CASE 1. ACTIVE SOLAR RETROFIT

A. The Client's Request

Kelle Kersten and Bob Flatley are forming an intentional community near State College, PA (http://ahimsavillage.org/index.htm). They wanted to retrofit the old farmhouse with active solar heating, the impetus coming from sixty or so hot water collectors their neighbor Robert Forsberg had salvaged from the roof of the manufacturing plant outside Philadelphia.[1] They retained us to analyze and propose some alternatives and give them a cost estimate. After speaking with them initially, we added three additional criteria:

- Operation to be simple, transparent and largely automatic;
- Installation within skills and capabilities of couple and friends who would help; and
- Low-tech, low cost (below $4,000), easily maintained and repaired.

Right: Picture 1. Site meeting with Frank Higdon, Bob Flatley and Kelle Kersten.

B. General Considerations and Parameters

Early on we encouraged the couple to consider how the following three principles could be applied to their farmhouse:

First, REDUCE USE. Can you turn down thermostats (or install a programmable thermostat), wear warmer clothes indoors (e.g., thermals), replace old appliances with energy-savings models, close off areas not in regular use? Reducing use often represents the easiest and cheapest things to do.

Second, REDUCE HEAT LOSS. Can you improve house insulation? Reduce leaks (weatherize windows and doors)? Replace old doors and windows if necessary?

Third, IMPROVE SOLAR INSOLATION. Can you capture and use incoming solar radiation, including reducing shade factor from trees? Solar comes last. No sense adding solar collectors when the heat collected goes back out through the walls, leaky windows and drafty doors.

Even a well-designed passive solar house might supply only half of its winter heat load from the sun (Kachadorian).[2] In retrofitting an older house, we learn to temper our expectations. Active solar heating contributes much less to overall heat requirements than we might hope. Older homes, often poorly designed and sited for solar, are challenging to make more weather-tight and solar-friendly beyond a modestly improved level.

To get a sense of this, compare for example the BTU content of home heating oil with wood and solar:

- Home heating fuel oil produces 140,000 BTU/gal. If furnace burns at 78% efficiency, you get only 109,200 BTU worth of heat/gal.[3]
- 1 cord of wood produces 17,000,000 BTU. If you have a stove that is 85% efficient, you get only 14,500,000 BTU.[4]
- For solar panels, the rule of thumb in the northeast is that 1 sq.ft. of collector area displaces 1 gallon of fuel oil <u>during the entire heating season</u>.

Thus, using two retrofitted solar panels (48 sq.ft.) will offset only 48 gals of fuel oil, the equivalent of 0.36 cords of wood or 1535 kwh (at 0.08/kwh this is equivalent to $123 worth of electricity).[5] That's something, but not a lot. At $2.50/gal for fuel oil, 48 gallons comes to $120, very close to the cost of the displaced electricity, so fuel oil savings of solar trade off equally with electricity savings at current prices.

