Build a Solar Heater for $350

Gary Reysa

Gary Reysa's shop is heated by this inexpensive and easy-to-build solar hot air collector, installed on the building's south face.

After walking into our new workshop one December morning and finding the inside temperature to be a bone-chilling 10°F (-12°C), I decided that it was time for a heating system! Given the rising costs of propane and our environmental concerns about using nonrenewable fossil fuels, a solar solution seemed fitting.

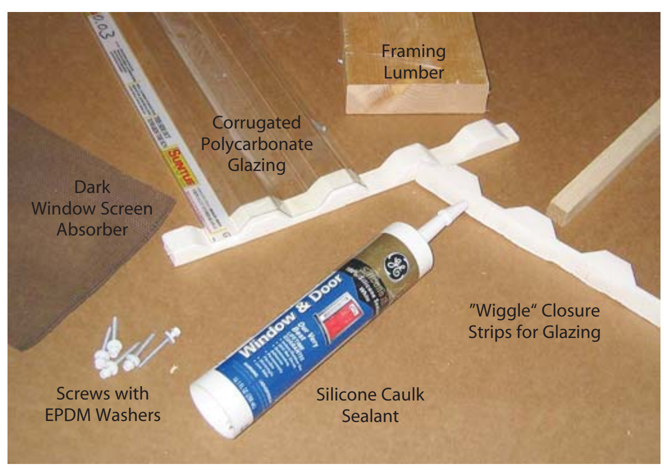
I reviewed many solar collector concepts, and finally decided to install a thermosiphon air collector on the south wall of the building. The concept is elegant and simple. A thermosiphon design uses only the buoyancy of heated air to circulate air through the collector, eliminating the cost, maintenance, and energy consumption of fans, sensors, and controllers commonly used in other collector designs. On a sunny day, in a cold climate like ours here in Bozeman, Montana, this simple system can produce the heat equivalent of burning about 2 gallons (8 l) of propane.

To minimize material use, I integrated the collector within the building's structure. I also tried to make the collector easy to construct using readily available materials. In fact, making this collector should only take one trip to the hardware store and US$350. Set aside two or three days to complete the project.

How It Works

The thermosiphon collector consists of clear, corrugated polycarbonate panels fastened to vertical 2 by 6s. The clear panels, on the building's south face, admit sunlight. An absorber—in this case, two layers of black metal window screen—suspended inside the collector captures the sun's heat energy. The air around the mesh expands and rises as it warms, creating a convection current. Vents located at the top and bottom of the collector allow air to circulate and become heated. Cool air enters the lower vent, is heated by the absorber, and rises through to the upper vents that exit into the building's interior. This circulation of air continues as long as the sun shines on the collector.

Materials used to construct the thermosiphon collector can be found at most lumberyards and hardware stores.



At night, as air in the collector cools to outside temperatures, airflow tries to reverse. Air in the collector sinks through the bottom vents and attempts to pull the warmed air from the building through the top vents. Use of flapper valves on the top vents helps prevent this reverse circulation and keeps the heat inside.

Nuts & Bolts

The collector is 20 feet wide by 8 feet high (6.1 x 2.4 m) for an overall area of 160 square feet (15 m^2). The collector is 6 inches (15 cm) deep. In most cases, make the collector as large as your south wall allows (see sidebar). The top vent and bottom vent areas should each be at least 50 percent of the collector's horizontal cross-sectional area (again, more is better).

The collector frame is constructed from wood, and consists of six vertical members, a bottom sill, and a top sill. The six vertical 2 by 6s divide the collector into five, 4-foot-wide (1.2 m) bays. A 2 by 6 is used for the bottom sill. A 2 by 8 is used for the top sill, which should be sloped at about 10 degrees to shed rain. The collector frame attaches to the building by lag bolts from the inside.

