Designing and Conducting Experiments

OVERVIEW

Students design and conduct experiments to determine how various factors affect the PV system performance. Students formulate a research question concerning the PV system's performance and predict the expected behavior. After determining what information is needed to address the question, students collect data, account for different variables, make graphs, and analyze their results. In conclusion, they revisit their initial predictions and determine what further research is needed. They also determine an appropriate audience and method for publishing their work.

PRIOR KNOWLEDGE

Students will be most successful with these investigations if they are familiar with their school's PV system and Soltrex monitoring system, as well as the basic concepts and vocabulary for photovoltaic. See lessons and activities in "Learning the Tools of the Trade" for ideas on providing students with sufficient background.

TIME

Varies depending the approach used (see notes under PREPARATION)

MATERIALS

- Experimental Design Planning Template (1 per group / experiment)
- Access to Soltrex - www.soltrex.com
- Access to the internet or daily papers for researching weather conditions
- Thermometer (optional)
- Graph Paper
- Weather condition icons

PREPARATION

- Review Procedures and determine how you wish to use these notes/lessons to help your class conduct investigations with the PV system.

- Review the Experimental Design Planning Template (both student and teacher versions): This template is meant to be a detailed aid in helping students set up a scientific investigation. It takes them through an entire process from initial brainstorming, to creating data tables, to thinking through logistics and practical considerations, to analyzing results, to determining an appropriate audience for their research. Depending on the level of your students and how much time you wish to spend working with the PV system, you may choose to use this template in a variety of ways. For example, if students are conducting several individual experiments in small groups, this template could guide them through necessary steps. On the other hand, if your class as a whole decides to pursue a single experiment, the template could serve as teacher's notes as well as an organizational outline for the process. Or use the template as a basic approach that you alter to your own specifications. To decide how to proceed, review the templates as well as the sample experiments and data.

- Arrange for your students to access Soltrex, school weather station (if applicable), and web sites as needed for their experiments.

- Introduce the project – explain to students that you will be designing and conducting experiments to learn about the PV array's performance by collecting actual data from the PV array itself.

- Experimental Design – spend time using the template to design the experiments.

PREPARATION (cont.)

- Approve the Designs – when students have completed the templates to your satisfaction and show a clear plan for their research, give them the "approval to proceed" with actual research.

- Conduct the Experiments – time needed for this step will vary.

- Automated Excel spreadsheets for power, kWh and irradiation can be generated for any time periods using Soltrex. Just input your dates and select any of three data choices. These can be viewed and printed.

- Graph and Analyze Data – once all data have been collected and graphs completed, have students consider the questions from Step 7 of the template. There are several different methods to graphing. **1) use Soltrex automated graphs; 2) input data into Excel and make your own graphs; 3) manually graph by hand.**

- Share Results – Find a public forum for your students to share their results. Experiments conducted on the school's PV array would be appropriate for inclusion in an Energy Portfolio or Scrapbook submitted to the Ohio Energy Project.

Experimental Design Planning Template
Student Version

Now that you've learned the tools of the trade and become familiar with your PV system, here's your chance to put your imagination and expertise to work. What experiments can you conduct to learn about the behavior of your PV system under different conditions?

Before starting experiments, scientists spend time making many decisions about what questions to research, what data to collect, how to collect it, when to collect it, and how they plan to share their results. This template will guide your team through a process to help you make important decisions needed for designing and conducting an experiment. You may wish to include a copy of this planning template in your *Researcher's Journal* to document your initial ideas on the experiment.

List your team members here:

Step 1 – BRAINSTORM

Make a list of all the different factors that you could track that might affect the performance of the PV system.

Step 2 – FORMULATE A RESEARCH QUESTION

From your brainstorming above, choose a few factors you'd like to examine more carefully. Create research questions that an experiment would attempt to answer. Your questions might take the following forms:

- What is the relationship between the output of the PV system and __________________?
- OR What seems to be stronger, the relationship between PV output and ________________________ or PV output and ____________________?

After creating ____ different questions, decide which one to focus on. Circle it.

Step 3 – MAKE PREDICTIONS

What do you expect you will find in answer to your question above?

Step 4 – OBSERVATIONS AND DATA COLLECTION

- Scope – For how long will you conduct your experiment? __________________

  Start: Date______________ Time _____________
  End: Date ______________Time _____________

- Past Data – Will you need to collect historical data from a different season / month / time of year? If so, what range of dates and times will you need data from?

- Frequency – How often do you hope to make observations or collect data?

- Record keeping – How will you record your data and observations?

