RENEWABLE ENERGY SYSTEMS

This chapter provides guidelines for:

Passive Heating and Cooling (Guideline RE1)

Solar Thermal Hot Water Systems (Guideline RE2)

Solar Pool Heating (Guideline RE3)

Wind (Guideline RE4)

Geothermal Heat Pumps (Guideline RE5)

Photovoltaics (Guideline RE6)

OVERVIEW

This chapter presents guidelines for using renewable energy systems for part of a school's required energy load. As demand on fossil fuel reserves and existing electricity grids increases, a growing number states are facing energy shortages and skyrocketing utility costs. The problem will continue to worsen as the nation's energy needs are expected to grow by 33% during the next 20 years.[1] Renewable energy can help fill the gap. Renewable energy sources not only release less pollutants into the environment than traditional energy sources, but they save school districts money in the long term while also serving as valuable teaching tools for students and faculty.

Environmentally Friendly Energy Resources

Renewable energy systems are those that use fuels from renewable resources, including the sun, wind, and the Earth's heat. Renewable energy technologies are often referred to as "clean" or "green" because they produce few, if any, pollutants. Burning fossil fuels, however, sends greenhouse gases into the atmosphere, trapping the sun's heat and contributing to global warming.

Unlike fossil fuels, renewable energy resources are abundant. Every day, more energy falls on the United States than is used in an entire year. The total amount of solar energy per year falling on the conterminous 48 states is 46,700 Quads/year. (A Quad is one quadrillion ($1.0*10^{15}$) British thermal units (Btus). Compare this to 94.2 Quad/year, the U.S. energy consumption rate in 1997.[2]

Wind power is an increasingly common renewable energy source. Good wind areas, which cover 6% of the contiguous U.S. land area, could supply more than 1.5 times the 1993 electricity consumption of the entire country. California now has the largest number of installed turbines. Many turbines are also being installed across the Great Plains, reaching from Montana east to Minnesota and south through

[1] http://www.eren.doe.gov/erec/factsheets/renew_energy.html.

[2] Ibid.

Texas, to take advantage of its vast wind resource. North Dakota alone has enough wind to supply 36% of the total 1990 electricity consumption of the lower 48 states. Hawaii, Iowa, Minnesota, Oregon, Texas, Washington, Wisconsin, and Wyoming are among states where wind energy use is rapidly increasing.[3]

Geothermal power may be one of the lesser known renewable energy sources, but more than 500 schools nationwide have installed geothermal heat pump systems to provide their heating and cooling needs.[4]

Cost-Efficiency

Over the past two decades, the cost of renewable energy systems has dropped dramatically. Improvements in analytical tools are making passive solar technologies cost effective as well; they can be implemented into schools with less than a two-year return on investment. Wind turbines can produce electricity at less than $0.04/kWh — a seven-fold reduction in energy cost. Concentrating solar thermal technologies and photovoltaics have dropped more than three-fold during the last 20 years. GSHPs can have a 20% to 50% energy cost savings over traditional heating and cooling systems.[5]

By reducing its dependency on traditional electricity sources, the school will not only save in utility costs, but faces less risk of losing valuable teaching time due to rolling blackouts and power outages.

Renewable Energy as a Teaching Tool

In addition to providing economic and environmental benefits, these renewable energy systems are an important "living laboratory" to teach students about energy technologies of the future. Input from teachers early in the design process ensures that energy features are incorporated in a way that optimizes the learning experience. Buildings that teach offer students an intriguing, interactive way to learn about relevant topics like renewable energy sources.

Resources

The Center for Energy Efficiency and Renewable Technologies. http://www.cleanpower.org/index.html

The Renewable Resource Data Center. http://www.rredc.nrel.gov/.

U.S. Department of Energy's Energy Information Administration. "U.S. Renewable Energy Consumption." *Renewable Energy Annual 2000*. http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/chapter1.html.

U.S. Department of Energy's Energy Efficiency and Renewable Energy Network (EREN) "Renewable Energy: An Overview." Consumer Energy Information: Erec Fact Sheets. http://www.eren.doe.gov/erec/factsheets/renew_energy.html.

U.S. Department of Energy's Energy Efficiency and Renewable Energy Network (EREN) "Geothermal Heat Pumps Score High Marks in Schools." Geothermal Energy Program. http://www.eren.doe.gov/geothermal/ghp_schools.html.

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[3] http://www.eren.doe.gov/erec/factsheets/renew_energy.html.

[4] http://www.eren.doe.gov/geothermal/ghp_schools.html.

[5] Ibid.

GUIDELINE RE1: PASSIVE HEATING AND COOLING

Recommendation

Increase energy efficiency and comfort in school buildings by incorporating passive solar design.

Description

Sunlight can provide heat, light, and shade and induce summertime ventilation into the well-designed school. Passive solar design has been used for centuries, but now designers have access to building materials, methods, and software that can improve the design and integration of solar design principles into modern buildings.

Passive solar features such as additional glazing, added thermal mass, and larger roof overhangs can pay for themselves. NREL/PIX 10684

Applicability

Passive solar design strategies vary by building location and regional climate, but the basic techniques remain the same: maximize solar heat gain in the winter and minimize it in summer. For commercial and school buildings, the first priority is to use passive solar design for light.

Reduce the window area on east- and west-facing walls. In northern states such as Montana, also reduce north-facing windows. In most climates, north-facing windows offer good, diffuse light. Daylighting should be mostly achieved through north and south windows. South-facing windows should have a high Solar Heat Gain Coefficient (SHGC) — usually 0.60 or higher — to maximize solar heat gain, a low U-factor (0.35 or less) to minimize thermal loss, and good light transfer. The south windows should also be shaded to avoid summer overheating.

Applicable Climates

Applicable Spaces		When to Consider	
Classrooms	■	Programming	■
Library	■	Schematic	■
Multi-Purpose	■	Design Dev.	■
Gym	■	Contract Docs.	■
Corridors	■	Construction	■
Administration	■	Commissioning	■
Toilets	■	Operation	■
Other	■		

Use more north-facing windows and shade south-facing windows. Shading from overhangs, landscaping, shutters, and solar window screens helps lower heat gain on windows that receive full sun, but window shading design should still maximize daylighting efforts. Cost effective windows for cooling climates have a U-factor below 0.4 and a SHGC below 0.55 (a lower SHGC cuts cooling costs).

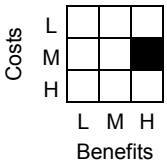
Integrated Design Implications

Passive solar design should be considered using the whole-building approach. Specific techniques include:

- Start by using energy-efficiency design strategies.
- Orient the building with the long axis running east/west.
- Select, orient, and size glass to optimize winter heat gain and minimize summer heat gain for the specific climate. Consider selecting different glazings for different sides of the building (exposures).
- Size south-facing overhangs to shade windows in summer and allow solar gain in winter.

- Direct solar gains may cause problems (hot spots, glare) that will make learning difficult. It may be better to optimize school design for daylighting instead of heating. Trombe walls should be looked at as an alternative to direct solar gains.
- Add thermal mass in walls or floors for heat storage.
- Use natural ventilation to reduce or eliminate cooling needs.
- Use daylighting to provide natural lighting.

Cost Effectiveness



Passive solar features such as additional glazing, added thermal mass, and larger roof overhangs, or other shading features can pay for themselves. Passive solar design often means less heating and cooling requirements; therefore savings can accrue from reduced HVAC unit size, installation, operation, and maintenance costs. Passive solar design techniques often require higher first costs but are less expensive over the life-cycle costs of the building.

