An American Passive Home

Story & photos by Victor Zaderej

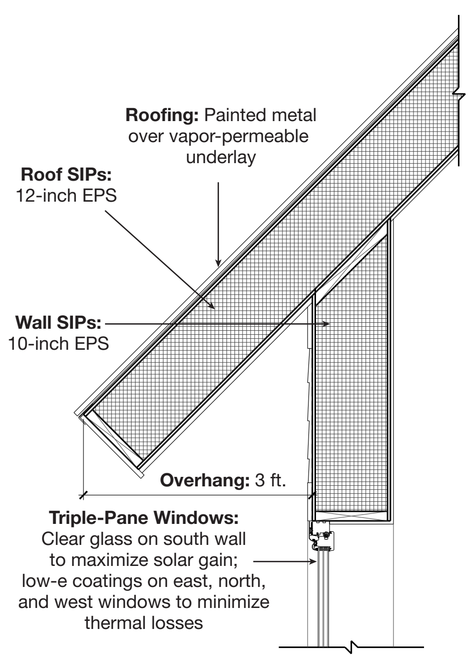
While studying engineering at MIT in the 1980s, I was given an assignment to calculate the cost of building a 2,000-square-foot home that uses 80% less energy to heat and cool than the average home being built at the time. From that assignment many years ago, the results still apply: The cost to *conserve* energy by optimizing insulation, proper passive design, improving the home's thermal enevelope, and by using simple but state-of-the-art HVAC systems is one-tenth of the cost to *burn* energy, when calculated over a 30-year "life" of the home.

If we can keep this lesson in mind, we can address a significant portion of our country's energy challenges. This lesson completely changed my outlook on home building, and led me on a 30-year quest to find the most affordable way to build comfortable, energy-efficient homes.

The "American passive home" (APH) is a building philosophy intended to assimilate the positive aspects of the German Passivhaus standard into a new standard for Americans, achieving the energy-performance standards set by the Germans at a cost that compares to a Prius instead of a Mercedes. APH is based on the following goals and principles:

- Cost-optimize the amount and type of insulation for all surfaces.
- Optimize the type, orientation, and surface area of all windows to take advantage of the solar energy
- Eliminate or minimize the "thermal bridging" that often occurs at wall, window, and floor junctions.
- Minimize infiltration losses by using airlock entries, tight wall joints, high-performance windows, and well-sealed doors.
- Create a low-cost geothermal system that helps eliminate the need for a conventional HVAC system and provides continuously filtered fresh air.
- Source North American-made components and materials to reduce the home's overall embodied energy.

Roof Detail



A timber-frame structure, Pura Vida demonstrates an efficient home that looks and feels conventional.

Insulated concrete forms include the support that keeps the forms from being pushed apart during the concrete pour.

Although many of the basic concepts of APH are similar to those used to achieve the German Passivhaus standard, the German standard adheres to an energy-use specification independent of the local climate—and the economics of achieving that standard. For instance, building a home that can be heated with 1 watt of energy per square foot (the approximate Passivhaus standard) in Minnesota is very different than building the same home in Tennessee, since insulating to this specification in Minnesota may be economically impractical. A more affordable strategy would be to use building methods that are commercially available but still achieve a reduction in energy use of between 60% and 80%, or 1 to 2 watts per square foot.

Pure Life

Pura Vida, a common saying in Costa Rica meaning "pure life," is the name of a demonstration home that my wife Polly and I built in Oregon, Illinois, in 2007. It was intended to be an affordable, comfortable, and energy-efficient home—and a showcase for my building design company. Although I feel that homes should be smaller, we built Pura Vida large enough (3,200 sq. ft. plus a 1,300 sq. ft. walk-out basement) to host guests and seminars for those interested in affordable and energy-efficient living. In the past five years, more than 3,500 guests have visited.

Design Process

The first design step was to determine the most cost-effective and commercially available approaches to minimizing energy losses. The insulation techniques that are commonly available in the United States are shown in the "Cost of Insulating" table below.

Cost data and R-value were collected for each of the construction methods, and a "dollar per R" calculated for each. This calculation reveals the lowest-cost, highest value insulation techniques for the walls, roof, basement walls, and floors.

