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Solar Greenhouses

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by Stephen Kass

I. *Introduction—Unit Outline*

This unit is designed for middle and high school science/ architecture students. It can be included in studies on alternative energy or solar architecture. The material can be used in a flexible manner, depending on teacher needs. The unit can last from one week to four weeks.

II. *Why Learn about Solar Greenhouses* ?

In the state of Connecticut, the energy crisis affects every person and industry. New England as a region and Connecticut, in particular, rely heavily on nuclear power and oil. There is growing agreement that nuclear power plant construction and oil supplies will dwindle dramatically in the next twenty years. This creates a rather dismal energy future.

In order to deal with these facts, science educators are beginning to reevaluate energy programs, Traditional energy studies have focused on fossil fuels; in particular, oil, coal, and natural gas. Many educators now realize this approach is very short-sighted. An alternative energy project can introduce the important concept of the finite nature of energy and natural resources.

This unit on solar greenhouses meets the following objectives. As an alternative energy project, it: 1) encourages the study of inter-disciplinary subject matter; 2) increases knowledge of small scale technology; 3) stresses the use of a renewable energy source, conservation of energy, and food production; and 4) provides the schools with a socially responsible demonstration project. At the same time, vocational students can be involved with the actual construction of the building. Horticultural students can learn about plant life and food production. Science students can experiment with energy concepts. Urban and rural communities can be exposed to low cost energy conservation.

For the homeowner, an attached solar greenhouse is a popular addition It offers three major benefits: 1) an inexpensive, attractive, bright living space; 2) a heat collector; and 3) a place for growing plants or vegetables. Traditional residential architecture tried to create these aesthetic and practical benefits of solar greenhouses in the form of bay windows, sun rooms and breakfast places. With greater understanding of energy conservation and solar energy, future homes can derive more benefits with less costs through solar greenhouses.

Another important energy issue largely unknown to the public is that the American food system requires massive amounts of fossil fuel energy. One major answer to the question why learn about solar greenhouses" is to provide an alternative solution to this problem.

One hundred years ago, Connecticut was close to being self-sufficient in food production. Today about ninety percent of the state's food is shipped in from outside the state. To supply the state with that food requires an elaborate energy-intensive system, which requires more energy than is returned as food. Many steps are necessary to get food from the ground to peoples' tables. In total, the systems needed to produce, transport, process, distribute, and prepare food require about seventeen-and-a-half percent of the national energy budget.

Until less energy-intensive ways of feeding people are explored, a severe energy crisis will also mean a food crisis. For these reasons, the food and heat producing solar greenhouse is an appropriate response to the insure energy situation for educators.

III. *Solar Energy*

The earth has always indirectly depended on the sun for energy. Its rays provide the heat that human, animal, and plant life need to survive. With the discovery of fire, wood became the first source of controllable energy, and even today one-third of the world's population depends on firewood as its principal source of fuel.

Bathed in the sun's rays for millions of years, the remains of plants and animals were chemically changed into the fossil fuels-coal, oil, and natural gas.

The sun continuously evaporates some of the earth's waters, which return as rain to feed streams and rivers, Water mills powered early industry, and modern hydroelectric plants are an import ant source of power.

Finally, the unequal amounts of solar heat falling on different parts of the earth's surface generate winds, which move sailing ships and power windmills.

Compared with other ways of producing energy, solar energy has many advantages. Clearly, enough solar energy reaches the earth to make it a significant resource. The total solar energy striking the United States in one year is equal to one million times the energy output of an average electric power plant. Solar energy is inexhaustible, available everywhere, requires no fuel, does not damage the environment, and cannot be rationed by other nations. However, solar energy does have some disadvantages. It is spread diffusely over the earth. Although solar energy is in a sense free, it must be collected to make it practical to use. It is also intermittent and therefore requires some means of storing energy when there is no sun.

The challenge to all designers is the inexpensive capture and efficient use of the sun's renewable resource. This is the only way to gain widespread use of the solar energy.

In Connecticut, a conventional home with its longest axis facing south receives as much as 14 percent of its energy for space heating from the sun. Add sufficient insulation and double-glazed windows along the southern exposure and the figure rises to 25 percent. With heat storage, the contribution of solar to the energy needs of the home is 50 percent! Yet, only 10 percent of the 169 towns and cities in Connecticut have used their zoning regulations to encourage solar techniques. An attached solar greenhouse may be a partial solution to increased use of the sun's energy for existing houses in Connecticut.

