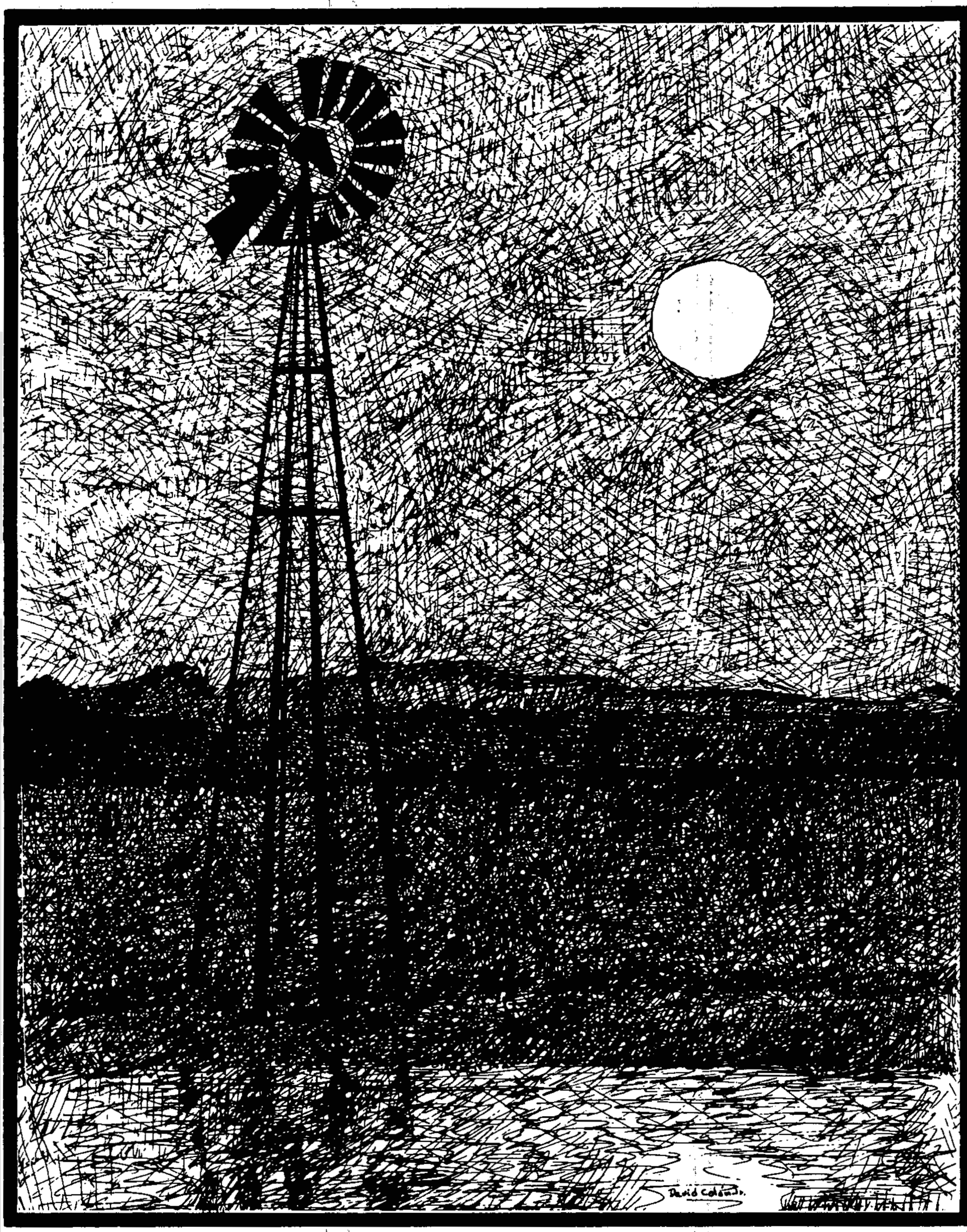
DOE/CS/34039--T11

U.S. Department of Energy

Solar Energy Education

February 1981



MASTER

Student Activities

INDUSTRIAL ARTS

Field Test Edition

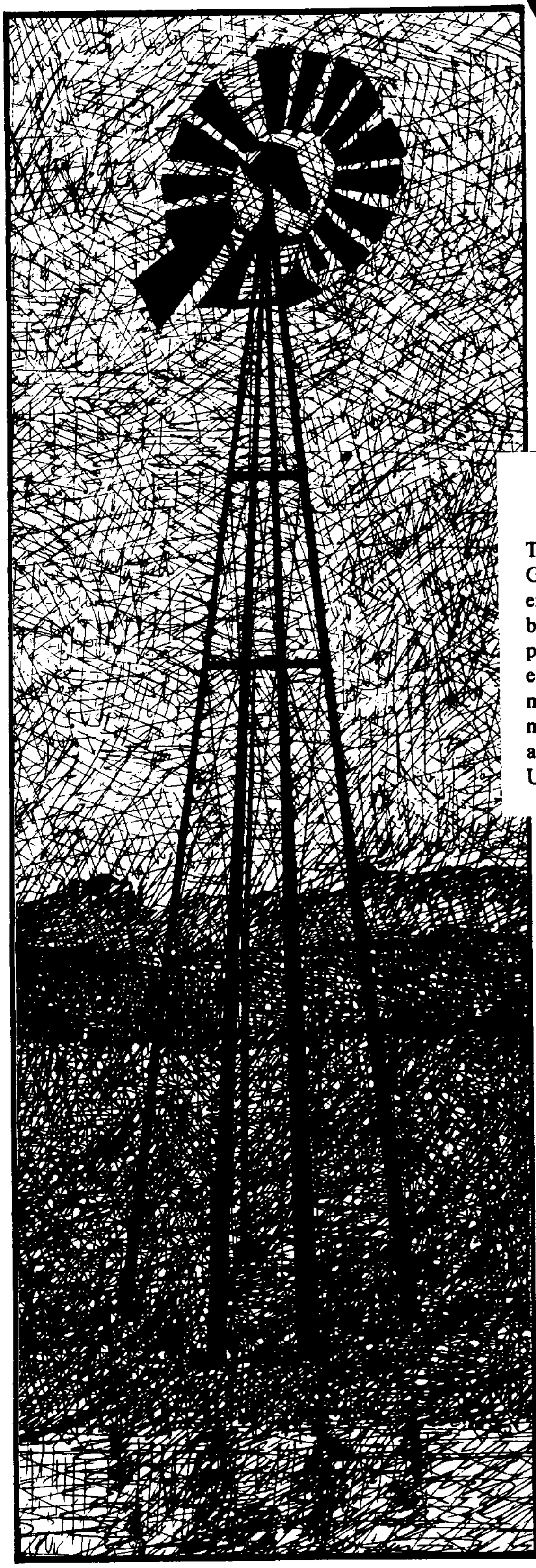
NOTICE

Information on the Solar Energy Education curriculum may be obtained from:

Solar Energy Project
c/o New York State Education Department
Albany, New York 12234

Your comments on and evaluation of this field-test edition are solicited.

Solar Energy Education



INDUSTRIAL ARTS

Student Activities

Field Test Edition

Prepared For:
U.S. Department of Energy
Office of Conservation and Solar Energy
Office of Solar Applications for Buildings
Washington, D.C. 20285

Prepared By:
Solar Energy Project
New York State Education Department
in cooperation with
SUNY Atmospheric Sciences
Research Center
Albany, New York 12234

Under Contract Number
ACOI-77CS 34039

To the Teacher

Other Solar Energy Project Materials

This industrial arts booklet is one of several curriculum units on solar energy produced by the Solar Energy Project, under contract from the U.S. Department of Energy. Other curriculum materials in print or in preparation include a solar energy text, a reader, booklets of activities in the sciences, home economics, social studies, language arts, and the humanities, and a teacher's guide to accompany each subject area booklet.

Using the Activities

The activities in this booklet are written for student use. Data collection pages are placed separately at the end of each activity and are marked with a gray square ░ for ease in locating and reproducing them.

A teacher information section follows each activity and contains suggestions for implementing the activity in the classroom. This section is identified by a gray strip along the sides of the pages.

Additional information on using the activities is provided in the accompanying Industrial Arts Teacher's Guide.

Field-Test Evaluation

The Solar Energy Project actively seeks your comments on and evaluation of this field test edition, as well as the comments and evaluations of your students. We invite you to send us any original activities you may have written. Any activities received will be considered for inclusion in the revised edition.

Suggestions and inquiries may be sent to

Solar Energy Project
c/o New York State Education Department
Albany, New York 12234

TABLE OF CONTENTS

Staff

Thomas Boehm
Project Director
RoseAnne Fogarty
Publications Coordinator
Carolyn Graham
Field-test Coordinator
David Colon
Graphic Artist
Karen Blaustein
Administrative Assistant
Lisa Rice
Administrative Assistant
Lesa Schissler
Secretary/Layout
Ellen Altschuler
Typist/Proofing
Margaret Hasselwander
Typist/Proofing

Edward T. Lalor
Douglas S. Reynolds
John V. Favitta
Project Advisers

Acknowledgements

While many individuals and organizations have contributed to this industrial arts solar curriculum, we would like to acknowledge especially the following:

The New York State Education Department's
Division of Curriculum Services,
Bureau of Science Education, and
Bureau of Industrial Arts
The SUNY Atmospheric Sciences Research Center
Volker Mohnen, Director, and
Ronald Stewart, Associate Director
The participating teachers
John Ditton
Robert Dodds
C. David Gierke
Charles Haley
Robert Muller
Consultant - John Kwasnoski
Reader - Al Sholtes

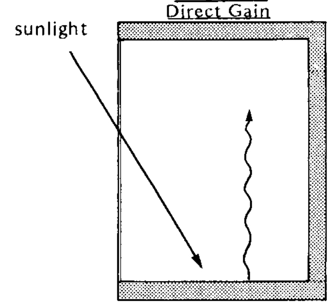
DRAFT

Passive Solar Demonstrators

Introduction

Buildings can be and are being heated by the sun. One successful way to do this is to use the building itself as a heat collector and storage unit. If this process uses fans or pumps, it is known as an active system. If no auxiliary source of energy is used to transfer heat within the building, the system is called passive.

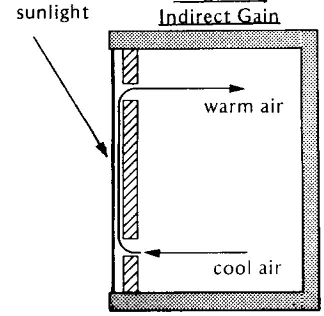
Diagram I
Direct Gain



One type of passive system is called direct gain. Sunlight enters the building through the glazing and is absorbed by the mass of the building interior. Light energy is trapped inside the room and reradiated as heat energy.

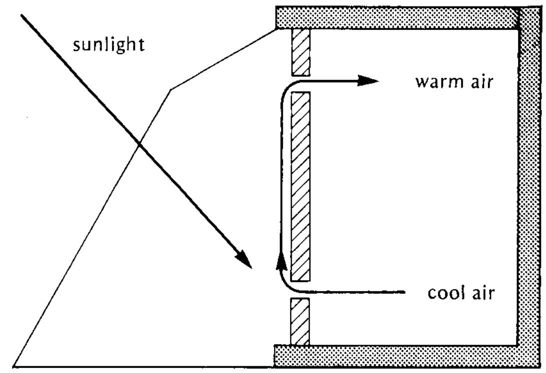
A second type of passive system, called indirect gain, works in much the same manner as the direct gain system, but with a heat storage wall placed close behind the glazing. The sunlight striking the storage wall is converted to heat and slowly moves through the wall and into the room. Vents added at the top and bottom of the wall help distribute the heat from the wall's dark, front surface to the room's interior by natural convection.

Diagram 2
Indirect Gain



The third type of passive system is called isolated gain. This system is identical to the direct gain system except that the building is heated by a separate room or structure which collects solar energy and delivers heat. A heat storage wall may be added to combine the advantages of both direct and indirect gain. This greenhouse or "sunspace" may be used to grow food, provide heat, or both.

Diagram 3
Isolated Gain



Objectives

At the completion of this activity, you should be able to

- identify and explain how the three types of passive solar heating systems work,
- construct models of these systems using standard fabrication techniques, and
- identify ways your own home could be adapted for passive solar energy.

Skills and Knowledge You Need

Reading drawings

Measuring and layout

Cutting, shaping, and drilling

Assembling and finishing

Inspecting

Materials and Equipment

4 tote trays or dish-pans (approx. 3½" x 14½" x 19")

4 screen-door handles

4 scrap pine blocks (for back rest)

8 RH stove bolts (3/16" x 1/2" x NC) (for handles)

8 RH wood screws (8" x 1/2")

1 piece plywood or hardboard (¼" x 14½" x 19")

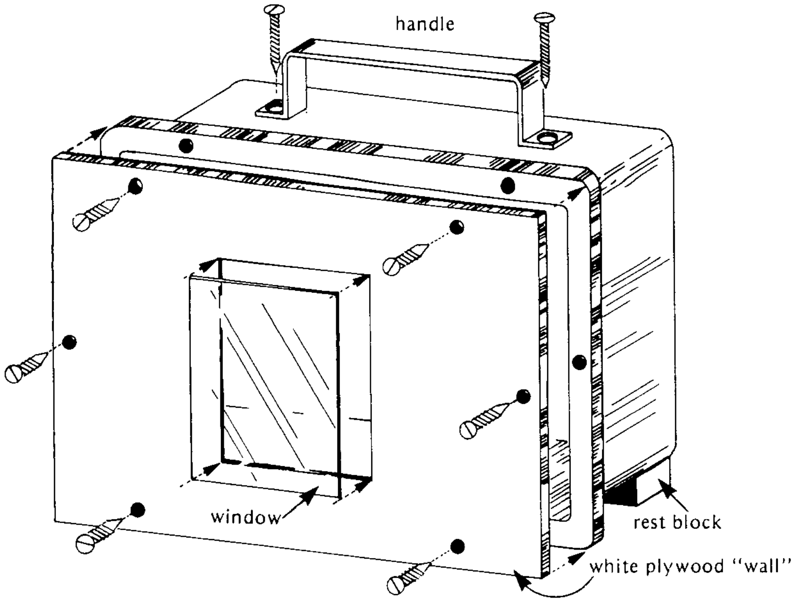
4 aluminum angle clips (1/2" x 2")

1 piece acrylic glazing (.100 x 36" x 72")

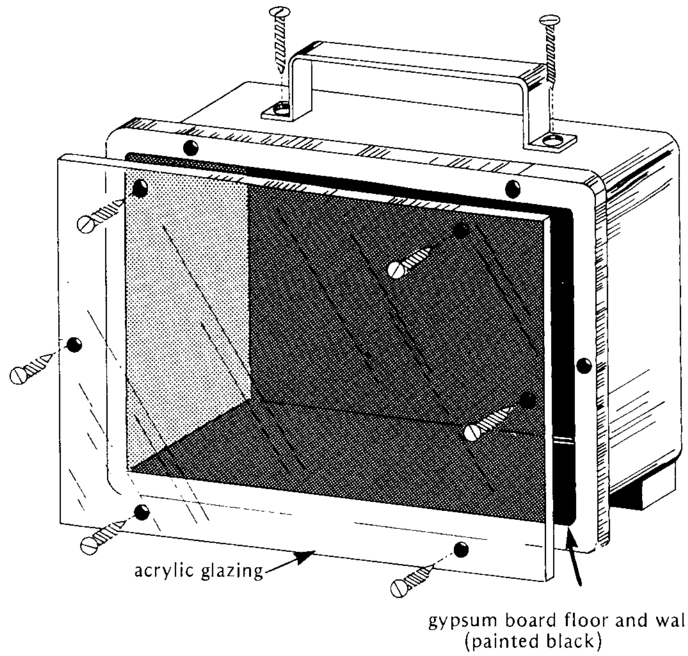
1 sheet gypsum board (½" x 4' x 8')

1 box rope caulking

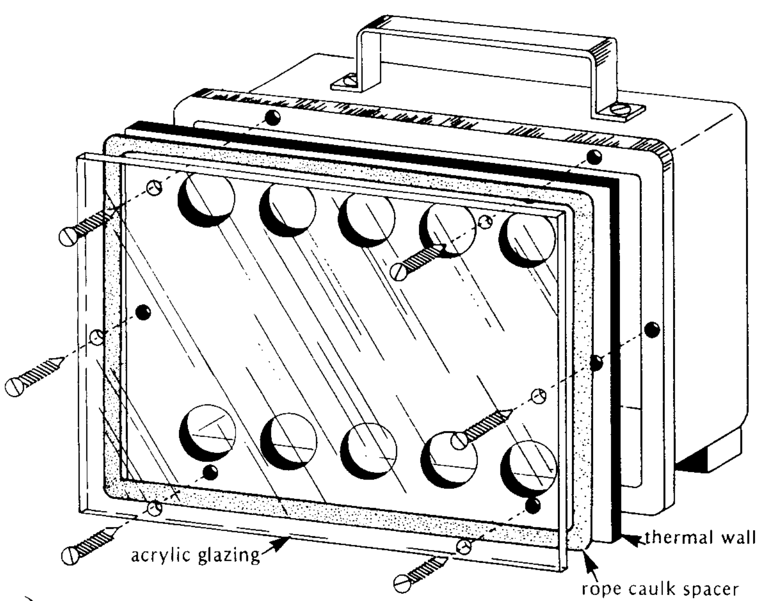
(1) Average Window (Control) Model



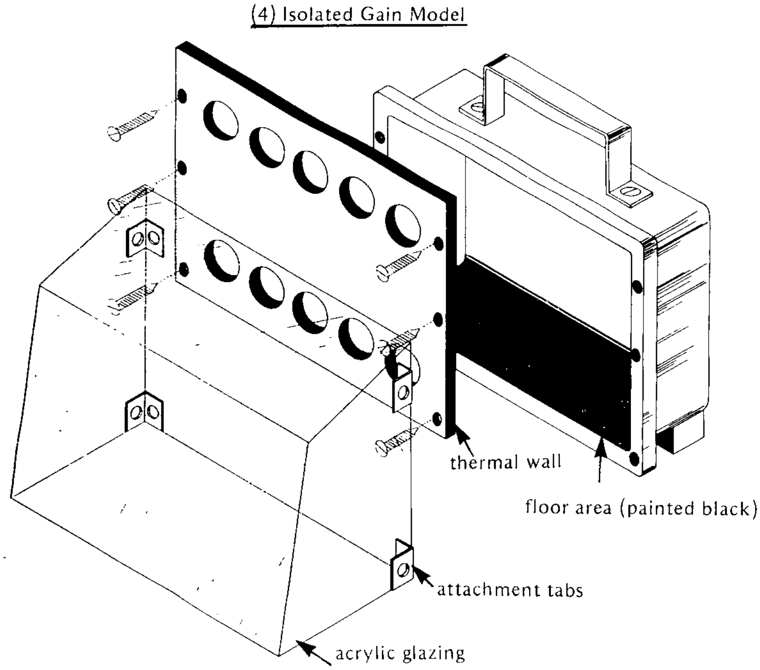
(2) Direct Gain Model



(3) Indirect Gain Model



(4) Isolated Gain Model



Construction Procedure

You are going to build four models. They will re-present

an average building,

a direct gain solar building,

an indirect gain solar building, and

an isolated gain solar building.

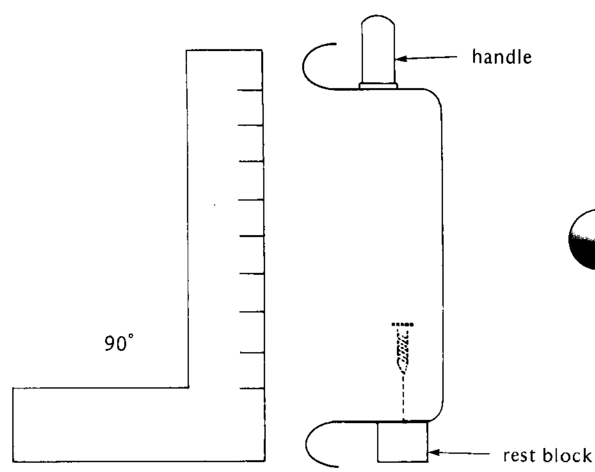
Work carefully and read directions thoroughly before proceeding. When these models are completed, they will be used to show passive solar principles. Let's get started . . .

1. Gather all the materials found in the bill of materials.

2. Set each tray on its long side and measure the height needed for a rest block to wedge the tray front plumb. (Diagram 4.) Also measure the length of the trays and then cut four rest blocks to these heights and lengths. Smooth and paint them.

3. Mark the location of each rest block, drill two mount holes, then screw or bolt the block to the tray.

Diagram 4



4. Center a handle on the top side of each tray and mark the mount holes. Drill the holes and and fasten with bolts and washers.

Average Building Model

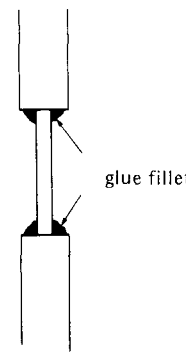
5. Place one tray, opening down, on a corner of a scrap piece of 1/4" plywood. Even two adjacent sides flush with two adjacent edges of the plywood. Trace the tray rim outline on the plywood.

6. Using a band, jig, or sabre saw, cut along the tracing. Shape and smooth the edges.

7. Mark off a small window opening, approximately 4" x 6" in size, in the center of the plywood piece. Drill entry holes and cut out. Sand all edges and surfaces smooth.

8. Cut a small piece of clear acrylic plastic sheet to fit this opening. Center this sheet in the opening and apply a bead of thermal glue or silicon sealant to "fillet weld" both the front and back of the window. (Diagram 5.) Glue all around.

Diagram 5

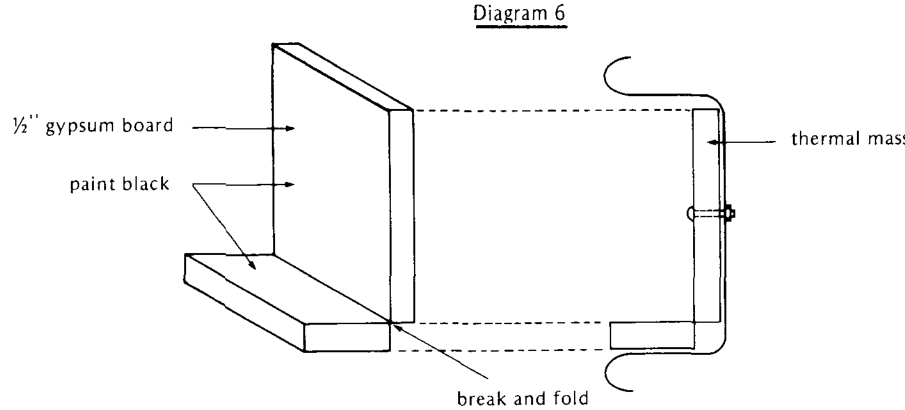


9. Prime and paint the plywood panel white. (Don't paint the window.) Align the panel with one of the tray units. Drill and bolt together in 6 places (2 top, 2 bottom, 1 each side). Congratulations! You have just completed one of the four models.

Direct Gain Model

10. Place a second tray on the corner of a piece of acrylic plastic as described in Step 5. Trace, cut, sand, and buff the edges of the plastic sheet. Try not to scratch the plastic.

Diagram 6



11. Cut, score, and bend a piece of 1/2" gypsum board to fit the tray's back wall and floor (lower side). (Diagram 6.) Paint this flat black and bolt to the tray interior.

12. Align the plexiglass with the tray front. Drill and bolt together in 6 places. You have now completed the direct gain model.

Indirect Gain Model

13. Repeat Step 10 to fabricate another acrylic glazing.

14. Select a piece of gypsum board (sheet rock) and repeat Step 10 once more. Cut the board with a utility knife.

15. Lay out ten one-inch diameter holes as shown in Diagram 7. Drill carefully half way through with a hole saw. Flip over and finish drilling. Smooth all edges and holes.

16. Repeat Steps 14 and 15 to construct a second thermal wall unit.

17. Smooth both gypsum wall units and paint flat black on all surfaces.

18. Align the third tray unit, a thermal wall unit, and an acrylic plastic glazing. (Diagram 8.) Clamp lightly, lay out, and drill six bolt holes. Check the assembly drawing for details.

19. Remove the glazing and apply a bead of rope caulk around the edge of the acrylic plastic. Do not pinch flat. Reassemble as shown in Diagram 8 and bolt together using the fingers only. <u>Remember, finger tight only</u>.

Diagram 7

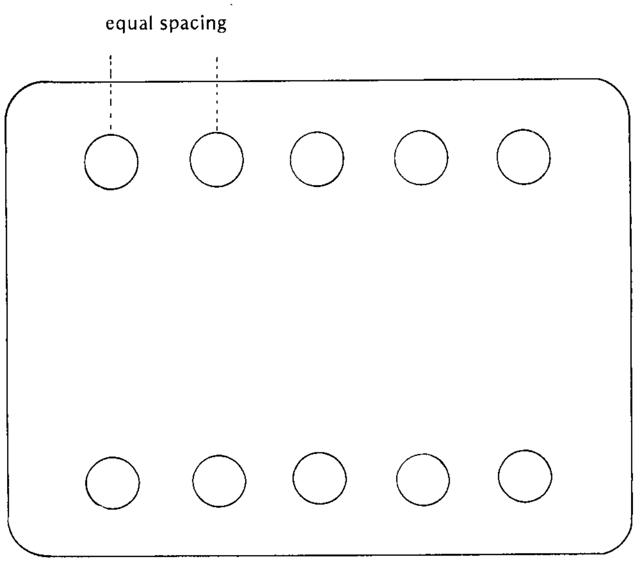
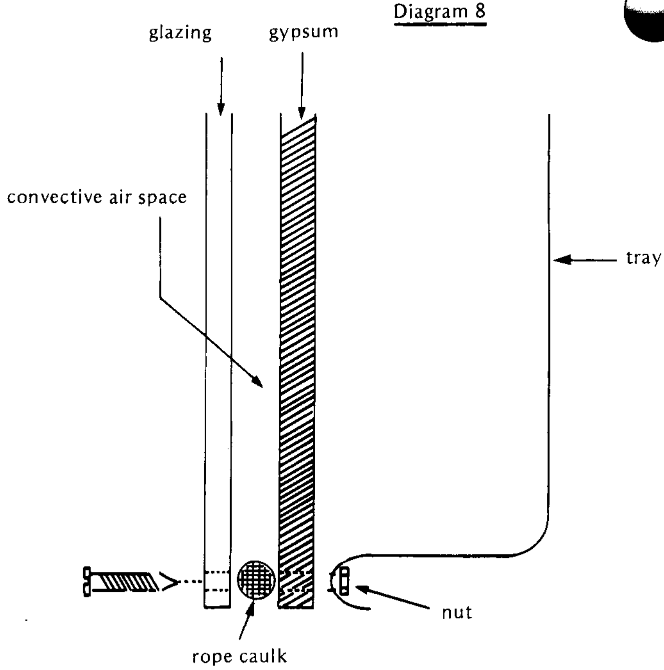


Diagram 8



20. Turn all six bolts a half turn more with a screwdriver to flatten and seal the caulk. Only one more model to go.

Isolated Gain Model

21. Paint the floor area of the remaining tray unit flat black. Let dry.

22. To finish the last model you need to build a model greenhouse. Obtain a sheet of clear acrylic plastic. Build a five-sided greenhouse as shown in the assembly drawing. Since exact sizes will vary with the tray size you're using, you will have to plan the sizes of the sides yourself. Allow a 1/2" wide air escape slot adjacent to the roof/thermal wall joint, as shown in Diagram 9. Lay out each side, then cut, sand, and buff the edges.

23. Cut, punch, and bend four attachment tabs as shown in Diagram 10. Attach these tabs to the two side pieces of the greenhouse according to the assembly drawing.

24. Use plexiglass glue to glue the greenhouse sides together. Start with the bottom and side pieces, then add the front piece and finally the top.

25. Line up the attachment tabs of the greenhouse with the second thermal wall unit constructed in Step 16 and the remaining tray. Mark off the holes, drill, and bolt the pieces together.

26. Label and clean up all four units. You're finished! Now it's time to see how the models work.

Diagram 9

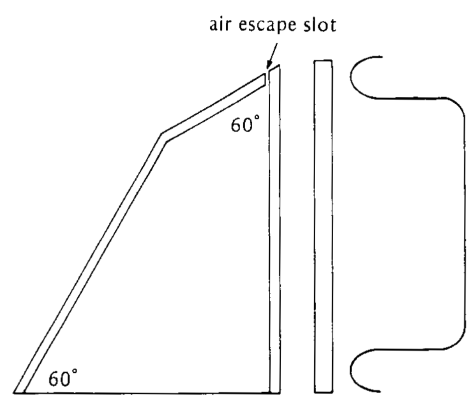
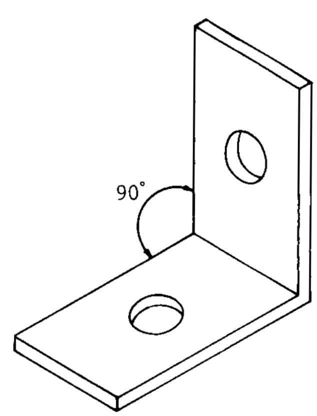


Diagram 10



Questions

1. List and then explain how each of the three passive solar heating systems works.

2. Predict which type would be most effective in trapping the sun's energy. Why did you predict as you did?

3. Predict which type would be least effective in trapping heat energy. Why did you predict as you did?

4. Which type would be least effective in retaining heat at night? Why?

5. List one advantage and disadvantage of each type.

6. Select one system and describe how your home could be adapted to use it.

Looking Back

You have now constructed four mini-buildings. One model represents an average wall with one window. Each of the other three represents one of the major passive systems. As you look over the models, can you see the major differences among them?

In the next two activities, you will test and compare these models for both passive heating and passive cooling. Which model do you think will provide the most heat and which the most cooling? Can you think of ways to adapt the models for cooling their interiors?

Going Further

Ask your instructor for a list of books on passive and active solar heating systems.

Visit local solar homes and report on the operation of their systems.

Build a solar storage shed and sell it for profit.

Build thermosiphoning air panels, bread box hot water heaters, or add-on greenhouse kits.

Design a passive solar home.

Look for problems, such as night-time heat loss, and develop solutions.

Is there a local architect or builder of solar designs willing to visit your school to talk about his/her work?

Suggested Grade Level and Skill Area

8th Grade Industrial Arts
General Shop
Power Mechanics
Woods/Carpentry
Architectural Drawing
Alternative energy courses

Skill Objectives

Basic fabrication skills necessary to construct passive solar models, including layout, cutting, assembling, finishing, and inspecting

Content Objectives

Passive solar homes are designed to maximize heat gain from the sun.

The three major passive systems are the direct gain, indirect gain, and isolated gain systems.

Heat from the sun can be stored in a thermal mass wall.

Background

Every house on earth is 92% solar heated, because without the sun the earth's temperature would be that of space, about -240°C. When we use fossil fuels to heat our homes, we are actually providing only 8% of the total heat needed, even though our pocketbooks might tell us differently. The goal of a passive solar house, then, is to reduce that 8% as much as possible and to provide nearly 100% solar heating.

Passive solar can be easily incorporated into house design. It becomes simply a matter of making people aware of passive solar concepts and their simplicity. This activity illustrates passive design concepts through the building of four house models.

The first model represents an average room with one window. Solar gain is low and slow. This serves as a control model.

The second model represents the direct gain concept of passive solar heating. A large window area transmits the sun's energy and the black thermal mass of the room absorbs and converts this radiant energy into heat. Most direct gain systems have thermal mass in the form of masonry floors, fireplaces, or water containers. In our model, heat collection occurs readily and storage is provided by the black gypsum-board walls and floor.

The third model represents the concept of indirect solar gain. Sunlight strikes an absorber or collector surface just inside the glass wall of a room or building and is converted to heat. The wall and surrounding air are warmed by conduction and reradiation, and when vents are added to the top and bottom of the absorber, convective air loops are set up which help to heat the room. The wall can absorb large amounts of the sun's energy, thus providing heat storage and reducing heat loss, but at the expense of immediate thermal gain. Temperature swings, however, are reduced. Solar cooling can also be coupled with this technology.

The fourth model represents the concept of isolated gain. An added-on room becomes a collector which can provide its own heat and heat the house as well. This technology embraces both the heat-producing greenhouse and the food-producing greenhouse, which differ primarily in the location of the thermal storage mediums. These mediums include water, sand, rock, phase change materials, and zeolites. This "add-on" passive unit lends itself well to retrofit applications as well as to new construction.