The next step in the design process was to optimize the amount of insulation based on the temperature difference between the inside of the home and the temperature on the opposite side of the surfaces being insulated. Then, by using the cost per "R" for commercially available insulation systems, the most cost-effective R-value for each exterior surface can be determined. For example, in northern Illinois, given the temperature difference between the inside of the home and the average midwinter temperatures, a roof or wall can be effectively insulated with an R-45 structural insulated panel (SIP). However, using greater levels of insulation requires building techniques that are less cost

Cost of Insulating

Type	R-Value	Cost per R-Value / Ft.^{2}
XPS (under floor)	R-20	$0.050
Polystyrene SIPs	R-45	0.156
Polyurethane SIPs	R-40	0.175
I-joist, 12 in.	R-36	0.278
Double wall, 6 in.	R-36	0.312
ICF, 8 in.	R-22	0.680

Selected Insulation

Surface	Avg. Winter ∆Temp.	Insulation	R-Value
Roof	45°F	SIP, 12 In.	R-45
Outside walls	40°F	SIP, 10 In.	R-39
Basement walls	30°F	ICF + 4 In. Wall	R-35
Floor	20°F	XPS, 4 In.	R-20

effective or not commercially available in North America. For example, the cost of increasing the R-value of the wall by roughly 20% (R-55) could double the cost of building the walls because SIPs are not commercially available with an R-55 rating and other building techniques are much more expensive per R-value.

Let the Sun Shine In

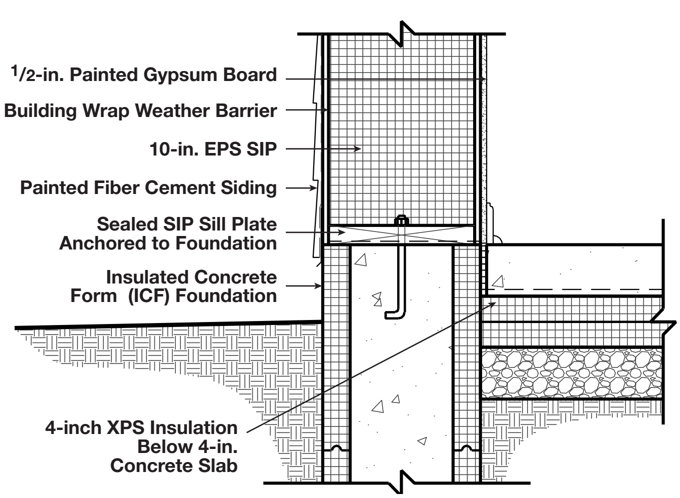
Passive solar homes use the sun's energy to provide significant home heating. It feels almost magical to walk into a 70°F home on a sunny, 0°F day and know that no heating system is operating. Although there is nothing new about harnessing the sun's heat, the materials and design knowledge for capturing solar heat and storing it for night use have improved dramatically in the last 30 years.

We chose Canadian-made Loewen windows. Not only are they beautiful Douglas-fir windows, but Loewen's Access line of windows looks and acts like an awning window and can be "flipped" to be cleaned from the inside. The windows on the north, east, and west sides are Loewen's Heat Smart III—argon-gas-filled, triple-pane units with two layers of low-e coatings and energy spacers. Because standard low-e coatings are meant to block solar radiation, we specified double-pane Loewen windows with a hard low-e coating and a solar heat gain coefficient of 0.65 for the south-facing windows. I have recently started specifying triple-pane windows without low-e coatings for southern exposures. They cost less than the special-order hard-coat low-e windows and the performance is slightly better.

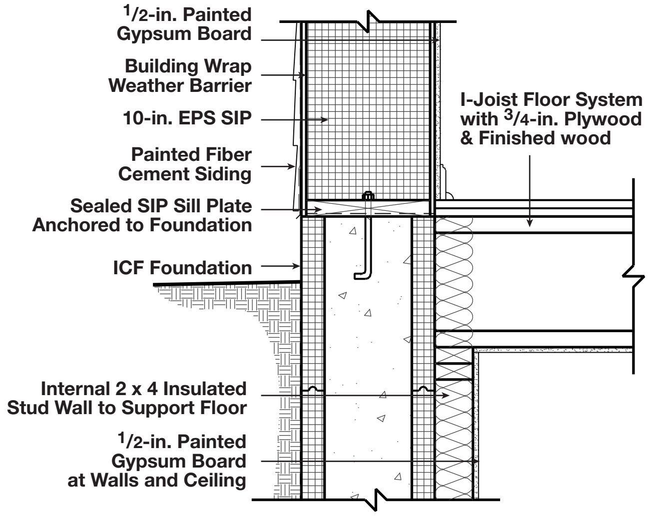
To benefit from passive solar gain, the area of the south-facing windows should be between 10% and 15% of the

Large south-facing windows, specified for their high solar heat gain coefficient, admit ample sunlight to warm the house on sunny winter days.