The collector is glazed with clear Suntuf corrugated polycarbonate panels (see Access). These panels have an ultraviolet light-resistant coating on their sun-facing side to extend their life. Each panel is 26 inches (66 cm) wide by 96 inches (244 cm) high. There are ten panels. Pairs of 26-inch-wide panels are joined over a 1- by 1-inch (2.5 x 2.5 cm) vertical wood strip to make the 4-foot-wide panels for each bay. Two, 1- by 1-inch horizontal members provide additional support for the glazing.

The absorber is installed on battens placed about halfway between the glazing and siding. After measuring the thermal performance with one, two, and three layers of window screening, I found that two layers work best.

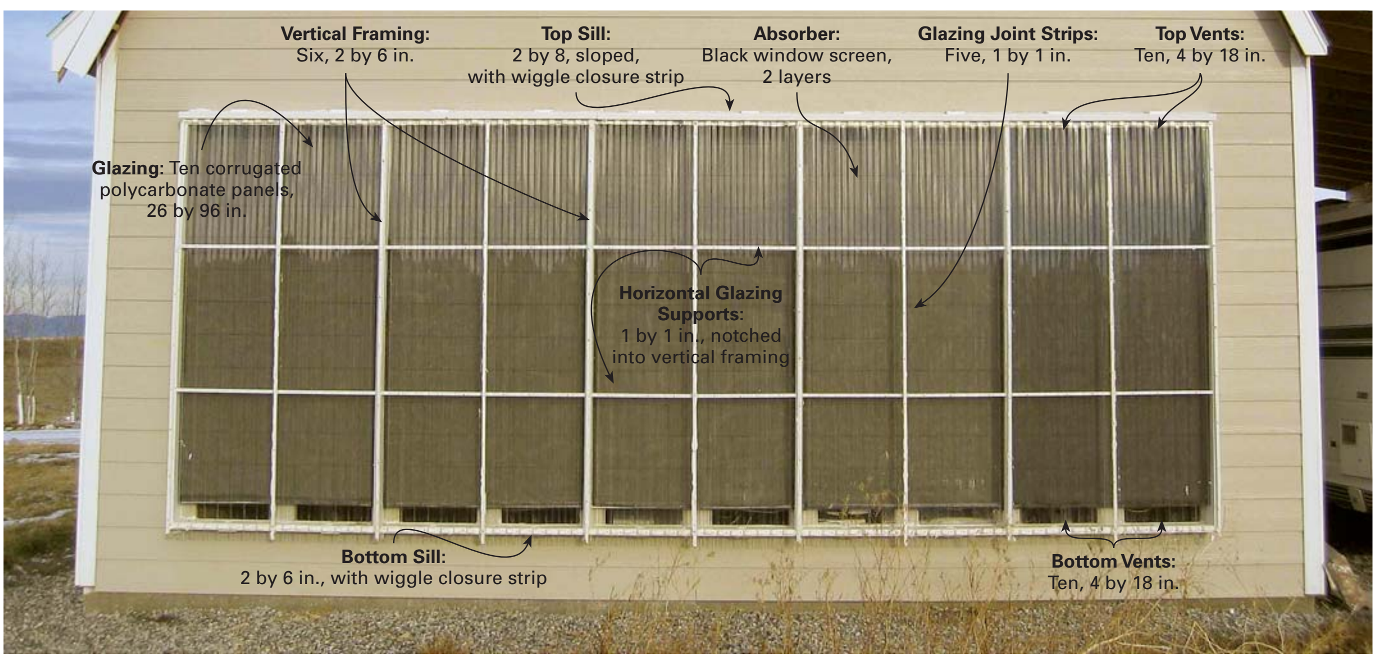
Sizing the Collector

Usually, the bigger the collector, the better. The reasons for this are:

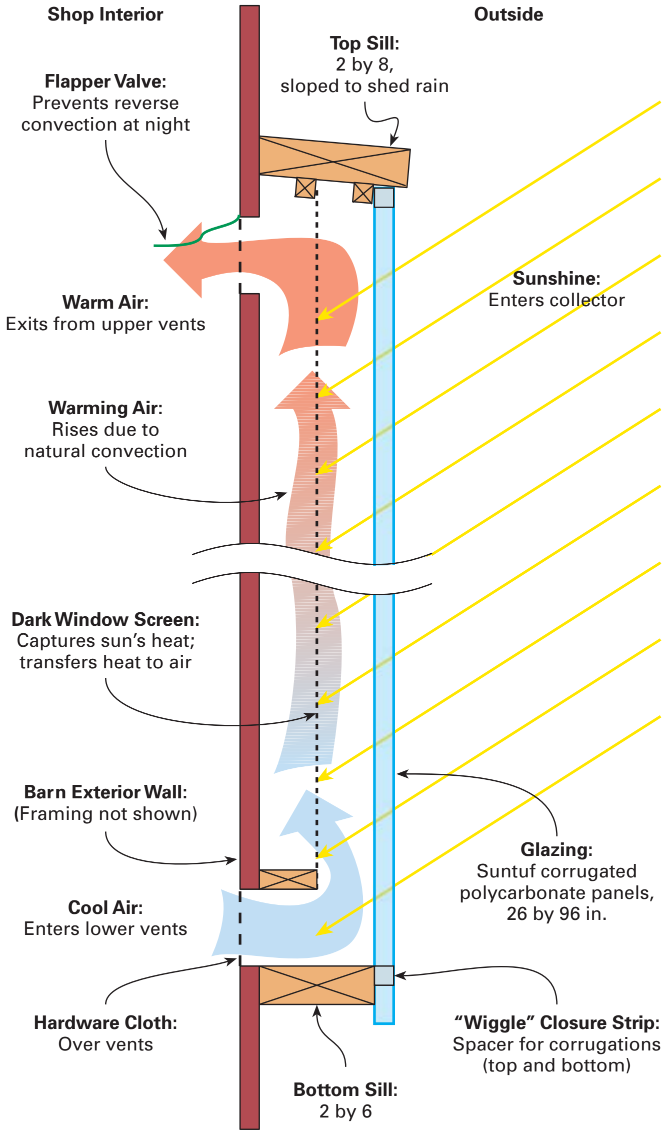
- Most outbuildings suffer high heat losses due to high infiltration rates and a lack of adequate insulation. The heat a large collector generates can be put to good use.
- With this collector design, overheating is usually not a problem. Upper vents can be easily closed off or thermal mass, such as water containers or PVC pipes mounted on the ceiling near collector exit vents, can be incorporated. This has the added benefit of reducing nighttime interior temperature swings.
- More collector area provides some allowance for partly cloudy and thinly overcast days.
- The added time and material cost to build a collector that uses the full wall versus part of the wall is small.

Exceptions to using the full south wall for the collector include locations with mild climates, well-insulated and well-sealed buildings, or buildings that are much longer along their east-west axis than their north-south axis. If the full south wall is not available, using a portion of the wall still pays off.

The simple design of this thermosiphon collector makes for easy construction and installation.



Solar Heater Construction & Function



Each of the ten top vents and ten bottom vents measures 4 by 18 inches (10 x 46 cm). These are simply holes cut into the building. Inside the building, ten flapper valves made from light plastic sheeting prevent backflow through the upper vents at night. Half-inch (1.3 cm) hardware cloth is installed under the plastic sheets to prevent the flappers from being sucked into the vent at night. In the summer, blocking off the top vent openings helps prevent the building's interior from overheating. I just staple a piece of cardboard over each top vent, but you could install hinged vent doors. Shading or covering the panels during the summer might also be effective. In the spring and fall, you can close some vents and leave others open to control the temperature inside.

Construction Tips

It took me about three, eight-hour days to build and install the collector. Follow these suggestions and you may be able to do it in less time!

