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Solar Schools
for British Columbia

A collection of lessons to assist teachers and students with their exploration of solar energy

SolarBC

Join the Solar Revolution

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Real-time Solar

Analyzing solar energy output

What will happen

Students will analyze data collected from a solar thermal or photovoltaic system and design a display panel to showcase how it works.

Students will

- Understand factors that affect solar energy production;
- Analyze the data collected by a solar thermal or photovoltaic system;
- Interpret data from meters recording energy output of a solar hot water heater and a PV system;
- Design a display panel that showcases solar energy output data.

Total Time 1½ - 4½ hours + homework	Establish what students know	Activity Part A	Activity Part B	Activity Part C	Debrief what students learned
	20 - 30 minutes	20 - 30 minutes	60 minutes	60 - 120 minutes	20 - 30 minutes

What you need to know

Solar energy is a clean and abundant energy resource that can be used to supplement many different energy needs. Two of uses of solar energy are as a heat source and as a source of electricity. Solarthermal systems capture the sun's energy to produce heat while solar electric systems use photovoltaics (PV) to which converts the sun's energy into electricity.

Solar thermal is used for water heating system or space heating and is one of the most cost-effective uses of solar energy. Solar hot water provides hot water for showers, dishwashers and washing machines. From sunrise to sunset solar panels absorb the sun's energy and heat liquid that runs through insulated piping to connect with an array of collectors. The solar collectors are mounted on a roof, the side of building, or on the ground. The heated liquid is pumped to a heat exchanger, where the heat is transferred to a hot water supply for the building. The heated water is kept in an insulated tank until it's used. Many solar water heaters include a small photovoltaic module to power the pump in order to circulate the solar-heated liquid through the collectors which also allows the solar hot water heater to function when there are power outages. Other systems combine solar with traditional hot water heating systems for days when the sun isn't shining.

Photovoltaics allow sunlight to be converted into electricity. This technology provides a safe, cost-effective and environmentally friendly source of power. PV systems range in size from those that generate a fraction of a watt to multi-megawatts. PV systems can be used to generate electricity for many things such as homes, vehicles, boats, traffic lights, signs, and pumping water. There are different types of PV systems depending on the need, location and budget.

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Measuring Solar Energy Outputs

The energy output of a solar energy system can be estimated and measured in several ways: computer simulation models (estimated), real-time data collection and calculations (measured), heat meter (measured), or energy bills (estimated).

Solar thermal hot water systems use a heat meter to measure the amount of heat a solar collector is adding to a fluid at a given point in time. The rate at which solar energy is absorbed by the collector can be determined from the change in temperature of the fluid before and after it passes through the solar panels, the flow rate in the solar loop, and a constant called the Specific Heat of Water. The amount of energy absorbed over a given time can then be calculated. By taking measurements at different times of the day, under various weather conditions, a reasonable estimate of solar collector performance can be determined.

PV systems use meters to measure how much electricity is being generated. The electrical energy output of a photovoltaic (PV) panel changes based on the angle between the PV panel and the sun. The angle at which the sun hits a PV panel determines its efficiency and is used to design an efficient PV system for a specific location. By monitoring the energy output of a PV system it is easy to see how much energy is being produced and if it is performing as effectively as possible.

Evaluating Solar Energy Potential

The potential for capturing solar energy at a site is based on these factors[2] :

- **Location** - Solar energy is not evenly distributed over the surface of the earth, and geographical location – specifically latitude - is an important factor.
- **Orientation to Sun** - The degree of orientation to South, of that part of the roof or walls where the solar panels might be placed, is more likely solar "friendly".
- **Slope/angle** - Ideal slope or angle for the placement of the solar panels depends on location and local climate. Together these factors determine whether a steeper or gentler slope increases the potential for solar energy gain.
- **Shading** - Shadows created on solar panels by surrounding trees, buildings, and hills reduce the amount of solar energy available.
- **Weather** - is another significant factor in determining solar energy potential.

