6

Solar Energy

Basic Concepts

- Identify the reason solar energy is considered to be an inexhaustible energy resource.
- State why solar energy is one of the only long-term options for energy independence.

Intermediate Concepts

- Explain the difference between open loop solar collection and closed loop solar collection.
- Summarize how solar energy creates heat.
- Describe three basic types of active solar collectors.
- Give examples of three passive solar collection schemes.
- Discuss how a photovoltaic cell works to convert sunlight to electricity.

Advanced Concepts

- Differentiate between active solar energy and passive solar energy techniques.
- Discuss advantages and disadvantages of various solar collection schemes.
- Perform calculations to determine the payback period associated with the cost of installing solar collection equipment and techniques.

The sun is considered an inexhaustible source of energy. Life on earth would not exist without the energy from the sun. The sun supplies the earth with an extremely large amount of energy. Its diameter is 110 times that of the earth. If the sun was 18″ in diameter, the earth would be 1/16″ across. The sun is so huge that it is twice the weight of the earth, even though it is gaseous. It is 93 million miles away from the earth. Considering the distance, it is hard to imagine that we receive so much energy from the sun. Only one of every 2 billion portions of the sun's rays reaches

GREEN TECH
Solar energy is currently being used in some residential areas for heating homes and water. It can also be used in other ways, such as keeping greenhouses warm.

the earth. Yet, it is estimated that 2.5 times the amount of energy necessary to sustain a home for a year strikes that home in the form of sunlight every year.

Collecting Solar Energy

The sun provides us with several forms of energy, including light and heat, often referred to as solar energy. If we knew a way to collect a bigger portion of the sun's energy, we would have all the energy we would need. Solar energy is not that easy to collect because it is spread out all over the surface of the earth. The current methods used to collect the sun's energy are insufficient and rather expensive, compared to other energy sources. It is also hard to store solar energy.

Solar energy does provide a great amount of heat for some homes and industries. Solar panels are used to trap solar energy. See **Figure 6-1.** The energy is used to heat water or air. Hot water or air can then be used directly. Heated water can be stored in a tank for later use. Heat can also be stored in a bin full of rocks or in storage media, such as ceramic tile, concrete, or water tubes, for heating the surrounding environment.

Figure 6-1. Solar energy can be captured to provide heating or electrical power for a structure. Two different capture methods are being used in this home, which was designed to make extensive use of solar energy. The flat-plate collector on the left captures solar energy and uses it to heat water for household uses. The photovoltaic panels on the right convert the sun's energy to electricity, which is then stored in batteries for later use.

The development of solar energy collection schemes has been around since ancient times. Many civilizations, including the ancient Greeks and Native American Indians from the West, incorporated passive solar concepts into their architecture. These techniques often included the orientation of their living structures to capture and store the radiant energy, which is energy traveling as electromagnetic waves, from the sun. They also included the use of overhangs to block the sun from entering during summer months when it is high in the sky, while allowing the sun to enter during winter months when it is low in the sky.

More recent technological developments in solar energy were brought about as a result of the oil embargos of the 1970s. Solar research boomed in the 1970s, but it began to fade in the 1980s, as tax credits for the installation of solar energy devices expired and were not renewed. The stable fossil fuel prices of the 1990s further diminished interest in solar energy. Yet some significant research in solar energy continues, and many people feel it is in America's best interest to continue to pursue solar energy as a key resource for the future, as fossil fuels dwindle.

Measuring Solar Energy

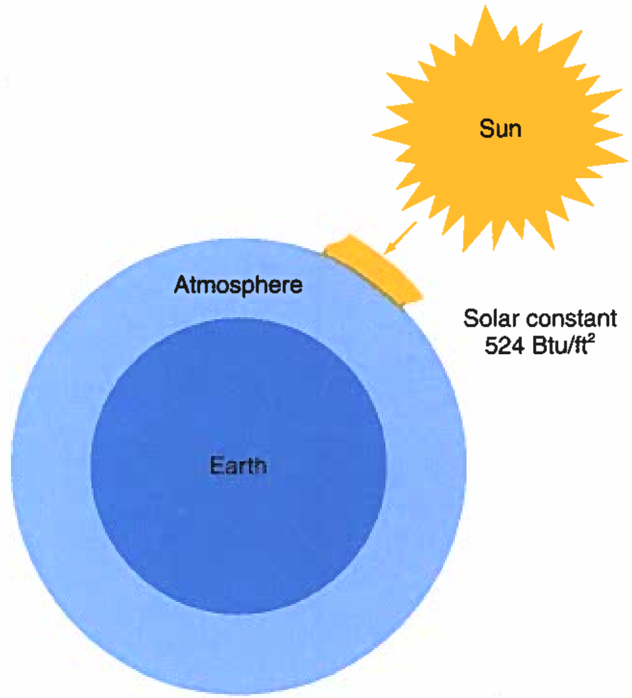
There are three terms that are used most frequently when discussing the measurement of solar energy. The *solar constant* represents the amount of energy in all forms of radiation reaching the earth's outer atmosphere. See **Figure 6-2.** The solar constant can be measured in British thermal units (Btu) per square foot (ft^2)

per hour, often represented as Btu/ft²/hr. It is not often used, as it is primarily a theoretical term representing a value that exists at the outer edge of our atmosphere.

A more useful term is the *insolation value*, sometimes referred to as the value of incident solar radiation. Insolation can also be measured in Btu/ft²/hr, but it represents the amount of energy available on a specific square foot of earth in a given location. See **Figure 6-3.** The insolation value is more useful than the solar constant because it is a measurement of energy that can actually be collected. This is generally somewhere between 0–360 Btu/ft²/hr, depending on cloud cover, location, altitude, air temperature, time of day, and angle at which the sunlight is measured.

A third term for measuring solar energy, known as the *Langley*, is primarily used by weather agencies such as the National Oceanic and Atmospheric Administration (NOAA). One Langley is approximately equal to 221 Btu/ft²/hr. Charts often refer to solar intensity over periods of time, such as months or years, in Langleys. In countries using the metric system, the values are expressed in megajoules per square meter per hour (MJ/m²/hr). See **Figure 6-4.** The higher the number is, the greater the exposure to solar radiation is.

Figure 6-2. The solar constant is a measurement of the amount of solar energy reaching the earth's outer atmosphere.



Solar Energy Collection Concepts

There are two types of solar energy collection: active solar energy collection and passive solar energy collection. ***Active solar energy collection*** systems use circulating pumps and fans to collect and distribute heat. Some active solar heating systems are capable of