Construction of the models fits well into industrial arts projects and the learning of fabrication skills. Operations from planning to finishing and inspection are included. Best of all, a useful teaching/learning aid is produced to advance the basic principles behind the most easily adapted and practical of solar technologies.

Advance Planning

Read up on passive solar. You may well want to build more than just a model.

Gather materials well ahead of time. Lab thermometers may be borrowed from science teachers, but be prepared to lend them your finished products. They'll be in great demand.

Don't hesitate to substitute parts and/or improve the design, but make sure you change any directions that are affected by the substitution.

Try to use scrap or recycled materials as much as possible. Students may be able to bring discarded materials from home.

Develop a good passive library and mark your books. Don't lend, but make copies for interested folks.

Suggested Time Allotment

Time will vary with length of periods, student ability, and grouping.

With eight students (2 per model) working 30 minutes each day, 5 days a week, and including lessons, tests, and practical exams, the units should take from two to four weeks to construct.

Suggested Approach

Fabrication lessons and demonstrations may have to be given prior to steps that involve planning, layout, cutting, shaping, smoothing, assembly, and finishing.

To minimize errors, spend time going over and interpreting plans.

To cut down on fabrication time and expense, two or three students could be assigned to build one model.

Plan field trips to local passive homes and assign students to report on their findings.

Invite solar dealers and contractors to discuss passive design with the class.

Precautions

Don't leave the units in the sun for protracted periods of time.

Keep the units as similar as possible to avoid uncontrolled variables in testing.

The units may require some small vent holes to allow proper venting.

Oversee student progress and anticipate problems.

Points for Discussion

Identify and discuss the basic fabrication techniques.

Discuss alternative construction methods.

Identify and discuss construction problems.

Compare active solar heating with passive solar heating.

Ask students to list passive system advantages and disadvantages.

Compare a high-technology approach to a low-technology approach.

Discuss the meaning of appropriate technologies.

Typical Results

Students might encounter some of the following construction problems.

> Fastening the window in place in the control model might be difficult. Develop alternatives.

The direct gain model must have a scratch free glazing. Drill slowly with light pressure so as not to chip the acrylic.

Use care in cutting and drilling the acrylic and gypsum board on the indirect gain model. The torque on the assembly bolts should just seal the glazing yet allow a 3/16" convective air space in front of the mass wall.

If students display a lack of desire to achieve quality workmanship, remind them that accurate test results will depend on consistent and well-built models.

Evaluation

Were the plans accurately followed?

Are the handles and backrest block well-centered, located, and secured?

Are the component parts well-made?

Are the joints well-fitted and fastened?

Is the overall product attractive and well-finished?

Ask the students to evaluate their own work and then discuss their and your evaluation with them.

Develop a written instrument to indicate the students' understanding of the content objectives.

Modifications

Use tote trays to build water and air collectors.

Scale models larger.

Substitute materials as desired but keep parts standard across units to achieve equivalent results under testing.

Add insulation, shutters, and thermal mass alternatives.

The greenhouse could pose the greatest problem in this construction unit. Brainstorm alternatives. Did you consider stereo covers, bubble packaging, clear plastic trays, and a folded and stapled storm window plastic sheet?

References

Home Energy for the Eighties, Ralph Wolfe & Peter Clegg. (Garden Way Publishing Company, Charlotte, VT 05445, 1979, $10.95/ paper.)

New Inventions in Low Cost Solar Heating, William A. Shurcliff.
(Brick House Publishing Company, 3 Main Street, Andover, MA 01810, 1979, $12./paper.)

Other Homes & Garbage, Jim Leckie, et al.
(Sierra Club Books, 530 Bush Street, San Francisco, CA 94108, 1975, $9.95/paper.)

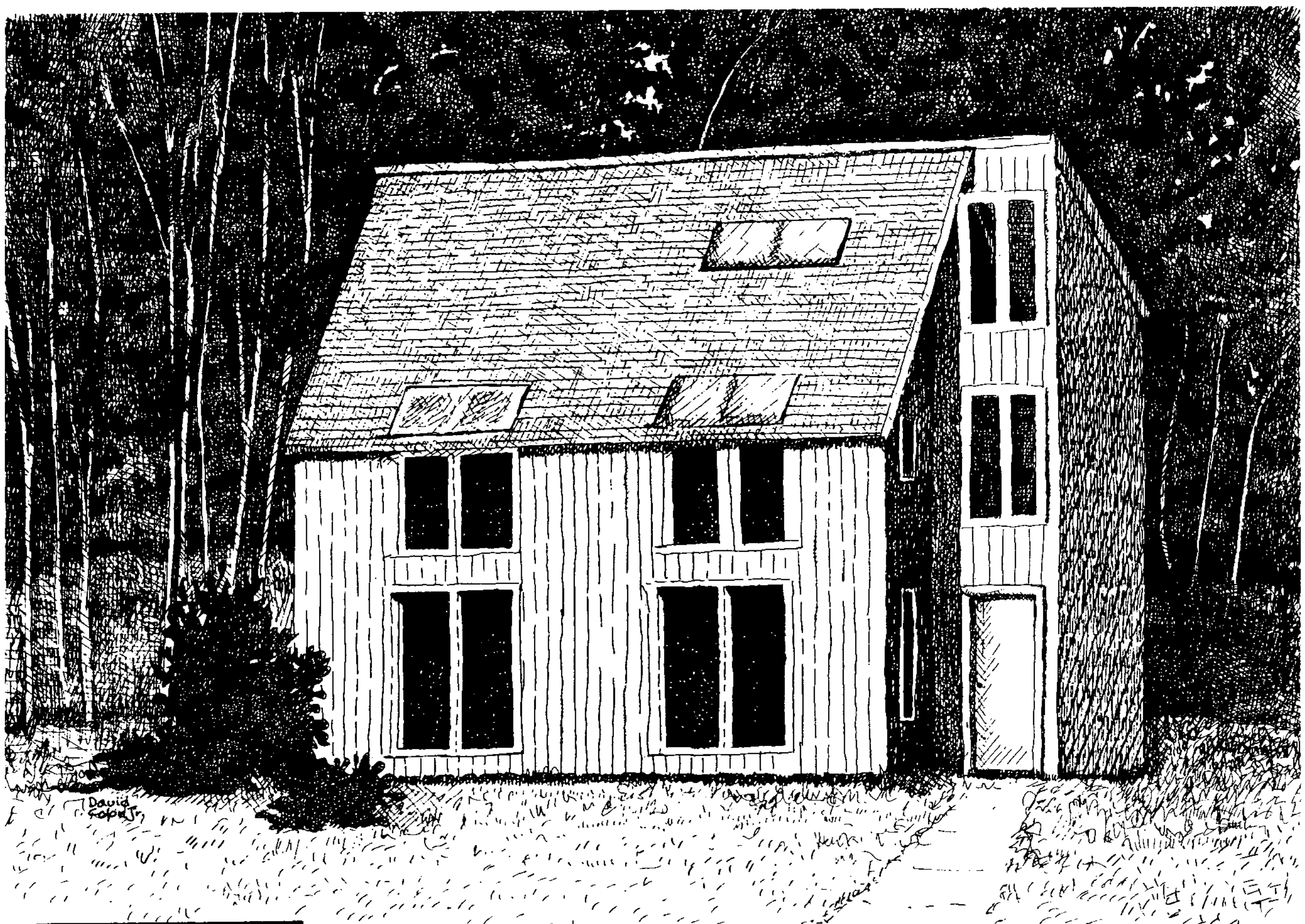
The Passive Solar Energy Book, Edward Mazria.
(Rodale Press, 33 East Minor Street, Emmaus, PA 18049, 1977, $8.95/paper.)

Sun/Earth, Richard Crowther.
(Scribner & Sons, 597 Fifth Avenue, New York, NY 10017, 1978, $8.95/paper.)

Thermal Shutters & Shades, William A. Shurcliff.
(Brick House Publishing Co., 3 Main Street, Andover, MA 01810, 1980, $12.95/paper.)

Your Energy Efficient House, Anthony Adams.
(Garden Way Publshing Company, Charlotte, VT 05445, 1975, $8.95.)

Passive Solar Heating



Introduction

A passive solar home functions like a giant solar collector. In such a home, solar radiation is collected through south-facing windows and converted to heat. Large amounts of insulation then trap this heat within the home for as long as possible.

In the previous activity, you constructed models of four housing designs. In this activity, you will use these models to see how each functions in passive solar heating. Although your models don't have insulation to keep the heat in, their collection and storage capabilities will be obvious. How well will each design work to collect and store heat from the sun? Which design do you think will provide the greatest amount of solar heating?

Objectives

At the completion of this activity, you should be able to

- o adapt the mini-buildings for thermometers,
- o record and graph data on the heating and cooling of the models,
- o explain how each model functions in collecting and storing heat, and
- o determine which models function best in collecting and storing heat.

Skills and Knowledge You Need

How to read a laboratory thermometer and stop watch or wrist watch.

How to record and graph data

Materials and Equipment

the four building models:

the average house model (control)
the direct gain model
the indirect gain model
the isolated gain model

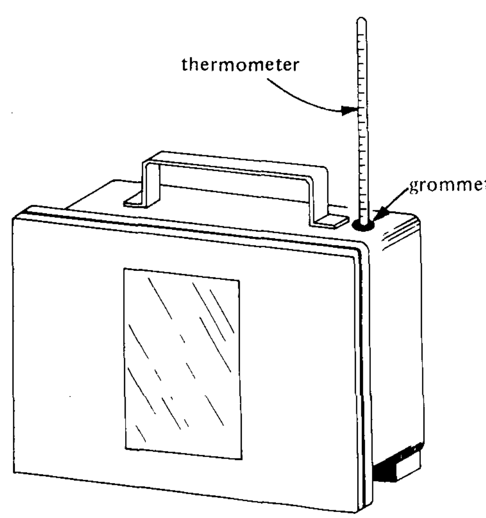
five laboratory thermometers (glass tube or dial type)

four rubber grommets to fit thermometers

stop watch or wrist watch with second hand

graph paper

colored pencils



Procedure

1. For each building model, mark off and drill a hole in the same location in the top corner of the tray, as shown in the diagram above. The hole should match the outside diameter of the grommet tube.

2. Attach the grommets and then insert the thermometers to the same depth in each model. Shield the thermometer bulbs from direct sunlight using white paper and tape.

3. Allow the thermometers to stand a few minutes. Then record indoor temperature readings for each model on Data Table 1.

4. Find a level spot outdoors in the sun which is protected from the wind. Face the extra thermometer and the models into the sun. Immediately take thermometer readings and record them.

5. Continue to record temperatures at one minute intervals until all temperature readings level off. You will know this has occurred when readings remain about the same for several minutes. This is the saturation or stagnation temperature.

6. Bring the four units back into the laboratory. Use Data Table 2 to continue recording until all temperatures return to room temperature, about 20 minutes.

7. Prepare graphs of the data you have collected. "Time in minutes" should appear on the x-axis and "Temperature in Celsius" on the y-axis. If you record all data on the same set of axes, use colored pencils and a key to distinguish each model's temperature curve.

Questions

1. Which models heated the fastest? The slowest? Which models cooled the fastest? The slowest?

2. Which models heated to the highest temperature? The lowest temperature?

3. Which model held the heat the longest? The shortest?

4. Which model functioned best to just collect heat?

5. Which model functioned best to store heat?

6. Explain why each unit functioned as it did.

7. What do you think would happen if more thermal mass were added to Models 3 and 4?

8. What do you think would happen if more insulation were added to the models?

9. Which of the three passive solar techniques would you choose to incorporate into a house of your own design? Why?

10. Describe how the technique you chose would actually function in this house. Describe modifications you would make to improve the functioning. Some suggestions include insulating shutters, overhangs, landscaping. Why would these modifications be necessary?

Looking Back

Did the four mini-buildings function as you predicted? Your data should have indicated that the control model (normal wall with single window) collected and stored little heat. The direct gain model should have reached the highest temperature and then cooled slowly, showing some heat storage.

The indirect gain and isolated gain models may have functioned similarly to one another, showing a modest temperature rise and then slow cooling. Your graphs will have appeared more level, showing that as heat was collected it was stored in the mass wall (instead of causing high temperatures in the models) and then released slowly to maintain temperatures when the models were taken out of the sun.

By now you've learned the three basic ways that buildings can collect and store the sun's energy. In the next activity, you will find out if buildings can also be cooled by the sun.

Going Further

Try adding insulation, thermal shutters, or additional thermal mass to your models. Record and graph data. Do they function differently than before?

Tape small plastic flaps above the top row of holes on the back of the thermal walls of Models 3 and 4. Explain how these flaps would work to slow the cooling of the models. When and how would flaps such as these actually function on a mass wall?

Send for information from passive home builders and review their individual building systems.

Organize a field trip to nearby passive solar homes.

Design working retrofits for your own homes and build them.

Data Table 1

Time (minutes)	Outside Air Temperature	Model 1 Control	Model 2 Direct Gain	Model 3 Indirect Gain	Model 4 Isolated Gain
Indoor Temp.	X				
Heating Phase 1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					

Data Table 2

Time (minutes)	Room Air Temperature	Model 1 Control	Model 2 Direct Gain	Model 3 Indirect Gain	Model 4 Isolated Gain
Cooling Phase 1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					

Passive Solar Heating

Suggested Grade Level and Skill Area

8th Grade Industrial Arts
General Shop (9-10)
Power Mechanics
Woods/Carpentry
Architectural Drawing
Alternative energy courses

Skill Objectives

Proper instrumentation of models

Sequential timing for data collection

Collecting, recording, and interpreting data

Comparing and evaluating passive heating systems

Content Objectives

Additional glazing on the south side increases both solar gain and heat loss in a building.

Thermal mass increases heat storage and maintains temperature stability.

A normal wall with a single window will show the smallest heating effects from solar energy.

Direct gain passive systems will demonstrate rapid heating to high temperatures during sunlight hours and slower cooling without sunlight.

Indirect and isolated gain systems will moderate temperature fluctuations through heat storage in mass walls. Temperatures will rise slowly during the day and fall slowly at night.

Background

The four major types of modern homes include the low energy home (LEH), the active solar home, the passive solar home, and the hybrid solar home. Low energy homes are well insulated, are above or below ground, and require air handling and conditioning systems. Active solar homes are also well insulated, but are heated by solar collectors and require pumps or fans to operate. Passive solar homes are well built, insulated, and use the sun for heat, but require no auxiliary power for fans or pumps. A passive solar home can be easily turned into a hybrid home, incorporating many or all of the features of the above systems.

The mini-buildings constructed in the previous activity illustrate the major types of passive design. The control model in the activity will reflect the sun's warming rays from its white exterior. The small standard window will allow only minimal sunlight to enter. Heat gain will be low and the increase in temperature slow.

The direct gain model will collect heat rapidly through its large window wall. The black gypsum board thermal mass will absorb the sun's energy, store it, and then reradiate it as heat. This model will show immediate and high increases in temperature when in the sun, and will then cool more slowly when removed from the sun. Its large window will radiate heat away and temperatures will fall as heat is removed from the storage mass.

The indirect gain model will collect heat rapidly, but not warm the room immediately, as the thermometers will show. As sunlight strikes the black thermal wall, it is changed to heat and stored by the high heat capacity of the wall. When removed from the sun the wall will release its heat slowly and continue the warming effect. Temperatures will moderate over time. Many different kinds of wall types are actually used to provide desired interior environmental effects in buildings.

The isolated gain or greenhouse model will operate much like the indirect gain model, with the greenhouse area warming quickly and the room more slowly. In this model, thermal mass is located between the two rooms in the form of a common wall. However, the mass can be located either in the greenhouse itself or in the adjacent interior room. In a real building the kind and location of thermal mass will determine whether the greenhouse is used to provide just food, just heat for the home, or both.

Advance Planning

For best results, perform the research on a clear day. Plan other back-up activities and pull this one out of your sleeve on that bright, sunny day.

Group your materials, including the pre-constructed building models, thermometers, grommets, graph paper, stop watch.

Additional insulation, thermal mass, and insulated shutter materials can be collected and left nearby for that imaginative group of students.

Obtain different insulation materials such as foil, polystyrene foam, foil-foam combinations, Thermax and high-R sheathing, spun glass, and loose-fill for students to experiment with.

Collect mass containers and substances such as water bottles, water cans, anti-freeze, rocks, masonry, bricks, phase-change chemicals, and zeolites.

Suggested Time Allotment

One/two periods to conduct activity and graph results.

One to two weeks for additional research and testing using various insulations, thermal masses, and insulating shutters.

Suggested Approach

Students can be divided into groups of three of four, with one student assigned to handle a model, another to read temperatures, and a third to record data. Others can serve as assistants. This can be done for each model. One student can serve as class timer.

Set up the outside test area in advance.

Do a dry run inside for practice, then de-bug and reorganize.

Hold a discussion session the day after the activity is performed. Encourage students to go further.

Precautions

Don't allow the units to overheat.

Sunglasses reduce reflections from the glazings.

Thermal mass does get hot. Use gloves or tongs if handling it.

If insulation is used, have students take appropriate precautions such as wearing goggles, face masks, and gloves.

Points for Discussion

How well did each unit function in collecting and storing heat?

What are the operating principles behind each unit?

How is heat storage accomplished in each unit?

Compare the advantages and disadvantages of each unit in providing heat from solar energy.

If we were to design a passive solar home, which system should we choose? Why?

How could we adapt this system to our design in order to improve and regulate solar gain and to reduce heat loss? Would house site be important to our choice of system and adaptations? Why or why not?

Which system would work best in a retrofit application? Why?

Typical Results

The control model will show the smallest and slowest temperature increase and will rapidly return to the original temperature.

The direct gain model will show a rapid temperature increase and then slower decrease upon removal from the sun. This model should reach the highest temperature.

The indirect and isolated gain models will show temperature modulation. Temperatures will increase and also decrease slowly, indicating heat storage in the mass walls.

Evaluation

Check students' adaptations of the models for passive heating.

Examine data and graphs for accuracy.

Check answers to questions for evidence of student understanding.

Ask students to explain the differences in performance of the models.

Modifications

Additional insulation, thermal mass, and use of thermal shutters can demonstrate increased heat storage.

Various types of insulation can be tested to determine greatest resistance to heat loss.

Various types of thermal mass can be tested to determine greatest effectiveness in heat storage. Suggestions include water, anti-freeze, rocks, bricks, phase-change chemicals, and zeolites.

References

Home Energy for the Eighties, Ralph Wolfe & Peter Clegg. (Garden Way Publishing Co., Charlotte, VT 05445, 1979, $10.95/paper.)

Homeowner's Guide to Solar Heating, Sunset Books. (Lane Publishing, Willo & Middlefield Roads, Menlo Park, CA, 94025, 1979, $3.95.)

New Inventions in Low Cost Solar Heating, William A. Shurcliff. (Brick House Publishing, 3 Main Street, Andover, MA 01810, 1979, $12.00/paper.)

1979 NYSERDA Passive Solar Design Awards. (NYSERDA, Albany, NY, 12234, 1979, $7.00.)

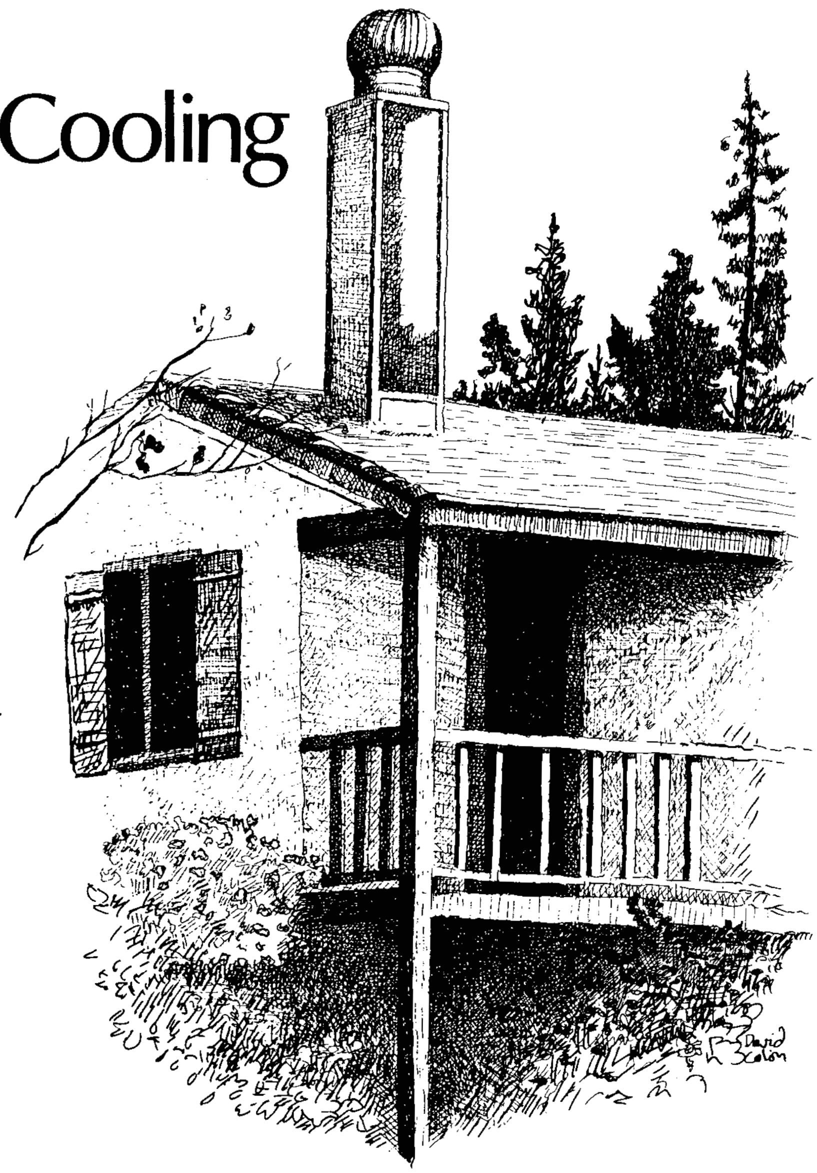
Other Homes & Garbage, Jim Leckie, et al.
(Sierra Club Books, 530 Bush Street, San Francisco, CA, 94108, 1975, $9.95/paper.)

30 Energy Efficient Houses You Can Build, Alex Wade & Neal Ewenstein.
(Rodale Press, 33 East Minor Street, Emmaus, PA 18049, 1979, $8.95/paper.)

Your Energy Efficient House, Anthony Adams.
(Garden Way Publishing Co., Charlotte, VT 05445, 1979, $10.95/paper.)

DRAFT

Passive Solar Cooling

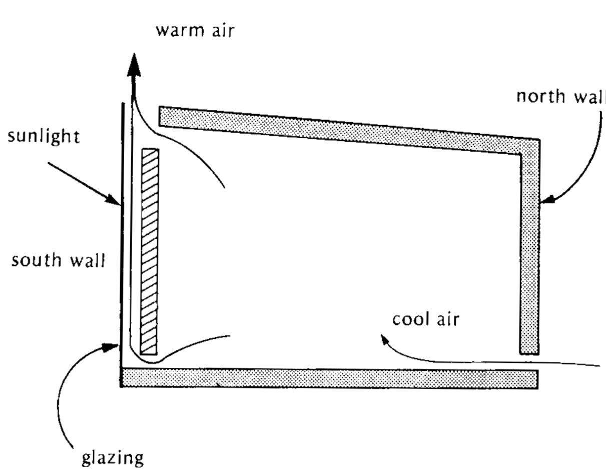


Introduction

You have seen that passive solar techniques can be used to heat buildings. But they can be used to cool buildings as well. In this activity you will adapt your building models for passive solar cooling by adding inlet and outlet vents and overhangs. Then you will test them to see how well they perform in cooling. Which model do you think will provide the coolest temperature?

A roof overhang that shades south-facing windows from the hot summer sun is the most obvious means of passive cooling. The overhang prevents the sun's direct rays from entering the windows, thus reducing heat build-up in the house.

Diagram 1



In addition, passive solar cooling can take advantage of convection currents to vent warm air from a building and to draw cool air in. Outlet vents are added to the roof of a building and inlet vents to the cool north side. Or underground inlet tubes are added to cool the air as they draw it in. As air is warmed in this building, it rises and escapes through the roof vents. Cool air moves in through the north side vents or underground tubes to replace it. As a result, convection is used, without pumps or fans, to cool the building.

Open skylights, wind-activated turbine ventilators, and solar chimneys can be used as roof vents. The solar chimney is a new technique in the United States. A plywood box is built through the roof with glazing on the south side and siding on the others. The interior of the chimney is painted black to convert sunlight to heat. The air inside the chimney is heated and rises from the vent, and a convection current is set up. A black stove pipe will also produce this effect and provide passive cooling when a cool air intake vent is added to the house.

Objectives

At the completion of this activity, you should be able to

- o explain how convection currents work to provide passive cooling in your models,
- o record and graph data on the passive cooling of your models,
- o determine which model functions best in passive cooling,
- o describe how each model operates in passive cooling, and
- o explain the importance of overhangs and shading in passive cooling.

Skills and Knowledge You Need

Basic fabrication skills

How to read a thermometer and a stop watch or wrist watch

How to collect and graph data

Materials and Equipment

general shop equipment including drills, jig and table saws, hand tools, and workbenches

the four passive building models

compass

five thermometers

graph paper

cardboard, thin plywood, or sheet metal for overhangs

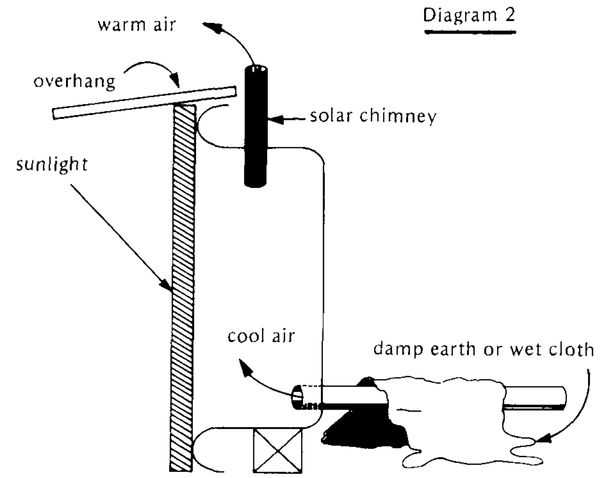
four pieces 2" copper or steel tubing, 6 - 8" long and fitted with a flange about 1 - 2" from one end

four 2" copper or steel pipes or conduits, 18 - 24" long

damp earth or wet cloths

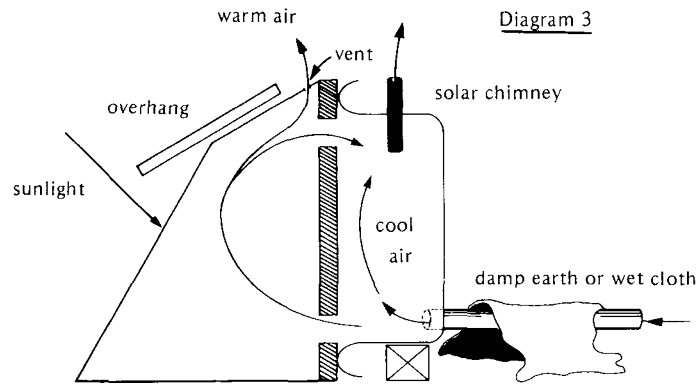
colored pencils

Procedure

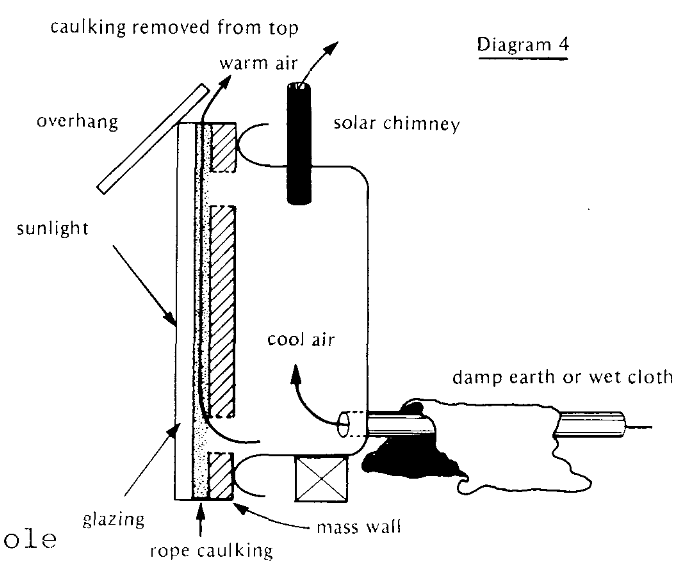


1. Drill a two-inch hole in the bottom center of the back wall in each building model, as shown in the diagrams. Obtain the four long pipes to place in each hole. These will act as your underground cooling tubes.

2. Drill a second two-inch hole in the top of each model. Obtain the four flanged pipes and paint them black. They will act as stovepipe vents or solar chimneys.



3. For each model, cut a strip of cardboard, thin plywood, or sheet metal the length of the model and of sufficient width to shade the glazing when it is in the sun. The control and direct gain models should be completely shaded, the isolated and indirect gain models partially shaded (about 75%). Before you cut, experiment in the sun with these overhangs to determine the correct width. Tape the overhangs in place. In the greenhouse model, cut the overhang to cover the top of the glazing and to extend out over the front. (Diagram 3.)



4. Place the indirect gain model on the workbench. With an awl or curved pick, remove the strip of rope caulking from the top only. Leave the caulking intact on the sides and bottom. (Diagram 4.)

5. Take all four models outside in the sun. Use the compass to face them south. Place the roof pipe into the hole in the top of each model. Place the cool air pipe into the hole

in the back of each model. Tape in place. Then cover the cool air pipe with damp earth or a wet cloth.

6. Insert a thermometer into the grommet in each model. Use a fifth thermometer to record outside air temperatures. Immediately take a reading on each thermometer and record it in the Data Table.

7. Continue to record temperatures every minute for 30 minutes.

8. Return the building models to the classroom and store them safely.

9. Graph the data you obtained. Plot "time in minutes" on the x-axis and "temperature (^{O}C)" on the y-axis. If you plot the data for each model on the same set of axes, use different colored pencils for each line. Remember to key or label each line.

Questions

1. Explain how each model functioned to provide passive cooling.

2. Which of the models showed the smallest temperature increase? The largest?

3. If you were to design your own home, which model of passive solar cooling would you incorporate? Why?

4. How could strong breezes affect natural venting? How could these natural breezes be used to aid in cooling?

5. How did the roof overhang function in passive cooling? Why were the indirect and isolated gain models only partially shaded?

6. Compare passive heating curves with passive cooling curves for each model. If you were to design your own home, which model would you incorporate to provide both passive heating and cooling? Why did you choose this one?

7. How could passive heating and cooling be controlled in an actual home?

8. What are the advantages of owning a passive solar house? The disadvantages?

Looking Back

When the sun's energy strikes a dark object, it is absorbed and reradiated as heat energy. In a passively heated solar house, the purpose is to trap and store this heat energy for as long as possible, releasing it as needed when the house cools.

But a passively heated house can also be passively cooled. In a closed space such as a house, the trapped heat will warm the air, the warmed air will rise, and cooler, more dense air will replace it. By placing outlet vents, such as a solar chimney, at the top of the house and inlet vents along the north side of the house, convection currents can be created. The warmed air will rise and leave the house and cool air will be drawn in from outside to replace it. Long, underground inlet vents will increase this cooling effect. The result is a passively cooled solar house.

By now, you've learned that this passive cooling really works. Your model buildings heated only slightly, even in the direct rays of the sun, and they remained well below the temperatures obtained in the passive heating activity. But your models are small and cannot provide a large convection air flow. Imagine the passive cooling capacity of a real house.

What are the advantages of homes that are heated and cooled by the sun? Besides the fact that energy in these homes is free (after the initial cost of installing the systems), the environment is also free -- from air pollution caused by burning fuels, from ravaged land caused by strip-mining, from water pollution caused by oil spills.

Going Further

In summer, homes are kept cool by the natural shading of deciduous trees, which leaf out and shield the entire house from the sun's rays. This kind of natural shading can reduce inside temperatures by as much as 5°C. Use potted plants to provide your models with this kind of shading and redo the activity. Did it change the results? Why or why not?