Slab-on-Grade Insulation Details



Floor Joist at Basement Wall



home's total floor area. Too little glazing means that you won't collect as much energy as you could; too much may result in overheating. Pura Vida's south-facing window area to floor area percentage is 11%.

Reducing Heat Transfer through the Envelope

One of the most important aspects of German Passivhaus design is the level of effort made to eliminate thermal bridging at floor, wall, and roof interfaces. The problem occurs when something without much R-value—like a wall stud—bridges between the inside and outside of the building without intervening insulation. While designing Pura Vida, builder Rick McCanse and I spent many hours discussing the details of how this could be easily—and affordably—accomplished.

Where the floor meets the wall, the 4 inches of extruded polystyrene (R-20) under the 4 inches of poured concrete floor were butted up to the insulated concrete form's (ICF) frost wall. Since the insulation under the concrete was in direct contact with the ICF insulation that extended below the frost line, there was no path for heat loss from the concrete floor.

At the main floor level, an internal 2-by-4 wall was added on the inside of the ICF to increase the R-value of the walls in contact with the earth to R-35 (R-22 from the ICF plus R-13 fiberglass in the stud wall); provide a space to run electrical wiring; and provide floor support that was inside the ICF and structural insulated panel's thermal envelope.

Besides thermal bridging compromising a home's efficiency, air leaks can account for 50% of winter energy loss in a typical home. With fewer and easier-to-seal joints, SIPs and ICFs minimize infiltration compared to "stick-built" homes. While APHs are built quite tight, infiltration losses can be further reduced by double entries (mud rooms, also known as airlocks). Mud rooms were common in farmhouses, but most modern homes do not include this energy-saving feature. The mud room should be insulated and use a well-insulated, sealed external door and an exterior-quality second door into the interior of the home.

The "earth room" under construction. Once complete, this space will provide a source of free heating and cooling.

Earth Room

In addition to capturing solar gain, Pura Vida takes advantage of another source of free heat (and cooling): from the relatively constant temperature of the ground. In Europe, earth tubes are often buried around the foundation of homes to provide tempered fresh air, but in the United States, there has been concern that earth tubes can grow mold or mildew. With Pura Vida, and subsequent buildings I have designed, an "earth room"—a modified approach to earth tubes—has been successful.

In Pura Vida, the earth room lies below the front porch. A short, 12-inch-diameter tube brings fresh outdoor air into one end of the earth room. The air flows the length of the 48-foot-long room where it is preheated (in the fall and winter) or precooled (spring and summer) through direct contact with the concrete walls prior to entering a heat recovery ventilator (HRV). The earth room is like a large thermal battery, storing heat in the summer for use in the fall and winter and storing "coolness" in the winter for use in the spring and summer. The earth room eliminates the need to use a conventional mechanical heating system for about two months of the year (October and November) and eliminates the need to run a cooling system from mid-May to mid-June. Throughout the rest of year, the earth room significantly reduces the heating and cooling loads.

Buy North American

There are a variety of energy-efficient building products manufactured in Europe, but because of their cost and transport, it is not affordable nor "sustainable" to import them. Buying local was important—not only does the manufacturing process and product assembly contain significant amounts of embedded energy, but the transportation of materials from remote locations can add significantly to a building's total energy content. All of the critical components used to build Pura Vida were manufactured in North America.

A 4.5 kW Marathon water heater (right) provides hot water to the heat-exchanger coils within the all-in-one Enerboss (left), a heating, filtration, and heat-recovery ventilation system.