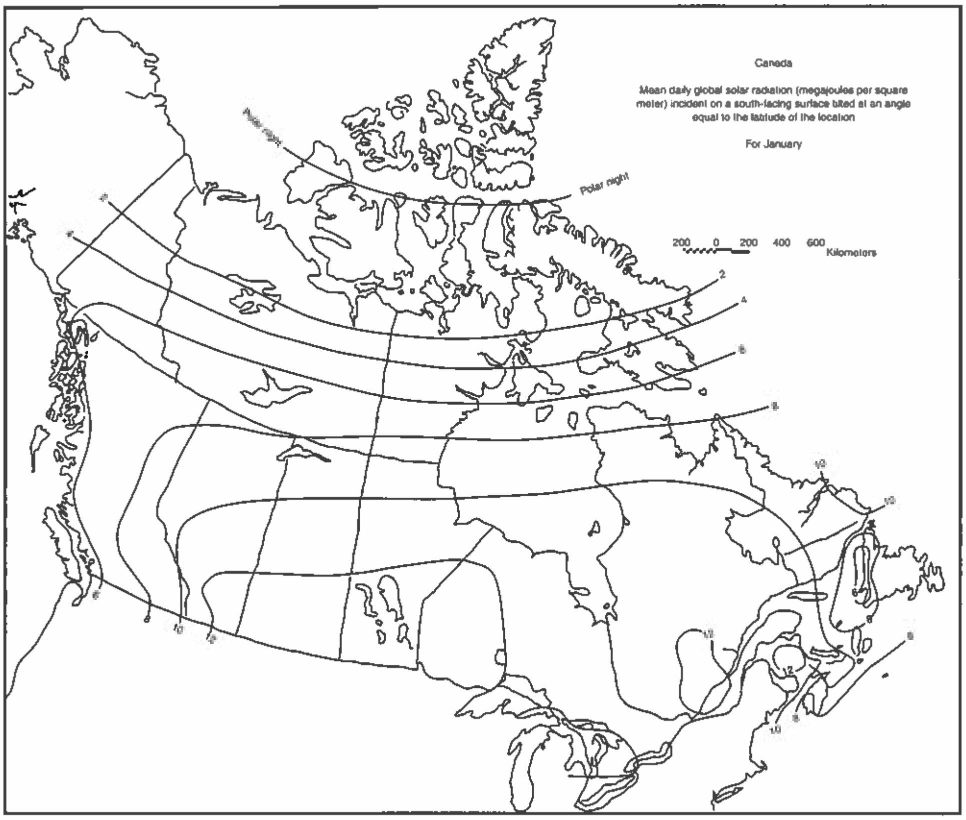
Active solar energy collection: Systems that use circulating pumps and fans to collect and distribute heat.

Variations in Insolation for Selected Cities					
		December		June	
City	Latitude	I_H*	I_T**	I_H	I_T
Miami	26°N	1292	1770	1992	1753
Los Angeles	34°N	912	1496	2259	1920
Washington, D.C.	38°N	632	1068	2081	1790
Dodge City	38°N	874	1652	2400	2040
East Lansing	42°N	380	638	1914	1646
Seattle	47°N	218	403	1724	1465

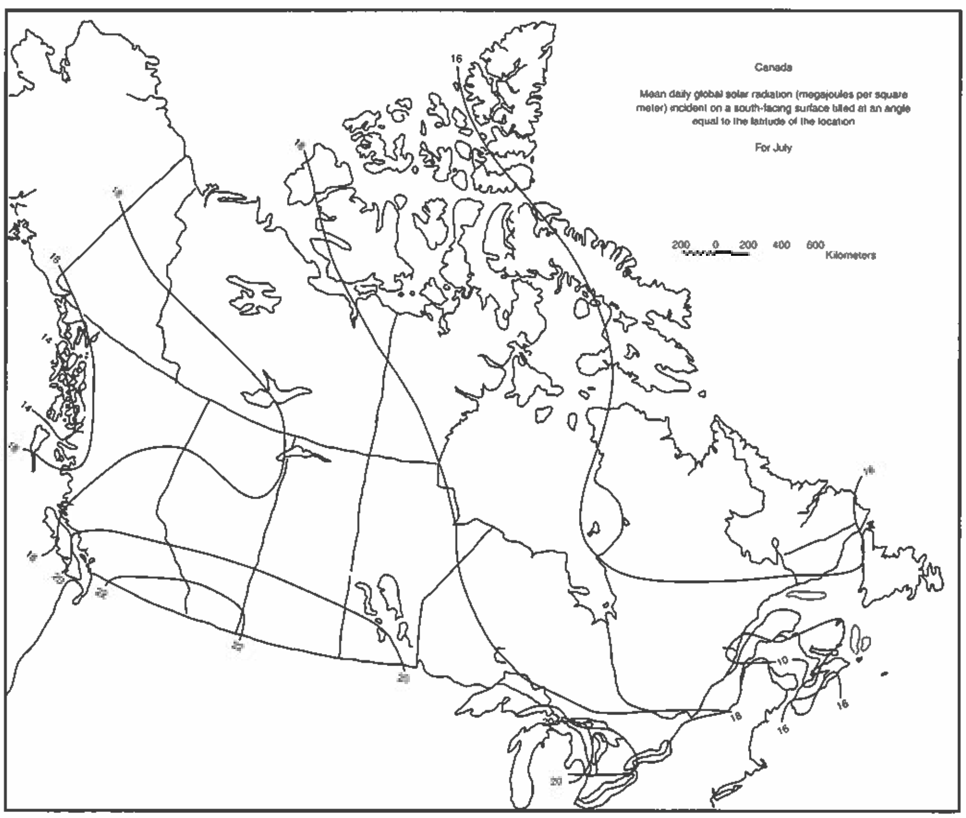
*Insolation on a horizontal surface (in Btu/ft²/d)
**Insolation on a surface tilted at an angle equal to the latitude (in Btu/ft²/d)

Figure 6-3. The amount of energy reaching a square foot of the earth at a given location is the insolation value for that location. This table shows insolation values for cities across the United States during selected winter and summer months. Values are shown in Btu/ft²/day.

Figure 6-4. Differences in solar radiation reaching the earth's surface vary dramatically with latitude and season. These maps of Canada show the average daily solar radiation across the country during the months of January and July. Since Canada uses metric measurements, the values on these maps are shown in megajoules per square meter per hour (MJ/m^2/hr). One Langley is equivalent to 23.88 MJ/m^2/hr. (Canadian Solar Industries Association)



January



July

concentrating solar energy. Thus, they can reach higher temperatures than passive solar heating systems. ***Passive solar energy collection*** techniques do not make use of any externally powered, moving parts, such as circulation pumps, to move heated water or air. A passive solar system typically makes use of gravity; natural principles of heat movement, such as convection (the fact that hot air rises); evaporation; and architectural design to store and move heat. Passive solar architecture frequently incorporates concepts for capturing heat into the design of a structure. See **Figure 6-5.** Both active and passive solar collection systems can also be utilized as either open loop or closed loop systems, which are described in the following sections.

Passive solar energy collection: Systems that do not make use of any externally powered, moving parts, such as circulation pumps, to move heated water or air.

Open loop solar collection

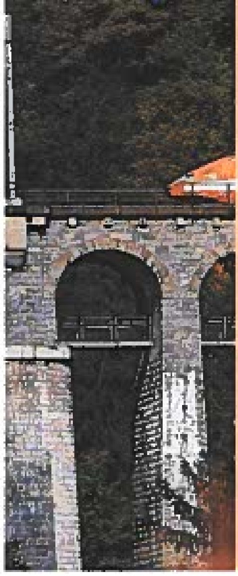
In an ***open loop solar collection*** system, the heated water or air is directly distributed for use. See **Figure 6-6.** In the example, the water that flows through the collector is actually what will come out of your water faucet. The solar collector is not required to provide all the heat for the water. On a very sunny day, in the right climate, the collector might actually be able to send water down to the tank at 130°F. If this is the case and you call for hot water by turning on a sink, the water from the tank will

Open loop solar collection: Systems in which the heated water or air is directly distributed for use.

A

B

Figure 6-5. This new home is designed for efficient use of solar energy. A—In addition to active solar and photovoltaic panels on the roof, this home is designed to make use of passive solar principles. The south-facing side of the house has large windows to gather maximum sunlight during the winter months, when the sun is lower in the sky. Wide overhangs shade the windows during peak sunlight hours in the summer. B—Inside the home, ceramic tile floors and furniture absorb solar energy during daytime hours and then release it slowly during the evening. This photo was taken on a late summer afternoon, when the roof overhangs limit the amount of sunlight falling on the floor tile.



