A SOLAR-HEATED COMMERCIAL-GREENHOUSE DEMONSTRATION

GRANT NO. DE-FG4481R410479

FINAL PERFORMANCE REPORT

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SUMMARY

Poly Solar Company was formed to design and fabricate a demonstration of a solar heating system for commercial greenhouses in moderate climates. This system is built of readily available materials, and can be constructed using conventional techniques available to most builders and farmers. Construction began on the demonstration project in August 1981 and the system was placed into operation that winter.

Energy savings were calculated by monitoring the running time on an oil furnace in a duplicate greenhouse with the same crop as the solar heated greenhouse with an oil back-up furnace.

The first monitoring period was before the Christmas season with poinsettias used as the comparison crop with 60°F to 64°F. During this period the 126 ton mass storage and waste heat recovery sections of the system were used. These trials showed energy savings over the 100% oil heated structure to be 23.4%.

After the crops were removed from the greenhouse trials were run which showed this portion of the system could maintain night time temperatures as high as 56°F with no other heat source and an outside temperature of 26°F.
The 1860 sq. ft. solar collector/storage system was monitored with a winter-spring crop of geraniums at a nighttime temperature of 60°-64°F. Collector temperatures were recorded between 95° and 130°F with a 6500cfm air flow. These temperatures were more than adequate with this large volume of air, however moisture from irrigation cut the storage efficiency. This created a total projected system savings of about 40%.

Visitors to the site during the demonstration included local agricultural agents, horticultural students and professors, interested non-growers plus the customers and associates of Low Meadows Farms. Chris Turner of Applican State University visited the site and distributed an article and photographs (attached) to 36 newspapers through his Reusable News column. We also prepared a short video tape which is available on a loan basis.

In April 1982 a severe storm with wind gusts in excess of 50mph (as reported by the National Weather Bureau, Charlotte, N.C.) destroyed a section of duct that feeds heated air from the collector to the rock storage bed and caused light damage to the collector itself.
Since April 1982 the Solar collector has not been used.

Funds are not available for the necessary repairs and modifications to prevent moisture incursion in the storage area.
REPORT

The first step in planning is to calculate the heat loss through the outside walls of the greenhouse using the formula:

Conductive heat loss = .7 x surface area x the difference in ambient and outside temperatures.

To this a convective heat loss estimate is added using the following formula:

.02 x Temperature differential x Greenhouse volume.

After the heat loss has been calculated collector size can be determined by the following formula:

Sq. ft. Collector = Heat Loss/35% Efficiency/Btu per Hr available Solar Radiation per ft^2/Hours of available sunlight.

Average solar radiation available can be obtained from the National Weather Service.

Rockbed size is determined by the formula:

Heat Stored = .2Btu/°F Temperature Differential, storage minus ambient temperatures x lb. of rock used for storage.

This gives the volume of rock needed to store enough heat for the greenhouse through one night.
Dimensions of this rockbed are critical, however, there are no set formulas available to determine this. For proper air flow we found a rock bed depth of 3 ft to be sufficient with a washed granite rock ranging in size from 1" to 2". For smaller gravel the depth should be less and for larger gravel the depth should be more, this will insure proper air flow through the entire rockbed. Sizing the rock too large however, will reduce the effective heat exchange area in the rockbed.

During daylight a typical greenhouse requires no heating to maintain 80°-90°F ambient temperature. This allows all air from the collector to be routed to storage with cooled air from the rockbed exhaust entering the greenhouse to aid ventilation and dehumidification.

At night ducts to the collector are closed by reversing the air flow. This also opens a duct from the fan housing to the greenhouse creating a cross air flow from the fanbox to the open end of the rockbed, promoting even heating through the greenhouse and good air circulation for crops.
Air for the collector cycle is supplied by a 1/2 hp motor driving a high pressure fan. This inflates the collector via a manifold at the bottom and exits the collector via a manifold at the top (see photos). This manifold is connected by a 3 ft. diameter duct that supplies heated air to the main fan which routes it under the rock bed via a 16 in. x 8 ft. x 90 ft. plenum.

The flow of air rises through the rockbed to a 16 in. high plenum on top of the exits at the far end of the plenum.

Construction of our demonstration began by removing one end wall of the greenhouse. This allowed access with a front end loader to dig a 3 ft. deep trench 8 ft. wide from this end of the greenhouse to a point 2 ft. short of the opposite wall. 6 1/2 ft. locust fence posts were placed every 4 ft. inside the perimeter of this trench. 1 x 3 in. steel mesh was mounted inside these posts beginning 16 in. above the floor of the trench. Inside this a .006 in. x 6 ft. polyethylene sheet was placed around the perimeter for a moisture barrier. 8 in. concrete blocks were stacked 2 high and 6 across in rows every 3 ft. for the length of the trench on top of this a 14 gauge steel mesh was placed so that it reached from edge to edge inside the trench. This forms a platform leaving a 16 in. plenum below the rockbed to allow a uniform airflow.
After the rock is placed on the platform 1/8 in. steel cables were stretched every foot across the width of the rockbed. Black polyethylene was stretched over this and lapped over the moisture barrier on the sides. This keeps irrigation water out of the rockbed. The original benches in the greenhouse were placed on top of the locust post to provide growing space over the rockbed.