Remove the roof overhangs and redo the activity. How were the results changed? Which models should have roof overhangs to aid in cooling?

Add insulation to the four models. Redo the activity to see if this increases passive cooling. Try different types of insulation to see if they affect results.

Read about passive cooling techniques. Especially research current magazines for new information on solar chimneys and ventilation systems.

Place thermometers in the intake and exhaust vents to record cool and hot air temperatures. Place small pinwheels at vents to indicate rate of air flow. Compare models for intake and exhaust temperatures and rate of air flow.

Data Table

Passive Cooling

Time (minutes)	Outside Air Temperature	Model 1 Control	Model 2 Direct Gain	Model 3 Indirect Gain	Model 4 Isolated Gain
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					

Suggested Grade Level and Skill Area

8th Grade Industrial Arts
General Shop (9-10)
Power Mechanics
Woodworking/Carpentry
Architectural Drawing
Alternative energy courses

Skill Objectives

Using general fabrication skills to adapt the building models for passive cooling

Reading, recording, and interpreting data

Comparing and evaluating passive cooling systems

Content Objectives

Convection currents can be utilized to provide passive cooling in homes.

Intake vents will draw cool air in and outlet vents will release warmed air.

Underground tubes will cool intake air. Solar chimneys will heat air inside them to increase the rate of convection flow.

Overhangs and natural shading are needed to reduce solar gain in passive buildings.

Background

The three passive systems in the solar heating activity demonstrate the production, storage, and retention of building heat. But this heat can also be vented to the outside, creating strong convection currents in the building. These currents draw cool air through inlet vents to replace the hot air exhausted to the outside.

Underground tubes, north wall inlet vents, and roof-top outlet vents are constructed in passive homes. Coupled with shading devices such as trees, vines, awnings, and roof overhangs, this passive system provides natural air conditioning. Warm air rises and leaves the building through the outlet vents in the roof, while cool air flows in through the underground tubes and inlet vents to replace it.

Passive cooling is an age-old technique used extensively in hot, dry climates. We recommend that you keep up with passive cooling techniques by reading the current literature.

Advance Planning

Most of the materials and apparatus have been constructed and/or acquired in the previous two activities.

Conduit and copper waste pipe shorts can be used for the inlet and outlet vents.

Suggested Time Allotment

Two to four days to modify the building models.

Two to four days to run the activity and graph data.

Continued experimentation could continue for another one to two weeks.

Suggested Approach

Use the approach that worked best for you in the solar heating experiment, such as assigning a small group of students to each model.

Precautions

Don't allow any modification to the models that will prevent future classes from using them in the heating activity.

Points for Discussion

Discuss Bernoulli's principle. How can vents be constructed to utilize this principle? Why use it in passive cooling?

Describe the application of Venturi tubes to the activity.

Describe the process of convective air flow.

How can Bernoulli's principle, Venturi tubes, and the convection process be combined to naturally remove air from a building with a direct gain system? An indirect gain system? A greenhouse?

Where are outlet vents best placed in buildings?

How can incoming air be naturally cooled? Where should inlet vents be located?

Using natural air movement principles, design a cooling system for a small building.

Which model would work best in a new design? In a retrofit design?

How can convective air flow principles be used to cool an existing house, without making construction changes?

Typical Results

All units will heat when placed in the direct sunlight, as does a real house. However, temperatures should rise only slightly, not nearly as much as in the passive heating activity.

The indirect and isolated gain models should show the greatest cooling effects. They will have the lowest temperatures. The indirect and isolated gain models should only be partially shaded by roof overhangs because it is important to maintain the thermosiphoning effect of the systems. This provides an increased convective air flow and increased passive cooling.

Evaluation

Examine the quality of workmanship and design of each model's cooling system.

Check students' graphs and answers to questions.

Ask students to describe how each unit functioned in passive cooling.

Ask students to sketch designs for full-size passive or hybrid solar homes.

Develop a short test to evaluate students' achievement of content objectives.

Modifications

Any modifications are acceptable that do not interfere with the solar heating or cooling techniques described.

Adaptations of natural shading features, such as potted plants and vines, can be used in testing the models. Students can investigate whether these shading features increase passive cooling effects. Caution: Don't set indoor plants in direct sunlight. Instead use outdoor potted plants, trees, or shrubs for shading.

If obtaining short lengths of pipe for the roof vents is a problem, large diameter plastic tubes (one side painted black), rolled sheet plastic, or rolled black construction paper can be substituted.

The solar chimney can be replaced by a skylight which vents to the outside. Plastic bubble packs can be used for these skylights.

References

Design for a Limited Planet, Living With Natural Energy, Norma Skurka & Jon Baer. (Ballantine Books, 201 E. 50th St., New York, NY, 10022, 1976, $5.95.)

Natural Solar Architecture, A Passive Primer, David Wright. (Van Nostrand Reinhold Co., 135 W. 50th St., New York, NY, 10020, 1978, $7.95.)

Solar Dwelling Design Concepts, The AIA Research Corp. (Superintendent of Documents, US Government Printing Office, Washington, DC 20402, #023-000-00334-1, 1976, $2.30.)

Sunspots, Steve Baer. (Cloudburst Press, 2116 Western Ave., Seattle, WA, 98121, 1979, $5.95.)

The Passive Solar Energy Book, Edward Mazria. (Rodale Press, Inc., 33 E. Minor St., Emmaus, PA, 18049, 1979, $10.95.)

"Cool Tubes", Julie Lalo. (New Shelter, Rodale Press, Inc., 33 E. Minor St., Emmaus, PA, 18049, July/August 1980, Vol. 1, No. 5, pp. 22-25.)

"Passive Cooling Systems in Iranian Architecture", Mehdi N. Bahadori. (Scientific American, 415 Madison Ave., New York, NY, 10017, February, 1978, Vol. 238, No. 2, pp. 144-154.)

"The Thermal Chimney", John Burton and Jeff Reiss. (New Shelter, Rodale Press, Inc., 33 E. Minor St., Emmaus, PA, 18049, July/August, 1980, Vol. 1, No. 5, pp. 25-28.)

DRAFT

A Photovoltaic Demonstrator

Introduction

Have you ever wondered why solar collectors are often mounted at angles different from those of the roofs they are placed on, or about the effectiveness of the different kinds of glazings (transparent cover materials) you see on different collectors? In this activity, you are going to build a solar demonstrator to help you determine the answers to these questions.

This demonstrator will consist basically of a photovoltaic (solar) cell connected to a milliammeter. A photovoltaic cell converts sunlight directly into electricity. The intensity of the sunlight determines the amount of electricity produced. This fact will allow you to measure a number of things, such as

how much light different collector glazings transmit,

the position of the sun in the sky at any particular time,

the direction and angle at which a solar collector should be placed to receive maximum solar energy at any particular time, and

how weather conditions affect solar intensity.

Objectives

At the completion of this activity, you should be able to

- o construct a solar demonstrator,
- o measure the output of the demonstrator as a function of the sun's azimuth, altitude, and intensity, and of the demonstrator's angle of inclination,
- o measure the output of the demonstrator as a function of the transmittance of glazings, and
- o define transmittance, azimuth angle, solar altitude, angle of inclination, and glazing.

Skills and Knowledge You Need

Woodworking skills, including safe use of drill press, table saw, router, and hand tools

Graphing skills

Materials and Equipment

3/4" plywood

photovoltaic cell

hinges (two)

clips (two)

milliammeter

wire for electrical connections

screw type electrical connectors

screws

plexiglass sheet

compass

several solar collector glazings, such as glass, plastic, acrylic, and various commercial products

1/2" band iron

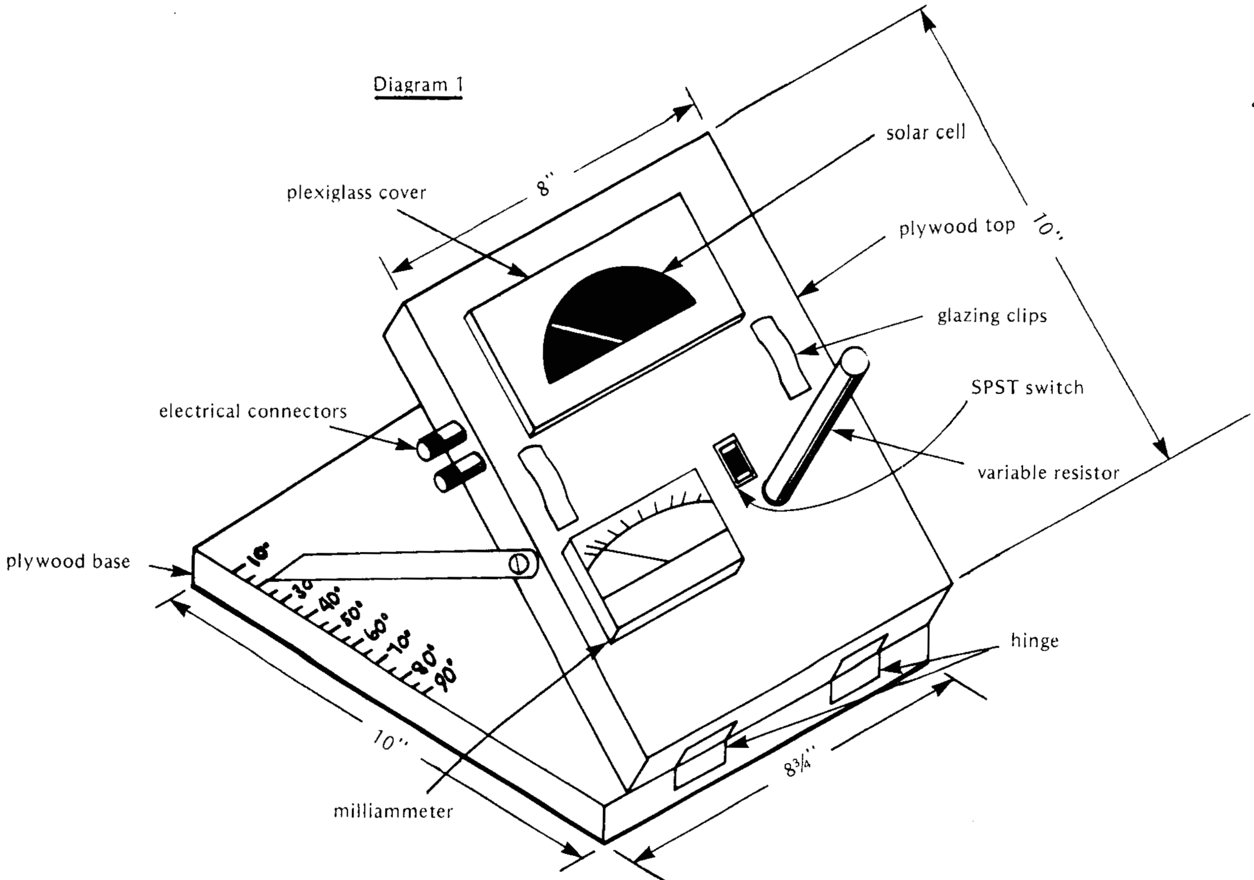
epoxy

variable resistor (5K)

SPST switch

protractor

Diagram 1



Construction Procedure

1. Cut out, sand, and finish wood parts to the specifications shown in Diagram 1. Cut 6" of band iron and sharpen one end as shown in the diagram.

2. With a router, rout out a depression slightly larger than the solar cell and 1/16" deep. Also rout spaces for the wires and a space for the SPST switch.

3. Drill holes for the solar cell wires, milliammeter, and the variable resistor.

4. If the solar cell does not have presoldered wire leads, a lead must be carefully soldered to either side. Use extra care to make sure no solder leaks over edge.

5. Assemble the wooden sections as shown in Diagram 1. Attach band iron support.

6. Insert the solar cell into its depression. Feed wires through the drilled hole.

Caution: Solar cells are very expensive and very fragile. Mount the cell very carefully.

7. Cut the plexiglass sheet to cover the solar cell and screw it into place.

8. Attach the milliammeter, variable resistor, electrical connectors, switch, and remaining wiring.

9. Wire the circuit as shown in Diagram 2. Be sure to wire the variable resistor in parallel with the meter. Be sure to check the polarity of the solar cell before final connections are made.

10. Attach two clips to hold glazings.

11. Align a protractor with the demonstrator's hinges. Lift the top section of the demonstrator, stopping at 5^o intervals. At each stop, carefully mark the position of the sharpened end of the band iron with a felt-tip marker. Label each mark neatly in degrees of inclination.

Diagram 2

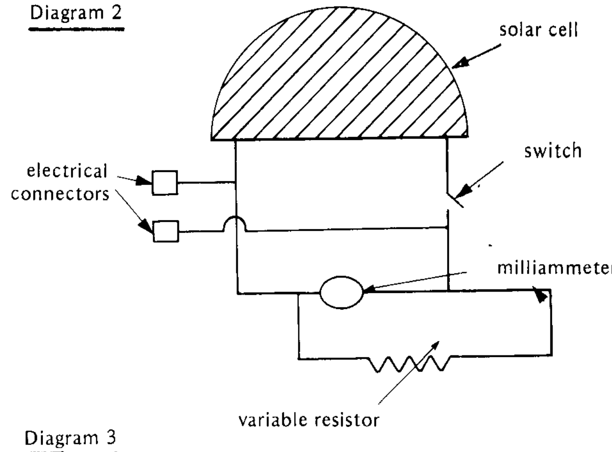
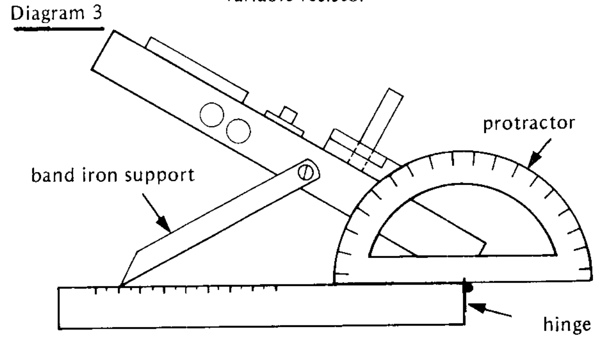


Diagram 3



Procedure

1. Determining the angle of azimuth of the sun (the distance of the sun from true south)

   a. Set the demonstrator at 45^o in an outside area free of shadows, buildings, or trees. Note the time of day.

   b. Sight the demonstrator along the following compass points: N, NE, E, SE, S, SW, W, and NW, and take a meter reading at each point.

   c. Plot readings on Graph 1.

   d. Select the compass point with the highest reading. Sight the demonstrator at 5^o intervals around this compass point. The highest reading will give you the approximate angle of azimuth of the sun for the time of day you noted. Solar azimuth tells you the distance of the sun from true south.

   e. Repeat Step 1 for another time of day.

2. Determining the best angle of inclination for the demonstrator by finding the altitude of the sun (the height of the sun in the sky)

   a. Set the demonstrator at the angle of azimuth you found in Step 1.

b. Position the top section of the demonstrator at 5° inclination intervals and take a meter reading at each interval. Start with 0° and end with 90°.

c. On Graph 2 plot meter readings vs. degrees of inclination.

d. Select the inclination with the highest meter reading. Subtract from 90° to obtain the solar altitude for the time of day you noted. Solar altitude tells you the height of the sun in the sky.

e. Repeat Step 2 for another time of day.

3. Determining solar intensity

a. Keeping the same angle of azimuth, set the solar demonstrator at the angle of inclination which yielded the highest reading in Step 2.

b. Take meter readings several times a day over several days, carefully noting time, day, meter reading, and especially sky and weather conditions.

4. Determining the transmittance of glazing

a. Set the demonstrator at the angles of azimuth and inclination found in Steps 1 and 2.

b. Use the variable resistor to set the meter to 1.

c. Insert test glazings between the clips and record the meter readings.

d. Construct a bar graph representing types of glazings and the percent of light transmitted.

Questions

1. What angle of solar azimuth did you find for the first time of day? For the second time of day?

2. Were these angles of azimuth the same? Why or why not?

3. What angle of solar altitude did you find for the first time of day? For the second time of day?

4. Were these angles of altitude the same? Why or why not?

5. If you were to install a solar collector that would work at peak efficiency, for what time of day should you choose azimuth and altitude angles? Why?

6. As the seasons progress, what happens to the values of the sun's azimuth and altitude?

7. Based on your observations in Step 3, what are the effects of time of day and weather conditions on the output of a photovoltaic cell? How would these affect a solar collector?

8. Why was the meter set at 1 in Step 4?

9. Which glazing produced the greatest transmittance in Step 4? The least?

Looking Back

You found that there were many factors which affected the performance of your solar demonstrator, including solar azimuth and altitude, angle of inclination of the demonstrator, time of day, weather conditions, and transmittance of the glazings placed over the cell.

Data such as you collected in this activity can be used to help you actually choose and orient a solar collector. You now know the percentage of light various glazings transmit, as well as the proper angles for placing a collector at a particular time of day. With this information, you are well on your way to installing your own solar collector. But remember that solar azimuth and altitude angles change over the course of a day and of a year. For this reason, solar collectors are usually installed at angles averaged on a daily and yearly basis for your latitude.

Going Further

Find the solar altitude and azimuth angles at solar noon. You will have to research how to determine solar noon.

Graph solar altitude and azimuth as a function of time of day on September 21, December 21, March 21, and June 21. This will give you a sun chart for your latitude.

Visit local solar installations to find out which collector angles are used and why.

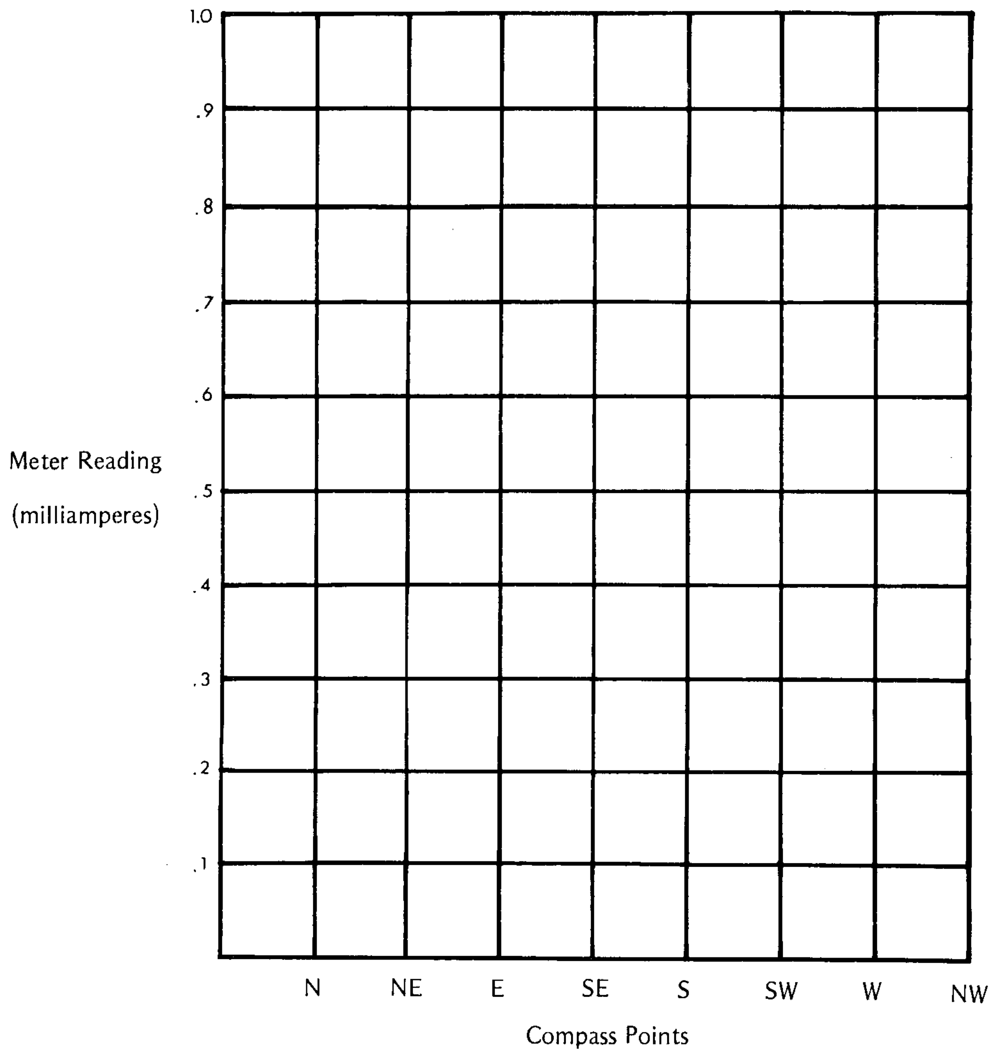
Compare the prices of various glazings with the transmittance measurements of those glazings.

Prepare weekly, monthly, seasonal, and yearly averages of optimum angles of inclination at noon for solar collectors in your area.

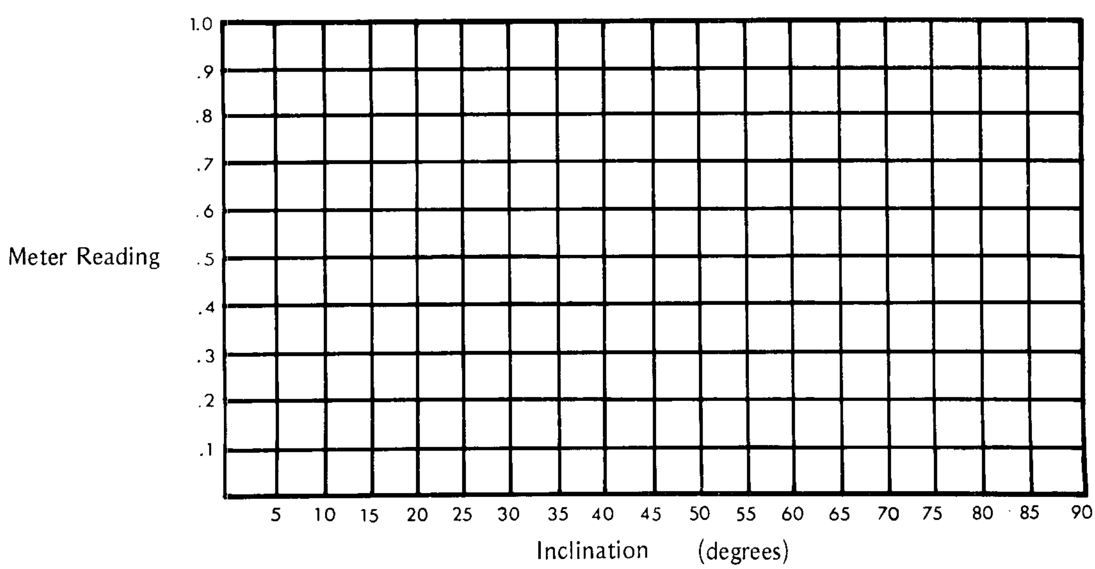
Convert meter readings to langleys and determine average amounts of insolation for sunny, hazy, overcast, and very cloudy days.

Compare your values of transmittance for various glazings to the manufacturers' specifications.

Graph 1



Graph 2



Teacher Information

A Photovoltaic Demonstrator

Suggested Grade Level and Skill Area

9-12 Industrial Arts
Woodworking
Electricity
Energy Technology

Skill Objectives

Using a table saw, router, drill press, and some basic woodworking tools

Soldering and basic wiring.

Reading, collecting, graphing, and interpreting data

Determining solar altitude and azimuth from data

Content Objectives

Solar altitude and azimuth are a function of the time of day and season of year.

Different kinds of glazings (cover materials) will transmit different amounts of light.

The angle of inclination of a solar collector should be a function of the solar altitude.

The compass direction of a solar collector should be a function of the solar azimuth.

Weather and sky conditions will affect the performance of a solar cell.

Background

A photovoltaic or solar cell is a thin disc or rectangle composed of two layers of a semi-conductor, usually silicon, "doped" with arsenic for the negative N-layer and with boron for the positive P-layer. When light strikes the semi-conductor layers, its energy knocks electrons loose. These electrons flow through connecting wires, creating an electrical current.

This production of electricity in the presence of light is a continuing process. No materials are consumed and the cell will thus operate indefinitely. However, solar cell life expectancy is dependent upon both heat and the innate fragility of the thin discs and tiny electrical connections.

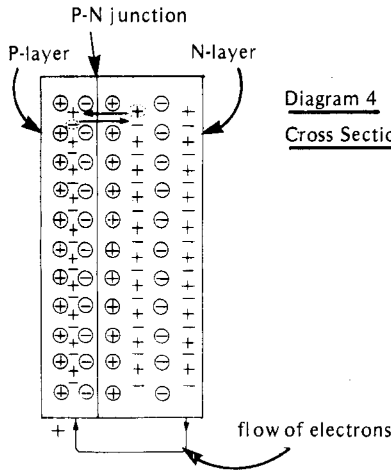


Diagram 4

Cross Section of a Photovoltaic Cell

Today, because of their high cost, solar cells are used only in remote applications, where power grids are not available. They power our satellites and remote weather stations, harbor buoys, and microwave stations. But concentrated research may soon result in a manufacturing process that will reduce solar cell costs substantially.

The solar cell can easily be used as a test instrument because of the direct relationship between sunlight striking the cell and the electricty produced. The solar demonstrator constructed in this activity is just such an instrument. It can be used by students to study the daily and seasonal movements of the sun, as well as the transmittance of different kinds of glazings. From this, students can learn how to orient solar collectors and choose glazings for them. In the process they will learn something about the properties of solar cells.

Advance Planning

Be sure to allow enough time for construction of the demonstrator prior to its use.

Suggested Time Allotment

Allow a minimum of 10 class periods for construction.

Each of the lab activities takes about one class period.

Suggested Approach

Once the apparatus is constructed, it can be used in other years for the lab exercise.

Define and explain altitude and azimuth before students begin collecting data.

It is best to give students background information on photovoltaics prior to the activity. Also have several references available to the students for clarifying terms and further reading.

Use the activity as a lead-in to active solar heating.

Precautions

Solar cells are extremely fragile. Caution students to treat them gently. (In some cases, you may want to mount the cells yourself.)

As always, all shop rules apply when constructing this project, especially wearing safety glasses and knowing the correct use of the tools.

Caution students against looking into the sun.

Points for Discussion

Go over the questions in the student section and stress the implications of the answers.

Why would you possibly orient a collector a little east of south?

Why does a solar collector work even on an overcast day?

At what azimuth and inclination angles would you set a solar collector for a swimming pool? For a hot water heating system? Why?

Typical Results

Various solar books, such as Bruce Anderson's The Solar Home Book, contain average solar azimuth and solar altitude angles for all latitudes in the United States.

Sun charts, such as those found in Edward Mazria's The Passive Solar Energy Book, will give altitude and azimuth as a function of month and time of day. Student results will vary somewhat from these values.

Azimuth angles at midday will vary slightly from true south, depending on student accuracy.

Students should obtain some values for the meter readings even on cloudy days.

Modifications

Collect various glazings ahead of time. Solar collector dealers may be a source of test samples.

A multimeter may be substituted for the milliammeter and variable resistor. Connect multimeter to electrical clips.

References

Direct Use of the Sun's Energy, Farrington Daniels.
(Ballantine Books, 201 East 50th Street, New York, NY, 10022, 1974, $1.95/paper.)

Solar Energy, John Hoke.
(Franklin Watts, 730 Fifth Avenue, New York, NY, 10019, 1978, $4.90.)

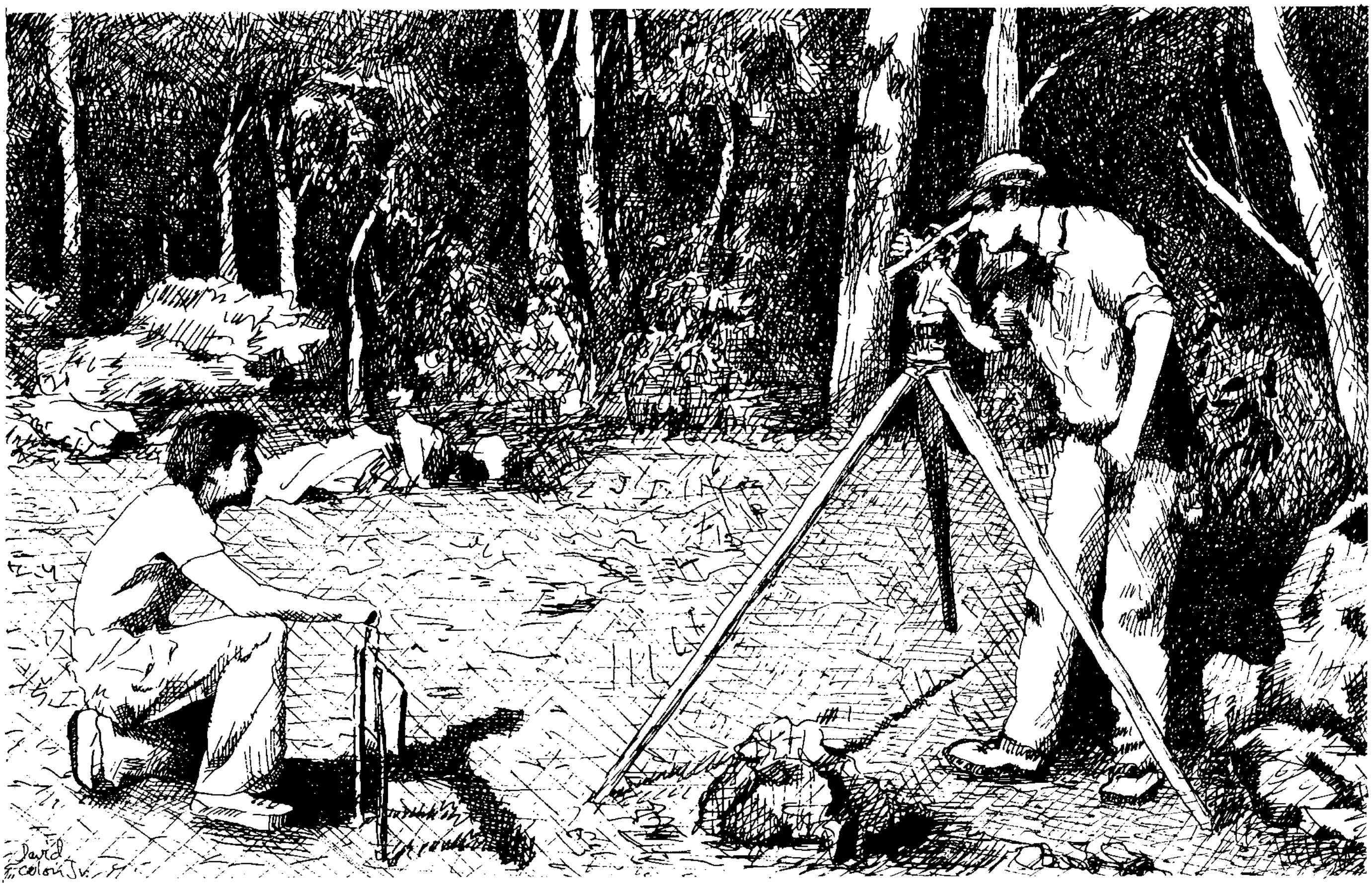
Solar Science Projects for a Cleaner Environment, D.S. Halacy, Jr.
(Scholastic Book Service, 50 West 44th Street, New York, NY, 10056, 1974, $.85.)

The Passive Solar Energy Book, Edward Mazria.
(Rodale Press, 33 East Minor Street, Emmaus, PA, 18049, 1979, $10.95.)

The Solar Home Book, Bruce Anderson and Michael Riordan.
(Cheshire Books, 514 Bryant Street, Palo Alto, CA, 94301, 1976, $8.50/paper.)

DRAFT

How to Site a Solar House



Introduction

Recently you may have heard people talking about building solar homes. Someone you know may even be building one. A solar home can employ either an active or a passive solar heating system. In an active system, solar collectors trap the sun's energy and change it to heat, and pumps or fans circulate the heat collected to the interior of the house. In a passive system, the house itself acts like a giant solar collector.

No matter what kind of solar house is being built, though, certain solar siting features can increase both solar collection and energy conservation. In this activity, you'll select a plot of land and analyze its potential as the site for a solar house.

