Solar Schools
for British Columbia

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

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pilot

The Power of PV

Measuring the power and energy of photovoltaic systems

What will happen

Students will learn how to calculate the efficiency of a solar panel and convert devices to solar using PV technology.

Students will

- Understand how solar energy output is measured;
- Determine the voltage, current, and power using Ohm's law of a given PV cell;
- Convert a battery operated device to solar.

Total Time 2½ - 3½ hours + homework	Establish what students know	Activity - Part A	Activity - Part B	Debrief what students learned
	10 - 20 minutes	50 - 60 minutes	60 - 90 minutes	10 - 20 minutes

What you need to know

When sunlight hits a solar panel it converts that solar energy into electrical power. The energy output from a solar electric (PV) system is a function of a number of factors, including shading, temperature, angle to the sun, type of PV cell and the resistance of the electrical load to which it is connected. These are all factors that can contribute to the **solar rating** of a PV system which is determined by the amount of sunlight available at a particular location at a given time. The two common methods to measure the energy output of a PV systemsare **solar irradiance** and **solar insolation**. Radiance is the power from the source per area into a certain solid angle. Irradiance is the power onto a surface per area

Solar irradiance varies throughout the day and is strongly dependant on location and local weather. Solar irradiance is a measure of intensity of solar power in watts/m^2. The measurements are taken using either a pyranometer (measuring global radiation) and/or a pyrheliometer (measuring direct radiation).
Solar insolaton is a measure of the amount of solar radiation received on a square metre of the earth's surface in a single day, kWh/m2/day. Solar insolation measurements are taken from satellite images of the Earth. In PV technology the greater the insolation the more solar energy can be converted to electricity by a solar panel.

Electrical power is a product of current (I) and voltage (V) and measured in watts (W). The power released by the solar panel is directly influenced by the electrical load resistance linked to the panels. This resistance is measured in the unit of Ohm and can be calculated according to Ohm's Law, which includes dividing voltage by resistance to get the estimation of the current. An analogy to help understand these terms is a system of plumbing pipes. The voltage is equivalent to the water pressure, the current is equivalent to the flow rate, and the resistance is like the pipe size.[1]

The amount of the sun's energy that reaches the edge of Earth's atmosphere is known as the solar constant. While the solar constant varies slightly, the average value is 1,368 watts per square meter (W/m^2), meaning the sun produces 3.9 x 10 26

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watts of energy every second. To visualize this amount of energy, imagine the energy of thirteen100-watt light bulbs spread over a single square-meter surface. The amount of this energy that actually reaches Earth's surface on a sunny day varies according to the time of year. The following values are estimates for how much energy reaches Earth's surface on a sunny day, according to the time of year:

- 1000 watts/m^2 on a sunny summer day.
- 900 watts/m^2 on a sunny autumn or spring day.
- 700 watts/m^2 on a sunny winter day.

Depending on the time of year, one of the values above is the power input from the sun that is converted into electrical energy by your PV cell. Photovoltaic efficiency is the proportion of sunlight energy that the cell converts to electrical energy. Efficiency of the solar cell can be determined by comparing output power to input power. Most solar panels range between 15-20% for efficiency [2]. There is ongoing research and development in solar technology to make solar panels more efficient.

[1]How Stuff Works: What are Amps, watts, Volts and Ohms?
http://science.howstuffworks.com/

[2] How Solar Cells Stack Up. CalFinder: Nationwide Home Solar Power Contractors and Information.

What might surprise you

- A solar-powered airplane flew more than 4,000 kilometres across the United States in 1990. Source: www.greenlearning.ca

What you need

- To do this experiment you will need materials for groups of 4 students.

Vocabulary

- **Voltage-Volts (V) -** The electrical force that makes electricity move through a wire and is measured in volts. The bigger the voltage, the more current will tend to flow.
- **Current - Amps (I) -** Current is the steady flow of electrons and is measured in amperes or Amps.
- **Resistance- Ohms (R)** - Resistance is a measure of the restriction of the flow of current through a material. Ohms law determines the relationship between Voltage (V), Current (I), and resistance (R). Ohm's law: V = I * R
- **Power- Watts (W)** - Power is the rate at which work is performed or energy is converted and is expressed in watts (W). A watt is the product of the current, in amperes (A), and the voltage, in volts (V). Something that uses 1 W uses 1 Joule of energy per second. The bigger the voltage and bigger the current, the more power you get, for example the more appliances that are used at the same time, the more power is required.
  - *Watt (W)* = amps x volts (unit of power, rate of working of one joule per second).
  - *Kilowatt (kW)* – power of 1,000 watts.
  - *Kilowatt-hour (kWh)* – amount of energy equal to one kilowatt operating for one hour.