First, measure your building's south wall to determine what changes you will have to make to the collector design. Pay particular attention to the vertical height available and to stud spacing. Next, lay out the vent locations. They should be offset enough from the wall studs to allow the verticals to be lag-bolted from *inside* the building. Mark the vent locations on the inside and outside of the building to ensure no conflicts exist. After you are certain the layout is correct, take a deep breath, and cut all of the vents.

For the frame, cut the top sill long enough to lap over the end verticals by at least 1 inch (2.5 cm). Bevel the back of the top sill so that it slopes about 10 degrees when fitted against the siding. Next, cut all the verticals, noting that the two end verticals are longer because they extend below the lower sill. The tops of the verticals must be cut to match the slope of the top sill. Gang the verticals together and cut the notches for the two, 1- by 1-inch horizontal glazing supports.

Prime and paint everything. Although you do not need to repaint the siding under the collector, painting it a dark color will improve the collector's efficiency slightly. Keep in mind that a muted version of this color will show through the collector screen, so be sure it meets your aesthetic sensibilities.

After the paint has cured, mount all of the verticals to the siding. Take care to keep everything level, plumb, and straight—this will save you a lot of four-letter words later. I fastened the verticals to the wall sheathing and siding from the inside using lag bolts. If your siding is not strong enough for this, consider mounting the verticals from the outside, using lag screws through the verticals and into the wall studs.

Next, attach the top and bottom sills. Use flashing above the top sill if desired. Then, seal the collector frame with silicone caulk. Mount the battens that will support the

The frame is mounted on the outside wall after the vents are cut.

Horizontal support strips run along the back side of the corrugated panel sections. Vertical strips inside the corrugations tie the panel sections together.

screen absorber. Staple the window screen onto the battens. You can fold the edges of the screen to make it fit in the slightly less than 48-inch (122 cm) bay widths.

Make five 4- by 8-foot (1.2 x 2.4 m) glazing panels by joining pairs of the 26-inch-wide by 8-foot-long corrugated panels. Overlap the panels by one corrugation, and apply a light bead of silicone between the overlapped sheets. Fasten the overlapped corrugations to a 1- by 1-inch wood strip using screws with EPDM washers.

A close view of the lower sill, lower vent, left end's vertical glazing supports, and screen absorber. "Wiggle" closure strips secured to the sill plates help seal the glazing panels.

Hot Air Collector Pros & Cons

Pros:

- Simple (not much to go wrong or watch over)
- Easy to build
- Long life and little maintenance (so far)
- Low initial cost (one-tenth the cost of most commercial panels)
- Good economic return on the initial investment
- Operation produces no greenhouse gases
- Output can be adjusted by opening and closing vents—summer output can be made zero
- Does not impact use of building (I can still pile stuff against the interior wall, but now it's not junk—it's thermal mass)
- Does not require changes to the building structure
- My wife doesn't think it's ugly (or at least not too ugly!)

Cons:

- It hurts a bit to cut holes in the wall (but you get over it)
- The building might require additional thermal mass and insulation to keep inside temperatures from dropping too much at night

Install the horizontal 1- by 1-inch glazing support strips to the collector frame. The surface of the strips should sit flush with the surface of the collector's frame when installed in the notches of the 2 by 6s. Do any cleanup, caulking, or other work you need to do inside the collector frame now! You won't be able to get to the inside after the glazing is applied.

Next, mount the glazing panels. Install the "wiggle" closure strips, which fill in the contours of the corrugations, on the top and bottom sills. Run caulk beads on the first set of verticals and mount the first glazing panel section. (You'll quickly find out how square your frame is.) Fasten the panel sections to the frame using screws with EPDM washers. Install the rest of the sections in the same way. Overlap each new section over the last section by one corrugation, using a bead of caulk in the overlap.

Make the flapper valves for the ten inside top vents. I used two thicknesses of plastic garbage bag for each flapper. Before attaching the flapper, attach $^{1}/_{2}$-inch hardware cloth over each vent. Then, staple the flappers along the top edge of the vent, just above the vent opening.

