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II - What Exactly Is a Passive Solar Greenhouse?

All greenhouses serve the same basic purpose: to create a protected environment where plants can thrive, even when outdoor conditions aren't ideal. As explained in the previous chapter, early examples like brick walls, cloches, cold frames, and glass houses were designed to harness the sun's heat to extend the growing season of valuable crops like fruits and vegetables, or to grow them out of season in northern or southern climates. These structures shielded plants from cold temperatures, wind, and snow. However, from fall to spring, their effectiveness was limited by the one resource in shortest supply: sunlight.

Conventional greenhouses are often built with clear, uninsulated plastic or glass stretched over steel or aluminum frames. These materials let in sunlight but lose heat quickly, making it hard to keep a consistent temperature inside. During the day, these greenhouses can get too hot—even in winter—requiring ventilation. At night, they lose heat rapidly, often falling well below optimal growing temperatures (see an example of a high tunnel in the text box on the next page). Although some of the sun's warmth gets absorbed into the soil or floor, it's usually not enough to keep the plants warm overnight. In colder climates, this leads to a heavy reliance on fossil fuels for heating, which is costly and reduces profit margins for growers.

In Boone, NC (elevation 1000 m/3300 ft), with an average of about 5200 heating degree days (base 65^0 F/18.3^0C), the economics of running heated greenhouses just do not work. After energy prices began rising in the 1970s, many growers in the Appalachian region shut down their greenhouse operations. Unlike many products, food prices often don't reflect rising energy and production costs because consumers are accustomed to cheap food.

Some confusion exists around the term "solar greenhouse," since all greenhouses use sunlight. However, most conventional greenhouses aren't designed to use solar energy effectively. They rarely prioritize the collection and storage of heat or the prevention of heat loss. To address these issues, Yanda and Fisher (1980) outlined three essential elements for solar greenhouse design:

1. Efficient collection of solar heat energy
2. Storage of that solar energy
3. Reduction of heat loss during and after collection

These elements can be achieved through smart design - by adjusting the orientation of the greenhouse, choosing the right shape and angle of the glazing to match the sun's path in winter. A passive solar greenhouse (PSG) captures and stores the sun's heat through its structure and materials, rather than relying on heaters, fans, or pumps powered by fossil fuels. Greenhouses that need external energy for heating and cooling are considered "active" systems. A well-designed PSG needs very little electricity, mostly just for lighting or ventilation (which can be provided by solar panels). The rest of the climate control (heating and cooling) is handled passively through design for which greenhouse orientation and shape are critical.

Many traditional greenhouses and high tunnels are oriented on a north-south axis so both sides receive sunlight evenly: east-facing in the morning, west-facing in the afternoon. But this orientation doesn't make the best use of the low-angle winter sun, which hugs the southern horizon. A better setup is to orient the greenhouse east-west, so the south-facing glazing gets full sun during the day. Castilla and Montero (2008) found that this approach improves light transmission and boosts winter yields in Mediterranean greenhouses (roughly the same latitude

as Boone, NC). For free-standing greenhouses in most U.S. climates, an east-west orientation is typically preferred.



Figure II.1. Light bouncing off the side of a gothic style high tunnel in Zionville, NC shortly after solar noon. The greenhouse is on an E-W axis, tilted 10^0 to the West. Image by Google Earth, Nov 7, 2013.

To show how dramatically a traditional greenhouse can heat and cool, consider a real example: a 36-by-72 ft high tunnel (a single-layer plastic-covered hoophouse) in Zionville, NC (Figure II.1). From January 30 to February 13, 2014, temperatures inside soared to 34–42°C (93–108°F) on sunny days but dropped overnight to -13 to -6°C (9–21°F) - well below freezing (Table II.1). The interior temperatures far exceeded the ambient temperatures during the day, but at night plummeted to equal ambient temperatures. Even though the raised beds absorbed some heat during the day, they couldn't hold enough heat to prevent the air temperature from plummeting overnight.

Table II.1. Statistical analyses of the thermal performance over the same period.

	min	max	mean	st dev
Ambient at +1m	-23.44 ^{0}C	20.95 ^{0}C	-0.21 ^{0}C	6.78 ^{0}C
Interior at +1m	-20.24 ^{0}C	42.46 ^{0}C	3.47 ^{0}C	10.42 ^{0}C
Raised bed, -10cm [a]	-0.61 ^{0}C	12.93 ^{0}C	6.60 ^{0}C	2.41 ^{0}C
Delta-T [b]	-3.99 ^{0}C	29.86 ^{0}C	3.68 ^{0}C	5.72 ^{0}C

[a.] Soil, in raised beds or not, acts as a thermal mass *provided* it contains sufficient moisture. It is the water in the soil that stores heat - dry soil stores little if any heat.

