Colorado Wind for Schools Curriculum For Middle and High Schools

Colorado State University
Extension

Colorado Wind for Schools Curriculum for Middle and High Schools

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INTRODUCTION AND ACKNOWLEDGEMENTS

Introduction

Congratulations! Your school has a Wind for Schools turbine. People who see your turbine will have lots of ideas about its value, but one of the things they may not think of right away is that your school turbine provides your students, teachers and staff a great chance to observe, collect and analyze data, and practice drawing and supporting conclusions. This little curriculum just scratches the surface of things you could do with turbine data, so its purpose is to introduce a few topics and then inspire you to dig deeper. The math that is used in these activities is mostly applied. However, most of the math based activities can be expanded to include trigonometry and calculus. References in the Resource section will show you where to find higher math applications.

What if your school does not have a turbine? There are multiple opportunities for students to access and apply data from Colorado Wind for Schools turbines, as well as those from other states around the country. Many of these activities can be done with data from the Wind for Schools website. There are instructions for accessing this data in both the Primer and the Appendices.

While many of our Wind for Schools partners already know about the Wind for Schools program, here is a short introduction for those who are unfamiliar with this program. One of the goals of this curriculum is to make the data from these school turbines more widely available in order to give students a chance to work with real time turbine data.

The U. S. Department of Energy's Wind Powering America and the National Renewable Energy Laboratory (NREL) launched the Wind for Schools project in 2005 with a small pilot project in Walsenburg, Colorado that included the installation of one small wind turbine, the development of some wind energy curriculum and the creation of great enthusiasm for the future potential of the Wind for Schools project.

The Wind for Schools project goals are to:

- Equip college juniors and seniors with an education in wind energy applications
- Engage America's communities in wind energy applications, benefits, and challenges
- Introduce teachers and students to wind energy.

The general approach of the Wind for Schools project is to install small wind turbines at rural elementary and secondary host schools while developing Wind Application Centers at higher education institutions. Teacher training and hands-on curricula are implemented at each host school to bring the wind turbine into the classroom. The Wind for Schools project built on the success in Walsenburg and, in 2012, had installed over 120 systems in rural K-12 schools in 11 states (Alaska, Arizona, Colorado, Idaho, Kansas, Montana, North Carolina, Nebraska, Pennsylvania, South Dakota, and Virginia.) The Wind Application Center in Colorado is located on the Colorado State University campus. Students at the Wind Application Centers act as wind energy consultants, assisting in the assessment, design, and installation of the small wind systems at the host schools. They also participate in class work and other engineering projects in the wind energy field, preparing them to enter the wind workforce once they graduate.

Providing educational opportunities at the primary and secondary level is also crucial to the project's aim of developing a workforce for the future. This aspect is completed by implementing age-appropriate curricula such as this one and others like the NEED Project (http://www.need.org) and KidWind (http://learn.kidwind.org/teach).

The purpose of this Colorado-based curriculum is to provide procedures and activities that will allow students and teachers to use real time or archived data from the Wind for Schools turbines to explore topics in science, engineering, math and technology and to give them the skills to develop their own activities around their school turbines.

Acknowledgements

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Christy Fitzpatrick, Regional STEM Specialist for CSU Extension, led the development of this curriculum along with Co-PIs Front Range STEM specialist Claire Dixon, and Cary Weiner, CSU Clean Energy Specialist. The Project Team gratefully acknowledges the significant contributions of Michael Kostrzewa, Director of the CSU Wind Application Center.

The Wind For Schools turbine at Cherry Valley Elementary School

Superclusters™ Clean Energy

HOW TO USE THIS CURRICULUM

How to Use This Curriculum

The curriculum is primarily intended for middle and high school science and math teachers and informal energy and 4-H educators, but it can be utilized by social science and other teachers as well. We have designed it to be flexible and practical, and have included suggestions for teachers to make use of the material in a number of different ways.

Primer
The primer is intended for both students and teachers. It can be used to prepare teachers to introduce and execute lessons with proper background knowledge, but can also be used to provide reading selections for students.