Benefits

Passive solar design can reduce heating and cooling energy bills, increase spatial vitality, and increase comfort.

Design Tools

One of the best ways to design an energy-efficient building incorporating passive solar design techniques is to use a software simulation program. The U.S. Department of Energy sponsors a variety of appropriate software tools including its latest, EnergyPlus. Another tool, Energy-10 is a PC-based design tool that helps identify the best combination of energy-efficiency strategies including daylighting, passive solar heating, and high-efficiency mechanical systems. Another tool to optimize window size and aid in window selection is RESFEN.

Design Details

Passive solar design integrates several building features to reduce or eliminate the need for mechanical heating and cooling and artificial daylighting. Designers and engineers need to pay particular attention to the sun to reap passive heating, cooling, and daylighting benefits. The design does not need to be complex, but it requires knowledge of solar geometry, window technology, and local climate. Given the proper building site, virtually any architecture can incorporate passive solar design.

Passive solar heating techniques generally fall into one of three categories: direct gain, indirect gain, and isolated gain. *Direct gain* is solar radiation that directly penetrates and is stored in the building space. *Indirect gain* collects, stores, and distributes solar radiation using some storage material (e.g., Trombe wall). Conduction, radiation, or convection then transfers the energy indoors. *Isolated gain* systems (e.g., hallways and atriums) collect solar radiation in an area that can be selectively closed off or exposed to the rest of the building.

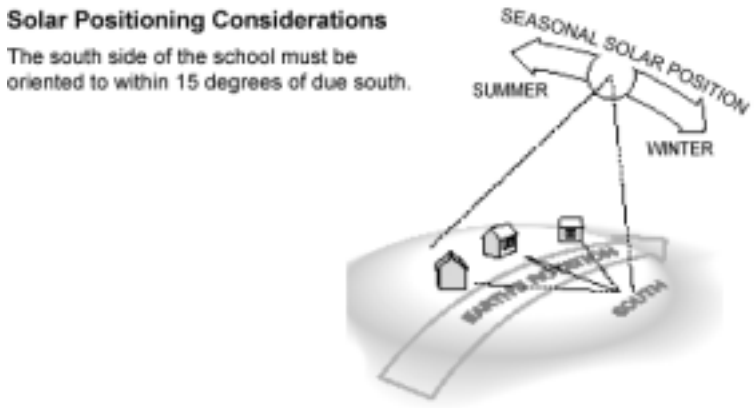


Figure 1 – Solar Positioning Considerations

For passive cooling, consider operable windows to provide an opportunity for natural ventilation in milder temperature months when interior loads on buildings exceed exterior temperatures. Night purging, letting cooler air into the building at night, can reduce HVAC startup loads the next morning. It is also necessary to optimize the building overhangs to reduce the cooling loads that result from unwanted solar gain.

Operation and Maintenance Issues

Passive solar design offers many benefits with minimal maintenance risks over the life of the building.

Commissioning

None.

U.S. Department of Energy-sponsored energy software tools including EnergyPlus, Energy-10, and RESFEN are available at http://www.eren.doe.gov/buildings/energy_tools.

Energy Efficiency and Renewable Energy Clearinghouse (EREC) 1-800-DOE-3732 or http://www.eren.doe.gov/.

Sustainable Buildings Industry Council, http://www.sbic.org/.

Efficient Window Collaborative website, http://www.efficientwindows.org/.

GUIDELINE RE2: SOLAR THERMAL HOT WATER SYSTEMS

Recommendation

If conditions permit, augment high-efficiency, gas-fired boilers used for space heating and domestic hot water with a solar thermal system and/or recovered thermal energy.

Description

A solar thermal system can be either direct or indirect and classified as either active or passive. A direct system heats water directly in solar collectors. An indirect system uses a working fluid (usually a glycol-water mixture) in conjunction with a heat exchanger to increase the water temperature. Direct systems contain fewer elements and are less expensive, but they are prone to freezing and cannot be used in all climate zones without drain-back systems. Indirect systems use an antifreeze mixture and can be used in any climate zone. Active and passive refers to the method by which fluid reaches the collector. If the fluid moves through natural convection, the system is termed passive, and if pumps are used, it is active. Solar thermal systems consist of the following elements:

- **Solar radiation collector:** Collects solar radiation for heating.
- **Heat exchanger:** A heat exchanger is used in an indirect system to pass heat from the working fluid to the water supply.
- **Hydronic distribution system:** Supplies water to the collector for direct systems and to the facility for both direct and indirect systems.
- **Storage tank:** Stores heated water for facility use or for boiler feed water supply.

Solar thermal hot water systems are applicable to any situation where a significant amount of space heating and/or water heating are required. NREL/PIX05183

Applicable Climates

Applicable Spaces	When to Consider
Classrooms	Programming
Library	Schematic
Multi-Purpose	Design Dev.
Gym	Contract Docs.
Corridors	Construction
Administration	Commissioning
Toilets	Operation
Other	

Applicability

Applicable in any situation where a significant amount of space heating and/or water heating are required. A solar thermal water heating system has the potential to be the main hot water source in some situations. For example, an elementary school in the desert could easily meet most of its hot water needs through solar energy utilization. In most areas it could at least augment the boiler system.

Integrated Design Implications

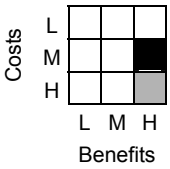
A radiant slab heating system works extremely well with solar thermal water heating. Solar thermal systems can generally achieve the low inlet temperatures (90°F to 120°F) required by a radiant slab system.

Because the performance of a solar thermal system is dependent upon the weather, it works best when used in conjunction with another heating system. Depending upon the situation, the solar system can be

the primary heat source or can be used to augment and increase the efficiency of a boiler system. The increased efficiency is accomplished by preheating boiler feed water with solar thermal energy.

The use of a solar thermal system must be addressed early in the planning stages, as its viability is highly dependent upon available roof space and building orientation. It is also important to plan the placement of any other roof systems to avoid shading by packaged HVAC systems, stacks, walls, etc.

Cost Effectiveness



Initial costs are higher than that for a boiler system. Most systems cost between $30/ft^2 and $90/ft^2 of collector area. Maintenance costs are low and fuel expenses are zero.

The initial cost for solar thermal systems is somewhat more than boilers. However, the fuel is free and thus the system will eventually pay for itself. For a slab system, it may be the more cost-effective option since it is heating to its maximum while a boiler would need to be run at a lower, less efficient setting. The cost effectiveness of a solar system varies from site to site, as the payback period is dependent upon climate and available solar radiation. Solar thermal systems will be most cost effective in schools with substantial summer occupancy as this is the time of greatest available solar radiation.

Benefits

- Free fuel.
- No worry about changing fuel prices.
- Non-polluting. No fumes means healthier for students and teachers. No operational greenhouse gas emissions
- Great for teaching. The system itself can be a topic in science classes.

Design Tools

- The Transient System Simulation Program (TRNSYS), developed by the University of Wisconsin-Madison Solar Energy Laboratory is capable of modeling entire solar water heating systems.
- The National Renewable Energy Laboratory has extensive data regarding annual totals of solar radiation for different cities.
- *Solar Engineering of Thermal Processes* by John Duffie and William Beckman is a great resource for solar energy applications.

Design Details

System requires a differential thermostat to ensure heat is not being dumped to the collectors. The most important element of a solar thermal system is the solar collector. Solar collectors can be either fixed or track the sun. The latter is generally more expensive and is saved for high-temperature applications. Fixed collectors should be oriented facing south and tilted based on seasonal load. A good rule of thumb is to use the location's latitude as the tilt angle with respect to the horizontal.

