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III - How Passive Solar Greenhouses Manage Light, Heat, and Climate

Modern greenhouses are often built to grow crops year-round, regardless of weather or seasons. However, many rely on large amounts of fossil energy to control temperature, humidity, and lighting, especially during the winter months. While this can work economically in the short term when fuel is cheap, it's not sustainable in the long term. The SunCatcher team set out to create a better option: a year-round greenhouse that works with nature, not against it. This chapter explains how SunCatcher passive solar greenhouses (PSGs) use sunlight and smart design instead of constant energy input.

Working with nature

At their core, PSGs use the sun to manage heating, cooling, and ventilation. They operate with little to no fossil energy, can offer a CO_2-rich environment for plant growth, and can produce food year-round in most climates with adequate sunlight. The SunCatcher design takes full advantage of the sun's changing angle during the day and over the seasons, bringing in maximum light and heat in winter while minimizing overheating in summer. In cold months, the PSG acts like a natural thermostat. It captures solar heat and uses it to warm the space while also venting stale air and drawing in fresh air. In warmer months, the design allows mostly diffuse light to enter, reducing heat gain but still supporting photosynthesis. Shade cloths can help fine-tune solar input while reflective night curtains can reduce night-time heat loss.

The leaky bucket analogy

To help you understand how a PSG works in the winter, lets look at a standard greenhouse as a bucket with holes in it (Figure III.1). If you're trying to fill that bucket with water (heat), but it leaks, you will need to constantly add more water to keep it full. That's how conventional greenhouses operate, they lose heat rapidly, so you have to keep replacing it. Heating and cooling a conventional greenhouse can be like trying to fill a leaky bucket with water!

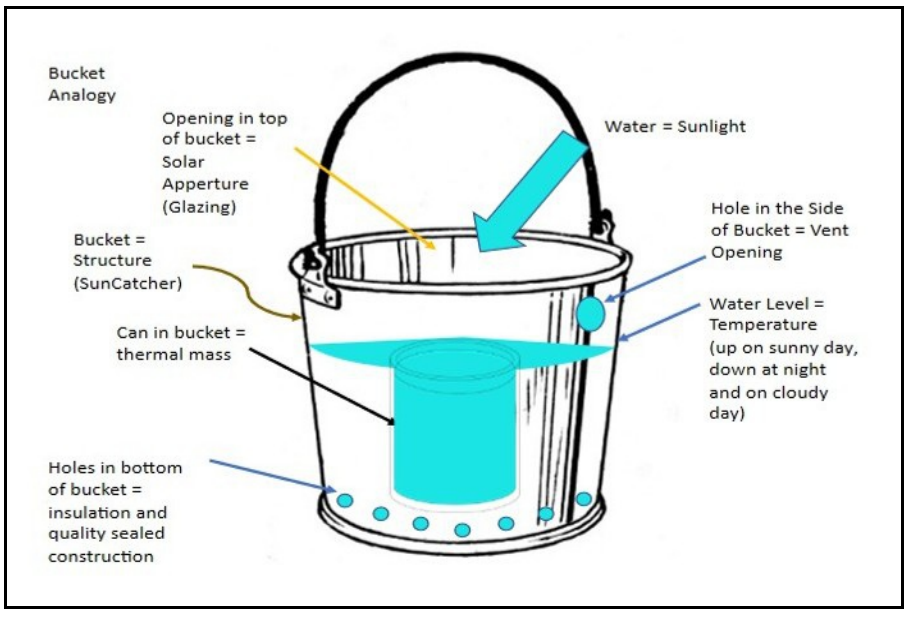


Figure III.1 A greenhouse as a leaky bucket.