Once the rockbed was completed a transition was built from the lower plenum end which is 16 in. x 8 ft. to the outside wall with a 3 ft. x 3 ft. opening this transition was built of concrete block with a 3 in. poured - in place concrete cap. On the outside of the greenhouse a 3 ft. x 4 ft concrete form was built to direct the air flow up. The opening on top of this form was 6 in. above ground level. A wooden frame was bolted to the top edge of this form and a 36 in. reversible fan with a 3/4 Hp. motor was placed on top of this 2 in. x 4 in. wooden mount. This 2 x 4 mount was also used to anchor a 3 ft. x 4 ft. x 4 ft. insulated housing over the fan. This housing was butted to the wall of the greenhouse with a 36 in. aluminum shutter mounted in the greenhouse wall to allow air to flow from the fan housing into the greenhouse.
A second 36 in. shutter was mounted perpendicular to the greenhouse wall. This shutter allows air to flow from the collector into the fan housing.

The collector was built on 6 in. diameter creosote piles on 12 ft. centers along the 72 ft. length of the collector. The face of the collector sloped at a 50° angle with a 26 ft. face. This extra collector height was used to study the temperature rise along the collector face. This study showed that there was a significant drop in heat gain at a point from 16 ft. to 19 ft. from the bottom of the collector. A more efficient shape would use this as a limit for collector height.

The collector face was covered with 2 in. mesh wire to help support a double glazing of standard 4 and 6 mil greenhouse glazing film. This was supported by 16 ft 2 x 4's spliced 6 ft. in the middle to make a 26 ft. total length. These supports were braced under the splice by a 2 x 6 running perpendicular to the ground on top of 12 ft. creosote pilings. The back side of this framework was covered with 2 layers of black polyethylene. This forms an absorber plate and an insulating layer separated by gravity.
Air supplied by the collector fan is directed into a 36 in. diameter manifold formed from polyethylene. This manifold opens into the collector along a 2 in. slot running the full length of the collector. As air rises under pressure through the collector it is heated and exits through a slot along the top edge of the collector, here it is collected in a manifold and exits the collector into a 36 in. duct made of 3 layers of 6 mil polyethylene supported by 3 1/8 in twisted steel cables held in place at each end by the collector and the fan housing and anchored in the center by 1 1/1 in. diameter aluminum support set in concrete. This duct supplies air to the fan housing.

Controls for this system were built using 2 differential controllers. The first differential controller activates a relay when the collector is warmer than the rockbed. This relay turns off the power to the night time heating circuit and starts the fan at the collector input 1 minute later. The main fan starts forcing heated air from the collector through the rockbed. This relay shuts off when the rockbed temperature is within 5° of the collector temperature. The second differential control is turned on by a thermostat in the greenhouse when heat is needed. This controller only
comes on if the rockbed is 10° warmer than the greenhouse. If this condition is met the controller activates a relay which reverses the fan and circulates warm air from the rockbed through the greenhouse.

Monitoring was done by visiting the site daily and checking overnight high and low temperatures as recorded by special thermometers placed in each greenhouse involved in the trial. Temperatures were also monitored at the collector input and output and the rockbed output. Rockbed temperatures were also monitored along with outdoor high and low temperatures. Periodically, late night visits were made to check operation and relative humidity.

Later in the project a digital display was built which would show a visitor present temperatures at 9 points in the system and the control greenhouse at the touch of a button.
CONCLUSION

After operating this system for a short time it seems to have potential for use in commercial greenhouses in moderate climates. Future use of designs such as this one or the Rutgers University Solar Heating System when combined with improved conservation and energy management techniques should prove to be cost effective on a large scale.

We found a problem with soil born disease in the poinsetta crop because of a slightly lower than optimum operating temperature (60°-62°F vs 64°-66°F). The geranium crop, however, excelled under this system and the solar heated house had the best crop on the range. This shows that these systems must be designed with the intended crop culture as the main consideration.

At present we have cost estimates for repairs of storm damage and improvements in rockbed drainage. We have contacted two manufacturers of agricultural films. Both expressed willingness to participate in future trials by supplying material samples. But we have been unable to find funds to supply other materials and labor.

The system is presently being used for waste heat storage and ventilation only.
If any further information is desired, please contact:

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We will be glad to assist you.
RECOMMENDED READING


Gabbay S.M. Degradation and Stabilization of Plastics, Available through Academic Liaison Institute, Louisville, KY.