STEM Connection

Science: Principles of Heat Movement

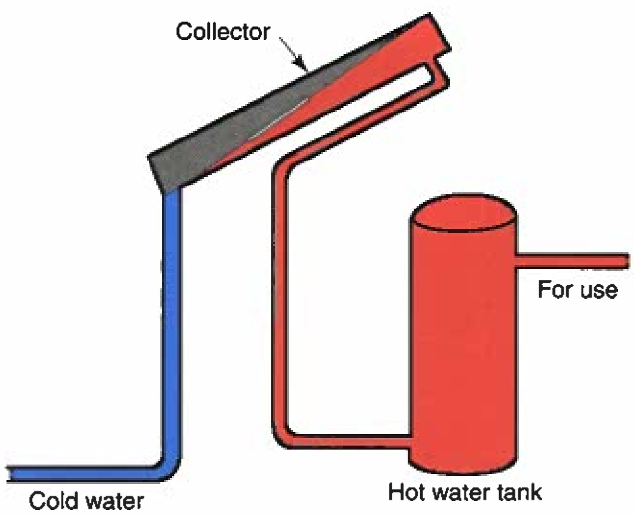
There are three basic principles of heat movement worthy of explanation. These three principles are known as *conduction*, *convection*, and *radiation*. Conduction refers to the transfer of heat from molecule to molecule, straight through a material or group of materials, such as those that comprise a wall. If the temperature outside of a structure is colder than the temperature inside the structure, heat will conduct through the wall toward the colder temperature. In warmer climates, heat often conducts inward from the exterior of a structure toward the climate-controlled interior of a structure.

Convection refers to the fact that a heated gas, such as air, tends to move in an upward direction. As the gas is heated, it expands and is pushed up by denser and cooler air. From a structural standpoint, this is why the upper floor of a home tends to be warmer than the lower floor of the home.

Radiation refers to the fact that heat travels with a frequency much the same as visible light. Heat transferred via radiation does not require a medium to travel through. Many types of structural heating devices, such as baseboard heaters, transmit heat to the surrounding environment via radiation.

be replenished with hot enough water that the thermostat will never turn on the conventional heating source (such as electricity or natural gas). Of course, this is not always possible. On days when it is cloudy, it might not be possible to heat the water flowing through the collector to above 100°F.

Figure 6-6. An open loop solar collection system. In this system, water heated by the sun flows directly from the collector to a storage tank for direct use by the household. On cloudy days or in periods of high demand, water in the tank can be heated by electricity or a gas burner.



Even so, any heat collected will result in less consumption of conventional energy to heat the water to optimum temperature. Both energy and money will be saved.

Closed loop solar collection

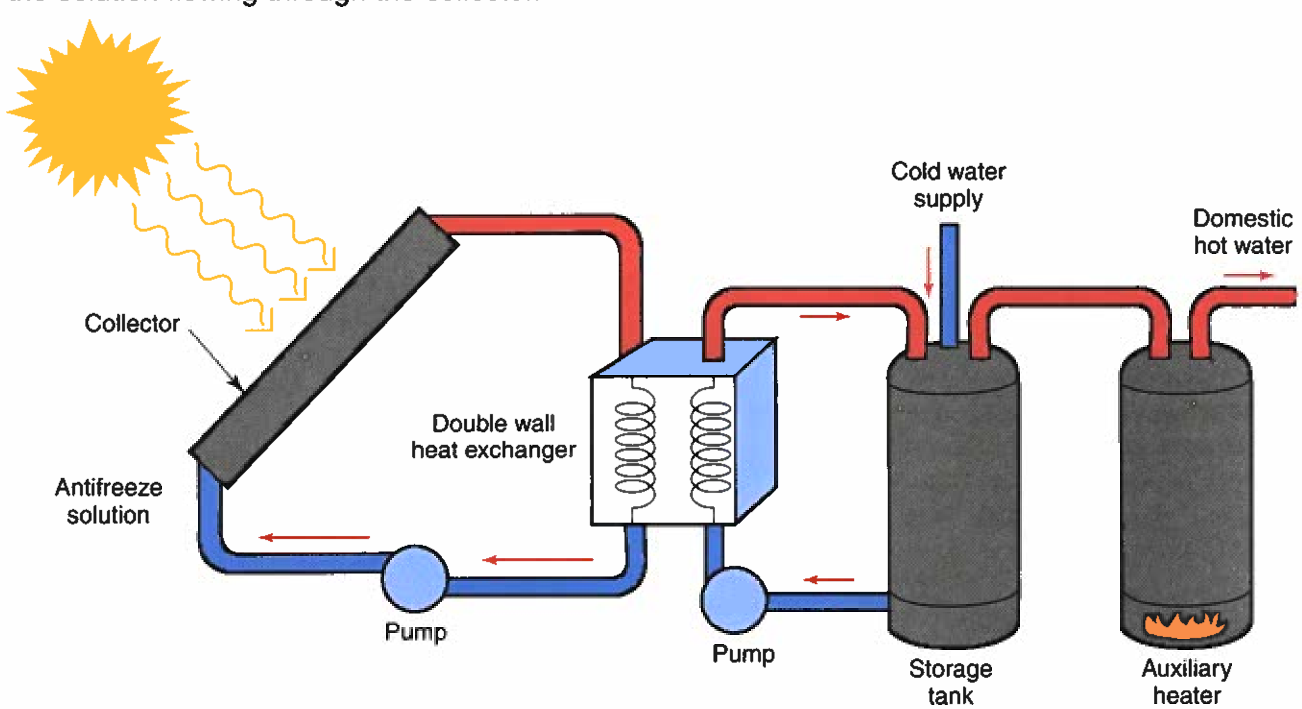
In a ***closed loop solar collection*** system, a collection medium is used to collect the heat and transfer it to water or air for end use. The liquid within the closed loop simply circulates from the collector down to a heat exchange tank and then back up to the collector again to collect more heat. It never comes in direct contact with the water being heated for end use in your home. See **Figure 6-7.** A closed loop solar collection scheme offers several advantages over an open loop system. It can avoid freezing by using a water-alcohol antifreeze solution in the closed loop. The water-alcohol solution serves as a collection medium to transfer the heat from the collector down to the storage tank. If the temperature on the roof is not suitable for collecting energy, the circulation pump attached to the closed loop does not have to run.

Closed loop solar collection: Systems in which a collection medium is used to collect the heat and transfer it to water or air for end use.

Types of Active Solar Energy Collection

There are essentially three types of active solar energy collectors. Each type may have some variation, but active solar collectors can be classified as flat-plate collectors, linear-concentrating parabolic collectors, or parabolic dish (point-focusing) collectors. Each type has certain advantages and disadvantages.

Figure 6-7. A closed loop solar collection system uses a heat exchanger to transfer energy from the solution used in the collection system to the water that will be stored for household use. Such a system is more practical than the open system in cold climates, since antifreeze can be added to the solution flowing through the collector.



Flat-plate collector: The most common type of active solar collector. It is typically stationary, mounted on a rooftop, facing south in the northern hemisphere. It has the ability to collect heat from diffuse sunlight, even on cloudy days.

Flat-plate collectors

The most common type of solar collector is the ***flat-plate collector***. See **Figure 6-8.** The flat plate offers several advantages, including an ability to collect heat from diffuse sunlight, which is sunlight that bounces off of clouds, even on cloudy days. Additionally, the flat-plate collector is typically stationary, mounted on a rooftop facing south in the northern hemisphere. It is not required to track the sun. Simplicity and reliability are distinct advantages of the flat-plate collector over other types of collectors. For these reasons, the flat-plate collector is the most popular collector, even though it has a relatively low collection ratio for the space it occupies. A collection ratio is the amount of energy collected per square foot compared to the amount of energy available for collection per square foot. It allows for the comparison of one collector to another.

Conduction: The transfer of heat from molecule to molecule, straight through a material or group of materials.

