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Active Solar Collectors for Farm Buildings

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Active or planned solar collection systems fall into two broad categories. They are

- The concentrating collectors
- The so-called flat plate collectors.

Concentrating collectors collect the sun's rays from a relatively large area and focus them on a point. If you ever used a magnifying glass to focus the sun's rays to start a fire, you have used a concentrating collector. In the field of solar collection, parabolic (bowl-shaped) mirrors (Figure 1) are generally used instead of a magnifying glass. The effect is the same.

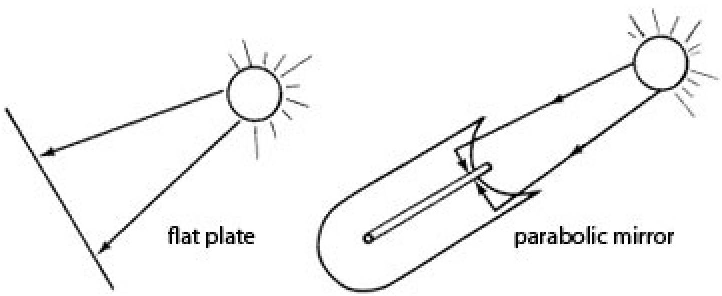

Figure 1
Two general types of solar collectors.

Parabolic mirrors can create extremely high temperatures (over 2,000 degrees). These can be used to generate steam, which can be used directly or to power electrical generators.

Concentrating collectors require precisely constructed surfaces and a tracking device to "follow" the sun across the sky during the day. Because of this, they are relatively expensive and need much maintenance. We generally don't consider them in agriculture because we rarely need the high quality, or high temperature, heat for warming farm buildings.

The flat plate collector requires no tracking device to capture the sun's energy. It absorbs energy directly from the sun as well as indirect or diffuse radiation reflected off nearby buildings, ground, or clouds. Flat plate collectors are capable of providing temperatures up to 150 to 200 degrees Fahrenheit and are relatively simple to build. These factors make the flat plate collector the logical choice for agricultural space heating needs.

There are many different designs for flat plate collectors, but they all have two basic characteristics:

- A flat plate to absorb energy from the sun
- A circulating medium to pick heat up from the plate and transport it to storage or the point of use.

The two media most commonly used for absorbing and transferring the heat are air and water.

Air collectors

An air collector can be as simple as a bare sheet of metal, like a metal roof, painted a dull black to absorb as much energy as possible, with air blown underneath in a duct of some type (Figure 2a).

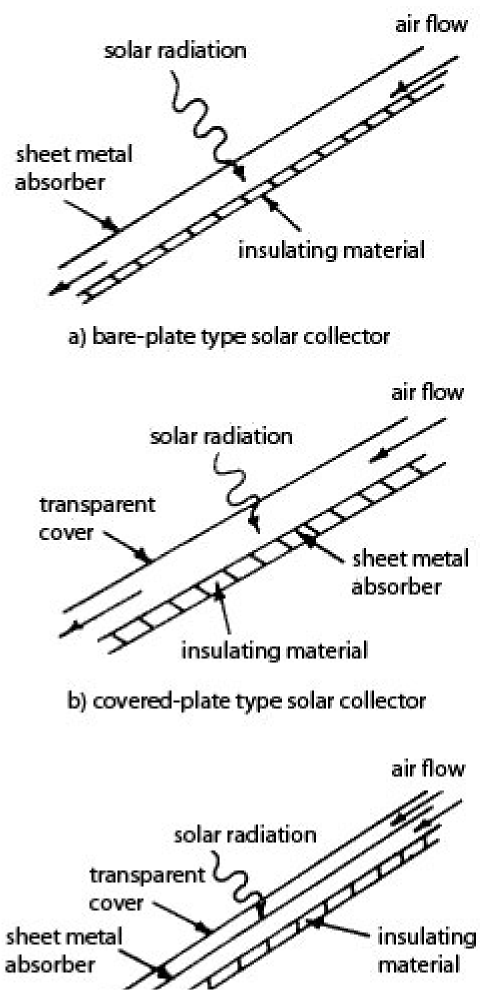

Figure 2
Typical air solar collectors

c) covered suspended-plate type solar collector

A second type, called a covered plate collector (Figure 2b), uses a cover plate of glass, plastic or fiberglass with air circulated between the cover and the absorber plate. The cover acts as a barrier between the wind and absorber and reduces heat loss from the absorber plate to the outside air due to wind blowing across the surface and taking away some of the heat.

A third type, called a covered, suspended plate (Figure 2c), has air circulated both above and below the absorber plate. This provides twice as much surface area for heat transfer from the absorber plate to the air. The top cover reduces convection loss from the wind across the surface, as it does in the covered plate type.

In most collectors, insulation for the back of the collector is necessary to reduce the conduction heat loss through the rear of the collector. A cover (as in 2b or 2c) also reduces radiation heat loss from the front of the collector.

Water collectors

A water collector has the same basic components as an air collector: an absorber plate and a transfer medium. The difference is in how the medium is passed over the absorber.