Objectives

At the completion of this activity, you should be able to

- make a sketch of a plot of land,
- identify landscape features which increase solar heating and cooling effects,
- choose a location for a house based on these solar landscape features, and
- analyze the advantages and disadvantages of a particular house site.

Skills and Knowledge You Need

Simple sketching

Identifying geographic features and evergreen and deciduous trees

Taking compass readings

Making cardboard models

Doing basic algebra

Materials and Equipment

sketch pad and pencils

100 foot measuring tape

tracing paper

compass

Procedure

1. Select a 1 to 2 acre plot of land as the potential site for your "dream house". You can choose the plot of land your own home stands on, land on the school property, or any other land you have access to.

Caution: Be sure to obtain the landowner's permission before you start.

2. Sketch the site from a "bird's eye" view. Include geographical features such as hills, valleys, streams, ponds, and rock outcrops. Add existing buildings, roads, trees, and shrubs. Draw all features approximately to scale and indicate both heights of features and the distances between them. (See Diagram 1.)

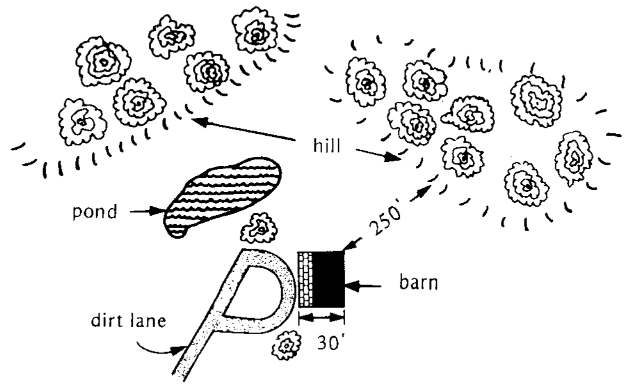


Diagram 1

To make an exact determination of an object's height, measure the height of a stick placed straight into the ground. Then measure the length of the stick's shadow and the length of the object's shadow. The height of the object can be found by:

$$\frac{\text{height of object}}{\text{height of stick}} = \frac{\text{shadow length of object}}{\text{shadow length of stick}}$$

3. Check for such things as wet spots, rocky soil, and rock ledges, and sketch on an overlay of tracing paper. You now have the start of an overlay map.

4. Find out the direction of the winter winds in your area and look for natural windbreaks on your site. These usually block the wind for a distance equal to five times the height of the windbreak. (See Diagram 2.) On another overlay of tracing paper, plot the areas that will be affected by windbreaks or existing buildings (same rules apply). Remember that only coniferous (evergreen) trees can act as windbreaks in winter.

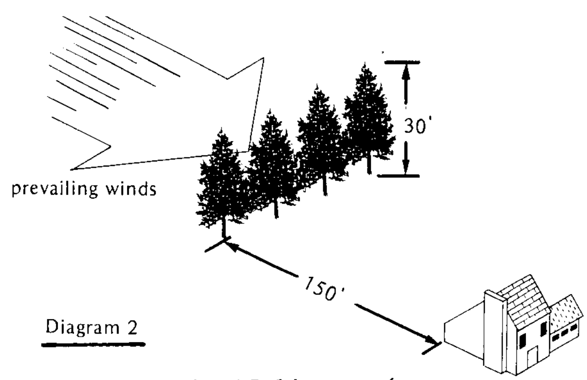


Diagram 2

5. In the same manner, plot the shading effect of deciduous (leafy) trees and existing buildings. Assume that these objects will shadow the area to their north a distance of 3/4 their height. (See Diagram 3.)

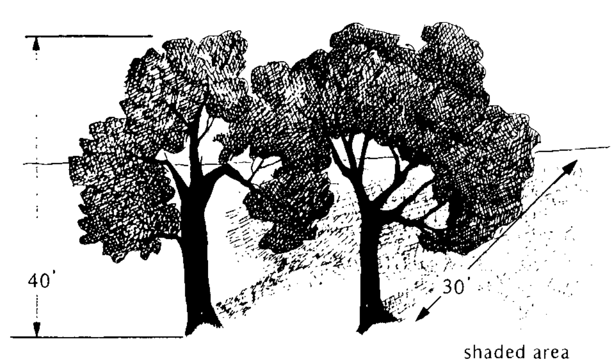


Diagram 3

6. Find true (solar) south for your site by determining the time that is exactly midway between sunrise and sunset. This is solar noon. Place a peg upright in the ground and observe its shadow at solar noon. It will point true north. True south is 180° from true north. Mark true north and south on your map. With a compass, measure the number of degrees they deviate from magnetic north and south. Note this on your map.

7. Choose a suitable location for your dream house by studying the maps and overlays. A scaled cardboard model of your house can be moved around the site map and will help you see the effects of the various features of the site.

   What factors contribute to siting a solar house? An ideal site would include

   - coniferous trees on the windward side to act as a windbreak,
   - shrubs in front of the windbreak to further reduce winter wind,
   - vegetation placed to channel the cooling summer breezes toward the house,
   - deciduous trees on the south side to block the hot summer sun; in winter, these trees will be leafless and the sun will shine through them to warm the house,
   - the south side of a hill in climates where the winter is cold and the summer temperate, the southeast side of a hill in climates where the winter is temperate and the summer hot,
   - a mid-slope location for the house in order to avoid the windswept peak and the cold valley, and
   - a house placed so most of its windows face south to catch the warming rays of the winter sun.

   Draw the location of your house on the map.

8. Obviously, an ideal house site is not always available. List the advantages and disadvantages of the site you chose. Don't forget to list such factors as view, road access, and ease of extending power lines, as well as the passive solar factors you considered above.

9. On another overlay, plan and sketch additional landscaping to increase the solar siting effect. Add windbreaks, shrubs, and deciduous trees as necessary.

Questions

1. What are the advantages and disadvantages of the site you chose?

2. What solar landscaping improvements did you make to the site?

3. Which solar landscape features were you able to use in locating your house?

4. What are the advantages of placing a house on the west side of a valley so that it faces east? On the east side so that it faces west?

Looking Back

How are home sites actually chosen? All too often home builders just place a home on a plot of land so that it faces the road. They don't bother to examine the site and determine its solar potential. With the high cost of energy today, can we afford to continue bulldozing all the trees from home sites? Can we afford to neglect the potential of the site itself to help warm and cool our homes?

In this activity you learned that coniferous trees and shrubs can act as windbreaks, that deciduous trees can provide cooling shade in summer but allow winter warming by the sun, and that geographic features affect solar siting. You also learned that additional landscaping can improve the solar effect of a site.

Going Further

Draw a side profile of the location you chose for your house. What additional information does this give you in analyzing the site?

Does your site show potential for an earth-bermed or underground home? Research current articles for information on siting these styles of passive solar house.

Perform a site analysis for someone who is building a house.

Have a solar builder speak to your class about choosing a home site. Ask to go along with him when he inspects a site.

Take some photos of the site you analyzed and have them reviewed by a professional builder.

Teacher Information

How to Site a Solar House

Suggested Grade Level and Skill Area

9-12 Industrial Arts
Alternative Energy
House Construction
Home Economics

Skill Objectives

Mapping a potential home site

Identifying the solar features of a site

Analyzing the effect of site features on a solar house

Properly orienting and locating a house on a site

Content Objectives

To receive direct solar gain, a house must be properly oriented on a site. The majority of windows should face the south, a few or none, the north.

Coniferous trees and shrubs should be placed to reduce wind force. Deciduous trees should be placed for shading in summer, direct gain in winter.

Vegetation should be planted to channel summer breezes toward the house.

The house should be placed among geographic features to reduce wind force and increase passive gain, except in year-round warm climates.

Background

From the time man first erected permanent wooden shelters, he knew that careful planning of the site could make the house more comfortable. Taking advantage of nature, colonial builders in the northeast erected saltbox houses. These houses directed the north winds over the sloping roof and faced two stories to the warming southern sun. At many of these home sites, the remains of pine windbreaks are still evident, as are the "bride and groom" trees planted in the front yard to block the hot summer sun.

In hot, humid climates the ranch house was developed, maximizing heat loss and minimizing heat gain by its large surface area. Builders added large windows and louvers for natural ventilation and extended overhangs for shade. In the hot, arid climate of the southwest, builders turned to adobe, which acted as a heat sink to moderate the wide temperature fluctuation between day and night.

Choosing and preparing a site were also important. Northern builders looked for a location where a hill would break the force of the wind. Lacking this, a barn or shed was placed on the windward side to protect the house. Windbreaks were planted on the side of the prevailing winter winds to further reduce wind force. Trees were removed from the southern and eastern sides of the site, except for a few well-placed deciduous trees, so that the sun could warm the house in the winter. The kitchen was usually placed on the east side of the house so that it would be the first room to heat in the morning.

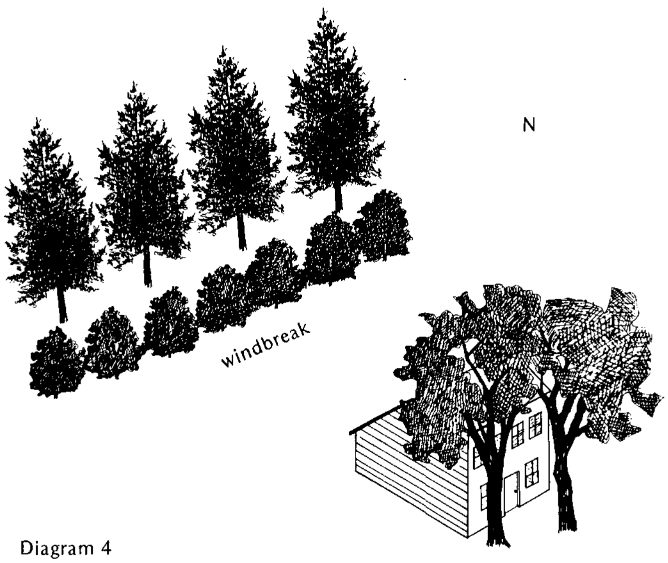


Diagram 4

Southern builders looked for a site on the eastern slope of a hill so that the house would be protected from the hot afternoon sun. Vegetation was planted so that it channeled the cooling summer breezes toward the house. Houses were often located at the crests of hills to take the maximum advantage of summer winds.

Unfortunately, many of these methods of siting a home were completely forgotten during the era of "cheap energy". But returning to these methods can significantly reduce the cost of heating a home. Just planting a windbreak, for example, can reduce heating costs by 12-15%.

Advance Planning

Inform students of the activity ahead of time so they can choose their sites.

Students should have background in solar design prior to the activity.

Review solar design concepts during the activity.

Have tracing paper and sketch pads available to students at the beginning of the activity.

Suggested Time Allotment

Allow approximately three weeks for total activity. Students will need time both to locate and to analyze the sites.

Each phase of the activity should take about 30 minutes in the field.

Suggested Approach

Choose a site on or near school property where you can run through the activity with the students before they select their own sites. They may need instruction in sketching, identifying geographic features, determining heights of trees and buildings, taking compass readings, and finding solar south.

If a suitable location exists on or near school property, all students could analyze this site with direct teacher supervision. It would be interesting to compare results among students. Each student could then be assigned to do an individual site analysis.

This activity provides a good lead-in to a discussion of career opportunities in solar energy fields, especially solar home design and construction. Local passive and active solar builders could be invited to speak to the class about career opportunities as well as solar home design, siting, and construction.

Precautions

Make sure students obtain the landowner's permission before selecting a site.

Caution students against such hazards as rotting buildings, poison ivy, poison oak, snakes, and old wells.

Points for Discussion

What are the advantages of making a site map?

Which are the most important considerations in selecting a passive solar site?

What effect would plans for an earth-bermed or underground house have on site selection? What additional site features would need consideration?

Students can display their site maps and discuss the reasons why the house locations were chosen.

Typical Results

Results will vary depending on the site the student has chosen. In general, proper siting should reflect the points discussed in the activity.

Answers to Question #4 should indicate that western slopes lose their snow earlier in the spring due to afternoon radiant heating, that eastern slopes catch the morning sun, and that a hill to the west deflects the prevailing northwest winds.

Evaluation

Check maps for neatness, accuracy, and completeness.

Students' rationales for site selection and orientation should be carefully scrutinized and discussed with them.

References

Natural Solar Architecture, David Wright.
(Van Nostrand Reinhold Co., 135 West 50th Street, New York, NY, 10020, 1978, $7.95.)

The Passive Solar Energy Book, Edward Mazria.
(Rodale Press, 33 East Minor Street, Emmaus, PA, 18049, 1979, $10.95.)

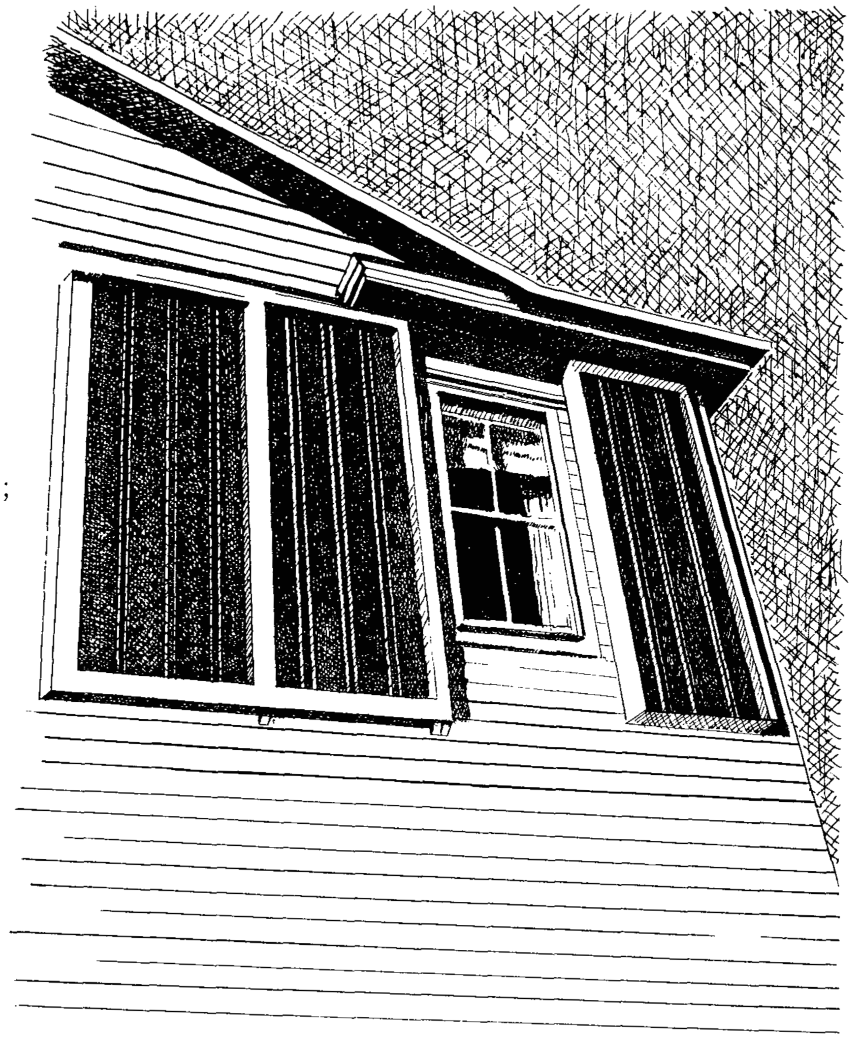
"Build and Remodel for Energy Efficiency", Save Energy, Save Dollars, Bulletin 17, Cooperative Extension. (Mailing Room, 7 Research Park, Cornell University, Ithaca, NY, 14853, $1.50.)

"How to Site a House", Terry Hallock.
(Yankee, Dublin, NH, 03444, May, 1980.)

"Landscape to Save Energy", Save Energy, Save Dollars, Bulletin 18, Cooperative Extension. (Mailing Room, 7 Research Park, Cornell University, Ithaca, NY, 14853, $1.50.)

DRAFT

A Thermosiphoning Collector



Introduction

Solar collectors are simply devices that convert the sun's radiant energy into heat energy, which can then be used to warm houses or buildings. A typical collector has four basic parts: a glazing (transparent cover material) which transmits solar radiation; an absorber plate which absorbs this radiation and converts it to heat; insulation which keeps this heat from escaping; and a transfer fluid, usually either air or water, which transports the heat to where it's needed.

Collectors which use air as a transfer fluid have several advantages. There is little maintenance, leaks won't cause damage, and the heated air can be fed directly into the house or building. And an air collector works well as a thermosiphoning system, which means that no pumps are needed to transfer the fluid.

But how does a thermosiphoning collector work? The collector is placed below the point where the heated air is fed into the building. As the air in the collector is heated, it expands, becomes less dense, and rises into the building. Cooler air then flows into the bottom of the collector to replace the rising warm air. In this way cooler air is continually heated and fed into the building.

In this activity, you'll build a thermosiphoning air collector, and then test it to see how it performs. Perhaps you'll even be able to connect it to your house or classroom to provide heat.

Objectives

At the completion of this activity, you should be able to

- o construct a working thermosiphoning air collector,
- o test the collector to determine how well it performs,
- o explain how a thermosiphoning air collector operates, and
- o suggest improvements in the design of the collector.

Skills and Knowledge You Need

How to safely use a drill press, a table saw or skill saw, and a metal band saw or sabre saw

How to use common woodworking tools

How to properly use a box and pan brake

How to fasten

How to record and graph data

Materials and Equipment

two 4" flanges

10' insulated flexible duct or vent hose

two 4" pipe clamps

two 2" x 6" x 8' boards (collector sides)

1/2" x 24" x 8' exterior plywood or Aspenite

two 20½" x 8' corrugated roofing tin sheets (for absorber plate)

1 sheet 1/2" insulated sheathing (Hi-R)

1 sheet of 22¼" x 8' glazing material such as Filon, Kalwall (.040" thickness), or tempered glass

two 1" x 6" x 24" pine (collector end pieces)

two 1" x 2" x 21" pine (collector middle supports)

two 1" x 1" x 21" pine (collector end supports)

two 1" x 1½" x 88" pine

table saw or portable circular saw

3/8" electric drill

drill press

metal band saw, sabre saw, or electric shear flycutter or hole saw (3" - 4")

pop rivet gun

box and pan brake

$1\frac{1}{2}$" x 8" screws

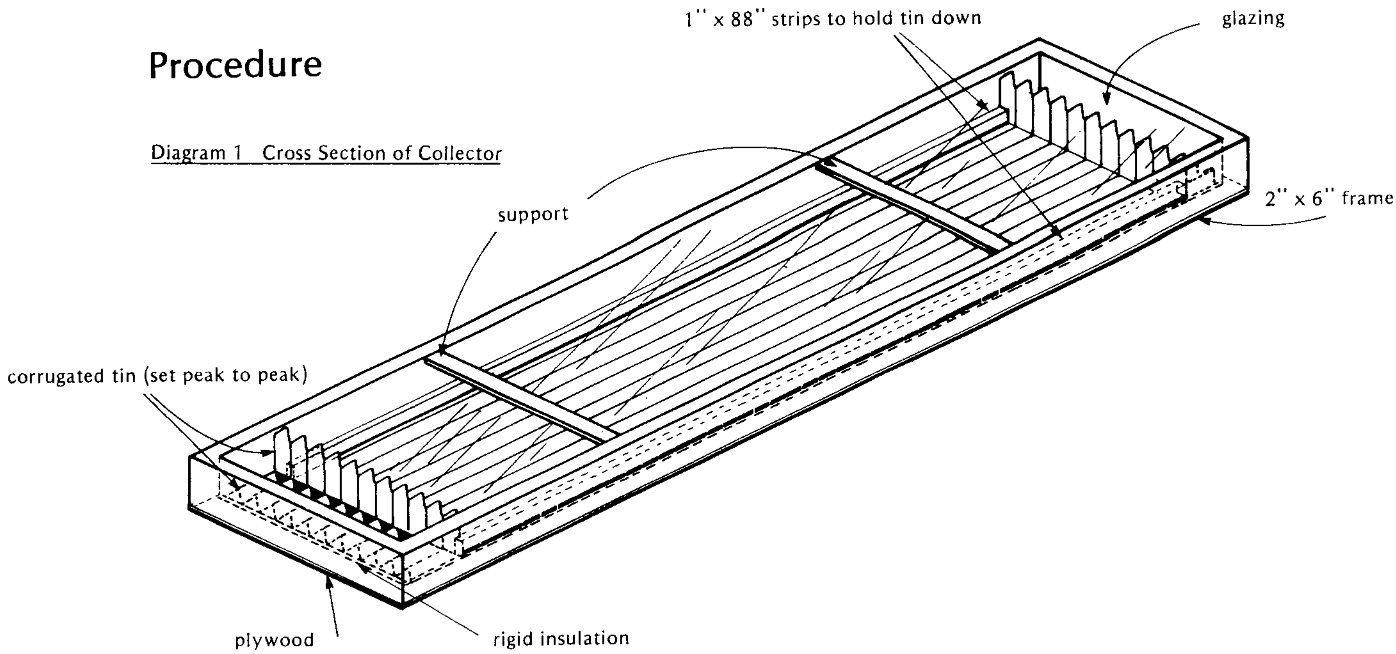
butyl or silicone caulk

flat black paint (If the tin is galvanized, use a paint with a zinc-chromate base.)

two thermometers

Procedure

Diagram 1 Cross Section of Collector



PART 1: Construction

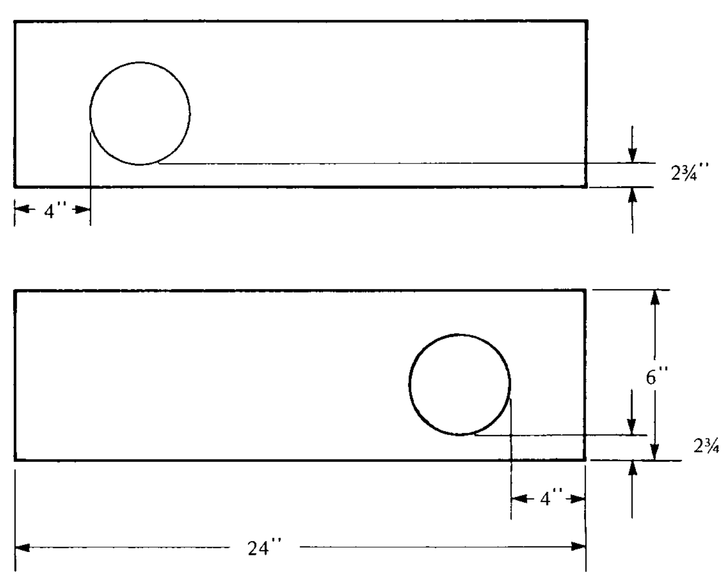
1. Dado a 3/4" deep kerf the entire length of each 2" x 6" board. The kerf should be 1/2" from the edge.

2. Cut the 4' x 8' sheet of plywood in half to obtain a 2' x 8' piece.

3. Screw the 2" x 6"'s to the plywood with the kerf edge away from the plywood and facing inward. Use 6 screws on each side.

4. With a flycutter or hole saw, cut a 4" hole at one end of each piece. The hole should be 2 3/4" from the edge and 4" from the end. (See Diagram 2.)

Diagram 2 End pieces



5. Cut two end supports 1" x 1" x 21" and two middle supports 1" x 2" x 21".

6. Nail or screw an end support onto each end piece, 1/2" from the top edge and 1½" from the ends.

7. Screw one end piece onto the collector frame.

8. Nail or screw the two middle supports 32" from each end. The top of the supports should be even with the bottom of the kerfs.

9. Caulk all seams with butyl or silicone caulking.

10. Paint the inside of the collector frame and the supports with any good quality dark paint. (You do not need to paint the plywood bottom.)

11. Cut the 1/2" insulated sheathing into a 21" x 8' piece.

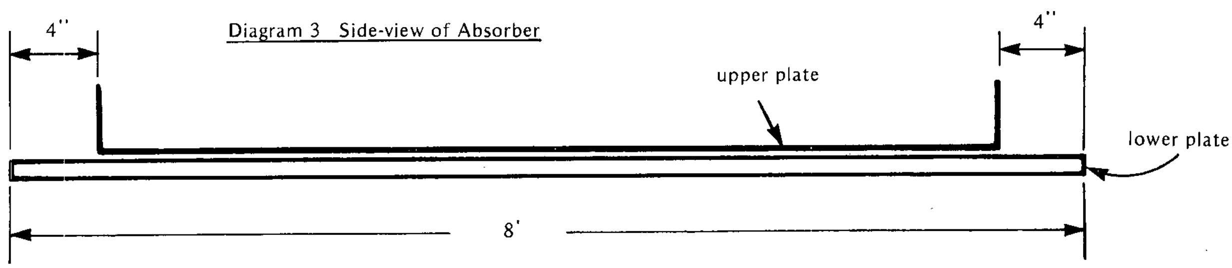
12. Lay the insulation over the plywood bottom.

13. With a metal band saw or electric shear, cut two pieces of tin to 20½" wide.

Caution: Edges are very sharp; always wear gloves.

14. On one piece of the tin, measure 4" from each end. Bend both ends straight up with a box and pan brake or over a piece of hardwood. (See Diagram 3.)

Diagram 3 Side-view of Absorber



15. With the ends straight up, center the bent piece of tin over the unbent piece. Pop rivet the two pieces together. The tin pieces should be placed peak to peak so that an air channel is created. You have now finished the absorber plate.

16. Paint the top (ends still straight up) of the absorber plate flat black.

17. Place the absorber plate inside the collector. Secure it by nailing the two 1" x 88" strips on both sides to hold it down.

18. Cut the glazing to 22¼" wide x 8' long.

19. Cut the lip off each flange. Mount it in the hole cut in each end piece. Use screws or epoxy to fasten the flanges, then caulk around them.

20. Slide the glazing into the kerfs and let it rest on the end support.

21. Caulk all contacting surfaces and attach the second end piece so that the flange extends on the opposite side from that of the first end piece. (See Diagram 2.)

22. Very carefully caulk the outside edges of the glazing to insure a weathertight seal.

23. Attach sections of vent hose to each flange with pipe clamps.

PART 2: Testing

1. Carry the collector outside and place it in an area free of shade. Face the collector into the sun and prop it at an angle which equals your latitude plus 15 degrees. This placement will simulate the use of the collector for winter heating.

2. Place one thermometer in the bottom duct and the other in the top duct. Record temperatures every minute for 30 minutes in the data table provided.

3. Use the graph provided to plot both inlet and outlet temperatures. Be sure to label your lines.

Questions

1. Why did you use flat black rather than glossy black paint?

2. What problems did you encounter in constructing this collector? How did you solve them?

3. Why were the ends of the upper piece of tin bent upward?

4. What was the highest temperature reached in the outlet vent? In the inlet vent? By how many degrees did the collector heat the circulating air?

5. According to the graph, did your outlet temperature level off? Explain why or why not.

6. How could you connect this collector to your home or classroom?

7. Describe how the hot air collector operates.

8. What improvements could be made to this collector so that it performs better?

Looking Back

The collector you've just built should function very well to provide heated air. You've discovered that the temperature at the top of the collector is substantially higher than the temperature at the bottom and that heated air actually flows from the top vent of the collector. This happens because the collector acts as a thermosiphon, in which heated air rises and leaves the collector, and cooler air flows in at the bottom to replace it.

This air collector can actually be used to heat your classroom or a room of your house, but only if it faces south. If you attach the collector to your house, the inlet can be connected through a cellar window and the outlet through a first-floor window. Heated air will then thermosiphon into the room when the sun is shining.

Going Further

Use the solar demonstrator constructed in Activity 4 to orient the collector.

Research and report on the similarities and differences between this collector and a commercial air collector.

Construct several of these collectors and install them to heat the shop.

Visit a building in which an air collector has been installed. Report on your findings.

Research and report on the similarities and differences between air collectors and water collectors, thermosiphoning and active collectors. Use what you learned in this activity to design and construct other air collectors. Test them against one another.

Determine the efficiency of your collector. To do this, you will need to know the rate of insolation (I) for your locality and the heat the collector delivers (Btu/minute). The rate of insolation can be found in a climatic atlas or from your local weather station. The heat delivered can be found by

$$H(\text{Btu/min.}) = .075 \times .25 \times (f) \times (T_{out} - T_{in})$$

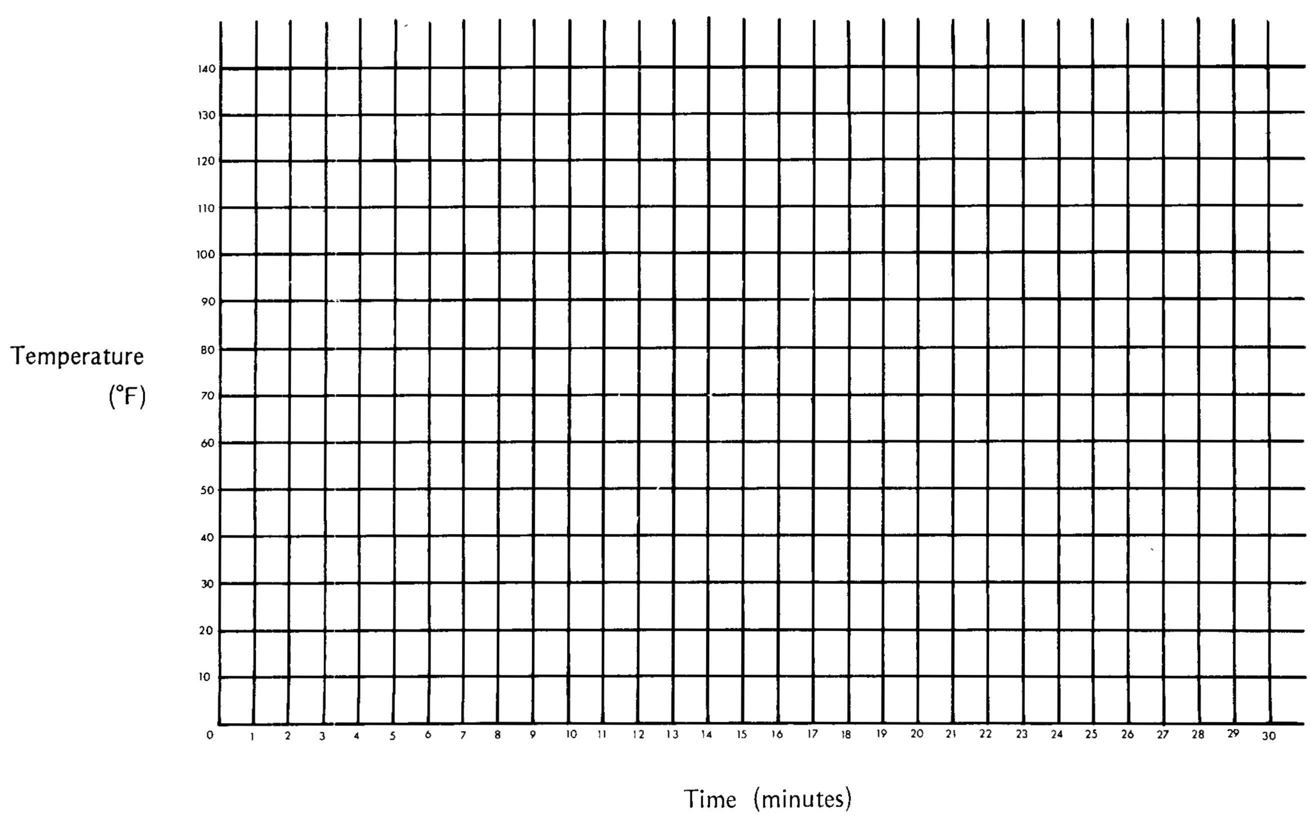
where f = the flow rate of the air, .075 = the weight of air (lbs./cubic ft.), .25 = the specific heat of the air, T out = the outlet temperature of the air (°F), and T in = the inlet temperature of the air (°F). A Dwyer vaneometer measures the flow rate and can be found in most physics labs. The efficiency of the collector can then be found by

$$\text{Efficiency} = \frac{H}{I}$$

Data Table

Time (min.)	Inlet Temperature	Outlet Temperature	Time (min.)	Inlet Temperature	Outlet Temperature
1			16		
2			17		
3			18		
4			19		
5			20		
6			21		
7			22		
8			23		
9			24		
10			25		
11			26		
12			27		
13			28		
14			29		
15			30		

Graph



A Thermosiphoning Collector

Suggested Grade Level and Skill Area

7-12 Industrial Arts
Woodworking
Metalworking
General Shop
Energy Technology

Skill Objectives

Constructing a thermosiphoning collector, using various woodworking and metalworking tools

Recording, graphing, and interpreting data

Evaluating the performance of an air collector to suggest improvements in design

Content Objectives

A solar collector has four basic parts: glazing, absorber, insulation, and transfer medium.