[b.] Delta-T is the difference between ambient and interior temperatures measured at +1m (+3.3ft) from the ground. In the performance graphs in this book, it is the difference between the blue and red lines. A negative Delta-T indicates that the interior temperature is lower than the ambient temperature; it occurs in the early morning during the winter as the greenhouse continues to lose heat before the sun is high and strong enough to start re-heating the structure.

Temperature readings were logged very 15 minutes, resulting in 96 data points per day and 1344 data points for the 14-day period. Min and max temperatures are the lowest and highest temperatures observed during the period of observation. Delta-T mean and standard deviation were calculated from the high and low temperatures at each 15 minute reading. The same method was used for the performance tables in Chapter IV.

This orientation can create light differences inside the structure: The east side gets more afternoon sun, and the west side more morning light (Figure II.2). These differences can be minimized by using higher roof angles, narrower structures, or glazing that diffuses light evenly throughout the interior.

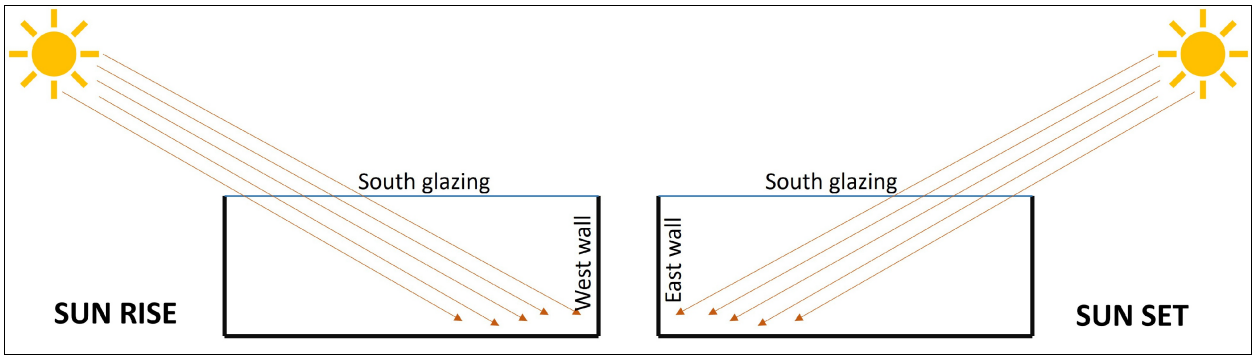


Figure II.2. Morning sun provides more direct sunlight to the west side of the greenhouse, whereas afternoon sun provides more direct sunlight to the east side.

The type of covering material influences both light penetration and how evenly it spreads. Single or double-layer polyethylene, glass, and multi-wall polycarbonate all have different optical properties. Materials that diffuse light can help reduce hot spots and shade lines inside the structure. At night, using thermal curtains, straw, or tarps to cover the glazing helps to reduce heat loss—a strategy used in traditional French gardening (using straw mats) since the 1600s.

The shape of the greenhouse also matters. Many hoop-style greenhouses (quonset [semi-circular] or gothic shapes) have roofs that reflect sunlight instead of letting it in. Low roof angles, around 15° from the horizon, are especially problematic for solar collection in winter as only the lower glazing surfaces on the south side efficiently transmit sunlight into the growing space. Even with an east-west orientation, the sunlight can bounce off the roof instead of entering, especially near the apex. During the summer, too much sun enters the greenhouse, making them too hot for growing plants without significant ventilation. Chinese Solar Greenhouses (CSGs) are a prominent example of solar greenhouse design with low roof angles (Figure II.3).