IV. *Solar History*

The direct use of solar energy has occurred throughout history. For thousands of years ancient people relied on the sun's energy to evaporate small pools of brackish water so that they might collect the salt. The earliest recorded history of solar dates back to around 700 BC when it is reported that the Vestal Virgins in Rome used the pure flame from the sun to light the altar fire at the Temple of Vesta in Rome. Five-hundred years later, the Greek Archimedes was reputed to have used solar reflecting mirrors to set fire to the sails of the attacking Roman fleet. A Frenchman, Lavosier, built the earliest solar furnace in the 1700's by using a 51-inch lens to concentrate solar heat to melt metals. In 1872 a large solar still was built in the Chilean desert to supply 6,000 gallons of pure water per day from salt water. Solar cookers were built and used in India in the 1880's. Small steam engines were powered by solar energy as early as 1878. In Egypt, a 50-horsepower engine was used in 1913 to pump irrigation water. Solar hot water heaters were popular in the southern states in the 1930's. Specifically, 80 percent of the new houses in Florida built between 1937 and 1941 were equipped with solar hot water heaters. The 1933 World's Fair featured a passive solar designed house. yore recently, NASA used solar energy to power satellites.

Despite the unique and long history of solar applications, the direct use of solar energy never caught on because there was always cheaper, alternate energy sources available: wood, water power, or fossil fuels. In reality, these sources were not cheaper than the sun's energy, which is free. The coats of building devices to utilize the sun's energy were greater, however, than the costs needed to utilize the other sources that were available.

As energy coats skyrocket, solar history must be remembered in order to encourage a rebirth of age-old principles, not the birth of a new technology.

The great tragedy of solar history is the decision of the American government in the 1950's to look to nuclear power as the answer to the 1975 shortage of fossil fuels so accurately predicted in a federal report in 1952. After 30 years of receiving massive amounts of federal money, the nuclear power industry only provides two percent of US. energy needs! How different our present might be if the US. had put that research and development into solar solutions rather than pursuing the course of nuclear power.

V. *The Reason for Seasons*

The sun is the most important factor in our lives and to us is the most important star in the universe. It is our source of heat and light. Without the sun, life on Earth could not have developed and could not be maintained.

The sun is a star, spherical in shape, and although its diameter is 109 times that of the Earth, it is by no means large in comparison with some other stars. In fact, astronomers classify it as a yellow dwarf star—even though its diameter is 865,000 miles. The main difference between the sun and any other afar, as far as Earth people are concerned, is that we on Earth are so close to it. The relative distances of the other stars can be appreciated by the fact that although light traveling at 186 thousand miles a second takes just over eight minutes to reach us from the Sun, it takes over four years to reach Earth from the nearest other star.

The Earth revolves around the sun at a mean distance of 93 million miles and its orbit is so nearly circular that this distance does not vary by more than one-and-one-half inches during the course of the year. It is of interest to note that the Earth is nearest to the sun in January and furthest away early in July showing that the variation in distance is *not* responsible for the seasons. The seasons are caused by the fact that the Earth's axis (which maintains an almost constant direction in space) is inclined to the ecliptic at 66,1/2°—or as more often stated, the Earth's equator is inclined to the ecliptic at an angle of 23, 1/2° (Figure 1). This means that during the course of the year the sun can be as far north of the equator as 23,1/2°, giving summer in the Northern hemisphere and winter in the Southern hemisphere. Also, it can be south of the Equator as 23,1/2°, giving winter in the Northern hemisphere and summer in the Southern hemisphere.

HOW THE EARTH'S ROTATION AROUND THE SUN

APPEARS IN DIFFERENT PLACES ON EARTH

SUN'S DECLINATION	NORTH OF THE EQUATOR	OVER EQUATOR	SOUTH OF EQUATOR	
Time of year	March 21- September 2	March 21 and September 2	September 2 March 21	
Seasons	Summer in northern hemisphere	Equinoxes	Winter in northern	hemisphere
	Winter in southern hemisphere	Equinoxes	Summer in southern hemisphere	
Observer 's latitude: North Pole	Perpetual daylight_	Days & nights of equal length	Perpetual darkness	
A high northern	Long days,	Days & nights of equal	Short days,	

latitude	short nights	length	long nights
The equator	Days & nights of equal length	Days & nights of equal length	Days & nights of equal length
A high southern latitude	Short days, long nights	Days & nights of equal length	Long days, short nights
South Pole	Perpetual darkness	Days & nights of equal length	Perpetual daylight

At the Equator, throughout the year, whatever the season and wherever the Sun, days and nights are of equal length.

