WindWise Education

Wind Energy Activities for Students

LESSON 7: CAN WIND POWER YOUR CLASSROOM?

WindWise Education Curriculum

ISBN 978-1-4951-4354-0

LESSON 7

CAN WIND POWER YOUR CLASSROOM?

KEY CONCEPT

Students conduct a simple energy audit for the classroom and estimate what size wind turbine could power their classroom under local wind conditions.

TIME REQUIRED

1–2 class periods

GRADES

6–8
9–12

SUBJECTS

Physical Science
Technology/Engineering
Mathematics

Kid Wind PROJECT

www.KidWind.org

BACKGROUND

The power coming from wind turbines varies with wind speed, just as the power we consume fluctuates throughout the day depending on what we turn on or plug in. This lesson will give students a sense of how much electricity they use on a daily basis and what it would take for a wind turbine to provide that amount of electricity. Students will learn how to determine how much power their classroom is consuming, analyze real wind turbine data, interpret wind speed and turbine power output graphs, understand basic wind energy economic concepts, and understand the difference between energy and power.

OBJECTIVES

At the end of this lesson, students will:

- understand the relationships among wind speeds, power generation, power consumption, and economic value
- know how to analyze wind data
- know how to interpret wind speed and power output graphs
- understand the difference between energy and power
- discuss energy consumption concepts

METHOD

Students will estimate classroom power consumption by adding the average power draw of all electronic appliances in the room. Next, students will examine wind energy data to understand the relationship between wind speed and turbine power output. Using these data, students can assess the potential and economic feasibility of powering their classroom or school with a wind turbine.

MATERIALS

- ❑ Real-time data from wind turbines (data websites or supplied data sheets*)
- ❑ Computer with Internet access
- ❑ LCD projector (recommended for displaying live data sites)
- ❑ Student reading passages and student worksheets*

Optional

- ❑ Classroom wind turbine models
- ❑ Box fans
- ❑ Wind speed meters
- ❑ Anemometer

*included in this activity

Additional Resources for every lesson can be found at http://learn.kidwind.org/windwise/. Resources include presentations, videos, extension activities, and other materials.

POWER

Watt (W)	Joules / Seconds
kilowatt (kW)	1000 Watts
megawatt (MW)	1,000,000 Watts

Students have been exposed to the concepts of energy and power. Take a few minutes to discuss and clarify the difference between these terms, as this can be very confusing. For helpful analogies and explanations, refer to the "Difference Between Energy and Power" table.

GETTING READY

- Before class, check out the various live data sites. Find 3–4 turbines of various sizes and in various geographic regions. If possible, find a turbine geographically close to your school.
- To save time during the classroom energy audit in Step 3 (Worksheet 1), make a list of all the electronic appliances in your classroom and how much power they draw. If you do not know this information, check out the "average power consumption" website found under additional resources.
- The energy audit can also be conducted in students' homes as a homework assignment. It might be simpler to look at one room at a time.

ACTIVITY

Step 1: Beginning questions for students

- What happens to a wind turbine as the wind speed increases? What if the wind stops?
- Is there such a thing as too much wind for a wind turbine? Could this be dangerous?
- How many watts would a wind turbine have to generate to power your whole home or classroom?
- How do homes with wind turbines get electricity when the wind is not blowing?
- What happens when a residential wind turbine produces more electricity than a home uses?

Step 2: Estimate classroom power consumption

Ask the students to look around the room and name all the things currently using electricity—lights, computers, projector, fans, clock, etc. List all of these electric devices in the table under Question 1 on the "Can Wind Power Your Classroom" worksheet (page 126).

Estimate the power draw (in watts) for each device, using the average power consumption website found under Additional Resources. How much electricity is required to power your classroom? How many kilowatts is this? (1 kilowatt = 1,000 watts.) Complete the table under Question 1.

Difference between energy and power

	ENERGY	POWER
	Quantity	**Rate**
Unit	Kilowatt-Hour (kWh)	Watt, kW, MW
Water Analogy	Gallons	Gal/Min
Car Analogy	Number of gallons of gas in the tank?	Engine HP
Wind Turbine Application	Electricity produced and sold to the utility company	Rated Capacity

Step 3: Sample wind turbine power output
Now look at the power curve for the wind turbine. Is this turbine capable of powering your whole classroom? What wind speed would be required for the turbine to power the classroom?

How often do you think the wind actually blows this fast? According to the "Wind Speed Probability" graph below, what percentage of the time does the wind blow this fast or faster? Answer Questions 2, 3, and 4 on the worksheet.

Step 4: Research your local wind speed
Find your current local wind speed. If you have an anemometer, you can measure the wind speed outside your school. If you do not have an anemometer, see the WindWise resources pages — http://learn.kidwind.org/windwise/ — to find websites to determine your current local wind speed

Look back to the wind turbine power curve. Based on your current local wind speed, how much electricity would the turbine produce if it were located near your school? Is this enough to power your classroom based on the energy audit you conducted previously? Answer Questions 5 on the worksheet.

Step 5: Analyzing sample wind turbine data
Using the sample wind turbine data (page 132) found in this lesson, answer the questions under the "Sample Wind Turbine Data" section of the worksheet.

Step 6: Analyzing live wind turbine data
Using the wind turbine data websites, answer the questions in the "Live Wind Turbine Data" section of the worksheet.

Step 7: Wrap up
Once students have finished their worksheets, follow up with these questions:

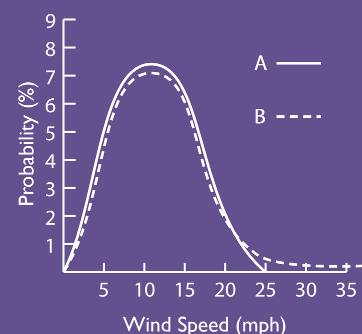
- How much electricity does your classroom draw?
- Estimate how much power your whole school might consume on average.
- Is the wind around your school adequate for a wind turbine?
- What are some ways you could use less electricity in your classroom?
- Should your school buy a wind turbine?

EXTENSION

Using Data to Understand Residential Wind Energy Economics
In many states, wind turbine owners can sell excess energy to the utility company. For example, in Minnesota, if a wind turbine produces more electricity than the owner consumes in a month, the utility company would send a check at the end of the month instead of a bill. Most states and Washington, D.C., have similar programs; some are state mandated and others are voluntarily offered by utilities.