C. <u>The Ahimsa Village Site: Specific Considerations</u>

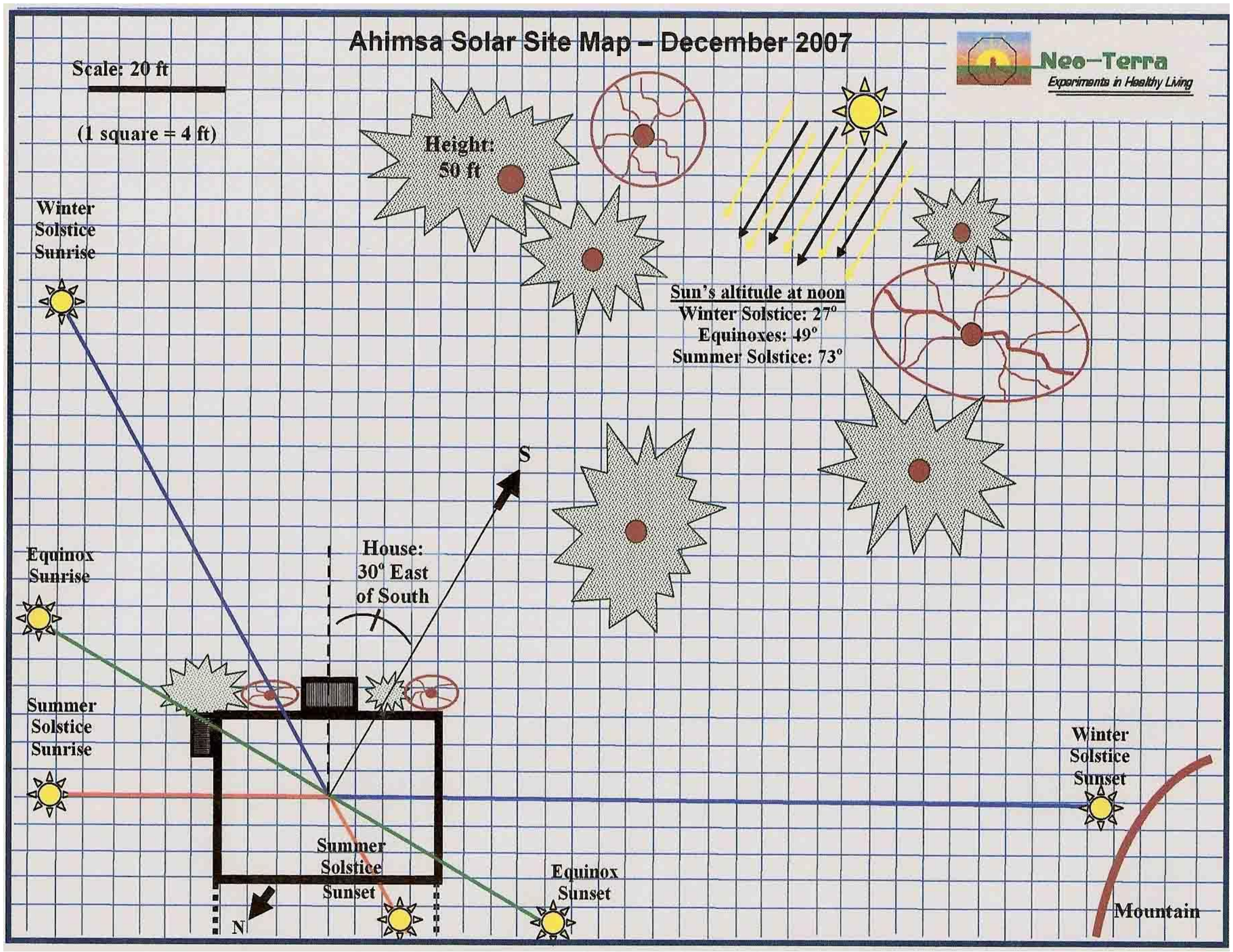
To assess the farmhouse's solar potential we prepared a site map showing key features (see Ahimsa Solar Site Map below).

For solar calculations, we placed the house at 41 deg latitude, fortuitously the latitude of the Williamsport, PA solar reporting station (http://rredc.nrel.gov/solar/pubs/redbook/PDFs/PA.PDF). We used this latitude in the following rules of thumb to gauge potential performance for Ahimsa's hot water solar system:

<u>Ideal winter collector angle</u> for winter space heating is latitude + 15 deg or a 56 deg tilt angle. Plus or minus 15 degrees has almost no effect on performance (range 41 – 71 deg). While the farmhouse roof, at 30 degrees (measured from a photograph), is less than the low end of this range, overall winter performance will not be affected, as better performance in March and April will offset poorer performance during December and January.

