Heading for ZERO

Smart Strategies for Home Design

by Jim Riggins

Our goal was straightforward: build a net-zero energy house, emphasizing passive features, while minimizing the environmental impact both during and after construction. While we weren't seeking formal certification, this house followed the German *passivhaus* design philosophy of combining a super-insulated and air-sealed shell with passive solar design to reduce heating loads. Combined with using only Energy Star-rated appliances and solar water heating, computer modeling predicted this all-electric house, dubbed Heliospiti (Greek for "sun house"), would achieve net-zero annual energy input by adding a 4-kilowatt (kW) PV system.

Where to Begin

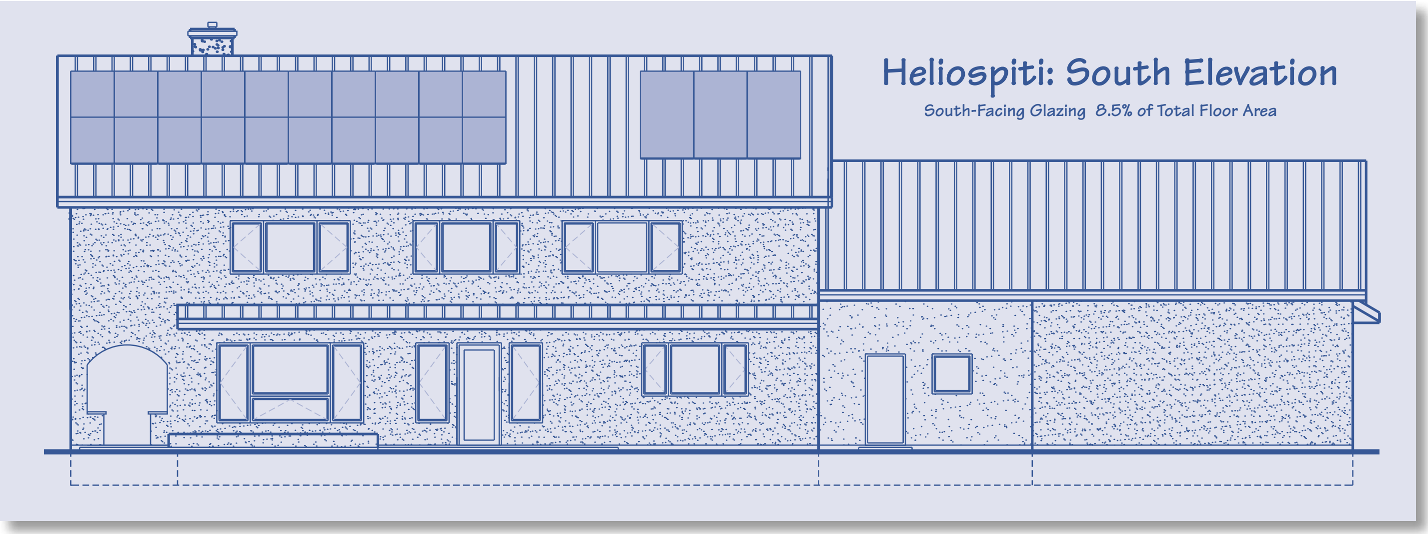
To start the energy modeling and design, my wife Elise and I defined the basic features of the house:

