NORTH CAROLINA
SOLAR CENTER

SOLAR CENTER INFORMATION

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Do It Yourself Solar Applications:
For Water and Space Heating

When homeowners are looking at ways to reduce energy costs, a common misperception is that solar applications are too expensive to be practical. However, as the cost of energy from fossil fuels increases, Americans can use solar energy to reduce their household energy costs. According to a 1993 government survey of residential energy use, American households spent an average of 4 percent of their yearly income on energy, which can be much higher for some families. For low-income families, this amount can rise to over 10 percent and become the second largest family expense after rent or the mortgage payment.

This factsheet looks at solar additions, retrofits and construction techniques that are low-cost. These systems are described and compared to each other in terms of energy benefits, initial costs and ease of maintenance. Before investing in any of these systems, the most cost-effective home improvement is to caulk, weather strip, increase insulation, and install low-flow shower heads to maximize the energy efficiency of your home. All of the solar systems described below will have the greatest benefit if used in an energy efficient home.

General Guidelines for Solar Systems

All solar systems have three elements: a collector, heat storage and a distribution system. The collector is often a combination of glass or plastic glazing and an absorptive material to capture the sun's energy. The collection surface must be facing south but can be up to 30° from true south and still be effective, depending on the type of system. The collected heat must then be distributed where it can be used or stored for later use. Distribution systems can be ***passive***, where they depend on the natural movement of heated air and water, or they can be ***active***, relying on a mechanical method to move heat, such as a pump or fan. Sometimes a combination of active and passive techniques is used for maximum efficiency. All solar systems must be constructed to minimize heat loss to the outdoors.

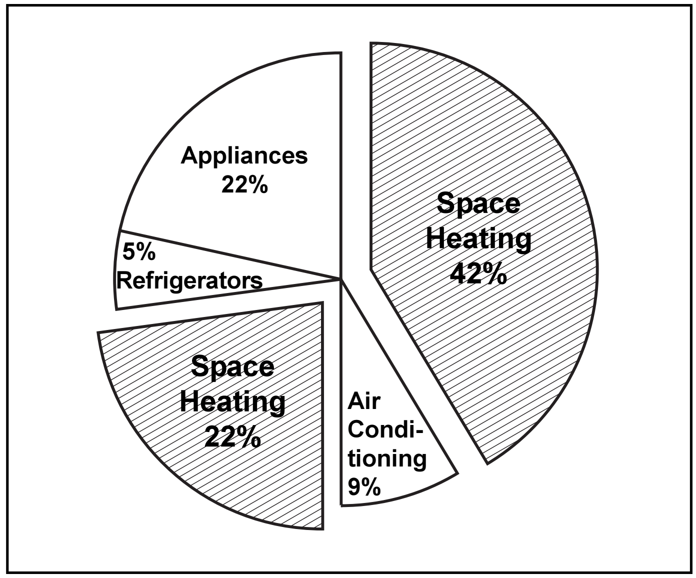

Chart 1: Average annual home energy use in North Carolina.

Solar Space Heating vs. Solar Water Heating

The average North Carolina household uses 64 percent of its total annual home energy for space and water heating at an average cost of $900. Chart 1 illustrates the breakdown of typical home energy use. Of course, energy costs vary widely across the state. For this factsheet, the different systems will be evaluated by energy performance and compared to average energy costs for both electricity and natural gas. Fortunately, using solar energy for space or water heating is relatively inexpensive and there are many easy-to-install options for improving the energy performance of your house.

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Options for solar space heating that are discussed in this factsheet include: 1) ***wall collectors*** (both thermosiphoning and active collectors), 2) ***attached heat-producing greenhouses***, and 3) ***passive solar construction*** (both sun-tempering and direct gain). Since space heating accounts for 42 percent of the total yearly energy usage, the potential savings can be dramatic.

Heating water is another area in which solar energy can contribute greatly to energy savings. The average household uses 22 percent of its total energy for heating water. In smaller houses, this can be as high as 40 percent of the total energy bill. Before installing a solar water heater, the most effective measure you can take is to reduce the hot water you use. For example, low-flow shower heads can reduce the amount of water used for bathing by 50 percent. Any steps taken to reduce hot water consumption will produce significant savings.

Once you have worked to reduce hot water use, the next step is to consider installing a solar hot water heater, several of which are discussed in this factsheet. Two passive water heating systems are described: *1)* ***integral collector storage systems***, and *2)* ***thermosiphoning systems***. These are contrasted with two active systems: *1)* ***drainback systems***, and *2)* ***pressurized glycol systems with PV control and side arm heat exchanger***. The advantages and disadvantages of these systems will be discussed, and they will also be evaluated on the basis of cost vs. performance.

Solar Space Heating

Solar Wall Collectors

A solar wall collector is a simple and low-cost way to capture heat from the sun and bring it into your house. It is a shallow box, mounted on the south side of a house, covered with glass or other glazing material. Inside the box is an absorber, made of a piece of metal painted black, which absorbs sunlight and converts it to heat energy. Air from the house is passed through an air space behind the absorber plate, heated, and returned to the house through vents in the wall.

There are many different plans that are available for inexpensive solar wall collectors. However, certain design features will work best in southern climates such as North Carolina. The use of a single layer of glazing is recommended. Double or triple glazing does not significantly increase efficiency and may lead to overheating of the collector. Some designs call for air to be passed between the glazing and the absorber plate, but this is not recommended because of the difficulty in keeping dust and debris out of the collector. Therefore, a design that passes the air behind the collector plate is recommended. While it is a little less efficient, the ease of maintenance makes the collector superior.

The best site for a wall collector is on a south-facing wall that receives full sunlight in winter (from 9 a.m. to 3 p.m.). It also is advisable to examine the inside of your house to determine where you need heat delivered. Although it is possible to move the solar heat with fans or ductwork, it is most economical to deliver the heat directly to the space where it is desired. Remember when selecting a place on the wall, you must have vent holes for air distribution through to the inside. It may be possible to install the collector in the place of existing windows or doors.

There are two major varieties of wall collectors. The differences between them are based on how the air is distributed to the house. A ***thermosiphoning air panel*** uses natural convection to move heated air into the house. Air expands and becomes less dense as it is heated. Denser cool air enters the collector from the house through the bottom vent, and the warm air rises within the collector and flows into the house through the upper vent.

An ***active solar wall collector*** uses a fan, which moves the air through the system more quickly for better heat gain. The use of a thermostatically controlled blower can increase efficiency by 20 to 50 percent, which can more than offset the cost of electricity to run the blower. It may also be possible to connect the collector to existing ductwork and deliver heat to other parts of the house. When using a blower, a series of baffles should be built that force air to follow a serpentine pattern through the collector, increasing its exposure to the heated absorber plate.

