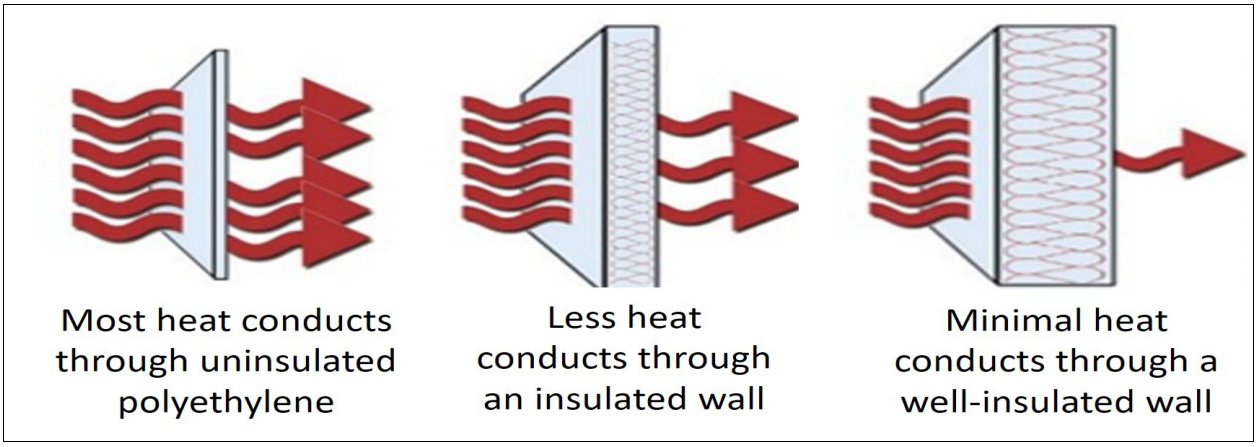
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XIV -- Conserving Energy

The most cost-effective way to reduce energy use of any building is to use energy conserving materials and techniques for its construction and operation. The tighter and well insulated a building is, the less energy is needed for heating and/or cooling the structure and the easier it is to keep the building within a desired temperature range regardless of outdoor temperatures and weather conditions. This is true regardless of the type of energy used, whether natural gas, propane, wood, grid-electric, or [our favorite] - the sun. While that may mean a higher initial cost of materials and labor, in the long run that should mean lower annual energy use and costs (which you cannot control and undoubtedly will go up in future years).

Insulation slows heat flow through surfaces like the walls, floor, roof, and glazing. The measure of how much thermal resistance a material has is called R-value. Higher R-values provide better resistance to heat loss, helping to maintain warmth and reduce heating costs during winter and cooling costs in summer.

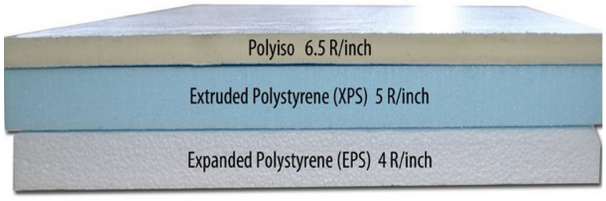


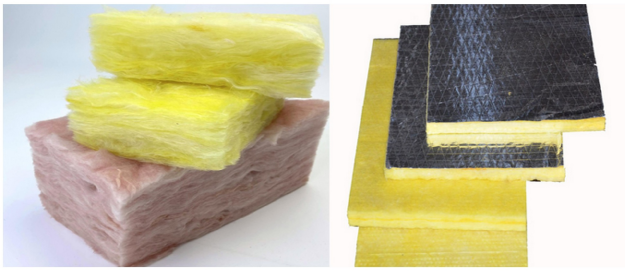
Like all energy efficient structures, PSGs should be tightly-build and be well insulated in order to trap and to conserve heat. The PSG roof, the north, east and west facing walls are well insulated to keep the heat loss to a minimum since these areas receive little or no direct solar radiation in the winter, but certainly can lose a lot of heat if not well insulated. In cold climates, the recommended insulation levels are typically R-49 to R-60 for attics and R-13 to R-21 for exterior walls[1], depending on the specific materials used and local climate conditions (Table XIII.1). We suggest maximum insulation for colder climates (if building in warmer climates, this is an item to save on material costs).