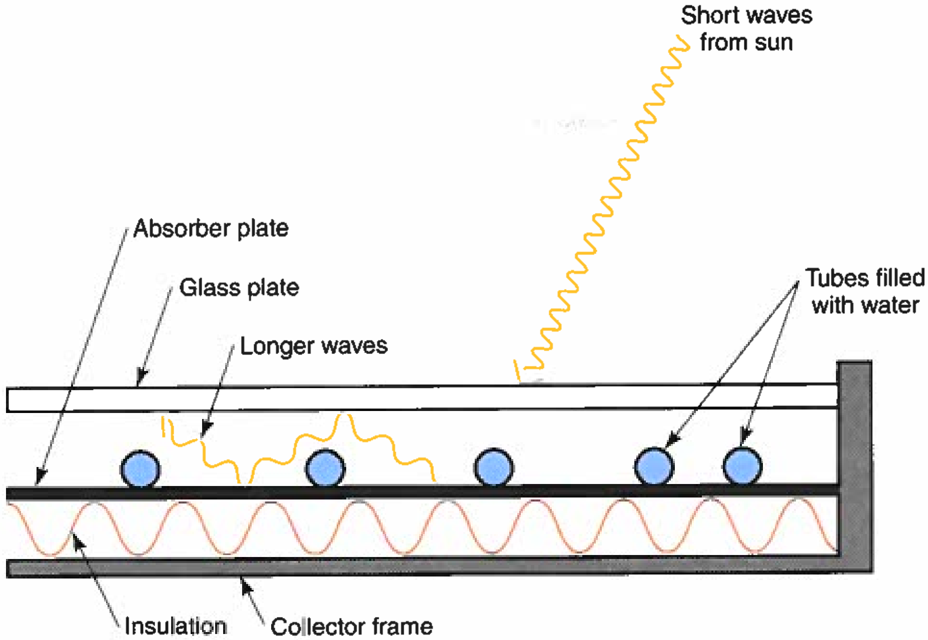
As shown in **Figure 6-9,** visible light is radiated at a frequency that readily passes through glass. Once the light passes through the glass, it strikes the absorber plate, which is typically painted flat black. The color is important, since lighter colors tend to reflect light, whereas darker colors tend to absorb light and reradiate it in the form of heat. Even glossy black does not convert light to heat as well as flat black. Once light is converted to heat, it is a fundamental law of physics that the heat from a mass at a higher temperature will move to a mass at a lower temperature. This phenomenon is known as ***conduction***, the transfer of heat by molecule to molecule from a body at a higher temperature to that of a lower temperature. Some of the heat is not absorbed by the absorber plate, but rather, it is radiated outward. The infrared wavelengths are longer than those of visible light, however, and they cannot pass through glass as readily. Thus, a partial trap has been created, and the heat is held within the collector. The same principle of converting light to heat is applicable to other types of collectors and passive solar architecture techniques. Note that infrared energy has a lower frequency than visible light radiation. This means it has a longer wavelength.

Linear-concentrating parabolic collectors

The next type of active solar collector is the ***linear-concentrating parabolic collector***. Parabolic collectors must track the sun from east to west in what is known as the *azimuth path*. The ***azimuth path*** is the path

Figure 6-8. The flat plate is the most common type of active solar collector and is usually mounted in large panels on the south-facing roof. Flat-plate collectors may heat either water or air, depending on the system design.

Figure 6-9. Cross section of a flat-plate collector, showing how the sun's heat energy is transferred to the water inside the tubes.



the sun travels daily. In a country in the northern hemisphere, such as the United States, the sun rises in the east and sets in the west, traveling across the sky throughout the day. See **Figure 6-10.** The collector can be mounted to a roof facing south, like a flat-plate collector. It must be capable, however, of moving with the sun. See **Figure 6-11.** If the collector does not move a little bit every few minutes, the rays of the sun will not hit the focal line of the collector. Mounted along the focal line is often a single collection tube through which water flows. When linear-concentrating collectors are on track, they can collect much more energy than a flat-plate collector, in much shorter periods of time, while

Linear-concentrating parabolic collector: An active solar collector that tracks the sun's movement, generating temperatures of hundreds of degrees Fahrenheit on a clear day. Mounted along the focal line is often a single collection tube through which water flows. This type collects much more energy than a flat-plate collector, in much shorter periods of time, while occupying much less space.

Azimuth path: The sun's movement from east to west.

GREEN TECH

Parabolic dish collectors collect solar energy to be used for electricity. These collectors are usually found in power generating stations, such as the largest station in the world, which is in California.

Figure 6-10. The azimuth path is the sun's movement from east to west, which a linear-concentrating parabolic collector must follow to operate most efficiently. The zenith angle is the vertical angle of the sun from the horizon. In the winter, the zenith angle is low; in the summer, it is high.

Azimuth and Zenith Paths of the Sun

Position of sun at noon for latitude 40° N.

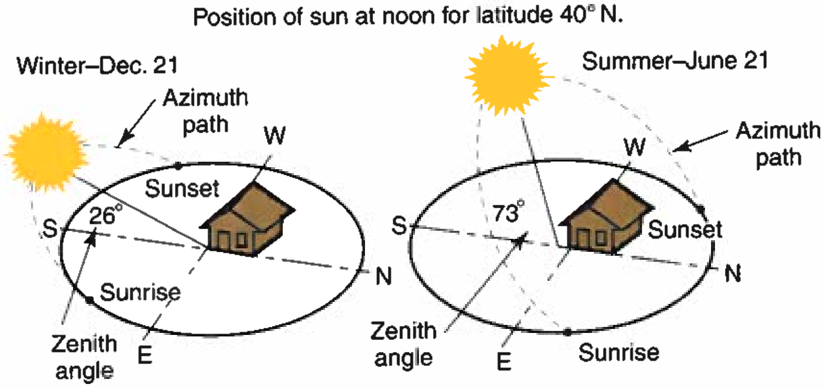


Figure 6-11. The linear-concentrating parabolic collector mounted on this home tracks the sun's azimuth path. The water heated by the sun is stored for household needs, such as dish-washing, showering, and washing clothes. (Howard Bud Smith)

occupying much less space. Linear-concentrating collectors can generate temperatures of hundreds of degrees Fahrenheit, when tracking on a clear day. Can you think of disadvantages of such a collector design? Disadvantages include the fact that this type of collector requires direct sunlight. Therefore, it is not suitable for all climates. Also, the tracking mechanism may need to be calibrated periodically. If the tracking mechanism drifts off, the collector will miss the focal line, and heat will not be collected.

A ***compound parabolic collector*** is a combination of a flat-plate collector and a parabolic collector. This type of collector offers advantages of both types of collectors previously described. It is stationary mounted and does not need to track the sun. This type of collector is also a linear-concentrating collector, so it offers a greater collection ratio than a flat-plate collector. It is best used in direct sunlight, like a parabolic collector, however, and the curvature of the reflectors must be generated for a specific location. For instance, the curve that works in Phoenix, Arizona could not be expected to work on a roof in New York City.

Compound parabolic collector: A combination of a flat-plate collector and a parabolic collector, offering advantages of both types. It is stationary mounted and does not need to track the sun. It is also a linear-concentrating collector, offering a greater collection ratio than a flat-plate collector.

Parabolic dish collectors

The third main type of active solar collector is known as a ***parabolic dish collector***. See **Figure 6-12.** Parabolic means it is point focusing. This type of solar collector has a tremendous collection ratio. Large point-focusing collectors are capable of producing temperatures of thousands of degrees Fahrenheit, but they obviously require a very sophisticated tracking mechanism. Not only must this type of collector track along the azimuth path of the sun, but it must also track the height of the sun in the sky. This is referred to as the ***zenith path*** of the sun. Refer to Figure 6-10. The net result is that the collector is almost constantly making some minor adjustment to track the sun. When in focus, it has a collection ratio that far exceeds other types of collectors. This type of collector is actually used in some countries along the equator to collect heat for the production of steam to generate electricity. It is not, however, a collection scheme easily modified for residential use.