When deciding which type of collector to build, it is important to determine the system size you need for heating the desired space. A wall collector can work well to heat a room, a group of rooms, or even the whole house if sized properly. While a thermosiphoning air panel is cheap, easy to build,

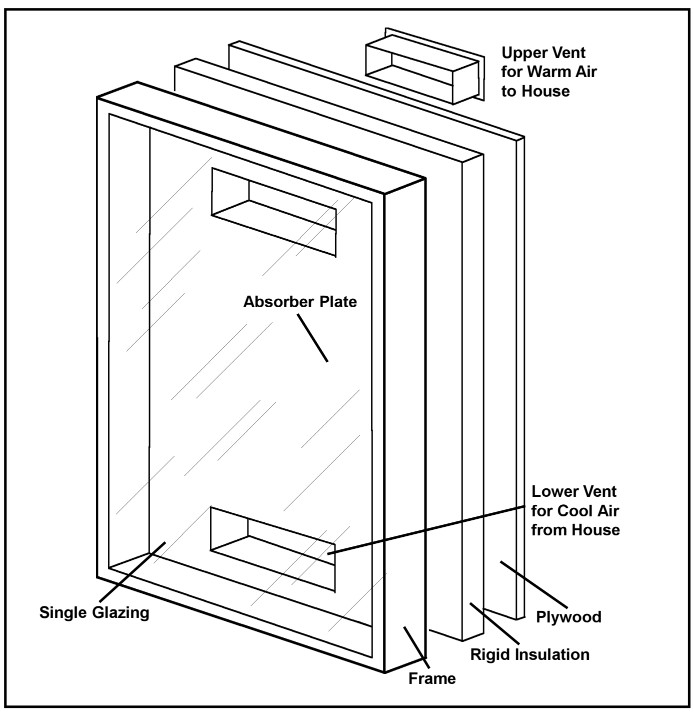

Figure 1: Thermosiphoning air panel.

and requires little technical expertise or maintenance, it may be that a smaller and more efficient active solar wall collector will perform comparably. This may be preferable because of size restrictions or aesthetics. Also, as *Table 1* illustrates, when comparing two 4'x 8' collectors, an active solar wall collector will provide a faster economic return than a thermosiphoning collector. To reduce the possibility of overheating and to maximize efficiency, it is necessary to calculate the total area of south-facing glazing, including that of the collector and existing windows. For a thermosiphoning air panel, this total should be no more than 15 percent of the area to be heated and, for an active solar wall collector, no more than 10 percent.

With the top and bottom vents to the inside open, the wall collector will provide heat during the cold months of winter, fall and spring. In the hot summer, vents to the inside should be closed to keep unwanted heat from circulating into the room. Both types of wall collectors must be protected from overheating during the summer. Temperatures can easily exceed 150° inside the collector, which can result in serious degradation of a wood collector. Steps should be taken to avoid overheating, including covering or shading the collector during non-heating season and building vents into the air flow space of the collector, which can be left open during warmer weather. One or both of these strategies should be used and care must be taken to repeat these procedures every year. It is also important to choose materials for the collector that will not degrade or release toxic gases when exposed to high temperatures. *Table 1* lists maximum operating temperatures of solar glazing. Materials for which this maximum temperature is less that 200°F should not be used in a solar wall collector.

Air leaks are the major hindrance to good collector performance. These are most likely to occur through seams or joints between various materials in your collector. The best practice is to caulk every joint. Silicone caulk is recommended because it adheres well and endures the high collector temperatures. Since caulk is your primary protectant against air leaks and is relatively inexpensive, do not be afraid to use it generously.

If the wall collector moves air with an active fan system, it is important to size the blower correctly for the system. The blower should provide approximately 3 cfm (cubic feet of air per minute) for each square foot of collector glazing area. The fan system should be installed at the lower inlet vent to push air through the collector. Smaller collectors usually use a fan with a plug, which avoids the cost of wiring the collector into the house wiring. Larger fan systems will need to be hard wired to the house electric system and provided with a separate circuit breaker. This should be done by a trained electrician. Larger blowers may be too bulky to fit in the space of the wall and will protrude into the living space. A decorative housing should be built around the blower, both for aesthetic reasons and to protect it from dust.

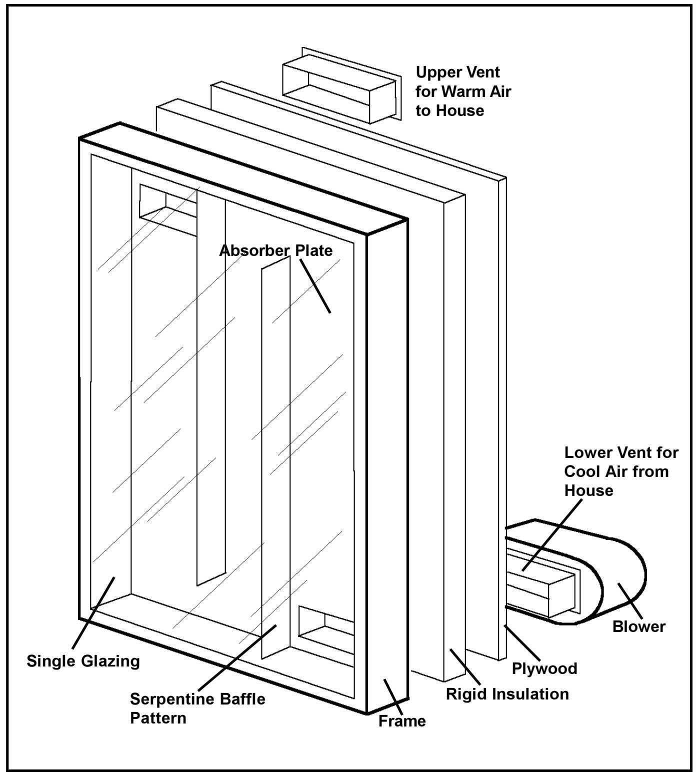

Figure 2: Active solar air panel.

When selecting a thermostat for an active system, it is recommended to install an adjustable one in an accessible location. The thermostat should be located at the collector outlet in a position where it can measure the temperature of the air that is leaving the collector. A good rule of thumb is to set the system shut-off temperature from 5° to 20°F higher than the desired room temperature. If the warm air stream is located away from people, the temperature can be closer to room temperature. Systems that blow onto people should be set higher to avoid discomfort. The turn-on temperature should then be 15° to 20°F higher than the shut-off temperature, but not exceeding 120°F.