Complete the Extension Activity Worksheet.

WIND SPEED PROBABILITY DISTRIBUTION



A wind speed probability (or distribution) graph shows the percentage of time the wind blows in a given range of wind speeds. While these two distribution curves may have the same "average" wind speed, a turbine sited at a location with curve "B" is likely to produce more energy over time due to the occurrence of higher wind speeds.

VOCABULARY

energy – The capacity for doing work; usable power (as heat or electricity); the resources for producing such power.

kilowatt (kW) – One thousand watts. A useful unit of power when discussing household electrical consumption. 1 kW = 1000W.

kilowatt-hour (kWh) – A unit of energy useful for quantifying household energy use. One kilowatt-hour of energy is equal to the power used at a rate of one kilowatt for a period of 1 hour.

megawatt (MW) – One million watts or one thousand kilowatts. This unit of power is useful when discussing industrial scale wind turbines or large power plants. 1MW = 1,000kW = 1,000,000W

megawatt-hour (MWh) – One million watt hours, a useful measure of energy when discussing large power plants and wind farms. 1 MWh = 1000 kWh

power – The rate at which energy changes form from one form to another, or the rate at which work is done.

power draw – The amount of electrical power used by an appliance. Measured in watts.

rated capacity – The maximum output rating of a wind generator. A wind turbine with a 1.5 MW rated capacity will produce a maximum of 1.5 MW.

watt (w) – A unit of electrical power, or how fast electrical energy is transformed into heat and or light. One electrical watt of power is equal to a current of one ampere times a potential difference of one volt. Power = amps times volts. ($P = I \times V$) One watt is equivalent to one joule of electrical energy transformed each second.

wind speed probability distribution – A graph showing the percentage of time that the wind blows at different wind speeds. The taller the bar, the more likely it is that the wind will blow at that wind speed. An important tool for predicting how much power a turbine will produce in a given location.

CAREER PROFILE: JOHN ANDERSON
SENIOR SYSTEM OPERATOR, MIDWEST ISO

An Independent System Operator (ISO) controls and monitors the operation of the electric power system of a state. My job is to simultaneously monitor and match electric consumption and production. If the generators (power plants) are producing more electricity than the cities and towns in the system are using, some power can be diverted to external systems that may not have enough electricity. If the generators are not making enough electricity, we can import some power from external systems. If there is too much electricity or not enough electricity to go around, this can lead to power outages.

As you have learned from this lesson, wind energy is a variable resource; the power coming from wind turbines varies with the wind speed. The variability of wind power makes my job interesting, but even more challenging, since a wind farm could go from producing 200 MW to 0 MW in a matter of minutes if the wind speed slows down. My coworkers and I must analyze wind forecasts to predict when a wind farm will be producing electricity and how much power it will be making. We also predict how much electricity consumers will be using at any time. The production and consumption of electricity has to match up.

To get an idea of the challenges I face in my job, try monitoring and controlling this virtual power grid: http://tcipg.mste.illinois.edu/applet/pg/. After you become familiar with the system, try the five challenges on the left sidebar.

Name______________________________ Date______________ Class________

CAN WIND POWER YOUR CLASSROOM?

watt (W)	joules / second
kilowatt (kW)	1000 watts
megawatt (MW)	1,000,000 watts

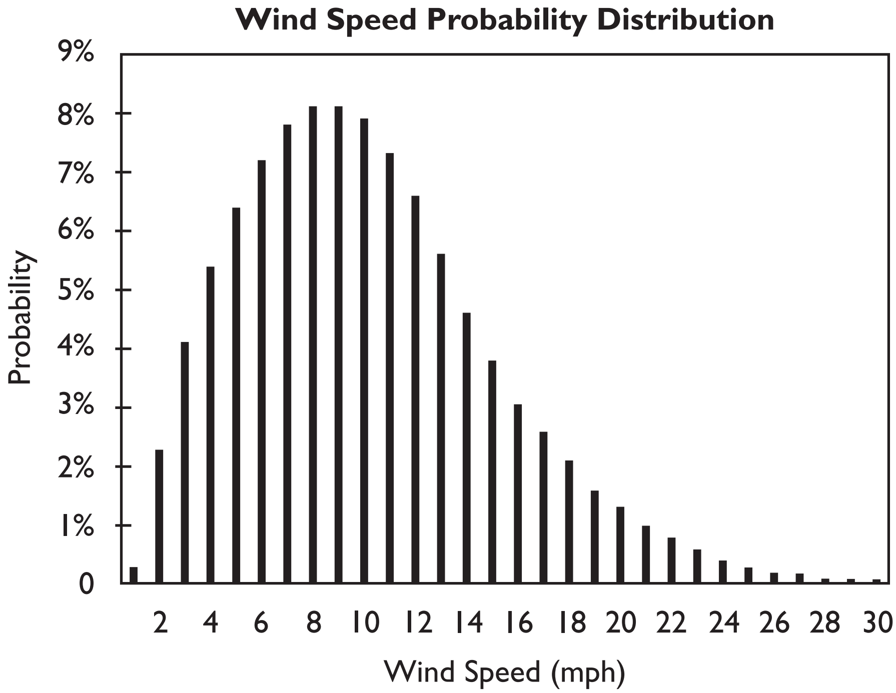
Do an energy audit for your classroom

1. Complete the table. List all the appliances and devices using electricity in your classroom. Estimate the total amount of electricity being used in the classroom right now (in watts). Find resources to help you estimate here: http://learn.kidwind.org/windwise/.

