the gaia project
realistic environmentalism

Project Guide: Solar Thermal Panel Construction

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Solar Thermal Panel Construction

A guide to delivering a solar thermal panel construction and testing project in your classroom

The Gaia Project is a charitable organization dedicated to providing project based learning opportunities in the areas of energy, environment and sustainable engineering.

We develop projects, provide professional development, technical support and ongoing project support for teachers and students. Our projects aim to incorporate three key principles, which symbolise our focus on realistic environmentalism.

1. **Data Informed Decisions** – We want students to be able to explain why, and quantify the effect of each decision they made along the way to their final solution.
2. **Economic Assessments** – We expect students to be able to assess the cost effectiveness of their solutions, and be able to optimize their projects with limited budgets.
3. **Environmental Impact and Lifecycle Assessments** – We need students to take a holistic view to their projects. This means looking at their projects from cradle to grave, as opposed to just examining the use phase, and acknowledging that greenhouse gas reduction is not the only environmental issue at stake.

For more information, please visit www.thegaiaproject.ca

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Solar Thermal Panel Construction

Solar thermal panels are based on the idea that you can convert the light energy from the sun into thermal energy to heat air or water. They are relatively easy and cheap to build, and you can experiment with multiple factors to find ways to improve the thermal efficiency of your panels.

This document will cover how to build a solar thermal panel and variables that can be manipulated to experimentally determine the most effective heating.

Construction Principles

Energy from the sun is received largely in the form of light. When this light energy strikes the earth's surface it is either reflected back into the atmosphere, or absorbed and converted largely into heat. This heat is then re-radiated back from the Earth's surface and back into the atmosphere.

Solar thermal panels take advantage of this process by using the light to heat up something that we can use, and that would otherwise have to be heated using electricity or fossil fuels.

Solar thermal heating is incredibly simple conceptually, and could be as simple as leaving a bucket of water outside to heat up in the sun; however, there are several variables we can change to improve the amount of energy that we obtain, and to make the collection of that energy a little more user friendly.

Discussing with your class

Ask students where they've seen solar panels—were they solar thermal or photovoltaic panels? What is the difference?

Have students sketch diagrams for constructing a solar thermal panel to heat air for their house and identify what they think might be important variables. How would this design differ for water? Which would they pick for their house—a solar heater for air or water?

Basic Components

Collector Tube

The collector tube is responsible for holding and circulating the water/air in the solar thermal panel.

Water

Any type of piping material capable of holding water can be used for this, whether it is hose pipe, flexible PVC pipe, PVC pipe, ABS pipe or metal piping. An interesting use of recycled material is to use the radiator coils from the back of a discarded refrigerator. It`s important that these be safely and professionally drained of refrigerant prior to using them, but they can probably be obtained from your local Solid Waste Commission.

Air

Any type of channel through which air can be directed (and sealed) is useful. Air requires much larger diameter piping to be used compared with water. Aside from the materials listed for water, dryer vent and ducting can be used. An interesting use of recycled material here would be to use pop cans. The tops and bottoms can be cut open, and the cans sealed end-to-end with a small piece of flexible ducting used for snaking the air channel.

Frame

This can easily be constructed from wood – even scrap wood cast off from other projects. All that is needed is a box deep enough to accept the heat collector piping, and wide enough to accept the piping. The front will be left open for either a glass or Plexiglas covering.

Fasteners / Sealers

Fasteners will be required construct your frame, and to fasten your collector tube to your frame. Sealant may be required to seal any joins in your connector tube, and also when adding a transparent pane to the front of your collector to seal the frame of the solar thermal panel. Duct tape works well!

Hot / Cold Water Reservoirs

Hot and cold water reservoirs will be required. Depending on how flow is created you may or may not want to make these the same reservoir.

Layout

The layout of the solar thermal panel can take many forms, however two primary layouts exist below in Figures 1 and 2. Figure 1 indicates a snaking arrangement where the collector is snaked back and forth throughout the frame.

