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PLATINUM WITH PV

Kelly Davidson (4)

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by Kelly Davidson

The process began with a chance meeting at the 2006 Solar Decathlon in Washington, D.C., an international competition that challenges collegiate teams to build solar-powered homes. Architecture student Adam Rude, who helped design the University of Colorado (CU-Boulder) house, ended up giving the last tour of the day to Robert Freling, executive director of the D.C.-based nonprofit Solar Electric Light Fund. Freling was taken right away with Rude's design philosophy, and by the end of the tour told him, "I have a friend in Colorado who is looking for an architect. I think you two should meet."

The home's south face was designed to capture direct solar gain in the winter, reducing the need for supplemental space heating. A 7.02 kW awning-mounted PV system is anticipated to offset all of the home's electricity use.

The home includes a ground-level office that doubles as a guest bedroom when the sliding doors are closed.

Finish materials used in the home were carefully selected to satisfy LEED point requirements and preserve indoor air quality. Forest Stewardship Council-certified white ash paneling is used for the walls of the first level, as well as on the stair treads and veneered interior doors.

Weeks later, back in Boulder, Rude sat down for his first meeting with Freling's friend, Kitty Brigham, a retired nonprofit administrator who wanted to build a net-zero energy home. "I liked him instantly. I just took the leap and said, 'Why don't you design a house for me?'" Brigham recalls. "I told him that I liked angles and trilevels, and he took it from there."

Rude, who graduated shortly after that initial meeting, didn't have the resources to take on the project on his own, so he turned to his mentor and design advisor from the Solar Decathlon—Mark Sofield, a local architect who ran his own shop. The two partnered on the project, with Rude taking the lead on the schematic design, under Sofield's direction as architect of record. Two additional members of the CU-Boulder Decathlon team—engineer Chad Corbin and lighting designer Todd Gibson—signed on for the project as well.

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A deck on the third story affords sweeping views of the Flatiron Mountains. The solar-electric canopy provides electricity for the house, as well as some protection from the rain and sun.

Performance First, Then Form

Every architect's dream, Brigham gave the design team few constraints, with only one real demand: "Performance first, then form." Driving the design was her pursuit of LEED Platinum certification, the highest ranking awarded by the U.S. Green Building Council. "I knew building to platinum standards could be a costly venture, but I wanted to showcase what's possible and hopefully inspire people to walk the talk," Brigham says.

From the start, Brigham envisioned the home as a space she would "share" with the nonprofits and committees that she works with. SELF, for one, plans to use the space to host retreats for its board members. "The central living space had to be very open—a place where I could host meetings," says Brigham, who holds volunteer leadership roles for several nonprofit organizations, including SELF, Boulder County Audubon Society, and Oregon Shores Conservation Coalition. "And I wanted a rooftop living space," she adds.

Rude scoured the foothill communities near Boulder looking for land in the mountains, but for one reason or another, none of them worked. The design team ended up finding an ideal site farther east in Longmont, literally in Sofield's backyard.

Brigham purchased two lots along the street that makes up the southern boundary of Prospect New Town, a new urbanist housing community that transformed an 80-acre tree farm into a walkable, multiuse neighborhood. With a horse pasture and farm fields to the south, the site—a little less than 0.25 acres—offers views of Boulder's Flatirons rock formations and the foothills in the distance. And, with any luck, Brigham says, new building restrictions imposed by the city should keep the views intact for many years to come.

Not only does Sofield live in Prospect with his family, he also wrote the architectural guidelines for the community and designed several of the homes and buildings there. Prospect—which won a Governor's Smart Growth Award in 1996 for its innovative alternative to suburban sprawl—boasts a mix of businesses, detached homes, row houses, live/work lofts, and apartments, all in a broad range of traditional and modern architectural styles in a rich spectrum of colors. Even with its strikingly angled and geometric form, Brigham's home fits right in.

Ample south-facing glazing admits direct solar gain, which is absorbed by the concrete floor. This heat energy, stored in the floor, is released when interior temperatures drop below the floor's temperature.

Overhangs provide some protection from the summer sun, although heat-blocking shades are also used.

Meticulous Planning for High Performance

Six years of planning, design, and construction led to a 2,302-square-foot trilevel home that uses a fraction of the energy that a conventionally constructed house in Colorado might use. With energy-efficiency measures and a 7 kW solar-electric system rooftop canopy, the all-electric home is on track to produce as much energy as it uses each year and receive LEED Platinum certification (see sidebar.)