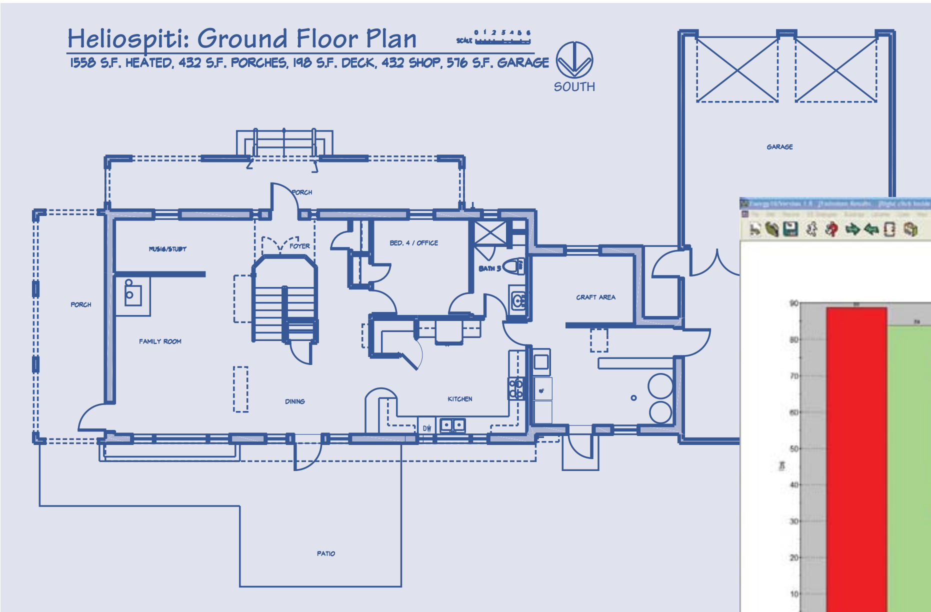
- A floor plan that would be spacious enough to accommodate our two children, but small enough to be an "empty nest" home, with no wasted interior space.
- An open interior to avoid wasted space and promote airflow through the house.
- Slab-on-grade design with the concrete slab as our main floor and the thermal mass needed for passive solar.
- Two-story, rather than ranch style, to maximize the house's volume-to-surface area ratio, and minimize thermal loss.
- Rectangular shape with long east-to-west axis to maximize solar gain and daylighting.
- A garage that would share minimal wall area with the main house to reduce the risk of harmful fume migration into the living area.
- Defining the thermal boundary at the roof, not the attic floor, for ease of air sealing and to keep the attic as a semi-conditioned mechanical room.
- Compliant with the Environmental Protection Agency's WaterSense guidelines to minimize water consumption.

The Energy Design

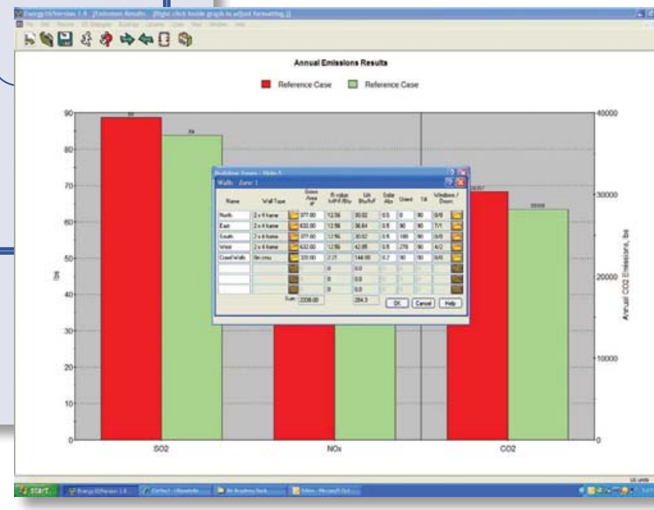
With a basic idea of what we wanted, we turned to Debra Rucker Coleman's book, *The Sun-Inspired House*, for the fundamentals of passive solar design (see "Designing Your Place in the Sun" in *HP116*). On her website, we found a design very close in size and floor plan to the house we had already sketched out. That set our architectural design path—we bought those plans, and set about modifying them to go from high-efficiency passive solar to net-zero energy.

Since I owned Energy-10 software for my consulting business, we had the tools already at our fingertips. Designed by the National Renewable Energy Laboratory (NREL), Energy-10's hour-by-hour simulation capability and extensive NREL validation make it excellent for capturing the complexities of passive solar design. This all-in-one software