Figure 1: Snaking Layout

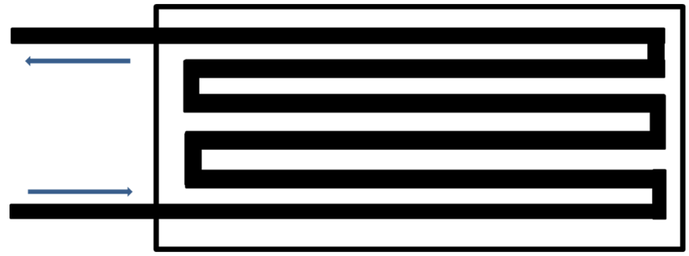
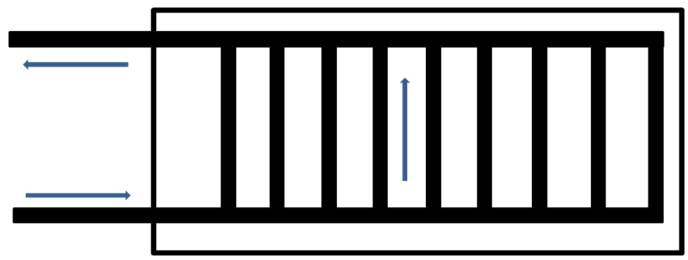


Figure [2] on the other hand shows a parallel configuration.

Figure 2: Parallel Layout



Both layouts will allow for roughly equivalent residence time inside the collector, with the snaking layout providing a longer travelling path but faster moving water, and the parallel layout providing a slower travelling path and slower moving water.

Creating Flow

To make solar thermal panels practical, there needs to be flowing water/air. This can be achieved through the use of a pump (water), or a fan (air), however, there are simpler, lower cost alternatives.

Gravity Flow (Water Only)

Gravity flow requires that the cold water reservoir and the hot water reservoir be separate.

By locating the cold water reservoir at a greater elevation than the hot water reservoir, water will flow from the cold reservoir to the hot reservoir due to gravity. Due to the friction losses inside the pipe, the cold water reservoir may need to be significantly above the hot water reservoir. The longer and thinner the piping, the greater the friction losses, and the greater the height difference will need to be to overcome them.

Figures 1 and 2 show the inlet for the collector at the bottom and the outlet at the top. This should ideally be reversed for gravity flow (although with enough height difference between your cold and hot reservoir, it will flow regardless – after the system has been primed).

Thermal Flow

Due to the fact that hot air and water have a lower density than their cold counterparts, hot air and water will naturally rise above colder air and water due to a process called convection.

The can be taken advantage of in a solar thermal panel. Using a combined hot/cold water reservoir located above the collector, colder water can be taken out of the bottom of the reservoir, enter the bottom of the collector, leave the top of the collector and be returned to the reservoir (above the cold water outlet).

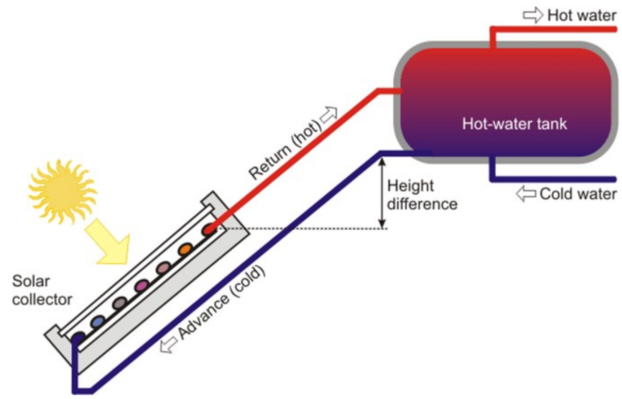
This layout is indicated in Figure 3.

If using an old refrigerator coil, the inlet and outlet may be next to each other. This setup will not allow for thermal flow, and so either a cut will need to be made in the refrigerator coil, or gravity flow will need to be implemented.

Minimizing Resistance

The forces driving thermal flow can be weak (especially with air), so it is important to minimize resistance in the design. Sharp bends should be avoided, as well as restrictions in the collector. Larger cross sectional collectors will also help.