  1. What qualitative observations do you plan to make?

  2. What quantitative data do you plan to collect?

  3. Contributing Variables – Unlike a laboratory setting where scientists have a lot of control over factors affecting their experiments, the PV system is exposed to the outside world where many uncontrollable events can affect its performance simultaneously. To make things even more complicated, some of these uncontrollable variables affect each other! (A cloudy day will probably be cooler than a clear day). Although you cannot control variables such as cloud cover, amount of sunlight or average temperature each day, you still need to take them into account since they significantly affect the PV system. So, take another look at the data you plan to collect. Are there any contributing variables that you haven't noted that you should?

4. Make a sketch of any data tables you will need in the space below. Before starting the experiment, create the actual data tables you will use and put them in your *Researcher's Journal*.

5. Graphing – Thinking ahead, how would you like to graph your data? Could there be factors that would be useful to see on the same graph (for example: average daily temperature and daily PV output)?   Will you graph it as you collect it? Sketch the graphs you expect to make in the space below. You may decide to make different or additional graphs once you've started collecting and analyzing your data. That's part of the process!

Step 5 – LOGISTICS

- Where will the data come from? Make a list of each type of data you will collect and how you will collect it.

Data	Source

- Materials and Permissions - Do you need any of the following materials or permissions to collect your data:

    - Access to Soltrex and the internet?
    - Access to the PV panels?
    - Daily Newspapers?
    - Weather Station at your school (if applicable)?
    - Thermometers?
    - List any other special materials you may need in the space below

- Responsibilities - Determine team members' responsibilities for collecting data

Name	Data to collect

- Where will you store your *Researcher's Journals*? Will you each have your own complete data log or will you share? If you share, how will you guarantee that all team members can get the information they need when they need it? If you have your own logs, how will you share data and keep one another updated?

Step 6 – CONDUCT YOUR EXPERIMENT

- After all this planning and preparation, it's time to get the "okay" from your teacher on your experimental design, make your data tables, and start!
- Have FUN!!

Once you have finished taking data and making graphs, return to this sheet to consider the questions listed under Steps 7 and 8. Discuss the questions below in your *Researcher's Journal.*

Step 7 – ANALYSIS and CONCLUSIONS

- From your graphs, what conclusions can your draw? What patterns do you see?
- Has your experiment answered your original question? How well did your predictions correspond to your results?
- Looking at your experiment as a whole, identify at least 2 things that were surprising or unexpected. These can be the results, or these can be things about the process of doing the experiment.
- What further questions do you have? If you have no further questions, what would you like to research next?

Step 8 – PRESENTATION

- What would be an effective format for presenting your findings?
- Who is the ideal audience for sharing your research?

Experimental Design Planning Template
Teacher's Notes

Now that you've learned the tools of the trade and become familiar with your PV system, here's your chance to put your imagination and expertise to work. What experiments can you conduct to learn about the behavior of your PV system under different conditions?

Before starting experiments, scientists spend time making many decisions about what questions to research, what data to collect, how to collect it, when to collect it, and how they plan to share their results. This template will guide your team through a process to help you make important decisions needed for designing and conducting an experiment. You may wish to include a copy of this planning template in your *Researcher's Journal* to document your initial ideas on the experiment.

List your team members here:

Step 1 – BRAINSTORM

Make a list of all the different factors that you could track that might affect the performance of the PV system.

Possible ideas: time of day, outside temperature, humidity, precipitation, sky condition (level of cloud cover), particulate matter count (ozone, allergens, pollution), amount of sunlight (measured by a pyronometer), hours of daylight, time of year/seasons.

Note: This might be best done as a full class activity to get students thinking about all the factors that affect the PV system. There may be factors not listed above that would be appropriate for research. The goal is for students to appreciate the complexity of the system.

Step 2 – FORMULATE A RESEARCH QUESTION

From your brainstorming above, choose a few factors you'd like to examine more carefully. Create research questions that an experiment would attempt to answer. Your questions might take the following forms:

- What is the relationship between the output of the PV system and __________________? Is the correlation strong, weak, or not apparent?
- OR What seems to be stronger, the relationship between PV output and ________________________ or PV output and ____________________?

After creating ____ different questions, decide which one to focus on. Circle it.

Possible Questions:

- How much power is the PV array contributing to our school's power grid?
- At what time of day does the PV array produce the most power?
- How is the amount of energy produced affected by the weather?
- How does the PV efficiency vary during a day?
- What is the relationship between the number of hours of daylight and the amount of energy produced by the PV? Or sunlight concentration on the PV array?
- What's the difference between the energy produced on a sunny day, a partly cloudy day, an overcast day, and a rainy/snowy day?
- What is the relationship between PV output and season?
- How much energy does the PV produce in a week?

