

Active Solar Systems

Unit: Renewable Energy

Problem Area: Renewable Systems

Lesson: Active Solar Systems

■ **Student Learning Objectives.** Instruction in this lesson should result in students achieving the following objectives:

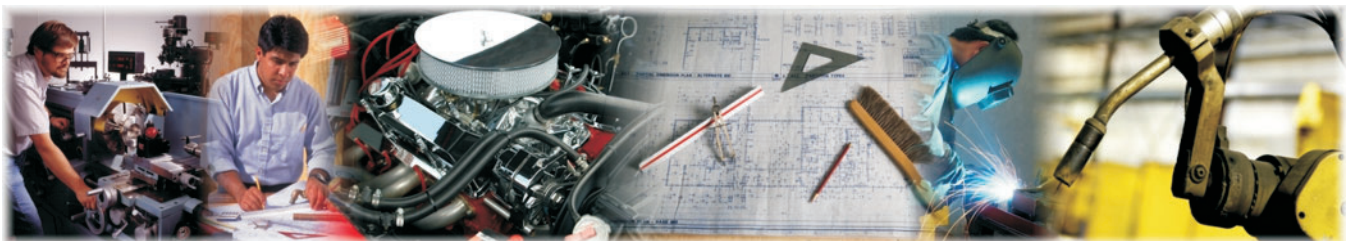
- 1 Identify components of active solar systems.**
- 2 Explain the uses of active solar systems.**
- 3 Describe the proper techniques for sizing solar systems for residential and commercial buildings.**
- 4 Identify and evaluate proper installation of active solar systems for new and existing structures.**

■ **Resources.** The following resources may be useful in teaching this lesson:

“Active Solar Heating,” *U.S. Department of Energy*. Accessed June 20, 2011. <http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12490>.

“Average Daily Solar Radiation per Month,” *National Renewable Energy Laboratory*. Accessed June 20, 2011. <<http://www.energysavers.gov/pdfs/130.pdf>>.

Knier, Gil. “How Do Photovoltaics Work?” *NASA*. Accessed June 20, 2011. <<http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/>>.



“Maintenance and Operation of Active Solar Heating Systems,” *Naval Facilities Engineering Command*. Accessed June 20, 2011.

<<http://www.scribd.com/doc/2980057/MO405-Maintenance-and-Operation-of-Active-Solar-Heating-Systems>>.

“RETScreen® Clean Energy Project Analysis Software,” *Natural Resources Canada*. Accessed June 20, 2011. <<http://www.retscreen.net/ang/home.php>>.

Seifert, Richard D. “Active Solar Heating Fact Sheet,” Cooperative Extension Service: University of Alaska Fairbanks. Accessed June 20, 2011.

<<http://www.absn.com/files/EEM-01256%20Active%20Solar.pdf>>.

“Solar Calculator,” *coolerplanet*. Accessed June 20, 2011.

<<http://solar.coolerplanet.com/Articles/solar-calculator.aspx>>.

“The Solar Power Prospector,” *National Renewable Energy Laboratory*. Accessed June 20, 2011. <<http://maps.nrel.gov/node/10/>>.

“Space Heating with Active Solar Energy Systems,” *North Carolina Solar Center*. Accessed June 20, 2011. <http://www.ncsc.ncsu.edu/include/_upload/media/pubs/20acspht.pdf>.

■ **Equipment, Tools, Supplies, and Facilities**

- ✓ Overhead or PowerPoint projector
- ✓ Visual(s) from accompanying master(s)
- ✓ Copies of sample test, lab sheet(s), and/or other items designed for duplication
- ✓ Materials listed on duplicated items
- ✓ Computers with printers and Internet access
- ✓ Classroom resource and reference materials

■ **Key Terms.** The following terms are presented in this lesson (shown in bold italics):

- ▶ active solar systems
- ▶ closed-loop systems
- ▶ concentrating collectors
- ▶ evacuated-tube collectors
- ▶ flat-plate collectors
- ▶ glazing
- ▶ inverters
- ▶ open-loop systems
- ▶ parallel circuits
- ▶ photovoltaic solar systems
- ▶ radiant floor heat
- ▶ semiconductor materials
- ▶ series circuits
- ▶ thermal mass
- ▶ trusses

- **Interest Approach.** Use an interest approach that will prepare the students for the lesson. Teachers often develop approaches for their unique class and student situations. A possible approach is included here.