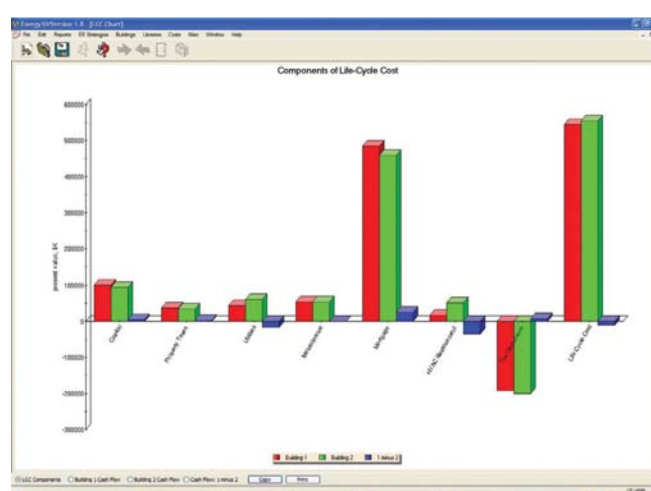
Below: Energy-10 software can predict heat gain and loss, emissions and financial payback.



costs $375; but a set of mostly free, component-by-component analysis tools can be found on the Department of Energy's website (see Access).

We began with a bioclimatic assessment of our climate (see "Be Cool—Natural Systems to Beat the Heat" in *HP108*). The assessment showed our Colorado climate, with its low humidity and cool summer nights, to be well-suited to passive cooling in the summer and passive heating in the winter. We planned to use natural convection to passively cool by including low windows on the first floor and high windows on the second, both of which would be opened at night. Warm air moving out the upper windows would draw cool air across the thermal mass. Excellent resources for historical local climate and solar data are found at the National Weather Service and the NREL PVWatts program (see Access).

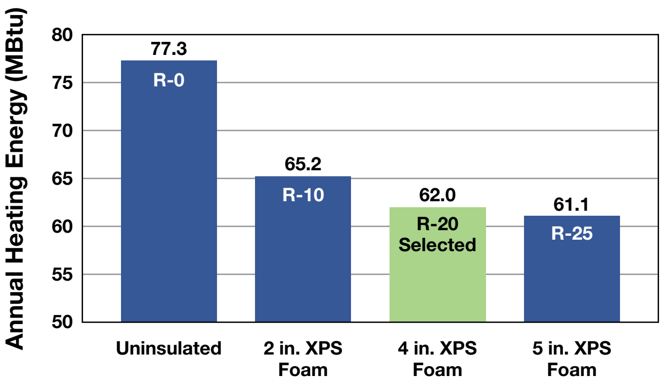
For parametric studies, we modeled a reference home of the same size and shape of the Sun Plans design, and proper southerly orientation for our Monument, Colorado, location. The reference house was standard 2-by-4 construction, with an R-30 insulated ceiling. From there, we changed one parameter at a time to explore its impact on the home's overall energy consumption.



Efficient Construction & Materials

This article focuses only on the energy design of our home, Heliospiti. It does not cover the efficient construction techniques and green products we used, which includes everything from minimizing site impact and recycling construction materials, to eco-friendly countertops, floors, paints, and cabinets. For the construction, we followed the Built Green checklist and the Green Building Guidelines from the U.S. Department of Energy (see Access).