Colorado Academic Standards Matrices
The standards matrices provide at-a-glance looks at which lessons meet Colorado state academic standards (evidence outcomes) for science, math, and social studies (as adopted in December 2009).

If using this curriculum to meet state standards is your primary objective, choose your lessons based on these matrices. Keep in mind that although some lessons may address standards from multiple grade levels, they may need to be adapted in order to be age appropriate.

Lesson Plan Logic
It should be noted that the lessons are intended both to be "stand-alone" and to work in conjunction with one another. In other words, an individual lesson can be taught without the need to teach other lessons from the curriculum or lessons can be strung together in order to present a more comprehensive picture of energy.

Lesson Plan Suggestions
Suggested combinations of lesson plans include:

- "Getting to Know Your Turbine" activity with any other lesson plan
- "Modeling Power Efficiency and Tip Speed Ratios" after both "Power in Practice and Theory" and "Tip Top Tip Speed"

Students should be familiar with units of energy before participating in the more technical lessons.

Lesson Plan Content
While much of the lesson plan makeup is straightforward, it is important to have some understanding of certain parts of the lesson plan template.

First, Grade Level is listed according to standards met in any subject area. Check the standards matrices to see if a given lesson plan meets standards for your subject and grade level. In addition, teachers may find that certain lessons can be adapted in order to meets the needs of their students in a certain grade.

Materials are listed and an estimated cost is provided according to what is recommended for each group of students and what is recommended for the class as a whole. Of course, this list may change depending on how many students are in a class and the resources available to a teacher.

In terms of Duration, a class period is assumed to be about 40 minutes. Most lessons give a range of class periods as a Duration (i.e. 1-2 class periods) since it will vary based on how the teacher decides to assign and review the activities and activity sheets. While the activities themselves are only appropriate for the classroom, activity sheets can often be completed as homework and can either be graded individually or reviewed together as a class and even expanded upon once reviewed. For these reasons, the Duration is often given as a range.

The Primer section of each lesson plan lists only the units of the Primer of most relevance to the lesson. This material can either be copied and provided to students as reading or used by the teacher as context for the lessons depending on the specific lesson and the inclination of the teacher. It may be helpful to include additional primer material not listed for the lesson in some cases as well.

The next sections – from Engagement to Elaboration – follow the inquiry-based 5-E Learning Cycle but allow teachers to design their own evaluation techniques (this fifth E is not covered here):