At the Equinoxes (March 21 and September 2), all places have equal days and nights.

VI. *Sun Paths*

A. Site Location

The mayor consideration in designing solar greenhouses is the availability of direct sunlight. In order to learn about the availability of direct sunlight, it is necessary to understand how the sun moves across the sky. The sun rises in the east, follows an arc through the southern sky, and sets in the west. The sun travels a different path in the winter than in summer, thus solar radiation falls on the earth's surfaces (and on your greenhouse) at different angles during each season (Figure 2). During the cold part of the year the Earth's tilt causes the sun to appear low in the southern sky, rather than overhead as in summer. Since the sun rises and sets sky the southern sky, east and west walls can see very little sunlight in the dead of winter. The north wall loses out completely. But a double-glazed south-facing window gains more solar heat in eight hours than it loses over the entire 24-hour day.

An attached solar greenhouse must be constructed on the south aide of the existing building. A glass-exposed south wall area will have adequate daily exposure to the sun and a southern sky. However, shading obstruction to the south will affect your site. Nearby buildings, trees and hills can block the southern sun and limit a greenhouse's efficiency, During the winter months, there must be few obstructions when maximum solar exposure is critical.

B. Latitude, Altitude, and Azimuth

The length of the days and the intensity of the sunlight is mainly determined by the latitude. Connecticut is approximately 40° north latitude, so corresponding figures have been chosen. Different angles are needed for other latitudes.

To avoid shade covering the solar greenhouse before costly contraction begins, it is important to know two particular solar angles: altitude and azimuth (Figure 3). The importance of knowing these two angles cannot be overestimated, to insure adequate site selection.

The altitude is the angle formed by the sun and the horizon. In Connecticut, the noon sun is at the low altitude of' 26,1/2° on December 21, the shortest day of the year. On June 21, the longest day of the year, the sun la at a high 73, 1/2° altitude. During the Spring/ Fall equinox the altitude angle is 48,1/2°.

The azimuth is the angle made between the horizontal direction to the sun and a true north-south line. A 20° variance east or west is acceptable. It is important to remember that in Connecticut the magnetic north is 13° west of true north.

An effective solar greenhouse must be designed with the full knowledge of the sun's path during all the seasons (Figure 4). Since the coldest weather occurs during January, the sun's path on January 21 most directly determines the solar greenhouse design.

-On January 21 in Connecticut	Altitude	Azimuth
the sun rises at 7:00 a.m.	0°	S 65° E
-At 10:00 a.m. the sun is at	25°	S 32° E
-At 12:00 noon the sun is at	30°	0°
-At 2:00 p.m. the sun is at	25°	S 32° W
-At 5:00 p.m. the sun seta at	0°	S 65° W

This table points out the symmetric nature of the sun's path.

A solar greenhouse should be ideally placed due south, that is, facing azimuth angle 0°. In addition, the south glass or glazing should be at right angles to the incoming sunshine on the coldest day. It is the noon altitude angle on the coldest day that determines the most efficient angle for the south wall of the greenhouse. The altitude angle in Connecticut on January 21 at noon is 23,1/2°. In order to accept as much sunlight as possible, the angle of the south glass on the greenhouse should be 66,1/2°: 66,1/2°+23,1/2°=90°,

These angles are not critical. A 20° variation results in less than a fifteen percent difference in received solar energy. When clean snow covers the ground, the reflected radiation favors a vertical glazing.

VII. *Solar Greenhouses vs. Conventional Greenhouses*

The solar greenhouse differs from conventionally designed and operated greenhouses in that it does not rely on outside sources of energy for winter heating and summer cooling. A conventional greenhouse is usually all glass and pays no attention to direction of the sun. The solar greenhouse tries to get as much solar energy as possible by using glazing on surfaces with southern exposure to permit the entry of heat and light. The northern walls are insulated to reduce heat loss at night. Vents promote natural circulation to help keep the interior cool. A storage mass, usually in the form of steel drum filled with water, helps to reduce the difference between day and night temperatures. The south side of the solar greenhouse is calculated to permit the winter sun, but exclude the summer sun.