Parabolic dish collector: An active solar collector that is point focusing. It has a tremendous collection ratio, permitting large point-focusing collectors to produce temperatures of thousands of degrees Fahrenheit. This type of collector tracks the height of the sun in the sky, as well as the azimuth path.

Types of Passive Solar Collection

Passive solar collection involves three primary methods. These are the direct gain approach, the indirect gain approach, and the isolated gain approach. Each method has advantages and disadvantages.

The direct gain approach

The most common type of passive solar collection is the ***direct gain approach***. Direct gain means there are no significant architectural provisions made to collect solar energy, other than facing windows in the proper direction. An example of the direct gain approach is a car with the

Figure 6-12. Researchers at Sandia National Laboratories in New Mexico make final adjustments to a parabolic dish collector being developed for use by Native American farmers in remote areas of the American Southwest. The collector concentrates the sun's energy on a receiver unit. (U.S. Department of Energy photo by Randy Montoya)

Zenith path: The height of the sun in the sky.

Direct gain approach: The most common type of passive solar collection. In this type of system, there are no significant architectural provisions made to collect solar energy, other than facing windows in the proper direction.

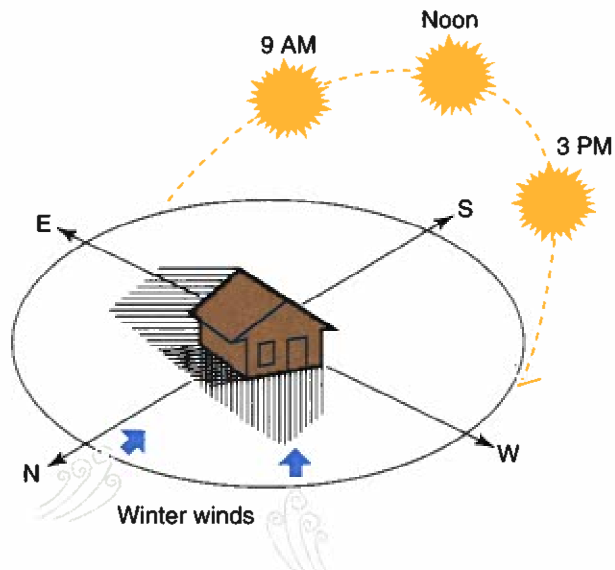
windows rolled up. In such a situation, the sun can heat the car up significantly. Solar energy passes through the glass and is converted to heat. Just like solar collectors, the darker the interior of your car is, the more sunlight gets converted to heat. Similar to the way a car collects heat, architects and designers can design a home to collect solar energy by properly orienting the home. See **Figure 6-13.**

Some basic requirements of passive solar architecture include the following:

- Good southern exposure.
- Window areas facing south, east, and west and representing about 10%–15% of the home's square footage.
- Very few windows facing north.

These requirements are necessary because, by the time the sun comes around to the north side of a home in the northern hemisphere, it is probably too low in the sky to provide any significant solar gain. These homes are also generally well insulated and tightly sealed. Note that orientation and window space are the key factors considered for solar gain, when using the direct gain approach. An intentional storage medium is not used with the direct gain approach.

Figure 6-13. Proper orientation is important for capturing solar energy. South-facing walls with plenty of glass area take fullest advantage of the sun's rays, especially during the winter months. A properly insulated home with few window and door openings on the north side will shelter against winter winds and minimize heat loss.



Indirect gain approach: A type of passive solar collection that makes use of a storage medium to store heat for later use. The storage medium may be rocks, concrete, or water.

Trombe wall: A common application of the indirect gain approach. The Trombe wall is heated throughout the day. The storage medium takes a long time to heat up, but it gives off its heat slowly throughout the night, requiring less use of conventional energy.

Phase change: A change in a substance's state (liquid, solid, or gas).

Passive solar architecture also makes significant use of roof overhangs. Using a solar angle reference manual, it is possible to calculate the ideal overhang for a structure in any location to maximize solar gain in winter and minimize solar gain in summer. Another concept frequently used to block excessive summer sun is the planting of deciduous trees to provide shade in summer, but allow sunlight in winter. Deciduous trees are trees that maintain their leaves throughout the warm months and shed their leaves annually each fall or winter.

The indirect gain approach

The ***indirect gain approach*** makes use of a storage medium to store heat for later use. The storage medium may be rocks, concrete, or water. A ***Trombe wall*** is a common application of the indirect gain approach. It is a wall specifically designed to act as a thermal storage medium. A Trombe wall is often made of concrete or masonry material, but it can also be made of water stored in tubes or barrels. See **Figure 6-14.** The Trombe wall is heated throughout the day. The storage medium takes a long time to heat up, but it gives off its heat slowly throughout the night, requiring less use of conventional energy. Less conventional applications of the indirect gain approach include the use of storage pools and specialty products, such as eutectic salts, which melt when heated and give back heat to the environment as they experience a phase change when cooling back into a solid. A ***phase change*** occurs when a substance changes its state (liquid, solid, or gas) to another state. Such a change occurs when liquid water freezes and becomes a solid in the form of ice.

The isolated gain approach

The third passive solar collection scheme is known as the ***isolated gain approach***. See **Figure 6-15.** In the isolated gain approach, the solar collector is isolated from the structure to be heated. The collector is typically located next to or beneath the home, and the system relies on convection to carry heated air up to the structure. Cold air return vents

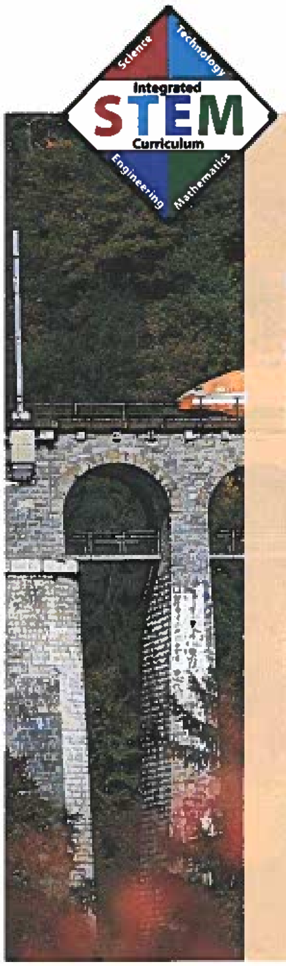
Career Connection

Architects

Architects are needed to design buildings. Their responsibilities also include planning for energy efficiency. When an architect is designing a structure, heat loss must be taken into account to more accurately plan for energy conservation.

The job of an architect consists primarily of designing structures, but architects must also prepare for construction. The proper contracts and permits must be obtained in order for work to begin, and architects must perform frequent checks on the site once construction begins. Apart from these tasks, architects must also work directly with the clients to meet their needs for the projects.

Architects should have good communication skills in order to work with clients. They must also have knowledge of engineering, mathematics, and design. A bachelor's degree is required for architects. The yearly salary may range from $45,000 to $120,000.