[1] 2000 An Introduction to Solar Water Heating Systems, Natural Resources Canada. Inventory No. M27-01-1321E

[2] 2003. Solar Rating Online, GreenPower labs for Solar BC. http://www.solarbc.ca

What might surprise you

- Solar thermal is typically 3-5 times more efficient that PV in converting the sun's rays into useful energy. Source: Solar on the Brink. Canadian Consulting Engineer. May 2010 pp30

What you need

- **Measuring Solar Energy Output and Analyzing PV Output** worksheets.
- Access to your schools data monitor for your solar hot water or PV system.
- Internet access or copies of sample school monitoring data for schools with PV systems.

Vocabulary

- **Energy - Energy Joules (J) or Kilowatt hours (kW/h)** - Energy depends not only on the power required by your appliances, but also on how long and how often you use them. Energy is expressed in kilowatt-hours (kW/h) for a given period of time (per day, month or year). It is defined as the power times the number of hours the equipment is used over this time period. The accepted unit of measurement for energy is the SI unit, the joule.
- **Energy Production Graph** - some data monitors will run graphs of the solar today, week, month or year).
- **Irradiance**- the amount of power available from the sun at any instant in time. Irradiance is measured using a device called a pyranometer. The units for irradiance are watts per meter squared (W/m^2).
- **Lifetime CO_2 Avoided** - the amount of CO_2 measured in kilograms that would be have been emitted into the atmosphere, over the lifetime of the system, if this amount of electrical energy had come from the grid.
- **Lifetime KWh** - the total amount of energy produced over the lifetime of the system measured in kilowatt-hours (kWh)
- **Output Power** - measured in watts (W)
- **Panel Current** - measured in amperes or amps (A)
- **Panel voltage** - measured in volts (V)
- **Power**- the rate at which work is performed or energy is converted; for example, the rate at which electrical energy is being produced by the solar electric system. Commonly measured in joules/sec or watts and kilowatts.
- **Temperature**
  1) **PV Cell** – the temperature of the PV cell is measured on the back of the PV module using a thermocouple.
  2) **Ambient**- the ambient air temperature is measured by a thermocouple enclosed in a white plastic globe that prevents it from being heated by the sun. It is located near the solar electric system.
- **Specific Heat Capacity** - is the amount of heat required to change a unit mass of a substance by one degree in temperature. The specific heat of water is 4.184 joules per gram (or kJ per kg) per degree Celsius.
- **Wind** - some data monitors have an anemometer and wind vane to measure wind speed and direction.

Establish what students know

1. Review the factors that affect the potential efficiency of a solar energy system. Other lessons may include The Power of PV and the Magic of Solar Thermal.

2. Review key vocabulary terms and units for measurement.

Main Activity Part A

Part A Calculating Solar Energy of a Solar Hot Water Heater

What you do

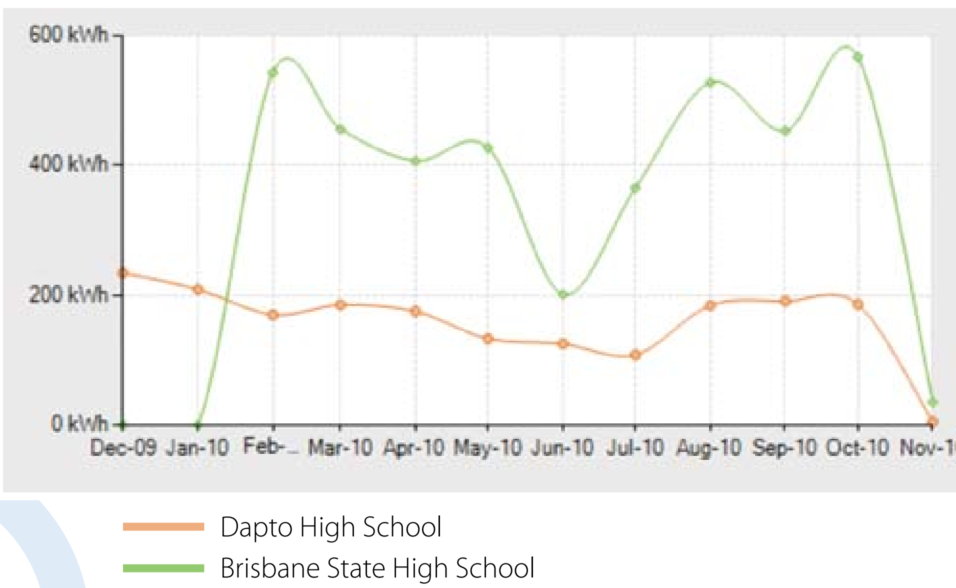
1. Introduce a real-life example of a solar thermal energy system from a school in Vancouver, BC. described in the worksheet: **Measuring Solar Thermal Energy**. At this point, students just need to know that it is a clear sunny day and the temperature differential between the tank and the solar return is 200 Celsius.