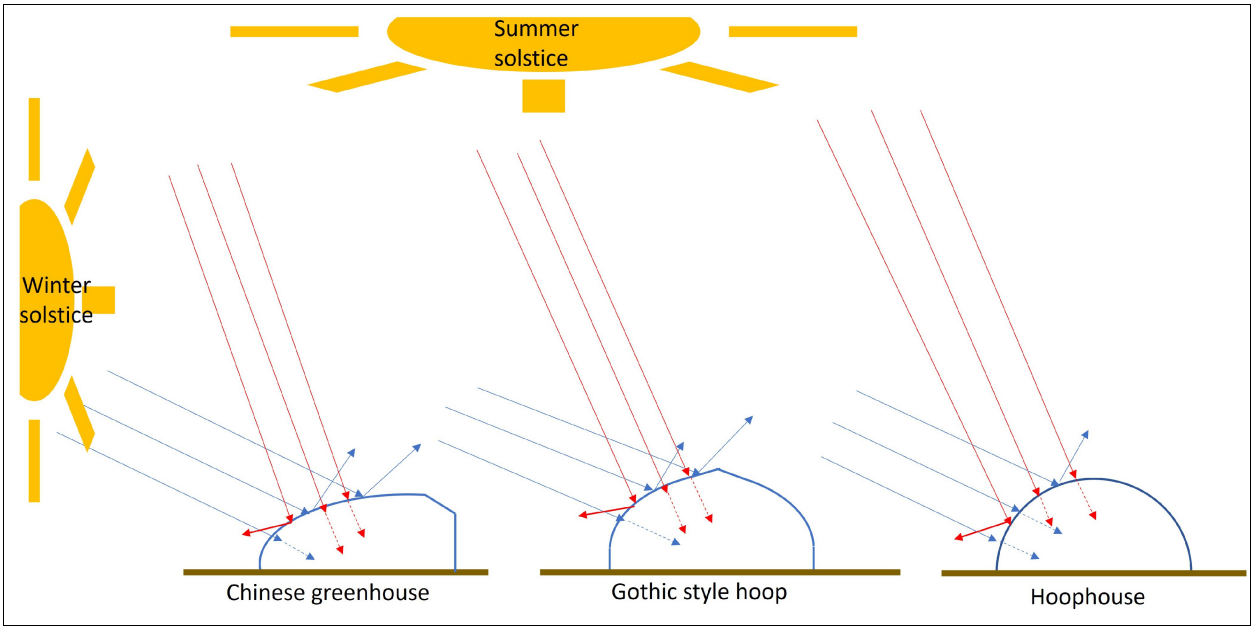


Figure II.3 Sunlight entering and reflected off the glazing of differently shaped greenhouses during the solstices. Too much light enters the greenhouse in Summer and too little in Winter for plant growth and heating the structure.

Despite their drawbacks, CSGs have become popular worldwide, including in North America and Europe. They help reduce energy use and CO_2 emissions, but they have limitations. Gao et al. (2010) reported issues like poor CO_2 levels, high humidity, low light intensity, spring through fall overheating, poor winter performance, and insufficient thermal mass. Other challenges include phototropism (plants growing toward light) and vulnerability to extreme weather which are problems that can also affect conventional greenhouses.

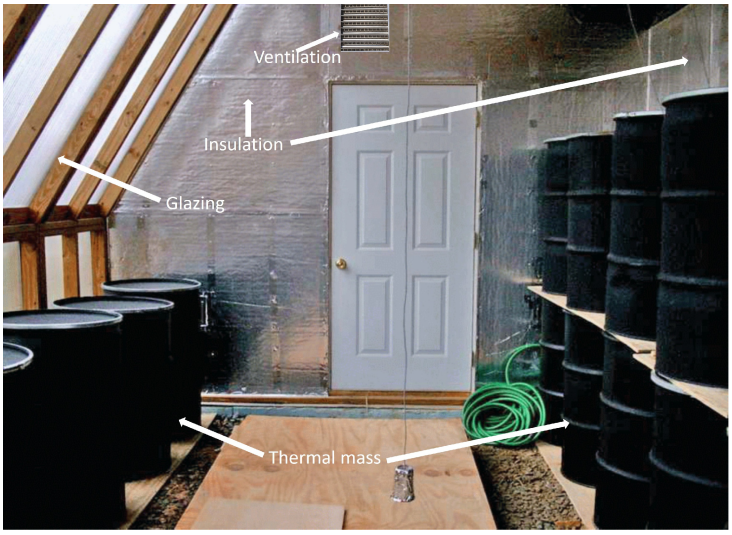
The SunCatcher passive solar greenhouse was designed to address these challenges. Through the strategies described in this manual, the SunCatcher design manages internal conditions such as temperature, humidity, carbon dioxide, and light levels using passive principles. With only soil, seeds, and water as inputs, a SunCatcher can support robust plant growth year-round. In contrast, conventional greenhouses often ignore these environmental factors and then rely on energy-intensive systems to compensate.

Key Differences Between Greenhouse Types

Conventional Greenhouses:

- Build with clear plastic (polyethylene), glass, or rigid plastic (acrylic or polycarbonate)
- Usually ignore solar orientation
- Depend heavily on electricity and fuel for heating and cooling due to:
  * Large radiative heat loss during the winter period, requiring heaters, fans, electricity, fuel tanks and fuel deliveries to maintain optimal temperatures.
  * Overheating on sunny (summer & winter) days requires installation (and later removal) of shade cloth or other means to reduce solar gain, and electric exhaust fans or roof vent-openers to vent excess heat.
- Plants often suffer from overheating, high humidity, and poor air exchange
- Typically have a 20-year life span
- Vulnerable to wind, hail, and snow damage
-

Passive Solar Greenhouses (like the SunCatcher**):**



- Use 60° angled south-facing glazing to capture low winter sun
- Oriented east-west for optimal light collection during the winter period
- Store solar heat in thermal mass and release it as needed
- Avoid summer overheating while maintaining sufficient light
- Ventilate naturally with fresh air and ambient CO_2
- Use super-insulated walls and roof to retain heat
- Strong, permanent, and low-maintenance structures

Passive solar greenhouses are designed to collect, convert, and store solar energy so they can maintain optimal growing temperatures year-round, 24 hours a day. The SunCatcher PSG design is based on five basic design elements:

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

We'll cover each of these design elements in more depth in Chapters V – X.

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