An Energy-Efficient Solar-Heated Greenhouse Produces Cool-Season Vegetables all Winter Long

By Andrew L. Thomas, Anastasia Becker, and Richard J. Crawford, Jr.
University of Missouri-Columbia, Southwest Research Center, Mt. Vernon, Missouri

Various strategies are commonly used to extend the spring and fall growing seasons by a few weeks, but those bleak mid-winter months leave many of us yearning for anything fresh and crunchy that has not been shipped from thousands of miles away. An energy-efficient, solar-heated greenhouse can provide an inexpensive and successful tool to fill the gap for those of us with winter garden-envy. A variety of cold-hardy species, including vegetables, salad crops, restaurant garnishes, and fresh cut flowers can be successfully and economically cultivated in a properly-designed solar-heated winter greenhouse with little or no added heat.

A successful example of such a greenhouse was erected at the University of Missouri's Southwest Research Center near Mt. Vernon in 1988. This simple inexpensive structure is energy efficient and heated only by the sun. For more than ten winters, it has proven to be an ideal winter sanctuary for growing nearly any cool-season crop imaginable, including salad greens, broccoli and spinach (see Table 1). The Southwest Center's solar-heated greenhouse is situated on the top of a windy, exposed hill in southwest Missouri, the logic being that if it will work at this challenging site, it should work almost anywhere in reasonably mild, temperate climates. In keeping with the theme of simplicity these cool-season crops were grown with no supplemental heat or light to determine how they would fare. Crops were usually direct-seeded into the raised beds in early November, with some fast-growing crops such as lettuce being successively seeded throughout the season. Of course, plants raised elsewhere could easily be transplanted into the greenhouse in November providing a substantial jumpstart on the season. Usually by the first of April the greenhouse becomes too warm and is shut down for the summer.

Design

Over the last 25 years, many different greenhouse designs and technologies intended to maintain a favorable winter greenhouse climate at low cost have been studied. Many of the most successful passively-heated greenhouses take advantage of the thermal storage capabilities of either

Community Food Systems and Sustainable Agriculture
University of Missouri—Columbia
Department of Rural Sociology
204 Gentry Hall
Columbia, MO 65211

University of Missouri — Southwest Center
14548 Hwy. H
Mt. Vernon, MO 65712

OUTREACH & EXTENSION
UNIVERSITY OF MISSOURI
LINCOLN UNIVERSITY
"IMPROVING PEOPLE'S LIVES"

rock masses or large volumes of water. Stored water can be integrated into a greenhouse design in various ways, such as in water-filled plastic sleeves placed on or below the soil surface, or held in large containers placed in various positions inside the structure. The Southwest Center's greenhouse relies on its efficient, low profile design, insulation, and a large volume of water to moderate interior temperatures. This simple, efficient greenhouse was built of low-cost and recycled materials for approximately $1,500 by C. Daniel Wooley.