Greenhouses

Attached greenhouses can provide three different functions for the homeowner: 1) collecting heat from the sun, 2) providing a space for growing food, or 3) enhancing the living areas in the home. While there are many ways to change the design of the greenhouse to maximize each of these benefits, this factsheet focuses on the attached, heat-producing greenhouse. This type of greenhouse is *not recommended* as a year-round living space, because it can get too hot on sunny days. A sunspace designed as a year-round living space will be a more expensive solar option and will be designed much differently. See the Solar Center factsheet *Sunspace Design Basics* (FS 121) for more information. Also, the attached, heat-producing greenhouse design discussed here is not appropriate for growing large numbers of plants, because of the health-related problems caused by excess moisture getting into the house. However, it is a relatively low-cost way to generate a lot of heat for the house.

Although the word "greenhouse" is used for many types of structures, a solar greenhouse has certain design features that make it unique. It must take advantage of southern solar access, and have double glazing, insulation in the walls that are not glazed, and storage materials for capturing and holding the sun's heat. When designed properly, a solar greenhouse can heat itself and contribute significant heat to the rest of the house. Since greenhouses vary greatly in size, quality and cost, it is wise to decide what level of performance you want from your greenhouse and look realistically at your budget.

It is also important to do some preliminary analysis of the house. For a solar greenhouse to be effective, it must be attached to a south-facing wall that receives winter sun with little obstruction from trees or neighboring buildings. There must be a way for air to flow between the house and greenhouse. You may be able to use existing windows and doors. If not, it will be necessary to make an opening in both the top and bottom of the wall that separates the house from the greenhouse.

The amount of south-facing glazing in the greenhouse should not exceed 30 percent of the square footage of the floor area of the house to be heated. This glazing also should be reduced by three times the area of south-facing windows which are not covered by the greenhouse. The traditional heat-producing greenhouse has a tilted south wall, which

Type of glazing	Cost / Sq. Ft.	Brand Names	Advantages	Disadvantages	Labor	Max. Temp.	Lifespan
Laminated safety glass	$5.00- $6.50	many distributors	•Will not shatter--good for overhead applications •Resists scratching	•Expensive •Heavy •Requires precise framing and installation	High	400°F	Indefinite
Tempered glass	$4.25- $5.50	many distributors	•Transparent •Good resale value •Small expansion and contraction •Resists scratching	•Expensive •Heavy •Requires precise framing and installation •Cannot cut or modify on site	High	400°F	Indefinite
Standard plate glass	$2.50- $4.50	many distributors	•Transparent •Cheaper and easier to work with than tempered glass •Resists scratching	•Easy to break •Requires precise framing and installation	High	400°F	Indefinite
Recycled storm windows or sliding glass door panels	Low to free	many distributors	•Easy to install •Can be hinged for venting •Can be paired for double glazing •Resists scratching	•May need refinishing or reglazing •Not safe for overhead glass •Requires precise framing and installation •Cannot cut or modify on site	Low if in good condition, High if not	400°F	Indefinite
Double-walled extruded polycarbonate panels	$1.50- $2.00	*Twinwall* *Lexan* *Thermoclear*	•Strong •Can cut to odd sizes •UV resistant	•Requires expensive gasket and seal mounts	Moderate	200°-260°F	7-15 yrs
Acrylics	$2.00- $4.00	*Plexiglas* *Lucite* *Cyrolon*	•Transparent or translucent •Easy to install •Good weatherability	•High contraction and expansion •Low temperature applications only	Low	170°F (Not recommended for use in wall collectors)	10-15 yrs
Polycarbonate sheet	$3.25 $1.30- $2.00 for corrugated	*Tuffok* *Lexan*	•Transparent •Hard to break •Lightweight •Easy to install	•Scratches easily •Expensive •Large expansion and contraction •Color change and embrittlement over time	Low	200°-260°F	7-15 yrs
Fiberglass reinforced polyester (FRP)	$1.75- $2.00	*Filon* *Lascolite* *Kalwall* *Sunlite* *Sunwall*	•Easy to install •Good strength	•Not transparent •Large expansion and contraction •Glass fibers protrude with age (can be refinished)	Low	225°F	5-15 yrs
Polycarbonate film	$.85- $1.00	*Lexan film*	•Easy to install •UV resistant •Very strong for films	•Infrared heat transmission •Some hard to install •Can be expensive	Low	200°-260°F	7-15 yrs
Polyethylene film	$.50- $.90	*Many brands*	•Very low cost •Easy to install •Covers large spans •High availability	•Last only 2 to 3 yrs •Easily punctured •Infrared heat transmission	Low	140°F (Not recommended for use in wall collectors)	2-3 yrs for films with good UV protection

Table 1: Comparison of different glazing materials. For greenhouses, double-walled panels and inexpensive films are good low-cost alternatives. For wall collectors, FRP film is good for an exterior glazing and polycarbonate film for an interior glazing.

Storage System	Advantages	Disadvantages	Cost
Water in 55-gallon drums	•Few units needed •Structurally strong •Not likely to freeze •Release heat slowly	•Requires cleaning, rust-proofing and painting •Heavy when filled •May be hard to find	•Low (if recycled)
Water in 5- to 35-gallon metal containers	•Higher surface area increases heat absorption •Easier to handle when full •Compact	•Requires cleaning, rust-proofing and painting •More susceptible to freeze damage than large drums	•Low (if recycled) •Plastic-lined metal water containers designed for civil defense shelters work well
Water in 1/4- to 10-gallon plastic containers	•Higher surface area increases heat absorption •Requires no painting or rust-proofing •Very compact	•Plastic degrades in sunlight, must be replaced •More susceptible to freeze damage than larger containers	•Low (if recycled) •Large plastic pickle barrels work well
Water in large plastic containers designed for heat storage	•Attractive •Variety of sizes available •Require no painting or rust-proofing	•Cannot support more than their own weight •Heavy when full •Expensive	•High
Masonry	•No freezing problems •Doubles as floor or wall •Requires little or no maintenance	•Stores less heat per unit of volume than water	•Moderate to high

Table 2: Advantages and disadvantages of thermal storage materials.

allows the maximum sunlight to enter. In North Carolina, the ideal tilt for this wall is about 55° to 60° from horizontal (or a 3:2 slope). As an alternative to a tilted wall, there are some advantages to building a greenhouse with a vertical south wall; it is easier to install, waterproof and shade, but still gets 85 percent of the available solar heat.