DEVICE	WATTS
TOTAL POWER	watts
	kilowatts (W/1000)

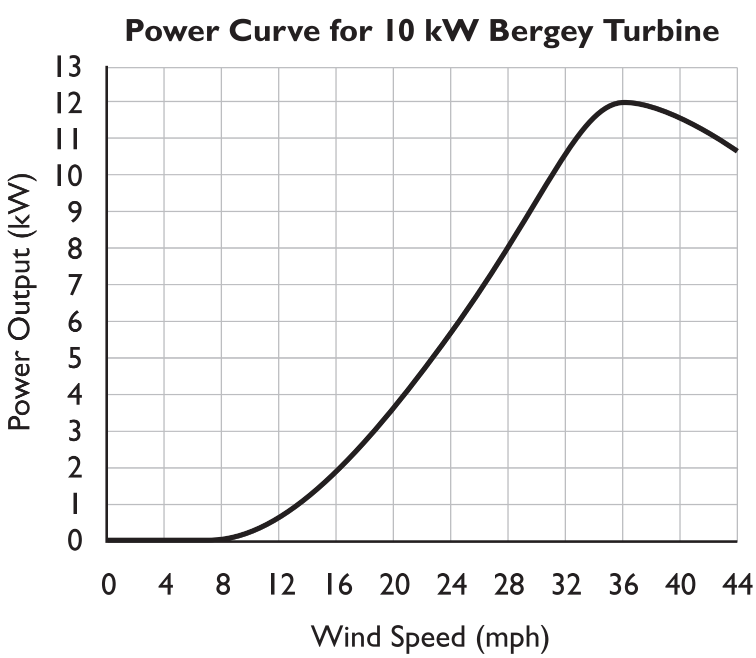
2. Look at the sample wind turbine power curve provided on the next page. Could this wind turbine make enough power for your classroom? (Remember: 1 kW = 1,000 watts.) If so, how fast does the wind have to be blowing to make enough electricity for your classroom?

3. Look at the "Wind Speed Probability Distribution" graph. What percentage of the time does the wind blow at the wind speed that you identified in your answer to Question 2? Is the wind normally faster or slower than this?



This curve shows the percentage of time that the wind blows at a given wind speed. The sum of the bars equals 100%. The taller the bar, the more likely it is that the wind will blow at the speed of that bar.

4. Examine the power curve and the wind speed percent of time graph. What percentage of the time does the wind blow at a speed that makes 4 kW on the power curve?



Name______________________________________ Date________________ Class_________

5. How fast is the wind currently blowing? (Use an anemometer or check here: www.wunderground.com) Would this be enough wind to power your classroom if you were using this turbine?

Sample wind turbine data

1. Look at the wind turbine data sheet. Imagine that wind turbine 3.A is outside your school powering your classroom. The wind is blowing at 4.5 mph, and the turbine is barely spinning and is producing 21 watts. What percentage of your classroom electric consumption is this turbine currently supplying?

2. Suddenly a cold-front starts coming through and the wind picks up to 18.9 mph. The turbine starts spinning very fast and is now producing 1.3 kW (1,300 watts). Is the turbine supplying enough electricity for your whole classroom now? If not, what percentage is it supplying?

3. Where do you think your electricity comes from when the wind turbine is not producing enough power for your classroom (what energy source or "fuel")?

Live wind turbine data

To answer these questions, find a turbine on the Internet producing live data.

1. Where is this wind turbine located?

2. What is the rated capacity of this turbine? (How many kW can it produce?)

3. How fast is the wind blowing? (mph *or* m/s?)

4. How much power (watts or kilowatts) is the turbine currently producing? What percentage of full capacity is this?

5. How much energy has the turbine made today? This week? This month? This year? (kWh)

6. Divide the energy produced this week by 168 (the number of hours in a week) to find the average power produced by the turbine.

7. Since you already know how much power your classroom uses on average, did this turbine produce enough electricity on average over the week to power your classroom?

Name______________________________ Date______________ Class________

CAN WIND POWER YOUR CLASSROOM? EXTENSION ACTIVITY

1. Electricity is bought and sold in units of energy such as kilowatt-hours (kWh). The average cost of electricity in the US today is about 11.4 cents per kWh. The average US household uses about 950 kWh in a month. That means that the average American spends about $108 per month on electricity! How much power is the average American house consuming at any given moment (in kW)?

2. Look at the "average monthly power output" on the sample wind turbine data sheets. Given that the average household uses about 950 kWh per month, which turbine would provide about all the electricity needed for a house?

3. Imagine your family uses the average amount of electricity in a month (950 kWh). You have turbine 2.A in your backyard, and this month it produced 912 kW. How much energy will your family pay for this month? If your electricity costs the average US price (11.4 cents per kWh), how much will you owe the utility company this month?

4. You are tired of paying electric bills, so your family starts conserving electricity. You swap out incandescent light bulbs, unplug your cell phone chargers, and switch off unused lights and power strips. The next month you have reduced your consumption to 800 kWh. Congratulations! It also happened to be a very windy month, and your turbine produced 1,025 kWh. At the end of the month, the utility company will pay you the wholesale rate of electricity (4.5 cents per kWh) for your net excess generated electricity.

    a. How much money will the utility company owe you at the end of the month?

    b. If you did not have a wind turbine and you had to buy all of your electricity from the utility company, how much would you have owed this month?

5. Explain the change that Independent Service Operator Jim Anderson would have noticed when your family stopped purchasing electricity from the utility company and began selling excess energy instead.

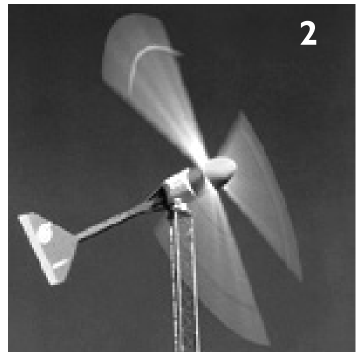
WIND TURBINE DATA SHEETS FOR WINDWISE LESSON

1.A

Turbine Rated Capacity	100 kW
Wind Speed	13.1 mph
Power Output	14.3 kW
Generated Today	23 kWh
Generated This Year	57,340 kWh
Average Monthly Energy Output	6,332 kWh

1.B

Turbine Rated Capacity	100 kW
Wind Speed	20.3 mph
Power Output	60.0 kW
Generated Today	225 kWh
Generated This Year	57,993 kWh
Average Monthly Energy Output	6,404 kWh



2.A

Turbine Rated Capacity	10 kW
Wind Speed	12 mph
Power Output	1 kW
Generated Today	4.6 kWh
Generated This Year	11,122 kWh
Average Monthly Energy Output	930 kWh

2.B

Turbine Rated Capacity	10 kW
Wind Speed	24.1 mph
Power Output	5.7 kW
Generated Today	19.2 kWh
Generated This Year	12,083 kWh
Average Monthly Energy Output	1010 kWh

3.A

Turbine Rated Capacity	1.8 kW
Current Wind Speed	4.5 mph
Current Power Output	21 watts (0.021 kW)
Generated Today	2.2 kWh
Generated This Year	1,916 kWh
Average Monthly Energy Output	177 kWh

3.B

Turbine Rated Capacity	1.8 kW
Wind Speed	18.9 mph
Power Output	1.3 kW
Generated Today	5.1 kWh
Generated This Year	2,596 kWh
Average Monthly Energy Output	240 kWh

4.A

Turbine Rated Capacity	20 kW
Wind Speed	9.3 mph
Power Output	1.3 kW
Generated Today	7.7 kWh
Generated This Year	19482 kWh
Average Monthly Energy Output	1766 kWh

4.B

Turbine Rated Capacity	20 kW
Wind Speed	21.6 mph
Power Output	11.8 kW
Generated Today	46.7 kWh
Generated This Year	21,322 kWh
Average Monthly Energy Output	1810 kWh

CAN WIND POWER YOUR CLASSROOM?