After passing through the earth room, the air enters the Nu-Air Ventilation Enerboss, a complete heating, filtration, and HRV system. An efficient fan constantly pulls air from the bathrooms and kitchen, which is exhausted, while the same amount of fresh air is evenly distributed throughout the home by an airflow-balanced high-velocity duct system. The system has operated flawlessly for the past five years. The Enerboss system requires an external source of hot water for heating the air to be distributed. In Pura Vida, we use a 4.5 kW Marathon water heater to provide hot water to the heat exchanger coils within the Enerboss. Air conditioning is provided by a 3-ton, 16 SEER Lennox Elite. The evaporator for the AC unit is mounted on top of the Enerboss.

An air-to-water heat pump provides domestic hot water.

Visitors to Pura Vida often comment how fresh the air is and how quiet it is within the home. The comfort provided by constantly filtered fresh air moving throughout the home makes it difficult to go back to living with a conventional HVAC system.

Domestic Hot Water

A small Nyle Systems air-to-water heat pump mounted on a wall in the earth room provides domestic water heating. A timer is programmed to turn it on in the evenings when the time-of-use electricity price is $0.02 to $0.03 per kWh. The hot water is stored in a well-insulated 105-gallon Marathon water heater for use during the day. The average monthly cost for domestic hot water is about $5. (The timer is bypassed when we have guests or need to use more hot water.)

We also have a GFX Technologies wastewater-to-water heat exchanger. Although the concept of recovering the energy in hot water going down the drain is an interesting one, the high cost of copper makes this technology too expensive to be cost effective for the amount of preheated water the unit provides.

Demonstrated Performance

Six Lascar temperature and humidity sensors were placed throughout the home, outside, and in the earth room. Data collected from these sensors every 30 minutes for the past five years—along with energy use data collected from several TED (The Energy Detective) units and our utility bills—have validated the home's performance.

The all-electric home's advantage is that we can measure and directly compare the energy use for every appliance and system. Having collected data on the efficiency of the air-to-water heat pump in the earth room for providing domestic hot water, I plan to modify the heating system to include a second heat pump, instead of the existing water heater, for space heating. This should reduce the electricity demand for space heating by at least 60%.

When the home was built, we also decided to sign up for time-of-use utility metering. This utility billing method provides us with cheaper energy during off-peak times, and more expensive energy during peak times. The risk we took with this decision was that if we needed to use large amounts of energy during peak times—like running air conditioning midday during the summer—the cost could be significantly higher. The table (upper right) shows our average annual energy use for the various portions of the property along with an approximate annual cost for each.

Average Annual Energy Use & Cost

Item	Annual Usage (kWh)	kWh per Ft.^{2} (4,500 ft.^{2})	German Passivhaus Standard (kWh per ft.^{2})*	Cost
Space heating	6,700	1.49	1.39	$450
Cooking, refrigeration, lighting, air handling, entertainment systems, washer & dryer	3,500	0.78	0.60	200
Domestic water heating	2,500	0.56	0.33	60
Air conditioning & dehumidification	2,000	0.44	1.39	200
Well pump	1,500	n/a	n/a	100
Barn lighting & heating	1,500	n/a	n/a	100
Totals	**17,700**	**3.27**	**3.71**	**$1,110**

*The German standard does not differentiate in the same way as the table, so 0.93 kWh per sq. ft. per year is divided up somewhat arbitrarily between the DHW & cooking rows

Because of the relatively high upfront cost of renewable electricity systems, we felt it was important to first design and build a home that is as efficient as possible—and then get a good understanding of the home's energy demands. A year after the home was completed, we applied for and received a state grant to measure the effectiveness of residential small wind systems.

A small wind-electric generator offsets a small portion of the home's electricity use. It would produce much more on a tower tall enough to clear all obstructions in the area.

We installed a 2.4 kW Southwest Windpower Skystream 3.7 turbine on a 60-foot tower (at the time, we did not understand that height is too short for nearly *all* applications). The utility account was converted to net metering so that we could sell our excess energy back to Commonwealth Edison. The energy production from the Skystream was monitored through a Zigbee data system and logged on a computer.

We believed we had a wind resource that was sufficient to justify a wind-electric system. Our chosen turbine, the Skystream, is prediced to produce about 2,600 kWh per year given an 11 mph resource, and about 900 kWh per year in 8 mph winds. After several years of operation, the system has produced roughly 500 kWh per year, or the equivalent of $50 of energy, which is expensive electricity when you consider the $21,000 installation cost.