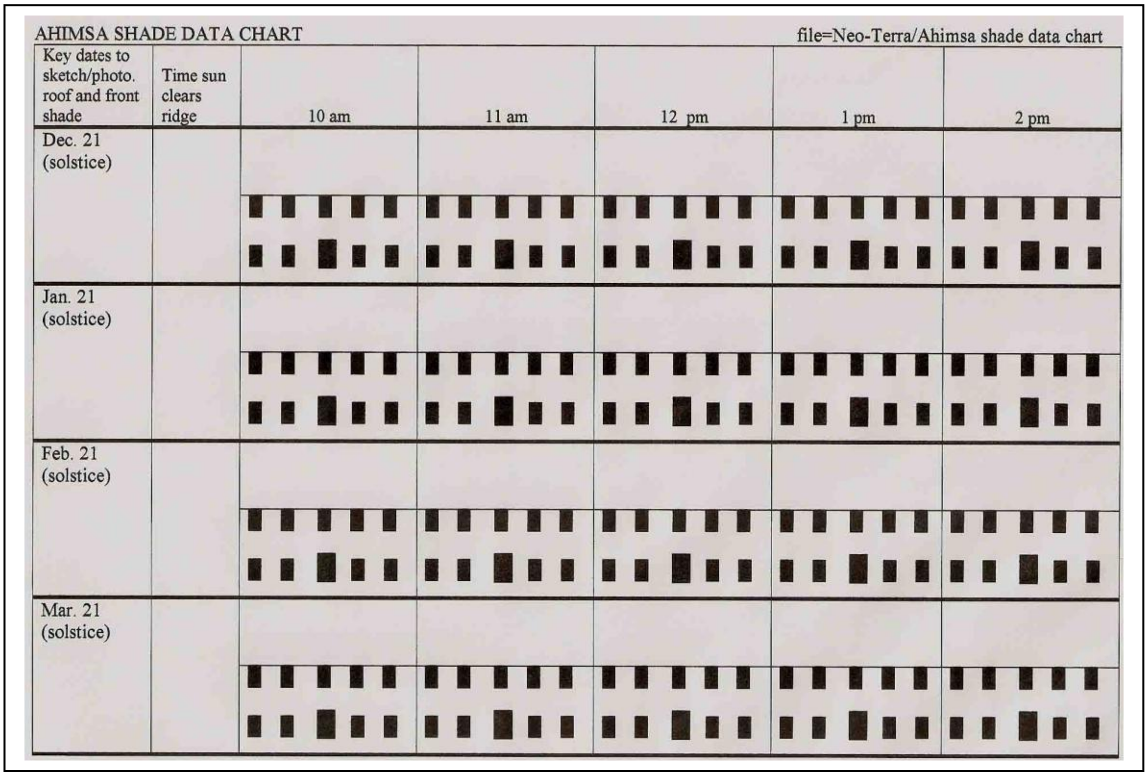
<u>Ideal summer collector angle</u> for domestic hot water is latitude – 10 deg or 31 deg tilt angle. The farmhouse 30 deg roof is on the money.

Since there is more heat to collect in the summer than the winter, and given that savings in fuel oil and electricity are equivalent, we suggested that Ahimsa focus on collecting summer over winter heat.[6] Even more strongly, as Bob and Kelle burn wood in the winter, at far less cost than oil, we suggested they lean to offsetting more expensive electricity use at any time of the year. Following this logic, we suggested that the solar panels should be used not for space heating, but to heat cold water coming from the well prior to entering their hot water tank.



Above: Ahimsa Solar Site Map. House is the box in the lower left-hand corner. Conifers and evergreen trees are green-filled angular figures, while deciduous trees, leafless in winter, are depicted as brown ovals with a network of brown branches stemming from the round central trunk.

Ideal roof orientation is south. The house roof orientation, corrected for compass declination,[7] is actually 30 deg east of south. Not good. A variation of 20 degrees east or west will not appreciably affect performance, but the farmhouse is off by 30 degrees. Since the western quadrant of the site is heavily shaded, this reduces further the maximal sunlight which the roof panels can collect, especially in the fall, winter and spring. From the site map we determined that most of the heat collected will occur during the morning under present conditions. We explained to Kelle and Bob how to collect solar shading data for the roof to help assess just how much solar insolation we might expect to collect (see Shade Data Chart below). They could then determine whether installing three or four rather than two collectors would be required to realize appreciable solar collection in the winter, and independence from using electricity to heat the hot water tank in the summer. “If,” we said, “you decide to install two collectors to start, leave plumbing stubs on the ends so you can add one or two more collectors later.”