STEM Connection

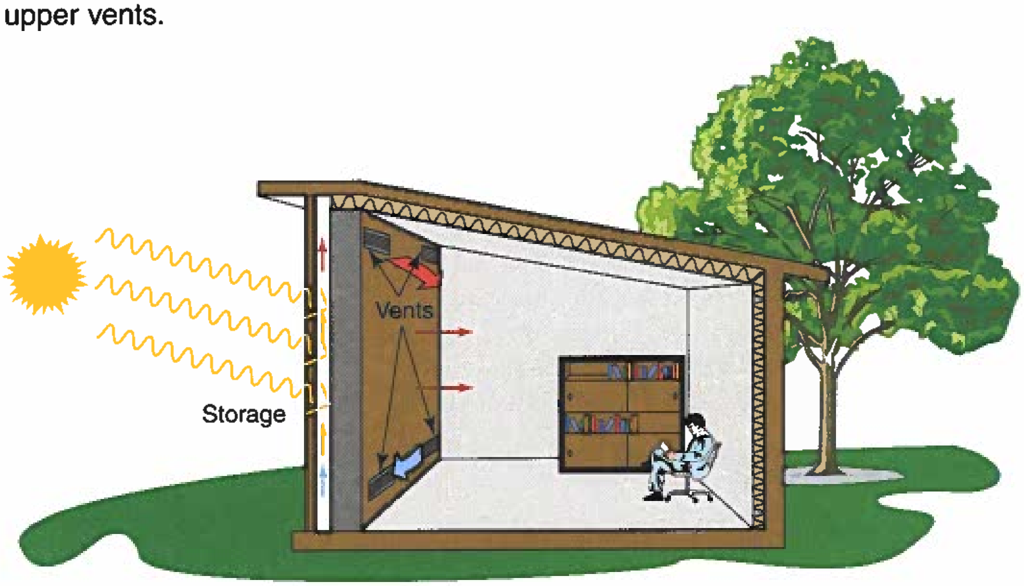
Technology: R-Values

An R-value is a convenient measure of the resistivity to heat flow that is used to compare the heat loss allowed by various types of insulation and other construction materials. See **Figure 6-A.** If a building's structural components have high R-values, the building has a high resistivity to heat loss by conduction. By increasing the R-values of building materials or adding insulation with higher R-values, the rate of heat loss in a building is reduced, which helps to conserve energy.

Material	R-Value
.5″ gypsum board	.5
5.5″ fiberglass insulation	19–23
3.5″ fiberglass insulation	11–13
8″ concrete block	1.6
Vinyl siding	.33
.5″ wood siding	.5
.5″ sheathing (oriented strand board)	.5
.5″ sheathing (insulating board)	.5

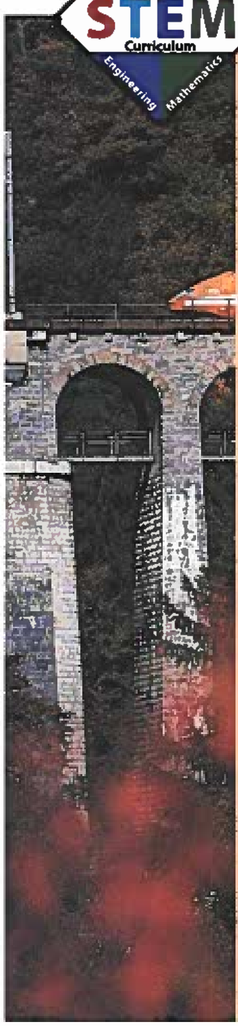
Figure 6-A. The R-values of some typical products used in construction.

Figure 6-14. A Trombe wall is a thermal mass used for heat storage in an indirect gain system. It is typically a masonry wall located a few inches behind a large expanse of glass. Sunlight slowly heats the mass during daylight hours, and then the mass gradually releases stored heat to the living space at night. Vents allow the passage of cooler air into the space between the wall and the glass. As the air is heated, it rises and exits to the room through the upper vents.



Isolated gain approach: A type of passive solar collection in which the solar collector is isolated from the structure to be heated. The collector is typically located next to or beneath the home, and the system relies on convection to carry heated air up to the structure. Cold air return vents typically allow cooler air to return to the collector.

Figure 6-15. The thermal mass in an isolated gain system might be a concrete floor and wall, bins of rocks, or barrels of water (water has greater heat storage capacity than masonry). Heat moves to living areas by convection.



STEM Connection

Math: Calculating a Payback Period

Even though solar energy is a free energy source, it costs a lot, due to the expense of the equipment necessary to collect and distribute it. These costs may or may not be justifiable, depending on a number of factors, including geography, installation costs, the demand for heated air or hot water, the cost of conventional energy to do the same amount of heating, and the life expectancy of the system. Since active solar systems are often used to heat hot water, we will perform a payback calculation for the installation and use of a solar hot water system. A payback calculation (also sometimes referred to as the *breakeven point*) is used to determine how many years something will take to pay for itself. The following is the information you need to perform a payback calculation for an active solar hot water system being considered for installation by a family of four.

- The cost of a domestic solar hot water system = $2800.
- An average family of four uses 100 gallons of hot water per day.
- Hot water is heated from 55°F (average ground temperature below the frost line) to 125°F for use all 365 days per year.
- The conventional heating source is a natural gas hot water heater.
- Natural gas for this area costs $.010 per cubic foot ($ft^3$).
- 120 ft^3 of natural gas can produce 100,000 Btu.
- 1 Btu = the energy necessary to raise 1 lb. of water (H_2O) 1°F (1ΔT°F).
- The solar collector manufacturer estimates savings of conventional energy in your region at 40%, if a solar collection system is installed.

Step 1. Determine how much energy is needed to heat the water for 1 day.

$$\frac{\text{Btu}(125-55\ \Delta T°F)}{1\ \text{lb. } H_2O\ 1\Delta T°F} \times \frac{100\ \text{gal}}{\text{day}} \times \frac{8\ \text{lbs. } H_2O}{\text{gal}} = 56{,}000\ \text{Btu/day}$$

typically allow cooler air to return to the collector. In this way, a ***convective loop*** is formed that does not require any circulating pumps or fans. A storage medium, such as masonry, crushed stone, or water, can be used to store some heat for later use. Note that the collector need not be a part of the structure when using the isolated gain approach to passive solar heating.

Convective loop: The loop created when convection carries heated air from an isolated gain solar collector up to a structure, and cold air return vents allow cooler air to return to the collector. It does not require any circulating pumps or fans.

Photovoltaic Cells

The process of converting sunlight to electricity begins with tiny bundles of light known as photons. It has been known since the late 1800s that, when photons strike certain metals, free electrons are emitted. This is referred to as the ***photoelectric effect***. A photon strikes a ***photovoltaic cell,*** which is a semiconductive material that emits free electrons when exposed to light. The free electrons result in the flow of electricity. If

Step 2. Determine how much it will cost to heat the water for 1 year using a conventional energy source.

$$\frac{56{,}000\ \text{Btu}}{\text{day}} \times \frac{120\ \text{ft}^3}{100{,}000\ \text{Btu}} \times \frac{\$.010}{\text{ft}^3} \times \frac{365\ \text{days}}{\text{year}} = \$438/\text{year}$$

Step 3. Determine what percentage of domestic hot water will be saved using an active solar collection system. This number must be estimated based on geographic location (to predict the insolation value) and system efficiency. We will assume an anticipated yearly savings of 40% for the Midwest. Actual savings will vary, based on system efficiency and geographic location.

Step 4. Determine dollars saved by installing a solar collection system.

.40 × $438 = $175/yr anticipated savings

Step 5. Determine the payback period for solar collection system installation.

$2,800/$175 = 16-year payback at the current cost of energy

Whether or not this is an acceptable payback period depends on a number of factors, but generally speaking, improvements to conserve energy should pay for themselves in less than 10 years. Otherwise, they are usually not considered worth doing. If this system was being installed in a home in Albuquerque, New Mexico, and the anticipated savings in yearly energy was estimated at 80% because of the number of sun hours Albuquerque receives, the payback period would be reduced by half, to about 8 years. This is why solar collectors are frequently installed on residential homes in the southwestern United States. It is economically viable to install them and expect homeowners and new home buyers to pay for them.

Remember to factor in maintenance costs and life cycle renewal of parts. One of the reasons longer payback periods are ill advised is that, as a system ages and wears, it will be subject to maintenance and repair. These costs could also be factored into a more extensive payback calculation, although a conventional hot water heater heating system might also need maintenance, repair, and perhaps even replacement within 10 years.

Photoelectric effect: The emission of free electrons when photons strike certain metals.