The author inspects the thin plastic flapper valve that prevents reverse airflow and helps keep heat inside the building.

Performance

On sunny winter days, the collector raises daytime interior temperatures to between 60 and 75°F (16–24°C), providing a comfortable workspace. In my neck of the woods, that's 25 to 35°F (14–19°C) above the outside temperature. The workshop temperature rises about 10°F (6°C) for each hour the sun hits the collector. Warming the workshop from 35 to 65°F (2–18°C) usually takes about three hours. Through the night, and by morning, the building typically cools to about 8 to 15°F (4–8°C) above the outside temperature. On heavily overcast days, the collector does very little heating, but on partly cloudy days or with a thin overcast it does provide some useful heat.

For optimal heating performance, be sure to provide adequate insulation and to control air infiltration. No solar collector will do a good job of heating a workshop that is drafty and uninsulated. With the walls and roof insulated to R-19, my 576-square-foot (54 m^2) workshop has a heat loss of about 190 Btu per hour for each degree Fahrenheit difference. So, if it's 60°F inside and 30°F outside, the heat loss is: (60°F - 30°F) x 190 Btu/hr = 5,700 Btu/hr. During periods of full sun, the collector will gain heat at a rate about three times greater than this.

The graph shows my collector's typical heating performance on a mostly sunny midwinter day. Although outside temperatures never rose above 40°F (4°C), the collector heated the building from 38°F (3°C) to almost 70°F (21°C) during the day. At night, when the collector isn't working, the building's temperature drops quite a bit. In the morning, it takes a few hours of sun to raise the temperature inside the workshop to a comfortable level—a good excuse to sleep in! If you are determined to start work early, more insulation, more thermal mass, or an early morning blast from a backup heater would be in order.

One of the advantages of having a relatively large collector is that once the sun is on the collector, the heat gain rate is several times the heat loss rate. This excess heat raises the temperature of the building's thermal mass fairly quickly. At midday, under typical sunny winter conditions, the collector provides a 50 to 60°F (28–33°C) temperature rise from the lower vent to the upper vent, and an average upper vent velocity from 110 to 120 feet per minute (34–37 m/min). The total gain on a sunny day is about 130,000 Btu (38 KWH). This is equivalent to burning about 2 gallons of propane at 70 percent efficiency.

Heat gain estimates are based on measurements of the collector temperature rise and the vent exit velocity. Combining these with the density of air at temperature and the specific heat of air gives the collector's heat output. I consider these estimates to be approximate, but solid enough to get a good feel for how well the collector works.

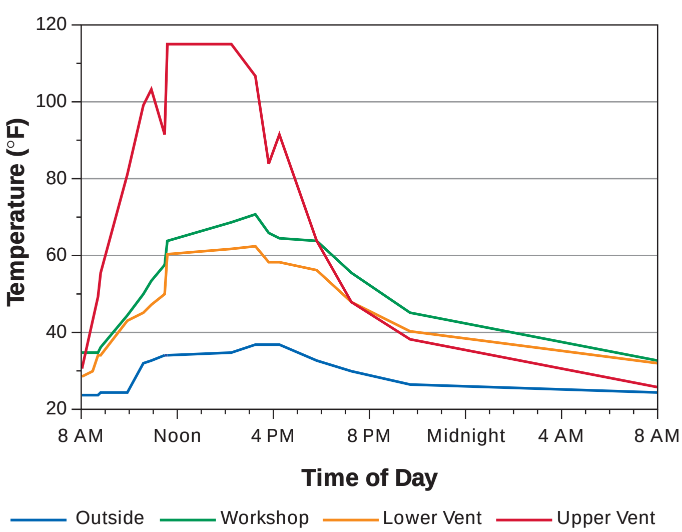
The rate of heat gain was estimated using the following equation:

$$G = A \times V \times D \times (T_u - T_l) \times H$$

Where G is the heat gain rate; A is the vent area; V is the velocity of air through the vent; D is the air density; T_u is air temperature at the upper vent; T_l is the air temperature at the lower vent; and H is the specific heat of air.