Do an energy audit for your classroom

1. Complete the table. List all the appliances and devices using electricity in your classroom. Estimate the total amount of electricity being used in the classroom right now (in watts). Use this website to help you estimate: www.absak.com/library/power-consumption-table
   Student observations

2. Look at the wind turbine power curve. Could this wind turbine make enough power for your classroom? (Remember: 1 kW = 1,000 watts) If so, how fast does the wind have to be blowing to make enough electricity for your classroom?
   Yes, this turbine should be able to power your classroom. Wind speed required will vary depending on your consumption, most likely between 12 and 20 mph.

3. Look at the "Wind Speed Probability Distribution" graph. What percentage of the time does the wind blow at the wind speed that you supplied in your answer to Question 2? Is the wind normally faster or slower than this?
   Answers will vary. This should be between 1 percent and 6 percent. Wind is normally slower than this.

4. Examine the power curve and the wind speed probability graph. What percentage of the time does the wind blow at a speed that makes 4 kW on the power curve?
   According to the power curve, the turbine will make 4 kW at 21 mph. According to the wind speed probability curve, the wind blows at 21 mph 1 percent of the time.

5. How fast is the wind currently blowing? (Use an anemometer or check here: www.wunderground.com) Is this enough wind to power your classroom if you were using this turbine?
   Student observation

Sample wind turbine data

1. Look at the wind turbine data sheet. Imagine that wind turbine 3.A is outside your school powering your classroom. The wind is blowing at 4.5 mph, and the turbine is barely spinning and is producing 21 watts. What percentage of your classroom electric consumption is this turbine currently supplying?
   Answers will vary depending on electric consumption, but this will be a VERY small percentage.

2. Suddenly a cold-front starts coming through and the wind picks up to 18.9 mph. The turbine starts spinning very fast and is now producing 1.3 kW (1,300 watts). Is the turbine supplying enough electricity for your whole classroom now? If not, what percentage is it supplying?
   Answers will vary, but this will be a larger percentage, possibly more than enough electricity.

3. Where do you think your electricity comes from when the wind turbine is not producing enough power for you classroom (what energy source or "fuel")?
   Acceptable answers include: coal, nuclear, natural gas, hydroelectric, solar, oil, etc.

Live wind turbine data

To answer these questions, find a turbine on the Internet producing live data.

1. Where is this wind turbine located?

   Student observations

2. What is the rated capacity of this turbine? (How many kW can it produce?)

   Student observations

3. How fast is the wind blowing (mph *or* m/s)?

   Student observations

4. How much power (watts or kilowatts) is the turbine currently producing? What percentage of the full capacity is this?

   Student observations

5. How much energy has the turbine made today? This week? This month? This year? (kWh)

   Student observations

6. Divide the energy produced this week by 168 (the number of hours in a week) to find the average power produced by the turbine.

   Student observations

7. Since you already know how much power your classroom uses on average, did this turbine produce enough electricity on average over the week to power your classroom?

   Student observations

CAN WIND POWER YOUR CLASSROOM? EXTENSION ACTIVITY

1. Electricity is bought and sold in units of energy such as kilowatt-hours (kWh). The average cost of electricity in the US today is about 11.4 cents per kWh. The average US household uses about 950 kWh in a month. That means that the average American spends about $108 per month on electricity! How much power is the average American house consuming at any given moment (in kW)?

   950 kWh per month / 30 days in a month / 24 hours in a day = 1.32 kW

2. Look at the "average monthly power output" on the sample wind turbine data sheets. Given that the average household uses about 950 kWh per month, which turbine would provide about all the electricity needed for a house?

   Turbines 1A, 1B, 2B, 4A, 4B

3. Imagine your family uses the average amount of electricity in a month (950 kWh). You have turbine 2.A in your backyard, and this month it produced 912 kW. How much energy will your family pay for this month? If your electricity costs the average US price (11.4 cents per kWh), how much will you owe the utility company this month?

   Your family would pay for (950 – 912) = 38 kWh this month. 38 kWh x $0.114 = $4.33

4. You are tired of paying electric bills, so your family starts conserving electricity. You swap out incandescent light bulbs, unplug your cell phone chargers, and switch off unused lights and power strips. The next month you have reduced your consumption to 800 kWh. Congratulations! It also happened to be a very windy month, and your turbine produced 1,025 kWh. At the end of the month, the

utility company will pay you the wholesale rate of electricity (4.5 cents per kWh) for your net excess generated electricity.

a. How much money will the utility company owe you at the end of the month?
1,025 – 800 = 225 kWh sold. 225 kWh x $0.045 = $10.13

b. If you did not have a wind turbine and you had to buy all of your electricity from the utility company, how much would you have owed this month?
800 x $0.114 = $91.20

5. Explain the change that Independent Service Operator Jim Anderson would have noticed when your family stopped purchasing electricity from the utility company and began selling excess energy instead.
If you stopped buying electricity from the utility company, the Independent System Operator (ISO) would notice a slight decrease in demand for electricity from the grid. If you were selling your excess energy to the utility company, the ISO would have another source of electricity to draw from to meet electric demand.

COLLECTING WIND SPEED DATA AT YOUR SCHOOL

BACKGROUND

Wind speed data is vital to understanding how much energy a wind turbine could produce at a particular site. While you can find general wind data on a number of weather websites, it will usually not be very accurate or relate to your exact location. This lesson helps you collect and analyze wind data from your location using some fairly inexpensive hardware and software.

Wind engineers use anemometers, towers, and sophisticated data logging systems to collect at least a year of data before they install a large wind farm. While this kind of equipment is expensive ($20,000+), it is much cheaper than installing a $1,500,000 wind turbine based on simulated or modeled data.