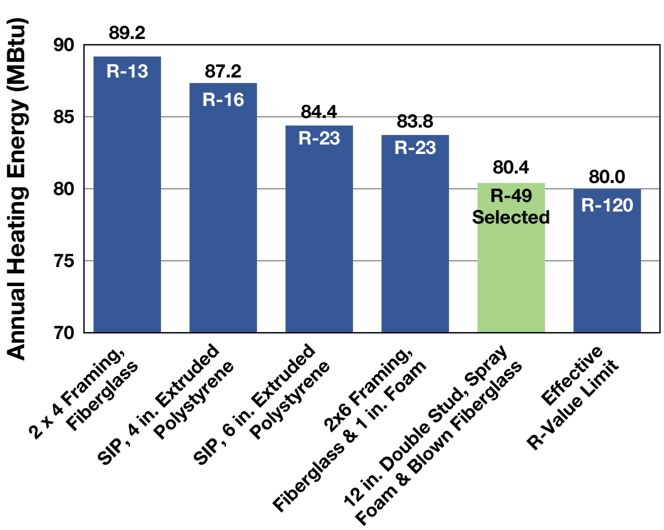
Slab Insulation



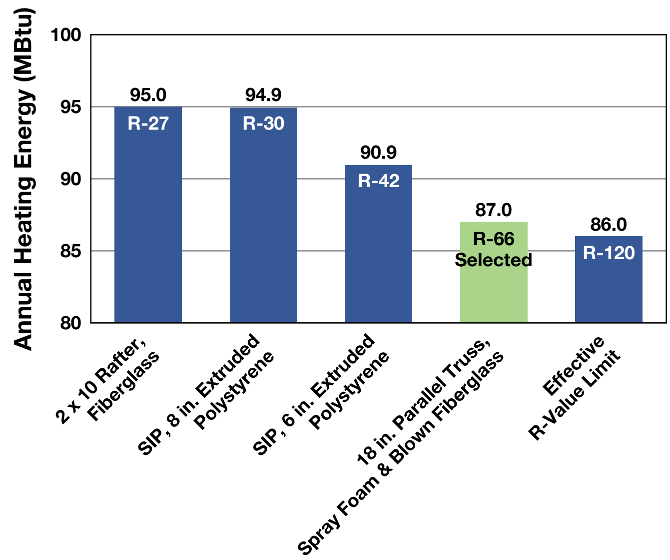
Slab insulation analysis came first and the resulting graph shows the change in annual heating energy for incrementally higher levels of perimeter and under-slab insulation. The slab thickness is fixed at four inches to balance thermal mass and thermal lag. As shown, the impact of slab insulation is greater from R-0 to R-10 and begins to level off at R-20. As a balance between cost and performance, we chose R-20 for both the perimeter and under the slab.

Wall analysis was next, with worst-case scenario being fiberglass-batt-insulated, 2-by-4 frame wall (R-13). The upper limit is shown by an R-120 value. Most of the initial modeling runs were for structural insulated panels (SIPs), both polyurethane (PUR) and expanded polystyrene (EPS) of varying thicknesses. The 2-by-6 wall was modeled using R-19 fiberglass batts in 16-inch-wide stud cavities, plus 1 inch of rigid polyisocyanurate foam on the exterior surface for R-23. Our initial preference was to proceed with 6-inch-thick SIPs, but like other decisions, this would change later when we factored cost into the equation.

Wall Construction



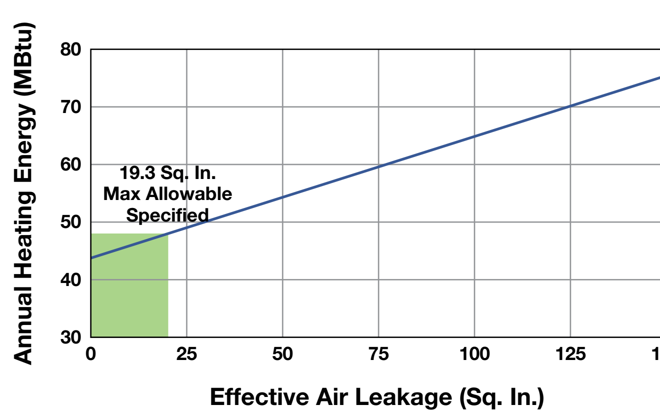
Roof Construction



Roof analysis was similar to the walls with its hypothetical R-120 value for an upper limit. We could not meet our R-60 roof goal with SIPs. The highest-performing panel, a 12-inch-thick extruded polystyrene, reached R-57 and was significantly more expensive than other alternatives. We transitioned to a new plan—a parallel truss system.

Sealing. A home's overall energy performance is affected heavily by air leakage, and the analysis confirmed this. One needs to place as much (or more) emphasis on air sealing as on insulating. Energy-10 plots heating energy use against several "effective leakage areas" (ELAs), to visualize the impact. To ensure the house met its performance goals, we had written into our construction contract the requirement for a blower-door test (before drywall is installed), with a maximum air leakage of 350 cubic feet per minute at 50 pascals of pressure—the equivalent of 19.3 square inches of effective leakage area (ELA). This was a compromise between an extremely tight envelope and what is realistically achievable. By comparison, the typical house in the United States has approximately 165

Air Leakage



square inches of effective leakage area. Although our target is an aggressive air leakage limit, the passive house community has shown that even more stringent limits can be reached. Of course, this level of air-tightness necessitates mechanical whole-house ventilation.