[1]More detailed information about insulation materials and requirements in different climate zones can be found at https://www.insulationrvalues.com/r-value-chart

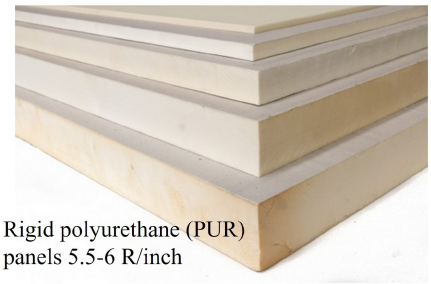
Table XIII-1. R-values for different insulating materials

Material	R-Value Per Inch	R-Value at 3.5" (2×4)	R-Value at 5.5" (2×6)
Closed-Cell Spray Foam	6.0 – 7.0	21 – 24.5	33 – 38.5
Polyisocyanurate (Polyiso)	5.6 – 6.5	19.6 – 22.8	30.8 – 35.8
XPS Rigid Foam	4.5 – 5.0	15.8 – 17.5	24.8 – 27.5
High-Density Fiberglass Batt	3.7 – 4.3	13 – 15	20 – 23.7
Mineral Wool / Rockwool	3.8 – 4.3	13.3 – 15	20.9 –-23.7
EPS Rigid Foam	3.6 – 4.4	12.6 – 15.4	19.8 – 24.2
Dense-Pack Cellulose	3.5 – 3.8	12.3 – 13.3	19.3 – 20.9
Open-Cell Spray Foam	3.5 – 3.8	12.3 – 13.3	19.3 – 20.9
Standard Fiberglass Batt	3.0 – 3.7	11 – 13	19 – 20.4
Loose-Fill Cellulose	3.2 – 3.8	11.2 – 13.3	17.6 – 20.9
Blown-In Fiberglass (Attic)	2.2 – 2.7	7.7 – 9.5	12.1 – 14.9





Fiberglass Batt and rigid aluminum faced fiberglass boards



Rigid polyurethane (PUR) panels 5.5-6 R/inch



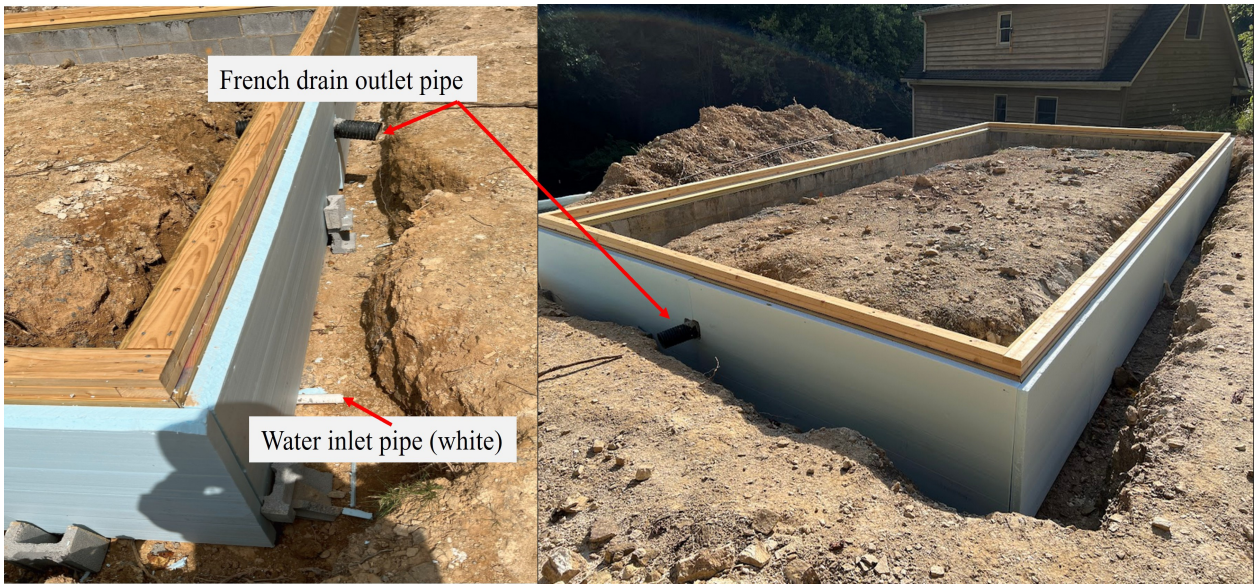
Rock/mineral wool board and faced batt

Suggestions to make your greenhouse more energy efficient

Insulate the foundation

Energy conservation starts at the foundation. In cold climates, it is important to place the footer below the frost line (2 ft or 60 cm, or according to code for your area), whether you use a block wall foundation, continuous concrete wall, or concrete piers. In frost areas, insulate the foundation all the way down to the frost line with 2 in (5cm) thick rigid, closed-cell insulation (EPS [blue board]), either inside or outside of the foundation. When placed inside the foundation, it helps to isolate the dirt from heat loss. We prefer exterior insulation as it adds the mass of the foundation to the PSG's thermal mass. For part of the foundation that is above ground, 2-3 inches of rigid insulation are fastened on the outside and coated to prevent damage. If you plan to have a concrete slab floor in your greenhouse, it is best to place the insulation on the exterior; if you

prefer to have all insulation on the interior side, you should place insulation between the edge of the slab and the foundation to prevent heat loss through thermal bridging.