The energy (water in our analogy) entering a greenhouse as sunlight plus all other external fossil energy used to

heat the greenhouse is the same amount of energy that eventually leaves the greenhouse, i.e. heat (water) loss. However, the longer the energy entering any structure stays in the structure before leaking out, the warmer the structure becomes (higher water level in our analogy). Moreover, a larger bucket opening takes in more water (sunlight or solar energy) if needed due to such things as reduced water flow rates (sunlight intensity).
In PSG design, we reduce heat loss (plug the leaks) and improve heat capture which are

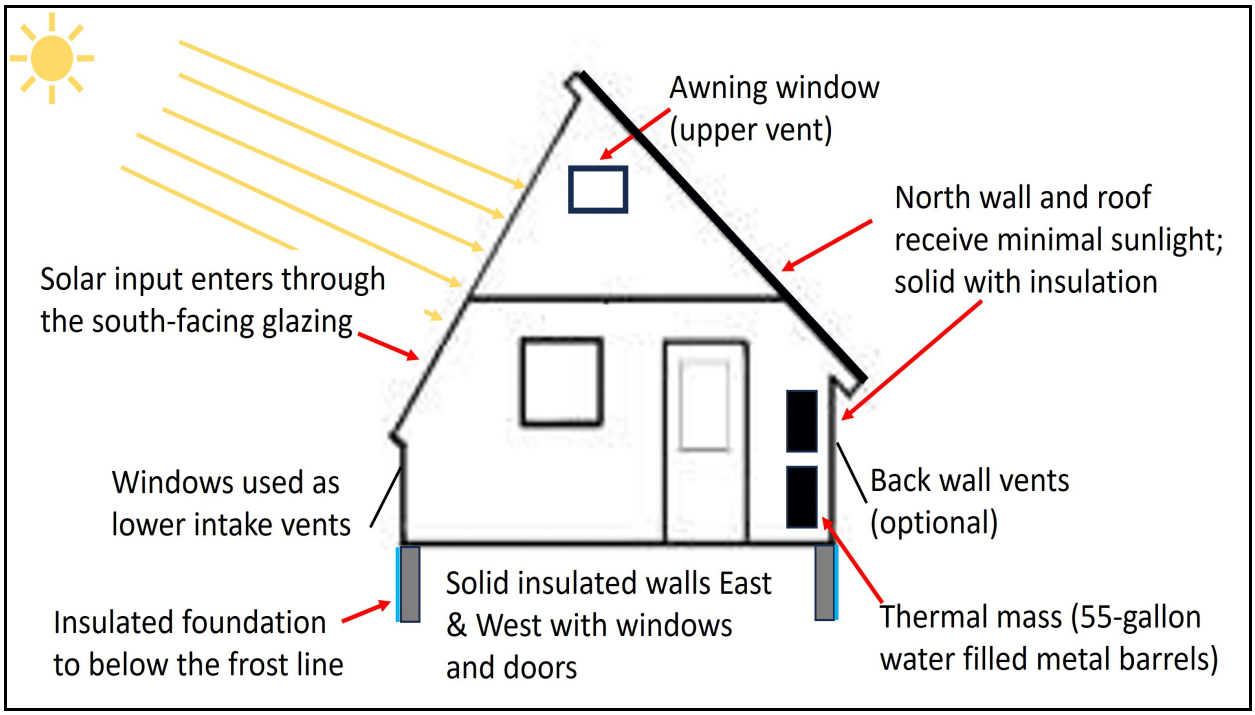


Figure III.2 How a SunCatcher PSG fixed the leaks in the bucket.

accomplished by:

1. Tight construction and good insulation – PSGs are built with insulated walls (especially on the north, east, and west sides that don't get direct winter sun) and roof sections that face away from the sun. Unlike greenhouses made entirely of glass or plastic, SunCatcher PSGs reduce heat loss through smart material use and tight construction. Simply insulating the non-sun-facing parts of the structure and caulking the seams between SIPS wall panels (if used) can increase energy efficiency by 60-70%.





2. Solar Aperture – The size and angle of the south-facing glazing determine how much solar energy enters the greenhouse. With glazing at a 60° angle, the sun hits the glazing nearly head-on in winter during the day, maximizing heat gain. At night, heat escapes easily through the glazing, so a reflective, night-time insulation curtain can help trap more of that warmth.