- *Total kWh of electricity consumed* = Total hours of use x appliance wattage ÷ 1,000 (converts watts to kilowatts) for example, the number of kWh of electricity to run a clothes dryer for two hours: 2 hours (total usage) x 5,000 watts (wattage for clothes dryer) ÷ 1,000 (watts to kilowatts conversion) = 10 kWh.

- **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.

Establish what students know

1. Review electrical circuits, including voltage, current and power.
2. Brainstorm ideas that might impact the energy output of the PV system. E.g.'s: time of day, time of year, weather, geographic location, amount of available solar energy (solar irradiance), and temperature.
3. If possible invite a solar installer to lead a tour of the PV system for your students. Students prepare questions about the system, the work the installer does, and how they got involved in the solar industry. A list of installers can be found on the SolarBC website. www.solarbc.ca

Main Activity Part A

Part A Calculating PV Efficiency

What you need

- Meter Ruler
- 100 - 150W Portable Light Source
- Multimeter(s)/ group of 4 students
- Small Solar Panel
- Alligator clips to connect panels to multimeter
- Small motors (optional for further investigation)

What you do

1. Explain the efficiency of solar cells is calculated by determining how much of the sun's energy it converts to electricity.
2. Review basic concepts of voltage and current.
3. Give a demonstration of how to read the multimeter prior to students conducting the experiment.
4. Put the solar cell in a circuit that results in maximum power output (in watts). Record voltage and current readings. **Note:** watts = volts x amps (power = voltage x current).
5. Measure the dimensions of the solar cell and calculate the surface area in square metres (m^2).

6. Calculate the power output in W/m^2 (watts per square metre).

   Power Output of the PV cell =

   $$\frac{\text{voltage x current (=watts)}}{\text{area } (m^2)}$$

7. Using the estimated power input of sunlight in W/m2 (watts per square metre) reaching the Earth's surface for each of the following:
   - 1000 W/m^2 on a clear summer day
   - 900 W/m^2 on a clear autumn or spring day
   - 700 W/m^2 on a clear winter day.

8. Calculate the efficiency of the solar cell, using the equation:

   $$\% \text{ Efficiency} = \frac{\text{Energy output}}{\text{Energy input}} \times 100\%$$

9. For further investigation have students design and conduct an experiment that addresses one of the questions below. Prepare a lab report that explains your hypothesis, procedure, data analysis, and conclusions.
   - How does the distance from a light source affect the power output of a PV cell?
   - How does the color of light affect the power output of a PV cell?
   - How does temperature affect the power output and efficiency of a PV cell?

Main Activity Part B

Part C Converting a Battery Operated Toy to Solar*

What you need

- Various toys or electronic devices that operate on AA batteries
- Scissors or wire strippers
- Electrical tape, Glue gun or solder iron
- Multimeter
- 1 volt, 400-500 mA solar panels with alligator clips* - 2per group

*Sunwind Solar www.sunwindsolar.com or Spectrum Educational Supplies

What you do

1. In student groups, each group is to select an AA battery operated toy, game, or electrical device to convert to solar power or one that operates at one to four volts with current requirements of less than 400 mA.

2. Remove the installed batteries. This should expose the positive and negative terminals of your device's power inputs.

3. Strip about a half-inch of insulation off the ends of your solar panel's wires with the wire strippers or scissors.

4. Fasten, with electrical tape, glue or solder, the stripped end of the solar panel's positive wire (denoted with a "+" on the back of the panel) to the positive power input of your device. One or two drops of solder should be more than sufficient to cement the connection, and should be allowed to dry thoroughly.

5. Fasten, with electrical tape, glue or solder, the negative wire from the solar panel (denoted with a "-" symbol) to the negative power input on your device. Allow the solder to dry thoroughly.
6. Place the toy in a source of bright, consistent sunlight and engage its function. If you've done everything correctly, your solar panels should provide your device with enough power to operate normally.
7. Establish what conditions allow their new solar powered device to draw the most power.
8. Host a solar equipment day to promote their solar powered device and test their toy's performance.