Play the game of firsts with your students. Give them three dates, three locations, and three events. Working in teams of three, ask them to put them in order, with the proper location and the proper event. Ask each team to present their list while explaining the thought process used to develop it. While the students aren't expected to know the answers, hearing their thought process is desired.

[Teacher's Note: The three dates, locations, and events are presented as follows in the correct order]

- ◆ Dates: 1767, 1878, and 1904
- ◆ Locations: Geneva, India, and California
- ◆ Events: First solar collector built, first book about solar energy, and first solar company

CONTENT SUMMARY AND TEACHING STRATEGIES

Objective 1: Identify components of active solar systems.

Anticipated Problem: What are the components of active solar systems?

- I. **Active solar systems** are mechanical systems that collect, concentrate, and store energy from the sun to produce heating and/or cooling. Active solar systems have three main components: collection, storage, and distribution.
 - A. There are three types of active solar collectors: flat plate, evacuated tubes, and concentrating.
 1. **Flat-plate collectors** are insulated, weatherproof boxes containing a dark absorber panel and one or more layers of glazing. **Glazing** is the transparent material used for windows. It is usually glass or plastic.
 - a. The first solar collector, designed by Horace de Saussure in the 1700s, consisted of these basic elements that Saussure called “hot boxes.” An avid mountain climber, Saussure carried his “hot boxes” to the tops of mountains to determine if the temperature inside the boxes would rise if he were closer to the sun. They did not.

- b. Today's active flat-plate collectors include pipes underneath the absorber plate. The pipes carry water or a heat-conducting fluid. As the temperature of the absorber plate rises, so does the temperature of the fluid in the pipes. Flat-plate collectors are the most common types of solar collectors.
 2. **Evacuated tube collectors** are devices that use rows of glass and/or metal tubes and evacuate the air in the tubes to create a vacuum.
 - a. As with flat-plate collectors, there is a surface that absorbs the sun's heat. However, the vacuum eliminates conductive and convective heat loss, which can result in very high temperatures and makes these solar panels effective even in low temperatures or overcast conditions.
 - b. Because of the high temperatures that can be achieved, these collectors are often used in commercial applications. If the seals are compromised, the tubes will lose the vacuum and the systems can shut down. Therefore, reliability can be a problem.
 3. **Concentrating collectors** are mirrored surfaces, often shaped like a parabola, that concentrate the sun's heat onto an absorber tube. The mirrors intensify the heat, creating very high temperatures. These collectors are used in commercial applications.
- B. With all three types of collectors, the heat from the sun is concentrated onto a dark or specially coated surface that absorbs the heat. In turn, the surface heats air or a liquid solution contained in tubes near the absorbing surface. The tubes continue into a heat storage system. **Thermal mass** is a building material that provides heat storage capacity. As with passive solar systems, thermal mass is achieved through the use of water or masonry. The water absorbs heat faster because of the convective water currents. The rule of thumb is to use one to two gallons of water for every square foot of collector. Also, the water tank should be insulated for greatest efficiency. The tubes carrying the now heated liquid solution are run through the thermal mass, which absorbs the heat. Fluids are moved using pumps. Active systems can be open- or closed-loop systems.
 1. **Open-loop systems** are systems that use pumps to circulate tap water through the collectors. Problems occur if the local water is hard or acidic because scale or corrosion will interfere with operation. Also, these collectors are problematic in cold climates where temperatures could fall below zero.
 2. **Closed-loop systems** are systems that circulate heat transfer fluid, such as antifreeze mixtures, through the collectors. While more expensive, these systems are more reliable in cold climates.
- C. Distribution is how the stored heat is distributed to the desired areas. Those areas could include space heating, domestic water heating, or swimming pool heating. The stored heat can be used for heating using a heat exchanger in the case of air to air systems or hot water heat in the case of air to water systems.
 1. Another option is **radiant floor heat**, which is hot water pumped through tubes underneath a concrete floor. The concrete absorbs the heat and releases it over a period of time. This comfortable heating method is gaining popularity.