- Flat-plate collectors consist of a metal frame box containing a layer of edge and backing insulation, an absorber plate with parallel piping, and glazing. The absorber plate is generally constructed of copper or aluminum with a high-absorbance coating. The glazing layer reduces convective and radiation heat loss and involves one or more sheets of glass. Solar thermal systems with flat-plate collectors are very common.
- Integral Collector Storage (ICS) systems use the storage tanks themselves as solar collectors. The tanks are painted black and are set on the roof alone or in insulating boxes with transparent covers angled south. ICS systems are applicable only in mild climates, as freezing and significant heat loss become issues in colder regions. This system is very simple and cost-effective.

- The evacuated tube collector is a long, thin version of a flat-plate collector where the box has been replaced by a glass tube and the insulation by a vacuum. These collectors are extremely efficient but are fragile and expensive.
- Concentrating collectors use a curved surface to reflect and concentrate the solar radiation onto a pipe containing fluid. These collectors are generally used for high-temperature applications and almost always configured to track the movement of the sun.

Operation and Maintenance Issues

- Collector glass should be cleaned regularly to ensure maximum efficiency.
- Direct systems must be drained when freezing conditions exist.
- Roof-integrated systems should be designed to allow easy removal when roof replacement is required.

Commissioning

Commissioning is important for solar thermal systems because the general contractor may not be familiar with them. Solar systems must be considered whenever rooftop decisions are made. The efficiency of the system is wholly dependent upon collector orientation and minimizing shading. It is important to have a solar expert on hand whenever the system is being considered, even for such things as storing collectors before installation. (Some collectors can be damaged if stored in the sun without fluid passing through them.)

References/Additional Information

ASHRAE Handbook: HVAC Applications, 2000.

ASHRAE Handbook: HVAC System and Equipment, 2000.

Beckman, J.A. and Beckman, W.A. *Solar Engineering of Thermal Processes.* New York: Wiley-Interscience, 1991.

Energy Efficiency and Renewable Energy Network. http://www.eren.doe.gov/.

Federal Energy Management Program. http://www.eren.doe.gov/femp/.

Solar Engineering Laboratory. University of Wisconsin-Madison, 1500 Engineering Drive, Madison, WI 53706. Phone: (608) 263-1589. Fax: (608) 262-8464. Email: trnsys@sel.me.wisc.edu. Web site: http://www.sel.me.wisc.edu/trnsys.

GUIDELINE RE3: SOLAR POOL HEATING

Recommendation

Use solar heaters for swimming pools as an environmentally friendly and cost-effective solution to pool heating requirements.

Description

Most solar pool heating systems consist of three basic components: a collector, a pump, and a controller. Unlike domestic solar water heating systems, which raise a small amount of water to a high temperature of about 140°F, pool heaters raise the temperature of several thousand gallons of water to about 80°F by circulating the water at a relatively fast rate through the collectors. This circulation allows most of the solar energy falling on the collectors to transfer to the pool water.

A solar heating system requires very little or no maintenance since it has no burners or moving parts. NREL/PIX08590

Applicable Climates

Applicable Spaces		When to Consider	
Classrooms		Programming	
Library		Schematic	
Multi-Purpose		Design Dev.	
Gym		Contract Docs.	
Corridors		Construction	
Administration		Commissioning	
Toilets		Operation	
Other			

The collector consists of a large area of pipes that absorb solar energy in the form of heat. They are made from plastic or rubber compounds that can withstand continuous exposure to sunlight. The collector is positioned for maximum access to sunlight. The pump circulates water through the collector to continually absorb heat. The hot water is then pumped back into the pool. This pump may be separate (especially in retrofit situations) from the regular pool pump that circulates pool water through a filter. The pump is automatically switched off when the temperatures of the water in the pool and the collector approach each other. The controller regulates the flow of water within the collector based on the temperature of the outgoing water using a diverting valve, the only moving part in a solar pool heating system. This valve controls whether or not the water circulates through the collector loop. When the collector temperature is sufficiently greater than the pool temperature, the water is diverted from the filter systems through the collector loop. The water bypasses the solar collectors during nighttime or cloudy periods. Some smaller systems are operated manually or with timers, but larger systems may be operated through electronic sensors.

Strip, panel, and tube systems are the three major types of solar collectors available. All three perform to a more or less equal standard, although strip systems are the most commonly used type.

Applicability

Solar heating for swimming pools is feasible for all climate types, even those that experience sub-freezing temperatures. Waterways on strip systems can expand to accommodate the increased volume of frozen water.

Most sloping roofs can be fitted with solar collectors. Relatively lightweight strip systems are suitable for sloping roofs. Strip collectors can be fitted to follow the roof contours and can be curved around

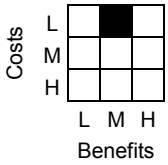
obstructions, such as chimneys and skylights. Panel collectors are limited by their rigid sheet design and can be applied to flat or plane roofs only.

Integrated Design Implications

Although solar heated swimming pools can easily be accommodated later in the design or construction phases, the following issues should be considered beforehand:

- **Building aesthetics.** Installing solar collectors on rooftops may conflict with building aesthetics. Consider placement and orientation of the collectors early in the design phase to avoid this conflict.
- **Space availability.** Solar collectors may occupy an area equivalent to 75% of the pool's surface area. This roof area must be available near the location of the swimming pool for unobstructed access to sunlight (although it's possible to mount the collectors at ground level).

Cost Effectiveness



Collectors made of copper are more expensive than those made of plastic, although they last longer. Plastic collectors are less conductive than copper, but are inert to chemicals and have about a 10-year lifespan. On an average, solar heating systems for pools cost around \$7.50/ft^2 to \$10/ft^2 (installed). An unglazed solar heating system for an average 600-ft^2 pool, including separate pump and automatic controller, costs around \$4,500 fully installed. The operating energy is practically free, as all the heating energy is solar.

Pool covers for an average size 600 ft^2-pool costs around \$400 to \$500 (not including the roller, which has a starting cost of around \$300). Using the above figures for the cost of running a gas heater, heating the pool with solar energy can save from 3.8 tons to 5.1 tons of greenhouse gas emissions (CO_2) per year.

Benefits

- Since solar pool heating collectors operate just slightly above the ambient air temperature (80°F), such systems typically use inexpensive, unglazed, low-temperature collectors made from especially formulated plastic materials.
- The alternative system — a gas pool heater — has a starting price of around \$2,000, plus additional heating costs varying from \$600 to \$900 per year. The solar heating system will therefore repay the extra cost in less than three to four years, and will have much lower running costs thereafter.
- A solar heating system requires very little or no maintenance since it has no burners or moving parts. A gas heater or heat pump requires far more maintenance and typically lasts only one-third the life span of a solar system.
- Solar heating systems' warranties are typically more inclusive and much longer (12 to 15 years) than warranties for gas heaters (five years) and heat pumps (typically 10 years).
- A good solar pool heating system can generally be expected to increase pool water temperature by 9°F to 18°F above the unheated water temperature from October through March. However, temperatures will vary depending on local climate conditions. The graphs below show the temperature differences claimed by one manufacturer in two climate extremes.
- Attic insulation gets saturated with radiant heat from roof decks that increases air conditioning bills. Collectors mounted on the roof will considerably lower air conditioning costs for that space.