Note: As noted above, this step might be effective as a whole class discussion. It presents a good opportunity for students to practice making research questions. Discuss how a question that is too broad, such as "How is the amount of energy produced by the PV affected by the weather?" can be difficult to research since so many factors come into play. This would be a good question to break into several smaller questions. On the other hand, a narrow question, such as "How much energy will the PV produce on Tuesday, October 26?" is straightforward to answer, but is not especially useful and gives us no general information about the behavior of the system. Discuss how, as researchers, they have to decide on a compromise between the complex and the simple for their experiments. Students will gain an appreciation of how an effective research question can be answered with an experiment AND yield useful information.

Step 3 – MAKE PREDICTIONS

What do you expect you will find in answer to your question above? Why?

Responses will vary. An ideal response will explain the reasoning behind the prediction.

Step 4 – OBSERVATIONS AND DATA COLLECTION

- Scope – For how long will you conduct your experiment? ____________________

  Start: Date_______________ Time ______________
  End: Date _______________Time ______________

- Past Data – Will you need to collect historical data from a different season / month / time of year? If so, what range of dates and times will you need data from?

- Frequency – How often do you hope to make observations or collect data?

- Record keeping – How will you record your data and observations?

Suggestion: Review the difference between qualitative observations and quantitative data. Discuss how both types of data are useful.

1. What qualitative observations do you plan to make?

   Possible observations: sky conditions, types of precipitation

2. What quantitative data do you plan to collect?

   Possible data: amount of energy or power produced by the PV array, average daily temperature, temperature at time of PV output reading, amount of precipitation, amount of sunlight, date and time of data collection.

3. Contributing Variables – Unlike a laboratory setting where scientists have a lot of control over factors affecting their experiments, the PV system is exposed to the outside world where many uncontrollable events can affect its performance simultaneously. To make things even more complicated, some of these uncontrollable variables affect each other! (A cloudy day will probably be cooler than a clear day). Although you cannot control variables such as cloud cover, amount of sunlight or average temperature each day, you still need to take them into account since they significantly affect the PV system. So, take another look at the data you plan to collect. Are there any contributing variables that you haven't noted that you should?

   This question is meant to give students to get a sense of the complexity of the system their experiments are looking at. It presents an opportunity to discuss the advantages of using models (can easily isolate variables, have more control over the variables you are researching). Contributing variables to note: season, hours of sunlight/day, other variables noted above under "quantitative data." Students don't have to record ALL of the variables, but need to make a decision on which are important to record in order to sufficiently answer their research question.

4. Make a sketch of any data tables you will need in the space below. Before starting the experiment, create the actual data tables you will use and put them in your *Researcher's Journal*.

   See some samples in "Sample Data and Graphs" at the end of this lesson.

5. Graphing – Thinking ahead, how would you like to graph your data? Could there be factors that would be useful to see on the same graph (for example: average daily temperature and daily PV output)? Will you graph it as you collect it? Sketch the graphs you expect to make in the space below. You may decide to make different or additional graphs once you've started collecting and analyzing your data. That's part of the process!

See some samples in "Sample Data and Graphs" at the end of this lesson.

Step 5 – LOGISTICS

- Where will the data come from? Make a list of each type of data you will collect and how you will collect it.

Data	Source

- Materials and Permissions - Do you need any of the following materials or permissions to collect your data:

  - Access to Soltrex and the internet?
  - Access to the PV panels?
  - Daily Newspapers?
  - Weather Station at your school (if applicable)?
  - Thermometers?
  - List any other special materials you may need in the space below

- Responsibilities - Determine team members' responsibilities for collecting data

Name	Data to collect

- Where will you store your *Researcher's Journals*? Will you each have your own complete data log or will you share? If you share one log, how will you guarantee that all team members can get the information they need when they need it? If you have your own logs, how will you share data and keep one another updated?

Step 6 – CONDUCT YOUR EXPERIMENT

- After all this planning and preparation, it's time to get the "okay" from your teacher on your experimental design, make your data tables, and start!
- Have FUN!!

Once you have finished taking data and making graphs, return to this sheet to consider the questions listed under Steps 7 and 8. Discuss the questions below in your *Researcher's Journal.*

Step 7 – ANALYSIS and CONCLUSIONS

- From your graphs, what conclusions can your draw? What patterns do you see?
- Has your experiment answered your original question? How well did your predictions correspond to your results?
- Looking at your experiment as a whole, identify at least 2 things that were surprising or unexpected. These can be the results, or these can be things about the process of doing the experiment.
- What further questions do you have? If you have no further questions, what would you like to research next?