2. Additional controls are used to regulate high temperatures and to guard against freezing. In particular, active solar systems require the integration of a differential thermostat. The thermostat measures the temperature difference between the heat in the collector and in the thermal mass. When the difference is between 10 and 20 degrees, the thermostat will turn on a fan or pump to move the excess heat where it is needed. The overall goal of the control system is comfort and reliability.

Teaching Strategy: Working in teams, have your students design a solar panel on paper. It is their choice what they will design, but they have to present it to the class and explain their choices. Use VM–A.

Objective 2: Explain the uses of active solar systems.

Anticipated Problem: What are the uses of active solar systems?

- II. Active solar systems can produce heat and electricity.
 - A. The heat produced from an active solar system can be used to heat air or water for space heating and domestic hot water. Space heating, as described earlier, is accomplished by heating air or water carried through tubes. The tubes are run through thermal storage, and heat is distributed throughout the building using fans or pumps.
 1. Solar heated domestic hot water can be used for typical household chores (e.g., laundry, bathing, and kitchen tasks).
 2. Solar heated water can be used in swimming pools.
 3. Commercially solar heated water is used in car washes and laundry facilities.
 - B. **Photovoltaic solar systems** are electrical devices that turn sunlight into electricity. **Semiconductor materials**, such as silicon, are items that cause electrons to separate from the atom. The electrons are captured through an electrical circuit, thereby providing usable electricity. Photovoltaic energy first became common practice for small electric appliances, such as calculators. As batteries for storing the energy became more efficient, photovoltaic energy has been used to supply greater amounts of electricity in various settings. Photovoltaic energy is most cost effective in remote locations where the cost of running a transmission line would be cost prohibitive. Examples are lighted signs along a highway, in outer space, off shore, in agricultural and rural settings, and in developing nations.
 1. Photovoltaic technology started in 1839 when a 19-year-old physicist from France, Edmund Becquerel, first noted the electricity producing properties of certain materials. Yet Albert Einstein’s work in 1905 won him a Nobel Prize in Physics and really launched the solar electricity industry. Today’s solar cell is based on the Bell Laboratories design first developed in 1954.
 2. The Bell Laboratories design produced electricity reliably but at a high cost. One watt of power could be produced for about \$250 as opposed to \$3 per

watt for coal-generated electricity. Over the years, technical progress combined with cost-cutting measures has reduced the cost to about \$5 per watt for a fully commissioned photovoltaic array.

Teaching Strategy: Ask your students to consider the use of active solar technology in the aftermath of the Haiti earthquake. Working in teams, ask them to develop a strategy for using this technology in Port-au-Prince, Haiti. They will present their strategies to the class. Use VM-B and VM-C.

Objective 3: Describe the proper techniques for sizing solar systems for residential and commercial buildings.

Anticipated Problem: What are the proper techniques for sizing active solar systems for residential and commercial buildings?

- III. Proper sizing of an active solar system is as important as proper sizing of a conventional HVAC system. Proper sizing allows for optimum comfort and cost-effectiveness in initial purchase price as well as operational costs.
 - A. An active solar system used for space heating and/or heating of domestic hot water should face south, should be in full sun between the hours of 9 a.m. and 3 p.m., and should be tilted equal to the latitude. However, the panels can be mounted flush on a sloped roof if it provides a more attractive installation.
 1. Active solar systems are usually designed to provide between 40 and 80 percent of a home's projected heating needs. Mortgage lenders and/or local ordinances usually require that a home have a back-up heating source. This can range from a conventional furnace to a wood stove. However, a well built and well insulated home may not need to use the back-up system much, if at all.
 2. To determine the proper size of the active solar system for space heating, the designer needs to consider access to solar radiation, projected heating needs, and building design. Solar radiation data is available online.
 - B. The parameters for sizing a domestic hot water system are based on the number of people who regularly reside in the home. One to two residents generally require a 50- to 60-gallon storage tank. Three to four residents usually require 80 gallons, and four to six residents will require 120 gallons. To obtain these numbers, the system will be designed to provide 1.5 gallons of hot water per square foot of collector. Therefore, if 80 gallons are required, the system will include 120 square feet of solar panels.
 - C. The parameters for sizing a photovoltaic system depends on the amount of electricity generation desired daily and access to solar radiation. To determine the daily electricity generation required, it is necessary to identify the wattage of the electrical appliances the system will be powering.
 1. To determine the watts of the proposed system, it is essential to multiply the wattage used by the facility on a daily basis by the time in hours that the elec-

trical appliances are in use each day. The formula is Daily Load = wattage × time in use. This determines the load profile.

