Solar House Tour - Oct. 6, 2007

Overview: Owners designed the house and had it built from Mar. to Nov. 1998 for $170,000 (not including property). Solar hot water ($3000) was installed in 1999 and is included in the $170,000. Greenhouse ($10,000) and solar electric system (2.6 kW at $8,000) were added in 2002 and 2003. More PV (1.6 kW at $5000) was added in 2007. Basic design is a 50 ft x 26 ft two-story cantilevered ranch bermed into a south slope with walkout south side. The long side faces south and has 200 ft2 of window area. The house is super-insulated and air tight with an air-to-air heat exchanger used in the cold weather. Backup oil system used for heat and hot water has been around 150-200 gallons of oil per year, depending on temperatures and sunshine over the winter. Modifications in winter 2007 were made to bring it to zero net energy which should be verified over the coming winter.

Earth-Berm Construction - House is bermed on the north, and partly on the east and west sides. Poured concrete is used only in the slab and walls underground; the rest is framed. Berming provides cool surfaces for the basement floor in summer, less heat loss in winter, and a cold storage area on the north side for storing garden food. It also reduces the house profile on the land, and reduces wind infiltration.

Superinsulated Tight Construction: The house is built with high R values (R = 60 in roof; R = 27 in walls; R = 3.3 for windows (Anderson HP windows); R = 16 under the slab; R = 6 for doors). Six inch studs with 6 inches of fiberglass plus one inch of foam insulation on the outside of the house provides R = 27. Sealing, weather stripping, a vestibule, and casement windows provide a very tight envelope estimated at n = 0.03 (recently measured as well). Attic entryway is sealed and insulated. Sealed Tyvek is used over the insulation in the attic. The heat loss value for the house is less than 3 Btu/ft2/DD, about 1/3 the heat loss of an average house. Envelope heat loss is about 45 million Btu's over the heating season.

Passive Solar Design: South Window Glazing Each of the four major rooms on the south side has combined picture/casement or just casement windows (each 5 ft x 10 ft). The house has 200 ft2 of south facing windows, excluding the greenhouse. This represents about 8% of the total floor area of 2400 ft2. E (29 ft2 window), W (20 ft2) and N (17 ft2) sides have much smaller window areas. Each ft2 of south facing window provides about 100,000 Btu over the heating season for a total of 20 million Btu's, or about half of the heating load. The greenhouse provides about another 10 million Btu. It is most useful in March, April and May when south windows are mostly shaded. A small fan on a timer enhances flow from the GH.

Daylighting: All rooms except the bathrooms have natural lighting from 2 directions. Rooms used in the daytime have south-facing windows, providing ample natural light even on fairly cloudy days. Semi-open design allows light transfer and air movement between spaces. Ceiling and walls are light colored to reflect light.

Efficient Lighting: Almost all fixtures use highly efficient fluorescent or CF bulbs. Efficient T8 fluorescent valence lighting is designed into the living room, dining room, and rooms downstairs. Task lighting used at desks and workplaces. Incandescent used mostly where use is minimal (closets and storage areas), or in a few places where CF bulbs don't fit.

Passive Cooling: Two-foot overhangs (roof overhang and cantilevered overhang) provide shading over all south windows. An east side screened porch roof and deck provides shading for the east side windows and porch doors. Reflective barriers are used on the west windows as needed (when temperatures > 90 degrees) until deciduous trees planted on the west side shade the windows in summer. Attic is vented by continuous eave and ridge roof vents. House foundation is bermed fully on the north and partly on east and west sides, keeping the downstairs very comfortable (< 75 deg) even in the hottest weather. Openable casement windows provide large openings to provide substantial area for ventilation. Two double hung windows (one upstairs and one downstairs) are designed to be used with sealed window fans. Efficient appliances and daylighting reduce waste heat from electrical use in the summer. No AC is needed.

Efficient Spatial Design: House is average size (2400 ft2 total, 2050 ft2 in livable space with 350 ft2 in furnace room and basement storage areas). Design provides for rooms used in the daytime to have natural lighting, solar heating, and efficient airflow and movement patterns (washer/dryer next to bathroom adjacent to bedroom; hallways for movement between rooms; vestibule with entry closet, easy access to porch and deck dining from kitchen, carport and entrance convenient to kitchen, greenhouse convenient to workroom and garden, etc).

Efficient Appliances: Appliances (refrigerator, freezer, clothes washer, clothes dryer, dishwasher) are relatively new and energy efficient (see www.aceee.org or www.energystar.gov for ratings of appliance efficiencies). There is a solar clothes dryer (aka. clothes line) outside, and an inside line in the furnace room. The electric clothes dryer is rarely used, even in winter. The total electricity usage averages 275 kWh per month, about 1/4th the average household. This is mostly due to efficient appliances, daylighting and efficient lighting, reduction of parasitic loads, together with low heating use (the boiler and pumps use 1 kW of power when running). The AAHE (70 watts) runs during the heating season.