The basic water collector consists of an absorber plate, generally with water tubes attached, a cover, and insulation behind the absorber plate (Figure 3). Heat from the absorber plate is removed by the water circulating in the tubes. Another type of water collector has no water tubes. The water simply flows down over the absorber in a sheet or in an open channel if the absorber is corrugated. The type with tubes is generally more efficient, but the open channel type generally costs less.

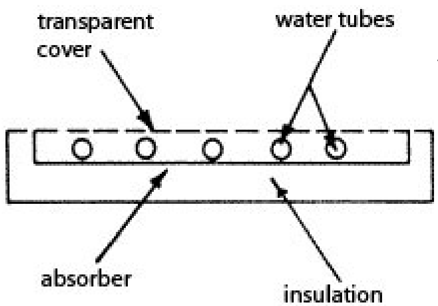

Figure 3
A water solar collector

Freezing in the winter can be a problem with water collectors. You can get around that problem by draining the collector when it is not in use or by adding antifreeze to the water. Other problems with water solar collectors include leaks in the plumbing and metal corrosion.

Solar air heaters are the most common choice for livestock housing because of the water collector's disadvantages and because air collectors do not require a heat exchanger for space heating.

Collector efficiency

The efficiency of a solar collector is defined as the ratio of the amount of useful heat collected to the total amount of solar radiation striking the collector surface during any time period.

One of the problems with flat plate systems designed to date has been the relatively low efficiency compared to other heating systems. Efficiencies are low because of the high losses in collection and transport of solar energy. Heat is lost through the front, sides and back of the collector, by reflection from the cover, and by direct radiation from the heated flat plate. Typical day-long efficiencies for different types of flat plate collectors are presented in Table 1.

Table 1
Collection efficiencies for flat plate collectors

Type	Day-long efficiency
Plastic tube type	25 percent
Bare plate	30 percent
Covered plate	35 percent
Suspended plate	40 percent
2-cover suspended plate	45 percent

Instantaneous efficiencies (collector efficiency at an instant during the day when everything is "right") can be considerably higher than the average day-long efficiency. Remember this when evaluating manufacturer's or designer's claims for a particular type of collector.

Several modifications of the basic collectors will improve efficiency. If the collector will operate at more than 50 degrees difference between the outside air temperature and the circulating medium's temperature, you can increase efficiency by adding an additional cover. Each additional cover reduces convection and radiation loss. But by adding a cover, you increase cost and reflection losses from the glass or other material. An optimum number of covers must be found. Two covers are best for home collectors while one cover is sufficient for livestock housing.

Another way to improve efficiency is by selecting the best absorbing surfaces. An absorber can be treated chemically so that it will absorb most of the radiation striking it without re-radiating much of the absorbed heat out to the surroundings. This treatment is fairly expensive, but it increases efficiency when you need higher temperatures.

Reflectors can also increase the amount of radiation striking the collector face. You may want to make other modifications, including various absorber plate designs that are more efficient: overlapping glass or corrugated, finned, or bonded tube-in-sheet design.

Weigh improvements in efficiency against the increase in cost and maintenance requirements of the system. Usually, the more efficient a collector is, the more costly it is. A less efficient but also less costly collector may prove to be more cost-effective in delivering a given amount of heat. As new design, manufacturing and installation developments occur, the relative cost effectiveness of alternate collectors will undoubtedly change.

Collector construction

Solar collectors are being made of many different materials and in a wide variety of designs. The materials used should be able to resist weather, as a roof or wall must, and the adverse effects of the sun's radiation. Water collectors should resist freezing and corrosion or clogging due to acidity, alkalinity, hardness of water, or the water-antifreeze mixture. Air collectors should be able to resist dust, moisture and breakage of the glazing (transparent cover) due to hail, thermal expansion or other causes. Your goal is a design that will economically produce useful heat with a minimum of repair, maintenance and replacement of parts.

Cover materials

Glass is most often the cover for solar collectors used for space heating of homes or industrial or public buildings. Glass reduces convection losses. It is also a good transmitter of the incoming solar radiation but radiates almost no heat from the absorber surface to the surroundings. This is the so-called "greenhouse" or "heat-trap" effect. This effect explains why the inside of your car gets hot on a warm summer day. The window glass traps the heat in the car.

However, all of the heat is not trapped by glass covers. The glass absorbs some of the heat radiated from the absorber, which causes the glass temperature to rise, and some heat is lost due to the temperature difference between the glass and surroundings.

Both single-strength and double-strength window glass are commonly used. Eighty-seven percent of the incoming solar radiation can pass through the glass; the rest is either reflected or absorbed in the glass.

Where there is high danger of hail or vandals breaking the glass, a one-half inch wire mesh can protect the glass from damage. The screen shades the glass and decreases the effective collector area by about 15 percent, so the total collector area must be increased accordingly.

Plastic films or sheets are also used as cover materials. Only a few types now available can withstand the sun's rays for more than one or two years. With plastics, solar radiation is 92 percent transmittable, but the plastics do not perform as well as a heat trap. They permit up to 30 percent of the long wave radiation to be radiated to the surroundings from the absorber. For livestock buildings or for temporary installations, the plastics do have certain advantages. They are flexible, which helps them withstand wind, hail, etc., and are easier to install and cheaper than glass. They provide a convection barrier in the same way glass does. In some designs with two covers, one layer of glass is used along with a layer of plastic underneath.