2. The next step is to size the system based on the amount of sunlight available in the area. This data is available online. For example, Chicago receives an average of 4.4 hours of sunlight per day. Therefore, if a building in Chicago required 5,000 watts per day, the formula would be $5,000 \text{ watts DC} \times 4.4 \text{ hours of sunlight per day} = 22,000 \text{ watt hours DC per day or } 22.2 \text{ kWh per day}$.
3. The production of electricity by various solar panels is rated in peak watts. By knowing the watt hours available per panel, a designer can calculate the number of panels required to achieve the desired load profile. This is not a straight calculation. Designers build in a factor of 15 to 20 percent power loss due to inefficiencies of batteries and inverters. Therefore, the daily load of 22,000 watts would be multiplied by 1.2 to determine the optimum load of 26.4 kWh per day. Assuming the selected solar panels were rated at 240 watt hours per panel, a designer would divide the optimum load by 240 watts to determine the number of panels required. The result is 110 panels.

Teaching Strategy: Ask your students to complete the photovoltaic sizing calculation for a commercial building in Chicago that requires 13,000 watts per day. The answer would be $15,000 \times 4.4 = 66,000$ $66,000 \times 1.2 = 79,200$ $79,200 / 240 = 330$.

Objective 4: Identify and evaluate proper installation of active solar systems for new and existing structures.

Anticipated Problem: How do you identify and evaluate proper installation of active solar systems for new and existing structures?

- IV. Properly installed active solar systems provide comfort and reliability for building occupants. Elements to consider are shading, sizing, building design, system components, and wiring.
 - A. Active solar systems are most effective when solar access is not obstructed. Even minor shading from other buildings or trees can reduce the efficiency of the system. Therefore, it is important to design the structure to avoid shading and to check local ordinances to be certain that solar access is protected.
 - B. Systems must be properly sized for the building's energy load profile. This requires the designer to research the solar radiation data for the location and to plan for a 20 percent efficiency loss factor.
 - C. Buildings can be designed to include solar during construction or as an optional retrofit at some point in the future. In either case, building orientation and roof strength are important factors. Active solar systems can be extremely heavy, so often the most expensive part of a solar retrofit is strengthening the roof. Photovoltaic systems weigh between 3 and 6 pounds per square foot. Solar thermal systems weigh between 2 and 5.5 pounds per square foot. Rather than

traditional beams, the designer should consider using roofing trusses. **Trusses** are structures composed of one or more triangular units made from straight members with the ends connected at joints. Roofing trusses provide greater strength than traditional beams. In addition to the weight of the solar system, the roofing design should consider local wind loads.

1. Metal roofing provides an extremely strong base for the installation of active solar systems. In addition, it sheds snow.
 2. When adding an active solar system to a building with an existing rubber roof, it is prudent to check the warranty. Often warranties for rubber roofs are voided if any penetrations are added.
- D. System component mismatch can be a serious problem in active solar systems. Many factors can contribute to mismatch, such as shading, the connections between the internal battery module, wiring, and inverter configurations. Mismatch results in a reduction in system power output.
1. **Inverters** are devices that change direct current into alternating current. They are rated according to the maximum voltage they can accept. Photovoltaic modules must be designed to provide the inverter less than its maximum voltage rating.
 2. The wiring configuration plays an important part in system efficiency. Electrical circuits can be designed in series or in parallel.
 - a. **Series circuits** are circuits connected in a single path with the current flowing through all components. Typically, active solar systems have been wired in series. However, if there is a break in the current anywhere in the series, the circuit will fail. This is similar to a string of holiday lights where one unlit bulb will result in the entire string failing.
 - b. **Parallel circuits** are circuits wired in a continuous loop to provide the same voltage to each component. This provides greater reliability and more power from the system.

Teaching Strategy: Ask your students to research roofing systems, including beams, three types of trusses, and metal roofing. They should provide the pros and cons of each type for use with an active solar system. Use VM–D. Assign LS–A.

■ **Review/Summary.** Use the student learning objectives to summarize the lesson. Have students explain the content associated with each objective. Student responses can be used in determining which objectives need to be reviewed or taught from a different angle. Questions at the ends of chapters in the textbook may also be used in the Review/Summary.