3. Thermal mass, (such as water barrels, masonry, moist soil or concrete) absorbs heat during the day and slowly release it overnight when needed. This keeps the interior from freezing even when outdoor temperatures drop.

The result? A well-sealed shell that holds on to heat much longer, just like a bucket with less leaks.

What you can expect – two examples of thermal performance

Figure III.3 on the next page shows the year-round performance of the 16x32 ft Carolina Mountain SunCatcher. The data were collected *before* adding thermal mass or automated vents. You can see the interior (blue) and ambient (orange) temperatures over winter, spring, and summer. During the Winter, interior temperatures were significantly warmer than outside (=the difference between the orange and blue lines - Delta-T). In Spring, the gap gradually narrows as outdoor temperatures rise. In the Summer, the interior and outdoor temperatures track closely, thanks to convective ventilation and direct sunlight reflected by the 60^0 angled, south-facing glazing. Unlike conventional greenhouses, the PSG did *not* overheat. The Fall would be a mirror image of Spring, with the gap gradually widening as outdoor temperatures fall. Note that even without fans or thermal mass, the greenhouse rarely exceeded 100°F, unlike conventional greenhouses that can soar to 140^0F (60^0C).

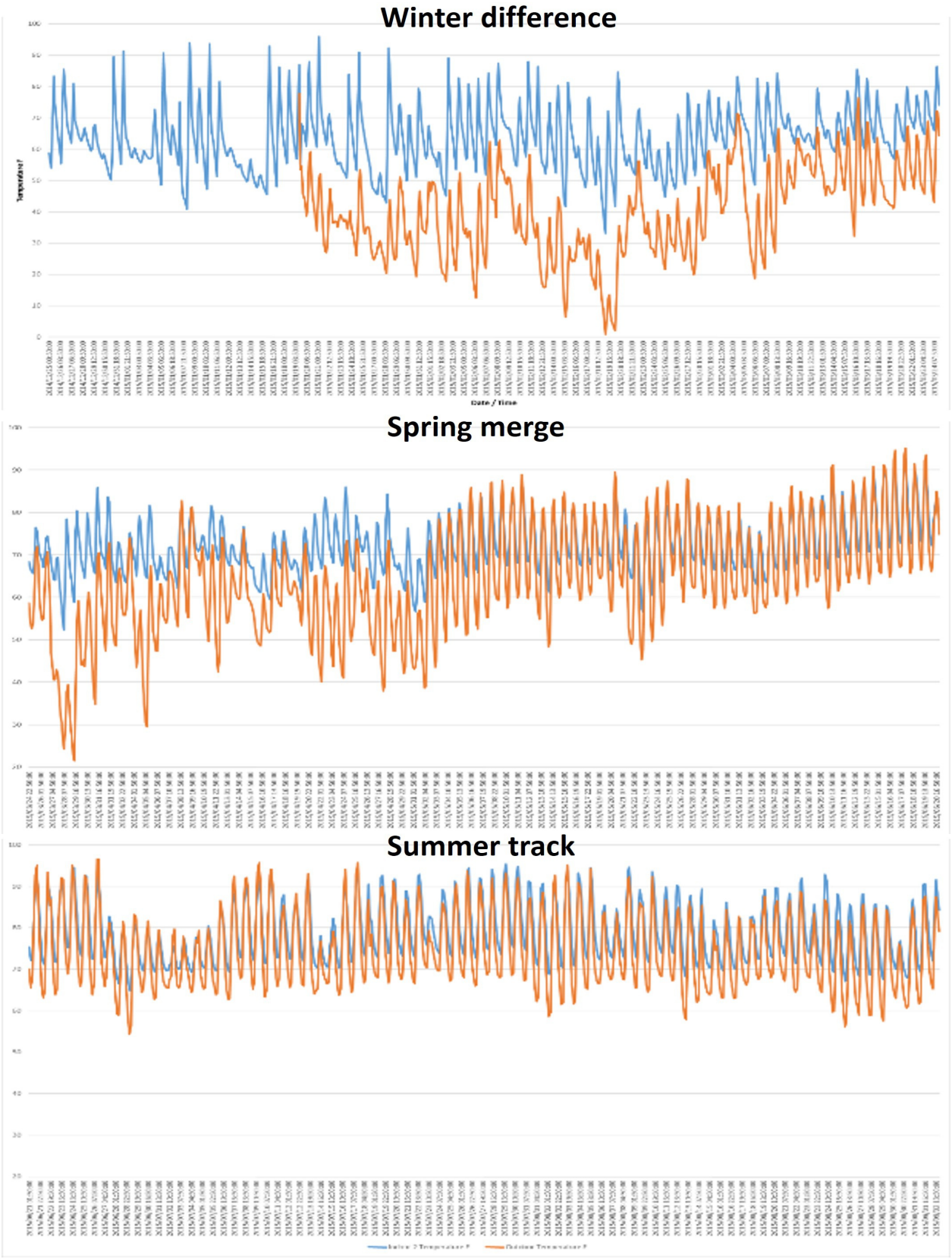


Figure III.3. Seasonal temperature performance of the Carolina Mountain SunCatcher; blue line = interior; orange line=ambient.

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Enhancing Thermal Performance