For smaller wind turbines installed at houses and farms, less data is collected as the costs could be more than the turbine! For these smaller scale systems, homeowners try to find wind speed information from a variety of online sources and make decisions based on the best data they can collect.

Recently some new wind data loggers have become available that make collecting data at your school more affordable and easier to analyze. In this lesson we will explore these tools and how to use them to collect and analyze the promise of a site for wind power.

Please keep in mind that to perform the data collection part of this lesson, you will need to purchase some type of wind data logger. We have suggested a few that are carried at KidWind, but there are many others to choose from. All provide data of varying degrees of accuracy and detail.

OBJECTIVES OF THIS ACTIVITY

Students will learn:

- how to collect and analyze local wind data
- tools used to collect data
- how to graph wind data
- important wind data variables

SUGGESTED LEVEL

High School

TIME REQUIRED

2–3 Class Periods for data analysis
Weeks or Months to Collect Wind Data

MATERIALS REQUIRED

- ❑ wind speed data logger (A variety are described in the lesson)
- ❑ computer with Microsoft Excel or other spreadsheet software

COLLECTING WIND DATA

There are ways to find wind data about your location that do not require you to install a data logging anemometer. Some of these online sources are free and others can be quite expensive, based on the quality of the data.

The list below outlines some online locations where you can start searching for wind data close to your site.

Websites

- Wind Powering America State Maps: http://apps2.eere.energy.gov/wind/windexchange/wind_maps.asp
- Wind maps in your state can be found through search engines. For example, search for: "Wind Map Minnesota."
- Websites for local airports or municipal offices

For siting a small wind turbine at your school, online data will work as long as you can find a location close enough to your school and with similar topography, also consulting with a local wind installer. But this would be too easy!

We encourage you to install an anemometer with a data logging system because analyzing this data can be a very informative process.

To collect wind data, you will need a data collection system. These systems can vary in cost from $100–$1,000. The more you pay, the more data you can collect, the more analysis you can perform, and the more accurate it becomes. There are a number of new systems available from $300–$500 that are quite adequate for collecting and analyzing local wind data. It's not hard; give it a try!

WIND DATA COLLECTION TOOLS

Smartphone Anemometers

Recently a few companies have developed anemometers for smartphones. Vavuud (http://vaavud.com/) makes an affordable smartphone anemometer that can record windspeed and direction over short amounts of time. This data is stored online and can be used with maps within the Vaavud phone app.

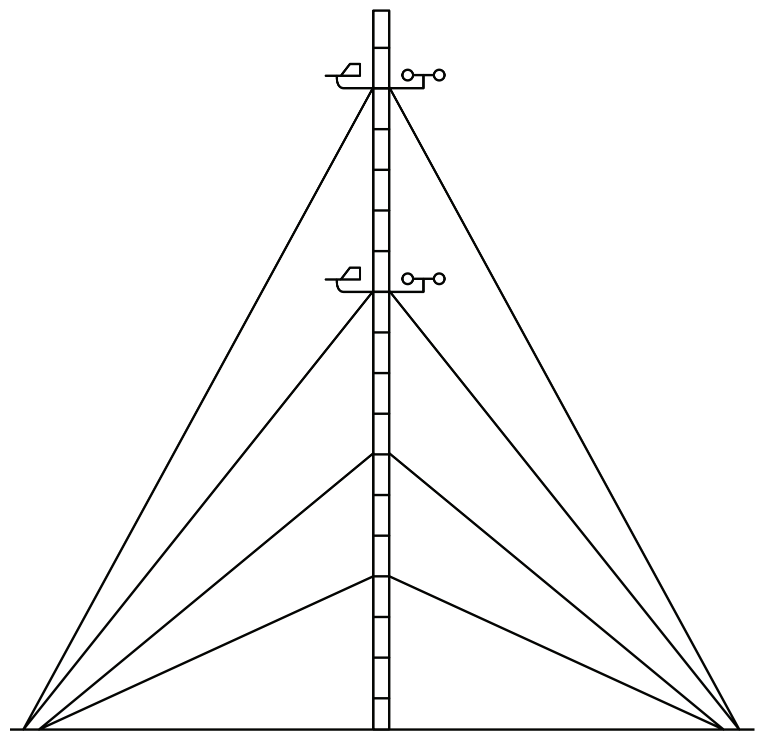
InSpeed Anemometers (www.inspeed.com)

InSpeed is a small US-based company that manufactures specialized anemometers and data loggers. They offer a wide variety of products to measure and record wind speed data. The items listed below could be used to collect and analyze local wind data.

Vortex Pole Mount ($100)

This kit includes an anemometer with digital display made from a bike computer. You can mount the sensor on a pole or tripod near a field or a building where you might install a turbine. The anemometer will record wind speeds up to 100 mph and is powered by a coin battery lasting several months under typical use. With this device you can continuously monitor wind speed, maximum speed, and average speed. This anemometer is great for applications where AC power is not available and for when directional data is not needed. We have used this device to log "wind miles" in a day, a week, or a month. Divide the "wind miles" by the number of hours the device has been collecting data and calculate the average wind speed in miles/hour (or kilometers/hour).

WindWorks Data Logging Kit ($290)
If you want a data logging system, the WindWorks platform provides comprehensive, accurate wind speed and direction data. It is compatible with the Inspeed Vortex wind sensor and electronic e-Vane, and includes interface electronics with USB cable and WindWorks software. One of the limitations is that you will need to have the interface plugged into a computer that is always on. The computer will also need to be near where you are in order to mount the wind and direction sensors. This can be problematic if your site is far from your classroom.


Commercial anemometer tower

Davis Weather Stations (www.davisnet.com/weather) ($500–$1,000)
Davis sells a number of home and business weather systems that can log wind and temperature data to a computer that is connected (by wire or wirelessly) to your weather system.

The data that is collected is transferable to Excel so you can do some basic analysis.

Logic Energy WindTracker (www.windlogger.co.uk/products/windtracker-unit-1) ($300)
Logic Energy makes a very robust data logger that can be used with anemometers made by Davis or InSpeed. Data is stored to a logger that does not need to be connected to a computer. This device is designed so that the logger can take data from two anemometers simultaneously, allowing you to measure wind shear. Stored data is collected on an SD card and can then be transferred to your computer for analysis. Once you have copied the data to your computer, it can be analyzed using Excel, software included with the Logic Energy data logger, or other tools.