Two inch blue board insulation installed on the outside of the foundation for the Hawk's Nest SunCatcher.

The junction of the foundation and the wooden sill is, over time, a critical area because of the potential for moisture-buildup that can lead to wood rot. Unless you use alkaline copper quaternary (ACQ) pressure-treated wood for the sill, treat the sills with copper naphthenate[2] as a preservative; it has both antifungal and insecticidal properties.

Tight construction

One of the major critical factors in the construction of a solar greenhouse is that all joining surfaces fit well together to reduce air leaks. It is one of the highest goals builders should work to attain. Tight construction is required to make the convective venting function effectively in a passive solar greenhouse. If the building is too leaky, the natural venting system simply won't work!!!

A construction option which significantly reduces labor cost is building your greenhouse using structural insulated panels (SIPs). SunCatcher has worked with Eco-Panels in Mocksville, NC to produce SunCatcher Eco-Shells for 24x12 ft and 32x16 ft passive solar greenhouses. The Eco-Shell creates a very tight, structurally sound, highly insulated (with sprayed-in fire-retardant

[2]Copper naphthenate is the only non-restricted use wood preservative in widespread use for "heavy duty" commodities such as utility poles, railroad crossties and timbers, pilings and fence posts (US EPA, 2010). The general use classification also allows copper naphthenate to be sold over the counter for consumer uses such as treated wood for fences and decking, and for brush-on application for end cuts and other areas where exposed wood may be subject to insect attack or decay. Products formulated or repackaged from these compounds must be labeled for "Exterior Use Only" (source: https://en.wikipedia.org/wiki/Copper_naphthenate, accessed 23 March 2026).

polyurethane foam) greenhouse which reduces the labor and time needed for construction. The panels have nominal R-values of 26 for a 4.5 in. [11.4 cm] wall, and 40 for a 6.5 in. [16.5 cm] wall/ceiling panel. Spray foam is used between the panels and the sill, and between individual panels. The effectiveness of the insulation used in EcoPanels can be seen in a short video (https://www.youtube.com/watch?v=N5w5coMImHA).

The installation of SIPS panels at the Laurel Ridge SunCatcher was done in one day, and can be seen in this short YouTube video https://www.youtube.com/watch?v=lQDGLMGTliE



EcoPanels kit for the Laurel Ridge SunCatcher: set-up in the factory and assembly on site – Much simpler construction, less room for error and a much tighter, well-insulated structure.



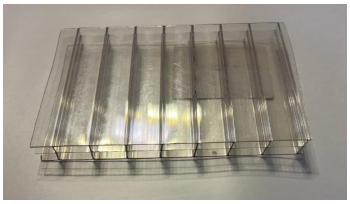
Apply caulking to the sill plate and to the seams between individual SIPS panels to ensure an air tight structure.

During each phase of building, ask yourself where heat loss is likely to occur. Wherever large surfaces are joined (such as the sill plate to the foundation, and the seams between EcoPanels), a double bead of spray foam insulation will help solve the problem. The importance of sealing insulation cannot be over-emphasized, as it can be the difference between the success or failure of your greenhouse (Yanda, p.75).

Insulation and moisture

Humidity levels inside a greenhouse can reach 100% on some days and nights, especially in the winter and in a tightly build and sealed passive solar greenhouse. When selecting wall and ceiling insulation, choose a material with no or minimal moisture absorbing properties. Fiberglass batt insulation is the cheapest option, but it can absorb moisture and lose its insulating properties. Wet insulation can cause mold growing inside the walls, cause rotting of studs etc., reducing the structural integrity and live span of your greenhouse. We therefore advise against using batt insulation in a PSG, choosing rigid EPS, XPS, PUR boards instead. Polyiso is an option in areas with relatively warm winters, but its R-value drops in colder temperatures from R 6-6.5 at 75^0F to R 3.5-4.5 at 25^0F and R 3-4 at 0^0F. It is worth your while to do some research into deciding on the best material for the application and your climate conditions.

Thermal Blanket



We have used triple-wall Polycarbonate glazing (R = 2.5) for a good balance between thermal insulating properties and light transmission. In warmer climates, double-wall Polycarbonate is suitable and provides some cost savings.