■ **Application.** Use the included visual master(s) and lab sheet(s) to apply the information presented in the lesson.

- **Evaluation.** Evaluation should focus on student achievement of the objectives for the lesson. Various techniques can be used, such as student performance on the application activities. A sample written test is provided.

- **Answers to Sample Test:**

Part One: Matching

1. b
2. c
3. e
4. f
5. a
6. d

Part Two: Completion

1. electrons
2. less
3. six
4. time in use
5. 80
6. portion (40 to 80 percent)

Part Three: True/False

1. T
2. F
3. F
4. T
5. T

Active Solar Systems

► Part One: Matching

Instructions: Match the term with the correct definition.

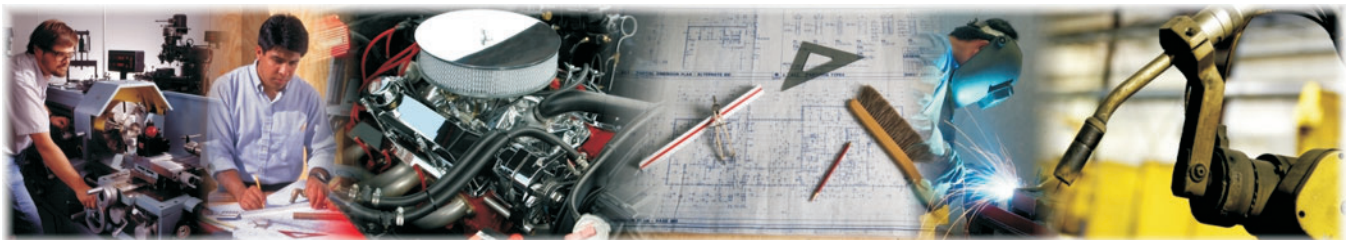
- | | |
|------------------------------|-----------------------------|
| a. evacuated-tube collectors | d. concentrating collectors |
| b. parallel circuits | e. radiant floor heat |
| c. inverters | f. closed-loop systems |

- ____ 1. An electrical system wired in a continuous loop to provide the same voltage to each component
- ____ 2. Devices that change direct current into alternating current
- ____ 3. Hot water pumped through tubes underneath a concrete floor
- ____ 4. Systems that circulate a heat transfer fluid—such as antifreeze mixtures—through solar collectors
- ____ 5. Collectors using rows of glass and/or metal tubes and evacuate the air in the tubes to create a vacuum
- ____ 6. Mirrored surfaces, often shaped like a parabola, that concentrate the sun's heat onto an absorber tube

► Part Two: Completion

Instructions: Provide the word or words to complete the following statements.

1. Semiconductors cause _____ to separate from an atom.
2. Photovoltaic modules must be designed to provide the inverter _____ than its maximum voltage rating.