An air collector can easily be constructed and will deliver a significant amount of heat.

An air collector can operate by thermosiphoning.

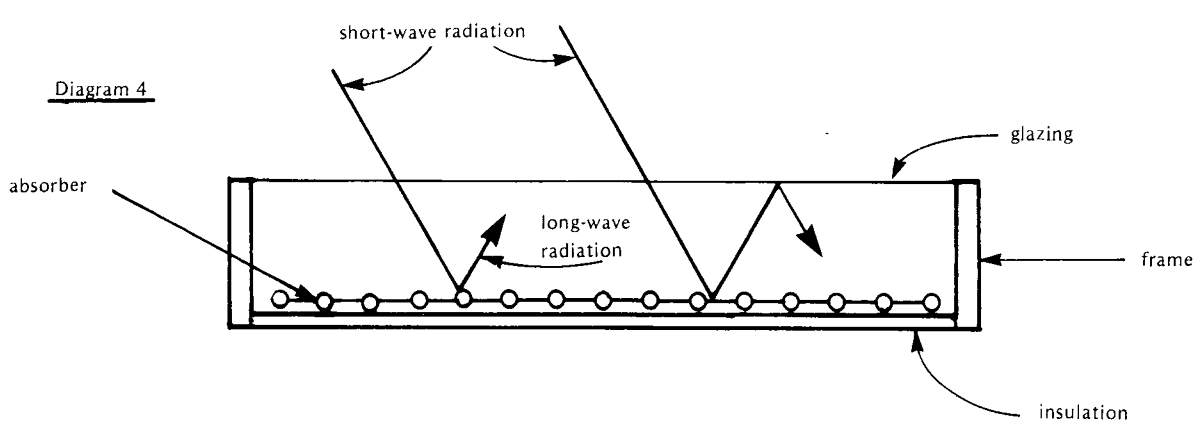
An air collector has certain advantages over a water collector.

An air collector should be oriented to face the sun at an angle of latitude plus 15° for winter heating.

Background

A solar collector must perform several functions. First, the glazing or cover on the collector causes heat to build up in the collector in what is known as the "greenhouse effect". Incoming short-wave solar radiation is changed to long-wave radiation as it is absorbed and reradiated by the absorber. Long-wave radiation, however, cannot pass out through the

Diagram 4



glazing and bounces repeatedly between the glazing and absorber plate, gradually being absorbed by the transfer fluid.

At this point the absorber plate functions as a heat exchanger, transmitting the heat gained from solar radiation to the fluid in the channels of the absorber. This fluid, either air or water, is circulated by means of a small pump or fan or by thermosiphoning. But for a thermosiphon to work, the storage or area to be heated must be higher than the collector.

Collectors can be damaged in several ways. In a northern climate, freezing temperatures pose a major threat to collectors. With an air collector this is not a problem, but with water, freezing could ruin the system. To prevent this an antifreeze solution such as ethylene glycol is used, or else the collector is designed to drain back into the storage tank at subfreezing temperatures.

Overheating can also damage a collector. Many materials, such as the glazing, caulk, and paint, may deteriorate quickly at temperatures over 100°C. These temperatures are rapidly reached in the summer if no fluid is circulating through the collector. Stagnation temperatures can be prevented by covering the collector in the summer or dumping the waste heat. Cracking, separation, and warping of the collector can also occur due to expansion of materials. This must always be allowed for, especially with the glazing.

Advance Planning

All materials, with the exception of the glazing, are available in local lumber yards.

If all the materials described in the student section are purchased, the collector will cost $40-$50. With some scrounging and use of scrap materials, this cost can easily be reduced.

Suggested Time Allotment

12-15 class periods

Suggested Approach

Have students start constructing the collector before a unit on active solar systems. In this way students will be familiar with the parts of a collector and interested in its performance when this topic is covered. The collector can then be used as a model in evaluating collector performance.

Try to hook the collector up to actually heat a room. Students will be impressed with the results.

With junior high students, this activity can be run as a class project.

Precautions

Students should never look directly at the sun.

Students should never hold their hands near the outlet of a water collector or touch the absorber plate of any collector. Very high temperatures can occur.

Caution students to be especially careful of sharp, ragged edges of tin.

If the collector is actually hooked up for use in a classroom or home, make sure to prevent the reverse thermosiphoning which can occur when the sun is not shining. A sheet of plastic taped at the top of the outlet vent is a simple way to adapt the collector.

Points for Discussion

What amount of space do you think a collector will heat?

How can a collector be placed to pull warm air out of a room and draw cool air into it? Discuss passive cooling.

What are the advantages and disadvantages of water collectors as compared to air collectors?

What improvements could be made in this collector?

What are the advantages and disadvantages of a thermosiphoning system as compared to an active system?

Typical Results

Even on slightly overcast days or in late afternoon a minimum of a 30°C temperature increase can be expected.

The collector will heat a 10' x 12' room on a sunny, subfreezing day.

Evaluation

The concepts involved in this activity are as important as the construction itself. Therefore, understanding of the system should weigh as heavily in evaluation as the appearance and performance of the collector.

In evaluating the collector itself, check for appearance, tightness, caulking, evenness of air channels, and performance.

Check students' answers to questions, as well as their tables and graphs, for accuracy and completeness.

Modifications

Any material which has numerous air channels can be used in place of the tin.

The collector can be mounted vertically on a south wall or on a self-supporting stand.

Surplus tempered-glass panes can be used in place of more expensive glazing as long as the panes will extend across the width of the collector. Several panes can be slid into the kerfs, then sealed at the joints with caulk or tape.

References

Kalwall Solar Components Catalog.
(Solar Components Division, PO Box 237, Manchester, NH, 03105.)

New Inventions in Low-Cost Solar Heating, William A. Shurcliff.
(Brick House Publishing, 3 Main Street, Andover, MA, 01810, 1979, $12.00/paper.)

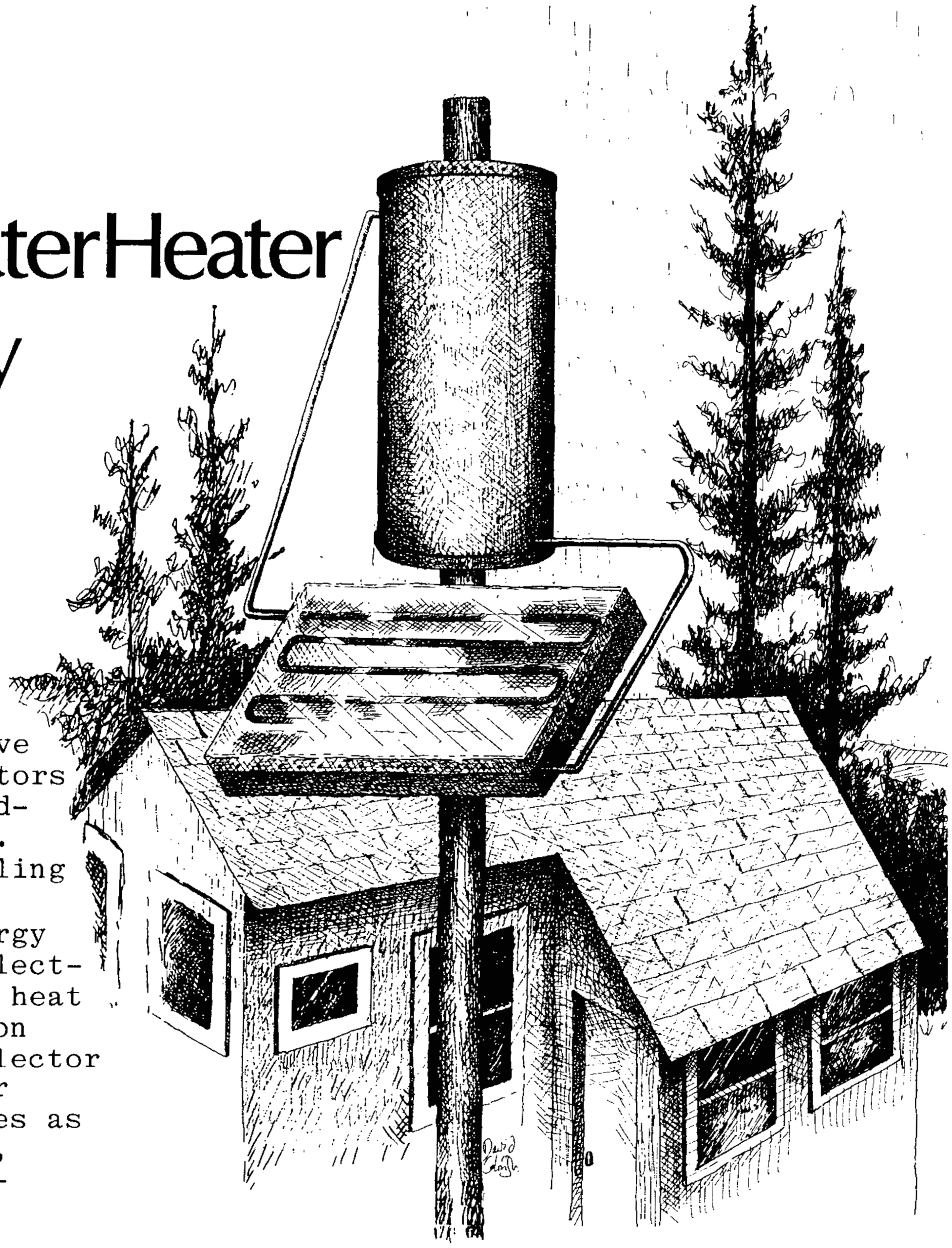
New Low-Cost Sources of Energy for the Home, Peter Clegg.
(Garden Way Publishing, Charlotte, VT, 05445, 1975, $10.95.)

Other Homes And Garbage, Jim Leckie, et al.
(Sierra Club Books, 530 Bush Street, San Francisco, CA, 94108, 1975, $9.95/paper.)

The Solar Home Book, Bruce Anderson.
(Cheshire Publishers, 514 Bryant Street, Palo Alto, CA, 94301, 1976, $8.50/paper.)

DRAFT

A Solar Water Heater in a Tote Tray



Introduction

Perhaps you've seen solar collectors on houses or buildings in your area. People are installing these collectors because solar energy can easily be collected and changed to heat energy. One common kind of solar collector can heat water for such household uses as showers and baths, laundry, and dishwashing.

In this activity you'll build a model of a typical solar hot water system. It will contain the same parts as an actual system: a collector to absorb and trap the sun's energy as heat, pipes or hoses to transfer this heat energy, and a tank to store the energy. You'll also compare your model with different versions made by other students in your class. Which collector model is going to function best to collect heat energy?

Objectives

At the completion of this activity, you should be able to

- o construct a solar collector system to heat water,
- o name and describe the function of each part of a solar collector,
- o determine the amount of heat (in Btu) absorbed from the sun per square foot of collector, and
- o determine the combination of collector materials which produces the most heat per square foot of absorber plate surface.

Skills and Knowledge You Need

Reading a thermometer and a watch or other timing device

Using measuring equipment

Operating a pocket calculator

Materials and Equipment

Plastic storage tote tray

Glazing cover

Different kinds of insulation, such as fiberglass or styrofoam

Sheet steel or other metal to use as an absorber plate

Scrap copper tubing, 1/4" O.D.

2 pieces of rubber hose, 1/4" I.D.

A 1 gallon thinner or ditto fluid container

Acid core solder

Flat black spray paint

Support post

Thermometer in a one-hole rubber stopper

Propane torch

Sheet metal cutting equipment

Procedure

1. Ask your instructor for a plastic tote tray and a glazing cover.

2. Place one kind of insulating material in the bottom of the tray.

3. Cut a piece of sheet steel to fit into the tray.

4. Bend the copper tubing into an "S" shape. This can be done by hand or the tubing can be bent around a pattern made from scrap wood. (Diagram 2.)

5. Solder or glue the copper tubing to the sheet steel absorber plate as shown in Diagram 3. If the tubing is soldered, clean any excess flux from the plate after soldering.

6. Spray the absorber plate with flat black paint. Let dry.

7. Place the absorber plate in the plastic tray. Determine the location of and drill two holes in the side of the tray through which the rubber hoses will be connected to the copper tubing.

8. Connect the rubber hoses to the ends of the copper tubing.

9. Cut two short lengths of copper tubing. Drill a hole in the lower right side and in the upper left side of the 1 gallon can. (See Diagram 1.) The holes should be sized so that the copper tubing fits snugly into them. Solder the tubing pieces to the holes. These will act as hose connectors.

10. Attach the lower hose of the collector to the lower connection on the gallon can and the upper hose to the upper connection.

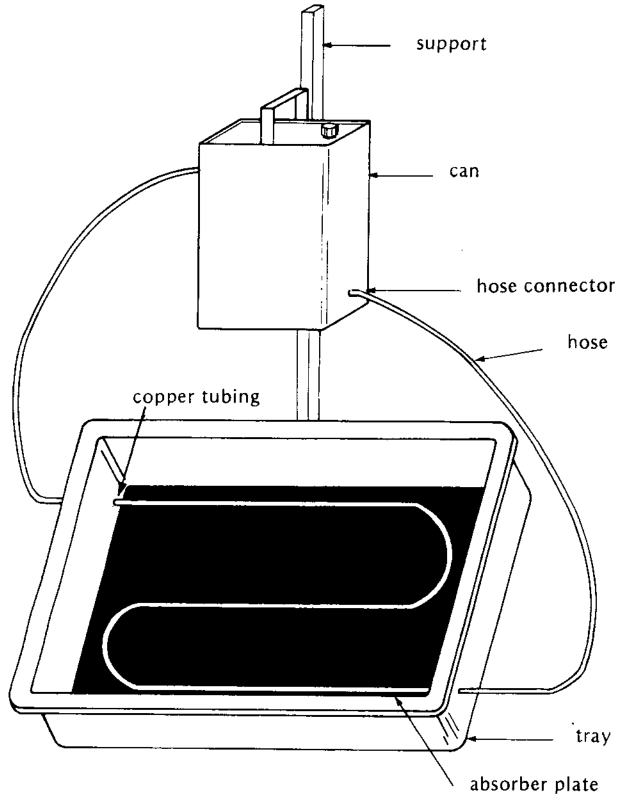


Diagram 1

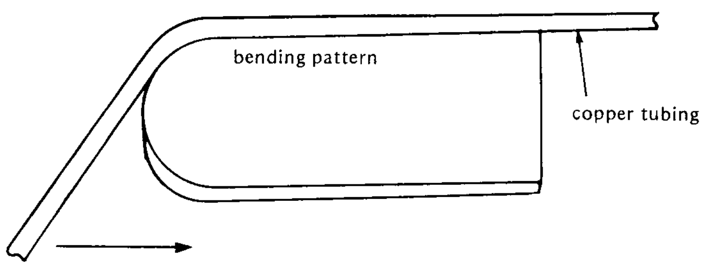


Diagram 2

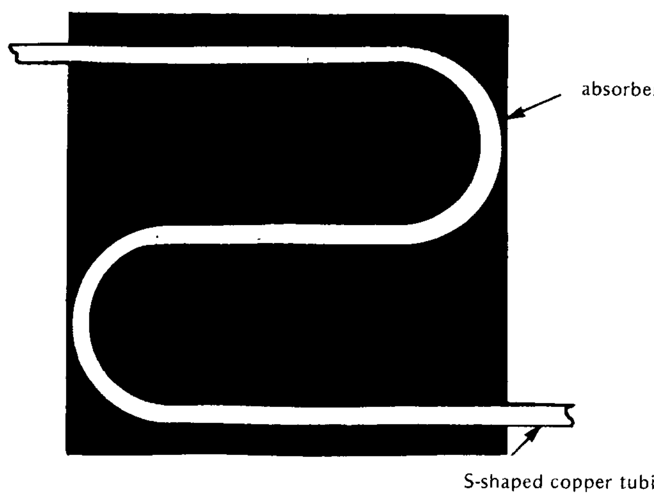


Diagram 3 Completed Absorber Plate

11. Put the glazing cover on the collector and take the entire apparatus outside. Aim your solar collector at the sun by leaning it against a support post driven into the ground.

12. Attach the gallon can storage tank to the support post above the collector. (See Diagram 1.)

13. Fill the storage tank with exactly one gallon of water. Place the rubber stopper containing the thermometer into the opening of the can. Make sure the thermometer bulb is in the water. Read and then record in the data table the beginning temperature of the water.

14. Continue to record the temperature every 15 minutes over the course of the test period or until the temperature stops rising.

15. Plot the data, temperature vs. time, on the graph. Compare your results to the results of students who used other materials in their collectors.

16. Determine the increase in the temperature of the water (ΔT) from the beginning until the end of the test.

$$T(\text{end}) - T(\text{beginning}) = \Delta T$$

17. Calculate the total amount of heat collected in Btu. Multiply the mass of the water by the temperature change. The mass of 1 gallon of water equals 8.3 lbs.

$$\text{Heat(Btu)} = 8.3 \times \Delta T$$

18. Determine the surface area of your absorber plate by multiplying its length in feet by its width in feet.

$$\text{Area(sq.ft.)} = \text{length} \times \text{width}$$

19. Determine the relative efficiency of the heat collected in Btu per square foot of absorber plate. To do this, divide the Btu collected by the number of square feet of absorber plate.

$$\text{Efficiency(Btu/sq.ft.)} = \frac{\text{Btu collected}}{\text{sq.ft. of absorber plate}}$$

Questions

1. What are the parts of a solar collector? Explain the function of each part.

2. What kind of glazing and insulation did your collector use?

3. Why is it necessary to use insulation in a solar collector?

4. How much heat (in Btu) was absorbed by your collector?

5. What was the Btu/sq.foot value for your absorber plate?

6. How did this compare with the values collected by other students?

7. Why were these values different for different collectors?

8. Of those materials used in this activity, which combination of glazing and insulating materials would you recommend for a solar collector? Explain why.

Looking Back

How well did your own model collector work? Which student model functioned the best? By now you should know that the best model trapped the greatest amount of heat energy per square foot of absorber surface. It did so because it contained the best combination of glazing and insulating materials.

Water can indeed be easily heated by the sun. All it takes is a properly constructed solar collector, with glazing to transmit solar energy, an absorber plate to absorb the energy and change it to heat, and insulation to contain the heat. Since the absorber plate is in contact with the water, it transfers the heat energy to the water, and hot water rises to be stored in the tank.

Going Further

What effect does the angle at which a collector faces the sun have on the temperature attained? Try different angles of orientation to the sun and record the results obtained.

What effect would sub-freezing temperatures outdoors have on temperatures attained? Would solar collectors be practical in colder climates?

How do wind or cloud cover affect the collector's performance?

How would changing the color of the absorber plate affect the energy collected?

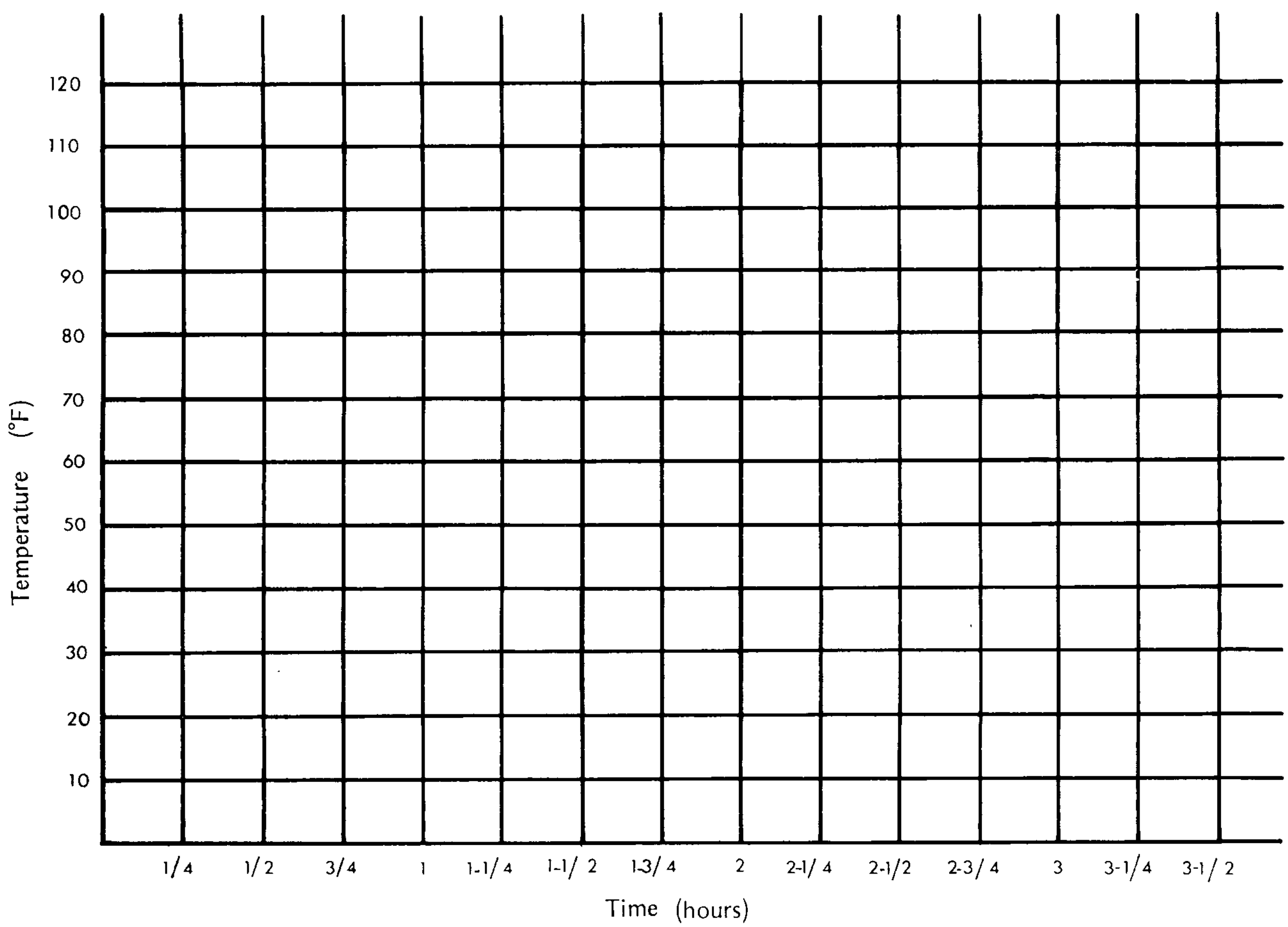
Convert this thermosiphoning system into an active system by adding a pump. Recalculate efficiency to see how it is affected.

Design and construct a solar hot water system to provide hot water for your classroom.

Data Table

Time (hr.)	Temperature °F	Time (hr.)	Temperature °F
Beginning		2	
1/4		2 1/4	
1/2		2 1/2	
3/4		2 3/4	
1		3	
1 1/4		3 1/4	
1 1/2		3 1/2	
1 3/4			

Graph



Teacher Information

A Solar Water Heater in a Tote Tray

Suggested Grade Level and Skill Area

Junior High Industrial Arts
Metalworking
Power
Plastics

Skill Objectives

Using sheet metal equipment, a tubing cutter, a thermometer, and some basic hand tools

Soft soldering using a propane torch

Recording and graphing data

Constructing a model solar hot water system from inexpensive and easily available materials

Content Objectives

A solar hot water system consists of a solar collector(s), transfer pipes, and a storage tank.

A solar collector has five basic parts. (These are described in the Background Information.)

The relative efficiency of one solar collector as compared to another can be determined by the amount of heat collected in Btu/sq. foot/unit of time.

Relative efficiency can be measured by

$$\frac{\text{mass of water heated(weight)} \times (\text{T(final)} - \text{T(beginning)})}{\text{sq. ft. of absorber surface}}$$

The efficiency of a solar collector will depend, in part, on the insulating and glazing materials used in its construction.

Background

A typical solar domestic hot water system consists of a solar collector, transfer pipes, and a storage tank to contain the hot water until it's needed for use.

The collector itself has five basic parts. One major part of the collector is a covering material, called glazing, which transmits as much solar energy as possible. Its purpose is to transmit the sun's energy into the collector. The glazing should be able to withstand high temperatures without decomposing or melting, and it must be able to withstand impact from objects that might fall on it.

Another part of any solar collector is a plate which absorbs the energy transmitted by the glazing and converts it to heat. The absorber plate is usually coated with a dark colored material that increases the absorbance of the solar energy. The absorber plate and its coating must be able to withstand high temperatures without vaporizing or otherwise breaking down. The absorber plate is often made from copper or aluminum but other materials may be suitable.

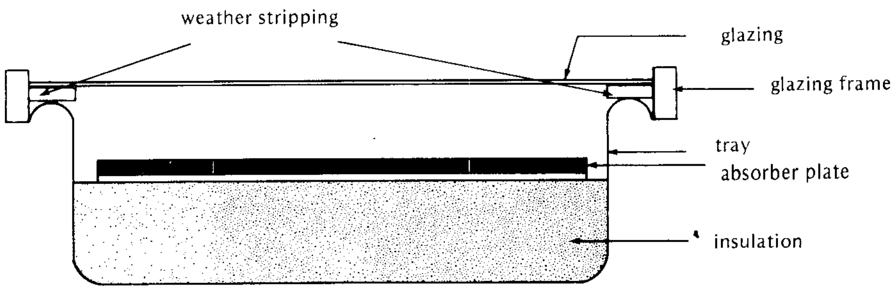


Diagram 4 Cross Section of Solar Collector

A third part of the collector, the collector box, houses the various parts of the collector. It can be made from materials such as aluminum, wood, fiberglass, or steel. It must be sturdy and able to withstand temperature extremes.

A fourth part of the collector is the insulation that surrounds five sides of the collector box. Conduction losses of heat energy are substantial unless the collector box is well insulated. Fiberglass is commonly used for this purpose.

The fifth part of the collector is either air or a liquid. It is used to transfer the heat energy to a system that distributes it to the space to be heated or to a storage substance. If water is used as the medium in cold climates, it is often mixed with an antifreeze.

The model system constructed in this activity has no pumps or mechanical devices to circulate the water. Instead, it operates on the thermosiphoning principle, in which a fluid, such as water, expands, becomes less dense, and rises as it is heated, with colder, more dense fluid flowing downward to replace it. In this system the heated water rises into the top of the storage tank and cooler water flows down from the bottom of the tank to be heated itself in the collector. Thermosiphoning hot water systems were once common in the south and southwest, but after World War II, cheap fossil fuels displaced them. Thermosiphoning systems remain common in Israel and Japan.

Advance Planning

Plastic tote trays commonly found in industrial arts storage cabinets can be used as collector boxes. Should these trays be unavailable, almost any other type of flat container might be adapted or built.

Prepare glazing covers for the collector trays ahead of time. These can be made with a wooden frame (see Diagram 4) and can incorporate almost any type of glazing material, including polyethylene film, Kalwall, Tedlar. Glass is not recommended for student use.

Several weeks before the activity is planned, have students start bringing in scrap insulating, glazing, and absorber plate materials to supplement the teacher-provided materials.

Collect one-gallon thinner or ditto fluid containers.

Select 1-hole rubber stoppers to fit the openings of the gallon cans. Insert the thermometers into the one-holed stoppers before the activity begins. Glycerin can be used to make this procedure easier. Students should not attempt this procedure as thermometers are fragile.

Suggested Time Allotment

Two weeks to construct the collectors

Two or three days for collection and interpretation of data

Suggested Approach

Students can work on a collector either individually or in groups of 2 or 3.

Present the students with a design problem:

> Using a tote tray, design, build, and test a non-concentrating solar collector capable of absorbing solar radiation and converting it into heat energy in the form of hot water. Attempt to produce the most efficient collector in your class.

Have each group scrounge for scrap insulating, glazing, and absorber plate materials to use in its collector.

It will be necessary to teach students the skills and safe work habits required for the equipment and tools used.

If possible, have each group collect data under the same environmental conditions. This will limit the number of variables.

Should working outside prove to be a problem, use a flood light for testing.

Precautions

Dangers to students include

Sharp metal edges: use files and abrasives to remove them.

Soldering: allow materials to cool and then rinse with water. This will also remove any traces of acid flux.

Equipment and tools: provide adequate instruction in safety and supervise students carefully.

Glazing: glass is not recommended for student use. Use other glazings which are easier to work with.

Fiberglass insulation: always wear gloves when handling.

The water storage container must be located above the collector for thermosiphoning to occur.

All temperature readings should be taken at the same location in the storage can.

Points for Discussion

How might a solar collector be oriented for year-round operation?

How might a solar collector operate in sub-freezing conditions?

How might the solar collection system be made more efficient?

How could the model system be adapted to produce an active solar heating system?

Typical Results

The different combinations of insulation and glazing used will cause results to vary.

Higher R-value and larger amounts of insulation will increase the performance of a collector.

Higher transmittance glazings will increase collector performance.

Evaluation

The construction of the solar collector may be evaluated by examining the quality of workmanship.

The operation of the collector may be evaluated by comparing, under the same environmental conditions, its efficiency with that of other collectors.

Modifications

Substitute other containers and other absorber plate materials when necessary.

Materials other than copper may be used for the absorber tubes. Plastic tubing and refrigerator coils are good possibilities.

Since the metals in the ditto or thinner cans are radiators of heat energy, it is a good idea to insulate the storage tanks whenever possible. Gluing styrofoam board onto them or wrapping them with flexible insulation such as that designed for water heaters will produce better results.

Add a pump and convert the system into an active one.

References

Direct Use of the Sun's Energy, Farrington Daniels.
(Ballantine Books, 201 East 50th Street, New York, NY, 10022, 1976, $1.95/paper.)

Producing Your Own Power, Carol H. Stoner, et al.
(Rodale Press, 33 East Minor Street, Emmaus, PA, 18049, 1974, $3.95/paper.)

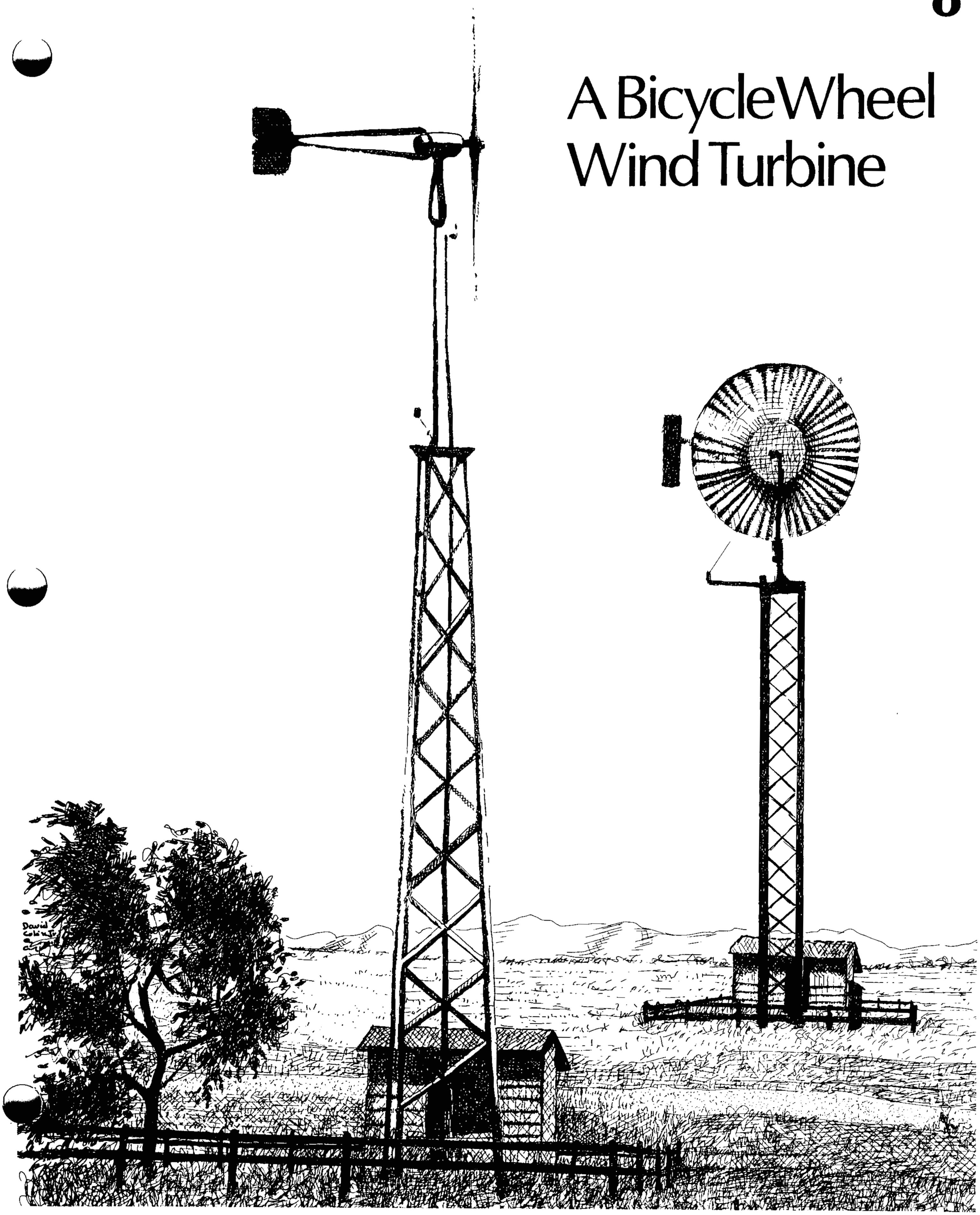
Solar Science Projects for a Cleaner Environment, D.S. Halacy, Jr.
(Scholastic Book Service, 50 West 44th Street, New York, NY, 10036, 1974, $.85.)