This section presents an opportunity for individual assessment. Each student should write an "Analysis and Conclusions" section.

Step 8 – PRESENTATION

- What would be an effective format for presenting your findings?

  Suggestions: pamphlets, websites, and article for the school or local newspaper, a bulletin board in the school, at a science fair, for a PTA meeting, as a goal for an Energy Portfolio or scrapbook.

- Who is the ideal audience for sharing your research with?

  Other classes within the school (using a Kids Teaching Kids approach), school principal and administrators who helped to fund the PV array project, other solar schools in Ohio, other solar schools in the country (see Connecting Science and Society for more suggestions).

Some sample and suggested explorations for PV System

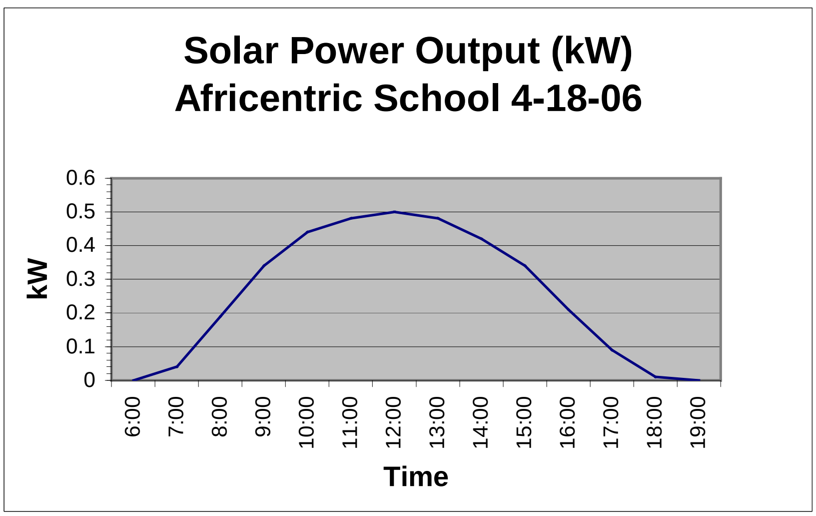
Research Question: How does PV output vary over a day?

Data table:

Date: April, 18, 2006, Africentric School, Columbus, Oh

Time	Power (kW)
6:00	0
7:00	.04
8:00	.19
9:00	.34
10:00	.44
11:00	.48
12:00	.50
13:00	.48
14:00	.42
15:00	.34
16:00	.21
17:00	.09
18:00	.01
19:00	0

Sample Graph (using Excel):



NOTE: The above example is of a clear and sunny day, which is indicated by the perfect bell-shaped curve. However, not all graphs will look this simple. Partly cloudy days may show spikes and abrupt changes in the graph. It is recommended that students take real-time, visual observations of the weather and cloud conditions if possible. Since weather can be highly localized, physical observations will be more reliable than information from the news or internet sources.

Sample and suggested explorations for PV systems

Research Question: How much kWh does the PV panel produce in one week?

Data table:

Date: 4/9 – 4/15, 2006, Africentric School, Columbus, Oh

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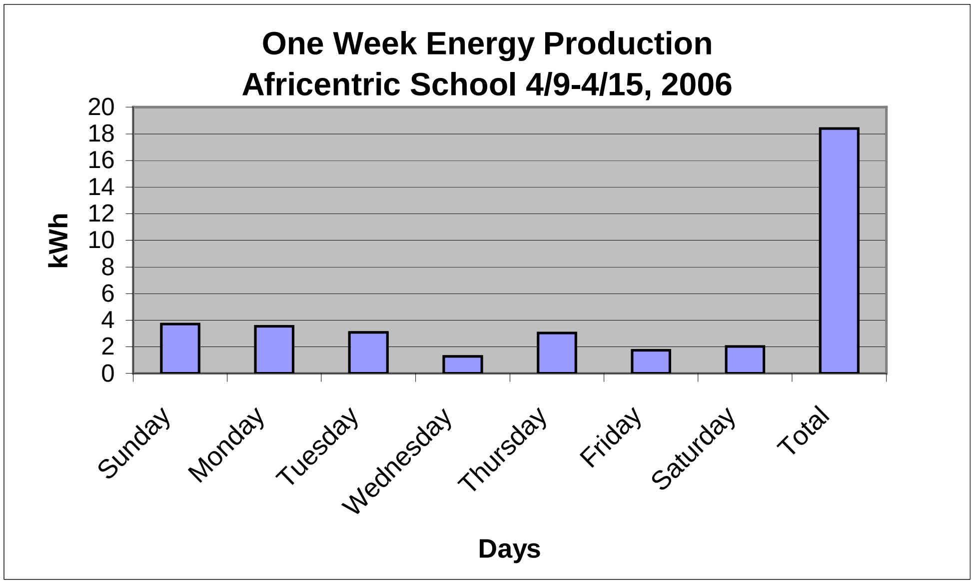
Day	**Total kWh**
Sunday 4-9	3.71
Monday 4-10	3.53
Tuesday 4-11	3.08
Wednesday 4-12	1.29
Thursday 4-13	3.05
Friday 4-14	1.72
Saturday 4-15	2.03
Total	**18.41**