Table 1 – Cost comparison for gas and solar pool heaters in a heating-dominated climate

Gas Pool Heater	Solar Pool Heater
Initial cost $2,400	Initial cost $3,495
Five year operating cost $6,000	Five year operating cost $0
Total five year cost $8,400	Total five year cost $3,495

Design Tools

Use the following simplified algorithm for arriving at the required collector area:

$$A = A_p \times O \times S \times Sol_{ins}$$

where,

A = Area of solar collector, ft^2

A_p = Effective area of pool (multiply the surface area of the pool with the shape multiplier from Table 2 below), ft^2

O = Orientation multiplier (from Table 3 below)

S = Shading multiplier (from Table 4 below)

Sol_{ins} = Solar insolation (from the figure below)

Table 2 – Shape Multiplier

Shape	Multiplier
Rectangle	1.00
Kidney/Freeform	0.85
Oval	0.90
Round	0.79

Table 3 – Orientation Multiplier

Orientation	Multiplier
South facing	1.00
East or west facing	1.25
Flat	1.10

Table 4 – Shading Multiplier

Shading (from 9 a.m. to 5 p.m.)	Multiplier
No shade	1.00
25% shade	1.10
50% shade	1.25
75% shade	1.50
100% shade	1.75

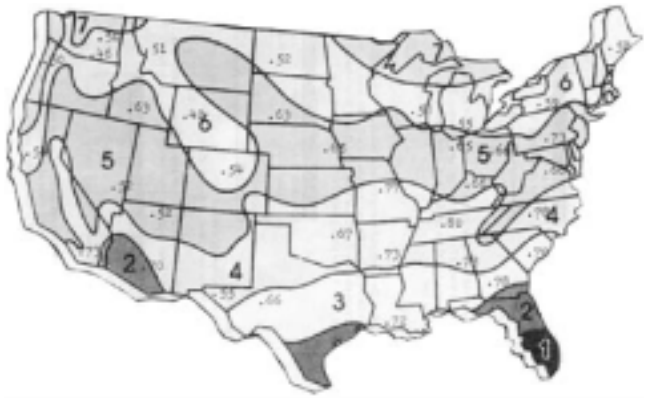


Figure 2 – Solar Insolation Levels in the United States

Free software is available from U.S. Department of Energy to analyze current energy consumption and project savings when implementing a variety of energy management systems from pool covers to solar systems. The *Energy Smart Pools* software uses hourly temperature and humidity data along with solar data to provide an accurate simulation of the heat losses and gains of a pool. Over 50 U.S. weather sites are currently available in the software. The program is intended to provide annualized simulation of

annual energy costs, other costs, savings, and payback of adding a pool cover system, as well as costs, savings, and payback of adding a solar heating system.

Design Details

As in all solar heating, the primary factor in determining the effectiveness of the system is exposure to the sun. The size and the location of the collector, controller efficiency, local climate, wind protection, and roof orientation all influence the functioning of solar pool heating systems.

- Use a minimum collector area that is 60% of the pool's surface area. This applies only for ideal conditions (see the Design Tools section for simplified sizing). Whenever conditions are unfavorable, for example in colder climates, the size of the collector will need to be increased, with a minimum area of 80% recommended for such installations. Increase collector area to 75% of the pool surface area if collectors are laid flat or if collectors face west. Other orientations are not recommended. In general, for every 20% of the pool surface area that is installed as solar collector, a 3°F rise in water temperature can be expected (based on collector rating at 1,000 Btu/ft^2 of collector area).
- A south-facing roof is the best location for these systems. Use a west orientation or a flat roof if south orientation is unavailable.
- Ideally, tilt the south-facing collectors by 30° to 32°.
- Consider installing pool covers. They are the most cost effective measure for reducing heat loss, water evaporation, and chemical use.
- Manual operation or a simple timer may be substituted for expensive automatic controls.
- Indoor pools that are used year round require glazed flat plate collectors, which should slope between 35° and 45°.

Operation and Maintenance Issues

Ensure that pools are manually and seasonally drained. In areas subject to winter freezing, the collectors and plumbing should be installed to allow all water to drain when the system is off.

Paint all exposed PVC plumbing to protect it from damage due to solar energy.

Commissioning

Carefully check how long the manufacturer has been in business and what warranty services are available. Use the Florida Solar Energy Center rating system (see References for more information).

References/Additional Information

American Solar Energy Society, Inc. (ASES). 2400 Central Avenue, G-1, Boulder, CO 80301. Phone: (303) 443-3130; Fax: (303) 443-3212, Email: ases@ases.org. Web site: http://www.ases.org.

National Spa & Pool Institute (NSPI). Phone: (800) 323-3996. Web site: http://www.nspi.org/.

The Energy Efficiency and Renewable Energy Clearinghouse (EREC).. P.O. Box 3048, Merrifield, VA 22116. Phone: (800) DOE-EREC (800-363-3732). Email: doe.erec@nciinc.com. Florida Solar Energy Center. 1679 Clearlake Rd., Cocoa, FL 32922. Phone: (407) 638-1000, Fax: (407) 638-1010, Pamphlets available by mail - call for costs, Collector Thermal Performance Ratings (publication FSEC-GP-16), Design and Installation Manual (publication FSEC-IN-21-82), System Sizing (publication FSEC GP-13). Web site: http://www.eren.doe.gov/consumerinfo.

Solar Energy Industries Association (SEIA). 1616 H Street, NW, 8th Floor, Washington, DC 20006. Phone: (202) 628-7979, Fax: (202) 628-7779. http://www.seia.org/.

GUIDELINE RE4: WIND

Recommendation

Small wind electric systems may be an option to provide some of the required electrical load from renewable energy for some schools.

Description

Wind is created by unequal heating of the Earth's surface by the sun. Wind turbines convert the kinetic energy in wind into mechanical energy that powers a generator to produce clean electricity. Turbine blades are aerodynamically designed to capture the maximum energy from the wind. The wind turns the blades, which then spin a shaft connected to a generator that makes electricity.

Applicability

A small wind electric system may be an appropriate technology to provide renewable power to a school if the following conditions are met:

- There is enough wind where the school is located (usually average wind speeds of 14 mph or greater are needed for cost effectiveness).
- Tall towers are allowed in the area.
- Enough space exists on the site.
- It makes financial sense for the school.

Integrated Design Implications

Before selecting a small electric wind system for the school, first make the building as energy efficient as possible. Reducing energy consumption will significantly lower the school's energy bills and will reduce the size of the wind energy system needed.

Reducing energy consumption at the school before selecting a small electric wind system will significantly lower energy bills and the size of system needed. NREL/PIX 09043

Applicable Climates

Applicable Spaces

- Classrooms ■
- Library ■
- Multi-Purpose ■
- Gym ■
- Corridors ■
- Administration ■
- Toilets ■
- Other ■

When to Consider

- Programming □
- Schematic ■
- Design Dev. □
- Contract Docs. □
- Construction □
- Commissioning □
- Operation □

Cost Effectiveness

Costs \ Benefits	L	M	H
L			
M			■
H			

A small wind turbine can cost anywhere from $3,000 to $35,000 installed, depending on size, application, and service agreements with the manufacturer. A general rule of thumb for estimating the size of a small wind system is $1,000/kW to $3,000/kW. Wind energy becomes more cost effective as the size of the turbine's rotor increases. Although smaller turbines cost less in initial outlay, they are proportionally more expensive.

Although wind energy systems involve a significant investment, they can be competitive with conventional energy sources when accounting for a lifetime of reduced or avoided utility costs. The length of the payback period depends on the system chosen, available wind resources, electricity costs, and how the wind system is utilized.