Figure 3: Thermal Flow Layout



While this is especially important with thermal flow, it is an important consideration with all designs. Friction in the collector will result in energy losses.

Priming the System

It is important to prime the system before you start collecting data in order for the solar thermal panel to work effectively. For a water panel, this means removing air bubbles from your system. This is especially true around any corners in the pipe where air bubbles may completely block the flow of water (especially without a pump).

If you are using additives to your water (such as antifreeze) ensure that you prime the system before adding the additives.

Variables

While there are many designs for solar thermal panels available, and many with the same features, it often goes unexplained why each of these features are incorporated. This very simple project can be made quite rigorous by incorporating these design features as variables. This allows the students to test and quantify the impact of each of the different changes, and to make decision as to whether certain changes are worth making considering cost, time, environmental impact, and performance.

When changing variables, it is important to only change one variable at a time in order to be sure of its impact. When changing multiple variables at the same time, it can be difficult to attribute any change in performance to a specific variable.

Transparent Covering

As discussed previously, light travels from the sun, is absorbed the earth, and re-radiated as heat. The purpose of a transparent covering is to make the solar thermal panel behave as a greenhouse. By using a covering that allows light to easily pass through, but resists heat flow through it, it is possible to greatly increase the temperature inside of the solar thermal panel compared to outside.

Any transparent covering will accomplish this – but the goal is to make the **R-value** (resistance to heat flow through the material) as high as possible while still allowing as much light to pass through as possible. Possible materials include:

- Saran Wrap
- Plexiglas
- Glass
- Double panes
- Coated glass

Colour

We see different colours because different surfaces absorb and reflect different quantities of light. White surfaces reflect virtually the entire visible light spectrum, while black surfaces absorb that same light spectrum. Since absorption of light results in the heating up of objects, we are interested in absorbing as much light as possible.

Changing the colour of the collector tube and other components of the solar thermal panel will have an impact on the amount of light energy absorbed and converted into heat in the water or air. Experimenting with several different colours and quantifying the results is valuable to empirically determine the impact of colour variants on heat absorption. This can be achieved through paint, or through different material use

The location of different colours will also play an impact. For example, if painting clear plastic tubing is being considered, it might be of interest to try:

- one where the whole tube is painted black, which would effectively block the light and heat up the tube

- one where only the back of the tube is painted black, allowing light to pass through (and be absorbed by) the tube and into the water/air, before being absorbed by the black paint on the back of the tube

Backing Material

The goal of the solar thermal panel is to heat up the desired medium (water, or air) to the highest temperature possible. We are not interested in heating up the frame of the solar thermal panel unless that results in a direct increase in temperature of the water and/or air.

This means that having a backing material that absorbs light may not be the most effective design. You could try changing the colour of the backing material from black to white (and anywhere in between), but you could also include some reflective materials, aimed as reflecting the light to pass it through the collector tubes a second time.

Consider using:

- Tin foil
- Mirror

as a backing material in place of painted wood and quantifying the impact of these changes.

Collector Material

As mentioned previously, the collector can be made out of any material suitable for carrying flowing water. The material itself will have a big impact on the amount of energy that the water/air can absorb from the sun and convert into heat.

The thickness of the material will also have a major impact on the efficiency of the solar thermal panel; however, this is a little harder to vary because most tubing materials are only commonly available in one thickness at a given diameter.

Collector Diameters

The diameter of the collector used may also have an impact on the amount of efficiency of your solar thermal panel. Larger diameter pipes will allow more water/air to flow, or the same amount of water to flow at a lower speed.

Collector Length

The length of the collector inside the solar thermal panel is another variable that can be altered for measurement. A longer collector should allow the water/air to spend more time inside of the solar thermal panel picking up heat.

Flow Rate

Altering the flow rate of water/air through the collector is another variable that can be tested. A simple way to achieve this is provide a blockage in one end of the collector, effectively reducing the flow rate without varying any of the other main variables (such as collector diameter).

Insulation

Insulating the solar thermal panel, hot water/ air pipes leaving the panel and reservoirs can be effective ways to increase the amount of energy retained by the water/air.