By adding thermal mass, light-colored shade cloths, reflective curtains, and automated vents, you can keep day- and night-time temperatures within the optimal range for your crops. These additions can make SunCatchers even more effective as shown in the data from Parkway Elementary and Laurel Ridge PSGs.

1. Parkway Elementary SunCatcher

Built in 2002, the Parkway SunCatcher in Deep Gap, NC, was our first prototype. Using a mathematical model developed by Carroll, we predicted that (1) No fossil fuel heating would be required in winter, and (2) the greenhouse would not overheat in summer. Data from its first winter confirmed the first prediction. The average indoor temperature was about 60°F, more than 25°F warmer than the outdoor (ambient) temperature. The coldest inside temperature recorded was 48°F, during a period of five overcast days when the thermal mass couldn't recharge. Use of a night-time curtain in late January showed that even with slightly warmer outdoor temperatures and less thermal mass charge, the curtain helped maintain stable indoor conditions.

Table III.1. Winter Thermal Performance - Parkway PSG.

Period	Dates	Ambient Avg (°F)	Interior Avg (°F)	Thermal Mass (°F)	Light %*
I	12/6-12/17	33.5	59.1	62.0	92%
II	12/17-1/9	34.6	58.9	63.6	74%
III	1/10-1/20	21.9	63.7	69.3	100%
IV**	1/20-1/30	25.4	63.7	67.6	84%

* Sunlight entering the greenhouse as a percent of the amount in Period III.
** Curtain used at night during this period.

Interestingly, the SunCatcher often got warmer inside when it was colder outside. Why? Because colder air holds less moisture, resulting in fewer clouds providing more sun and solar energy to the SunCatcher.