Controlling heat loss is a major aspect of solar greenhouse design. All glazed areas should be composed of an inner and outer layer of plastic, glass or fiberglass with an air space in between. This doubles the resistance of the glazing to heat loss (R-value). Insulated panels can be placed over the glazing at night to increase heat retention. The walls and roof should be well insulated and care should also be taken to prevent air leaks to the outside. Cracks around vents, windows, and doors should be caulked and weather-stripped. The foundation should be insulated with rigid foam on the outside to prevent heat loss from the floor and to allow the floor to serve as part of the heat storage.

The choice of glazing material can dramatically affect the cost and durability of the greenhouse. It is wise to consider whether you want to spend more money for a durable, higher-quality glazing material, or if you would prefer to lower initial costs by using a less expensive plastic film that needs to be replaced every two to three years. An important factor to note is that most of the glazing alternatives perform equally well as heat collectors, so the major differences are in durability and attractiveness. Your decision may be easier if it is possible to find recycled or low cost storm windows or sliding glass door panels. *Table 5* illustrates some of the advantages and disadvantages of many common glazing alternatives.

Heat storage materials store the sun's energy for use at night and on cloudy days. Thermally massive materials have a stabilizing effect on inside temperature, helping to prevent overheating on sunny days in both winter and summer. However, increasing the thermal mass to stabilize temperatures and keep the greenhouse warmer at night will mean less extra heat available to flow into the house. Therefore, it is important to determine the right balance of thermal mass and glazing for the size and function of your greenhouse. A rule of thumb is three square feet of 4-inch thick masonry (one cubic foot) or three gallons of water for each square foot of glazing. This assumes that at least half of the storage material is exposed to sunlight for half of the day.

Brick and concrete masonry are good choices for thermal storage because they serve double duty as the wall or floor. They require little maintenance and have no problems with freezing. Masonry does not store heat as efficiently as water, so the volume of masonry needed is larger than the volume of water needed. Water has a very high heat storage capacity, but can have problems with leakage, corrosion and evaporation. Also, any container for water will reduce available floor space in the greenhouse.

The most common containers for water are recycled 55-gallon drums. These are a convenient height to rest a shelf on and are quite strong. These and any metal containers need to be cleaned thoroughly, treated with a rust inhibitor (one-fourth cup of sodium dichromate or three tablespoons of tri-sodium phosphate per barrel), and well-supported because a full barrel weighs about 450 pounds. Any large container can be used for water storage. Plastic containers are inexpensive but may experience degradation after two or three years in direct sunlight and should be replaced. Large, UV-resistant plastic water storage tubes are available but tend to be expensive. Water stored in clear glass containers captures the sun's heat even more effectively than dark metal containers, but care must be taken to avoid breakage. Table 2 above outlines the differences between various storage materials.

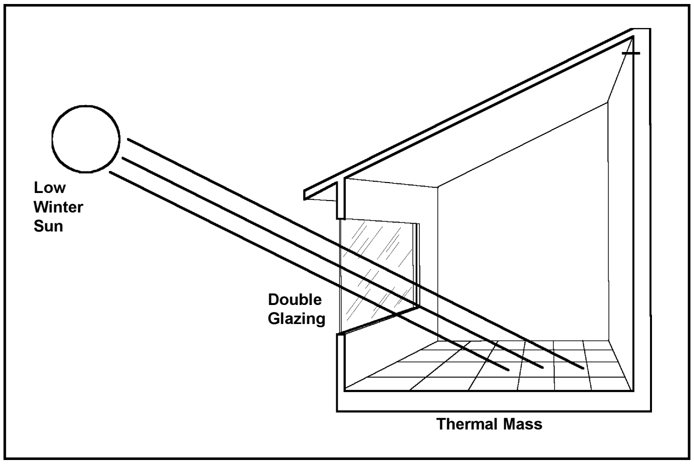

Figure 3: A direct gain system.

A tightly built attached solar greenhouse with good southern exposure can produce temperatures up to 100°F on a sunny winter day. Therefore, it is desirable to provide good ventilation into the house. When relying on natural air flow alone, at least one square foot of vent opening will be required for each 25 square feet of south-facing glazing. There must be vents both near the ceiling of the greenhouse to draw hot air into the house, and near the floor to allow cool air to return, with the high vent being one-third larger than the low vent. It also may be desirable to install a fan in either the high or low vent. An adjustable thermostat with a three to five degree temperature differential can be connected to the fan for automatic operation. The thermostat should be located on the back wall of the greenhouse in the shade. At night, vents in the common wall should be closed to avoid losing heat from the house.

During the summer, overheating can be avoided with the use of proper shading and ventilation. Roof overhangs will effectively shade vertical glass. Solar screens, movable shading or deciduous trees can be used for sloped glazing and east or west facing glass. However, the most reliable strategy for summer cooling is ventilation to the outside. The total square footage of exterior vents should be about one sixth of the floor area of the greenhouse, with both high and low vents. The circulating pattern is best if the vertical distance between the vents is maximized (at least six feet), with the high vent being one-third larger than the low one. It is necessary to check local building codes to see what requirements there are for greenhouses. If the design uses heavy panels of glass, the structure of the frame should be made strong enough to support the weight. For overhead glazing, be sure to use a material resistant to breaking, such as laminated glass or one of the plastic glazing materials. Table 3 gives an estimate of initial cost and expected payback for an attached heat-producing greenhouse in comparison with other systems.

Passive Solar Construction: Sun-tempered and Direct Gain Systems

If you are building a new home, one low-cost, high-payback alternative is to use passive solar construction. Passive solar design does not need to be complicated or expensive to be effective. However, it does require consideration from the preliminary stages of design.

The principle of a ***sun-tempered system*** is to capture sunlight with increased windows on the south side, while reducing heat loss by decreasing windows on the other sides.

Type of space heating system	Cost after 35% tax credit	Yearly energy produced in MBtus	Percentage of total space heating	Energy savings if replacing gas or electric energy	Economic indicators	Advantages	Disadvantages
Thermosiphoning air panel (4'x8')	$180	3	10	$35 for electric $27 for gas	5.1 yrs	•No moving parts •Can add panels as needed	•Less efficient than an active wall collector
Active wall collector (4'x8')	$240	5	17	$57 for electric $45 for gas	4.2 yrs	•Short payback for retrofit space heating •Can add panels as needed	•Large systems need to be professionally wired
Heat-producing attached greenhouse	$1,200	13.7 (or 13,300 Btu per sq. ft.)	50	$145 for electric $110 for gas	8.3 yrs	•Good for growing a few plants	•If sized to produce maximum winter heat, then unusable in summer
Suntempering	$0	11.6 (or 11,260 Btu per sq. ft.)	40	$135 for electric $105 for gas	0 yrs	•Strongly recommended for all new construction	•Cannot be used as a retrofit option •Not as efficient as direct gain
Passive solar direct gain system	$1,800	17.9 (or 17,380 Btu per sq. ft.)	60	$210 for electric $160 for gas	8.6 yrs	•Provides more than half of space heat •Energy savings mean positive cash flow	•Cannot be used as a retrofit option

Table 3: Comparison of solar space heating options. These figures are based on computer analysis of a 1030-square-foot house in Raleigh. Percentage savings based on average space heating requirements of 28.95 MBtu per year. Energy costs are assumed to be 8.5 cents/kWh for electricity and 65 cents/therm for natural gas. Actual space heating performance may vary with location, orientation, construction methods, and usage patterns.