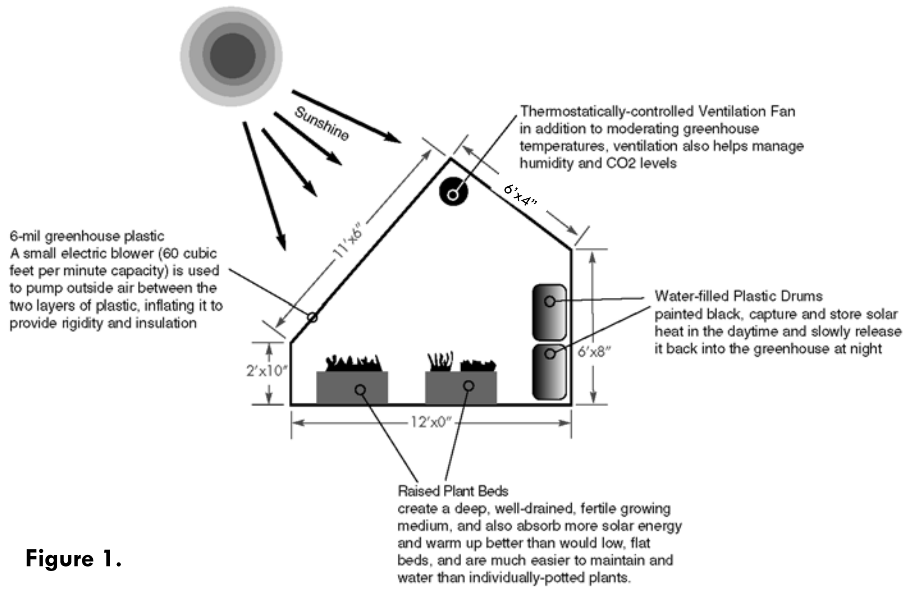


Figure 1.

The building measures 12x24 feet and is 11 feet high at its peak. The south side features a sloping 45° face that is 12x24 feet, resting on a 34-inch high vertical wall (Figure 1). This short south wall was originally built of untreated lumber, which rotted after about eight years of use; therefore it was replaced with treated lumber that is not in contact with the soil or plants being grown. Both of these south-facing surfaces are glazed with a double layer of 6-mil greenhouse plastic, which was installed simply by rolling the edges over finishing boards at the edge of the structure and nailing them in place. A small electric blower (60 cubic feet per minute capacity) is used to pump outside air between the two layers of plastic, inflating it to provide rigidity and insulation. A common question that is asked is whether pumping air from inside the greenhouse would provide better insulation. Although we have not tried this, we suspect that inflating the layers with warm, humid greenhouse air would lead to condensation and an accumulation of water between the two layers of plastic. Furthermore, we simply do not want to remove even the smallest amount of heat from inside the greenhouse, and it has worked just fine as it is.

The north, east, and west walls, and the north-sloped roof portion are 6-inch stud-wall construction with R19 fiberglass batt insulation. These interior walls were faced with plywood and the exterior sheathed with protective sheet metal siding. All interior surfaces are painted white to be highly reflective and to protect the wood. An insulated metal door was installed on the east side. A row of 20 black 55-gallon plastic barrels, stacked two-high and filled with plain water, line the north wall. For stability and solid footing the barrels sit on a narrow concrete pad that runs the length of the building. The barrels provide 1,100 gallons of water to capture and store solar heat in the daytime and slowly release it back into the greenhouse at night—a critical component of this very successful system. Metal barrels would be an option, but they may be prone to rust problems. Any containers chosen should of course, be dark-colored or painted black to maximize absorption of solar heat.

The growing area consists of two raised garden beds constructed directly on the soil floor of the greenhouse with untreated pine lumber, separated by a narrow walkway to provide easy access. These untreated boards will need to be replaced every few years, but we would not recommend using treated lumber in this type of environment. One bed measures 22x3 feet by 10 inches with the other being slightly shorter at 19 feet, to allow for a small entrance area; total growing area is about 123 square feet. A wholesome, fertile mixture of topsoil and compost fills the beds. In addition to creating a deep well-drained, fertile growing medium, these raised beds of dark soil may absorb more solar energy and warm up better than low, flat beds, and are much easier to

Table 1. Numerous cultivars of the following cool-season crops were successfully grown over several winters in the Southwest Center's solar-heated greenhouse with no supplemental heat.

Leafy greens	Vegetables	Flowers
Arugula	Beet	Calendula
Chard	Bok choi	Johnny jump-up
Cilantro	Broccoli	Linaria (Toadflax)
Collards	Broccoli raab	Pansy
Cornsalad (Mache)	Cabbage	
Cress	Carrot	
Dandelion	Kale	
Endive	Leek	
Escarole	Onion	
Lettuce	Pak choi	
Mizuna	Pea	
Mustard		
Purslane		
Radicchio		
Spinach		

maintain and water than individually potted plants. The interior growing space could certainly be increased, if desired, by placing large pots on top of the water barrels, or for example, growing additional plants in other elevated structures such as suspended guttering.