The solar greenhouse relies on passive solar energy. The advantage of passive solar heat is that it can be built right into a freestanding or attached solar greenhouse. The passive design will use very little mechanical equipment, extra piping or special maintenance, as active systems often do.

In more general terms, any solar greenhouse must contain the following parts to be considered a complete passive solar heating system:

A. A collector, such as the double layer of greenhouse window glazing (glass or plastic).

B. An absorber, usually the darkened surfaces of the walls, floors, and water-filled containers inside the greenhouse,

C. A storage mass, normally the concrete, brick, and/or water that retains the heat after it has been absorbed.

D. A distribution system, which is the means of getting heat into and around the house—fans, natural circulation flows.

E. A control system (or heat regulation device), such as movable insulation used to prevent heat loss from the greenhouse at night. Roof overhangs that block the summer sun and thermostats that activate fans are also controls. Some controls may be operated by the occupant.

VIII. *How a Solar Greenhouse Works*

The following principles briefly explain the basics of understanding how a solar greenhouse operates:

A. The sun shines through the clear areas in short waves.

B These waves strike objects in the greenhouse and are reradiated as long waves, The long waves do not readily return through the glazing. This is known as the greenhouse effect. The greenhouse effect is similar to hot air trapped in a car on a sunny day with the windows closed. The inside air becomes warmer than the outside air (Figure 5).

C. Massive (heavy) objects in the greenhouse such as masonry walls, rocks, water drums, concrete, etc., absorb heat during the day and return heat to the structure at night. Pound for pound, the most efficient heat storer you can get is enclosed water. It is necessary that the greenhouse have considerable mass in order to perform properly (about 2 gallons of water or 80 pounds of concrete per square foot of glazing). If this is done, the greenhouse will maintain temperatures as high as 30°F above outdoor lows in winter.

D. The warm air (80-90°F) from the greenhouse goes directly into the adjoining structure (Figure 6). This works best if there are high and low openings. The vents establish a natural air circulation system that benefits the home and the greenhouse. At night the openings can either be left open or closed, at the occupant’s option, If open, the greenhouse will draw on some home heat and will keep higher temperatures.

E. The partially shaded and insulated greenhouse roof will keep it warmer in winter and cooler in summer. Notice that the south face of the unit is tilted 60° according to the latitude on which the greenhouse is located. The tilt maximizes winter sun and reflects a large percentage of the summer sun off the front of the greenhouse. Thus, overheating is less of a problem (Figure 7).

F. How well the greenhouse keeps warm is largely determined by how well it is constructed and sealed. All cracks and joints in the greenhouse must be insulated and caulked to prevent “infiltration’ heat losses. The greatest heat lose area for the greenhouse is through the clear wall portions. A moveable insulator to cover these areas would greatly increase the winter performance of the greenhouse.

IX. *Solar Test*

The following questions relate to New Haven, Connecticut, which is in the Northern Hemisphere:

1. Where does the sun rise? set?
2. What direction does the sun appear to move across the sky?
3. How many hours does it take the Earth to make one complete rotation?
4. Now many days does it take the Earth to rotate around the sun?
5. The Earth is closest to the sun in January and farthest away from the sun in July. Does this fact determine the seasons? why?
6. What is the longest day of the year and approximately how many hours of daylight are there? Shortest day? How many hours of daylight?
7. What is the equinox? What two times of the year does it happen? How many hours of daylight?
8. How many degrees west of true north is magnetic north?
9. How many degrees in a circle? How many degrees does the sun appear to move across the horizon on the shortest day? Longest day?
10. Why is latitude important to know when solar angles are determined?
11. What is altitude?
12. What is the altitude on the longest day? Shortest day?
13. What is azimuth?
14. Using the sun path chart, find the altitude and azimuth angles on March 21 and September 2 for the following times:

	Altitude	Azimuth
Sun rise 6:00 a.m.		
at 9:00 a.m. the sun is at		
at noon the sun is at		
at 1:30 p.m. the sun is at		
at 3:00 p.m. the sun is at		
at 4:30 p.m. the sun sets at		

15. What color absorbs heat best? Reflects heat?
16. What is the greenhouse effect?”
17. What is natural circulation?
18. What is storage mass? What is the best storage mass? Why is it important?
19. How does a greenhouse shade itself from the hot summer sun?
20. Why is insulation important in a solar greenhouse? Where should it be placed?

