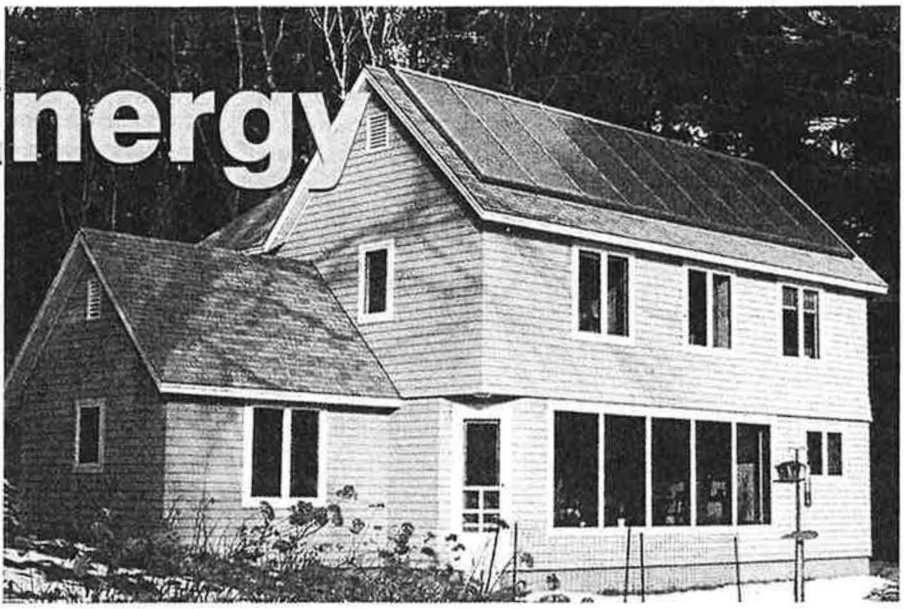
Solar Energy House



This house uses solar energy to heat a 1,200 gallon storage tank in the basement. The house's energy-efficient features save about $500 annually.

By Marc Rosenbaum, P.E.
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Late in 1991, I was asked to design a new home by a couple interested in pushing the envelope of low-energy use design. They wanted to live in a comfortable and durable home, built to a budget comparable to other custom homes in the area, and one that didn't look as though it had just landed from outer space. The home is about 1,800 ft^2 (167 m^2), plus a full basement.

I wanted to see how close we could get in the cold New Hampshire climate to a home that uses no supplemental energy for heat and hot water. We were vigilant about the energy used for lights, appliances, and mechanical systems, and incorporated as many other enviro mentally friendly features as possible, emphasizing resource efficient construction materials and a healthy indoor environment.

Build It Tight, Ventilate Right

In the northern New England climate, the sun is a welcome but occasional visitor, so a solar home must be a super-insulated home. Airtight construction was the top priority. Penetrations were minimized and carefully sealed. The result was a home with an Effective Leakage Area (ELA) of less than 5 in.^{2} (32 cm^2), including the basement. (ELA estimates how large the hole would be if all the holes and cracks in the house were combined into one opening.) Blower door test results projected an average natural infiltration rate of only 0.03 air change per hour.

For ventilation, we chose a heat recovery ventilator that recovers about two-thirds of the heat in the air exhausted from the house and transfers it into the fresh air coming in.

The computer modeling showed that we needed R-values of 40 for the walls and rim joists, and 60 for the roof. We achieved this with double 2 × 4 ft (51 mm × 89 mm) stud walls, with cellulose insulation blown into the 11.5 in. (0.3 m) deep cavity. The roof has R-60 blown-in cellulose. Basement walls are R-11, and there is 1 in. (2.5 cm) of extruded polystyrene foam under the slab. I estimate that the super-insulation added about $6,000 to the construction cost.

Super Glass

We chose Owens-Coming windows, in which the frame and sash are made from hollow, rigid fiberglass protrusions filled with rigid fiberglass insulation. This reduces heat loss through the opaque portion of the window compared to a wood or metal unit. The manufacturer provided casement windows without glass so we could site-glaze the windows using R-6.5 glass. This is achieved by using a polyester film with a low-e coating, suspended between two layers of glass.