A ***direct gain system*** is similar, but it also includes some sort of thermal mass to store the heat, increasing the efficiency of the system. This thermal mass is almost always a concrete slab floor or masonry walls because those materials serve as a part of the structure of the house. Heat energy from the mass in the floors and walls is released directly to the air in the living space when the inside air temperature is lower than that of the mass. While there are other kinds of passive solar home designs, the sun-tempered and direct gain systems are the simplest and most economical. As with other solar systems, the windows can face within 30°, plus or minus, of true south and still be effective. However, orienting the windows within 15° of true south will ensure maximum winter heat gain and minimum summer heat gain.

It is very important to use the right amount of south-facing glass in a passive solar system. If the windows collect more heat than the floor or walls can absorb, the space can become too warm. A ***sun-tempered system*** should have an area of south-facing glass which is no more than 7 percent of the floor area to be heated. For a ***direct gain system***, the area of south-facing glass can be up to 12 percent of the floor area to be heated. However, every one square foot of south-facing glass between 7 percent and 12 percent must be accompanied by five square feet of 4-inch-thick masonry to store the extra incoming heat. The thermal mass acts as a heat sink, absorbing excess heat from the air and serving to reduce temperature swings. Comfort is further improved if the mass is distributed evenly around the room because there is less chance of localized hot or cold spots.

The south-facing windows also must be adequately shaded during the summer months. Fortunately, since the summer sun is higher than the winter sun, roof overhangs that are sized correctly can provide shade well into summer and allow full sun into the house in the coldest part of winter. The size of the overhang varies according to the latitude of the house being built. In North Carolina, a two-foot overhang will shade between six and seven feet of vertical wall below it. The Solar Center factsheets, *Passive Solar Home Design Checklist* (FS 122) and *Passive Solar Options for North Carolina Homes (FS 102)*, give a more thorough description of the process of sizing roof overhangs as well as general guidelines for passive solar design.

Solar Water Heating

Basic Guidelines

Although there are countless options for solar space heating, the number of variations in solar water heating is even greater. However, the basic components of every solar water heating system perform the same functions. Like other solar systems, the solar water heater has a collector, heat storage, and distribution system, with the added necessity for freeze protection in climates such as North Carolina. The Solar Center factsheets, *Passive and Active Solar Domestic Hot Water Systems (FS104)* and *Troubleshooting Your Solar Hot Water System (FS 119)*, provide more information about solar water heating in general, as well as about some solar hot water systems that are not discussed in this factsheet.

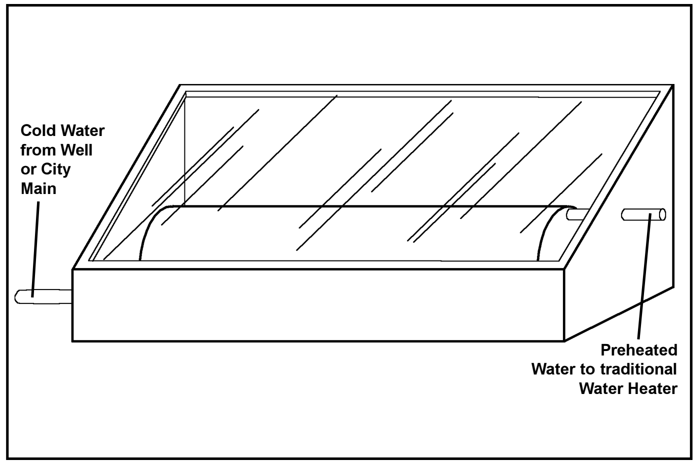

Figure 4: Batch water heaters are good do-it-yourself projects.

This factsheet focuses on solar water heating systems that can be made or purchased and be installed by the highly skilled do-it-yourselfer. For a quality installation with maximum benefit, one must first consider the commercially available and professionally installed system options that are available, which the Solar Center highly recommends over a do-it-yourself system. The most common professionally installed systems in North Carolina are pressurized glycol, drainback, and draindown systems. These professionally installed systems can cost between $2,500 and $4,000 for a family size system and can save the homeowner over half the energy to heat water for over 20 years if the system is well maintained. For a list of professional contractors, visit the Solar Center's website at www.ncsc.ncsu.edu or call 1-800-33 NC SUN.

Although there are several options for the do-it-yourselfer, the four systems described below can be used with traditional electric or gas water heater tanks. Two are passive systems that are cheaper and easier to install, but less efficient: ***integral collector storage (ICS) systems*** (including do-it-yourself batch heaters as well as manufactured units), and ***thermosiphoning systems*** (both direct and indirect). The other two are active systems, which require more complex installation, but are more efficient: ***drainback systems***, and ***pressurized glycol systems with photovoltaic (PV) control and a side arm heat exchanger***. Table 3 compares the initial cost, energy savings and simple payback of these systems.

When installing a system, extreme care must be taken to meet all the local building code requirements and ensure adequate freeze protection. Freezing of pipes or the collector can cause expensive damage to the solar equipment as well as damage to the house. Even if the air temperature is not below freezing, the collector or pipes can radiate heat to the open sky, causing freezing to occur, especially on clear nights.

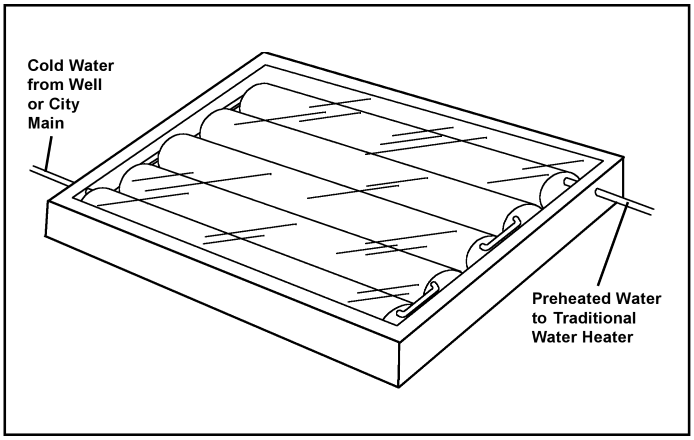

Figure 5: Progressive tube ICS systems are simple, easy to install passive systems.