Active Cooling: There is no use of or need for air conditioning (see passive cooling). Two double-hung windows (one upstairs and one downstairs) provide for sealed-opening window fans. House is vented in the day and closed up at night in very hot weather. Only the upstairs fan is installed in the summer, and it is needed only during prolonged hot spells, or very warm weather. Downstairs fan was never installed.

Green Material Use: Recycled plastic flooring (TREX) used for deck construction. No lead used in solder, no lead paint used, low VOC caulks and paint used. Environmentally sound products used for washing/cleaning. Half of concrete typically used in foundation eliminated by design. No asphalt used (gravel driveway, mulched walkways). Sealed combustion furnace eliminates materials for chimney. Carport eliminates need for materials for enclosed garage. No wall-to-wall carpets. Organic pest control.

Energy Management: Temperature reduction to 60 degrees at night, 68 degrees in daytime, and lowered temperatures when no one is home. Zoned temperature settings (5 thermostats). Minimal use of electric clothes dryer and dishwasher. Cold water clothes washing detergents used. CF, fluorescent and task lighting used extensively. Night venting with window fan, and day close up for very hot weather. Reflective foil barriers used on west windows for very hot summer days. Movable insulation used to cover windows at night in the winter.

Downstairs Storage Room:

Heat Recovery Ventilator (Air-to-Air Heat Exchanger): Provides about 80% heat recovery of the thermal energy in outgoing warm air to preheat the incoming cold air**.** Provides an air exchange rate of about 0.3-0.5 air changes per hour. Outgoing stale air is vented from the bathrooms, eliminating the need for bathroom fans. Indoor air pollution and humidity are controlled by low, high and intermittent fan settings, as well as a humidity set point, and timers in the bathrooms.

Thermal Mass: The existing basement slab (insulated underneath) plus tile provides additional thermal mass to store daytime solar gains and release the heat at night. Existing furnishings, sheetrock, etc. also provides substantial thermal mass to prevent overheating during sunny days and to store the energy for later use at night. In the summer, daytime highs rarely exceed 72 degrees downstairs and 78 degrees upstairs. In winter, night time temperatures seldom drop to the thermostat set point of 60 degrees; often it drops only 2-3 degrees from 68 degrees even if it is 20 degrees F outside. This is due to using movable insulation in the windows at night.

Food Storage: An extended three-season production garden minimizes storage need. Isolated basement room provides root cellar for cold storage of squash, potatoes, sweet potatoes, onions, shallots, garlic, apples and tomatoes throughout the winter. Freezer provides storage for fruits and vegetables. Food dryer provides for long-term storage of dried tomatoes and fruits.

Photovoltaic Solar Electric System: A 2.6 kW system (about 240 ft2) of Evergreen polycrystalline solar cells (12% efficiency) provides 600 volt DC electricity to an inverter and then to a net metering System. Meter runs forward and backward. System sized to provide about 3600 kWh per year, providing more than100% of yearly electrical load. The inverter and DC disconnect is seen in the food storage room. The system cost $8000 after NYS rebate and tax credit. Check web pages in NY (run by NYSERDA) www.powernaturally.org or in NJ www.njcleanenergy.com for details about rebates and list of approved installers. A REC program may eventually provide an additional rebate based on kWh production. See www.dsireusa.org for all state and federal tax incentives and rebates.

Downstairs: Workroom and GH

Attached South-Facing Greenhouse: An 8 ft x 12 ft attached solar greenhouse (unheated) provides additional heat gain on cold, sunny days, as well as great flexibility to vent unwanted heat gain on warmer days in spring and fall. 240 gallons of water storage and an insulated slab provides heat storage that typically keeps the GH 20 degrees above minimum ambient temperature. The additional south glazing area of about 100 ft2 increases the effective solar south-collecting area. Due to extra glazing losses and thermal storage for plants, useful heat gain over the winter is estimated at about 7.5 million Btu (less than a south facing window). The greenhouse is used for vegetable and herb production in the fall, winter and spring. Only hardy greens are grown in the winter. For passive solar gains, it is especially useful in March and April when the 2 ft overhangs over the south windows block a lot of sunshine (the March sun path is the same as September). A small fan on a timer enhances the heat transfer into the house.