We specified low-e glass as the inside pane; clear glass on the exterior; and filled the interior spaces with krypton. This provided excellent insulating value without cutting down too much on solar transmission, which is important because 75% of the glass is on the south side, helping to heat the house.

The five 46 in. by 76 in. (1 m by 1.9 m) fixed pane units in the living/dining area use two layers of the polyester film, between two layers of clea glass, achieving an R-value of 9. These units were direct set to 4 by 6 fir framing, using setting blocks, glazing tape, and finger-jointed redwood battens. The insulated steel doors and skylight are glazed with the same glass.

Staying on the Sunny Side

As a result of the super-insulation, the house has a design heating load of about 20,000 Btu/h (~6 kW) at –25°F (–32°C). The house could be heated by four good size blow dryers, but neither of the occupants has big hair, so we needed another strategy.

We analyzed a number of heat and domestic hot water (DHW) systems for their estimated installed cost, annual operating cost, and 20-year life cycle cost. Fuels included oil, propane, and electricity, and equipment included boilers, water heaters, and active solar systems. Several systems had similar life cycle costs. Most interesting were the systems where the size of the solar water heater grew to supply much of the space heat and DHW load. We found that eliminating fossil fuel combustion entirely and putting the up-

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front cost into a larger solar system actually made sense, even though electricity at 11 cents per kWh was a costly backup fuel.

After extensive computer modeling, we sized the solar system at 360 ft^2 (33 m^2)of collector and 1,200 gallons (4542 L) of water storage. To achieve 100% solar energy use, we would have needed twice the system size, which was not economical. We chose a solar installer experienced in site-built roof integrated collector arrays, in which the collectors replace the roof surface. This saves cost, looks better, and yields a collector more efficient than nine separate 4 ft by 10 ft (1 m by 3 m) solar collectors mounted above the roof, because the site-built collector has much less edge area to lose heat. The copper absorber has a selective surface coating that reduces radiant heat loss. We installed a single layer of low iron solar glass. Additional roof area below the collector is available for future solar electric conversion.

The system design is a drain back. The collector is empty until the sensor mounted on the absorber indicates that there is energy to collect. Then the pump turns on, lifting water from the bottom of the storage tank to the roof, where it passes through the collector and returns to the top of the tank. Drain-back systems do not require heat exchangers or antifreeze, since the collectors have no water in them unless the sun is out. This makes for a simpler, more efficient system.

In the basement, the 1,200 gallon (4542 L) water storage tank is a site-built work of art fabricated from copper sheet soldered together. This creates a highly corrosion-resistant tank that can always be repaired. DHW is stored in a separate 52 gallon (197 L) tank, polybutylene lined with 2 in. (5 cm) of foam insulation. As hot water is drawn from the tank, makeup water passes through a heat exchange coil made of 50 ft (15 m) of ¾ in. (1.9 cm) copper tubing immersed in the top of the solar tank. Water also can be recirculated through this coil to keep tank temperature up when no water is being drawn. Backup heat for DHW is supplied by a 5 kW electric element in the tank. This element also serves as backup for the heating system (see later).

The collector heats the water in the storage tank. Heat is distributed to the house by forced air, using a four-pipe fan coil. The chilled water coil receives hot water from the solar storage tank, allowing 100°F (38°C) water to heat the home at design conditions, and the hot water coil gets hot water from the DHW tank, providing backup heat if the solar tank is not hot enough. The ductwork was sized carefully for low-pressure drop, and return grilles and supplies are located in each bedroom to ensure good heat distribution and to keep pressures balanced. The ducts were sealed with latex mastic, and insulated in the basement. Fresh air from the HRV is supplied to the return ductwork, which distributes fresh air throughout the house.

Graywater, Lights & Appliances

Graywater and toilet water waste piping were kept separate above the basement slab. This simple, low-cost strategy retains the option to reuse graywater for landscape watering, or to recover heat from it.

A mix of lighting technologies includes recessed lights with line voltage halogen lamps, hardwired compact fluorescent fixtures, and floor and table lamps with incandescent bulbs. Here, energy efficiency took a backseat to the feel of the house, as well as the desire to be able to dim lights in the main living area. The halogen lamps have a low emissivity coating on the glass, which returns waste heat to the filament. This achieves an extra measure of efficiency over conventional halogens with. Refrigeration is supplied by a conventional 21 ft^3 (0.6 m^3) refrigerator. The concession to increased energy savings was to place the unit on an exterior wall, permitting future use of the abundant New Hampshire natural cooling.

