High-elevation Off-grid Solar Residence in Colorado

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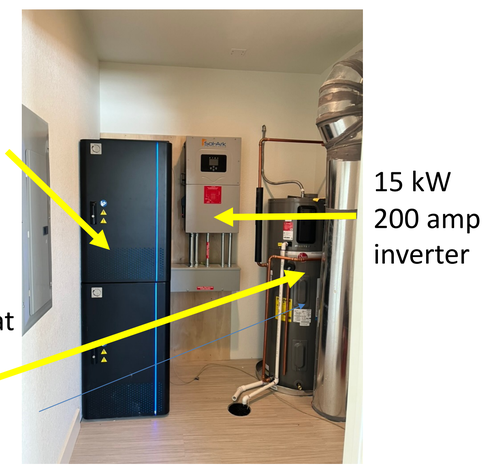
Photo courtesy Andrew Finanger, IPS

House exterior: Photo by the Authors

House interiror: Photo by the Authors



Utility room: Photo by the Authors

OBJECTIVES

Design, build and inhabit a completely sustainable, off-grid solar-powered home with no reliance on external or fossil fuel power sources. Share experiences to help others enhance their renewable energy / energy efficiency efforts.

APPROACH: DESIGN CONSIDERATIONS

- Conduct weather and solar assessment (see Figs. 1 and 2) for the home's location in a high-elevation (8850 ft) forested region of the Colorado Rockies
- Design 1300 ft² home (including loft) with high efficiency standards and passive solar principles
  - Outer wall insulation: R=27
  - Ceiling insulation R=54
  - Windows U=0.16
  - Fully conditioned crawl space allows for use of ducted HVAC
- Size a solar/battery storage system to meet loads 24/7
  - Solar = 7.3 kW
  - Battery storage = 24.0 kW
  - Inverter = 15 kW, 200 amp
- Install highly efficient lighting and appliances
  - Hot water provided by 40-gal. hybrid heat pump water heater
  - Kitchen appliances include induction stove, efficient mini-fridge
  - Efficient wood stove provides majority of winter-time heat during occupancy
  - HVAC is a ducted variable speed heat pump system with air handler

Result: Zero Energy Home with Home Energy Rating System (HERS) Index = -53

PRELIMINARY PERFORMANCE

- Solar system commissioned Aug. 18, 2023; Certificate of Occupancy issued March 16, 2024
- Solar system performance monitored at inverter using PowerView™ App
  - Shows how loads are met by PV, battery storage, and back-up generator (see Fig. 3)
  - "Phantom" loads (used to maintain battery and inverter performance) must be calculated separately; typically, they average around 1.6 kWh/day
  - When battery State of Charge (SOC) <20%, inverter shuts off power to house
  - Back-up generator is available for power outages, but must be started manually
- HVAC controlled by Ecobee™ thermostat; Ecobee ™ App monitors performance
- Solar system capacity is more than adequate to rapidly recharge batteries on sunny days; however, rapid recharging is limited under conditions of snow-covered panels or long, cloudy periods
  - On sunny days, much of the solar resource is curtailed after batteries achieve full charge
  - Nevertheless, current storage capacity is inadequate for various winter storm scenarios
  - Under these conditions, generator backup is necessary
- Using PowerView data, Fig. 4 shows the relative monthly contribution of PV and battery in meeting total household loads
  - Days when power is off or backup generator was used are not included in analysis
  - Much of December and January data are missing due to a failed inverter
  - Results show the importance of battery storage for meeting loads, especially during cooler months

LESSONS LEARNED

- Optimizing solar system design and load management can be challenging in an environment such as this high-mountain Colorado site; especially in winter
- Additional storage will be necessary to reduce the need for generator backup
- Operating an off-grid solar home requires active load management practices
- Maximizing efficiency measures in building construction and appliance selection is key
- **The Inflation Reduction Act is extremely beneficial by providing up to 30% cost savings for key renewable and sustainable energy components in a solar home**