*adapted from SolarPower Naturally, Northeast Sustainable Energy Association, Solar Kit Lesson#13, p2 and How to Convert Battery Power to Solar Power http://www.ehow.com

Debrief what students learned

- Most PV cells have efficiencies between 5 and 20 percent. How did yours compare?
- Describe variables that affect photovoltaic performance.
- Discuss what is required for their toys to be converted to solar

Extensions

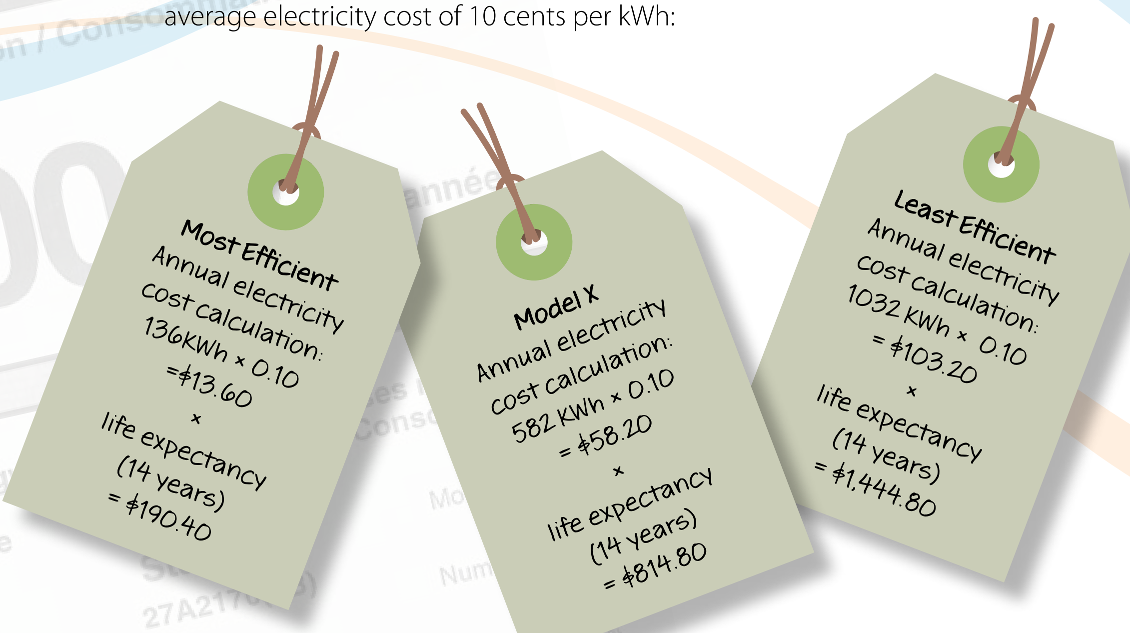
- **Build a PV Cell** - The photovoltaic process can be demonstrated using copper that has been coated with a layer of copper (I) oxide. Unit of Study No. 10, Estimating PV System Size and Cost www.InfinitePower.org
- **Estimate Your School Power and Energy Needs** - Conduct a school or home energy audit using the worksheet found in the Photovoltaic Systems Buyer's Guide for Natural Resources Canada http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/publications.html?ISBN:%200-662-86306-2
- **The 'Second Price Tag' of appliances** - An appliance's first price tag is easy to spot. It's the sticker price, or the cost of buying an appliance. The second price tag is the appliance's long-term operating cost. Some energy-efficient appliances cost slightly more than conventional equipment. But when you calculate the second price tag, these appliances save you money by dramatically reducing your energy costs over their lifetime. And because they use less energy, they help reduce greenhouse gas emissions that contribute to climate change.

  Calculating the second price tag is easy. Simply multiply the appliance's estimated annual energy consumption (the large number on the EnerGuide label) by your local cost of electricity – which is on your utility bill – to estimate quickly how much it will cost to operate the appliance for one year:
  - EnerGuide rating (kWh/year) × Local electricity costs ($/kWh) = Annual electricity cost.
  - Multiply your annual electricity cost by the estimated life expectancy of your appliance
  - Annual electricity cost ($/year) × Appliance life (years) = Lifetime electricity cost.

To calculate differences in operating costs for one example, review the following:

Refer to the EnerGuide label, affixed to clothes washer Model X. The label indicates that Model X uses 582 kWh per year. The most efficient standard model uses 136 kWh per year, and the least efficient washer uses significantly more energy – 1032 kWh per year.

Here are the second-price-tag calculations for all three washers, based on an average electricity cost of 10 cents per kWh:



The energy-wise and environmentally conscious choice may also be the most economical, as the most energy-efficient washer will cost you $624.40 less than Model X to operate over the life of the appliance. remember, when the cost of electricity rises, so will your savings.