Benefits

Depending on the wind resource, a small wind electric system can lower electricity bills by 50% to 90%, prevent power interruptions, and is non-polluting. A wind energy system can also be a good teaching tool.

The economics are best when:

- There is a good wind resource (greater than 14 mph average annual wind speed at the hub).
- There is net billing with 50 kW cap or higher, preferably annual over monthly netting period.
- Electric rates are above average ($0.08/kWh or greater).
- Large kWh usage allows larger wind turbines, which improves payback due to economies of scale.

When Does Installing a Wind Turbine Make Sense?

- When adequate wind exists at school location.
- When the site has acceptable space.
- When the state has policies that encourage renewable energy:
    - A good net billing law
    - Loan funds
    - Income tax credits
    - Buy down program
    - Property tax abatement
- When electric rates are above average (typically $0.08/kWh or more).
- Single part rate is more favorable than two part rate (demand and energy charges).

Design Tools

The formula for calculating the power from a wind turbine is:

$$\text{Power} = C_p 1/2\ \rho A V^3$$

where :

C_p = Power coefficient, ranging from 0.2 – 0.4, dimensionless (theoretical max = 0.59)

ρ = air density, lb/ft^3

A = rotor swept area, or $\pi D^2/4$ (D is the rotor diameter in feet, π = 3.1416)

V = wind speed, mph.

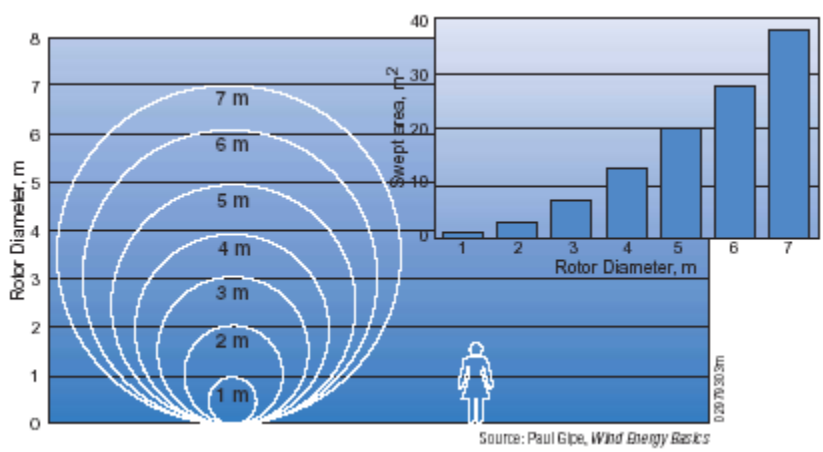


Figure 3 – Relative Size of Small Wind Turbines

The figure above shows the actual size of rotor diameters in relation to the size of an average person. This can help when examining the view of the turbine on a landscape.

The Wind Energy Design Payback Period Workbook, found at http://www.nrel.gov/wind under consumer information, is a spreadsheet tool that can help analyze the economics of small wind electric systems.

Design Details

Mounting turbines on rooftops is not recommended. All wind turbines vibrate and transmit the vibration to the structure on which they are mounted. This can lead to noise and structural problems with the building.

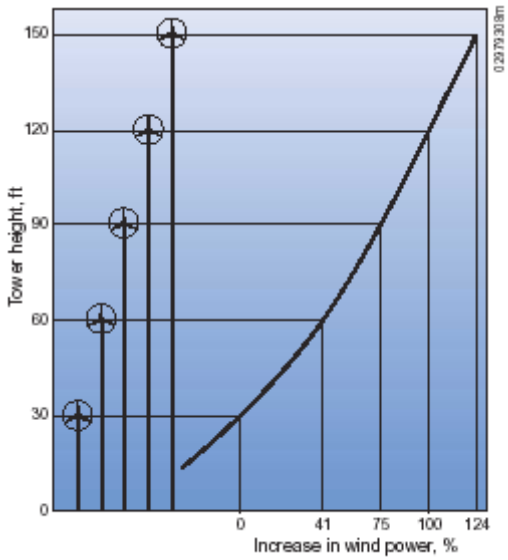


Figure 4 – Wind Speeds Increase with Height

Average wind speeds increase with height and may be 15% to 25% greater at a typical wind turbine hub height of 80 ft than at a typical airport anemometer height. As V^3 increases, power increases by approximately 60%.

Operation and Maintenance Issues

Although small wind turbines are sturdy machines, they do require some annual maintenance. Bolts and electrical connections should be checked and tightened. The machines should be checked for corrosion and the guy wires for proper tension. After 10 years, the blades or bearings may need to be replaced, but with proper installation and maintenance, the turbine should last 20 years or more.

Tilt-down towers provide easy maintenance for turbines.

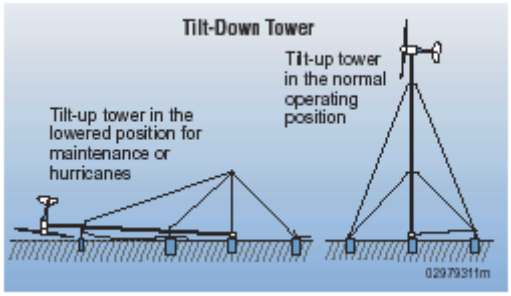


Figure 5 – Tilt-Down Towers

Commissioning

None.

References/Additional Information

Wind turbine manufacturers and dealers should be able to help size and install the system. A credible installer will provide many services, including permitting. State energy offices or local utilities can provide a list of local wind system installers.

More detailed wind resource information, including the *Wind Energy Resource Atlas of the United States,* published by the U.S. Department of Energy can be obtained at the National Wind Technology Center website at: http://www.nrel.gov/wind and the Windpowering America website at http://www.eren.doe.gov/windpoweringamerica. These sites also contain information on educational curriculum for teachers and students.

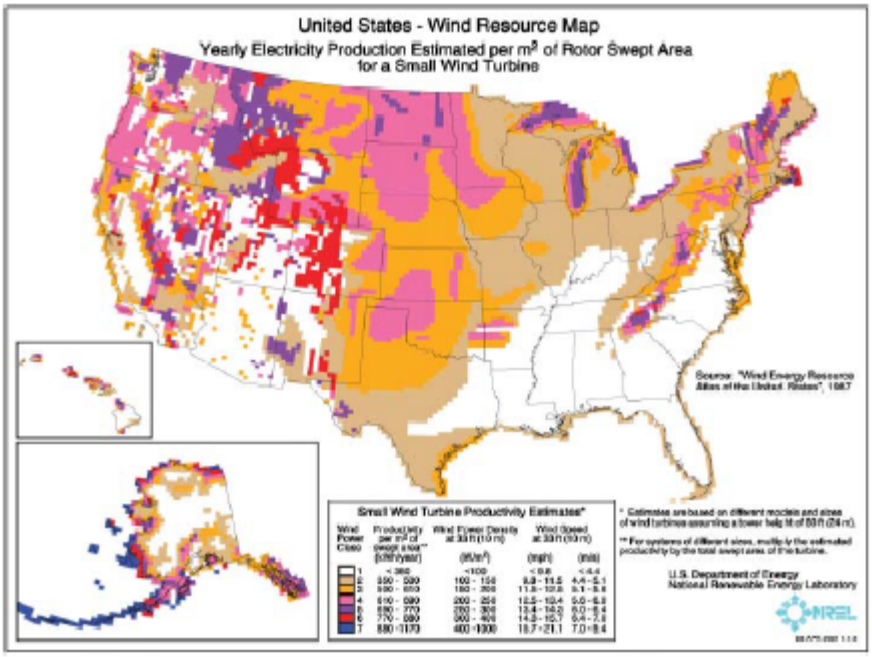


Figure 6 – Wind Resource Map

GUIDELINE RE5: GEOTHERMAL HEAT PUMPS

Recommendation

Consider ground source heat pump (GSHP) systems in locations with considerable heating and/or cooling loads, or when heating fuel is expensive.