Downstairs: Boiler Room

Efficient Backup Boiler: A 90% efficient oil-fired boiler provides backup heating for space and water heating. The system is a sealed-combustion unit, with no chimney needed and no potential for down drafting combustion gases and carbon monoxide poisoning. The unit vents through the basement wall to the N side of the house. Burnham and Energy Kinetics (System 2000) make the two highest efficiency small oil burners (See www.aceee.org for efficiency ratings of boilers and furnaces).

Efficient Heat Distribution and Controls: Pumps distribute boiler heat to the hot water tank, to the radiant heating tank, and to the upstairs baseboard heating system. A 40-gallon radiant heating tank provides low temperature (100-105 F) water to a radiant heating system imbedded in an insulated slab in the basement and to the upstairs bathroom floor. The rest of the upper floor uses hot water baseboard heat. There are a total of 5 heating zones in the house run by 5 separate thermostats (3 upstairs and 2 downstairs).

Solar Hot Water Heater: The non-toxic propylene glycol solution in the two 4 ft x 8 ft panels is circulated by a small 12 volt DC pump, with electricity provided by a small 15 watt PV panel. A small heat exchanger circulates the heat from the glycol to an 80-gallon tank by natural thermosyphoning where it then feeds into the regular 40-gallon hot water heater. The system provides about 10 million Btu's per year, about 75% of the hot water load for the year. Provision is made to bypass the regular tank entirely if desired (used in summer operation). System is made in Canada by Thermodynamics and sold in the U.S. by distributors. There are other manufacturers of similar systems such as Heliodyne. New types of solar water heaters such as evacuated tube collectors are on the market as well, but are more expensive.

Indoor Air Pollution: The house has radon collection pipes in gravel below the slab and a passive vent stack to the roof, giving ambient outside air radon readings in the house (< 1 pCi/l). The AAHE reduces excess humidity and indoor air pollution. No combustion appliances are used in the house (no carbon monoxide down drafting possible) No indoor carpeting is used (wood and tile floor surfaces). Source reduction - no toxic cleaners or materials used. Only natural pesticides used as needed. Kitchen fan vents as needed (window opened nearby). Whole house vacuum vents small dust particles outside.

Bathtub Heat Recovery/Heat Exchanger: Used warm bathtub water is routed and stored in a 40 gallon heat exchanger where incoming cold water to the solar tank is preheated whenever hot water is used. The heat lost from the heat exchanger helps to heat the house in the heating season. Water can be diverted for outside uses in the warmer weather (greywater reuse) if desired.

Outside: To Garden

Food Production: Three-season 3000 ft2 raised bed organic garden provides ample fruits and vegetables over spring, summer and fall. Greenhouse provides for winter growing of hardy greens, extending the season in the fall, and growing seedlings in the spring. A solar-powered electric fence and regular fence is used for critter control (woodchucks, raccoons and deer). A small orchard provides a variety of fruits. A small garden shed stores tools. A 9 ft high fence around the garden protects from deer.

Water Conservation: Two 500 gallon cisterns buried in ground collect rainwater from the roof for garden and tree watering. 1.6 gallon flush toilets. Low-flow showhead and faucets. Trees, plants and garden heavily mulched. Greywater recovery from bathtub.

Outside to South Shrub Area:

Green Landscaping: Small lawn area (< 800 ft2) is fertilized organically. A slower-growing, drought-resistant, and pest resistant lawn grass variety (see Garden's Alive) requires less maintenance. Weeds are composted. Leaves are recycled as compost and mulch. 80% of property left in native trees, shrubs, and grasses. Trees removed during construction replaced with a variety of drought-and-pest-resistant, mostly native species. Gravel driveway and bark and wood chip mulch used extensively.

South Roof: and Side: Looking at the south roof, you see the 360 ft2 PV system (36 Evergreen PV Modules) on the left, and the two solar thermal collectors (4 ft x 8 ft) with the small PV array on the right. You can see the inlet and outlet for the heat exchanger on the south cantilevered overhang as well (away from furnace exhaust, dryer exhaust, and vacuum exhaust on the north). Also see 200 ft2 south window and greenhouse.

Water: Drain tiles used around house eliminate basement moisture and flooding. Topography around house drains water away from house. Roof gutters go into drains and into cisterns for collection and use. Waterproof barriers used at roof edges to eliminate damage from ice dams. Water softener uses KCl salts instead of NaCl (K is a plant fertilizer). Water softener tanks insulated to reduce condensation.

Integration with the Site: House is oriented 10 degrees E of south to enhance early morning solar gains in winter. Roof angle (= 39 degrees which is the latitude) is good for both solar hot water and PV. Visual disturbance minimized through berming. Placement of porch and deck on east side provides privacy from road. Aesthetic views from all windows. Flat driveway and minimal distance reduces snow shoveling. Clothesline is convenient to washer location. Garden shed located next to garden. GH path to garden.