Use our Energy Cost Calculator for New Appliances to make your calculations and compare models.
http://oee.nrcan.gc.ca/residential/personal/appliances/appliances-costs.cfm?attr=4
http://oee.nrcan.gc.ca/residential/personal/appliances/improvements.cfm?attr=4
NRCan DATABASES
http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/sheu07/tables.cfm?attr=0

- **Cost of Christmas Lights & Electric Clock** - If the same Christmas lights are left on for five hours each night for 20 days, at a cost of 5.97 cents per kilowatt/hour (kW-h), how much will your power bill increase in the month of December? How much will it cost per year to operate an electric clock with a 6 watt rating, at a cost of 5.177 cents per kW-h?

Lesson Idea by: Dave Ward, Rutland Senior Secondary School Central Okanagan School District
http://www.bced.gov.bc.ca/careers/aa/lessons/aom13.htm

Assessment

- What factors do you think cause the differences in efficiency of the cell?
- What other factors will affect the energy output of a PV cell?
- List variables that can impact PV electricity generation.
- Explain how to measure the efficiency of solar energy.
- Describe some considerations for designing solar powered devices.

Check out

Calculators

- What's a watt? http://chuck-wright.com/calculators/watts.html
- Side Effects of Electricity Generation
  http://chuck-wright.com/calculators/electric.html

Lessons

- Calculating the Efficiency of a Solar Electric System lesson
  www.wattsonschools.com
- Madison Gas and Electric
  http://www.mge.com/environment/green/solar/curriculum.htm
- *Photovoltaic Systems and School Electricity Use*. 2009 The Need Project. Schools going Solar, p 30. How/where do I get this book

Videos

- Youtube video on how to measure solar cells energy output
  http://www.youtube.com/watch?v=2dE1HLDnWPg
- Photovoltaic potential and Solar Maps of Canada
  https://glfc.cfsnet.nfis.org/mapserver/pv/index_e.php

Student Background

Energy To Operate Items

Item	Watts (to operate for 1 hour)
Hot water tank	5 000
Clothes dryer	4 800
Electric oven	5 000
Clothes washer	1 850
Refrigerator	1 380
Microwave	1 350
Hair dryer	1 000
Toaster	1 200
Dishwasher	900
Computer – monitor & printer	215
Game station	170
Television (standard)	87
50 w Light bulb	50
25 w Light bulb	25
Central air conditioner	3 500
Room air conditioner (9 000 BTU)	1 050
Room air conditioner (6 000 BTU)	750
Ceiling fan	60
Portable fan	115
Stereo	30
TV-LCD, rear projection-52"	174
TV-Plasma-50" High Definition	357
Portable vacuum cleaner	800
Coffee maker	900
Dishwasher	1 300
Kettle	1 500
Toaster oven	1 000
Electric blanket	180

Source: http://www.smartmetersontario.ca/index.cfm?page=HowMuchDoIUse

Typical Wattages of Various Appliances

Here are some examples of the range of nameplate wattages for various household appliances:

- Aquarium = 50–1210 Watts
- Clock radio = 10
- Coffee maker = 900–1200
- Clothes washer = 350–500
- Clothes dryer = 1800–5000
- Dishwasher = 1200–2400 (using the drying feature greatly increases energy consumption)
- Dehumidifier = 785
- Electric blanket- Single/Double = 60 / 100
- Fans:
  - Ceiling = 65–175
  - Window = 55–250
  - Furnace = 750
  - Whole house = 240–750
- Hair dryer = 1200–1875
- Heater (portable) = 750–1500
- Clothes iron = 1000–1800
- Microwave oven = 750–1100
- Personal computer:
  - CPU - awake / asleep = 120 / 30 or less
  - Monitor - awake / asleep = 150 / 30 or less
  - Laptop = 50
- Radio (stereo) = 70–400
- Refrigerator (frost-free, 16 cubic feet) = 725
- Televisions (color)
  - 19" = 65–110
  - 27" = 113
  - 36" = 133
  - 53"-61" Projection = 170
  - Flat screen = 120
- Toaster = 800–1400
- Toaster oven = 1225
- VCR/DVD = 17–21 / 20–25
- Vacuum cleaner = 1000–1440
- Water heater (40 gallon) = 4500–5500
- Water pump (deep well) = 250–1100
- Water bed (with heater, no cover) = 120–380

Source: http://www.energysavers.gov/your_home/appliances/index.cfm/mytopic=10040?print