Photovoltaic cell: A cell that converts sunlight directly into electricity. This occurs when positively charged photons strike the cell and displace electrons from the valence shell of the material making up the cell. Sometimes referred to as a solar cell.

GREEN TECH
Solar panels and photovoltaic cells can be used not only for heating and electrical purposes, but also for cooling. Solar air conditioning abilities can be added onto these systems or used separately.

enough cells are combined, the flow of electricity can be substantial enough to perform useful work. Photovoltaic cells, sometimes referred to as solar cells, have the ability to convert sunlight directly into electricity without any moving parts. This occurs when positively charged photons strike the cell and displace electrons from the material making up the cell. The free electrons begin to collect along thin copper strips that feed a heavier copper conductor. The electrons are drawn away when placed in a circuit and connected to an electrical load, such as a lightbulb. **Figure 6-16** shows the operation of a photovoltaic cell. These cells are used most frequently in remote locations, where it is not feasible to power something with conventionally generated electricity. See **Figure 6-17.** One major purchaser of photovoltaic cells is the U.S. Coast Guard, which uses them to power navigational devices, such as buoys located along waterways. Since the electricity produced by photovoltaic cells is direct current (DC) electricity, it may be used immediately or stored in batteries for later use. It may also be inverted to alternating current (AC) electricity, such as the type used in a residence or commercial building.

Other Applications for Solar Energy

Solar energy has some other applications that may surprise you. Of course, one application of solar energy used much more extensively than solar heating is the use of solar energy for natural lighting. This is common in most structures. Did you know that solar energy can be used for cooling applications as well?

Figure 6-16. Solar cell construction and operation. The cell converts heat energy from sunlight to electrical energy. (Solar Power Corporation)

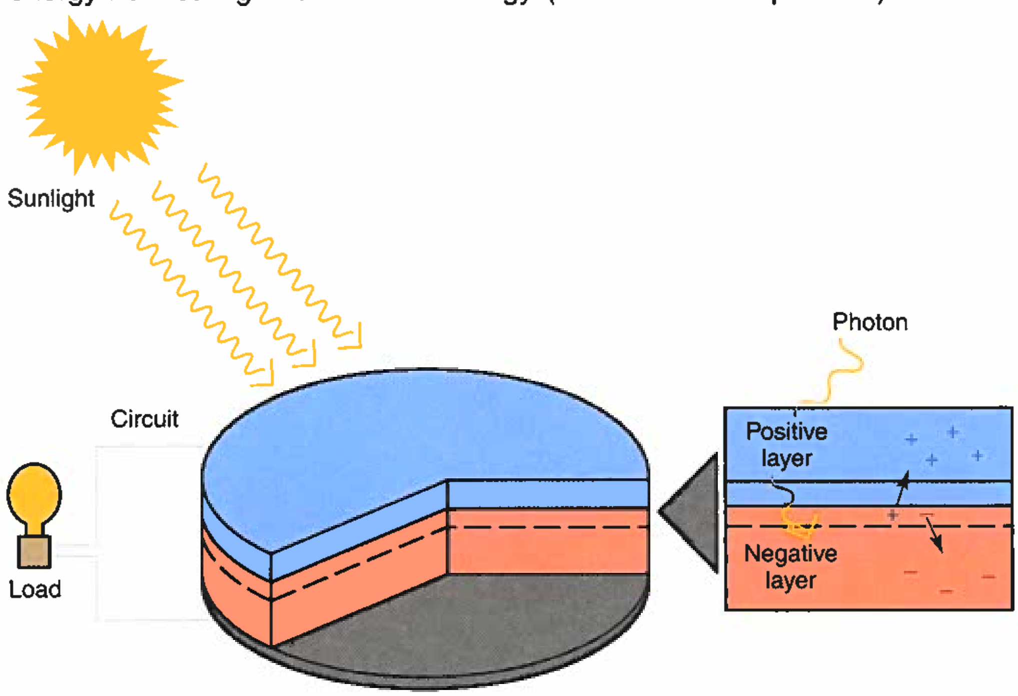


Figure 6-17. Photovoltaic panels are used to provide power in locations where electrical power is not readily available or where a separate power supply is needed that will not be affected by outages of the electrical distribution. This panel provides electricity to power a small radio transmitter that sends data from monitors at a large natural gas storage site. It permits the radio to operate independently and not depend on power from the electrical grid.

Solar Cooling

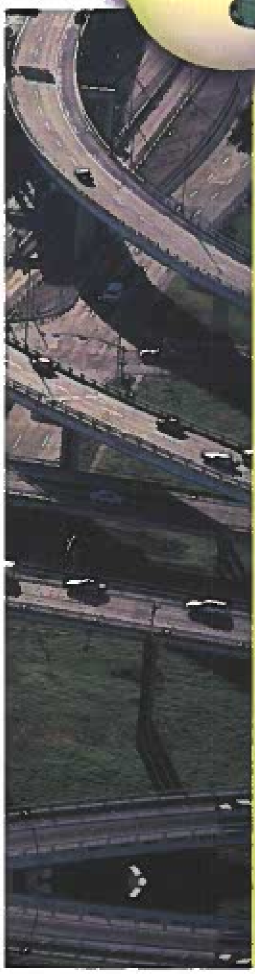
In cooling operations, the heat from the sun is used to boil a refrigerant, turning it into a gas. The gas is condensed into a liquid and transferred to the ***evaporator*** (freezing unit). The pure liquid refrigerant absorbs the heat from the surrounding area and turns back into a gas in the evaporator. It is then transferred to the ***condensing unit,*** where it is condensed back into a liquid and gives up its heat. The evaporator is located within a large room or building insulated from exterior heat for refrigeration. The condenser is located outside the refrigeration area and transfers heat out of the area to another environment.

Large-Scale Power Generation

Solar thermal energy conversion (STEC) is an experimental process used to generate large-scale electricity, such as that which could be used to power a community. See **Figure 6-18.** A STEC collector uses many mirrors, all aimed at one common focal point. Each mirror is controlled by a computer to position the mirror for maximum solar gain throughout the day. When the STEC mirror array is properly focused in direct sunlight, it is capable of generating thousands of degrees of heat at the focal point. This much heat can be used to create high-pressure steam to spin a turbine and generate electricity. The steam cycle process would be used to generate electricity the same way electricity is generated when steam is made by burning fossil fuels. Only the heat source would change.

Evaporator: A freezing unit used in solar cooling operations. Pure liquid refrigerant absorbs the heat from the surrounding area and turns back into a gas in the evaporator. The evaporator is located within a large room or building insulated from exterior heat for refrigeration.

Condensing unit: In solar cooling operations, the unit where refrigerant is condensed from a gas back into a liquid and gives up its heat. The condenser is located outside the refrigeration area and transfers heat out of the area to another environment.



Technology Link

Manufacturing: Solar Cell Production

Energy technology is important to our daily lives, as it provides us with light, heat, and other necessities and conveniences. In order to have the energy we use every day, we depend on many applications of manufacturing technology. Energy supplies, such as solar cells, need to be developed, produced, and distributed for use.

There are several types of solar cells. The most common are made of silicon. The process of manufacturing solar cells has four main parts, which occur in the following sequence:

- **Casting and wafering.** This typically involves metallurgical processes, such as crystal growing and casting. Molten silicon is processed at extremely high temperatures. The silicon is then shaped into wafers.
- **Solar cell manufacturing.** At a solar cell plant, the wafers are taken through a semiconductor processing sequence, where they become working solar cells. They must go through etching, diffusion, and screen-printing steps before being tested and graded.
- **Module assembly.** This usually involves soldering cells together to produce a string of cells, which is then laminated between glass plates and framed so it can be easily mounted.
- **Solar energy system assembly and installation.** The solar module has to be integrated into the structure for which it was designed. This may involve mounting it onto a roof or other structure. The module also has to be integrated into the other parts of the solar energy system, which involves connecting the inverters, batteries, wires, and regulators. Often, a computer software program is used to calculate the electrical load required by the customer.