Key to the home's energy footprint is a passive solar design that minimizes active heating and cooling needs. The German Passivhaus standard served as a guiding force during the design process.

The home's structural, thermal, and aesthetic spine is an exposed concrete mass wall, with all the floors and ceiling joists attaching to it. The wall bisects the floor plan in such a way that every room in the house, from top to bottom, benefits from the passive conditioning. The thermal mass absorbs heat during the day and releases it throughout the evening. Although the wall appears continuous, it actually addresses three different envelope conditions: interior only; interior/exterior; and exterior only. The two 8-inch-thick concrete faces are separated by 4 inches of insulation only in the interior/exterior portion to prevent thermal transmission. The contiguous face is also thermally broken where the roof attaches to the wall.

Wall thickness was driven by the structural requirements of the second condition (interior/exterior) more than any other consideration. Based on the glazing areas, however, it was calculated that 697 cubic feet of interior mass would be needed to adequately absorb passive solar gain. This amount is attained by the interior mass wall, and by the concrete and tile floors in the office, bedroom, and living room that receive direct solar gain.

The 9-inch-thick wood-framed walls and 12-inch roof cavities, as well as the space beneath the on-grade floor slab, contain polyisocyanurate spray-foam insulation—achieving an average wall R-value of 40 and an average roof R-value of 60. Fiberglass-framed, dual-paned Serious Materials 925 windows were selected to help maximize passive solar gain

A central mass wall forms the spine of the home and also serves as a passive solar collector, radiating heat when interior temperatures drop.

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A clever open-air drying rack, incorporated into this cabinet, eliminates the energy used to heat-dry dishes in a dishwasher. The countertops are made of Durat, a material that contains post-consumer industrial plastic.

on the south side, with solar heat gain coefficients ranging from 0.35 to 0.45. The south-facing master bedroom window and southwest-facing windows and doors on the first and second floors admit solar gain, which is absorbed by the floor slab and radiated when the house's air temperature is lower than the slab's temperature. Though also partially shaded by an architectural overhang, the southwest windows require sun-blocking shades to minimize solar gain during the summer. The first floor's south wall is slightly angled (at 80°), creating a sculptural angle and a tapering overhang that provides more shade as the sun gets higher in the sky.

Passive & Active Considerations

As project engineer, Corbin developed multiple energy models and analyses to determine the home's passive solar design and optimal mechanical makeup, taking into account the local climate and the area's abundance of sun (66% of all daylight hours are sunny and clear). An initial analysis determined that the home, as originally designed, would require supplemental cooling 11% of the year and supplemental heating 77% of the year. This ratio was a factor in several design decisions, including the glazing ratio.

As a result of the energy models, the glazing area was increased to approximately 28% of the floor area, mainly on the south side of the home—a decision that reduced the building's heating load at the expense of increased summer cooling demand.

"There's always a trade-off when you design a home for passive heating and cooling," Corbin says. "The large glazing area contributes to heating the building, but during the summer, it works against you. The key is finding the right balance."

To minimize heat gain during the summer, reflective shades are installed over the south and west windows. Brigham keeps the shades drawn from noon to sunset, if not longer, between May and September.

Only electric appliances were installed, including an induction cooktop, convection oven, and two on-demand tankless water heaters (see sidebar.) Brigham opted for passive alternatives to dishwashing and clothes drying. After being hand-washed, dishes air-dry in kitchen cabinet racks, where they are also stored. In the laundry room, a large floor-to-ceiling cabinet hides drying racks for clothing. A high-efficiency lighting scheme utilizes a combination of LED and fluorescents to help minimize energy consumption and meet LEED requirements.

An exterior door from the shower opens into a private outdoor vestibule, allowing an indoor/outdoor shower experience.


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With slotted steel risers, the home's central staircase acts as a giant vertical return, feeding the return air grille on the ground level.

Domestic hot water loads were modeled at 25 gallons per day per person, within the range of typical residential loads suggested by ASHRAE. This load represented cooking, cleaning, bathing, and waste water usage, but did not include the additional water required for a large soaking tub originally designed into the master bathroom. "It was one of the few things the homeowner really wanted," Sofield says. "But she opted not to build it after she saw the numbers." Each bath would have used 11.75 kWh and at least 100 gallons of water—more resources than Brigham felt comfortable consuming for what she considered to be a luxury item.

