, we'd take the bowls of beans outside, and pour the beans and pods from one bowl to another, letting the wind carry the lightweight pods away. We had to repeat the pillowcase dance several times.

When it was all said and done, we ended up with 38 pounds of dried Vermont Cranberry beans. They almost fill a 7-gallon bucket. At two cups of dried beans per meal, I think we are victorious in our goal of growing a major food staple.

Every year my garden is a question mark: What will grow this year? What new plant can I try?

I can't wait to get my hands on this coming season's seed catalogs.

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is growing her own kitchen scrubbers—luffa gourds—at her off-grid home in northernmost California.

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Batteryless & Battery-Based Grid-Tied Systems

Courtesy US Battery

Most grid-tied PV systems are batteryless. They rely on moving energy to and from the grid. Under "net-billing" agreements, the utility provides billing credit for any surplus electricity produced by the system. System owners can then draw on that credit when more energy is being used than the system is producing. Depending on system size and the energy-use habits of the system owners, some systems can earn enough credit during the summer months (greater production) to make up for winter's lower production, becoming a net-zero annual energy user.

The disadvantage of a batteryless system is that the system relies on the grid to operate, so if the utility grid stops working, the home is also without power—despite having an on-site source of power (PV system). For most people, this is no big deal because utility outages are usually short in duration. But there are situations in which a home must be able to continue using energy even when the grid is not working, such as relying on life-saving medical equipment, keeping computers running, or keeping food cold.

Some homes or businesses might be able get by with an uninterruptible power supply (UPS). But unfortunately, those normally operate only long enough to properly turn off computers or electronics without "crashing," which can cause data loss.

Other homes or businesses might be able to get by with a new class of batteryless inverters that, when the sun is shining and the grid is down, can provide a limited amount of AC energy (see page 72). These systems can be useful for running a fridge during the day, which will probably keep food cold enough to make it through the night until the next day. They can charge phones and other battery devices which otherwise could run out of battery energy. But they won't be helpful at night or during cloudy days. Only batteries can make up for that.

So why doesn't everyone include a few batteries for backup? First, including batteries adds complexity to a PV system, which adds expense. Second, battery-based systems are 10% to 15% less efficient compared to batteryless systems, since some energy is used to keep the batteries at a full state of charge—and that means less energy goes out to the grid. The larger the battery, the more self-discharge there will be, and the less net-billing credit you will get out of your system. Finally, batteries will likely need replacing sooner than the rest of the equipment in the system, generally two to four times over the lifetime of the inverter and other system electronics. If you decide to design and install a battery-based grid-tied system, use the smallest battery capacity that will serve your backup needs—to keep costs down and limit efficiency losses.

—Michael Welch

Example Battery vs. Batteryless Grid-Tied System Costs

Item	Batteryless	With Battery	Difference	% Difference
PV array & roof rack, 2 kW	$5,000	$5,000	$0	0%
Inverter	1,350	2,500	1,150	185%
Sealed batteries, 250 Ah at 48 V	0	2,504	2,504	—
Charge controller	0	630	630	—
Shipping	200	600	400	300%
Balance-of-system equipment	800	2,500	1,700	313%
Installation*	1,000	2,000	1,000	200%
Total Cost	$8,350	$15,734	$7,384	188%
Typical Annual Energy Output (kWh)	2,800	2,520	-280	-10%
Cost per AC W Output	$4.91	$10.28	$5.37	209%

*Installation costs are estimated and can vary greatly depending on the system's complexity.