Window analysis was more complicated because of the various parameters involved: window size, glass type, frame and sash material, orientation, surface area, and shading. It is easiest to analyze shading first and separately, and then work on the other parameters.

Great resources for shading analysis are the tools found at the Sustainable By Design website. Using their Window Overhang Annual Analysis tool, we selected an overhang depth of 2 feet, with 5- to 6-foot-tall windows starting 1 foot below the overhang. This gave us a good balance of winter solar gain and summer solar shading.

Selecting and analyzing the window type and performance is the nightmare of passive solar design. The "magic window" of very high solar heat gain coefficient (SHGC) to heat the thermal mass and very low U-factor (thermal transmittance) simply does not exist. For passive solar performance, we wanted south-facing glass that let in as much solar heat as possible in the winter and trapping as much of that heat as possible for night. Because SHGC tends to decrease as U-factor decreases, the goal of the analysis is to find the SHGC/U-factor combination that produces the lowest heat load for the specific climate—and still be able to afford those windows!

A great source of third-party ratings on windows is the National Fenestration Rating Council website (see Access). Using their data, plus speaking to window manufacturers, provided a wide range of window specifications for modeling. We narrowed our focus to fiberglass frames because of their excellent thermal performance in temperature extremes. Our average minimum temperature is 17°F and average maximum is 85°F, but the record low is a bone-chilling -27°F.

The window analysis graph shows a sample of the dozens of south-facing glass and window combinations that we analyzed. Down to a certain point, the solar heat gain was more important than thermal resistance. However, when you get to the very low U-factors available with some coatings, the U-factor becomes more critical than SHGC to reduce heat load. This will vary from design to design and with specific climate as the solar heat contribution is offset by thermal losses through the windows at night and on cloudy days.

We ultimately settled on argon-gas-filled, triple-pane windows with a high-gain, low-e coating, customized for the south face to be made with low-iron glass, which raised the center-of-glass SHGC by 11%. Although it was hard to justify these expensive windows, we decided to put money into the higher-performing windows simply for the energy savings. We also plan to enhance these windows with quilted, insulated window shades.

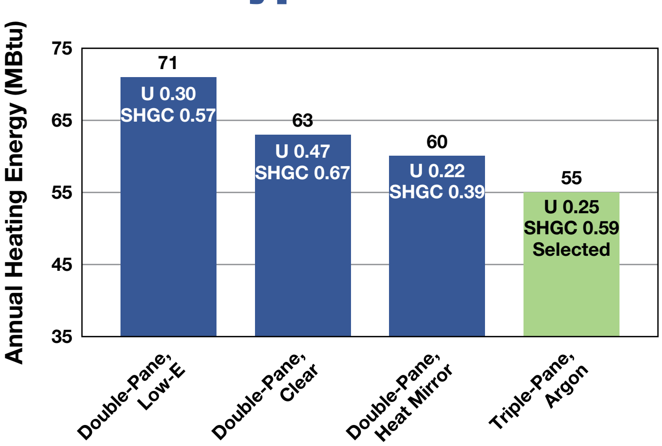
Solar Takes It to Zero

Passive and active solar technologies helped us meet our goal of a net-zero energy home.

Based on a detailed appliance-by-appliance analysis, including a charging station for a future electric vehicle, we calculated that a 4 kW PV system would take us to net-zero energy. For appliances not yet owned, we found the actual models we wanted and used consumption data from the Energy Star database. We used the actual data for the well pump, air-source heat pump, and the energy recovery ventilator. Then, we padded the load analysis a little for things like data monitoring and logging equipment. Working with a system installer, we decided upon 20 Sharp ND-224 PV modules, each matched to an Enphase M-190 microinverter—4.48 kW total.