Greenhouse-grade fiberglass is most often used as a cover in livestock buildings. It performs in about the same way as glass except somewhat less solar radiation is transmittable: 80 percent vs. 87 percent for glass. It also is less likely to break with expansion or contraction of the collector housing.

Absorber plates

Absorber plates should:

- Absorb as much of the sun's radiant energy as possible
- Lose as little heat as possible to the surroundings
- Transfer the heat retained to a circulating medium.

An absorber plate painted black will absorb more radiant energy than any other plate color. A black surface can absorb about 95 percent of solar radiation. A flat black paint should be used to reduce possible reflection.

Special coatings may reduce the amount of heat radiated from the plate to surroundings. These coatings absorb the same amount of radiant energy as regular black surfaces, but emit or radiate much less.

Materials generally used for collector plates are copper, plywood, aluminum and steel. Copper is the most expensive but also has the highest thermal conductivity. Steel is the least expensive but also has the lowest conductivity of the three. For water heating collectors especially, the conductivity is important. For copper, the water tubes, which are bonded to the absorber plate, may be spaced farther apart than for a material with less conductivity. If the entire area of the absorber is swept by the transfer fluid, the conductivity of the plate is much less important. See Table 2 for more information.

Table 2
Radiant energy absorption and emittance for several surface materials

Material	Solar absorption	Infrared emittance
Flat black paint	0.97 - 0.99	0.97 - 0.99
Concrete and stone, dark	0.65 - 0.80	0.85 - 0.95
Colored paints, brick, light brick, light	0.50 - 0.70	0.85 - 0.95
colored paints, firebrick, clay, glass	0.04 - 0.4	0.90
Aluminum paint (bright)	0.3 - 0.5	0.4 - 0.6
Dull brass, copper, galv. steel, aluminum	0.4 - 0.65	0.2 - 0.3
Selective surfaces		
White paint	0.23 - 0.49	
Copper treated with $NaClO_2$ and NaOH	0.87	0.13
Copper, aluminum, or nickel plate with CuO coating	0.08 - 0.93	0.09 - 0.21

Another important consideration is the bond of the water tubes to the plate. The soldering connection must be good or efficiency will suffer. Such bonding is more of a problem with aluminum. Some plates use bonded tube-in-sheet design, like many refrigerator shelves used to. This provides good thermal contact.

For air collectors, wood and plastics have been used as absorber plates. They generally do not perform quite as efficiently as the metals but are sometimes acceptable since the cost per square foot of collector might be reduced. Surface area of the plate also affects heat transfer in air collectors. Many designs include fins or corrugations to increase this area, thereby increasing heat transfer.

The housing may be a wooden, sheet metal, or fiber-reinforced plastic frame. A wood frame needs moisture-resistant backing. Paint sheet metal frames to prevent rusting.

Secure the cover sheet firmly with weather-resistant gaskets that allow expansion and contraction of the cover yet keep moisture out. This expansion-contraction joint is especially important with glass covers, since glass expands one and one-half times more than steel and two times more than wood. This joint is not nearly as important for plastic or fiberglass covers.

Add insulation to the back and exposed sides of the collector to reduce heat loss in those directions.

Stagnation temperatures, which occur during periods when the solar system does not operate, can approach 300 degrees Fahrenheit in flat plate collectors. For this reason, select insulating materials that can withstand high temperature without deteriorating. Mineral wood materials (fiberglass and rock wool) are most often used for collector insulation.

General design tips

Bare plate collectors:

- Design temperature rise through collector: 10 degrees or less.
- Maximum air velocity in collector: less than 750 feet per minute.
- Minimum air space dimension: 3/4 inch.
- Material acceptable for collector: black or dark colored plastic sheeting, sheet metal.

Covered plate collectors:

- Design temperature rise through collector: 50-75 degrees maximum.
- Maximum air velocity in collector: less than 750 feet per minute.
- Minimum air space dimension: 3/4 inch.
- Absorber materials acceptable: dark colored metal plates, dark wood surfaces.
- Cover materials: low iron content glass, ultraviolet-resistant plastic sheeting, fiberglass-reinforced plastic with tedlar coating.
- Double covers: use when design temperature in collector exceeds 75-80 degrees.
- Insulation for sides and back of collector: R = 13 or greater.

Liquids for heat transfer:

- Protect from freezing if required. Ethylene glycol can be used for freeze protection in closed systems.

- If fluid has boiling point below 300 degrees Fahrenheit, provide pressure relief valve in system.
- Design friction head loss: less than five to six feet.

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Related MU Extension publications

- G1799, Solar-Heated New Technology House http://extension.missouri.edu/publications/DisplayPub.aspx?P=G1799
- G1972, Saving Energy With Passive Systems http://extension.missouri.edu/publications/DisplayPub.aspx?P=G1972
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