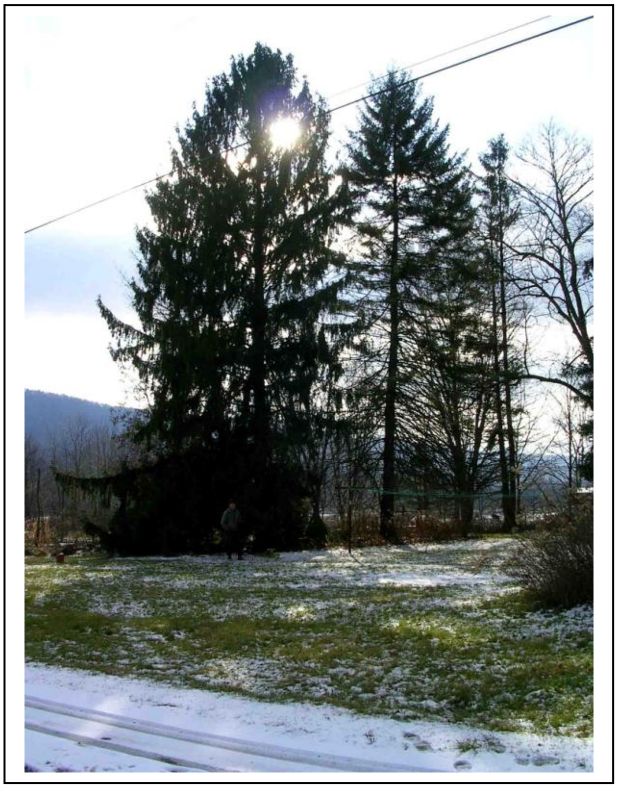


AHIMSA SHADE DATA CHART file=Neo-Terra/Ahimsa shade data chart

Key dates to sketch/photo. roof and front shade	Time sun clears ridge	10 am	11 am	12 pm	1 pm	2 pm
Dec. 21 (solstice)						
Jan. 21 (solstice)						
Feb. 21 (solstice)						
Mar. 21 (solstice)						

<u>Above</u>: Ahimsa shade data chart shows the 2D planar face of the front of the house at key solar-access times during the day during the winter months. Kelle and Bob were asked to sketch the shade falling on the house at each of these times for each of these four days to get a sense of how much sun was available to them in winter.

<u>Right: Picture 2</u>. Farmhouse showing shadow from tall conifers. The Ahimsa shade data chart depicts this front face to permit the shaded areas to be sketched at key solar access times. This photo reveals significant winter-time shade on both the vertical face of the house and the roof.



Left: Picture 3. Tall conifers shading farmhouse in winter. Note the adult standing in front of the base of the tree to get a sense of the scale.

Vertical panels, attached to the front of the house, are 90% as effective as those at 30 deg for the Nov-Apr 30 winter space heating interval, so this is a possibility. These have the advantage of not collecting snow in the winter. On the other hand, hanging lower on the house, these may be partially shaded by the tall conifers in winter. A vertical collector of 24 sq.ft. displaces 0.13 cords of wood if the wood is burned in a stove getting 85% efficiency (or ½ of this under conditions of half exposure to sun). These collectors could be connected to the cast iron radiators Bob had salvaged, preferably in separate circuits with a small AC pump (or DC pump with PV panel) if a convective thermosiphon flow could not be made to occur. You can use the same retrofitted collectors as for the roof installation. A rule of thumb for collectors, vertical or roof, is not to expect appreciable heat 1 month either side of the winter solstice; there are simply too many overcast days.

Savings and Calculating Payback. One cannot use all the heat energy that falls on your collectors for heating domestic hot water. In the winter time, you will lose some solar insolation during cold but sunny days on a 30 deg roof from any snow cover which will not slide off easily. Waxing the surface prior to the snow season may help (like waxing skis). During the summer, heat transfer declines as the temperature in the storage tank approaches the temperature of the collector.

From a savings point of view, electricity saved cannot exceed the energy consumed by your hot water heater without collectors. You will save your maximal amount in the summer if you can turn off your hot water heater – say May through September. By comparing your electrical use for a given summer month, say for July, before and after solar, you can estimate your summer savings and calculate your payback. In our own house, we saved about 270 kwh/month over five months for a total savings of $108 with electricity at $0.08/kwh.

Winter savings can be estimated by this same method of comparing winter electricity consumption with solar to winter electricity consumption without solar. If your solar exposure does not suffer from shading, you can use the $123 figure arrived at in section B above.

Payback calculations tell us how many years it would take to pay for an investment in solar with the savings we get by using solar. With winter savings from above of $123 and summer savings of $108, we could pay for a $4,000 system out of savings in $4,000/$231 or just over 17 years. If we assume a 70% increase in power rates in 2010 due to deregulation, we could pay back the same investment in just over 11 years.

Payback periods must consider the physical life of the solar system, and maintenance costs. For example, the circulating pump might last five years. These costs will increase the payback period.