Solar energy can significantly impact our society, economically and environmentally. Because it is so dependent on manufacturing technology, it has the potential to improve employment rates by creating long-term jobs. Lower prices and higher efficiency suggest that solar energy will be used more and more in the coming years.

Figure 6-18. Solar Thermal Energy Conversion (STEC) is an experimental program being evaluated at the Sandia National Laboratory of the Department of Energy (DOE) in New Mexico. A—Nearly 2000 large mirrors are arranged in an arc across 72 acres and are kept oriented to the sun. B—Sunlight reflected from the mirrors is focused on a receiver near the top of a tall tower. The resulting heat energy is used to generate steam and drive a turbine. Electrical energy to power 10,000 homes is generated by this system. (U.S. DOE)

A

B

Summary

The sun is considered an inexhaustible source of energy. Life on earth would not exist without the energy from the sun. Plenty of solar energy reaches the earth every day, but it is difficult to collect and store. Present solar collection techniques may be divided into the categories of active and passive solar energy collection. Passive solar collection techniques do not require external power sources to help in the collection or distribution of heat. These collection techniques include the direct gain approach, the indirect gain approach, and the isolated gain approach. Active solar collection systems use pumps for circulation. These collection systems include the use of flat-plate, linear-concentrating, and point-focusing collectors. Active solar collection systems may be configured as open loop systems or closed loop systems. Some active solar collectors must be capable of tracking the sun on its azimuth path. Photovoltaic cells have the ability to convert sunlight into direct current (DC) electricity. This electricity may be used, stored, or converted to alternating current (AC) electricity. Photovoltaic arrays are typically used to provide power in remote locations. All solar collection techniques offer some advantages and some disadvantages. While solar energy is not presently used extensively, the fact that it is an environmentally friendly inexhaustible resource makes it worthy of continued exploration and research. Solar energy will remain a viable source of energy as long as humans inhabit the planet.

Key Words

All the following words have been used in this chapter. Do you know their meanings?

active solar energy collection
azimuth path
closed loop solar collection
compound parabolic collector
condensing unit
conduction
convective loop
direct gain approach
evaporator
flat-plate collector
indirect gain approach
isolated gain approach
linear-concentrating parabolic collector
open loop solar collection
parabolic dish collector
passive solar energy collection
phase change
photoelectric effect
photovoltaic cell
Trombe wall
zenith path

Test Your Knowledge

Write your answers on a separate sheet of paper. Do not write in this book.

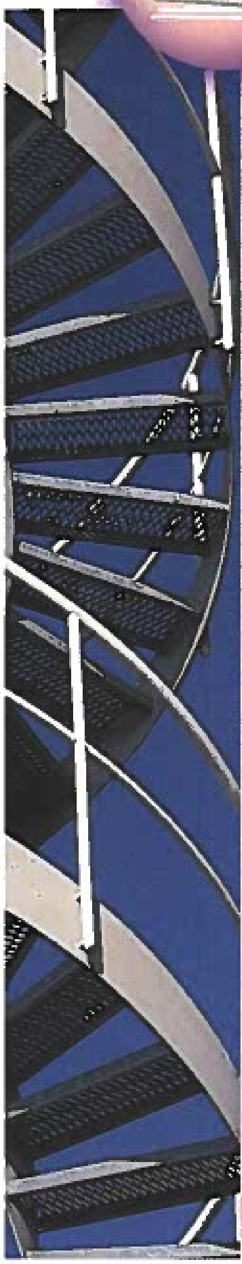
1. Write one or two sentences explaining why solar energy is considered to be an inexhaustible energy resource.
2. *True or False?* Ceramic tile, concrete, and water tubes can all be used as storage media for solar energy.
3. Why is solar energy one of the only long-term options for energy independence?
4. *True or False?* Passive solar techniques rely on tracking mechanisms and circulating pumps.
5. A passive solar home typically makes use of which method of heat movement to circulate air throughout the home?
   A. Conduction.
   B. Convection.
   C. Radiation.
   D. Infiltration.
6. What are the major differences between active and passive solar techniques?
7. *True or False?* An open loop solar collection system works best in a southern climate that is not subject to extensive cold weather and freezing.
8. Describe the purpose of the absorber plate in a flat-plate collector.
9. Flat-plate collectors work on the principle that:
   A. shorter light waves get longer when converted to heat.
   B. longer light waves get shorter when converted to heat.
   C. heat can be converted to light.
   D. wavelengths stay the same when light is converted to heat.
10. *True or False?* Visible light passes through glass easier than infrared energy.
11. *True or False?* A compound parabolic collector needs to track the sun.
12. *True or False?* The zenith path refers to the altitude of the sun in the sky.
13. *True or False?* Parabolic dish collectors are typically used to collect energy for residential use.
14. Passive solar collection techniques include:
    A. indirect gain.
    B. isolated gain.
    C. direct gain.
    D. All of the above.
15. *True or False?* A Trombe wall is often associated with the indirect gain approach to passive solar energy.

16. Eutectic salts may be used as:
    A. tracking devices.
    B. measuring devices.
    C. photovoltaic cells.
    D. storage media.
17. Explain three concepts associated with passive solar architecture.
18. Identify the advantages and disadvantages of the different types of solar collection techniques.
19. You install a small passive solar greenhouse on the rear of your home. Through a series of temperature-controlled vents, the warm air from the greenhouse is transferred to the living space within the home. You estimate the heat gained from the greenhouse will save about $300 in structural heating per year, and the greenhouse costs $2800 to purchase and install. What is the payback period for the installation of the greenhouse?
20. _____ have the ability to displace _____, causing the flow of electricity in a photovoltaic cell.
21. List three current applications for photovoltaic cells.

STEM Activities

1. Construct, test, and evaluate scale models of various types of collectors.
2. Construct a solar hot dog cooker.
3. Calculate the payback of a professionally installed solar hot water system.
4. Incorporate passive solar design techniques into architectural design.

Career Skills



Job Interviews

The interview gives you the opportunity to learn more about a company and to convince the employer that you are the best person for the position. The employer wants to know if you have the skills needed for the job. Adequate preparation is essential for making a lasting, positive impression. Here are some ways to prepare for the interview.

- Research the employer and the job. Know the mission of the employer and specifics about the job. Also, try to learn what the company looks for when hiring new employees.
- Be prepared to answer questions.
- List the questions you want answered. For example, do you want to know if there is on-the-job training or opportunities for advancement?
- List the materials you plan to take. This seems simple enough. However, if you wait to grab items at the last minute, you will likely forget something important.
- Decide what to wear. Dress appropriately, usually one step above what is worn by your future coworkers. For instance, casual clothing is acceptable for individuals who will do manual labor or wear a company uniform. If the job involves greeting the public in an office environment, a suit is more appropriate. Always appear neat and clean.
- Know where to go for the interview. Verify the address of the interview location by checking the site beforehand, if possible. Plan to arrive ready for the interview at least 10 minutes early.

Good preparation will make you feel more confident and comfortable during the interview. Be polite, friendly, and cheerful during the process. Use a firm handshake. Maintain eye contact at all times. Answer all questions carefully and as completely as you can. Be honest about your abilities. Avoid chewing gum and fidgeting. Also be aware of questions you legally do not have to answer, such as those related to age, marital status, religion, or family background.

A prospective employer may ask you to take employee tests. Some employers administer tests to job candidates to measure their knowledge or skill level under stress.

After the interview, send a letter to the employer within 24 hours, thanking him or her for the interview. If you get a job offer, respond to it quickly. If you do not receive an offer after several interviews, evaluate your interview techniques and seek ways to improve them.