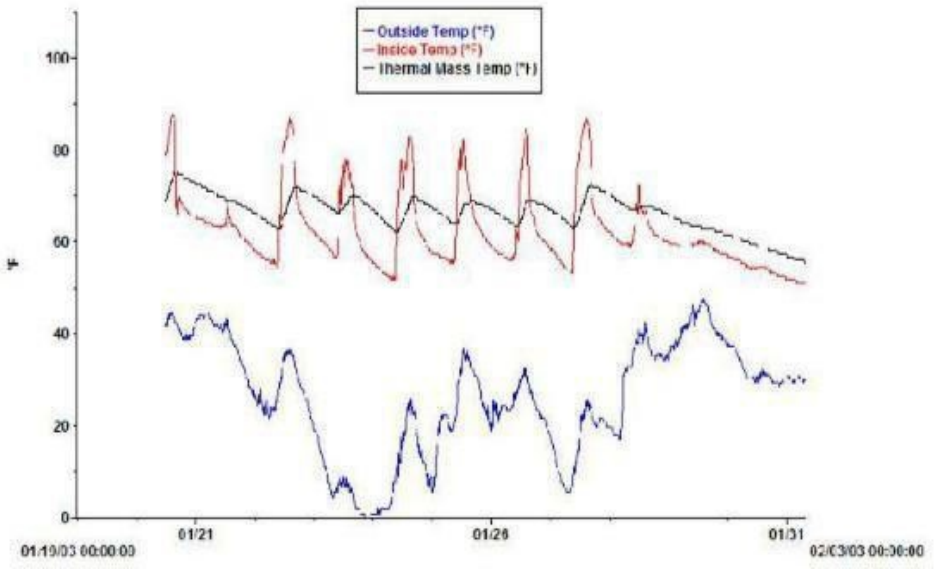


Figure III.4. Thermal performance of the Parkway SunCatcher, Jan 20-31, 2003.

2. Laurel Ridge SunCatcher



The impressive early data from the Parkway SunCatcher encouraged us to continue our research and development on a larger structure that would be more interesting for commercial farmers. The Laurel Ridge SunCatcher was built 10 years later and incorporated several design changes: lower vents on the South knee wall, upper vents on the top of the angled, south-facing glazing; and thermal mass with different colors (flat black; flat red and blue reflecting wavelengths most used by plants).

Despite being larger, it performed just as well. During the winter of 2012-2013, outdoor temperatures ranged from -3.9-0^{0}C (25-32°F) while indoor temperatures averaged 15.5^{0}C (60°F), a 16.7-19.4^{0}C (30-35°F) difference (Figure III.5 and III.6). On its coldest night on February 17, 2013, outdoor temperatures fell to -16.1^{0}C (3°F) after a cloudy day. Still, indoor temperatures stayed near 10^{0}C (50°F). That is what thermal mass and a tight envelope will buy you; the heat captured during the day stayed in the building well enough to ride out one of the coldest nights of the year. The next day was cold but clear, allowing the building to soak up the sun and pushed the afternoon interior to nearly 90^{0}F on a day the ambient temperature stayed well below freezing.