Recycling: Entry closet and carport provides space for holding materials (plastic, glass, metal, paper and batteries) to be recycled. Kitchen waste is recycled to the garden, or to a garbage can in winter and then to the garden in spring. Weeds are composted. Leaves used as mulch.

Lessons Learned:
1. During some summers, the cold storage area in the basement could use a dehumidifier (since bought).
2. Radiant heating has a significant time delay and doesn't work quickly through wooden floors
3. Attic air leakage is a significant heat loss (However, Tyvek in attic seems to work).
4. Do your outdoor construction projects before finishing landscaping.(cisterns)
5. Find a good solar contractor who installs and maintains solar hot water systems.

Future Additions: Note: these were all done over the winter of 2007

The house was designed as a low-energy use house. However, it appears to be possible to modify it to be a 100% solar zero net energy house with the following modifications (offsetting 200 gal. of oil).
1. Construction of **movable insulation** for most windows (save 50 to 70 gal oil per year)..
2. Adding more **insulation** to exposed basement walls (save 25 gal oil per year).
3. Adding an **electric switch/electric heating** to the solar hot water tank (to use PV electricity – saves 20 gal oil per year).
4. Adding an additional 1.3 **kW of PV** to the south roof. (generates 2000 kWh or the equivalent of 66 gallons of oil). There is easily enough room for this amount on the roof.
5. Adding R-19 to the existing R-40 in the attic. (save 25 gal oil per year)

Evaluation of Design and Performance

1. Use of fiberglass insulation works well only if you do a great deal of sealing which I did. You might be better off using icynene or high density cellulose which will seal much better. Many building experts now agree with this statement.
2. Get as much effective insulation as you can get in walls and roof since it reduces the size of your heating system. In fact, my maximum power load (at 0 F outside) is around 12,000 Btu/hr. However, it is presently impossible to get a properly sized furnace or boiler; they are all too large. If you have a super-insulated solar house, you might want to consider several small distributed power sources rather than a central heating system.
3. Heating a radiant floor slab takes many hours so it is not a great choice for a passive solar house where you really need quick, intermittent heating. Trying to heat radiantly through a wood floor (the upstairs bathroom) is virtually impossible (it again takes hours to transfer the heat). Either use thin lightweight slab floors (which will heat up quickly) or use European thin large area radiators to get the heat transfer more quickly. Radiant heating works well in Scandinavia where there is no sun and very cold winters so it can be left on all the time.
4. Because the fiberglass insulation installed in the attic is not well sealed, there is a lot of warm air loss through the attic. Covering and sealing the insulation with Tyvek has worked well for me. Tyvek allows vapor to escape so you don't have to worry about condensation (you should check it occasionally to make sure). But you must be able to make a good seal with Tyvek tape for this to be effective.
5. Movable insulation really reduces temperature drops at night over the cold weather. I am using window panels based on 1" thick isocyanuate covered with bubble wrap and then with fabric for some windows. I am also using a double layer of reflectrix insulation (2 layers of aluminum foil covering bubble wrap) for windows that already have a shade or curtain. I plan on using cellular shades on two upstairs windows. It takes 5-10 minutes per day to put them in and take them out, but the reduction in heat loss and improved comfort are significant and make it worth it.
6. Entryways to the attic can leak a lot of warm air. I made a cover consisting of plywood with 2 inches of foam board on top, and weather stripping around the edge. Hooks hold it down tight to provide a good seal.
7. All my windows are the same, R=3.3, low-e, gas-filled. They are good, but if I had to do it over again, I think I would choose different windows for different orientations of the walls. (Solar reflecting windows on the east and west side to reduce unwanted solar gain; higher R windows on the north side to reduce heat loss in winter).
8. Berming is highly effective in keeping the 1st floor (basement) cool in summer.
9. I have found that the solar clothes dryer (aka clothes line) works well all year long if you watch your weather forecasts. Sometimes, the electric dryer is used to bring almost dry clothes to a completely dry state.
10. An air-to-air heat exchanger or venting with a bathroom fan and adjustable air inlets in other parts of the house are necessary if you make an air tight house.
11. I have eliminated my oil-fired indirect hot water tank completely by just connecting the 80 gallon solar storage tank to electricity. The electrical connection can be put on a timer or a switch to minimize electrical backup energy.
12. The cheapest approach to heating a house might be to design an all electric super-insulated house with all the above solar features so that only a small amount of excess PV electricity from net metering is needed during the winter heating season. Eliminating the cost of the boiler, oil tank, and more complicated heat distribution system would pay for the additional PV. Besides the price of oil and propane are equal to electricity at this point in time (but electricity prices will be rising quickly).