We predicted hot water consumption based on our actual usage patterns, and converted gallons per day to Btu of heating energy per day. Our goal was to meet 100% of demand year-round with solar hot water. We used NREL's PVWatts calculator to determine the solar energy available at our location. Then, using efficiency data from the Solar Rating & Certification Corporation, we determined the system components and size (see Access). For simplicity and to avoid the need for a heat-dump loop for overproduction in the summer, we chose an unpressurized drainback system using three Sun Earth EC-40, 4- by 10-foot, flat-plate selective-coating collectors and a 120-gallon storage tank with dual heat exchangers and an electric resistance backup heater.

Window Type

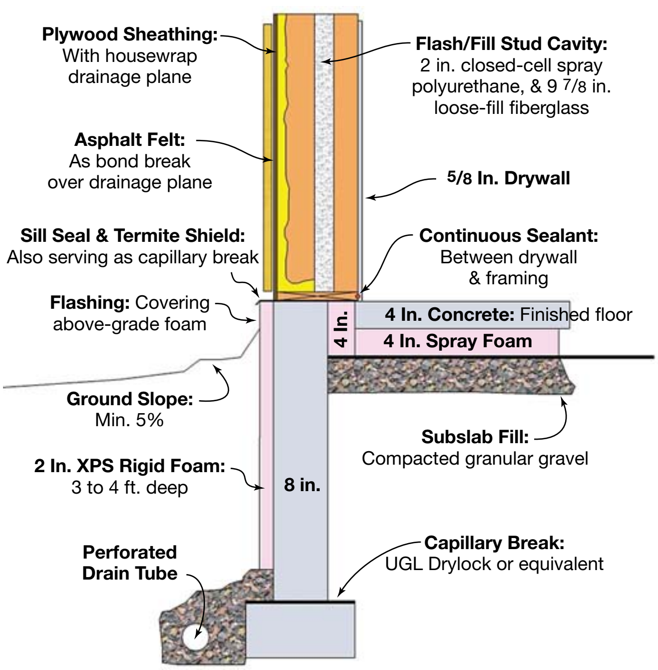


Energy Design Meets Reality: Balancing Efficiency with Economy

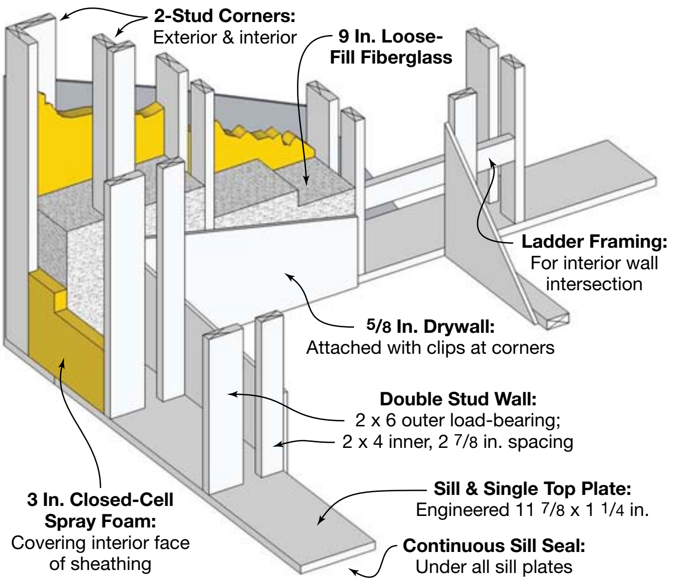
With the design concept complete, we hired local designer David Woody to meld our energy design into the Sun Plans design—and to make sure the home would meet local building codes. Our builder, Doug Strecker of Rampart Custom Homes, was anxious to tackle a net-zero energy home and provided a dose of local labor and materials cost reality.

Slab. A 4-inch-thick slab-on-grade, with R-20 closed-cell polyurethane spray foam insulation under the slab and on the outside of the stem-wall. This will thermally isolate the slab from the foundation wall and ground, and significantly reduces conduction loss through the floor into the relatively cool earth and foundation.