Sun Up to Sun Down: Understanding Solar Energy, Shawn Buckley.
(McGraw-Hill Paperbacks, 1221 Avenue of the Americas, New York, NY, 10020, 1979, $6.95.)

The Handbook of Homemade Power, Mother Earth News Staff.
(Bantam Books, 666 Fifth Avenue, New York, NY, 10019, 1974, $2.95/paper.)

DRAFT

A Bicycle Wheel Wind Turbine



Introduction

Wind machines were common in the American countryside until just a few decades ago. Perhaps you've seen some of these windmills, rusting away on the farms and ranches where they once pumped water. But today there is renewed interest in wind energy because of the large price increases in the once "cheap" fossil fuels which replaced our old windmills.

Today's wind machines are different, though, from those of the past. The traditional windmills operated at slow speeds, able to perform only mechanical work. The new machines are designed to turn at higher speeds, fast enough to drive an electrical generator and produce electricity. A wind electric system consists of four basic parts:

a propeller (or rotor) to "catch" the wind,

a generator to produce electric current,

a means of controlling the output of current, and

a means of storage.

In this activity you will use a bicycle wheel to construct a working model of a modern wind turbine. You will investigate how the propeller and the generator function to produce an electric current. In the process, you'll learn about some of the principles and problems associated with using the energy of the wind.

Objectives

At the completion of this activity, you should be able to

- construct a bicycle wheel wind turbine,
- adjust the components for smooth, friction-free operation, and
- connect the load (potentiometer, light bulbs) and measuring instruments to the generator.

Skills and Knowledge You Need

Reading technical drawings

Measuring with a rule, micrometer, and combination square

Using selected hand and machine tools

Using adhesives and fasteners

Soldering, brazing, and painting

Materials and Equipment

Blade Construction

- 1 bicycle wheel (27")
- 1/16" x 1" x 36" balsa wood (5 pieces)
- cyano-acrylate glue
- X-acto knife (#11 blade)
- 12" metal rule
- epoxy glue (one hour)
- paint brush (1/2" wide)
- acetone or lacquer thinner (for clean up)
- masking tape
- cutting board
- pencil
- 220 grit sandpaper (garnet)

Turbine Head, Tower, Tail Vane, and Bench Mount Construction

- bicycle "fork" assembly
- 3/4" electrical conduit (6' long)
- oxygen-acetylene welding equipment
- brazing rod and flux
- 1/2" steel tubing (6')
- .011 thick tinplate (16" x 18¼")
- 1/2" electrical conduit (18" long)
- solder and flux
- 1/4" long aluminum pop rivets (1/8" dia.) (about 14)
- pop rivet gun
- electric drill motor and twist drills
- sheet metal brake (bender)
- electric soldering gun
- 1/2" sheet metal screw (1)
- spray-can enamel paint
- 2" x 4"'s - fir (about 4')
- 2½" flat head wood screws (6)
- white glue
- screw driver
- countersink
- 1" U-bolts (2)
- steel plates
- hex nuts
- hold-down clamp
- hacksaw
- half-round coarse file (metal)
- 1/2" masking tape
- lacquer thinner
- 12" metal rule
- C-clamp
- wire brush
- flat file (metal)
- sheet metal shear
- 1/2" metal rat-tail file
- center punch
- hammer
- combination square
- micrometer

Electric Generator and Microswitch for RPM Counter

- microswitch (miniature, lever type)
- generator (permanent magnet, Edmund Scientific #40,872)
- generator friction wheel (½" dia. wheel from a model airplane)
- o-ring, (3/8" O.D.)
- nylon tie strips (6" long)
- music wire (3/32" dia.)
- fine copper binding wire (uninsulated)
- solder and flux
- brass tubing (1/8" O.D.)
- brass plate (.020 thick)
- sheet metal screws (3/8" long)
- steel sheet (.040 thick)
- machine screw (4-40)
- twist drills
- drill press
- needle-nosed pliers
- soldering gun
- X-acto knife
- center punch
- electric drill motor
- screw driver
- light force tension spring
- metal files (flat, half-round, rat-tail)
- metal lathe
- micrometer
- collet
- drive pin punch (1/16")
- sheet metal shear
- emery cloth (fine)
- clothes pin (spring-type)
- printed circuit board
- single conductor jacks (male and female) (4)
- speaker wire (double conductor) (2 feet)
- sheet metal screws (2-3/8")
- adjustable wrench (8")
- wire stripper
- jig saw
- sanding block
- combination square

RPM Counter

calculator
double conductor jack (1)
push button (on-off)
speaker wire (8-10')
single conductor jack (2)
flux and solder
soldering gun
needle-nosed pliers
twist drills
drill press
wire stripper
jumper wire (about 8" long)

Load Control Panel

voltmeter (Simpson, model 127, 0-5 DC volts)
ammeter (Simpson, model 125, 0-1 DC amps)
potentiometer (wire wound, 25w, 50 ohm)
selector switch (center-off DPDT)
toggle switch, SPST (6)
grain of wheat bulbs, 0-3 DC volts (6)
single conductor jack, male and female (4)
lamp cord (8-10', 18 gauge)
dry transfer letters and numbers (¼" high)
spray-can enamel (clear)
acrylic plastic tubing (1" O.D., about 3/32" thick) (6")
cyano-acrylate glue
pointer-type knob for potentiometer shaft
aluminum box (7" x 5" x 3")
hook-up wire
flux and solder
soldering gun
twist drills
drill press
compass with inking attachment
center punch
hammer
metal half-round file (coarse)
needle-nosed pliers
metal rule
micrometer, 0-1" (outside)
screwdriver
countersink
jig saw
metal flat file (medium)
india ink (black)
wire strippers

Diagram 1 Bicycle Wheel Turbine

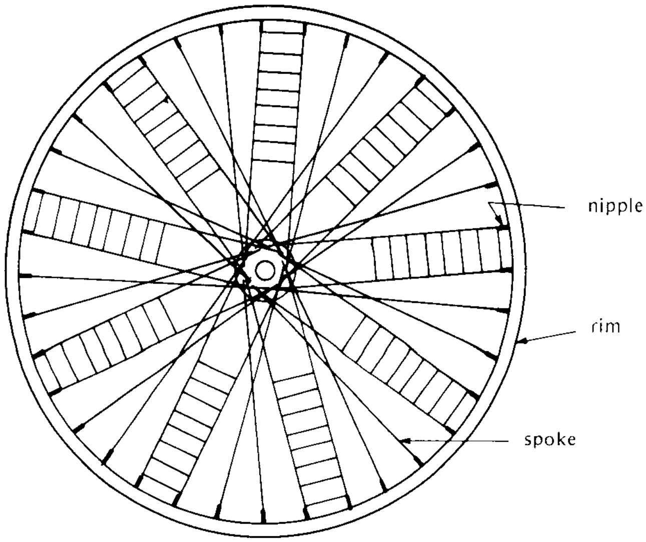
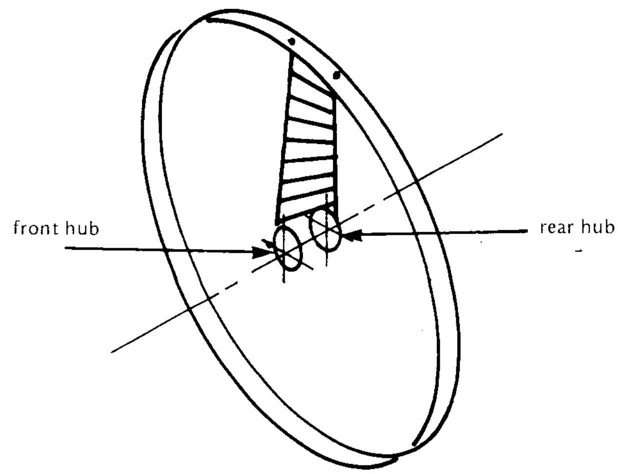


Diagram 2 Blade Twist



Procedure

Blades Assembly Procedure

1. Using lacquer thinner or acetone and a rag, carefully clean the rim, spokes, and inner hub assemblies of the bicycle wheel.

2. Identify the spokes which will make the 9 blades of the turbine. (See Diagrams 1 and 2.)

   Your 27" wheel should have 36 spokes. Count them.

   As you view the wheel from the front or back, the spokes used for blades are those which are adjacent (next to one another) and appear to be almost parallel. Wrap a small piece of masking tape around these spokes for identification. When finished, you should count 9 blades, each having two spokes.

3. Place a length of balsa (1/16" x 1" x 36") crosswise over two taped spokes, next to the rim and butted up against the spoke "nipples". (See Diagram 1.)

4. Press balsa down firmly and mark with a pencil along the outside of each spoke.

5. Using a metal straight-edge and the X-acto knife, cut the blade segment on the pencil line.

Caution: For cutting balsa wood, always use a cutting board and not the workbench. X-acto knives cut through balsa very easily and mar bench surfaces. Use X-acto knives carefully. They are very sharp.

6. Lightly sand the rough edges with #220 grit sandpaper.

7. Hold the segment up to its position on the two spokes so that it touches both spokes evenly along its width.

8. On the spoke side of the segment, apply a trail of cyano-acrylate glue, such as "Super Jet".

> *Caution: Always wear eye protection when using this glue. Do not let it make contact with your skin.*

9. Hold the glued balsa segment in place until adhesion is complete (about 30 seconds).

10. Now place the balsa cutting strip next to the first segment, allowing about 1/16" clearance between it and the first balsa piece. (A much neater appearing blade will result, with no apparent reduction in turbine efficiency.)

11. Repeat Steps 4-9 until seven segments are in place, forming one complete blade.

12. Repeat this procedure for each blade. (NOTE: This procedure may seem time consuming and tedious. But ultimately, the success of your wind machine will depend upon the care and patience you give here.)

13. Lightly sand (#220 grit) the completed turbine blades, in preparation for finishing.

14. Using a good 1/2" paint brush, carefully apply the epoxy glue finish to the turbine blades. Be careful to avoid "runs" by brushing the material quite thinly.

15. Clean the brush in lacquer thinner or acetone immediately after coating the blades. The brush will be ruined if epoxy is allowed to cure on its bristles.

16. Allow 24 hours for complete curing. Sand lightly again with #220 grit sandpaper.

17. Your turbine wheel is now complete, unless you wish to decorate the blades with different colors. Spray can enamel works well, providing that areas such as rims, spokes, and inner hubs are properly covered with newspaper and masking tape.

Turbine Head, Tower, Tail Vane, and Bench Mount Assembly Procedure

Turbine Head and Tower

1. Remove fork assembly from its frame components. Remove the nut, shaft, ball bearings, and bearing races from the end of the fork shaft.

2. Clean all components with lacquer thinner and a rag.

3. To cut round frame members, measure approximately ½" away from frame joiner on both members and mark with a pencil. (See Diagram 3.)

   Apply masking tape to edge of each pencil mark and wrap around frame member to show where cuts will be made.

   Clamp frame joiner in bench vise and carefully hacksaw the two round frame members close to the edge of the masking tape.

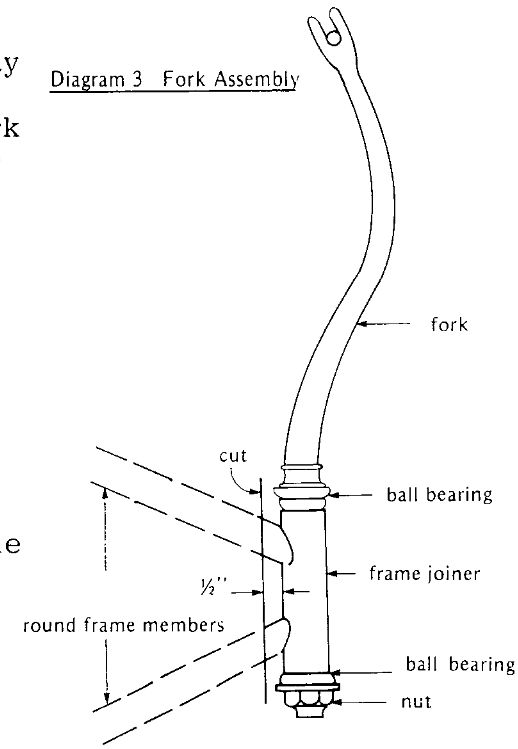


Diagram 3 Fork Assembly

4. Use a coarse, half-round metal file to file the ends of the round frame members so they fit onto the outside of the 3/4" electrical conduit. (See Diagram 4.)

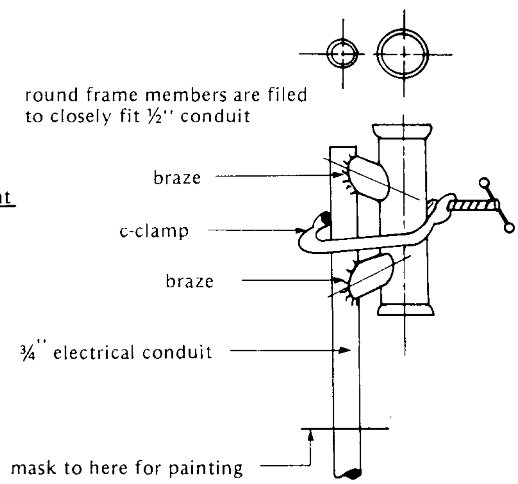


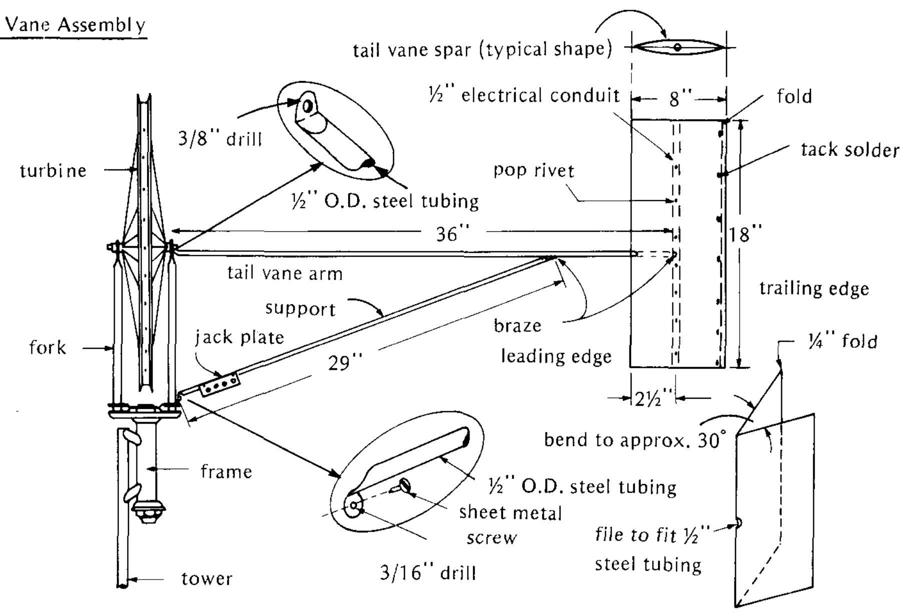
Diagram 4 Tower Mount

5. Use a C-clamp to hold frame members to electrical conduit. Braze members to conduit, then clean with a wire brush when cool.

6. Wipe components clean with lacquer thinner in preparation for painting. Apply spray paint to fork frame and electrical conduit tower in thin, even coats.

7. Reassemble components in reverse order from Step 1.

Diagram 5 Tail Vane Assembly



Tail Vane Assembly: (See Diagram 5.)

Tail Vane Arm

1. Cut ½" steel tubing to 36 3/4". Using the bench vise, flatten the last 3/4" and bend to 90°. Drill a 3/8" hole in bent end. With a flat file, file sharp corners round.

Tail Vane Spar

2. With a hacksaw, cut ½" electrical conduit to 18". File the sharp edges from the conduit. Clamp the tail vane spar to the end of the tail vane arm, making sure that it is square in all directions. Braze the joint carefully, using the oxygen-acetylene welding equipment.

Tail Vane Support

3. Cut ½" steel tubing to 29½". Using the bench vise, flatten the last ½" and bend slightly less than 90°. Drill a 3/16" hole in the center of the bent end.

4. Position the support arm between the fork assembly and tail vane arm as shown in Diagram 5. Mark the angle at which the end of the support arm must be cut in order to splice it with the tail vane arm.

5. Wrap the support arm with masking tape at the desired angle and clamp in a bench vise. Hacksaw the support arm, using the masking tape as a cutting guide.

6. With a half-round file, shape the end of the cut so it fits snugly against the tail vane arm.

Tail Vane

7. Cut the .011 thick tinplate to 18" x 16¼" with sheet metal shears.

8. Using the sheet metal brake (bender), make a ¼" fold on one end of the 18" side. (See Diagram 5.)

9. Then bend the tinplate to within 30° of being folded in half. (See Diagram 5.)

10. Use the rat-tail file to make a hole in the front center of the tail vane to accept the tail vane arm, as shown in Diagram 5.

11. Slide the tail vane over the front end of the tail vane arm and onto the tail vane spar.

12. Carefully snap the unbent edge of the tail vane into the pre-bent fold on the other edge.

    Push tightly into place, squaring each end of this "trailing edge". Sight along the vane, making sure it isn't warped. If a twist is detected, simply twist the vane in the opposite direction until straight.

13. Using paste soldering flux, tack solder the trailing edge of the vane in several places.

14. On the outside of both surfaces of the vane, draw a line 2½" in from the leading edge of the vane.

15. Measure equal distances of 2½" along the lines and center punch.

    Align the lines with the tail vane spar and drill 1/8" holes through the vane surfaces and spar. (Careful adjustment is necessary here.)

16. Using pop rivets and the pop rivet gun, attach the tail vane to the tail vane spar.

    (NOTE: No attachment is necessary where the tail vane arm passes through the hole in the leading edge of the tail vane.)

17. Hold the tail vane arm and its support at the proper angle and clamp in the bench vise. Braze together.

18. Clean the assembly with lacquer thinner and a rag. Mask the tail vane and spray paint the tail vane arm and its support. This completes the tail vane construction and assembly.

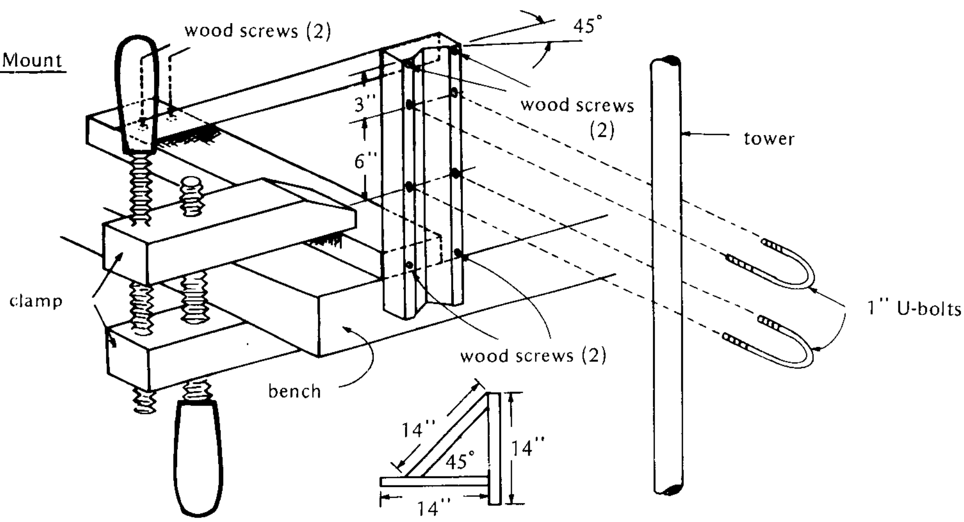
Mounting the Tail Vane Assembly

19. Slip the tail vane arm onto the stationary axle shaft of the bicycle wheel. (See Diagram 5.) Tighten the axle nut, making certain that the tail vane assembly is not being twisted.

20. Position the unattached end of the support arm on the fork so that the entire vane assembly is square with the turbine wheel.

21. Mark the hole position on the fork, center punch, and drill a 3/32" hole through the fork. Using a sheet metal screw, firmly attach the support arm to the fork.

Diagram 6 Bench Mount



Bench Mount

22. Using the circular saw, cut the three pieces of 2" x 4" to the dimensions indicated in Diagram 6. Cut a 45° V-slot down the center of the vertical member.

23. Using the electric drill motor, drill pilot holes, clearance holes, and countersinks for the six $2\frac{1}{2}$" flathead woodscrews. (See Diagram 6.)

24. Assemble with white glue. Then attach screws, checking squareness with a combination square.

25. As indicated in Diagram 6, mark the position of the holes for the U-bolts and drill $\frac{1}{4}$" holes.

26. Attach steel plates and hex nuts to provide fastening for the U-bolts. Slide the U-bolts over the 3/4" electrical conduit tower, pressing it securely into the V-slot of the mount. Tighten U-bolts.

27. Secure the bench mount to any horizontal surface with a parallel or C-clamp. Tower height may be changed by loosening the U-bolt fasteners and sliding the tower mount up or down, then retightening.

28. Finish the bench mount with a coat or two of varnish.

Electric Generator Assembly Procedure

Fastening the Drive Wheel to the Generator Shaft

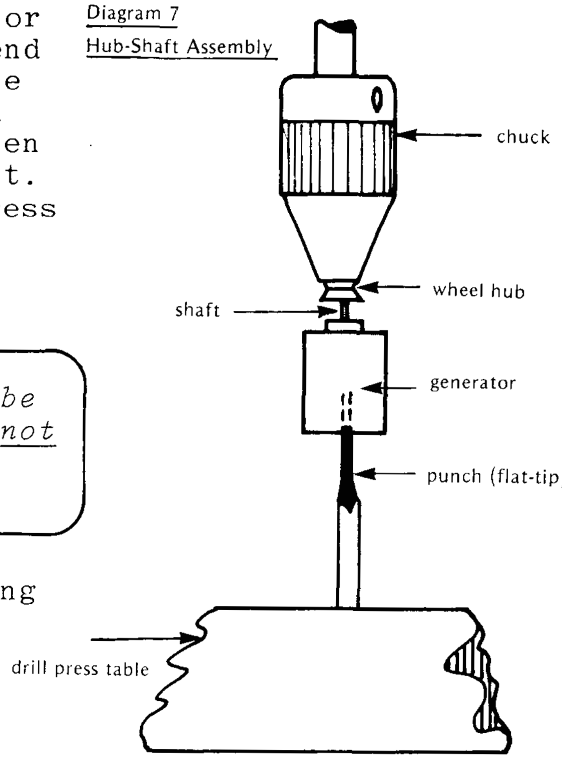
1. Use the micrometer to measure the diameter of the generator shaft. (If you use the Edmund generator, this diameter will measure .078".) You will drill a hole .003" smaller in the drive wheel hub. This will allow you to perform a "press fit" of the hub to the shaft. No other fastening methods will be required.

2. Remove the rubber tire from the hub. Use the micrometer to measure the outside diameter of the hub. Insert the hub into a collet of the same size for drilling on the metal lathe.

3. Install the collet in the head stock and a drill .003" smaller than the generator shaft diameter in the chuck (in the tail stock). Drill hub. (NOTE: This procedure is followed so that the hole is drilled straight and on center and the drive wheel will not wobble or run off center. Merely drilling the hole on a drill press or with an electric drill will not guarantee this accuracy.)

4. To press the wheel hub onto the generator shaft, hold the hub, generator, and punch as in Diagram 7. Since the generator shaft ends inside the generator case (on the opposite end of the drive wheel), use a 1/16" drive pin punch to support the shaft when pressing the hub onto it. Have a helper slowly press the hub onto the shaft, using the drill press chuck.

Diagram 7
Hub-Shaft Assembly



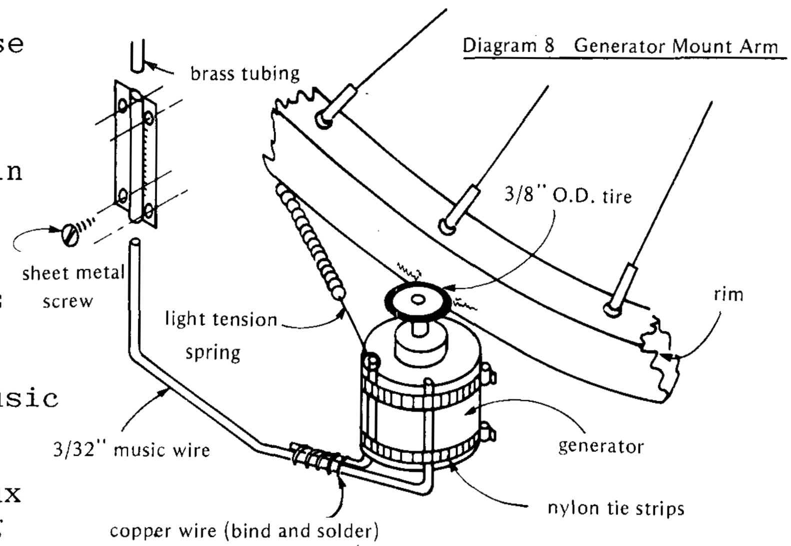
> *Caution: The chuck should be completely CLOSED. Do not turn the drill press on for this procedure.*

5. Snap the 3/8" O.D. o-ring onto the completed hub-shaft assembly.

Music Wire Generator Mount Arm

6. Using a bench vise and needle-nosed pliers, bend the music wire arm pieces as shown in Diagram 8.

7. Keeping the two vertical segments about 3/4" apart, wrap copper wire around the two music wire pieces.



8. Use soldering flux and the soldering gun for the final joining of the two music wire pieces. This music wire arm allows the generator to move freely away from and toward the rim of the turbine.

Mount Plate Assembly

9. Shear .020 brass plate to 1½" long by 3/4" wide.

10. Cut 1/8" O.D. brass tubing to the same length by setting the tubing on a flat surface. Place an X-acto knife (#11 blade works best) on the brass tube. Roll the tube under the blade while applying firm pressure. A clean, straight cut will be produced.

11. Clean the plate and tube with a fine emery cloth.

12. Position the tube on the plate as shown in Diagram 8. Hold in place with spring-type clothespin. Apply flux and solder using the soldering gun.

13. Center punch for the 4 holes in the plate where indicated in Diagram 8. Drill four 1/8" holes with the electric drill motor.

Generator Mount Assembly

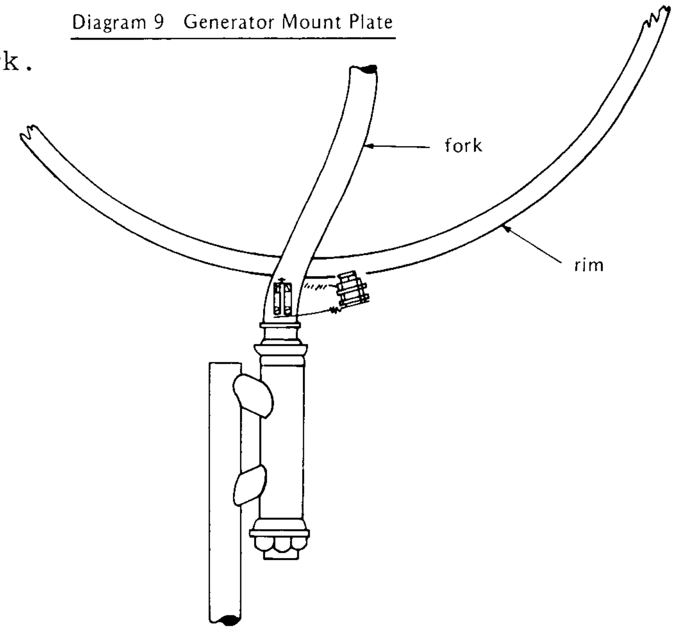
14. As shown in Diagram 8, solder a small piece (1/4" long) of brass tubing to the music wire arm to keep it from falling out of the mount plate.

15. Fasten the generator to the music wire arm assembly with nylon tie strips. Pull tight, using needle-nosed pliers.

Mounting the Generator Assembly

16. Hold the generator assembly up to the turbine wheel and fork. (See Diagram 9.)

Diagram 9 Generator Mount Plate



17. Mark where the four pilot holes must be drilled in the fork to accept the mount plate. Center punch these four points. Using the electric drill motor and a 3/32" twist drill, drill the four pilot holes.

18. Securely attach the brass mount plate to the fork arm, using 3/8" sheet metal screws.

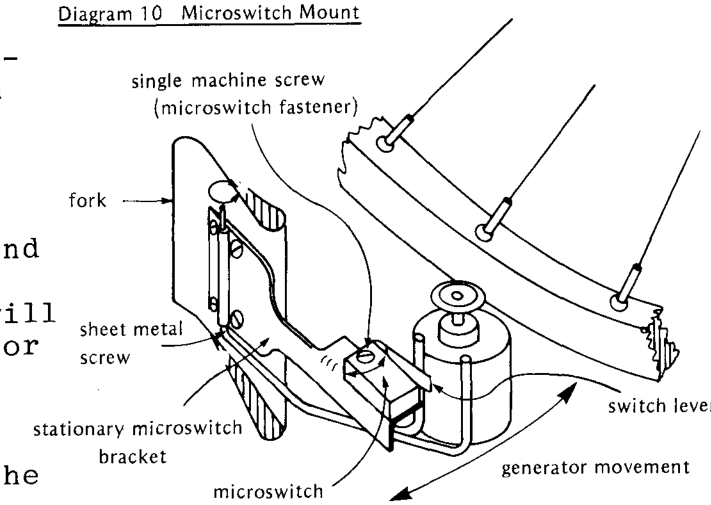
19. Slip one end of the light tension spring over one of the music wire arm vertical supports. Lightly stretch the spring so that the drive wheel tire (o-ring) contacts the turbine wheel rim. Attach the opposite end of the spring to the opposite side fork so that this tension may be maintained. Drill another 3/32" hole and insert a 3/8" sheet metal screw to act as an anchor point for the spring. This completes the mounting of the generator.

20. Experiment with various spring tensions. If the drive tire is too tight against the rim, it will "scrub" away valuable power in the form of high friction and its resultant heat. If the spring is too light, the drive tire may "skip", especially under high load conditions.

Microswitch Mount

21. The microswitch triggers the counter function on a hand-held calculator for the purpose of determining the turbine wheel revolutions per minute (RPM). Bicycle wheels which have been modified with wind-mill blades tend to "wobble" slightly from their plane of rotation, as much as 1/8". The wobble does not appreciably affect the turbine's performance, but does provide the opportunity to use this action to operate a counter switch.

Diagram 10 Microswitch Mount



22. Fabricate the micro-switch bracket from .040 thick sheet steel as shown in Diagram 10.

23. Shear, file, and bend the bracket so the microswitch lever will contact the generator somewhere on its surface. Drill the required 3 1/8" mounting holes in the bracket.

24. Use only one 4-40 machine screw to mount the micro-switch to the bracket. This enables you to "twist" the microswitch, thus providing a fine adjustment when the generator moves due to the turbine rim wobble.