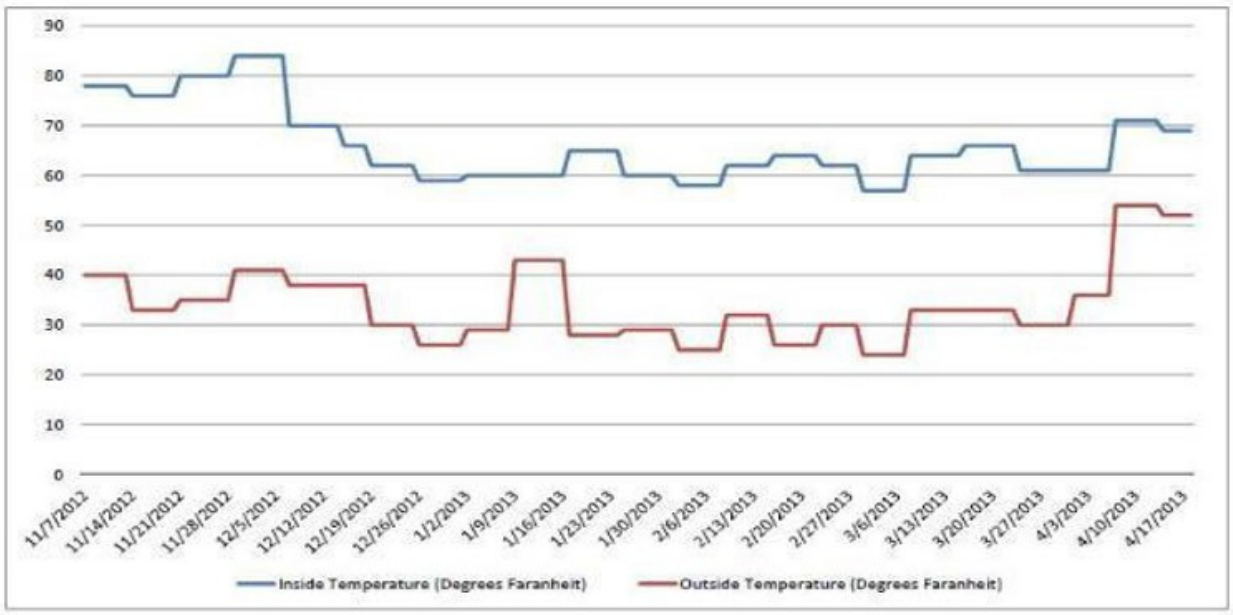


Figure III.5. Weekly average temperatures of the Laurel Ridge SunCatcher, Nov 7, 2012 through April 17, 2013.

By tracking sunlight levels, you can see how clear and cloudy days impact internal temperatures (Figure III.6). Clear skies provide more solar gain, while clouds limit the ability to recharge thermal mass. The difference between indoor and outdoor temperature is essentially energy saved, less propane burned and less CO_2 released.

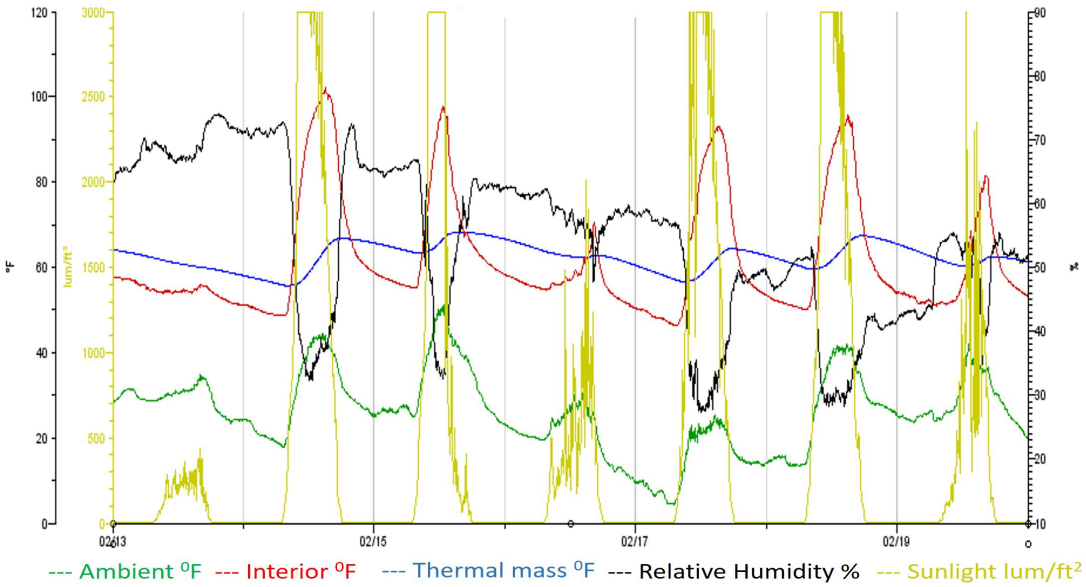


Figure III.6. Sunlight, temperature and relative humidity levels in the Laurel Ridge SunCatcher (February13-20, 2013) show the relationship between interior climate conditions and the amount of sunlight.



Figure III.7. Cucumbers in the Laurel Ridge PSG were already flowering in April 2014.

Summary: The five keys of PSG design

1. Efficient solar energy collection
2. Storage of energy as heat
3. Minimizing heat loss through the structure
4. Convective ventilation
5. Resilience against extreme weather

Together, these features enable SunCatcher PSGs to maintain stable growing conditions year-round with minimal external energy.