Throughout the home, fixtures and fittings satisfy the LEED requirements for water-use efficiency, meeting the set limits for average flow rates—less than 1.5 gallons per minute for the faucets and outdoor spigots, less than 1.75 gpm for the showerhead, and less than 1.1 gallons per flush for each of the two toilets. A small-capacity Energy Star clothes washer handles Brigham's weekly washing needs. Additionally, the home claimed the maximum LEED credits allowable for managing roof runoff. In Colorado, where water laws dating to the 19th century still grant usage rights to roof runoff to downstream users, rain retention is prohibited. Sofield enlisted a civil engineer to size the infiltration ponds appropriately to return water to the aquifer.

Heating & Cooling

The home's heating, ventilation, and air-conditioning system relies on a high-efficiency Carrier electric air handler capable of delivering 1,050 cfm in cooling mode and 945 cfm in heating mode. Modeling showed that the cost of the additional PV needed to operate the air handler was less than the cost of an air-source heat pump, the primary alternative considered.

The floor between the first and second levels houses the supply-air ductwork that provides conditioned air to all spaces. Return-air circulation occurs naturally through gaps beneath the doors into the bath and laundry rooms, and louvered doors into the first-floor office. With slotted-sheet steel risers, the staircase acts as a giant vertical return, feeding the return air grille on the ground level.

Cooling is accomplished with an earth tube (or ground-loop heat exchanger)—a 12-inch-diameter PVC pipe buried 3.5 feet deep beneath the home that runs along the perimeter of the foundation. Return air from the home circulated in the tubes is cooled by the ground temperature and delivered back to the house via the air-handler. Based on average earth temperature data from the National Renewable Energy Laboratory, the earth tube can provide air cooled to 78°F—even during the hottest months of July and August. Ideally, the earth tube, Corbin says, would have been trenched deeper into the ground to provide even cooler air, but digging deeper was cost-prohibitive.

Rounding out the HVAC system is a heat-recovery ventilation (HRV) system, which is required to meet LEED Platinum indoor air-quality standards. The system simultaneously exhausts stale, humid indoor air to the outside and introduces fresh, outside air to interior spaces. Heat between the two air streams is exchanged, reducing

A heat-recovery ventilator admits a continuous source of tempered fresh air to interior rooms, helping maintain good indoor air quality.

This rooftop canopy is enhanced by a unique building-integrated PV array that also incorporates clear glass panels. The Sanyo bifacial modules in the array harvest light energy from both sides, leading to increased energy production.

heating energy losses due to ventilation. A solar wall along the southwest corner of the home was considered for heating ventilation air but ultimately ruled out. The findings showed that the solar wall would have reduced the cost of the PV array (by approximately $1,150), but the construction costs for the wall would have been significantly greater than the PV cost savings.

The PV System

"We didn't just want to tack solar modules on the house. We wanted to integrate them into the design," Rude says. The team selected Sanyo's HIT bifacial modules. The double-sided modules—which can harvest solar energy from both faces—increase energy production within the fixed rooftop space. The design staggers HIT modules and clear glass panels in the grid of a steel canopy. Enough light passes through to grow plants underneath, while providing adequate protection for shade-seekers. Plus, the light reflecting onto the back of the modules adds about 5% to the array's annual output.

Rude designed the canopy for the 7.02-kilowatt system, which was sized to meet the home's projected energy load of about 9,000 kWh annually. Florian, a Cincinnati, Ohio, greenhouse company that also builds solar structures,

Tech Specs

Overview

System type: Grid-tied solar-electric with battery backup

System location: Longmont, Colorado

Solar resource: 4.89 average daily peak sun-hours

Production: 750 AC kWh per month (estimated)

Utility electricity offset: 100% (estimated)

Photovoltaics

Modules: 36, Sanyo HIP-195DA3, 195 W STC (+ backside irradiation contribution), 55.8 Vmp, 3.5 Imp, 68.7 Voc, 3.73 Isc

Array: 7,020 W STC. Six 6-module series strings (each string: 334.8 Vmp, 3.5 Imp, 412.2 Voc, 3.73 Isc)

Array combiner box: OutBack FLEXware PV combiner box with 15 A fuses

Array installation: Florian Greenhouse custom racking patio covers, facing south and east, 6° and 4° tilt

Energy Storage

Batteries: Four Fullriver sealed AGM, DC105-12 VDC nominal,105 Ah at 20-hour rate