Like other solar systems, orientation is very important. The solar water heater collectors operate best when facing within 30º of south. Although sloping collectors at angles equal to the local latitude (34° to 47º for North Carolina) will optimize performance, mounting the collector flush to most south facing roofs will cause only a small reduction in performance and will be more aesthetically pleasing. More critical than optimizing collector orientation is to be sure to install the collectors in a location where they will not be significantly shaded at anytime during the six hours around noon throughout the year. The Solar Center factsheet *Siting of Active Solar Collectors and Photovoltaics Modules (FS 112)* gives a more in depth discussion of siting and orienting collectors.

Passive Water Heating Systems: Integral Collector Storage (ICS) Systems

An integral collector storage water heating system has heat storage within the collector. This type of system is one of the simplest methods of heating water. An ICS system works to supplement an existing system by feeding preheated water into the conventional water heater tank whenever the hot water faucet is turned on inside the house. This system can contribute some solar energy to the water even on overcast days. The simplest version of this, the ***batch or breadbox heater***, is a system that places one or more water tanks directly in the collector. The heated water rises to the top of the tank(s), is drawn off from the top, and replaced with cold water at the bottom. While there are commercial versions available, the batch water heater can be easily and inexpensively constructed by a layperson. A ***"progressive tube" system*** is a more complex manufactured collector that allows heated water to rise through a series of tubes, with water being increasingly heated as it moves up through the series.

Because the ICS systems require no pump or moving parts, these can be inexpensive and simple to install. ICS systems can be prone to freezing, especially the piping to and from the collector unit. In most cases, it is best to drain the collectors and piping during the winter months.

Batch water heaters are a good do-it-yourself project. The design consists of a water tank inside an insulated, glazed box that preheats water before it goes to the traditional water heater. On sunny days, the batch water heater can provide water that is hot enough to use directly. Even on overcast days, it can provide some heat to reduce the load on the traditional water heater. It is important to optimize the proportions of glazing and size of the water tank to provide a reasonable volume of hot water, without requiring many hours of solar heating to achieve the desired temperature of 110°-120°F. The tank should hold from 1 to 2.25 gallons of water for every square foot of glazing on the batch heater enclosure. Long, narrow tanks are most effective because they have a larger surface area. Tanks that are mounted vertically are usually most efficient because this encourages stratification of the water, and hot water can easily be drawn off the top of the tank.

Heat loss is a major concern because stored radiation can easily escape to the outside air, especially at night when there is no solar input. The collector box should be tightly constructed with insulation and weatherproofing. To absorb the maximum amount of solar radiation with minimum heat loss, the tank(s) should be covered with a selective coating, such as electroplated black chrome. A double layer of glass also reduces heat loss. At night, movable insulation can be used to keep heat from escaping to the night air. However, a tightly built, double-glazed collector with a selective coating works almost as well and is much easier to maintain.

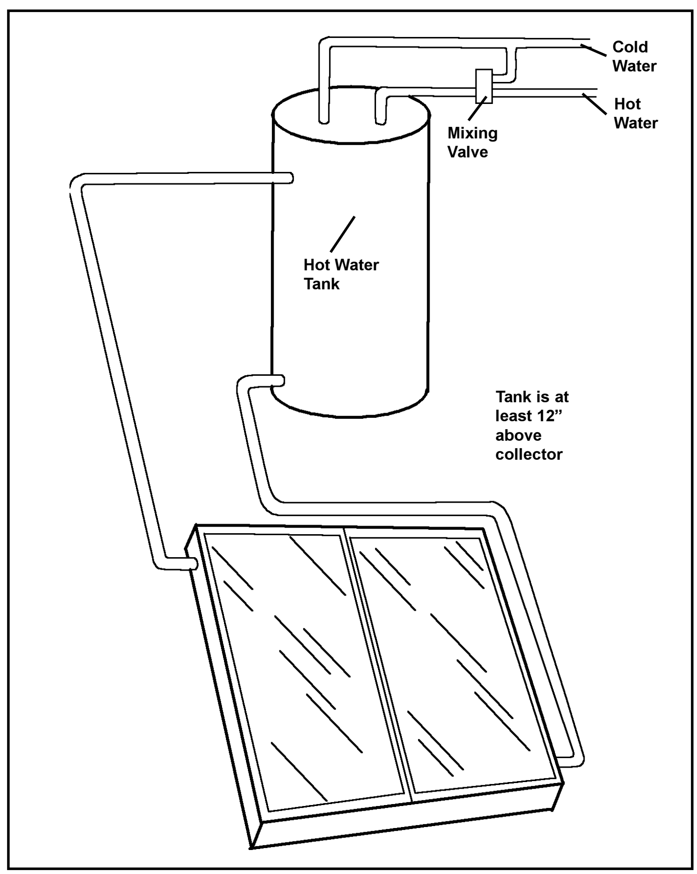

Figure 6: Thermosiphoning direct system.

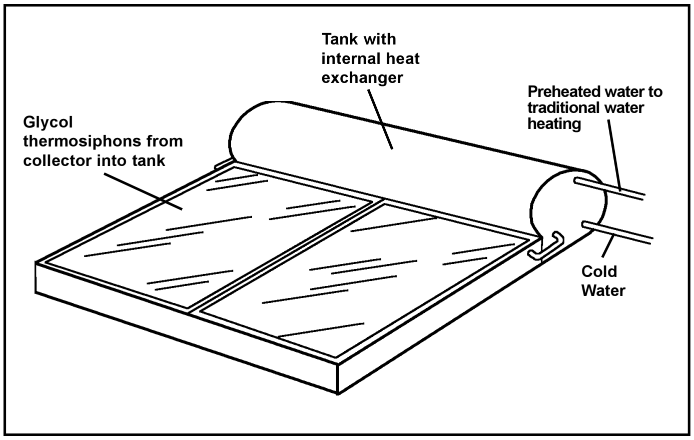

Figure 7: Roof-mounted indirect thermosiphoning system.

Batch water heaters are usually built on the ground, beside the south wall of the house. This makes them accessible if movable insulation is used, or when the system is drained during freezing weather. This and any type of ground-mounted solar water heating collector also can be built within an attached solar greenhouse, which would eliminate the need to drain the system for freeze protection, as long as the greenhouse was properly designed to avoid sustained freezing temperatures.

Progressive tube systems are similar in concept to batch water heaters but generally work more efficiently because of the progression of water through the tubes. They are also arranged in a flat collector, for roof mounting. With a flat collector, more surface area is exposed to solar radiation, and the substantial weight of the system is spread out, so additional structural bracing is not usually required for installation. While this manufactured model is more expensive than a homemade batch water heater, it operates with the same simplicity and lack of maintenance.