Foundation Construction



Wall Construction, R-49



Walls. Using 6-inch-thick polyurethane SIPs exceeded our budget. Switching to 2-by-6 walls, insulated with blown fiberglass in the stud cavities and 4 inches of exterior rigid (polyisocyanurate) foam on the exterior, would yield comparable performance. This was still a more expensive option (labor and materials combined) than the one we ultimately selected: double stud wall construction. Overall, SIP exterior wall construction ran 14% higher than the double-wall, and the 2-by-6 with exterior foam ran 5% higher. The economic argument will vary widely from city to city depending on local labor and material costs. The double-wall technique uses more lumber but goes up more quickly than a single wall with two layers of exterior foam plus more intricate sealing and trim work around the windows.

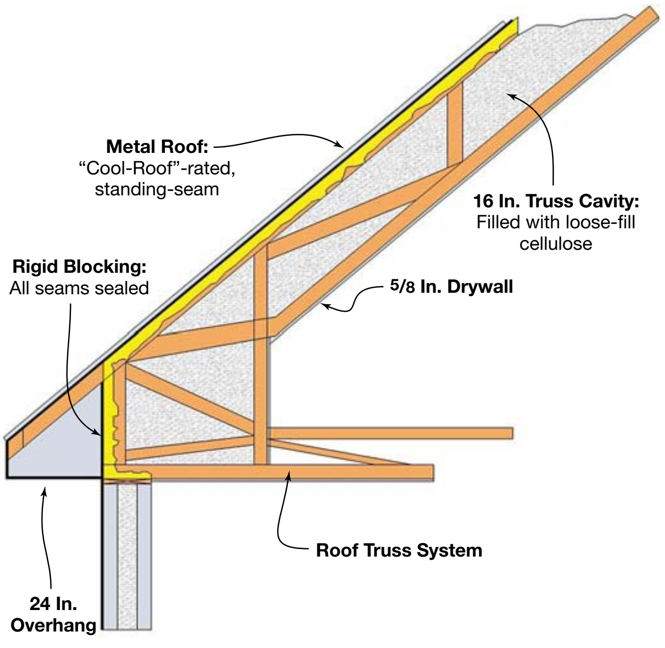
The double stud wall is constructed of 2-by-6 and 2-by-4 studs. Three inches space between the inner and outer studs provides a thermal break, resulting in a high-thermal performance wall. Three inches of closed cell spray foam along the outer sheathing and 9 inches of blown-in fiberglass yields R-49. Stud spacing at 24 inches on center, using "advanced framing" techniques, results in a more efficient use of lumber.

Roof. The roof was designed with a 40° pitch on the south side to be optimally oriented for a PV array. The north roof was sloped at 26° to reduce surface area heat loss. Parallel truss construction gave an open attic and mechanical space. With 3 inches of closed-cell spray foam and 15 inches of blown cellulose, the roof was insulated to R-66. A standing-seam metal "cool roof" helps reflect sunlight, helping to reduce the cooling load in the summer. As with the wall construction, the labor and materials costs were less than a SIP roof or 2-by-10 rafters with 4 inches of exterior foam on the roof deck.

Windows. The selected windows are triple-pane, foam-filled fiberglass from Accurate Dorwin Company of Winnipeg, Canada. Operable windows will be casement or awning types, which seal better than sliding or hung windows. South-facing windows will have a SHGC = 0.59 and a U-factor = 0.25; and north facing will have SHGC = 0.27 and U-factor= 0.16

Our passive solar design included no glazing on east or west faces, with limited glazing on the north side for daylighting. The south-facing glazing is about 8.5% of total floor area, well within established passive solar design recommendations.

Roof Construction, R-66



Air Sealing & Ventilation. The house's airtight design is aided by the barrier layer of spray foam inside the entire shell. The use of a condensing, non-vented clothes dryer and a recirculating range hood also helps keep the thermal boundary tight and eliminate pressure imbalances.

We chose the Ultimateair RecoupAerator whole-house energy recovery ventilator (ERV) with a high recovery efficiency (see Access). The ERV intake air will run through a 100-foot-long earth tube and a water-to-air heat exchanger using solar hot water for preheating.

Specific Design Modeling Results

With the overall design complete and windows specified, we re-modeled the house in Energy-10 to determine what backup heating system would be best. We had maximized the passive efficiency and solar gain of the building envelope within our budget. Now, in keeping with the *passivhaus* philosophy, we sought the smallest, most cost-effective backup mechanical heating system to satisfy the remaining heating load.