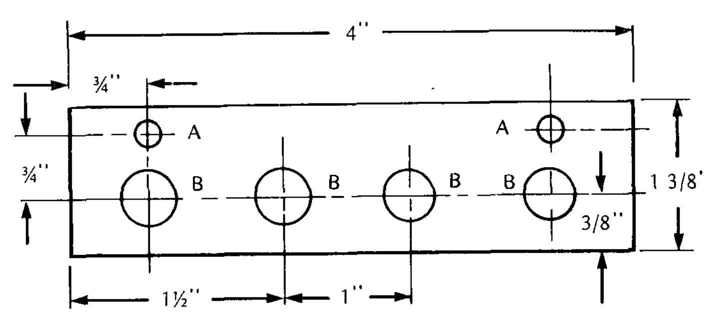
    Mount the bracket assembly on the generator mount plate and fork, using the generator mount screws. The bracket will now remain stationary.

Wiring Procedure

Fabricating and Mounting Jack Plate

25. Obtain a piece of printed circuit board from the electronics lab.

Diagram 11 Jack Plate



A - 1/8" drill
B - 3/8" drill

26. Using a combination square and pencil, lay out the length and width of the jack plate as shown in Diagram 11. Using a jig saw with a fine blade, saw close to the lines.

27. Smooth the edges of the board with a sand block (80 grit) or a medium flat file.

28. Locate the holes and center punch their positions accurately. Using the drill press (wear goggles), drill these holes to the sizes indicated in Diagram 11.

29. Hold the jack plate in position on the tail vane support arm (Diagram 5). Accurately mark the two mount holes. Center punch and drill (electric drill motor) to 3/32" dia. Install the jack plate, using 3/8" sheet metal screws.

30. Install the female portions of the four jacks on the jack plate. Hold them securely in place while tightening the hex nuts with a combination wrench.

Wire Stripping and Tinning

31. Using the wire strippers, remove about ¼" of insulation from the two conductors at one end of the speaker wire. Twist each wire bundle so that no "stray" ends remain. Apply a small amount of soldering flux to each conductor end.

32. Using the soldering gun, heat the conductor ends and apply a small amount of solder. This tins and prepares the conductor for soldering to the generator terminal.

33. Using the needle-nosed pliers, bend a small "fish hook" onto the end of each tinned conductor. Hook the conductors through the hole in each generator terminal. Squeeze tight, using the needle-nosed pliers.

34. Apply heat to one terminal with the soldering gun. Apply a bit of solder to the joint and allow it to "flow". Remove the tip of the gun. Repeat for the second generator terminal.

35. Run the speaker wire from the generator carefully to the jack terminals at the back of the jack plate. Leave a little slack. Never "stretch" wires from one point to another.

36. Repeat Steps 31-34, this time in preparation for hooking the other two ends of the conductors to the two jacks. Use the two center jacks for the generator connections. One jack should be red (+) and the other black (-).

37. Perform the same wiring operation for the microswitch. Use the normally open (N.O.) and common terminals.

38. Use two nylon tie strips to neatly fasten the speaker wires to the fork and tail vane support arm.

RPM Counter Assembly Procedure

Finding a usable calculator to function as the RPM counter

1. The counter will operate in the following manner. Each time the microswitch closes, completing the circuit, the turbine will have rotated one time. The calculator will add this impulse and record it on its display. If you record the number of times the microswitch closes in ten seconds, then multiply

this number times 6 (10 seconds x 6 = 60 seconds, or one minute), you will have found the turbine's RPM (revolutions per minute).

Some calculators will add these consecutive impulses (Texas Instruments, Radio Shack) while others will not. You will have to search for one that works in the following manner:

a. turn the calculator on,

b. press the "+" key,

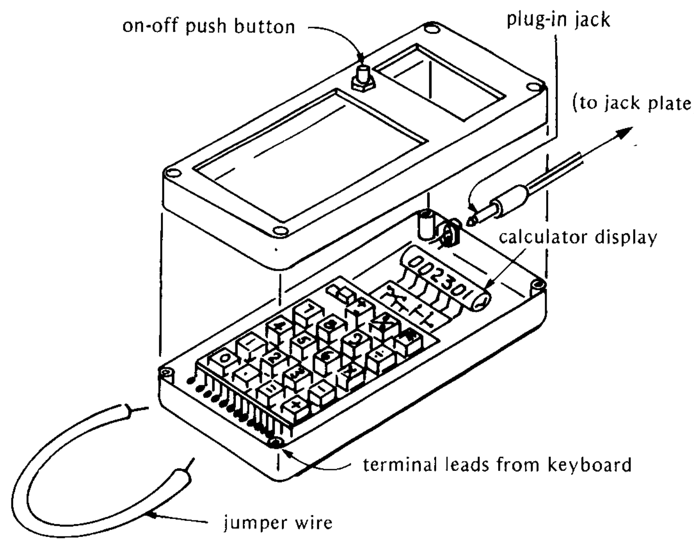
c. press the "1" key,

d. then press the "=" key several times,

e. the calculator will add one each time (1, 2, 3, 4, 5, 6, ...).

(NOTE: At turbine speeds of less than 5 revolutions per second, you can count the revolutions by eye. Use a line of white paint on the turbine axle shaft as a marker.)

Diagram 12 Calculator Modifications



Connecting the Counter Terminals

2. Remove the top cover of the calculator. Locate the terminal leads from the keyboard. (See Diagram 12.) Turn the calculator to the "on" position. Press the "+" key, then the "1" key.

3. To find the two terminals which control the "=" key, use the jumper wire to touch any two adjacent terminals. Your first attempts will probably not provide the additive counting which you are looking for. In fact, the calculator display will probably scramble. If this happens, clear the calculator, reintroduce the "+" and "1", and proceed to touch two more terminals at a time, until the proper two are located. When you find the correct terminals, you should be able to make the display count merely by successively touching the jumper wire across them.

4. Carefully solder the ends of the double conductor speaker wire to each identified terminal.

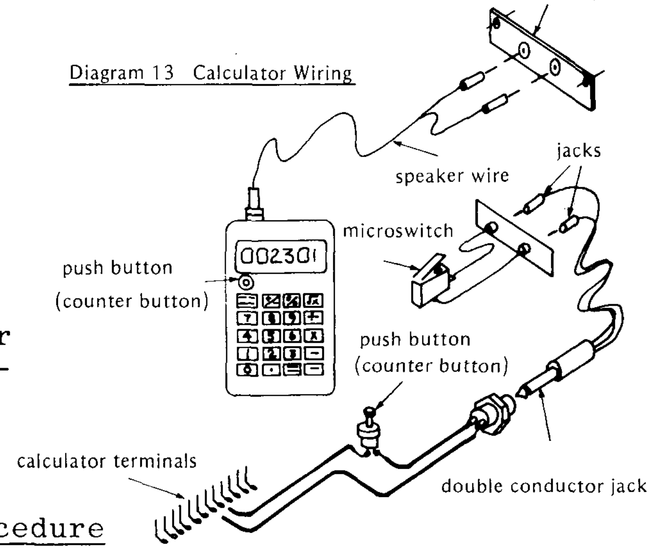
5. Then connect the speaker wire to an "on-off" push button switch and a double conductor jack. (See Diagrams 12 and 13.) Locate these devices where room will allow inside of the calculator. Drill appropriate holes with a drill press and install switch and jack.

6. Carefully solder the speaker wire to the switch and jack as shown in Diagram 13.

7. Carefully replace the calculator cover.

8. Cut, wire strip, and solder 8-10' of speaker wire between the calculator and turbine jack plate. (See Diagram 13.)

Diagram 13 Calculator Wiring

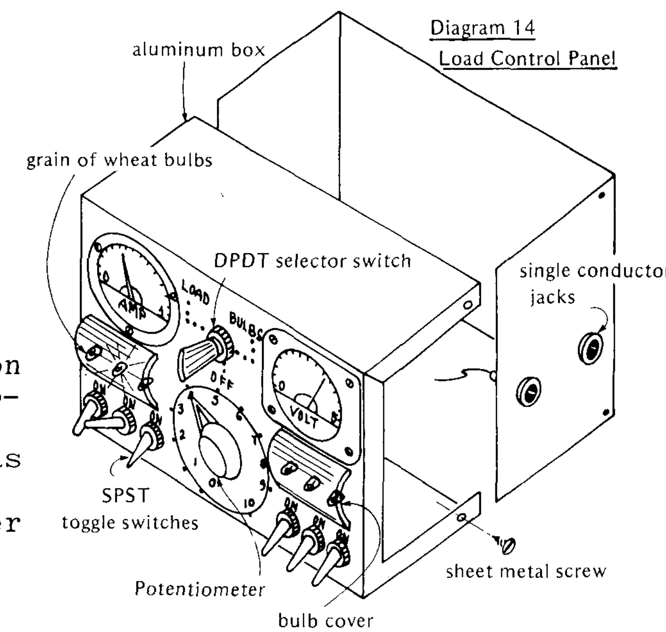


Load Control Panel Assembly Procedure

1. There are no dimensions associated with the load panel since the sizes and shapes of the components you are using may vary. Simply arrange the components in a manner similar to Diagram 14.

2. Lay out the holes for the meter bodies. (The Simpson meters include a simple-to-use cardboard template.) Note the meter positions as viewed from the front of the panel: ammeter - upper left, voltmeter - upper right.

Diagram 14
Load Control Panel



3. For support, place a piece of 2" x 4" under the section of box to be drilled. Using a 3/8" drill in the drill press *(wear safety glasses)*, drill many holes close together until the center section of each planned hole falls out.

4. Using a half-round, coarse metal file, smooth the rough edges of the holes until a perfectly round hole is formed out to the scribed line.

5. Center punch and drill the meter mounting holes. Remove "burrs" with a countersink from the back side of the box.

6. Accurately measure, mark, center punch, and drill all of the other holes indicated in Diagram 14. To determine the proper drill size, use the 0-1" outside micrometer to measure the threaded ends of the switches and of the potentiometer.

7. After drilling 1/8" holes for the grain of wheat bulb seats, glue the bulbs into position with cyano-acrylate glue.

8. To make the bulb covers, cut a 2" piece of plastic tubing with a saw. Using a fine blade on the jig saw, carefully saw the tube in half lengthwise. (See Diagram 14.) Using a flat file (medium), carefully smooth all sawed surfaces.

9. Remove all components from the instrument panel. Since the box is already painted, it is time to place the switch and potentiometer markings on its surface. (See Diagram 14.)

10. Using india ink in a draftsman's compass, swing an arc representative of the potentiometer's range (from 0 to full).

11. Mark off eleven equal spaces between the potentiometer's zero and maximum points. Place a dry transfer "period" (.) at each of these points to be numbered. (IMPORTANT: These divisions will be used for our first experiment. Take care and patience to produce an accurate scale. Using the pressure sensitive dry transfers, number the potentiometer points from 0 to 10.)

12. Label the selector switch: LOAD (on the left), BULBS (on the right), OFF (in the center).

13. Lightly clean the surface of the box with a dry, clean rag. DO NOT TOUCH the india ink line; it will smear.

14. Spray several light coats of clear enamel over the lines and letters. Allow to dry overnight.

15. Mount all components on the box. You should have

    2 meters

    1 selector switch

    6 grain of wheat bulbs

    1 potentiometer with knob

    6 on-off switches

    2 single conductor jacks

    2 acrylic plastic bulb covers

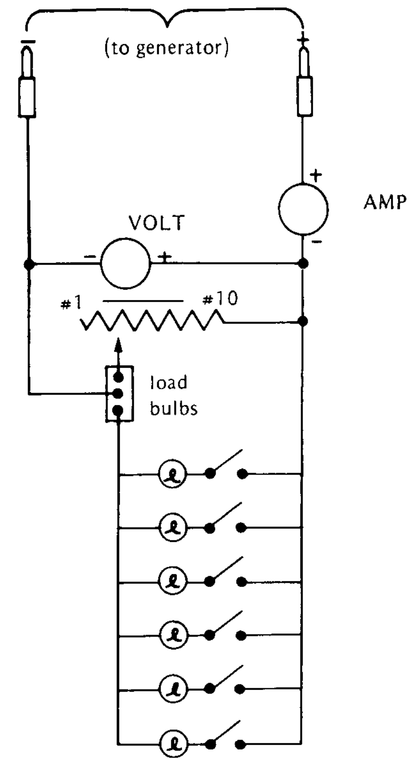
16. Attach acrylic covers with a small amount of cyano-acrylate glue.

17. Use the hookup wire to connect the components as shown in Diagram 15. Cut all wires slightly longer than their exact length. Never stretch a wire between two points. Strip, tin, and bend "fish hooks" in the ends of all wires. Solder into place.

(IMPORTANT: Avoid "cold" solder joints. Have your teacher check your progress after you've soldered several joints.)

Observe polarity. The meters have a + and a - terminal. Be sure they are arranged as shown in the wiring diagram. Remember to use a red jack for + and a black jack for -.

Diagram 15 Load Control Panel Wiring



18. Carefully solder the 4 male jack ends to the 8-10' of lamp cord. Connect from the jack panel on the turbine to the load control panel. Be sure that each conductor has the same color jack at opposite ends: connect red to red, black to black.

19. Screw the control panel box pieces together, using the sheet metal screws supplied by the manufacturer.

<u>CONGRATULATIONS!</u> You have just completed a fine piece of laboratory apparatus! Let's check it out to make sure everything is hooked up correctly.

System Checkout

1. Does the turbine wheel spin freely by hand when the generator tire isn't touching the rim? If not, adjust the inner axle shaft nuts, which control the ball bearing pressure.

2. If the turbine wheel shakes about slightly, the wheel may be out of balance. Remove the generator drive wheel from the turbine rim. Mark a point on the turbine wheel. Spin the turbine by hand, noting the stopping point (for example, the 6:00 position, as on a clock). If the wheel stops at approximately the same point after several trials, you may be certain that this is the heavy side.

3. Tape small machine screw nuts opposite the heavy side of the wheel and spin as before. Continue to add or subtract weight until the wheel stops randomly at points about its rim. Using cyano-acrylate glue, permanently fasten the weights in place. The turbine wheel is now in a statically balanced condition, and any operational vibrations should be eliminated.

4. Place an electric fan to within one foot of the turbine wheel. Turn the load control panel's selector switch to the "off" position. Plug in all other jacks. Turn on the fan. The turbine should start turning. (The fan will remain on for the rest of the system checkout.)

5. There should be a voltmeter reading (up to about 3 volts). If the needle is "pinned" to the left of the meter, the current polarity is wrong. Reverse the wiring on the meter.

6. Turn on the calculator counter. Press the "+" key, then the "6" key. Depress the push button "on-off" switch which you installed earlier. The calculator display should show a count in progress. If there is no count shown, check to make sure the microswitch is opening and closing from the motion of the generator. Twist as necessary to obtain switching.

7. Release the push button switch. The total count should remain on the calculator display. To determine the turbine RPM, do the following:

   a. Clear the display by pushing the "0" key.

   b. Depress the "on-off" button of the calculator as the second hand of a clock or watch passes a recognizable point.

   c. Release the "on-off" button at the end of exactly 10 seconds.

   d. Since the calculator was programmed to count by 6's, the display should read the actual RPM.

With the selector switch in the "off" position and the generator tire riding on the turbine rim, at least 190 RPM should be found. If your results are lower than this, there might be too much spring tension on the generator, or your motor may be weak.

8. Turn the selector switch to the "load" position. Turn the potentiometer to about the "5" position. The ammeter should read a positive current. If the ammeter needle is "pinned" to the left of the meter, the polarity is wrong. Reverse the wiring.

9. Turn the potentiometer load control to 10 (maximum). After a few seconds, observe the turbine wheel. It should slow to much less than 75 RPM. Check it with your counter.

10. Turn the load control knob to 0. The turbine should "unload" and operate at its greatest RPM. Failure of the apparatus to perform as indicated could mean improper wiring or a generator wheel which is slipping against the turbine rim.

11. Turn the selector switch to the "bulb" position. Flip on one bulb switch. A grain of wheat bulb should light up. The ammeter should indicate a positive current and the voltage should drop slightly from the "no load" condition.

12. Flip on two or three more bulb switches. The current should increase, and the voltage should drop. The turbine RPM should take a definite drop. Failure of bulbs to light when switches are turned on indicates that a mistake was made in wiring, especially if the voltmeter reads normally. Recheck the wiring.

If everything operates according to the previous description, you are ready to performance test the apparatus. This you'll do in the next activity.

Questions

1. Briefly review how you identified the correct bicycle wheel spokes on which to construct the individual turbine blades.

2. In reviewing the tail vane assembly steps, why wasn't the tail vane support brazed into place on the tail vane arm immediately after the tail vane spar was brazed to this arm? (If you wish, refer to Diagram 5.)

3. How does the tail vane keep the turbine pointed into the wind?

4. What are two important factors in making certain the turbine/generator assembly runs freely?

5. Why is heavy lamp cord wire used between the jack plate and the load control panel?

6. When "loading" the turbine wheel, the selector switch is positioned on "load" and the potentiometer load control turned toward number 10. Can you explain how this action makes the generator slow the turbine? (If you wish, refer to Diagrams 14 and 15.)

Looking Back

The heart of this wind turbine is the turbine wheel and its blades. As the blades "catch" the wind, the turbine wheel revolves and produces power. The tail vane assembly keeps the mechanism pointed into the wind. The fork assembly, tower mount, and bench mount support the turbine wheel. The generator changes the mechanical (motion) energy of the turbine into electrical current, which is transmitted through conductors to the load control panel. The micro-switch counts the turbine's revolutions and this information is transmitted to the calculator counter, which displays it.

The addition of a load panel permits us to "try out" the bicycle wheel wind turbine. With the load panel, you'll be able to simulate some of the actual operating conditions of an electrical-generating wind turbine. You'll learn about some of the characteristics common to all wind turbines.

Going Further

Use the next two activities to "try out" your bicycle wheel wind turbine. The first activity investigates the effect of increased load upon the turbine RPM. The second activity investigates the power potential of the turbine/generator.

Teacher Information

A Bicycle Wheel Wind Turbine

Suggested Grade Level and Skill Area

9-12 Industrial Arts
General Shop
Metalworking
Alternative Energy/Energy Technology

Skill Objectives

The construction of a horizontal axis, electricity-generating wind turbine

Adjustment of the turbine to produce smooth, friction-free operation

Connection of loads and measuring instruments to the turbine

Content Objectives

The bicycle-wheel wind turbine is an example of a horizontal axis, electricity-generating wind machine.

A tail vane provides lift and keeps the turbine perpendicular to the direction of the wind.

The turbine blades are constructed from bicycle wheel spokes which appear almost parallel when viewed from front or back.

Important factors in ensuring the free turning of the turbine-generator assembly are the generator and drive wheel alignment, the spring tension on the turbine rim, and the ease with which the turbine wheel spins on its ball bearings.

The bicycle wheel wind turbine can be instrumented to investigate the principles of operation common to all wind electric systems.

Background

The wind's energy originates from the sun. As the sun's radiation reaches the earth, the rays strike more directly at the equator than at the poles, causing the earth's surface at the equator to absorb more heat. This heat is transferred to the air above the equator's surface. The heated equatorial air expands and rises, and is replaced by denser, cooler polar air. In simplest terms, this, coupled with the earth's rotation on its axis, is how the global air currents, or "winds", are produced.

Wind is an indirect form of solar energy, and accounts for only 1% of the energy supplied to the earth by the sun. However, if we could convert all the energy available from the wind into electricity, we could provide more than 1,000 times the electricity now produced by the United States.

Windmills have been used for many centuries to pump water and grind grain. Wind machines were a significant factor in the rapid settling of the American West. In the late 1800's, one traveller reported that the prairie was practically alive with windmills. But, with the advent of the era of "cheap" fossil fuel energy in the 1940's, these windmills fell into disuse. As energy prices escalate, however, there is renewed interest in the energy of the wind.

A wind turbine has one of two common propeller orientations. In a horizontal shaft wind machine, the propeller is on a horizontal shaft which moves in a plane perpendicular to the wind. The propeller can be two, three, or multibladed, with blades composed of wood, metal, or fiberglass. A vane keeps the propeller facing into the wind.

The vertical shaft turbine has a rotor mounted on a vertical shaft or axis, with the wind-catching surface moving in the direction of the wind. These machines can thus accept wind from any direction.

Electricity-generating wind machines are usually designed to utilize winds between 10 and 25 mph. The force of the turning rotor turns the armature of the generator. Modern small wind machines generally operate at an overall efficiency of between 40% and 45%, and produce from 200 to 6000 watts.

For all wind machines, one of the most serious problems is energy storage. Research is continuing on such means of storage as battery banks, heating stones or water, electrolysis of water to produce hydrogen for fuel cells, flywheels, pumped water, and compressed air. Of course, the electric utility itself can serve as a means of storage, with excess electricity fed into the power grid (running the meter backwards) and electricity drawn from the grid when there is a shortage.

In this activity students will construct an operating model of a horizontal axis, electricity-generating wind turbine. In later activities they will test this wind turbine under actual operating conditions to determine the principles involved in generating electricity from the wind.

Advance Planning

Obtain the following items 1 or 2 weeks in advance, except as noted.

From a bicycle shop:

27" bicycle wheel, fork and frame assembly

From a hobby shop:
- balsa wood 1/16" x 1" x 36" (5 pieces)
- epoxy
- X-acto knife
- cyano-acrylate glue ("Super-Jet" is recommended)
- generator drive wheel - 1/2" dia. model wheel ("Perfect Products")
- music wire - 3/32"
- brass tubing - 1/8" O.D.
- brass plate .020 thick

From an electrical supplier:
- microswitch - miniature, lever type
- nylon tie strips - 6"
- single conductor jack - 6 assemblies
- speaker wire - 8-10'
- lamp cord wire - 8-10'
- double conductor jack
- push button, miniature, on-off
- selector switch - center off DPDT
- toggle switch - SPST (6)
- grain of wheat bulb - 0-3 DC volts (6)
- pointer knob for potentiometer shaft
- aluminum box - 7" x 5" x 3"
- hook-up wire - 16 gauge
- voltmeter - Simpson, #127, 0-5 DC volts
- ammeter - Simpson, #125, 0-1 D.V. amps
- potentiometer - wire wound, 25w, 50 ohm

(The voltmeter, ammeter, and potentiometer should be ordered 1-2 months in advance.)

From the school maintenance department:
- 3/4" electrical conduit - 6'

From a steel supplier:
- 1/2" steel tubing - 6'

From a rubber supplier:
- o-ring - 3/8" O.D. (generator tire)

From a plastics supplier:
- acrylic plastic tubing - 1" O.D. approx, 3/32" wall

From Edmund Scientific, 101 E. Gloucester Pike, Barrington, NJ, 08007.
- generator - #40,872
- (order 1-2 months in advance)

From a stationery story:
- dry transfer letters and numbers - black - 1/4" high

From the electronics lab:
- printed circuit board

Ask students to bring in old, inexpensive, or out-dated calculators for use as potential RPM counters.

Look for many of the items listed above in surplus supply or obtain from other labs and departments within the school. Also try to use scrap or recycled materials as much as possible. Ask students to bring in scrap materials from home.

The major expense will be for the ammeter and voltmeter. To save money, these may be found at surplus stores or perhaps borrowed from the electronics or physics lab. Simpson meters are suggested for this activity because of their accuracy. Less expensive meters may be substituted, but will not have small increments in values.

The Edmund Scientific generator listed is recommended for use. Others may not work on the turbine.

Suggested Time Allotment

Balsa blades/wind turbine assembly	8 hrs.
Fork and tower mount/bench mount	5 hrs.
Tail vane assembly	5 hrs.
Generator/microswitch assembly	3 hrs.
Calculator/revolutions counter	1 hr.
Load control panel	5 hrs.
	27 hrs.

Suggested Approach

This project can be used as part of a unit on energy sources. It can be used to illustrate electrical generation, the loading of energy systems, or changes in energy forms (mechanical to electrical to heat and light).

Students can be divided into groups and each group assigned a different portion of the construction procedure, as in a production method.

Once the apparatus is constructed, it can be used from year-to-year as demonstration equipment.

Construction of the wind turbine provides the opportunity for instruction in several skills. Demonstrations and instruction can be given in advance as students prepare to perform any of the skills involved in construction of the wind turbine.

Teachers in other subject areas, especially physics and general science, will definitely be interested in using the turbine for demonstration or performance testing. For industrial arts teachers who do not wish to perform the following two activities in their own classrooms, there may be science teachers who are interested in the follow-up.

Precautions

X-acto knives are extremely sharp. Demonstrate their proper use.

Eye protection should be worn while using cyano-acrylate glues. Advise students not to contact skin with these adhesives. An instant bond will occur, which is difficult to "unstick" with almost any material. Acetone works fairly well as a solvent.

Observe the standard welding precautions for this activity: eye protection, gloves, aprons, and shields.

Points for Discussion

What kind of wind machine is a bicycle wheel wind turbine?

What are the energy changes that occur during the turbine generator's operation? (Mechanical to electrical to heat and light.)

Under loaded conditions, the turbine wheel might turn at 100 RPM. Its effective diameter is 26". The diameter of the drive wheel is .375". How fast will the generator turn?

$$\frac{26''}{.375''} = \frac{x}{100 \text{ RPM}} \qquad x = 6{,}933 \text{ RPM}$$

Why do wind turbine blades twist? (The tips of the turbine blades revolve at a faster speed than the roots. The tips also move faster than wind speed, causing them to appear to be approaching at a flatter angle than the turbine's plane of rotation. With the roots moving slower than the wind speed, the relative wind appears to be approaching more from the front of the turbine.)

Typical Results

If aligning the generator with the turbine for friction-free operation proves a problem, note that the generator tire (o-ring) rides on the side of the rim. Slight adjustments may be necessary to prevent tire "scuff".

The answers to Questions 5 and 6 may need some explanation:

5. Heavy lamp cord is used in the generator circuit in order to reduce I^2R power losses, which could be great in direct current circuits. Large conductors provide small resistances. This keeps the product of $I^2 x R$ low.

6. By turning the load potentiometer toward the "10" position, the resistance of the generator circuit is reduced toward zero (see Diagram 15). This causes the current to increase in the generator circuit. Since electrical power is equal to current (amps) times voltage, the generator absorbs more power from the turbine. The turbine speed is reduced as a result, and the turbine is said to be in a "loaded" condition.

Evaluation

Check to make sure students have adhered to the dimensions in the technical drawings.

Look for proper use of materials, tools, and equipment, as well as for adherence to safety standards.

Evaluate the product in terms of craftsmanship, attention to detail, and operation.

Check the students' answers to questions for their understanding of the construction procedure.

Modifications

To evaluate turbine performance, a Prony brake (friction type) may be substituted for the generator.

References

Catch the Wind, A Book of Windmills and Windpower, Landt Dennis. (Four Winds Press, Scholastic Book Services, 50 W. 44th St., New York, NY, 10036, 1976, $8.95.)

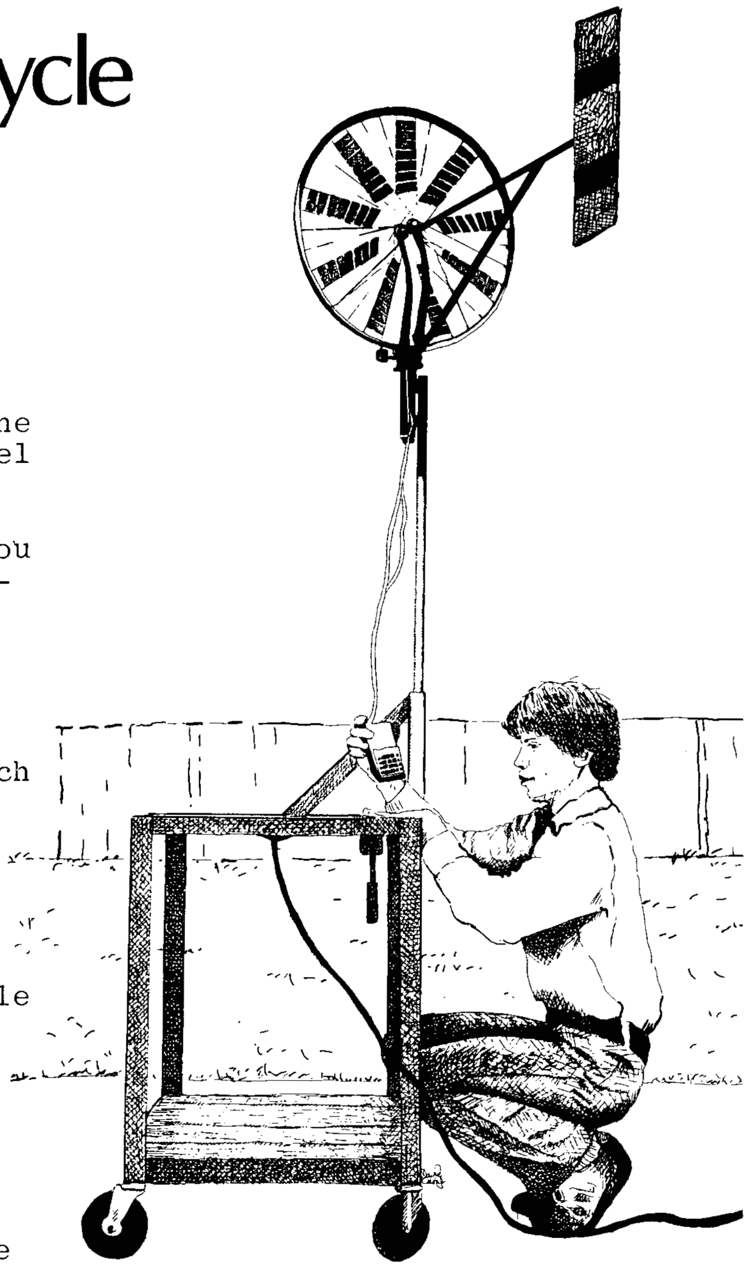
Electric Power From the Wind, Henry Clews. (Solar Wind Publications, Norwich, VT, 1974, $2.00.)

Harnessing the Wind for Home Energy, Dermot McGuigan. (Garden Way Publishing, Charlotte, VT, 05445, 1978, $4.95.)

Home Energy For the Eighties, Ralph Wolfe and Peter Clegg. (Garden Way Publishing, Charlotte, VT, 05445, 1979, $10.95/paper.)

Wind, Making It Work For You, Douglas R. Coonley. (The Franklin Institute Press, Box 2266, Philadelphia, PA, 19103, 1979, $7.95/paper.)

Loading the Bicycle Wheel Turbine



Introduction

You have just finished the construction of a bicycle wheel wind turbine. Now it's time to find out how this turbine operates. In this activity you will investigate the relationship between the speed of the turbine (in revolutions per minute) and the loads it is operating.

A load is any device which uses energy. This energy may be in mechanical, radiant, thermal, or electrical form. The light bulbs connected to your turbine by an electrical circuit are electrical loads. The potentiometer is a variable electrical load which can be set to simulate several different load conditions.

A load on an electrical circuit can be likened to the load on a car. When the car is started, the engine must be out of gear so that there is no load on it. This is much like the turbine when the light bulbs are turned off or the potentiometer is set at 0. When the car accelerates, the engine is subjected to a high load. In the turbine, this occurs when the light bulbs are turned on or the potentiometer is set at 10.

The load conditions are constantly changing for any energy converter. A car is continually changing speed. In an electrical circuit, as one device is turned off, others may be turned on. The amount of work the converter does is constantly changing, too. If a wind turbine is working hard pumping water or generating electricity, then it's operating under high load conditions. But if it's working easily, then it's lightly loaded.

Objectives

At the completion of this activity, you should be able to

- o operate the calculator/counter to determine the wind turbine's speed in revolutions per minute,
- o adjust the load control panel correctly,
- o collect and graph RPM data for all load points, and
- o describe the relationship between RPM and load.