<u>Maximum solar insolation</u>. With a 30 deg roof, the sun is orthogonal to collectors laid flat on the roof around April 19 and August 23. These will be the times when the heat collected will peak.

D. <u>Big Picture Work Program</u>

Installing an active solar system to is one element of the larger goal to improve the energy efficiency of the old farmhouse. Consider the following tasks for your Master Checklist, arranged in the following temporal sequence.

TASK 1. Improve ability of windows on east and south sides to take in sunlight in the winter. Take down the hemlock hedgerow on SE corner and the tall pine on SW corner. Clean window panes.

TASK 2. Even though you do not burn oil in the winter, you can still use the furnace fan on manual for short intervals (~15 minutes to conserve power) to redistribute heat from the wood burning stove to other parts of the house. You complained about rooms upstairs being cold, and this simple expedient may improve conditions. Do the furnace vents extend to the upstairs area? If not, consider cutting vents in the ceiling above the wood stove to allow warm stove air to rise upward and cool air to descend the open staircase.

TASK 3. Examine your roofing. Does it have 8-10 years of life? It will be a hassle to take the collectors off the roof to replace your roofing. Replace if necessary, at least on the collector side.

TASK 4. Collect data on seasonal shading of roof, using Shade Data Chart, and decide where to put collectors on the roof. Our guess now is upper right corner. Assess whether taking down one or more of the tall pine trees is warranted. Because of your emotional attachment to these trees, and the expense involved, start with the tree(s) presenting the most shade earliest in the day. Removing these may also improve sunlight to your garden, and this two-fold benefit may make this decision easier to make. From our site and trigonometric calculations, we determined you should clear shade on the east half of the roof from the closest conifer from ~ February 23 to October 18. The roof will experience increasing shade after October 18 through the winter solstice, at which point it reverses. Removing this closest conifer would be a big improvement.

TASK 5. Make decisions on the design of your solar system. The following four are critical:

Decision 1. Stick to using solar roof panels to displace electricity for domestic hot water tank only? Possibility of using vertical panels for winter space heating? Defer vertical panels until later?

Decision 2. How many collectors? We recommend two to start on roof with stubs so that you can add a third or fourth following assessment after first year of operation.

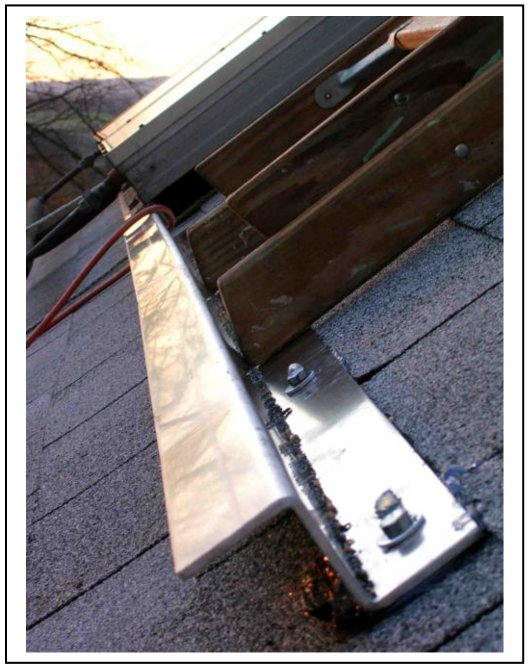
Decision 3. Which specific combination of components best meets your circumstances? For example, 120 volt AC for circulating pump or DC pump powered by PV panel? Pressurized glycol versus drainback system?

Decision 4. Have all costs been considered? Are these reasonable? Can any be reduced?

TASK 6. Install solar system. Following is an abbreviated work program:

1. Retrofit two collectors.
2. Locate and install panels on roof. Locate panels on upper right hand section of roof. Use roof brackets to hold panels off roof. These enable easy removal if repairs prove necessary. Consider also increasing angle of collectors a small amount – say to 38-40 degrees. Leave yourself room above and to the roof edge to work (2'). When you install the copper tubing, leave stubs so you can connect additional panels if desirable.

Right: Picture 4. Detail showing roof bracket bolted to roof rafters.



3. Run copper tubing and thermistor wire down to cellar.
4. Install plumbing in cellar.
5. Leak test entire system using air pressure.
6. Flush entire system, preferably with hot water, to remove residue on inside of (copper) tubing.
7. Wire up pump, controller, new hot water heater.