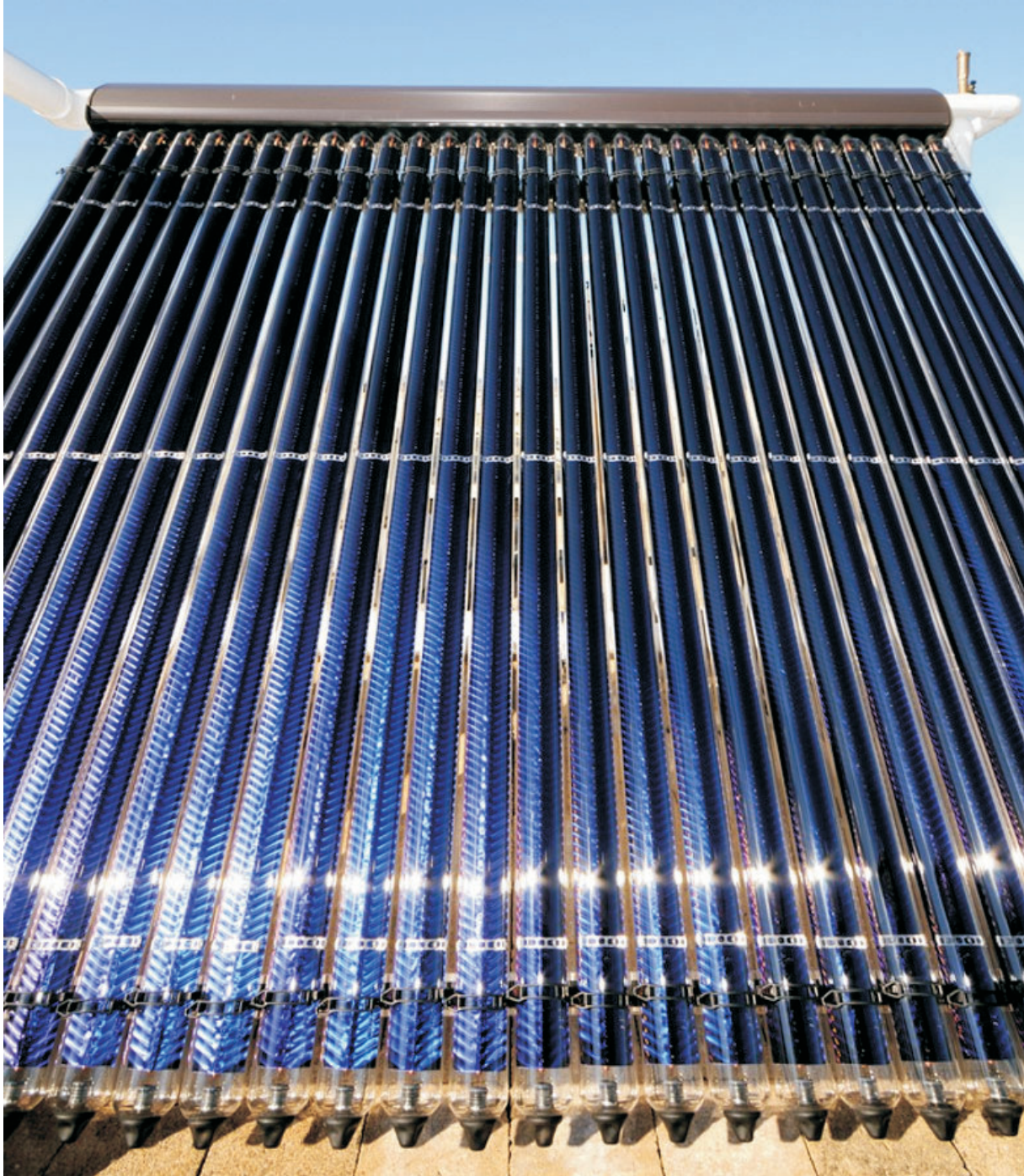
3. Photovoltaic systems weigh between three and _____ pounds per square foot.
4. The formula for daily load is wattage \times _____.
5. A family of four requires a(n) _____ -gallon water heater.
6. Active solar systems are usually designed to provide a _____ of a home's projected heating needs.

► **Part Three: True/False**

Instructions: Write *T* for true or *F* for false.

- ____ 1. Water absorbs heat faster because of the convective water currents
- ____ 2. Beams provide a stronger roof than trusses.
- ____ 3. Open loop systems are more expensive and more reliable.
- ____ 4. In a series circuit, if one component fails the entire system fails.
- ____ 5. Photovoltaic systems are most cost effective in remote locations.