Even so, more than 60% of the heat loss of the SunCatcher is through the sloped, south facing glazing from radiation, 2/3 of that occurring at night. It is similar to the frost on your car windshield on a cold night while side windows remain frost free. When it gets very cold, the skies are usually clear of clouds since the air cannot hold much moisture below freezing. Objects are constantly radiating heat and receiving heat radiation from everything a particular object can "see". So, the side windows of a car can see the house, woods and the other surroundings which are at about the same temperature as the side windows. The windshield, on the other hand, is seeing deep space, which is several hundreds of degrees colder than the windshield, so the windshield gives up a lot more heat and is colder than the surroundings. The colder windshield now provides a much colder surface for the little bit of moisture in the air to condense on it and form frost!



The sloping glazing of a PSG is like the windshield of your car – if the interior of the greenhouse and especially the thermal mass can "see" deep (very cold) space, it cools much quicker and to a

lower temperature than its surroundings! Covering the glazing surface of a PSG when it is not collecting solar energy reduces radiant heat loss similar to clouds keeping nighttime temperatures slightly higher on cold winter days compared to cloudless days and nights. In colder climates, especially on cold clear nights, the use of a "thermal blanket" covering the glazing is recommended to cut nighttime heat loss by as much as 50%, thereby increasing the performance and efficiency of your PSG.

The light-colored blanket or curtain can be as simple as a silver tarp as in the photo (Parkway students taking down the curtain in the morning after sunrise). It does not have to be tight fitting or snug, and does not need to be a [heavy] blanket. It can be applied either over the glazing on the outside (but subject to flapping in strong winds or blowing off altogether), or attached to the rafters on the inside as in the photo above. It primarily needs to prevent the plants and thermal mass from "seeing" the clear winter night sky, similar to the silver reflecting shields people put in their car windshields in the summer except in reverse. The effectiveness of a curtain to maintain interior temperature can be seen in Table XIII.2



Table XIII.2. The effect of a thermal blanket on interior temperatures of the Parkway School, winter of 2002-03. Temperatures are averages for each period.

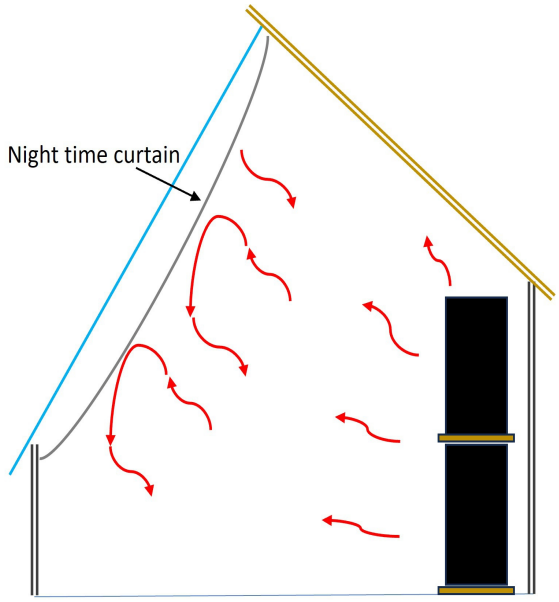
Period	Dates	Ambient ^{0}F	Interior ^{0}F	Thermal mass ^{0}F	% Light*
I.	Dec 6-17	33.5	59.1	62.0	92
II.	Dec 17-Jan 9	34.6	58.9	63.6	74
III.	Jan 10 - 20	21.9	63.7	69.3	100
IV.**	Jan 20-30	25.4	63.7	67.6	84

* % Sunlight entering the greenhouse relative to that in period III (Jan 10-20).
** Silver tarp used at night during this period.

Two things to note in the table above:

1. On average when it gets colder outside, it gets warmer inside the SunCatcher!
2. The greenhouse maintained its interior temperature at 63.7°F in periods III and IV even though period III was 3.5 ^{0}F colder and there was 16% less solar energy entering the SunCatcher in period IV resulting in less energy being stored in the thermal mass!

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At night, when the interior temperature of the SunCatcher drops below the temperature of the thermal mass, the latter will radiate extra heat energy into the interior to help keep it warm while dropping in temperature. Also note that the nighttime reflective curtain reflects heat back into the SunCatcher.

During the cold winter months closing the curtain at or before sundown will help maintain the temperature inside the PSG. In moderate climates the curtain is probably not necessary but in very cold climates it is required. Of course, the curtain will have to be removed or rolled up the next morning if the weather forecast calls for a clear, sunny day. Opening and closing the curtain is extra work, but it is worth it in cold climates.

We also recommend the use of a light-colored shade cloth in mid Spring and mid Fall to reduce overheating of the greenhouse.

References

U.S. Environmental Protection Agency. 2010. Summary of Product Chemistry, Environmental Fate, and Ecotoxicity Data for the Copper Naphthenate and Zinc Naphthenate Salts Registration Review Decision Document. July 26, 2010.

Further Suggested Readings

Schiller & Plinke, Chapter 6.