Windographer Software (www.windographer.com) ($400)
For more sophisticated analysis of wind data, we recommend Windographer software. Windographer is the industry leading tool for analyzing wind resource data. This intuitive software is extremely powerful and allows for an in-depth understanding of the wind resource in your area.

Once you have collected enough data, the software will allow you to visualize frequency distributions, wind roses, and shear. (These will be explored in the next section.) It calculates the air density, wind power density, turbulence intensity, power law exponent, and surface roughness for every time step. This software also lets you visualize and analyze data collected in many graphical formats. Lastly, you can apply this data to a variety of turbine power curves and see how much energy a turbine would produce at your school. This is the software that the professionals use!

ANALYZING THE DATA

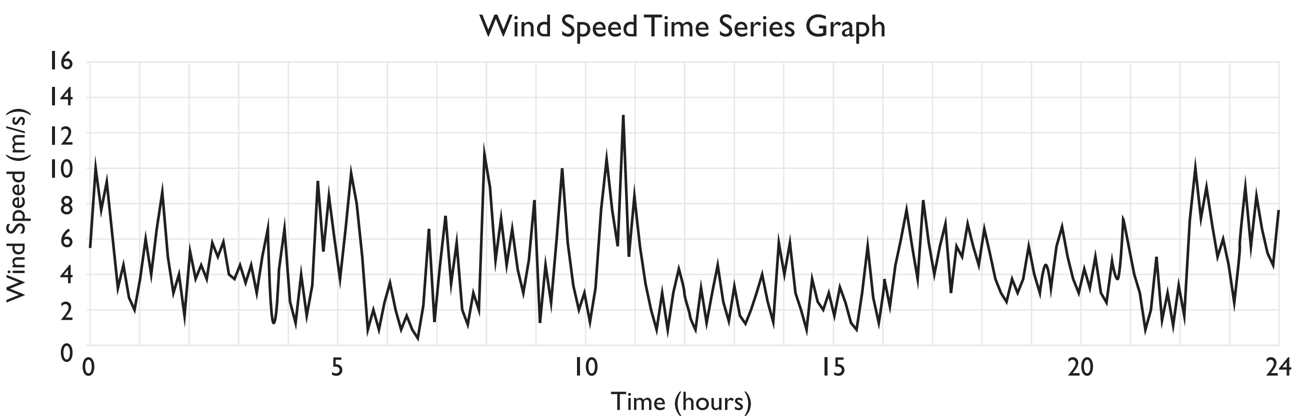
Once you have collected data, you need to perform analysis to see if your location is a high quality wind site. If you were planning to build a large wind farm, you would collect data for at least a year, probably more. For small wind sites or experimentation, you can collect data for any time frame you find interesting. Collecting a year of data would allow you to explore seasonal variability. You could also compare potential sites around the school simultaneously.

Let's assume you have collected piles of data. Below are some ways you can analyze your data. You can use Excel to perform some of these functions or purchase commercial software like Windographer.

SIMPLE WAYS TO ANALYZE WIND DATA

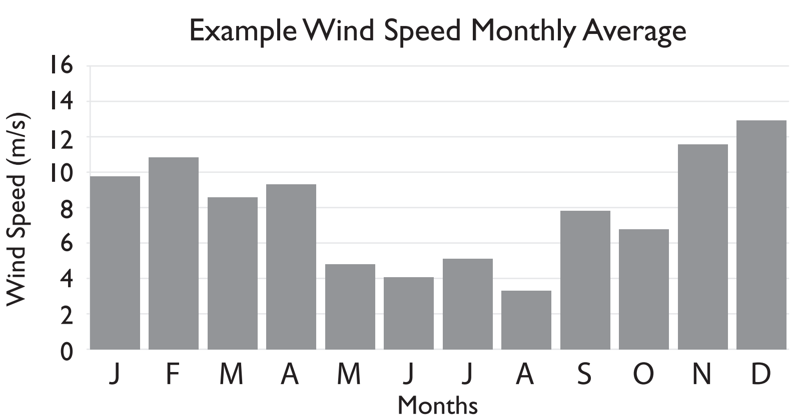
Time Series

This is a graph showing wind speed variation over a short period of time such as a day. This type of graph can give you some insight into the steadiness of your winds and their temporal variability. You can use Excel to generate these graphs.

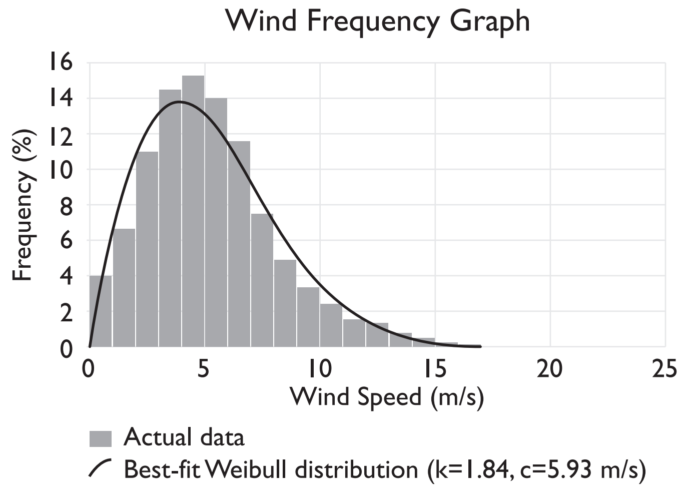


Monthly averages

By calculating daily, monthly, or weekly averages, you can explore daily or seasonal variations, answering questions like: When is it windier at our site? Morning or Night? Winter, fall, spring or summer? Use Excel to generate this data using the AVERAGE function.