Battery bank: 48 VDC nominal, 105 Ah total

Battery/inverter disconnect: 175 A breaker

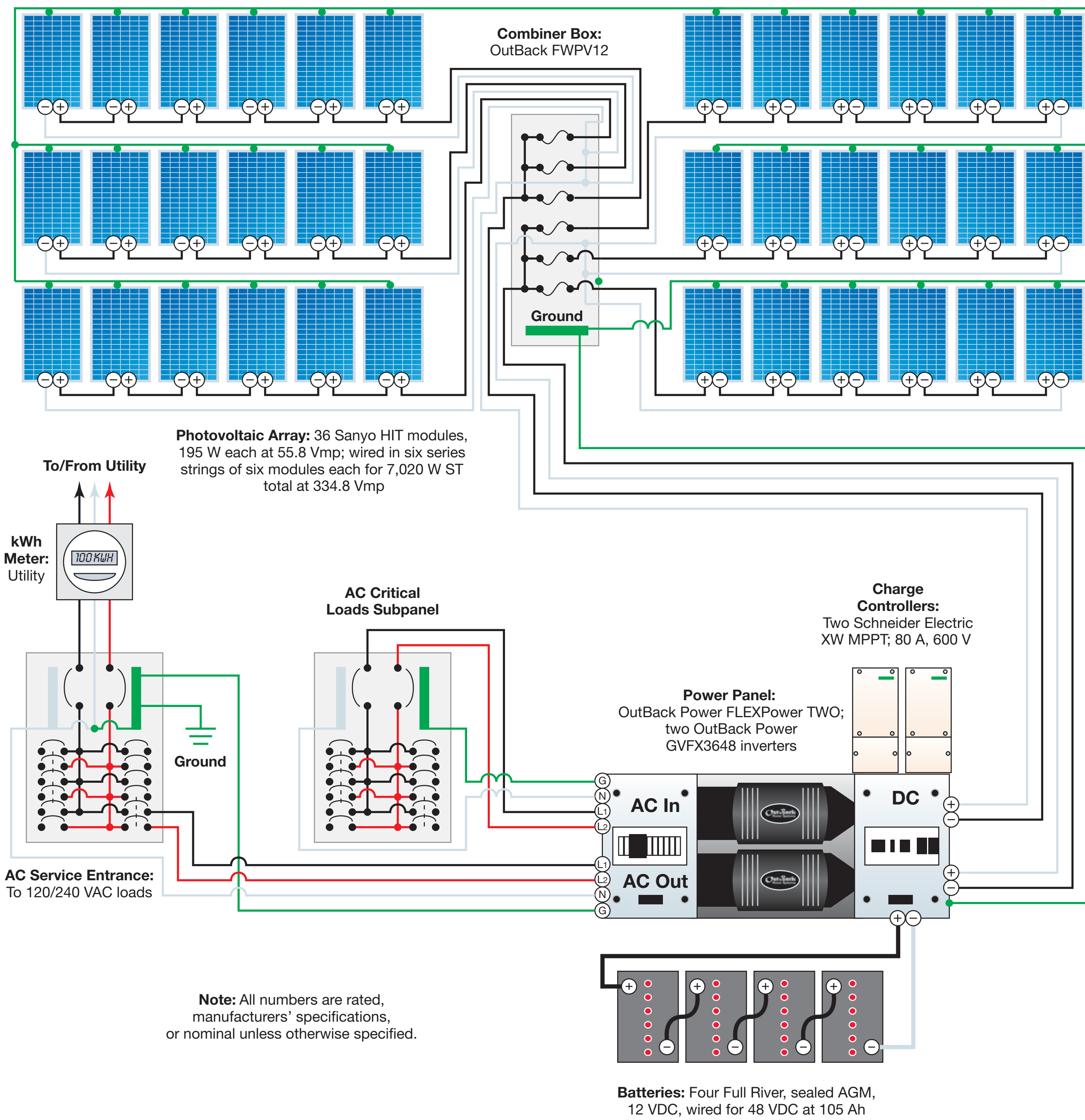
Balance of System

Charge controllers: Two Schneider Electric XW MPPT 80 600, 80 A, MPPT, 600 VDC nominal input voltage, 48 V nominal output voltage

Inverters: OutBack Power FLEXpower Two FP2-29 system consisting of two OutBack GVFX3648 inverters, 48 VDC nominal input, 120/240 VAC output,

System performance metering: OutBack MATE2

BRIGHAM GRID-TIED PV SYSTEM WITH BATTERY BACKUP



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

Positioned for Platinum

For architect Mark Sofield, the Brigham residence marks a career first. While he has long focused on green building and energy efficient design, he had never pursued LEED certification through the U.S. Green Building Council.