X. *How to Build a Model Solar Greenhouse*

Materials : cardboard, matboard (for insulation—black on one side and white on the other aide), masking tape, clear plastic wrap, thermometer, one small can painted black and filled with water (storage mass).

A. Cut out 3 rectangular sizes from cardboard: 8”x12”, 10”x12”. 4”x12”.

B. Cut out 2 identical right triangles, size 8’x 10 .

C. Assemble as shown in Figure 8. Use rubber cement on all parts except 10 x12 rectangle. Attach the 10 x12 rectangle with tape across bottom so it can open and close.

D. Use tape to attach plastic wrap.

E. Cut out 8”x12” matboard for insulation (black on one aide and white on the other aide).

XI. Classroom Experiments for a Model Solar Greenhouse

A. The Greenhouse Effect

1. Objective—observe the Greenhouse Effect.
2. Additional materials—thermometer.
3. Procedure:
a. Measure and record the outside temperature.
b. Insert the thermometer through the back wall of the model, face model toward sun and record the temperature every 5 minutes for 15 minutes.
c. Prepare a simple graph with temperature (degrees on one aide and time (minutes) on the other aide as shown below. Plot the temperature readings and then connect the dots with a continuous line.

(figure available in print form)

B. Absorbing Heat with Light and Dark Surfaces

1. Objective—measure heat-absorbing properties of different colored surfaces.

2. Additional materials—white and black matboard floor cover, thermometer.
3. Procedure:
a. Orient the model toward the sun, and insert white-side matboard on the floor. Place the thermometer inside.
b. Measure and record the temperature every 5 minutes for 15 minutes.
c. Reverse the matboard on the floor to the black aide. Again, place the thermometer on the floor and measure and record the temperature every 5 minutes for 15 minutes.
d. Compare readings on the dark and light surfaces.
e. Different colors may be placed on the floor and temperatures recorded to determine what colors have higher heat-absorbing qualities. Shiny and dull surface may be compared.
4. Observations:
a. What color surfaces absorb the most heat?
b. Ii you were putting a floor in a house near a south facing window to absorb heat, what colors might you select?
c. Are the temperatures in the house too warm for comfortable living? If so, what can be done to lower the temperatures during the day?

C. Storage Mass

Storage mass (thermal mass), usually in the form of water in containers, masonry floors and walls, or rock storage bins, are used in passive solar houses to store heat during the day and emit it into the living apace at night. Storage mass also is used to regulate heat within the space so that it is not too hot during the day or too cold at night.

1. Objective—determine how solar mass may be used to store heat.
2. Additional materials—thermometer, white and black matboard floor cover, black water container,
3. Procedure:
a. Orient the model toward the sun with black floor cover in place.
b. Place the thermometer on the black floor cover.
c. Measure and record the temperature every 5 minutes for 20 minutes.
d. Place the model in the shade and record the temperature every 5 minutes for another 20

minutes,
e. Open the back section of the model and allow it to cool to normal temperature.
f. Fill the container with water and set it inside the model near the window. Orient the model toward the sun.
g. Again, measure and record the temperature every 5 minutes for another 20 minutes.
h. Carefully place the model in the shade and record the temperature every 5 minutes for another 20 minutes .
i. Other experiments may be conducted by filling the container with small pebbles or sand instead of water and repeating each of the above procedures.
4. Conclusions:
a. What effect does storage mass have on daytime temperatures?
b. How is the temperature changed after the house has been placed in the shade?
c. How would you apply your observations to the construction of a passive solar greenhouse?

D. Insulation

The large areas of south-facing glazing on a passive solar greenhouse create a large amount of heat loss during the night, Many greenhouses use moveable insulation in the form of curtains or panels.

1. Objective—to determine the effect of moveable insulation in retaining heat.
2. Additional materials—thermometer, water container, insulation panel (white and black matboard).
3. Procedure:
a. Place the model in the shade with the thermometer inside,
b. Fill the water container with hot water. Record the temperature of the water and place the container inside the model,
c. Measure and record the temperature in the model after 30 minutes.

d. Remove and empty the water container,

e. Repeat step b, The water should be the same temperature,

f. Place the insulation panel over the plastic window glazing and repeat step c.

4. Conclusion:

a. How effective is the insulation panel?

b. How can you make the model solar greenhouse more energy-efficient?

c. What can be done to better insulate your model solar greenhouse?

(figure available in print form)

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