Description

GSHP systems are known by many names, including geothermal, earth-coupled, geoexchange, water-coupled, groundwater, ground-coupled, closed-loop, coiled, open- and water-source heat pump systems.

GSHP systems use a refrigeration cycle to extract and transfer heat. A ground source heat pump uses the earth as a source of heat in the winter and as a tool for heat removal from the building space in the summer.

GSHP systems can be grouped into two types: closed-loop and open systems, such as standing wells. The selection of the type of system depends on many factors, including the availability of groundwater and surface water, soil type, energy requirements, size of lot, and the experience of the designer and contractor.

An open-loop system takes water directly from a well, a lake, a stream, or other source, then filters it and passes it directly through the condenser loop of the heat pump system. When in a cooling mode, the water is warmed; and in a heating mode the water is cooled. The heated or cooled water is then released into another well or stream. Open systems are not permitted in most areas.

The closed-loop systems circulate a fluid (usually an antifreeze solution) through a subsurface loop of pipe to a heat pump. The system uses a subsurface loop and a refrigerant loop. The subsurface loop typically consists of polyethylene pipe, which is placed horizontally in a trench or vertically in a bore hole. This thin-walled pipe is a heat exchanger, transferring heat to and from the earth. Fluids inside the pipe circulate to the heat exchanger of an indoor heat pump where they exchange heat with the refrigerant. The refrigerant loop typically consists of copper pipes that contain a refrigerant.

Geothermal heat pump systems reduce peak energy demand and reduce the heat island effect, since waste heat is returned to the ground instead of the outside air. NREL/PIX 07191

Applicable Climates

Applicable Spaces		When to Consider	
Classrooms	■	Programming	□
Library	■	Schematic	■
Multi-Purpose /	■	Design Dev.	□
Gym	■	Contract Docs.	□
Corridors	■	Construction	□
Administration	■	Commissioning	□
Toilets	■	Operation	□
Other	■		

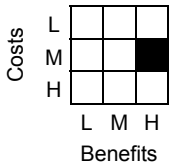
Applicability

These systems are applicable to all interior school spaces, including classrooms and administration facilities. The systems can also be used to heat water for the facility.

Integrated Design Implications

With a good design that includes elements like daylighting, thermal mass, and photovoltaic systems, GSHP systems can help a building become a “net-zero” facility, where all energy needs are supported on-site.

Cost Effectiveness



Large systems tend to have first costs that are similar, or slightly higher, to other high-quality HVAC systems with conventional energy sources. However, when compared to traditional HVAC systems, the energy savings offset the initial higher cost. GSHP systems can have 20% to 50% energy cost savings over conventional systems, with maintenance savings of approximately 30%.

Also, the payback period for the GSHP systems generally falls between 5 to 10 years. Some utilities offer incentives that make the systems more affordable.

Benefits

Energy use and fossil-fuel consumption in GSHP systems is reduced by 40% to 70% compared to systems that use air instead of the Earth to provide temperature control. Water consumption is also reduced since no cooling towers or water-cooled condensers are needed.

The systems reduce peak energy demand and reduce the heat island effect, since waste heat is returned to the ground, not the outside air.

The seasonal energy efficiency ratio (SEER) compares rejected heat to energy consumed to rate cooling efficiency. Higher numbers indicate more efficiency; values greater than eight are preferred. According to the Pennsylvania Ground Source Heat Pump Manual, advanced GSHPs are reaching SEER values of greater than 17.

Waste heat from the system can be used to heat water when the system is cooling the building.

Systems can be designed to use multiple heat pumps with dual-speed controls to improve part-load performance. Teachers can control the temperature in each classroom. Also, facilities staff can shut off unused zones during peak demand periods while allowing critical zones to operate normally without any decreased performance.

Since piping and pumps are buried or enclosed in the building, damage caused by inclement weather, insects, and vandalism can be greatly reduced.

Systems promote better aesthetics since no equipment needs to be placed on rooftops or outside the building envelope. They can be used with sloped roofs and work well with historic buildings, since the equipment is easily hidden from view.

Design Tools

Design tools available for GSHP systems include:

- HEATMAP© Geo, Washington State University Energy Program.
- GchpCalc Design Software for vertical ground-coupled heat pump systems design for commercial and institutional buildings, Version 3.1, Energy Information Services, Tuscaloosa, AL.
- Cycle Analysis Software Tool, National Renewable Energy Laboratory.
- Geocrack2D, Kansas State University.
- GEOCALC, Design Software, developed by Ferris State University, released by Thermal Works Software, Grand Rapids, Michigan.
- Wright Soft Geothermal Heat Pump Software, Lexington, MA.
- GL/GW-Source, Design Software, Kansas Electric Utilities Research Program.
- Geothermal Heat Pump Pipe and Fitting Program, Geothermal Heat Pump Consortium.
- Energy-Smart Choice for Schools, HVAC comparison tool, Geothermal Heat Pump Consortium.
- BuilderGuide, National Renewable Energy Laboratory, Golden, CO.

Design Details

In addition to the details below, it is recommended that the standards established by the International Ground Source Heat Pump Association (IGSHPA) for GSHP systems be followed.

Closed-loop systems

The heat transfer between the loop and the surrounding soil or rock depends on thermal conductivity, which is an important consideration when designing closed-loop systems. Consult a geological expert to evaluate the soil conditions at the site.

Non-toxic, biodegradable circulating fluids, such as food-grade propylene glycol or potassium acetate, are recommended for use in GSHP systems.

Loops should be at least 25 ft from any septic systems.

Configuration of subsurface loops can be almost any shape, including long trenches, parallel shorter trenches, radiating, coiled, and vertical borings.

Backfilling or grouting must be done at the end of the installation process to help provide good thermal contact and to protect the pipes.

Open ground systems

For standing column wells, the largest quantities of water will be produced during the coldest part of the winter, so the system must be sized to accommodate such a volume as well as handle extreme temperatures.

Selecting the appropriate groundwater pump size is important for open systems. The pump must be large enough to overcome the friction in the piping and to supply enough water for the heat pump and other uses. However, the pump must be small enough to be efficient in energy usage.

Subsurface disposal and recycling of water in a standing column well conserves groundwater and limits environmental problems.

At least 100 ft should separate wells from contamination sources such as septic tanks and livestock pens. Landfills should be separated by an even greater distance.

Acceptable drilling methods for wells include rotary, cable tool, and auger. The driller's method should be environmentally sound and prevent the introduction of any contamination.

Casing should be used when necessary to prevent collapse of the hole and the migration of surface pollutants into the drill hole.

Grout should be placed in the entire annular space between the surface casing and the drill hole.

Operation and Maintenance Issues

GSHP systems require little maintenance aside from regular cleanings of heat exchanger coils and strainers that filter the ground water, as well as regular air filter changes. These systems generally have an expected 25- to 30-year life cycle.

If a closed system is properly designed and installed, soil-freezing conditions do not create any system problems. At a soil temperature of 30°F, latent heat moisture in the soil adds considerably to the capacity of the system, allowing for very successful performance in northern climates.