EVACUATED TUBE SOLAR COLLECTOR



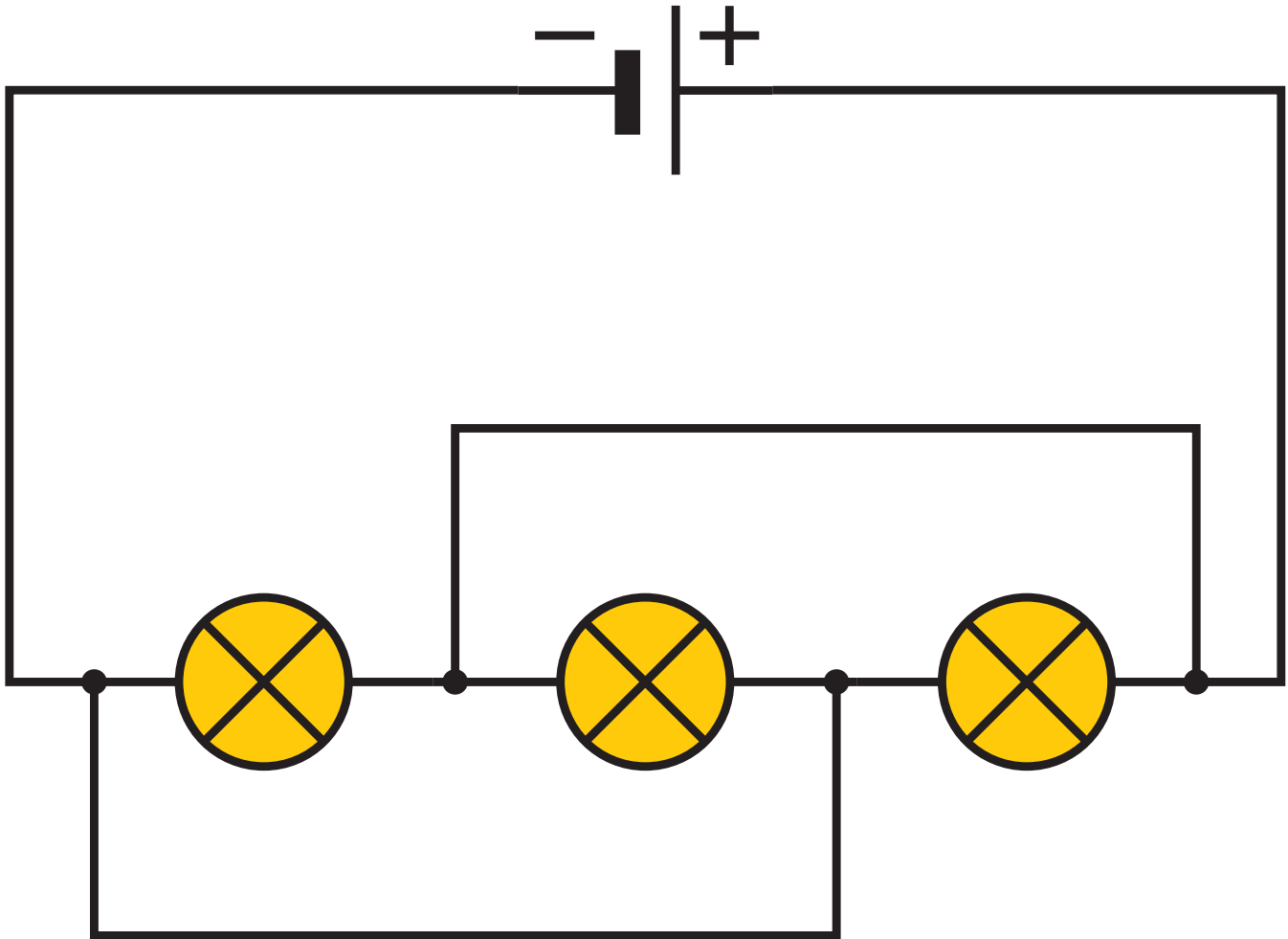
PHOTOVOLTAICS ARE ESPECIALLY USEFUL IN REMOTE LOCATIONS



PHOTOVOLTAIC PANELS PROVIDE ELECTRICITY WHILE SHADING THE WINDOWS



PARALLEL CIRCUIT



Building in Solar

Purpose

The purpose of this activity is to design an active solar system that meets the needs of a client.

Objectives

1. Design an active solar system that provides heating, domestic hot water, and electricity.
2. Explain the system that was chosen based on cost versus benefits.

Materials

- ◆ lab sheet
- ◆ writing utensil
- ◆ computer

Procedure

1. You will be working in teams to design an active solar system that best meets the needs of the Smith family. This can include any combination of active solar heating and domestic water heating using solar and photovoltaics.
2. Read the description of the Smith family's energy needs.
3. Discuss your ideas as a team. In addition, take notes on your lab sheet.
4. Create a PowerPoint presentation to share with the class.
5. Present your design via your presentation, and be prepared to explain your choices.

The Smith family is building a 3,000-square-foot home near Chicago. The family consists of Dan, the father who works outside the home; Mary, the mother who operates a consulting business from the home; and Mariah, the 14-year-old daughter. The Smith's architect assumes that with a conventional system, they will use 6,000 kWh of electricity per year and 400 therms of natural gas.