It is clear now that the information we started with was not sufficient to justify using wind energy at our site. Factors contributing to our turbine's lower-than-anticipated production include a tree line that sits about 800 feet to the west, resulting in turbulent wind from the prevailing wind direction. A taller tower would undoubtedly help with this problem, because the farther you get away from the earth and its obstructions, the more wind there is. As a well-known small-wind expert has said, we unknowingly chose expensive energy over an expensive tower.

Over the past several years, the cost of photovoltaic systems has come down dramatically. During that time, we collected information on the energy demand for Pura Vida. We found that during the fall and spring, when there was no energy use for heating or cooling, the average demand was between 600 and 700 kWh per month.

In 2011, we installed a 4.3 kW grid-tied PV system that should average about 400 kWh per month. Twenty-four batteries provide backup for power outages and provide enough energy to live without the grid periodically—assuming that the backup heating would be provided by the wood heater instead of electricity. Performance data is being collected by the OutBack Mate 3 energy monitor and we should have an accurate performance picture by the end of 2012.

Future of APH

We believe that building super-energy-efficient homes will have a significant impact on U.S. energy use. If the building cost of an APH is within 15% of a conventional building method, a conservative energy cost savings estimate is more than $1,000 each year per home.

One outcome of the recent economic downturn has been that the American consciousness has been awakened to the importance of common-sense solutions to important challenges. For families paying to heat and cool their homes—and as a nation that needs to use less fossil fuel—emphasizing energy efficiency in homebuilding is a simple yet promising way to address these challenges.

Two pole-mounted PV arrays offset about 27% of the home's electricity use.

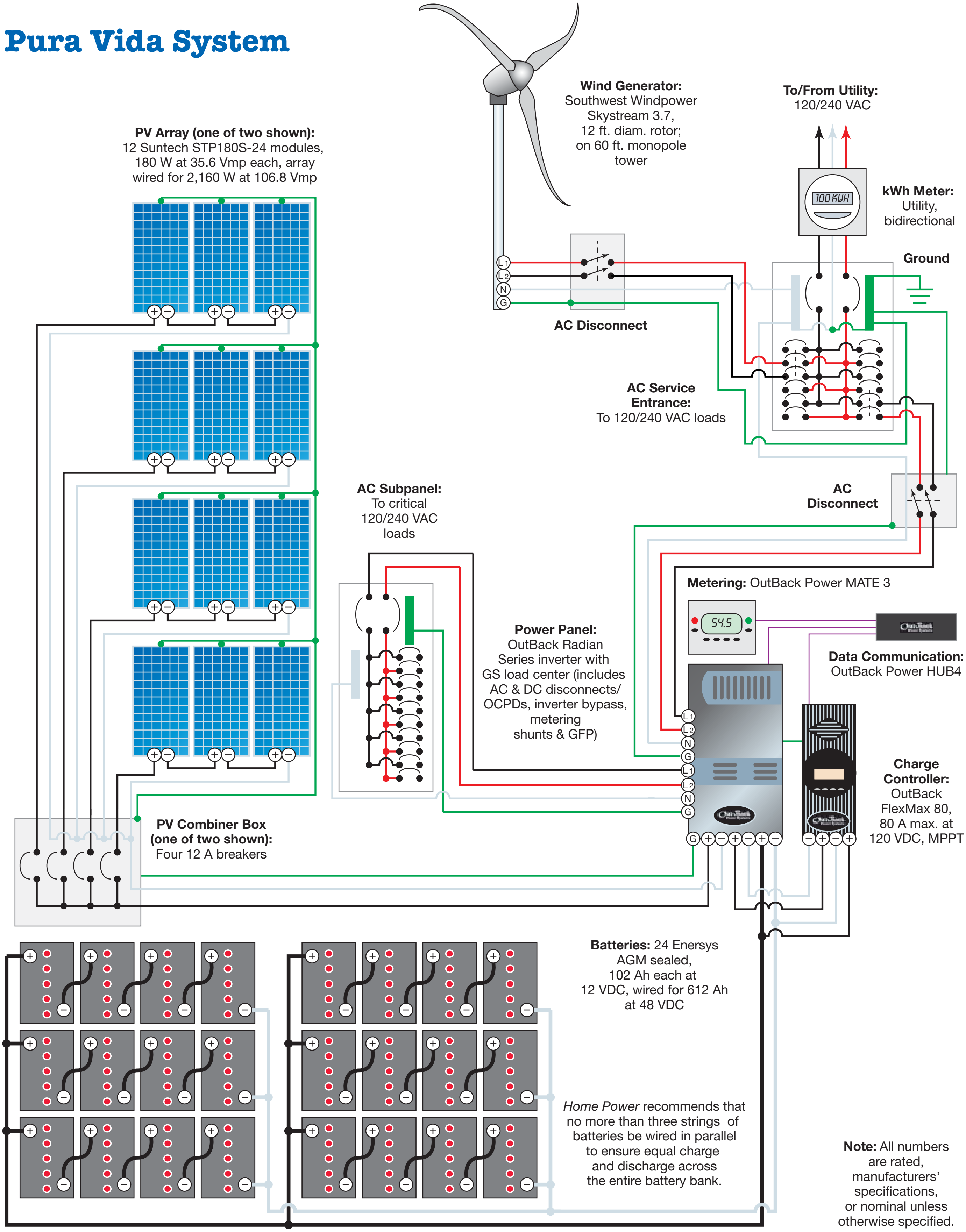
A battery bank provides backup power in the event of a utility outage.