However, aging, poorly installed, or improperly operated GSHP systems have a greater risk for system failure.

Commissioning

Closed loop

Flushing the loops will help to ensure the system is in good operating order. This process consists of debris flushing, air purging, pressure testing, and final charging of the system with antifreeze.

Also, the system "heat of extraction" and/or "heat of rejection" needs to be calculated, which can be done by non-technical staff using a probe thermometer and a probe pressure gauge. By measuring the temperature and pressure across the source heat exchanger and performing some basic calculations, the operating capacity of the system is determined. This capacity value is then compared with the manufacturer's printed capacity value.

References/Additional Information

American Society of Heating, Refrigerating and Air-Conditioning Engineers. *Design of Geothermal Systems for Commercial and Institutional Buildings*. 1997. http://www.ashrae.org/BOOK/bookshop.htm.

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Manheim Township School District, Lancaster, PA.

National Renewable Energy Laboratory's Geothermal Technologies Program. http://www.nrel.gov/geothermal/.

Oak Ridge National Laboratory. "Geothermal Heat Pumps in K-12 Schools: A Case Study of the Lincoln, Nebraska, Schools. http://www.ornl.gov/femp/pdfs/ghpsinschools.pdf.

Paint Lick Elementary School, Lancaster, KY.

West Central Secondary School, Barrett, MN.

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GUIDELINE RE6: PHOTOVOLTAICS

Recommendation

Install photovoltaic (PV) arrays to convert radiant energy from the sun to electricity. PV is ideal for isolated or stand-alone tasks, and can serve as an excellent teaching tool.

Description

PV converts radiant energy from the sun into direct current electricity, without any environmental costs (greenhouse or acid gas emissions) associated with other methods of electricity generation.

PV produces electricity from an abundant, reliable, and clean source. In fact, the amount of solar energy striking the earth is greater than the worldwide energy demand each year.

Photovoltaics are most cost effective in remote locations that are at a distance from an electrical grid, but they have zero environmental costs. NREL/PIX00006

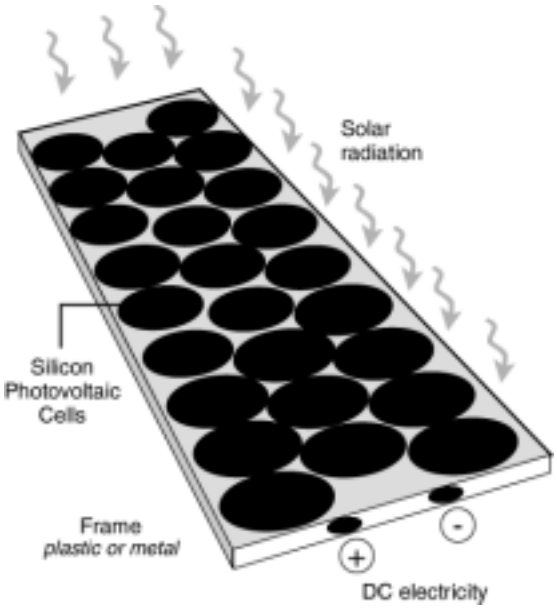


Figure 7 – Photovoltaic Module

Applicable Climates

Applicable Spaces		When to Consider	
Classrooms	☐	Programming	☐
Library	☐	Schematic	☐
Multi-Purpose	☐	Design Dev.	▒
Gym	☐	Contract Docs.	☐
Corridors	☐	Construction	■

The basic component of a PV system is a solar cell. Most solar cells are made of specially treated silicon semiconductor materials. Sunlight striking the cells generates a flow of electrons. This flow is directly proportional to the surface area of the cells and the intensity of the radiation (a cell of area 6.25 in.^{2} will produce 3.5 amperes in bright sunlight). Each solar cell produces approximately 0.5 volts. Higher voltages are obtained by connecting the solar cells in series. Solar cells are laminated; most have a tempered glass cover and a soft plastic backing sheet. This sealing protects the lodged electrical circuits from the outside elements and makes solar cells durable. Modules may be connected in series for higher voltages and in parallel for higher currents. The typical photovoltaic module uses 36 silicon solar cells, connected in series to provide enough voltage to charge a 12-volt battery. However, most schools do not require battery storage and can use grid-tied PV systems. A grid-tied system can provide electricity savings as well as provide additional shading or cooling benefit. Most schools can switch to a net metering rate schedule where utilities give credit for surplus electricity produced by PV systems.

Individual modules may be further combined into panels, sub arrays, and arrays. PV arrays with storage batteries are sources for uninterrupted power supply. Schools requiring emergency backup for communication systems in the case of an earthquake or rolling blackout can use this type of stand-alone system with batteries. Batteries store energy collected during the day for nighttime use. A battery charger controller may be included to avoid overcharging the battery. In addition, all systems include wire, connectors, switches, and electrical protective components. If the load requires alternating current (AC), an inverter is used to convert the direct current (DC) power to AC power. The energy collected during the day is stored for use during the night.

Applicability

- PV is very suitable for remote facilities that are more than one-third of a mile away from the electrical grid.
- PV is ideal for climates where plenty of sunlight is available. PV is also suitable for climates that may experience cloudy days periodically but have sunlight available on most other days. However, the availability of sunlight will influence the size and cost of the system. For example, a very small PV system designed to operate a 72-W load for eight hours/day would require a 120-W PV module in southern Arizona, as compared to a 240-W module in Wisconsin. This difference results from the fact that the daily solar insolation levels in southern Arizona are roughly twice the insolation levels in Wisconsin. Although applicable to a whole range of climates, including Hot and Dry and Cool and Dry, PV is more feasible in climates with high insolation levels. *The Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, published by the National Renewable Energy Laboratory, provides an accurate assessment of available insolation for 239 U.S. locations.
- PV is ideal for providing power to exterior and parking lot lighting, and for school zone flashers.

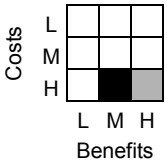
Integrated Design Implications

Building aesthetics. In the early design stage, consider mounting PV on rooftops for best results.

System integration. Since PV is most likely to be used in hybrid systems, the mechanical engineer needs to perform detailed planning in the early design stages.

Cost Effectiveness

PV panels typically cost anywhere between $3.50/W to $6/W for modules and $5/W to $20/W for the system, depending on the size and capacity of the installation (each W of PV array will produce 2 Wh to 6 Wh of energy depending on availability of sunlight). One-hundred-W installations will cost between $10/W to $12/W. Using typical borrowing costs and equipment life, the life-cycle cost of PV-generated energy generally ranges from $0.25/kWh to $1/kWh. The simple payback period for this system is 25 to 30 years.



Benefits

- PV is most cost effective in remote locations that are at a distance from an electrical grid. PV is typically three to six times more expensive than utility-supplied electricity. However, this figure does not take into account the “real” or environmental cost of utility-generated electricity or local rebates.
- PV is environmentally benign during use and does not produce any greenhouse gases or acid gas emissions associated with other methods of generating electricity. It has zero environmental costs.
- PV produces electricity from an abundant and reliable ”fuel” — sunlight. Coupled with storage batteries, PV is capable of supplying uninterrupted power.
- PV is available in modular building blocks; more arrays may be added as the demand for power increases.
- Wear and tear is minimized for PV, since it has no moving parts and produces power silently.
- Although PV may be combined with other power sources in hybrid systems to increase system reliability, PV itself requires no connection to an existing power source or fuel supply.