Sample Graph (using Excel):



NOTE: The one-week total of 18.41 kWh is equivalent to 18410-watt hrs. This is equivalent to the energy of operating 307, 60W incandescent light bulbs for one hour at the school. It would be interesting to compare a week in spring with another season, such as fall.

Suggested Explorations

- Have students keep a graph of how much energy the PV array is contributing to the school's grid. Discuss areas when the graph is steeper (a lot of energy must mean it is sunny) or not as steep (not as much energy must mean it is cloudy or less sunny).

- Compare the amount of energy produced for a day, week, and month during the spring, summer, winter, and fall. As the time periods get longer, the effects of day-to-day weather should become smaller and an overall pattern for each season should emerge. To understand why the earth gets different amounts of sunlight during each of the seasons, have students research the tilt of the earth.

- Compare your results with the results of other schools from Ohio and other states using the same monitoring system (Soltrex) as your school. Visit www.soltrex.com and select a state. Choose schools with similar KWdc ratings as your school. This will allow your school to compare with schools with similar sized PV arrays. Or see how a smaller or larger system varies from your system by choosing a school with a higher or lower KWdc rating. See how a school in Texas compares to your school!

- Compare the relationship between the amount of sunlight (irradiation) and PV array power output by using the data from the Soltrex pyranometer (measures sunlight on the PV array).

- Have students keep a daily graph showing how much energy the PV array contributes to the school's grid. Students take one reading a day. Include space on the graph to put an icon showing weather conditions for that day. Also, graph the high and low temperatures on the graph for that day. Have students look for patterns and make statements based on what they see on the graph. A page of weather icons is included for this on page 53.

- Have students use the Energy/Pollution Equivalents from Soltrex to compare how much pollution has been avoided and/or how much energy the PV array has produced from any time period you desire to input (see How Much? - Lesson 4 Connecting Science and Society)

- A note on graphs – Much of the data collected lends itself to a graph with time as the independent variable (x-axis) and PV output, temperature, or amount of sunlight as the dependent variable (y-axis). However, to look at the data in a different way, encourage students to make graphs that have a different independent variable (x-axis). For example, students can graph the following correlations:

    - Average daily temperature (x-axis) and PV output (y-axis)
    - Amount of precipitation (x-axis) and PV output (y-axis)
    - Cloud cover (x-axis, more subjective) and PV output (y-axis)

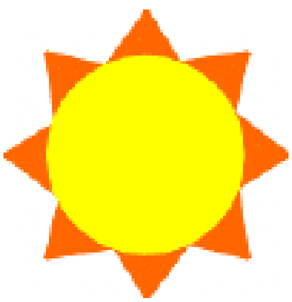
  Good for younger students and for weather correlations.

Recommended Websites and Weather Icons

www.Weather.com – the Weather Channel. Type in your zip code and you can get current weather conditions. If you click on "month" you can access the previous month's highs/lows, the current month's data (to date with a 10-day forecast), and next month's average highs/lows. You can also access archived hourly weather conditions for the past 5 days by clicking on an underlined day in the current month's calendar.

http://www.wattsonschools.com - This site and Soltrex both use the same interactive energy calculator. However, this site has good information and many other activities for classrooms to explore.

http://www.aperfectworld.org/weather.htm -Weather Clip Art (included below). Also a nice site for free clip art in general.



SUNNY

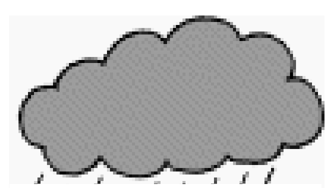
SUN and RAIN

SNOW

PARTLY SUNNY

MOSTLY CLOUDY

RAINY



**CLOUDY -
OVERCAST**