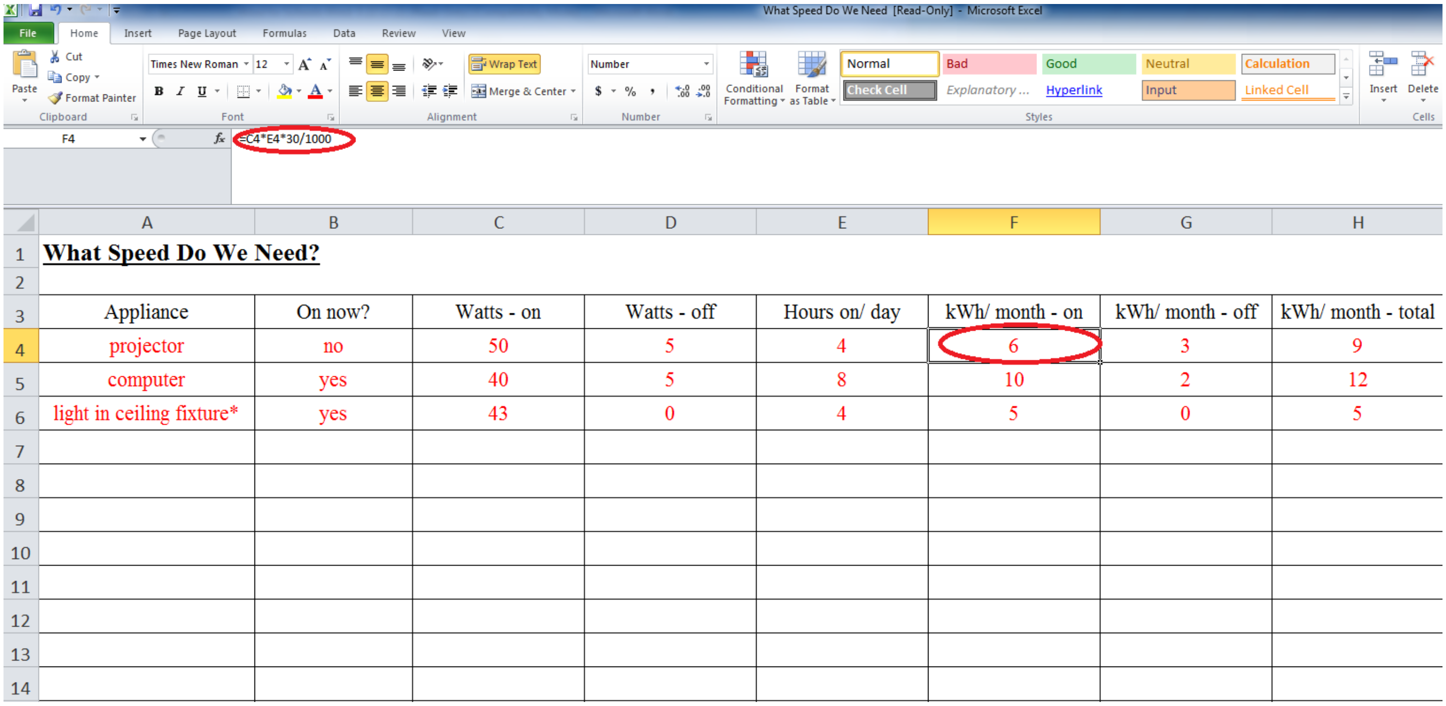
- The list of **Engagement** questions are designed to engage students through asking questions with real-world implications that initially don't need to be answered by the teacher.
- The Investigation section allows the students to conduct a hands-on activity and use Activity Sheets (*see below*) in order to "**explore**" answers to those questions experimentally through science.
- The Class Review consists of teachers asking students to share their findings from their activity/experiment with the rest of the class in order to see and understand similarities and differences in results with clarification and "**explanation**" from the readings and/or teacher.
- The Elaboration section requires students to go deeper ("**elaborate**") into the larger, more generalizable scientific theories behind their explorations in order to learn how the lesson can be applied to other real-world examples.
- The **Evaluation** is left to the teacher.

Activity Sheets

Activity Sheets (using Microsoft Excel) are provided both in blank form for student handouts and electronically (www.ext.colostate.edu/energy/k12.html) with sample data, formulas, and calculations for teacher use. Typically, Activity Sheets require students to enter experimental or research data in a table at the top of the sheet. That raw data is then used as the basis of calculations going from left to right across the Sheet. The raw data and calculations provide the evidence needed to help answer initial Inquiry questions, such as "What are the costs and benefits of renewable energy systems?".

Once all raw data is collected for a given lesson, calculations can be performed either in class or as homework. The list of Assumptions provided on most Activity Sheets exists in order to help students make correct extrapolations based on their raw data and wherever applicable were verified with external, Colorado expert sources. **That said, Assumptions are provided solely for educational and illustrative purposes and are not intended to be used as the basis of energy decisions.** The Questions at the bottom of the Activity Sheet reinforce the lessons learned from the raw data and calculations and teachers are encouraged to review the list of questions with the students as the Class Review.

The electronic versions of the Activity Sheets with sample data can be used by teachers to see how certain calculations build off each other, the raw data, and/or the Assumptions. Simply click or double-click on a given cell to see the calculation used to get the answer for that cell (see highlights below).



What Speed Do We Need?

Appliance	On now?	Watts - on	Watts - off	Hours on/ day	kWh/ month - on	kWh/ month - off	kWh/ month - total
projector	no	50	5	4	6	3	9
computer	yes	40	5	8	10	2	12
light in ceiling fixture*	yes	43	0	4	5	0	5

The circled formula shows how 6 kWh per month in cell F4 is a result of multiplying Watts-on (cell C4) times Hours on/day (cell E4) times 30 and then dividing by 1,000.