- For grid-tied PV systems, net metering allows schools to receive utility credits for the surplus electricity generated by PV systems.
- PV can withstand severe weather conditions including snow and ice.
- PV can be combined with other types of electric generators (wind, hydro, and diesel, for example) to charge batteries and provide power on demand.
- By putting power back into the electrical grid and shaving peak loads, PV can have far-reaching implications.

Design Tools

Most PV dealers will work with designers to engineer the best-customized system for the school. System requirements are determined by:

- Estimating the daily load demand.
- Determining the solar resource in the location.
- Calculating the battery size. (Note: A lead-acid battery is not a viable option.)
- Calculating the number of PV modules required.

For first estimates of the array size needed, consider the following variables that effect the production of power in an array:

- Outside air temperature. Use average annual temperatures.
- Amount of sunlight received, or Incident Solar Radiation, which depends on latitude, cloud cover, and angle of the array.
- Efficiency of the photovoltaic cells. This information should be available from the manufacturer and varies between 13% at unfavorable conditions to 30% under lab conditions.

$$P = (Sol_{ins} + \Delta t) \times A \times Eff$$

where,

P = Power generated, W

Sol_{ins} = Incident solar radiation, Wh/ft^2

Δt = Difference between the control and design temperatures (use zero if the design temperature is between 50°F and 60°F; for control temperature, use 50°F for colder weather and 60°F for warm weather)

A = Area of the array, ft^2

Eff = Efficiency of the system (multiply cell efficiency by efficiency of the storage unit)

A Macintosh software program is available for PV design and sizing, wherein designers can specify appliances and AC/DC loads, inverter efficiency, and site location. Based on these variables, the software recommends the number of solar modules and batteries. The software costs about $15.

PVWatts is another PV software program. Researchers at NREL developed PVWatts to allow non-experts to quickly obtain performance estimates for grid-connected PV systems at no cost.

Trnsys, a program developed at the University of Wisconsin, also helps size and locate PV systems. See the References section at the end of this guideline for more information.

Design Details

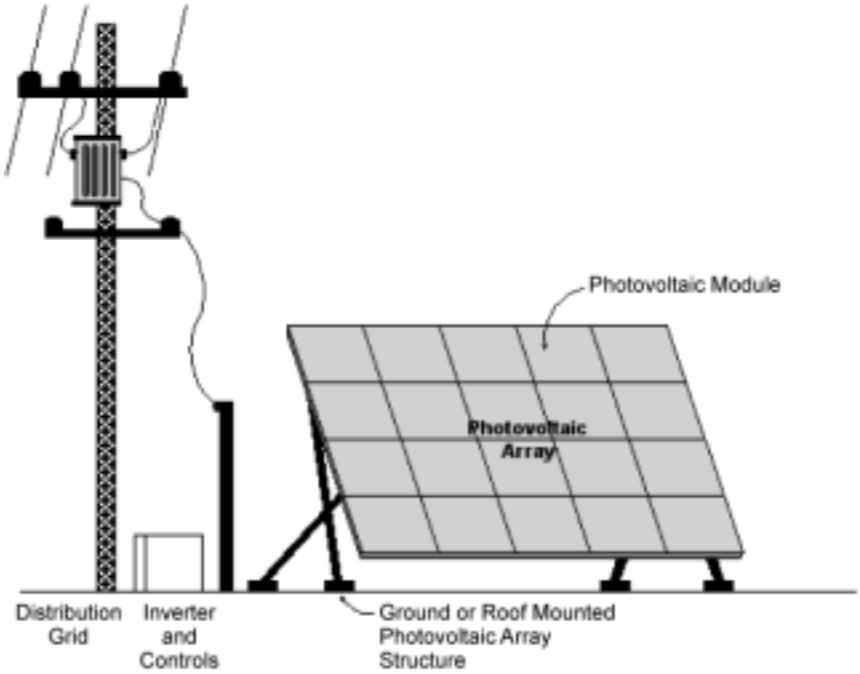


Figure 8 – PV Siting, Elevated

Source: Renewable Energy Project Analysis Software

- The most important aspect of installing PVs is siting. Shading can significantly reduce the output of solar cells. Mount PV arrays at an elevation or on roof tops. Consider both summer and winter sun paths and ensure that trees, neighboring buildings, or other obstructions do not shade any portion of the array between 10:00 AM and 3:00 PM.
- Mount the system for maximum southern exposure. The exact mounting angle will differ from site to site.
- Flat, grassy sites work better than steep, rocky sites.
- Use arrays as building components to economize to building materials and for unobtrusive design solutions. Arrays can be used as a finishing material on structures to create attractive roofs or skylights. Arrays can be used to break up and add interest to a large, uniform roof surface. They can double as shading devices, which not only block the sun but also capture it. Transparent arrays can be used as structural glazing instead of glass. Arrays can also be part of a curtain wall system.

Operation and Maintenance Issues

- PV systems require occasional cleaning to remove dust and debris. In cold, snowy climates, care must be taken to keep the array surface clear of snow.
- Some PV systems contain storage batteries that may require some watering and maintenance similar to that required by batteries in automobiles.
- PV modules are the longest living components of a PV system (20 to 30 years) and will likely outlive the batteries. Batteries may need replacement every six or seven years.
- No PV system is maintenance-free. Schedule regular inspections of the system to ensure that the wiring and contacts are free from corrosion, the modules are clear of debris, and the mounting

equipment has tight fasteners. Roof-integrated systems should be designed to facilitate regular inspection and maintenance.

- Monitor the power output of PV modules, the state-of-charge and electrolyte level of the batteries, and the actual amount of power that building loads use. Writing this information in a notebook helps to track the system's performance and determine whether the system is operating as designed. Monitoring will also help understand the relationships between the system's power production, storage capability, and load requirements.
- Roof-integrated systems should be designed to allow easy removal if roof replacement is required.

Commissioning

Do not compromise on the initial module cost of PV systems. Skimping on first costs results in having to pay later, in terms of higher operation ($/kWh) costs that amount to a much higher figure over the lifespan of a system.

Purchase PV systems from established and knowledgeable dealers who can help determine requirements specific to the site. Look for warranties of 20 years or more. Thoroughly check the rating system that the dealer/manufacturer is using for reliability.

Always engage a professional to design and install PV systems. A preliminary design is a necessity to determine the size, layout, and potential energy output of the PV modules. This design can be performed with computer simulation tools using estimated hourly weather, solar resource, and load data. The time required to prepare the preliminary design and detailed cost estimate typically falls between 30 and 60 hours, with fees ranging from $40/hour to $100/hour. Smaller scale projects with simple structural requirements fall at the low end of this time range. Larger scale projects requiring more difficult structural integration into existing buildings will be at the high end of this time range.

Fully commission panels and the entire array to confirm rated power is achieved.

References/Additional Information

U.S. Department of Energy, Energy Efficiency and Renewable Energy Network.

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Solar Engineering Laboratory, University of Wisconsin-Madison,1500 Engineering Drive, Madison, WI 53706, Phone: (608) 263-1589; Fax: (608) 262-8464, Email: trnsys@sel.me.wisc.edu, Web site: http://sel.me.wisc.edu/trnsys.

Solar Schoolhouse. Developed by the Rahus Institute, this web site contains information on PV systems, a database on schools using solar power, DSA approval checklists, lesson plans, etc. Site is expected to launch in June 2002. Web site: http://www.solarschoolhouse.org/.

Stand-Alone Photovoltaic Systems: Handbook of Recommended Design Practices, Sandia National Laboratory.