THE YEAR-ROUND
Solar Greenhouse

Lindsey Schiller explains the seven principles of designing a solar greenhouse and how they create year-round food with a low carbon footprint

Solar greenhouses vary in almost every way – their shapes, styles, sizes, building methods, and technologies. However, there are a few unifying elements that apply to them all. To put them in a nutshell, we've distilled them into these seven best practices:

1 Orient the greenhouse toward the sun. In the Northern Hemisphere, the majority of the glazing should face south to maximize exposure to light and solar energy.

2 Insulate areas that don't collect a lot of light. In the Northern Hemisphere, the north wall of the greenhouse plays a minor role in light collection. It should be insulated in order to reduce heat loss, creating a more thermally stable structure.

3 Insulate underground. Insulating around the perimeter of the greenhouse allows the soil underneath it to stay warmer, creating a 'thermal bubble' underneath the structure that helps stabilize temperature swings.

4 Maximize light and heat in the winter. To grow year-round without dependence on artificial lights or heaters, it is crucial to maximize naturally occurring light and heat during the colder months. This is done by using proper glazing materials and angling the glazing for winter light collection – in general, using the glazing area strategically.

5 Reduce light and heat in the summer. Growing during the warmer months can create problems with overheating. Strategic shading, glazing placement and angles reduce unnecessary light and heat in the summer.

6 Use thermal mass (or other thermal storage techniques). Thermal mass materials are materials that store the excess heat in the greenhouse during the day and slowly radiate it at night or when needed. This evens out temperature swings, creating a more controlled environment for growing. Almost all solar greenhouses have some mechanism to store heat, broadly called thermal storage.

7 Ensure sufficient ventilation. Natural ventilation ensures a healthy plant environment and controls overheating.

ABOVE The atrium at Amory Lovins' Greenhouse, nicknamed the 'banana greenhouse'

RIGHT The exterior of Amory Lovins' Greenhouse, 900ft^2 atrium greenhouse in Snowmass, Colorado

The Case for Solar Greenhouses

The graph below shows the temperatures in two unheated greenhouses over a few cold, winter days in Boulder, Colorado. The first is an uninsulated greenhouse, made out of a PVC frame and polyethylene plastic. The second is an insulated solar greenhouse designed with the principles listed to the left.

The standard greenhouse drops to a low of –17°C (2°F); the solar greenhouse stays above freezing.

Solar greenhouses are often described using nebulous terms like high-performance or energy-efficient, but this is what it simply comes down to: they are able to stay much warmer year-round, and thereby grow much more than conventional greenhouses, without relying on fossil-fuel heating. They also overheat less, because they do not have excessive areas of glazing. Hence, they maintain a more stable growing environment, conducive for plants and able to grow year-round, even in harsh environments.

We've addressed the top two most common questions about solar greenhouses, now let's address a third: do they get enough light? People often note that solar greenhouses look more like sunrooms or sheds than greenhouses. Indeed, they usually have less glazing because they work by balancing the glazed area with insulation for efficiency.

However, contrary to what you might expect, they still receive roughly equivalent or even greater light levels than conventional structures. This has to do with the directional nature of sunlight and the placement of glazing. When light enters a solar greenhouse, rather than being transmitted through the north wall, it is reflected back inside by an insulated north wall (usually painted white).

The effectiveness and production potential of solar greenhouses has been documented in research trials – and thousands of backyards – for decades. Notably, in the early 1970s, The Brace Institute at McGill University conducted a unique side-by-side study comparing a conventional greenhouse with one built according to solar design principles.

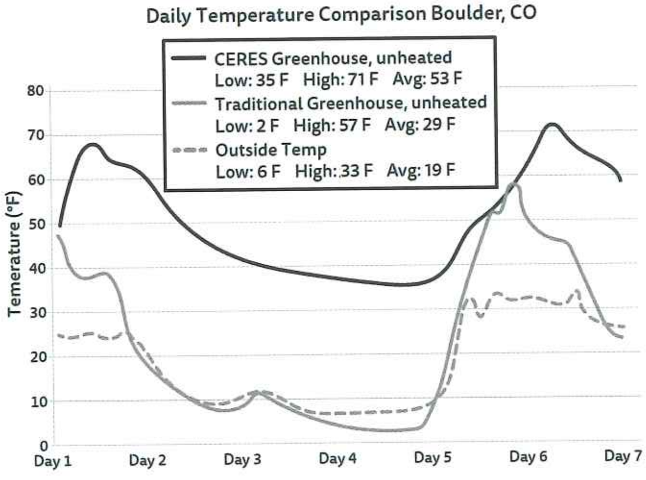
Made out of double-layer polyethylene plastic on all sides, the conventional greenhouse served as the control. The experimental solar greenhouse, called the Brace greenhouse, featured an insulated north wall, a double-layer plastic south wall and several other efficiency features.