Orientation

The direction and angle at which the panel is tilted will affect the amount of solar radiation (light energy) that reaches the panel, and thus affect its performance.

You can calculate the exact position of the sun in the sky for any given time in the past, present or future using an online calculator available at http://www.esrl.noaa.gov/gmd/grad/solcalc/ or by searching for NOAA calculator. This will allow you to correctly configure any tilting hardware in advance of testing.

Time

As the Earth rotates, the position of the Sun in the sky changes. The time of day greatly affects the distance that the sun's light must travel through our atmosphere. This has a large impact on the intensity of the sun throughout the day, and will thus impact the efficiency of any solar thermal panel.

Measuring Performance

Temperature

Temperature can be easily measured using a thermometer or available probes. There are a variety of places where temperature measurements can be taken, including:

- Cold water/air temperature entering the panel (essential for determining the power and energy)
- Hot water/air temperature leaving the panel (essential for determining the power and energy)
- Common water reservoir temperature (if the hot water leaving the panel is dumped into a common reservoir)
- Air temperature inside the solar thermal panel frame
- Outdoor air temperature
- Collector surface temperature at various points

Flow Rate

The flow rate of water/air through the panel can be measured relatively easily.

For measuring water flow rate, simply take a bucket with a known volume, and record the time taken to fill the bucket. Flow rate can be calculated by dividing the volume (in Litres), by the time taken to fill (in seconds).

For air, we take a plastic bag and record the time taken to fill the plastic bag. The volume of that bag can then be estimated by taking measurements.

Energy

The amount of light energy absorbed and converted into heat by the solar thermal panel can be calculated using the following formula:

$$Energy\ (Joules) = V\rho c\Delta T$$

where

- V is the volume of water/air in Litres
- ρ is the density of water/air in kg/Litre
- c is the specific heat capacity of water/air
- ΔT is the difference in temperature (°C) between the water entering the solar thermal panel, and the water leaving the solar thermal panel

For reference, at standard conditions:

- Density of water = 1 kg/Litre
- Density of air = 0.00123 kg/Litre
- Specific Heat Capacity of Water = 4186 Joules/kg-°C
- Specific Heat Capacity of Air = 1003 Joules/kg-°C

So for example, if a solar thermal panel increased the temperature of 10 Litres of water from 20°C to 45°C, the panel would have converted:

$$Energy = V\rho c\Delta T = 10L\left(\frac{1kg}{L}\right)\left(\frac{4186J}{kg\cdot{}^{\circ}C}\right) * (45^{\circ}C - 20^{\circ}C) = 1{,}046{,}500\ J = 1.05MJ$$

Power

Power is the rate at which the energy is converted to heat, so we can convert the average power rating of the solar thermal panel over a given time period using:

$$Power\ (Watts) = \frac{Energy\ (Joules)}{time\ (s)}$$

So if that same solar thermal panel used above managed to increase the waters temperature in a period of one hour, then the average power over that time would be:

$$Power = \frac{Energy}{time} = 1{,}046{,}500J\left(\frac{1}{3600s}\right) = 291\frac{J}{s} = 291\ W$$

Newfoundland-based solar thermal panel retailer.

R-value
http://en.wikipedia.org/wiki/R-value_(insulation)

Extensions

Using the performance data from the students' solar thermal panels, calculate how many would be required to meet the heating or hot water requirements for an average size home in your area.

Additional Resources

Calculating Savings: The Gaia Project
http://www.thegaiaproject.ca/sites/default/files/teacher-resources/additional-resources/calculating-savings.pdf
Shows how to calculate savings, perform simple cost / benefit analyses as well as complex Net Present Value Analyses

Build It Solar
http://www.builditsolar.com/
The website 'Build It Solar' provides hundreds of examples if DIY solar projects ranging from the very simple to the very complex. Many of these designs would be great for a project as long as we include the variable testing process described above. Simply following an existing design without understanding why and how each component is important to the overall functionality and efficiency of the device reduces the impact of the project.

Cansolair
http://www.cansolair.com/