I measured the temperatures with several US$2 Taylor thermometers from the hardware store. The vent exit velocity was taken using a Kestrel wind meter. Although this instrumentation might not meet Sandia National Laboratories' standards, I believe it does provide a solid estimate of the collector's performance.

Typical Sunny Winter Day Performance



Economics

Our only alternative would have been to heat the workshop with propane. And, although the cost of a propane heater would have been a bit less than the cost of building the solar collector, the ongoing cost of propane over our five-month heating season would have been US$150 to 200 per year.

Solar Heater Costs

Item	Cost (US$)
10 Suntuf corrugated polycarbonate panels, 2 x 8 ft.	$160
Black window screen, 4 x 70 ft.	70
Lower sill & studs, 2 x 6s, 68 ft.	42
Paint, caulk, lag screws, etc.	25
Upper sill, 2 x 8s, 22 ft.	18
Glazing 1 x 1 in. supports, 130 ft.	15
Suntuf "wiggle" closure strips, 40 ft.	10
200 Screws with EPDM washers	10
Total	$350

The simple payback period of the collector is a couple of years on materials cost. You also can consider it as an investment of US$350 that's reaping the benefits of an inflation-protected, tax-free return of 50 percent per year. If the collector has a life of 20 years, you are in effect paying in advance for all the heating the collector will produce in a lifetime—at fractions of a penny. Because I use the workshop intermittently, I can usually wait for a sunny day to warm the building. I haven't needed to buy a backup heater, which is an additional savings.

Collector Variations

With a bit more investment of time and money, a couple of variations could be made to improve the system's performance. Substituting dual-wall polycarbonate glazing in place of the single sheet of corrugated glazing would help reduce thermal losses through the glazing. This type of glazing, which provides two layers of polycarbonate sheets separated by support webs, also simplifies the glazing installation, since it requires less support and doesn't require sealing the corrugated edges. Buildings in cold climates will benefit the most with this change. Using this glazing may increase the cost of the collector by 50 percent or more.

Keep in mind that temperature fluctuations and solar exposure can reduce the life of the polycarbonate glazing to between ten and twenty years. Substituting tempered glass instead of polycarbonate glazing is another strategy, although it is more expensive and will require some design modifications.

Alternating collector and window panels on the south wall is another design option. This method would allow more light into the space and some direct gain through the windows, without the glare, high losses, and overheating problems that accompany full window walls. You can use the same concept to heat a house or cabin. With some refinement to integrate the vents with the finished wall, the same basic design can be used to provide daytime heat to living spaces.

A word of warning, though—the *National Mechanical Code* prohibits circulating conditioned air of more than 120°F (49°C) in wooden stud spaces. While this may not pose a problem for outbuildings, in buildings used for human habitation, consider constructing the collector with metal, rather than wood studs. As an extra measure of safety, wood areas immediately surrounding exit vents also can be flashed with sheet metal.

In making changes to the collector, keep in mind that a thermosiphon collector must provide low resistance to airflow. Make sure that any changes you make do not violate these guidelines:

- The depth of collector should be at least $^{1}/_{15}$th of the height;
- The absorber must have low resistance to airflow;
- The vent area should be at least 50 percent of the collector's horizontal cross-sectional area; and
- The air path through the collector should be as shown in the diagram on page 32.

Build It!

Building a solar hot air collector into new construction or adding one onto an existing building can be an easy and inexpensive heating solution. Following the simple principles and the plan outlined here will allow you to heat your workshop, barn, or even your home with free heat supplied by the sun. If it works here in Montana, it's bound to work wherever you are. Here's to your warmth and comfort.

Access

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Usenet newsgroup • http://groups-beta.google.com/group/alt.solar.thermal

Thanks to the crew at the Usenet newsgroup and Nick Pine in particular for making many helpful suggestions.