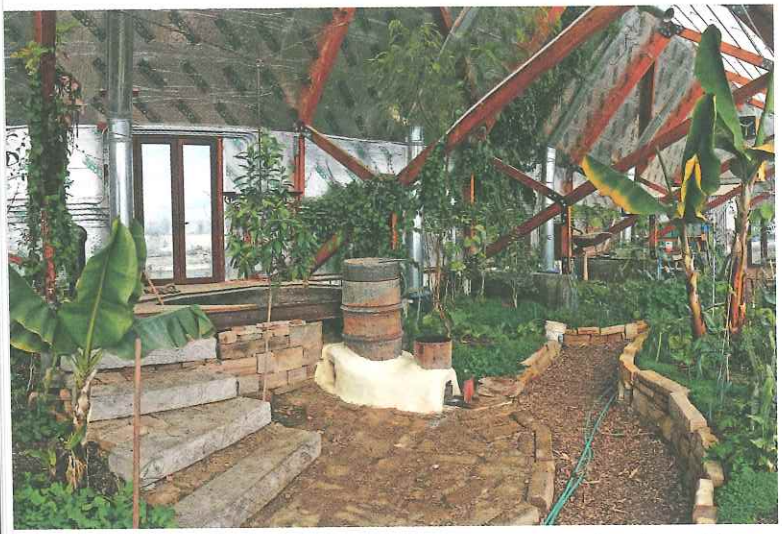
Both operated over a few seasons, and key data – temperatures, light levels and yields – were recorded. The Brace study found that light levels inside the solar greenhouse during the winter were comparable to the fully glazed structures. They were high enough to grow as much or more than conventional structures.

Here are some of their key findings:

- "The new design has yielded significant savings in energy requirements, of up to ⅓, compared to the conventional greenhouse."
- "Total weight of fruit produced in the Brace greenhouse was three times that produced in the control greenhouse."
- "Frost does not occur in the Brace greenhouse until one month after frost had destroyed the crops in the standard greenhouse."[1]

Daily Temperature Comparison Boulder, CO





The rocket mass heater at Golden Hoof Farm, Colorado, enables this 3,000 sq. ft off-grid commercial greenhouse to grow a forest of fruit trees including guava, avocado, mango, banana, lemon, dragon fruit and cinnamon

The Green Centre, formerly the New Alchemy Institute is a 1,800 sq. ft. residential greenhouse in Cape Cod, Massachusetts. It has developed over 40 years, starting as the 'Ark' in 1971, a research greenhouse for small-scale food growing, now it has integrated solar panels, a hot water system, aquaculture and a year-round permaculture garden.

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The Need for Solar Greenhouses

The greenhouses referred to in the above graph were both residential structures; however, commercial greenhouses encounter the same problems. Typically, energy costs are the third largest expense for commercial greenhouse growers in the US (behind labor and plant materials). As of 2011, 70% to 80% of energy costs went to heating the greenhouse through cold North American winters.[2] Moreover, because of the inherent inefficiency of most greenhouses, these energy costs are vastly greater than for other types of buildings, making it challenging to grow year-round profitably. For instance, currently, the heating/cooling costs for commercial year-round greenhouses in Colorado are \$3-4 per ft^2 (£2-3).[3] In comparison, the heating/cooling costs for an average Colorado home are between \$0.10 to \$0.50 per ft^2.[4]

As a backdrop to this situation, our agricultural system is precariously dependent on fossil fuels. For every calorie of food on your table, it took an average of ten calories of fossil fuel energy to produce it. Every step of the food production chain relies on fossil fuels, from growing (pesticides and fertilizers), to processing (emulsifiers, additives, preservatives), packaging (plastic containers), and transportation. For many fruits and vegetables, shipping increases the 10:1 ratio of 'energy in' to 'energy out'. For example, "97 calories of transport energy are needed to import one calorie of asparagus by plane from Chile [to the UK], and 66 units of energy are consumed when flying one unit of carrot energy from South Africa."[5]

Combined with volatile oil prices, finite oil supplies, and a warming planet, these statistics present a grim picture. Greenhouses are just one of many solutions that reduce the energy dependence of our food supply and re-localize food production. However, the current design of greenhouses has the potential to only shift the problem, not solve it.

Though many greenhouses provide local crops, the inefficiency of the structures can undermine the effort. For example, a study conducted by Cornell University compared the total energy needed for growing tomatoes in greenhouses in New York for local markets versus growing tomatoes in fields in Florida and shipping them to New York. Taking into account production and transportation, tomatoes grown in standard greenhouses used about six times more energy than the shipped tomatoes.

Though greenhouses created a local food supply, they increased the total demand for fossil fuels.[6]

Solar greenhouses hold tremendous potential as a way to reduce both food miles and fossil-fuel use, for commercial and home growers alike. The nature of solar greenhouses as warm year-round structures enables backyard gardeners to grow crops (like bananas, mangoes, avocados and vanilla) that are normally shipped thousands of miles across oceans. Unlike conventional greenhouses, which often struggle to stay above freezing, solar greenhouses greatly expand what we can grow, in any climate, by harnessing the sun.

1 T. A. Lawand, *Solar Energy Greenhouses: Operating Experiences*, Brace Research Institute, Macdonald College of McGill University, July 1976.
2 Scott Sanford, *Reducing Greenhouse Energy Consumption: An Overview*, University of Wisconsin-Madison College of Agricultural and Life Sciences, 2011, articles.extension.org
3 Personal communication with Steve Newman, Colorado State University.
4 US Energy Information Administration, *Household Energy Use in Colorado*, data from 2009, eia.gov
5 Norman J. Church, *Why Our Food Is So Dependent on Oil*, published by Powerswitch (UK), April, 1, 2005. Available at resilience.org
6 D. S. de Villiers, et al., *Energy Use and Yields in Tomato Production: Field, High Tunnel and Greenhouse Compared for the Northern Tier of the USA (Upstate New York)*, Cornell University, Ithaca, NY, goo.gl/OLCBu9

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