2. Students estimate what the rate of solar energy collection might be in kW or some equivalent,such as how much energy they think would be collected over a one-hour period and what equipment it could operate for what period of time. For example, the energy collected would power 100 laptop computers for 24 hours. Record and exchange their guess and rationale with another student.
3. Invite a few students to share their guesses and rationale with the class. Record their questions and explore as a class how to scientifically calculate the energy collection rate.
4. Introduce and explain the formula $q = (m)(c_p)(\Delta T)$ on the **Measuring Solar Thermal Energy** worksheet. Review the real-time analysis example for the Vancouver school provided at the bottom of the worksheet.
5. If available, students physically collect data from the temperature gauges and research the flow rate from their own school's solar energy system to calculate the rate and amount of solar energy collected. Otherwise, use fictitious data or values from another school as provided in the Case Studies sectionof this lesson.

Main Activity Part B

Part B Analyzing Photovoltaic School Data

1. Introduce the different components of data that are collected to measure energy output of a PV system such as voltage, current, power, and temperature.
2. The graph below displays energy output from two schools in Australia.



3. Use the graph to answer the following questions
   - Which month showed the lowest energy output? The highest?
   - How does the output change with the seasons?
   - In what month was the least energy produced, and how much energy was it?

4. Students work in pairs and select two schools, listed in the case studies section at the end, to compare solar energy output to their own school, using the data monitor for your PV system if available. If their school does not have a data monitor that measures the energy output from their PV system, select 3 case study schools.

5. Students collect information from the 3 different schools and record on the **Analyzing PV Output** Datasheet. Be sure students include time of day, time of year, weather, geographic location, amount of available solar energy (solar irradiance), and temperature. Review the key types of data collected and critical terms: irradiance, cell temperature, and ambient temperature.)

6.
   - Track the schools solar energy output for one week. When is the time of day for peak solar electric output?
   - Is solar electric output influenced by the ambient temperature?
   - Does geographic location impact solar electric output?
   - Is there a direct correlation between solar electric output and time of day?
   - Does time of year/season impact solar electric output?

7. Students prepare a display of the information collected and share results.

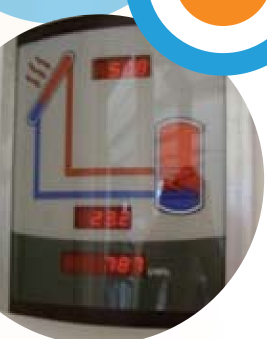
Main Activity Part C

Part C Display of Real Time Data

What you do

1. Using data collected in Part A or Part B, student work in small groups to design a display that showcases the real-time energy output of that particular system.

2. Provide students with guidelines and requirements, for example, the design will:
   - describe a series of variables required for ongoing energy audits;
   - explain each variable being measured;
   - illustrate the system and explain how it works;
   - appeal to peers, as well as other students (Grades 5 - 12) and their families;
   - invite or inspire viewers to do something interactive at the display;
   - provide a specific call to action; and
   - include a one-page rationale for the design.



An example of a real-time display of data to reinforce solar energy processes.