For our Heliospiti project, Energy-10 indicated an 18 kBtu per hour peak heating load without solar gains, and 4.5 kBtu per hour with passive solar gains included. We selected a mini-split air-source heat pump that the manufacturer claims should provide 100% heating capacity to 5°F and reduced heating, without electric resistance backup, down to -13°F. This unit has a maximum capacity of 10.9 kBtu per hour at 5°F. Only real-world experience will reveal if the mini-split heat pump performs up to the manufacturer's specifications and the passive solar design offers the heating predicted by the modeling software.

In Energy-10, the model reports heating and cooling energy consumption regardless of the energy source. On-site generation only shows up in the "Other" category as negative electrical consumption, and negative water heating energy. "Lighting" doesn't change for the same reason.

The predicted energy use modeled for our home is a net annual production of 8,335 kBtu (a result of the PV and SHW systems)—meeting our goal of true net-zero energy in an all-electric house. The graph compares our design to a high-performance reference home following Energy Star criteria with R-5 slab insulation, R-38 ceiling, 2-by-6 R-17 walls, and Energy Star-rated windows. Heliospiti's active solar systems aren't factored into the heating equation—the Energy-10 comparison just reflects the effects of insulation, air sealing and passive solar design (passive thermal losses and passive solar gain) with the reference house.

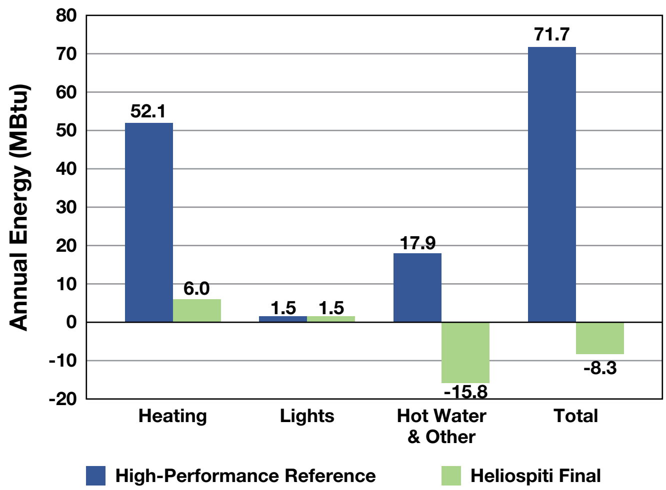
And now we look forward with anticipation as we watch the house go up—waiting to see how closely Heliospiti meets the modeling predictions.

Energy-10 Modeling Results

	Annual Energy Consumption (kBtu)	
	Without PV & SHW	With PV & SHW
Heating	5,954	5,954*
Cooling	0	0
Lighting	1,489	1,489
Other electric loads	19,946	-15,778**
Total Annual Energy Use	27,389	-8,335*

*SHW is used for domestic water heating only; none goes to space heating
**Negative numbers reflect the sum of all on-site production, both PV and SHW

Final Energy Comparison



Access

Jim Riggins (info@enersmartenergy.com) is the principal of EnerSmart Energy Solutions (www.enersmartenergy.com) and a Residential Energy Services Network (RESNET) certified home energy rater. He and his wife Elise plan to use Heliospiti as a showcase of affordable, energy-efficient construction.

Built Green checklist • www.builtgreen.org

Cool Roof Rating Council • www.coolroofs.org

Green Building Guidelines • www1.eere.energy.gov/buildings/building_america

Home Ventilating Institute product comparisons • www.hvi.org

National Fenestration Rating Council • www.nfrc.org

PVWatts Solar Calculator • www.nrel.gov/rredc/pvwatts

National Weather Service • www.nws.noaa.gov

Solar Rating & Certification Corporation • www.solar-rating.org

Sun Plans • www.sunplans.com

Sustainable By Design • www.susdesign.com

U.S. DOE/EERE's Building Energy Software Tools Directory • http://apps1.eere.energy.gov/buildings/tools_directory

U.S. EPA WaterSense Guidelines • www.epa.gov/WaterSense