Weight is a drawback to this type of collector. When dry, the collector weighs more than 300 pounds, which makes it difficult to hoist onto the roof. Generally, it is recommended to use a crane or truck hoist to reduce the possibility of injury and damage. Once on the roof, installation can be done by a layperson with some knowledge of plumbing skills, which would eliminate the labor costs associated with more complex system installation. Also, once installed, the weight of the full system is distributed over several rafters and does not ordinarily require additional structural support.

Thermosiphoning Systems

Thermosiphoning systems rely on the process of natural convection, but they differ from ICS systems because the storage tank is separate. These systems can be either *direct*, meaning potable water passes through the collector to be heated, or *indirect*, meaning a heat transfer fluid passes through the collector to be heated and then transfers the heat to potable water using a heat exchanger. In both cases of thermosiphoning systems, the storage tank must be located above the collector. In a direct system, when the water in the collector is heated, it becomes less dense and rises to the top of the collector, where it is drawn into the storage tank. Simultaneously, cool water from the bottom of the storage tank flows into the bottom of the collector. In an indirect system, this same principle is used, but the collector contains a non-freezing fluid that rises to a heat exchanger within the storage tank. Once the fluid has released its heat to the water in the tank, it falls back into the collector to be heated again.

The necessity of having the storage tank above the collector can present some logistical challenges. One common solution is to mount the collectors on the ground, so that pipes run directly to the storage tank in the house, which can simply be a traditional electric or gas water heater placed at least one foot higher than the highest point of the collectors. This does put the collectors in greater danger of being damaged. Also, the collectors must be installed in a location where they will receive adequate solar radiation. An advantage of this position for the collectors is that it is easily accessible by the homeowner for cleaning or seasonal draining. In a multi-story house, the collectors could be mounted on the roof of a south-facing single-story porch or greenhouse if the storage tank is placed in an upper-story location.

Another solution is to have a storage tank located on the roof above the collector panel. In these systems, the tank on the roof serves as a preheating tank, and the heated water is drawn into the backup water heater tank as hot water is used

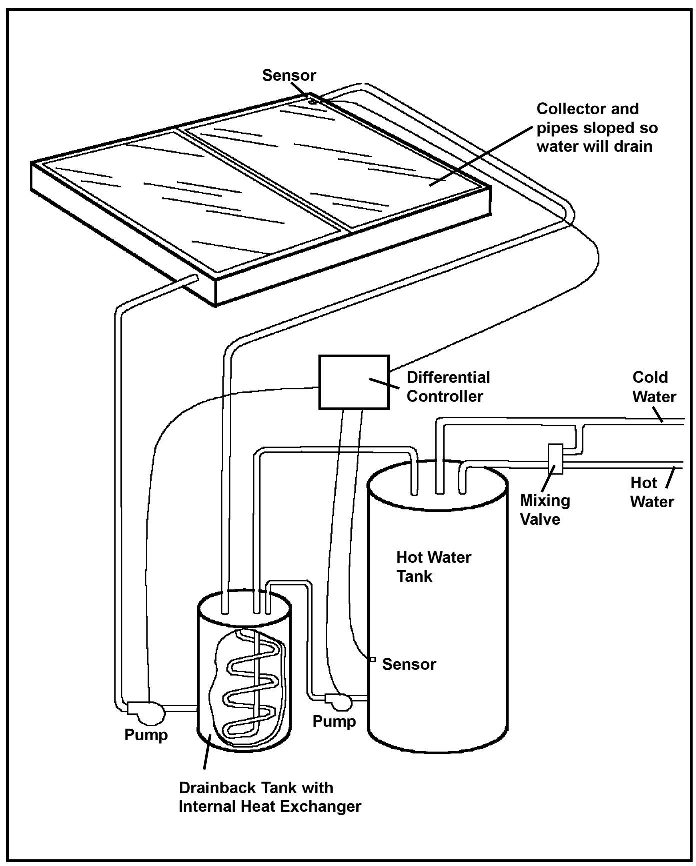

Figure 8: Drainback system.

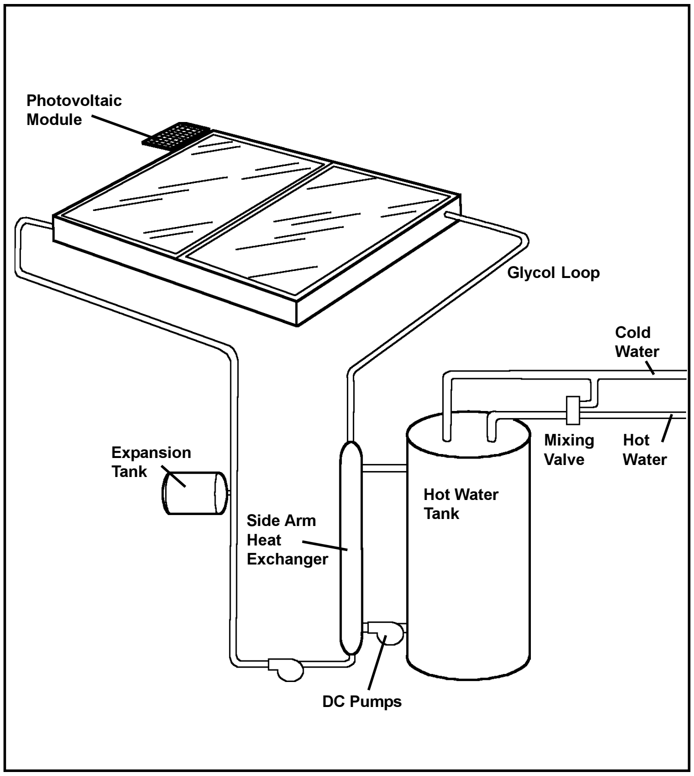

Figure 9: Pressurized glycol system with PV control and side arm heat exchanger.

in the house. Obviously, the weight of the filled roof top tank must be taken into consideration. Some manufactured units have a storage tank connected to the collector panel. These units are either direct or indirect. Direct systems would have to be drained during winter. An indirect system with a well-insulated storage tank and a minimum of exterior piping (also well-insulated) should be very resistant to freezing, but it is highly recommended to drain the potable water during the winter.

Active Water Heating Systems
Drainback Systems

A drainback system is an indirect system in which distilled water is pumped from a small drainback tank through a heat exchanger transferring heat to potable water and then up to the solar collectors to be heated. After passing through the collectors, the water falls back down into the drainback tank, as illustrated in Figure 8. When the collector(s) are not absorbing enough energy to heat the water, a differential controller turns the pump off, so that the distilled water drains back into the drainback tank and air fills the collector(s) and pipes above the tank. The pump must be located below the water level in the drainback tank when operating to prevent damage to the pump.