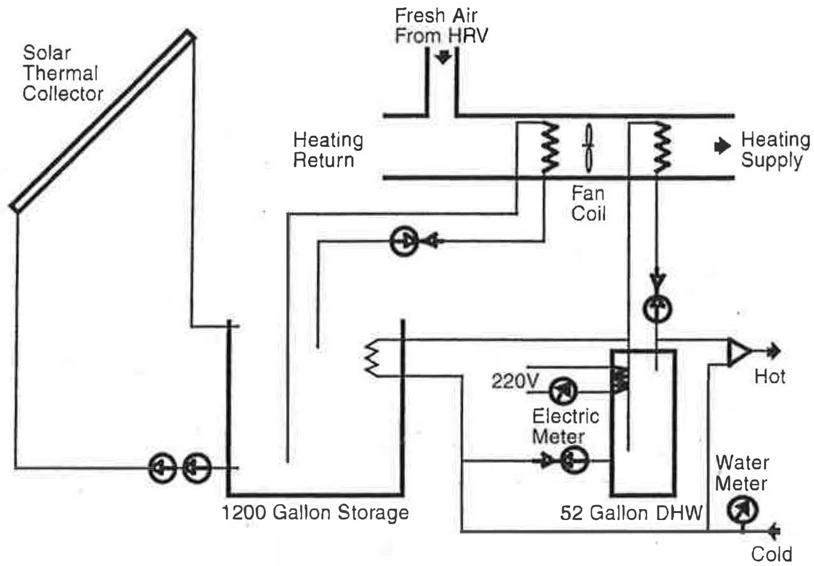

Figure 1: Schematic of solar energy house in New Hampshire.

Other Environmental Features

A safe and healthy indoor environment was ensured by having no combustion or fossil fuels on site, providing fresh air ventilation, using principally water-based paints and finishes, and choosing high quality, natural finish materials such as granite, tile, natural linoleum, and native hardwoods (instead of laminate, carpet, vinyl, and particleboard). Durability is a key element in environmentally friendly design, and the finish materials mentioned earlier all contribute to minimal maintenance and long-lasting beauty. A passive stack radon mitigation system was installed.

Materials efficiency was addressed by using wood I-beams for joists, oriented strand board for subfloors and sheathing, parallel strand beams for main structural members, and trusses for the roof. Little sawn lumber in the house is larger than 2 × 4 ft (51 mm × 89 mm). The cellulose insulation is made of recycled newspapers.

Dollars and Sense

The energy performance of the house has met our expectations, and has been close to the computer model projections. In the first five years, the house has averaged 1,720 kWh annually for backup heat and DHW. Total energy use was 5,068 kWh, at a cost of $550. In this area, I estimate that a typical new custom home using oil for heat and hot water, and electricity for appliances, mechanicals, and lighting, would use about $900 to $1,100 of energy annually, so my clients are saving perhaps $500 yearly. This savings pays for the super-insulation upgrades. The solar/mechanical systems in the house cost about $15,000 for heat, DHW, and ventilation. The typical home here would have an oil-fired forced hot water heating and DHW system, a woodstove, and a two-flue masonry chimney and hearth, at a cost of about $14,000. Adding a HRV, brings the price to $17,000. Therefore, I do not believe our mechanical system cost exceeded what is normally spent in this area—we just spent the money differently.

Potential Improvements

Energy consumption could be further cut by many measures. All of these projected savings would not be fully realized in practice, because some of the electricity used by lights and appliances helps to heat the house during the coldest months. More efficient motors in the solar system pumps and the fan coil blower could likely save 250 to 300 kWh annually. More efficient lighting and a super-efficient refrigerator might save another 300 to 400 kWh. Another 150 to 200 kWh might be cut by replacing the desktop computer in the home office with a laptop. And finally, we measured the power drawn by "phantom loads"—the energy used by the TV, VCR, stereo, microwave, answering machine, etc., when they are supposedly off. This power draw totaled at least 30 W, which is enough to require more than 250 kWh annually. As one person suggested, our appliances need three position switches: on, off, and *really* off.

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