Delta Municipal Hall, Delta BC

Debrief what students learned

- As a class, make a list of variables that can be measured and are needed to calculate the performance of a system for real-time analysis.
- Describe the data collected to determine the energy output of a solar hot water system and/or PV system.

Extensions

- **Calculate Your Solar Rating** - Rate the solar potential of your home using SolarBC's solar rating tool at http://solarrating.ca/index.php
- **Make History** - Write a case study on your school's solar installation. Include elements related to how it works, the life cycle of its materials and its impact on the school's carbon footprint. Submit your case study to SolarBC at http://www.solarbc.ca. Research where and how to share your case study beyond BC.

Assessment

- What are some factors that affect the potential for capturing solar energy?
- Describe the difference between the energy outputs of a solar hot water and photovoltaic system.
- What does the energy output of a solar PV cell depend upon?
- Provide reasons for using solar energy to heat water.

Check out

Calculators

- Hot Water Heating http://chuck-wright.com/calculators/hotwater.html

Links

- http://www.home-energy-metering.com/solar-thermal.html

Case Studies

- **St. Andrew's School Solar PV System** A 21.76 kW system was installed on the roof area of St. Andrew's School's gymnasium. This system serves to offset the facility's electrical consumption while serving as an educational tool for the school's students for decades to come. The online screen displays the most recent data samples uploaded to the PowerDash database. Hit your browser Refresh button to see any new data updates. http://chuck-wright.com/logger/tabs.php?loggerids[]=D25E70023C4E2E89&tab=0
- **Solar for Schools** http://www.solarforschools.ca/ Fort Nelson Secondary and Clarence Fulton Secondary in Vernon BC
- **Bonneville Environmental Foundation - Solar 4R School** www.b-e-f.org/solar4rschools
- **llinois Solar Schools** www.illinoissolarschools.org
- **New York State Energy Research and Development Authority** www.powernaturally.org/Programs/SchoolPowerNaturally/AboutSPN/ParticipatingSchools
- **PG & E–Pacific Gas and Electric** www.need.org/pgesolarschools
- **Soltrex** www.soltrex.com
- **Solar Schools.Net:** An Australian website dedicated to school energy monitoring http://www.solarschools.net/
- **Madison Gas and Electric:** Madison, Wisconsin solar photovoltaic array installations on high schools with monitoring equipment to allow students and others to keep track of energy output and weather information. http://www.mge.com/environment/green/solar/schools.htm

Measuring Solar Energy Collected

Measuring performance of a solar thermal system is achieved through observation and by calculation.

The rate at which solar energy is absorbed by the solar hot water collector can be determined from the change in temperature of the water before and after it passes through the solar panels, the flow rate in the solar loop, and a constant called the Specific Heat of Water. The amount of energy absorbed over a given time can then be calculated

Step 1 Specific Heat of Water c_p

The specific heat of water (also called specific heat capacity) is the amount of heat required to change a unit mass of a substance by one degree in temperature. The specific heat of water is 4.184 Joules per gram (or KJ per Kg) per degree Celsius)

Step 2 Temperature Differential ΔT

1. Check that the solar hot water system is circulating by looking for indicators that the pump is on.
2. Determine the temperature of the water before it enters the solar panels, in degrees Celsius.
3. Determine the temperature of the water after it leaves the solar panels, in degrees Celsius. If necessary, convert any temperature readings from Fahrenheit to Celsius using the formula: °C = (°F – 32) x 5/9.
4. Calculate the difference between these two temperatures by subtracting the tank temperature from the return temperature. This is called the temperature differential= ΔT

Step 3 Mass Flow Rate of Water m

Identify the pump flow rate =m, mass flow rate of water in the solar loop, in Kg/s (how do they get this? Dave says that it should be in the specs for the pump – usually a range depending on length/elevation of system)