Skills and Knowledge You Need

How to read the second hand of a watch or clock

How to graph data

Materials and Equipment

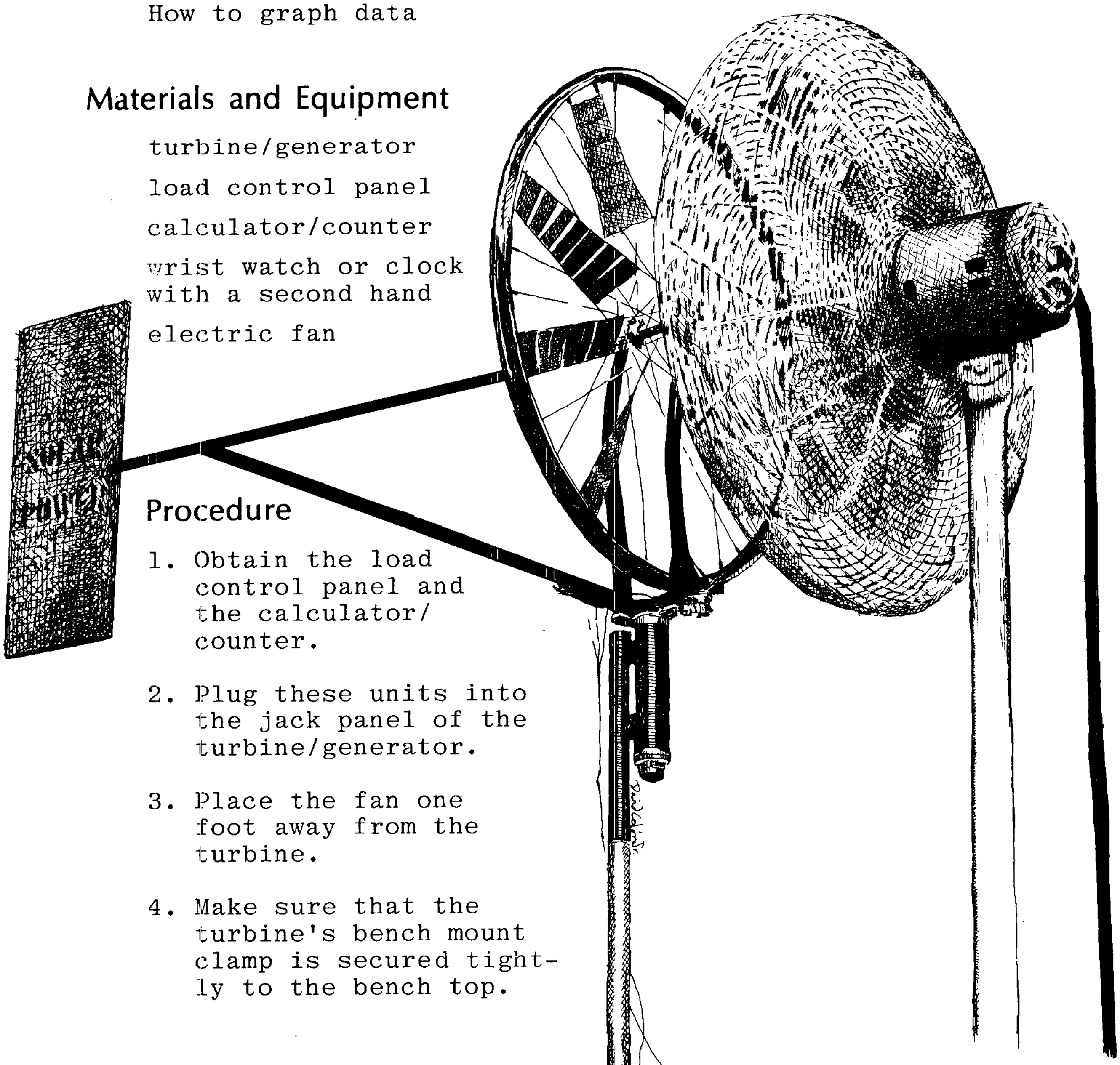
turbine/generator

load control panel

calculator/counter

wrist watch or clock with a second hand

electric fan



Procedure

1. Obtain the load control panel and the calculator/counter.

2. Plug these units into the jack panel of the turbine/generator.

3. Place the fan one foot away from the turbine.

4. Make sure that the turbine's bench mount clamp is secured tightly to the bench top.

5. Make sure that the selector switch on the load control panel is turned to "off".

6. Turn the fan switch to high speed.

Caution: Keep fingers away from the fan guard and the moving wind turbine.

7. Allow the turbine/generator to warm up for about one minute.

8. Turn the selector switch to the "load" position.

9. Adjust the load control potentiometer to maximum load (#10).

Caution: Turn this control slowly. Don't allow the ammeter needle to "peg" full scale.

10. Turn on the calculator/counter. Press "+", then press "6".

11. Allow at least 30 seconds for the turbine/generator to stabilize.

12. Start the calculator/counter by pressing the counter button. Release after exactly 10 seconds have passed.

13. On the data table provided, record the revolutions per minute (RPM) indicated on the calculator/counter display.

14. Zero the calculator/counter by pressing "0".

15. Perform a second trial to verify data. If the second trial is not the same as the first, perform the test again, and average all three trials.

16. Repeat Steps 11-15 for each of the load values given in the Data Table.

17. Plot turbine RPM vs. load on the graph provided.

18. Lubricate the turbine and generator bearings (3-in-1 oil works well) after every half hour of operation.

Questions

1. Why is the fan used for this experiment, rather than the wind outdoors?

2. Why is the calculator/counter programmed to count 6 for each turbine revolution?

3. What happens to turbine RPM as the load is decreased? Is this a direct relationship, an inverse relationship, or no relationship?

4. If you could increase the load further than the #10 position, would the generator stall (stop) the turbine?

5. There is a point on the RPM scale where small increases in load cause great reductions in turbine speed. At what RPM does this happen for your wind turbine?

6. Use your answer to Question 5 to determine the range of most efficient turbine speeds for your wind turbine.

Looking Back

By now, you should have discovered that when your wind turbine was lightly loaded, the rotor turned at high speeds. But when your turbine was highly loaded, the turbine revolved at slow speeds. In fact, you should have been able to identify a point on your graph where very small increases in load caused large reductions in turbine speed.

Any energy converter has a narrow range of conditions (speed, generator voltage, wind) under which it performs best. For your wind turbine, there is an optimum operating speed range. If the loads on the turbine are too small or too great, the machine does not perform efficiently. One task for any wind turbine control system is to keep the turbine functioning within the load limits that produce high performance. In the next activity you will investigate what these load limits are.

Going Further

List as many load applications as you can for wind turbines. (Hint: What kinds of tasks can they perform?)

List the advantages and disadvantages of using wind turbines rather than conventional methods to perform each of the tasks listed above.

Investigate the impact of wind machines on each of the following:

the use of non-renewable resources

the environment

the use of local materials

the use of local skills

self-sufficiency

small-scale and decentralized technology

Investigate the relationship between wind speed and the revolutions per minute of your wind turbine.

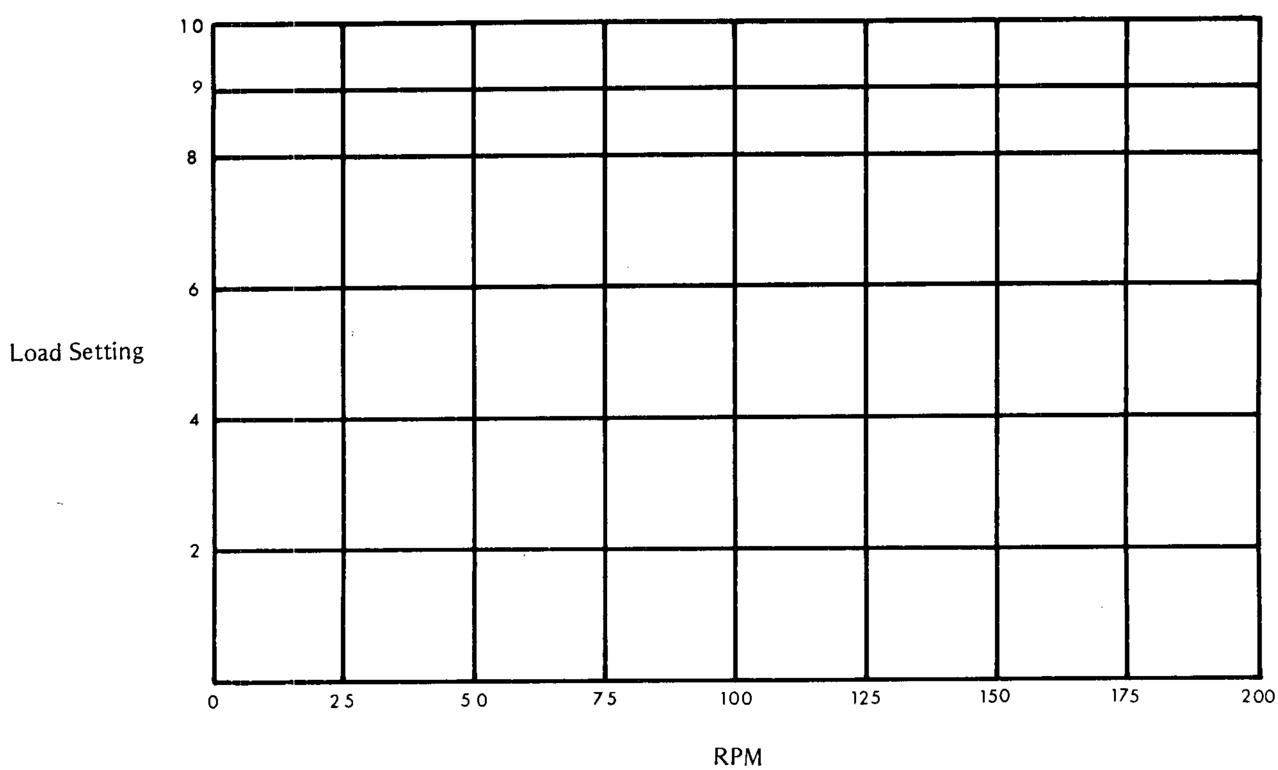
Research tip speed ratio, then determine this ratio for your wind machine.

Data Table

Load	RPM
10	
9	
8	
6	
4	
2	
0	

Graph

Load and Turbine RPM



Teacher Information

Loading the Bicycle Wheel Turbine

Suggested Grade Level and Skill Area

9-12 Industrial Arts
Power
General Shop
Electricity
Alternative Energy/Energy Technology

Skill Objectives

Operating a calculator/counter to determine turbine RPM

Operating a potentiometer to simulate load conditions

Collecting accurate data

Recording and graphing data

Inferring relationships from graphed data

Content Objectives

As the load on a wind turbine is decreased, the revolutions per minute (RPM) increase.

Wind turbines perform most efficiently within a narrow range of operating speeds.

A constant-speed fan is used in this activity as a control to replace outdoor wind, which would vary from moment to moment.

Background

Energy is extracted from the wind by slowing down the air. Energy (or power) is derived from a wind turbine by slowing down its blades. Many energy conversions take place in this process. The turbine converts the motion energy of the air to the motion energy of its blades. This energy, in turn, is converted to the motion energy of the spinning generator armature, then to electrical energy in the generator itself. Electrical energy is converted by the loads to heat or light, or even back to motion energy.

The potentiometer on the load control panel varies the resistance within the generator circuit. As the potentiometer value is increased from 0 to 10, its resistance decreases. As the resistance decreases, more current flows through the circuit, simulating more load on the turbine.

As more current flows through the generator circuit, more power is extracted from the wind machine. As this happens, the speed (RPM) of the machine decreases. The relationship between load and RPM, then, is an inverse one.

A fan is used in this activity to provide a wind that is constant in velocity. Outside winds are unsteady and rarely maintain a constant velocity for more than a few seconds.

Advance Planning

Duplicate data sheets ahead of time.

Make certain all equipment is operational: the turbine/generator, the load control panel, the calculator/counter, and the electric fan.

Suggested Time Allotment

One class period

Suggested Approach

Provide instruction to students on the concepts of load and work.

This activity may be performed by 2 or 3 students at a time. When one group completes its data collection, another group may proceed.

Precautions

Warn students not to stick fingers through the fan guard, or into the moving turbine wheel.

Points for Discussion

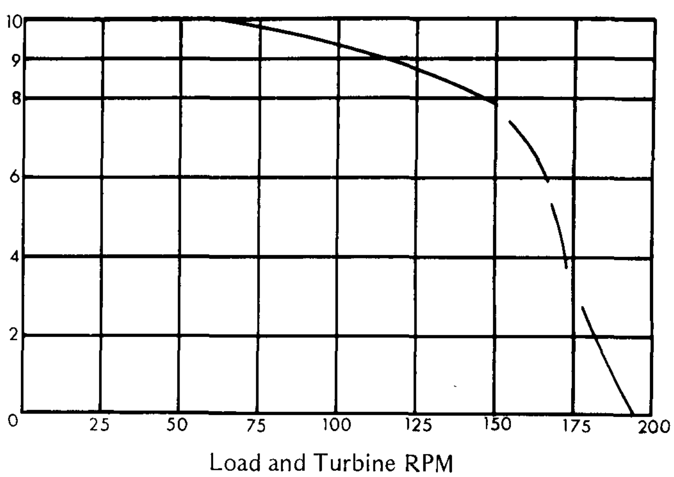
How does the potentiometer function in the generator circuit? How does changing the potentiometer value simulate loading the turbine generator?

After a certain point, why does turbine speed decrease rapidly with small increases in load?

Why does a wind turbine have a narrow range of optimum operating speeds?

Typical Results

A typical graph of load vs. RPM is shown at the right. The wind speed is 14 mph.



Evaluation

Observe your students' ability to follow instructions and to work with one another.

Collect and review the data and graph. Was the activity carried through carefully? Can conclusions be drawn from the data collected?

Check students' answers to activity questions.

References

Electric Power From the Wind, Henry Clews.
(Solar Wind Publications, Norwich, VT, 1974, $2.00.)

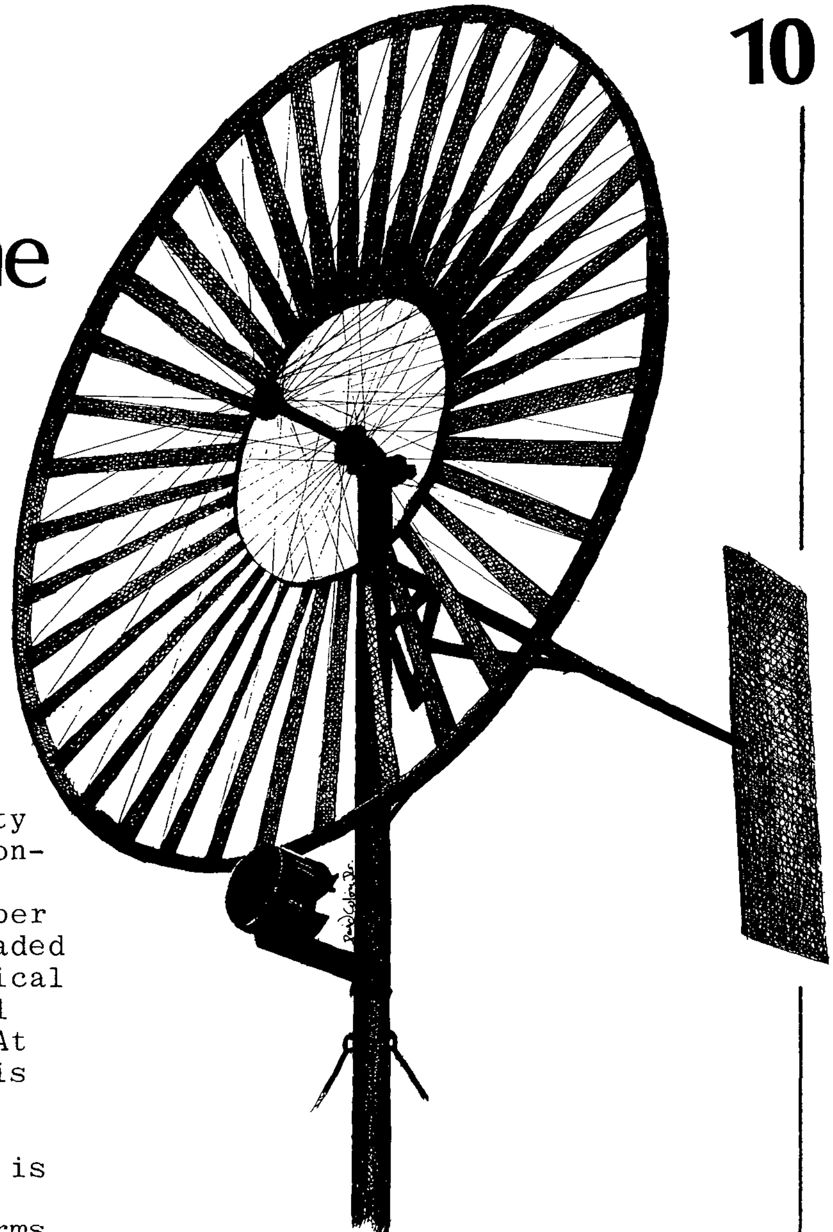
Harnessing the Wind for Home Energy, Dermot McGuigan.
(Garden Way Publishing, Charlotte, VT, 05445, 1978, $4.95.)

Home Energy For the Eighties, Ralph Wolfe & Peter Clegg.
(Garden Way Publishing, Charlotte, VT, 05445, 1979, $10.95/paper.)

Wind, Making It Work For You, Douglas R. Coonley.
(The Franklin Institute Press, Box 2266, Philadelphia, PA, 19103, 1979, $7.95/paper.)

DRAFT

Power From the Bicycle Wheel Turbine



Introduction

In the previous activity you investigated the relationship of the load on a wind turbine to its revolutions per minute. But under these loaded conditions, how much electrical power can your bicycle wheel turbine actually produce? At what load (voltage) does this maximum power occur?

The power of a machine is the rate at which it can do work. But in electrical terms, power is also equal to the amperage of a current times its voltage. Power (in watts) = amps x volts.

Your bicycle wheel turbine has a diameter of 27 inches or 2.25 feet. The power available to it from the wind can be determined by the formula

$$\text{Power} = .004\ D^2\ V^3$$

where D = propeller diameter and V = wind speed. Therefore, in a 14 mph wind, the power available to your wind turbine is 55.5 watts.

But will your bicycle wheel turbine actually deliver this much power? The only way to find out is to test it. In this activity you will load your turbine to determine the maximum power it can produce, also called its peak power output. You'll also determine the number of light bulbs that will produce this same peak load condition.

Objectives

At the completion of this activity, you should be able to

- o graph the relationship between power and voltage for the bicycle wheel wind turbine/generator,
- o find the turbine/generator's peak power (in watts) and the voltage at which this occurs, and
- o determine the number of light bulbs which duplicate the turbine/generator's peak power load conditions.

Skills and Knowledge You Need

Reading a voltmeter and ammeter

Operating the calculator/counter

Graphing collected data

Materials and Equipment

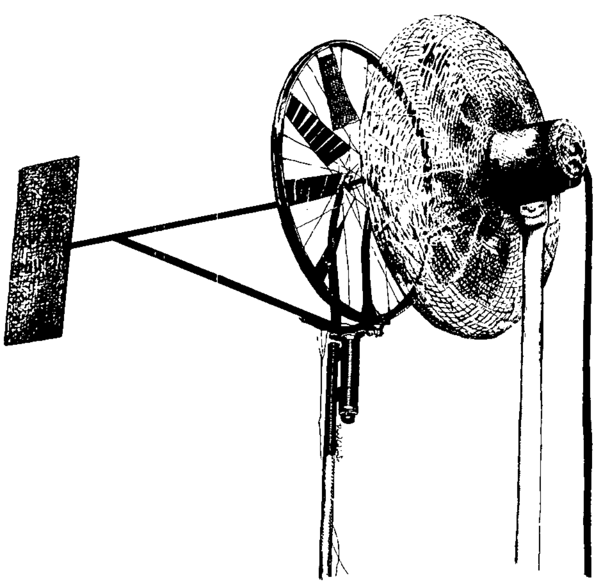
load control panel

calculator/counter

turbine/generator assembly

watch or lab clock with second hand

electric fan



Procedure

1. Obtain the load control panel and the calculator/counter.
2. Plug these units into the jack panel of the turbine/generator.
3. Place the fan one foot away from the turbine.
4. Make sure that the bench mount clamp is secured tightly to the bench top.
5. Make sure that the selector switch on the load control panel is turned to "off".
6. Turn the fan switch to high speed.

Caution: Keep fingers away from the fan guard and the moving wind turbine.

7. Allow the turbine/generator to warm up for about one minute.

8. Turn the selector switch to the "load" position.

9. Adjust the load control potentiometer toward the maximum setting, until the voltmeter reads .2 volts.

Caution: Move the load control slowly so the ammeter needle does not "peg" to full scale.

10. Allow the turbine/generator to stabilize for about 30 seconds.

11. Record the amperage in Data Table 1.

12. Use the potentiometer to increase the voltage by .2. Allow the turbine/generator to stabilize, then record the amperage in Data Table 1.

13. Repeat Step 12 until the maximum voltage is reached.

14. Turn the fan off.

15. Calculate the turbine/generator's power by multiplying each voltage by each amperage. For example,

    .2 volts x .5 amps = .1 watts of power.

    Record under "watts" in Data Table 1.

16. Plot generator voltage vs. watts on the graph provided.

17. Answer question #1 in the Question section.

18. Return the selector switch on the load control panel to the "off" position. Restart the fan in the high speed position.

19. Allow the unit (turbine/generator) to warm up for about one minute.

(Note: Remember to lubricate the turbine and generator bearings after each 1/2 hour of operation.)

20. Turn on the calculator/counter, press "+", then press "6".

21. Turn the selector switch to the "load" position.

22. Adjust the load control to the voltage where the maximum power is produced.

23. Allow the turbine/generator to stabilize for about 30 seconds.

24. Start the calculator/counter by pressing the counter button. Release after exactly 10 seconds have passed.

25. Answer question #2 in the Question section.

26. Turn the selector switch to the "bulb" position.

27. Turn on individual load bulbs one at a time, each time recording the voltage in Data Table 2.

28. Turn the fan off.

29. Answer question #3 in the Question section.

30. Carefully return all control knobs to their original positions.

Questions

1. At what voltage does the turbine/generator's maximum power (wattage) occur?

2. At what turbine RPM does the maximum power occur?

3. How many light bulbs were required to produce the voltage that indicates maximum power is being produced?

4. Why is it desirable to operate the turbine/generator at peak power (its maximum power point)?

5. Why is it important to know the operating characteristics of any energy-converting system?

6. How many watts of electrical power were produced at the turbine/generator's peak power?

Looking Back

Wind machines' designs vary, as does the power they can produce from the wind. Some wind machines are more efficient than others, but all have a range of conditions under which they perform best.

You have found the generator voltages at which your wind turbine functions most efficiently, and you have determined the peak power that your turbine will produce at the fan's highest speed. You have also found the number of light bulbs which produce peak power output. These light bulbs represent the most efficient load for your turbine at the fan's highest speed.

Wind machines function best within a narrow range of operating speeds. If loads are too little or too great, the machine does not perform efficiently. You observed this when you operated the light bulbs on the load control panel. When too many bulbs were turned on, the turbine revolved slowly and the bulbs were dim. When too few bulbs were turned on, the turbine operated at a high speed that did not produce its maximum power. In the operation of any wind machine, the purpose is to keep it operating within the load limits that produce maximum performance.

Going Further

Research performance data supplied by various wind machine dealers. One good source is A Guide to Commercially Available Wind Machines (REP-2836/3533/78/3), National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161, $10.00. Compare the performance data for these various wind energy systems.

Investigate the "cube law", which states that the power derived from the wind is proportional to the cube of the wind speed ($P \propto V^3$). This means that small increases in wind speed produce very large increases in power. For example, 8 times more power is produced in a 10 mph wind than in a 5 mph wind. Use a hand-held wind-speed indicator to determine the wind speeds from a variable-speed fan, and then measure the turbine/generator's power output at these various speeds. Graph the data collected to see if you can experimentally verify the "cube law".

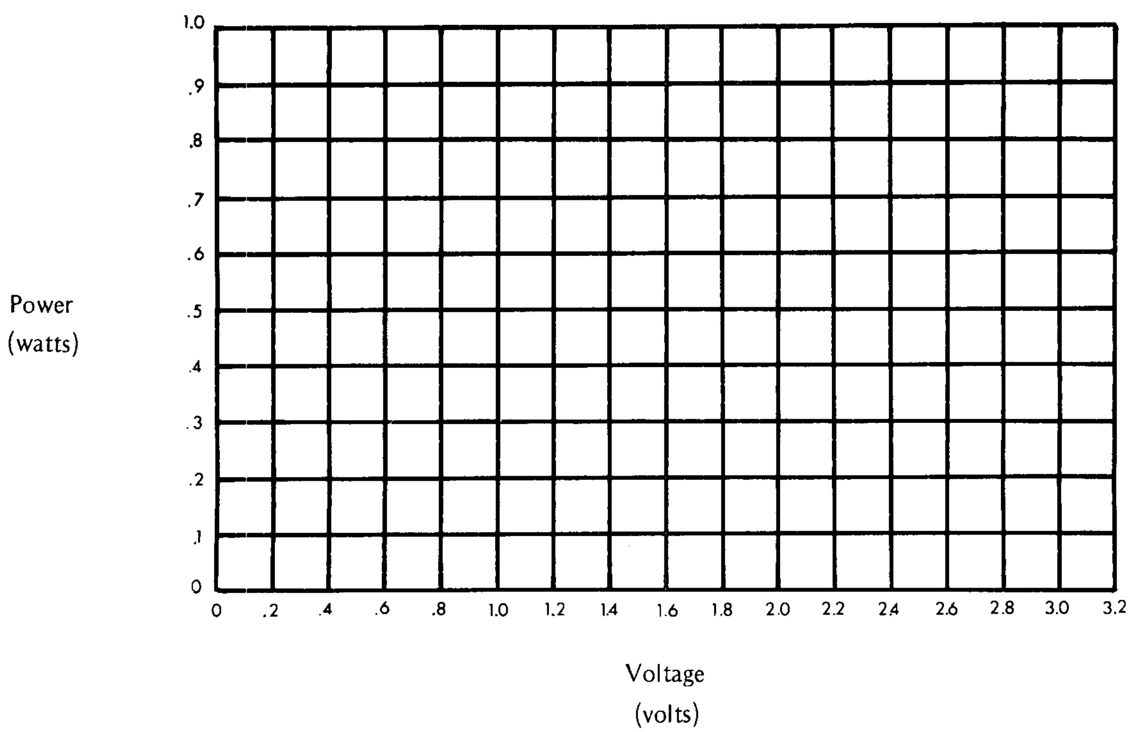
Data Table 1

Volts	Amps	Watts
.2		
.4		
.6		
.8		
1.0		
1.2		
1.4		
1.6		
1.8		
2.0		
2.2		
2.4		
2.6		
2.8		
3.0		
3.2		

Data Table 2

Number of bulbs on	Voltage
1	
2	
3	
4	
5	
6	

Graph The Turbine Generator's Peak Power



Teacher Information
Power From the Bicycle Wheel Turbine

Suggested Grade Level and Skill Area

9-12 Industrial Arts
Electricity
Power
General Shop
Alternative Energy/Energy Technology

Skill Objectives

Using the potentiometer to select voltages on a voltmeter

Measuring amperage with an ammeter

Determining wattage by the formula watts = volts x amps

Recording and graphing data

Determining the turbine's peak power from graphed data

Determining the number of light bulbs which will produce peak power output

Operating the calculator/counter to determine turbine RPM

Content Objectives

The turbine/generator produces a maximum power output, called its peak power, which can be determined by finding its wattage (power) for varying voltages.

A given number of operating light bulbs will produce this same condition of peak power output.

The turbine generator operates most efficiently at this peak power.

The turbine generator has a narrow range of operating speeds at which it performs most efficiently.

Background

This activity investigates the power available from the bicycle wheel turbine at a constant wind speed (high speed on an electric fan, about 14 mph). The potentiometer is set at varying voltages, the amperage is measured, and the power output (wattage) is determined. From this, the peak power of the turbine can be found, as well as the voltages and RPM at which the turbine operates most efficiently.

The term "power" is different from the term "energy". Energy is the ability to do work, while power is the time rate of doing work. The relationship is Power = Work (or Energy)/Time, expressed in watts. Students will experimentally determine the power produced by the wind turbine, but they will do so by determining the power delivered to an electric circuit by the generator, using Power = Volts x Amps. To find the energy that a wind turbine can deliver over time, the formula can be expressed as Energy = Power x Time.

There are three factors which influence a wind turbine's performance (power output). They are the wind velocity, the diameter of the rotor, and the density of the ambient air. For our purposes the density of air can be considered a constant (.08 lb/ft^3). The three factors interact according to the formula

$$P = .004\ D^2V^3$$

where P = Power, D = rotor diameter (in feet), V = wind speed (in mph), and .004 = a constant, correcting for air density and conversion to watts.

For example, the wind power available (in watts) to a 10 foot diameter turbine in a 20 mph wind can be calculated as follows:

$$P = .004\ D^2V^3$$

$$P = .004\ (10)^2(20)^3$$

P = 3200 watts or 3.2 kilowatts

Once the power available from the wind is known, the system's overall efficiency can easily be calculated.

$$\text{Efficiency} = \frac{\text{system output}}{\text{system input}} \times 100$$

The system input is the power available from the wind, and the system output is the actual power derived from the turbine/generator (which the students calculate). The turbine/generator will always produce the highest operating efficiency at peak power.

In order to obtain results similar to those reported in the typical results section, an electric fan which delivers an average wind speed of 14 mph should be used. A pocket wind meter (Edmund Scientific, $9.95) can be used to determine the fan's wind speed.

Advance Planning

Duplicate the data sheets ahead of time.

Make certain all equipment is operational: the turbine/generator, the load control panel, the calculator/counter, and the electric fan.

Suggested Time Allotment

One to two class periods

Suggested Approach

Provide background information to students on the relationship between energy, work, and power. Give instruction on how to calculate power and give a few examples.

This activity may be performed by 2 or 3 students at a time. When one group completes its data collection, another group may proceed.

Precautions

Warn students not to stick fingers through the fan guard or into the moving turbine wheel.

Points for Discussion

What is the relationship between power and energy?

What is meant by the term "peak power"?

What three factors influence the power available from the wind?

Discuss Betz's law, which states that maximum power (.593 of the wind's potential) is derived from the wind when wind speed is slowed to 1/3 of its initial velocity. The formula for useful power from the wind then becomes $P = .0024\ D^2V^3$.

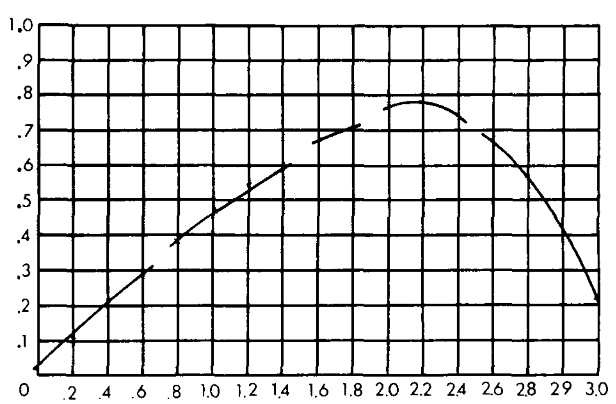
Why do wind turbines perform best within only a narrow operating speed?

What factors affect the efficiency of a wind machine in converting wind to electricity?

How is the formula for wind power derived? (Energy from Nature to Man gives detailed information.)

Typical Results

Typical results are shown on the graph.



The Turbine Generator's Peak Power

Evaluation

Observe your students' ability to follow instructions and work with one another.

Collect and review the data and graphs. Was the activity carried through carefully? Can conclusions be drawn from the data collected?

Modifications

Repeat the activity for different wind speeds to determine the peak power available from the turbine as a function of wind speed.

References

Electric Power From the Wind, Henry Clews.
(Solar Wind Publications, Norwich, VT, 1974, $2.00.)

Energy From Nature to Man, William C. Reynolds.
(McGraw-Hill, 1221 Avenue of the Americas, New York, NY, 10020, 1974.)

Harnessing the Wind for Home Energy, Dermot McGuigan.
(Garden Way Publishing, Charlotte, VT 05445, 1978, $4.95.)

Home Energy for the Eighties, Ralph Wolfe & Peter Clegg.
(Garden Way Publishing, Charlotte, VT 05445, 1979, $10.95/paper.)

Wind, Making It Work For You, Douglas R. Coonley.
(The Franklin Institute Press, Box 2266, Philadelphia, PA, 19103, 1979, $7.95/paper.)