Irrigation water is provided by a freeze-proof hydrant installed within the structure and weep-wall hoses that run the length of each bed and back. We prefer this type of drip hose because it distributes water evenly throughout the beds and minimizes water contact with the foliage. An irrigation timer could be used but our experience has been that it is better to monitor the water needs of the plants and irrigate when needed, saving the timer for use when you are away.

Ventilation

The power of the sun is very evident on clear winter days when the greenhouse temperature can easily rise to 110°F or more, making ventilation a necessity. In addition to moderating greenhouse temperatures, ventilation also helps manage humidity and CO_2 levels. Near the peak of the roof in the east wall we installed a thermostatically-controlled ventilation fan with 1,800 cubic feet per minute capacity. The thermostat is set to initiate ventilation at 80-85°F, depending on the crops being grown, in order to help heat the stored interior water. Initially a floor-level air intake vent was installed but the cold ventilation air entering the greenhouse proved detrimental to plants near the intake vent. The present intake vent is installed high on the west wall so that the fan can pull the hot air across the top and out of the structure without impacting the crops inside. To prevent cold air from seeping in through the fan and vent openings, both were constructed with two louvers, one set on the exterior wall and one on the interior. The exterior louver on the fan is positioned so that the wind cannot blow it open, whereas the exterior louver on the vent is electrically driven open and closed in concert with the fan, again to prevent it from blowing open. These two openings are probably the weakest link in the integrity of the building insulation-wise, and could be manually covered with a heavy blanket on bitterly cold nights if desired.

Water-filled barrels (on right) keep plants warm by absorbing heat from the sun during the day and releasing it into the greenhouse at night.

Temperature

The success and usefulness of this greenhouse design continue to be proven year after year. For more than ten winters, nearly any cool-season crop imaginable has been successfully grown and harvested within this simple, unheated structure. Detailed temperature data have been collected during several of these winters to document what is really going on inside of the greenhouse. Even during one of the coldest winters on record in southwest Missouri (1989-90), the greenhouse never dropped below the freezing point. On the coldest night ever recorded while the greenhouse was in operation, a bitterly cold –13°F in 1996 did not even phase the thriving plants inside, as the interior temperature held steady at 33°F. During several winters, recorded minimum nightly soil temperatures fluctuated between 40 and 56°F, quite acceptable for most cool-season crops. Minimum daily water temperatures in the barrels fluctuated between 43 and 79°F, while maximum water temperatures ranged from 48-91°F.

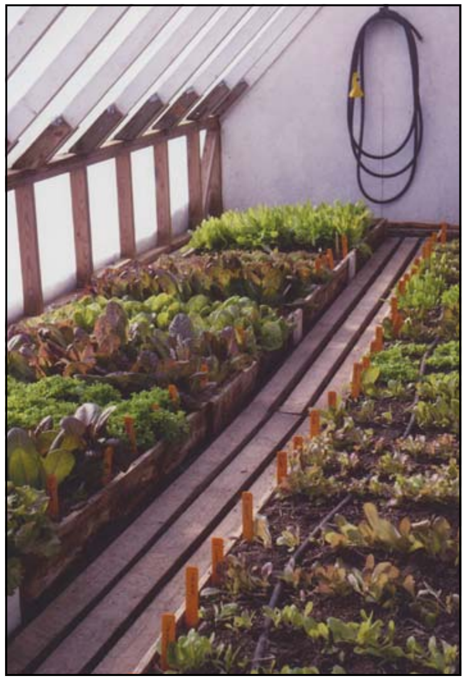
Our data revealed that the most important factor horticulturally, minimum greenhouse temperature, was significantly influenced by maximum and minimum outside temperatures and minimum water temperature inside the structure. While outside temperatures are logically the most influential in determining minimum greenhouse temperature, it is useful and intriguing to note that the water held in the barrels was statistically significant in determining the internal greenhouse climate. The minimum water temperature was also found to be statistically significant in influencing greenhouse soil temperatures. The stored water is, therefore, a critical component of this greenhouse system. For more details on these statistical results, refer to Thomas and Crawford (2001).