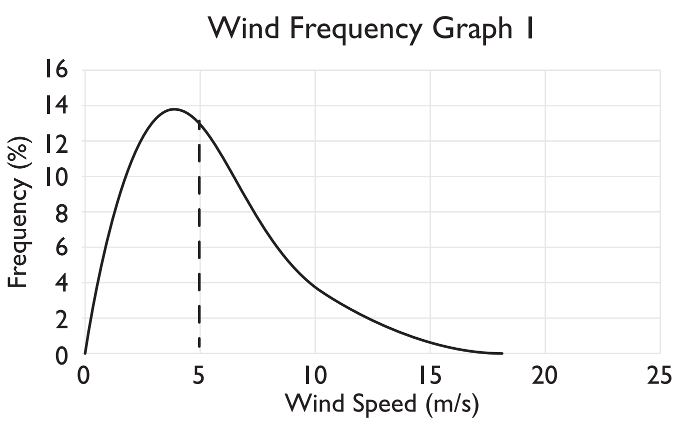


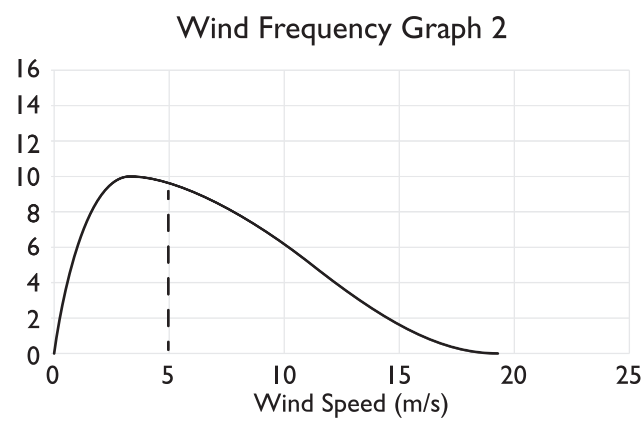
Wind Speed Distributions/Frequency
A frequency graph shows the percentage of time the wind has blown in a given velocity range. Understanding the frequency of wind speeds will offer you a better picture of the winds found at your site. The highest percentage may differ from the average wind speed, which can be important when determining how much energy you can generate. You can use Excel to generate this data using the function, but it can be a bit complicated to set up this analysis.



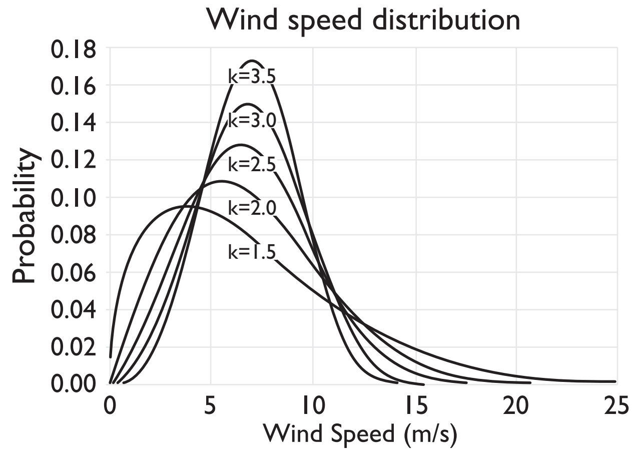
Why does the frequency matter?
Assume that you have two sites that have the same average wind speed, but one site may have lots of high wind-speed readings coupled with low wind-speed readings (the "either it's blowing or it isn't" phenomenon). The other site might have wind speeds clustered around the average. Even though the averages are the same, the site with the really high wind speeds will probably produce more electricity over the course of a year; this is due to how you calculate power in the wind (more on this later). See Lesson 7 for more information about wind speed and power output.

The graphs below show two locations with the same average wind speed but very different distributions. These distributions of wind would produce very different amounts of energy as the line with a value K=3.5 does not have as many high wind speeds as the K=1.5.





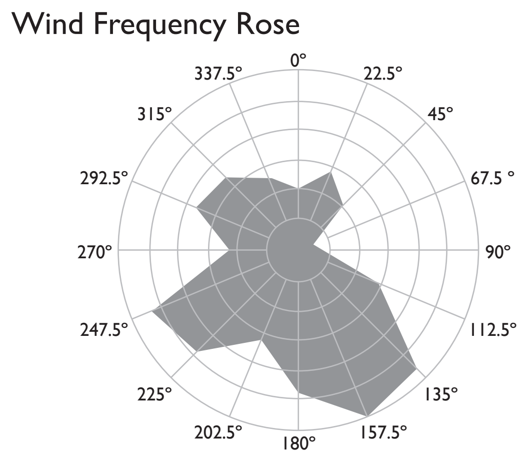
How does distribution affect energy output?
If you did not perform a frequency analysis before siting a wind farm, you could significantly underestimate or overestimate your production by using the average wind speed. The power in high wind speeds is vastly greater due to the fact the power in the wind is determined by the velocity cubed.



MORE ADVANCED WAYS TO ANALYZE WIND DATA

While you can use Excel to perform some of this advanced data analysis, this is where Windographer and other programs really show off their talents. Once you import the data, the software does all the work! Many of the images in this section are from Windographer software, using data from KidWind HQ in fall 2011.

Wind rose
A diagram that depicts the percent of time the wind comes from a particular direction and the average speed from that direction. This data can be very useful in siting turbines in complex topographies with building and other structures.



Wind shear and turbulence
Wind engineers usually place towers with three or four anemometers recording data at different heights above the ground. Wind speeds are typically faster and cleaner at greater heights as friction (ground drag) effects are reduced.

Understanding shear and wind speed
As altitude increases, the wind speed typically increases due to reduced friction between the moving air and the ground. There is a simple equation we can use to determine how much faster the wind is moving at altitude. This is critical as often we cannot install our anemometers at the same height we will be installing our wind turbine.

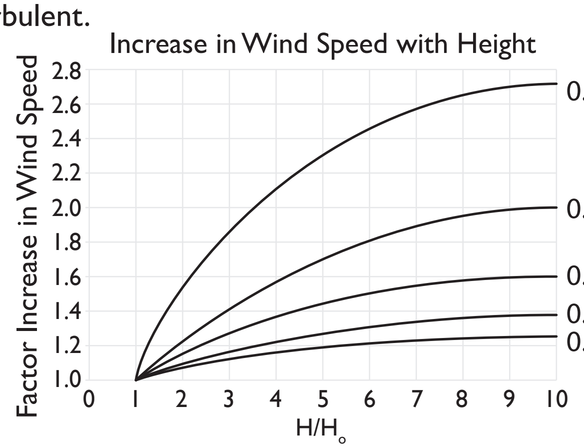
Calculating Wind Shear
V = wind speed at new height
V_o = wind speed at original height
H = new height
H_o = original height
a = wind shear exponent

$$\frac{V}{V_o} = \left(\frac{H}{H_o}\right)^a$$

We can record wind velocity at a standard height quite easily using mounted anemometers. The wind shear exponent is a factor of how rough a surface the wind is blowing over. A smooth surface, like an ocean or ice, might have a shear exponent of .07. A rough surface, like suburbs or forests, may have a value of 0.4.