8. Fill system with water to test pump and controller. Drain immediately so it doesn't freeze if you do this work in the winter.
9. If using a pressurized system, load system with proper mix of propylene glycol. Test pump and controller.
10. Turn on system, collect data, become familiar with operation.

There are many other details. Tom Lane has written a marvelous book, Solar Hot Water Systems: Lessons Learned 1977 to Today, 2004. Available through Real Goods and from the author at www.ecs-solar.com . The detail is overwhelming and can intimidate novices, and we will be happy to guide you through this once you have made the above decisions.

TASK 7. Improve house insulation. Here, the roof is more important than the walls. Is your attic floor insulated? Consider insulating either the joist cavities in the attic floor or the roof deck. Glass wool is a poor insulator at temperature extremes, traps moisture, and poses health hazards. You could spray in foam insulation (e.g., icynene or urethane), either through holes drilled through the floorboards, or directly on the undersurface of the roof deck. Icynene burns only if there is a flame source on it. Check with a contractor whether it is necessary, or at least smart, to replace old wiring in the ceiling and enclose new wiring in metal conduit to minimize fire potential. If you decide to spray the roof deck, spray after you install the collectors, as it will be hard to locate the roof rafters after the foam is in place. We have used both icynene and urethane at our place, and can share our experience and recommend local contractors.

TASK 8. Rethink and adjust your behavioral patterns. The amount of heat you collect depends on the temperature differential across your heat exchanger. Thus, a collector that is at 140 deg F will not transfer any more heat to a storage tank that is also at 140 deg F. To improve your harvesting of solar energy, schedule heavy use of hot water when the storage tank is hot – probably early to mid afternoon (e.g., laundry, showers). This allows the tank to recharge before the sun fades.

E. What Did the Client Do?

Our client did not move ahead to install a hot water solar system. Talking to them, our analysis demonstrated to the client that the system was more complicated and expensive than they had envisioned. For them, inexpensive retrofitted solar panels were the initial attraction, and they did not realize that the panels would be a minor part of the system and cost. Moreover, they realized that they could only get late spring and summer hot water.

We came back with suggestions for building a simple batch hot water heater for use during the non-winter months. This would feed into their existing hot water tank, and require only minimal plumbing and no electronic controllers. In the winter, they would drain it. This would be a nice project for the Ahimsa Village community members.

For more information, we suggested searching under "batch heaters." The following two sites looked good to us: http://www.dulley.com/docs/f695.htm and http://www.builditsolar.com/Projects/WaterHeating/water_heating.htm#Batch , especially the second entry with the warning, "some things NOT to do on a batch heater."

ENDNOTES

[1] If you are interested in getting some of these, contact Forsberg at fors1@mac.com . These require retrofitting, which Robert has done as demand warrants. The company making these went out of business when the Carter tax credits lapsed under Reagan in the early ‘80s. We have four on our roof, and they work quite well.

[2] We have come across two approaches for passive house designs that promise delivery of 100% of winter heat requirements. You may wish to review these when you consider adding structures at Ahimsa. These go far beyond conventional passive solar house. One of these approaches is represented by the Shrewsbury House, described by William Shurcliff in his *Super Solar Houses: Saunders's 100% Solar*, *Low-Cost Designs*. Brick House Publishing Co. 34 Essex St, Andover, MA 01810. Available in the Architecture library at Penn State. TH7414.S49 1983. The other approach, called Passive Annual Heat Storage (PAHS), stores heat during the summer for release during the winter. See http://www.earthshelters.com/ for PAHS and http://greenershelter.org/TokyoPaper.pdf and http://greenershelter.org/ for Annualized Geo Storage. The two concepts are distinguished in the later to sources.

[3] James Kachadorian, *The Passive Solar House*. Chelsea Green Publishing Co. White River Junction, VT, 1997. p. 171.

[4] Kachadorian, p. 171.

[5] Electricity conversion: 3,415 BTU/kwh.

[6] At 30 deg slope, the Nov-Apr insolation is only 64% of May-Oct insolation. Keep in mind that if collector is only open to the sun 1/2 day due to shading, this reduces total insolation by half.

[7] Declination correction calculator website: http://www.ngdc.noaa.gov/seg/geomag/jsp/Declination.jsp