BTU Calculations

One British thermal unit (BTU) is the quantity of heat required to raise one pound of water 1°F. The total weight of the 1,100 gallons of water in the greenhouse is approximately 9,130 pounds, and therefore 9,130 Btu's are released into the greenhouse for each degree F the water temperature drops at night. The impact of the stored water in heating the greenhouse at night was estimated by measuring the daily change in water temperature. In February and March 1998, for example, the water temperature changed an average of 8.0°F and 6.8°F daily, respectively. Therefore an average of 73,040 (February) and 62,084 (March) Btu's were captured by the water each day and released back into the greenhouse each night. While not a tremendous amount of heat, it was consistently adequate to keep the greenhouse temperature at or above freezing.

Insects and Diseases

Insect pests and diseases have never posed a problem with any of the crops cultivated from November through March. Insects and mites either remain dormant or are killed by the cool conditions in the greenhouse and no pest control measures have been required. Fungal root rots caused by very wet, cool soil conditions would probably be the most important diseases to monitor. By keeping foliage dry and watering infrequently but deeply, and by rotating crops, diseases have not been a concern in the greenhouse with any of the wide variety of crops we have grown. The greenhouse is empty during the summer (we usually cover the beds with cardboard to prevent weeds) which also helps reduce the proliferation of insects and diseases that might cause concern during the winter growing season. This fortuitous lack of insect and disease pressure makes raising crops organically in this setting a cinch.



Ten varieties of heirloom lettuce happily grow on a cold January day.

Lighting

Artificial lighting has not been used in this greenhouse to determine if sufficient light would be available in winter to grow crops without the added complexity and expense of fixtures, bulbs, and electricity. While all of the crops listed in Table 1 grew satisfactorily without supplemental lighting, additional artificial lighting would have undoubtedly increased the productivity of most crops while adding a small amount of beneficial heat to the greenhouse environment. Lights could be used on cloudy days and/or in the evenings to extend the day length, but would probably only be necessary for the serious commercial grower.

Conclusion and Options

This unheated greenhouse has proven to be extremely successful at doing exactly what it was designed for—growing cool-season crops in winter with few, if any, inputs. Of course, the beauty of this type of study is that once the basic design has been proven, variations and modifications can be made to suit each and every person's particular interest, needs, and situation. For example, more sophisticated heat and water handling equipment could be added, different glazing materials could be used instead of the double layer of plastic, the structure could be built into an existing structure or sunk into a south-facing hill, a rock mass could be added, etc. The greenhouse could be made larger, but we would encourage the grower to expand the structure lengthwise rather than in width and height to maintain the intimate, small space that will be impacted by the stored water. Another tool that could be used to add that extra degree of protection (which we never needed) would be floating row covers placed directly over the raised beds. An advantage to using this material inside such a structure is that there is no wind that would require securing the edges; the material could therefore be very easily installed and removed. For those who simply cannot give up the insatiable desire for winter greenhouse tomatoes, peppers, cucumbers, and other heat-loving crops, this basic design could certainly add tremendous energy efficiency to a greenhouse where substantial additional heat and light were used. With all the possible modifications and so-called improvements that could and will be made to this design, we can unabashedly state that this extremely basic, simple, efficient, and inexpensive design works perfectly well just as it is and will almost certainly never fail in providing fresh, nutritious, crunchy vegetables all winter long for many years to come.

For additional information, contact the authors at:
Southwest Research Center
14548 Hwy H
Mt. Vernon, MO 65712;
417-466-2148

Literature Cited

Thomas, Andrew L. and Richard J. Crawford, Jr. 2001. *Performance of an energy-efficient, solar-heated greenhouse in southwest Missouri.* Southwest Missouri Agricultural Research and Education Center 2001 Research Report. University of Missouri-Columbia.

Reprinted from *Small Farm Today* magazine, March 2003. Contact Small Farm Today, 3903 W. Ridge Trail Rd, Clark, MO 65243; 1-800-633-2535; www.smallfarmtoday.com