If we know that that wind is blowing over a flat surface like the ocean at 3 m/s at 5 meters in height, we can figure out how fast the wind is blowing at 50 meters. Solve for V and we find that wind velocity at 50 meters is around 3.5 m/s or around 16 percent faster.

As height increases (in this case the ratio of H/H_o), wind speed increases. This also shows that over rougher surfaces with a higher shear exponent, this increase in speed can be dramatic. With a shear value of .4 (as with suburbs or woods), winds can be two times faster at seven times the height. The problem is that with a high shear factor, these winds may be quite turbulent.



APPLYING YOUR WIND DATA

Why all this worry about wind speed, distribution and direction?

Wind engineers care about wind speed because the power that can be extracted from the wind relies primarily on velocity. This is why engineers spend so much time collecting wind data. Wind is fuel for the wind turbine, and the engineers and bankers need to understand how much fuel they have before they invest in constructing a wind farm! Residential owners should do the same so they do not install a wind turbine in a bad location.

The power in the wind is described by the following equation:

$$P=\frac{1}{2}\rho AV^3$$

ρ= density of the air (kg/m^3) (1.2754 kg/m^3 at standard temperature and pressure)

A = area of turbine blades (m^2) (calculated $A=\pi r^2$ for the wind turbine you want to install)

V = wind velocity (m/s)

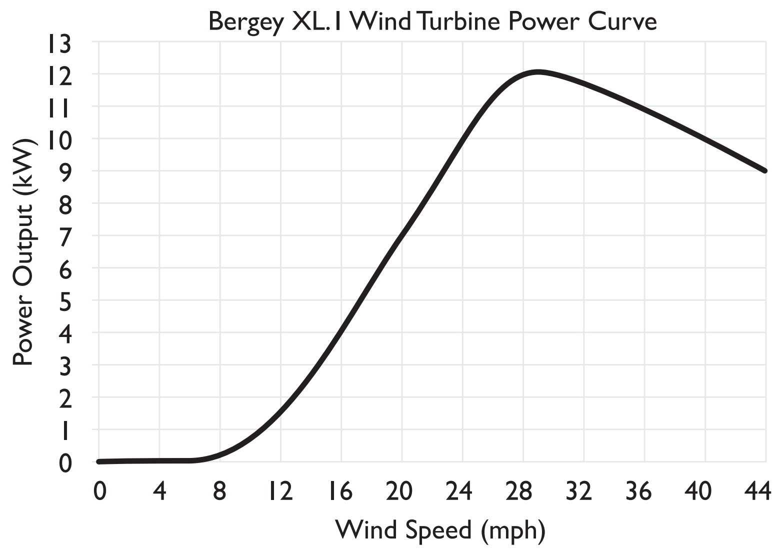
This equation allows you to calculate how much power is available in wind moving at a specific instantaneous velocity. Power output depends on two main variables: how fast the wind is moving and the swept area of your turbine. Look closely at this equation, above. A doubling of wind speed leads to eight times the amount of power due to the cubic function of velocity. This variable can make a huge difference and determines where developers site wind farms.

This equation sets the maximum amount of power that could be generated based on the velocity of the wind and the size of the column of wind being measured. In reality, wind turbines do not generate this much power because we cannot convert 100 percent of the wind into usable power. Most engineers are happy if their turbines can extract 40 percent to 45 percent of this maximum!

HOW MUCH POWER WILL MY TURBINE GENERATE IN THESE WINDS?

Wind power curves describe how much power a particular wind turbine can extract from the wind at a variety of different wind speeds. While these curves share a similar shape, they are specific to a particular turbine and offer insights when choosing a wind turbine for an individual location.

To the right is a basic wind power output curve for a Bergey XL.1 small wind turbine. From these types of curves, you can tell a great deal about the characteristics of a particular turbine such as when it will start making power, its maximum power output, and in what type of wind regime it will comfortably generate power.



Cut-in speed

This is the wind speed at which the wind transfers enough force to the blades to rotate the generator shaft. This number takes into account how smoothly the generator operates, the number and design of blades, and whether or not there are any gears or other frictional elements in the drivetrain.

Start-up wind speed

At the start-up wind speed, the wind turbine blades are moving fast enough and with enough torque that the turbine will start to generate electricity. While these numbers are pretty close to the cut-in speed, they are not the same. On a Bergey XL.1, the cut-in speed is around 5.6 mph, but the start-up wind speed is a little over 6.5 mph. While the wind turbine may be generating some electricity, at 5.5 mph it may not be enough to charge batteries or a sustain a connection to the electrical grid.

Maximum power output

This is the maximum amount of power the turbine can produce and is the peaking part of the curve. The maximum amount of power this turbine can produce is around 1,200 watts (1.2 kW) at about 29 mph.

The rated power (or nameplate output) for this turbine is 1,000 watts (1 kW) and, as shown in the graph this happens at around 24 mph.

These links will take you to some specification information from a variety of small turbine manufactures. You can examine their output curves and read more about the characteristics of small wind turbines. Some major manufacturers of small and large wind turbines include:

Bergey Windpower	http://bergey.com
Xzeres Wind	www.windenergy.com/
GE Windpower	https://renewables.gepower.com/wind-energy.html
Vestas	www.vestas.com
Suzlon	www.suzlon.com

HOW MUCH ENERGY WILL MY WIND TURBINE PRODUCE?

All the previous work leads us to the real question! The power a turbine can produce is helpful, but it does not tell you how much energy the turbine will produce. That is determined by how fast the wind blows and how much time wind is blowing that fast; that is why the frequency curve is so important. A huge wind turbine put in a place with no wind makes no energy! A small wind turbine put in a windy place produces lots of energy. When you are shopping for a wind turbine, it is more important to calculate how much it will produce, not its maximum output.

Combining the data you have collected about wind speed distribution with a wind turbine power curve will allow you to predict the amount of energy that the turbine could produce at your site. You could do this using Excel, but there are many specialized programs that make this calculation very easy. For example, once Windographer collates your frequency data, you can quickly calculate predicted energy output for a wide range of wind turbines.

CONCLUSION

Collecting and analyzing wind data can be quite a rich experience for students. Understanding the wind resource is critical to determining whether or not a particular site is appropriate for wind energy. Using some basic tools and analysis, students can get an idea of the wind energy potential of a site.