Step 4 Solar Energy Collected

Calculate the rate of solar energy collected in KJ/s (KW) =q

rate of solar energy collection

specific heat of water

temperature differential

mass flow rate of water in the solar loop

$$q = (m)(c_p)(\Delta T)$$

Heat Flow (Kwh) = Flow Rate of Water (Kgs/sec) x Specific Heat of Water(Kj/Kg °C) x Temperature Differential (°C)

Student Worksheet

Example

It is 11:00am on a clear day and the solar energy system is on. The dial thermometer on the tank reads 50 °C. The solar return temperature on the wall display reads 158 °F. The flow rate (m) of water in the solar loop is 0.25 Kg/s. It is assumed that the pump flow rate is consistent. The specific heat of water is 4.2 KJ/Kg °C.

a. Convert the solar return temperature to degrees Celsius. (158 °F - 32) x 5/9 = 70 °C

b. The temperature differential (ΔT) is 70°C - 50°C = 20°C

c. The rate of solar energy collection (q) is (0.25 Kg/s) x (4.2 KJ/Kg °C) x (20 °C) = 21 KJ/s or 21 KW

d. If you multiply this by a time factor, you can calculate the amount of energy collected. If the same temperature differential were observed over a one-hour period, there would be (21 KJ/s) x (3600s) = 75,600 KJ or 75.6 MJ of energy collected.

e. That's enough energy to operate:

- 1 KWh of energy = running a hot shower for three minutes
- 50 KWh of energy saved could run your dishwasher 20 times
- 100 KWh of saved energy could run your clothes washer 50 times – that's almost a free load of laundry every week for a year

Source: Solar Thermal Curriculum for King George Secondary by Morgan McDonald, 2008

High Schools Look Skyward to Heat Water Systems[1]

Five Vancouver high schools will install solar thermal panels this spring to heat water in a slow, but growing effort by the school board to "green" the district. Lord Byng, David Thompson, Vancouver Technical, Winder?mere and Charles Tupper will get the panels thanks to funding through SolarBC, a provincial organization that encourages less reliance on fossil fuels.

"If SolarBC wasn't doing this, we wouldn't be doing this. We couldn't afford the up front costs," explained Kevin Millsip, Vancouver school district's sustainability coordinator.

SolarBC and federal funding from the ecoENERGY for Renewable Heat Program cover most of the cost of the solar thermal panels. each unit is priced at about $24,000, but the school board will pay between $2,000 and $2,500 for each.

SolarBC selected 20 schools across the province for funding through its Solar for Schools project to help reduce the carbon footprint and energy costs for schools.

"[The units] should be installed mid-May through mid-June," said Millsip, a former COPE trustee who was hired as the district's first sustainability coordinator last may. His position is partly funded by the Vancouver Foundation.

Solar hot water systems convert sunlight into heat through solar collectors mounted on the roof. The supply of solar energy comes from radiation generated by the sun rather than just visible sunlight, so even cloudy days provide enough energy for a solar hot water system to be effective, according to the SolarBC website.

King George secondary installed the district's first solar hot water system in 2007. The Vancouver School Board now has a group called Solar Schools, with representatives from all six schools with solar panels, whose aim is to educate the community about the capacity of solar power and look for more opportunities to introduce it in the district.

[1] Vancouver Courier article found on solarbc http://www.solarbc.ca/news/2010/04/07/high-schools-look-skyward-heat-water-systems

Student Datasheet

Name: ____________________ Date: ____________________

Analyzing PV Output

Track 3 schools solar power output for one week.

School names and locations:

1. ____________________

2. ____________________

3. ____________________

Collect the following data:

		Time of Day Recorded	Time of Year	PV Size (KW)	Location (latitude if known)	Solar Irradiation (M/m^2)	Average Daily Temperature	Rainfall (mm)	Weather	PV Output (KW/h)
Day 1	School 1									
	School 2									
	School 3									
Day 2	School 1									
	School 2									
	School 3									
Day 3	School 1									
	School 2									
	School 3									
Day 4	School 1									
	School 2									
	School 3									
Day 5	School 1									
	School 2									
	School 3									