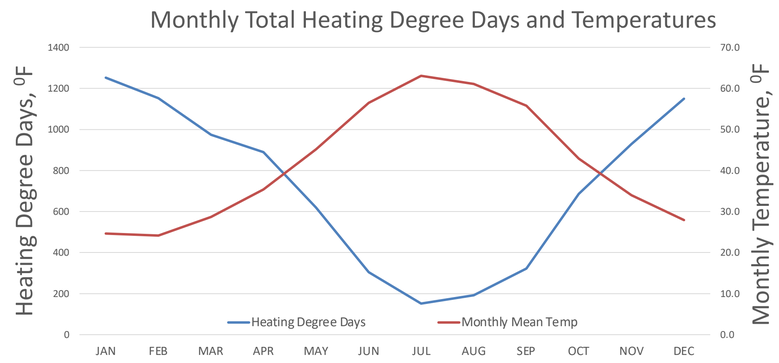


Fig. 1: Average total monthly heating degree days and monthly temperatures at the off-grid residence for the period August 2020 – March 2024

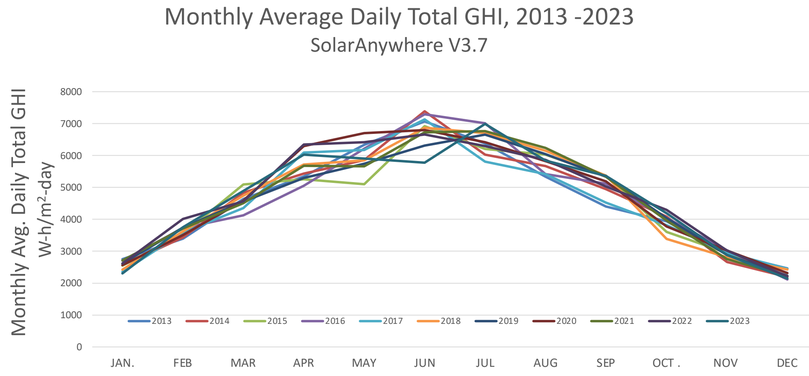


Fig. 2: Monthly average daily total GHI values at the location of the residence for the years 2013-2023. Data from SolarAnywhere™ Ver. 3.7, a product of Clean Power Research (www.cleanpower.com).

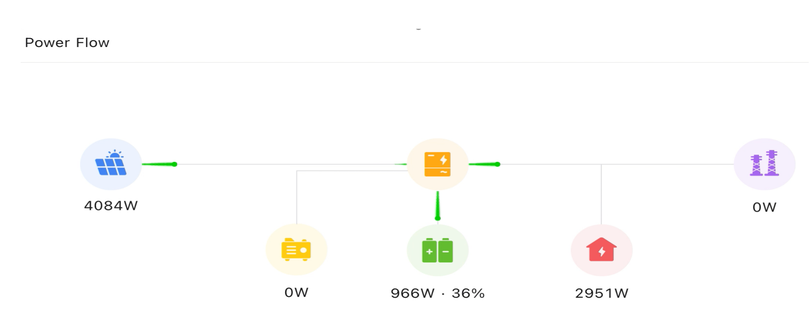


Fig. 3: Screenshot of typical sunny day power flow taken from PowerView™ app for this off-grid system. Generator (yellow icon) is not running. Power from the solar panels travels to the inverter (orange icon) and is distributed to the batteries (green icon) and load (red icon). Once SOC = 100% solar output is used to meet loads; any excess is curtailed.

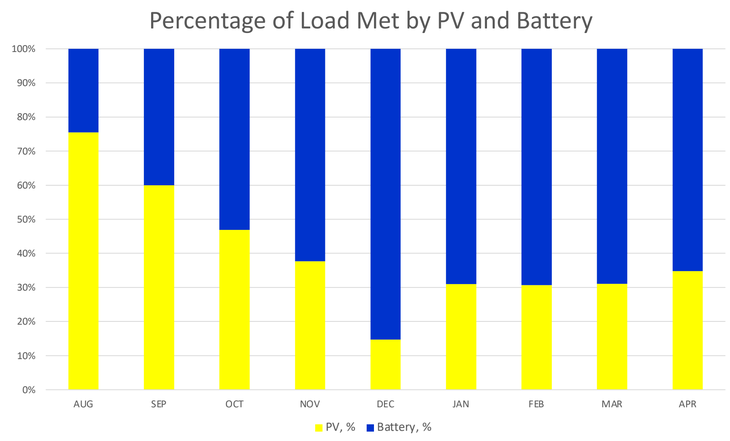


Fig. 4: Percentage of total load met by PV (yellow) and batteries (blue) on a monthly basis. Calculations based only on days when no external generator is used and inverter power to house is fully on.