"We weren't entirely convinced of its value at first. It is an expensive and extremely time-consuming process, and ultimately Kitty decided it was something she wanted to do. She wanted to put the home on the map and showcase what can be done," Sofield says.

Though the application is on hold until hardscaping and irrigation systems are complete, Sofield is confident the home will earn all the points necessary for Platinum status once the list is complete.

The LEED for Homes Rating System measures the overall performance of the home by eight categories:

1. Innovation and Design Process
2. Location and Linkages
3. Sustainable Sites
4. Water Efficiency
5. Energy and Atmosphere
6. Materials and Resources
7. Indoor Environmental Air Quality
8. Awareness and Education

Every decision, large and small, plays into the point system. The slab-on-grade construction eliminated the materials necessary for an additional subfloor and finish flooring, meeting the requirements for material-efficient framing.

"[LEED certification] is a complicated process and unbelievably time-consuming," Sofield says. "I appreciate the idea behind the criteria and it pushed me to learn new methods, but in some cases, I found the rating system to be an impediment to achieving our energy and sustainability goals. We ran into several frustrating junctures where we ended up spending more money and consuming more resources just for the sake of points."

A second hot water heater in the laundry room, for example, was added to satisfy a LEED requirement. "This was one of the cases when I questioned the LEED process," Sofield says. "We had to add a second small water heater to serve the washing machine and utility sink in the laundry room because the run from the primary heater was 5 feet too long to earn one LEED credit. It didn't seem to make practical sense in terms of the heat lost through the run compared to the life-cycle footprint of an additional unit, but that's what we had to do [to get the points needed]."

Sofield credits the rating system for introducing him to new techniques in exterior water management strategies and hardscaping—key points that fall under the Sustainable Sites category. Surface water management strategies include permanent erosion-control planting, permeable lot surfaces, and vegetative catch-basins and swales that direct all roof runoff to two infiltration ponds in the rear of the property.

To earn the one point for mitigating heat-island effects, light-colored, reflective paving stones were installed around the home's exterior. But when the stones and concrete did not meet the high-albedo requirements (a solar reflective index of at least 29), the team decided to satisfy the requirement by shading the hardscaped areas with trees and trellises. Completely shaded hardscaped areas earn an additional innovation credit.

fabricated the custom aluminum frame that holds the 36 PV modules and clear glass panels in place. The finished canopy faces south and east and is tilted at 6° and 4°. Ideally, Rude says, the canopy's southern tilt would have been tilted at 10° or greater, but neighborhood covenants restricted the canopy's height. "At a 40° tilt [the location's latitude], the system would have been rather obnoxious, and not well integrated into the design," Rude says.

The frame for the canopy was assembled on site by a local welder and hoisted into place by a crane. An installation crew from Boulder-based Namaste Solar mounted the modules and ran the wiring down to the ground-floor mechanical room.

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This OutBack Power FLEXPowerTWO is a fully prewired and factory-tested dual-inverter system. It comes complete with the required DC and AC wiring boxes and breakers, inverter input/output bypass assembly, and MATE monitoring system.

Kelly Davidson

Two Schneider Electric charge controllers protect the battery bank from overcharge and can accept the high DC voltage (412.2 Voc) from each subarray.

A small battery backup system—four 105 Ah batteries—has enough energy to power critical loads (air circulation, refrigerator, microwave, laptop, and some LED lights) for a limited time during a utility outage.

The PV was not commissioned until February 2013. Battery-based grid-tied PV systems can be complicated to meter, since power is flowing to the battery bank (the critical load center) and to the other household loads, with any surplus going to the grid. However, what has been recorded by reading the utility bidirectional meter indicates that from February to late September 2013, the PV system has exported to the grid 2,453 kWh in excess of what the home has used (3,550 kWh). Brigham records the incoming and outgoing energy every day, straight from the utility meter. The exercise has become part of her daily routine, like drawing the shades on the southeast windows. While a full year's worth of data hasn't yet been collected, Brigham is optimistic that the PV system will offset her household consumption. So far, over the late spring and summer months, she has only paid the monthly service charge of $21.50 to the City of Longmont. "I'd be happy with net-zero, but I'm aiming for net-plus," Brigham says.

Access

Home Power Associate Editor **Kelly Davidson** lives in Longmont, Colorado, where she and her husband are upgrading their 1970s trilevel home with new insulation, doors, and windows, in preparation for a PV system in the coming years. This season's project—two new windows—is being made possible by a low-interest loan through the local Energy Smart program.