The collectors must be sloped to ensure proper drainage and the plumbing must be installed so that all pipes will drain completely. Since the collectors and pipes will not be filled with water during non-heating periods, there will not be any freezing damage to the system. During normal operation and when the system is draining, there can be some gurgling noises, which can be an annoyance.

The heat exchanger can either be an external one or an integral one in the storage tank. Integral heat exchangers or large external heat exchangers will not require a pump for the potable water but rely on natural convection. Small external heat exchangers will require a pump to circulate the potable water as shown in Figure 8. The drainback system used for comparison in Table 4 uses a small external heat exchanger and pump on the potable water side.

Glycol Systems with Photovoltaic (PV) Control and Side Arm Heat Exchanger

This system operates by circulating an antifreeze solution through solar collectors and then through a heat exchanger, transferring heat to potable water. The antifreeze solution can be circulated using an AC powered pump with a differential control or with a DC pump powered with a photovoltaic (PV) module as shown in Figure 9. The beauty of a PV driven pump is it does not require electric power from the utility so it can provide water heating even when there are power outages. A PV driven system also does not require a controller as the sun acts as the controller. The pump only operates when there is adequate sunlight. When there is more sunlight, the PV module generates more power and the pump works faster, which coincides with the time when the collectors are capable of capturing more heat.

The most commonly used antifreeze in these types of systems is glycol. Often a propylene glycol solution is used since it is nontoxic, as opposed to ethylene glycol commonly used in the automotive industry. Because glycol fluids expand significantly when heated, an expansion tank is necessary. The expansion tank has a pocket of air and a rubber bladder that can absorb the increased volume of glycol when it is heated.

The heat exchanger can either be an external one or be an integral one in the storage tank. Integral heat exchangers or large external heat exchangers will not require a pump for the potable water but rely on natural convection. Small external heat exchangers will require a pump to circulate the potable water as shown in Figure 9. Heat exchangers should also be double-walled, meaning that there are two layers of copper pipe between the heat transfer fluid and the potable water. While this is not theoretically necessary when using a nontoxic propylene glycol solution, it provides an extra precaution against contamination in the event that toxic heat transfer fluid is used in the future. The glycol systems used for comparison in Table 3 use a large external heat exchanger and a single PV powered pump on the collector loop.

Sizing Your Water Heating System

You should determine the right size for the storage tank and collector, as well as the right ratio between the tank and

Type of water heating system	Cost after 40% tax credit	Yearly energy saved in kWh	Percentage of total water heating	Tax free energy savings if replacing electric	Simple payback	Advantages	Disadvantages
Batch ICS System (Used during non-heating time of the year)	$416	620	15%	$53	7.9	•Low cost, do-it-yourself project	•Freeze protection needed for exterior pipes •Winter draining advised
Progressive Tube ICS System (Collector 32 sq.ft., used during non-heating time of the year)	$1,168	1350	32%	$115	10.2	•Easy to install	•Freeze protection needed for exterior pipes •Winter draininghighly advised
Thermosiphon Direct System (Collector 32 sq.ft., used during non-heating time of the year)	$516	1410	34%	$120	4.3	•Simple system •No moving parts	•Winter draining necessary
Thermosiphon Indirect System (Collector 42 sq.ft.)	$1,248	1430	34%	$122	10.3	•Simple system •Panel is freeze proof	•Freeze protection needed for exterior pipes •Winter draininghighly advised
Drainback System (Collector 32 sq.ft.)	$1,639	2300	55%	$196	8.4	•Excellent freeze protection	•Pump uses some electricity and makes gurgling noise
Pressurized Glycol System w/ PV and Side Arm Heat Exchanger (Collector 32 sq.ft.)	$1,301	2100	50%	$179	7.3	•No electricity used for pumps •Excellent freeze protection	•Requires periodic maintenance
Pressurized Glycol System w/ PV and Side Arm Heat Exchanger (Collector 64 sq.ft.)	$1,723	3000	71%	$255	6.8	•No electricity used for pumps •Excellent freeze protection	•Requires periodic maintenance

Table 4: Comparison of solar water heating system performance in Raleigh. These costs are approximate and do not include professional installation or a back-up water tank (existing). Percentage savings are based on typical hot water use of 63 gallons per day (3-4 people). Energy costs are assumed to be 8.5 cents/kWh for electricity. Annual energy savings can be higher where water usage or energy costs are higher. As with any solar system, performance varies with location, orientation, equipment used, and water use patterns.

collector. While hot water needs vary widely, there are some basic rules of thumb for sizing systems. A 50- or 65-gallon tank is appropriate for one to three people and an 80-gallon tank is adequate for three or four people. For households of four to six, a 120-gallon tank is a good size. The area of the collector should be about 20 square feet for each of the first two family members and 10 square feet for each additional family member. A ratio of 1.5 to 2.5 gallons of storage capacity to 1 square foot of collector will prevent the system from overheating and provide good year round energy gain.

Conclusion

With North Carolina's 35 percent tax credit, the addition of solar water or space heating can be very economically feasible, with simple paybacks as short as four to five years. For a retrofit situation, installing a solar hot water system is usually more cost effective than installing a solar space heating system. In new construction, however, suntempering or direct gain systems will provide substantial energy savings for the life of the house.

Solar systems can have economic benefits which do not show up in a comparison of simple payback. If you are building a new home or refinancing your present home to do major renovations, the energy savings you experience from installing a solar water or space heating system will most likely exceed the difference in your mortgage payment. This results in a ***positive cash flow***. Invest in solar and you will not only save money on your energy bills but you can rest easy knowing that you are using a clean, renewable energy source.

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Organizations

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Take advantage of the state tax credit for solar energy!

North Carolina offers a personal tax credit of 35 percent of the construction, equipment and/or installation costs for renewable energy systems, including passive solar, active solar and photovoltaics. The maximum credit per year per system varies by technology, with any excess credit able to be carried over to the next year for up to five years. The maximum credit is $10,500 per photovoltaic system, $3,500 for passive or active space heating systems, and $1,400 for solar water heating. Maximum credits of $10,500 are also available for wind, biomass, and microhydro applications.

For commercial and industrial installations of renewable energy equipment, the corporate tax credit per year and per system is 35 percent, with a maximum credit of $250,000, with carry-over of excess credit for up to five years. The credit covers all renewable energy technologies, including solar, wind, daylighting, biomass, and microhydro applications.

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