An OutBack MATE 3 keeps tabs on the RE system.

Photo credit??

This OutBack Radian series inverter and load center also serves as an AC and DC enclosure. The system's charge controller sits to the right.

Pura Vida System



Tech Specs: PV

Overview

System type: Battery-based grid-tied PV

System location: Oregon, Illinois

Solar resource: 4.5 average daily peak sun-hours

Production: 400 AC kWh per month

Utility electricity offset: 27%

Photovoltaics

Modules: 24 Suntech STP180S-24, 180 W STC, 35.6 Vmp, 44.4 Voc, 5.05 Imp, 5.4 Isc

Array #1 (two identical arrays): Four three-module series strings, 2,160 W STC total, 106.8 Vmp, 133.2 Voc

Array combiner box: MidNite Solar with 12 A breakers

Array disconnect: Breaker (in power panel)

Array installation: DPW Power-Fab top-of-pole mounts; arrays set at a 28° to 40° tilt

Energy Storage

Batteries: 24 Enersys sealed AGM, 12 VDC nominal, 102 Ah at 20-hour rate

Battery bank*: 48 VDC nominal, 612 Ah total

Battery/inverter disconnect: 175 A breaker

Balance of System

Charge controller: OutBack FlexMax 80, 80 A, MPPT, 150 VDC maximum input voltage, 48 nominal output voltage

Inverter: OutBack Power GS8048, 48 VDC nominal input, 120/240 VAC output

System performance metering: OutBack MATE 3

Tech Specs: Wind-Electric System

Overview

System type: Grid-tied, battery-based wind-electric

System location: Oregon, Illinois

Production: 500 AC kWh per year

Utility electricity offset: 3%

Wind Turbine & Tower

Turbine: Southwest Windpower Skystream 3.7

Rotor diameter: 12 ft.

Rated energy output: 268 kWh/month at 12 mph ave.

Tower: 60 ft. Southwest, freestanding monopole

Balance of System

Inverter: Built in; 240 VAC output

System performance metering: SkyView

Access

Victor Zaderej (zaderej@alum.mit.edu) has been passionate about energy use in homes, businesses, and transportation for 30 years. He holds two engineering degrees from MIT, and an MBA. Through his company, Solar Homes, he helps design energy-efficient buildings. He is currently the manager of Advanced Solid State Lighting at Molex.

Solar Homes • solarhomesus.com • Green building design

McCanse Builders • mccansebuilders.com • Builder

Pura Vida Systems:

EnerSys • enersys.com • Batteries

Nu-Air Ventilation • nu-airventilation.com • Heating, cooling & heat recovery system

Nyle Systems • nyle.com • DHW heat pump

OutBack Power Technologies • outbackpower.com • Inverter & charge controller system

Southwest Windpower • windenergy.com • Wind generator

Suntech • am.suntech-power.com • PV modules

WaterFilm Energy • gfxtechnology.com • Wastewater heat recovery

Water Heater Innovations • marathonheaters.com • Hot water storage