If so inclined, teachers can ask students to complete the Activity Sheets using Excel, in which case the Sheets will reinforce computer skills.

Excel also enables teachers to easily customize the lesson to meet the needs of their students. For example, certain columns can be "hidden" or deleted if a teacher does not want the students to spend time on a given calculation. In other cases, teachers may choose to keep some pre-entered formulas in the electronic Activity Sheet they provide to students in order to adapt the lesson to a lower grade level. In this example students would still be able to draw conclusions from their raw data without having to perform as many calculations.

Glossary

The Glossary can support both student and teacher understandings of energy-related terms.

Appendices

The appendices are references that apply to multiple lesson plans, and include lists of materials and additional resources to support teachers wishing to take full advantage of this curriculum.

The Additional Resources appendix provides links to other resources for use by both formal and informal educators alike.

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PRIMER

Colorado Wind For Schools Wind Power Primer

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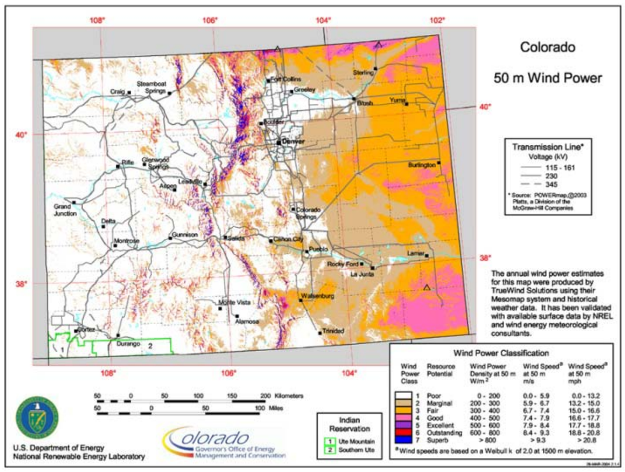
What is Wind and What is Wind Energy?

Winds are caused by the uneven heating of the atmosphere by the sun, the irregular topography of the earth's surface, and rotation of the earth. **Wind** is actually a form of solar energy. Moving wind is also a form of kinetic energy, or the energy of motion.

The term "**wind energy**" describes the generation of mechanical energy or electricity through the movement of wind. Wind turbines convert the **kinetic energy** in the wind into **mechanical energy**. Mechanical energy can be used for tasks like grinding grain or pumping water or spinning a generator which can convert this mechanical energy into electricity.

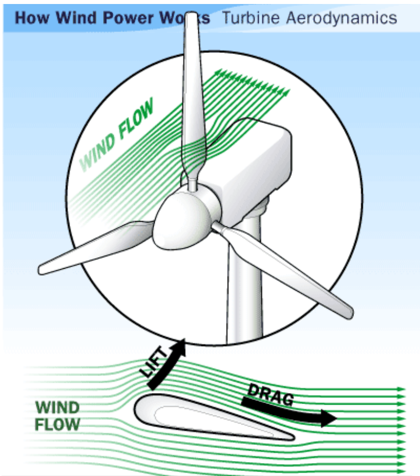


People have been harnessing the wind's energy for hundreds of years. From ancient Greece to farms in the United States, windmills have been used for pumping water or grinding grain. Today, the windmill's modern equivalent—a wind turbine—can use the wind's energy to generate electricity.

Wind turbines are systems that harness the kinetic energy of the wind to generate useful power. Wind flows over the **rotor** of a wind turbine, causing it to rotate on a shaft. The resulting shaft power can be used for mechanical work, like pumping water, or to turn a generator to produce an electrical current. Wind turbines come in a wide range of sizes, from small rooftop turbines generating less than 100 kilowatts up to large commercial wind turbines in the megawatt power range, many of which operate in large clusters called wind farms.

Although there are many different wind turbine designs, they are broadly grouped in two categories based on the orientation of the axis of rotation: Horizontal Axis Wind Turbines, or HAWTS, the most common type of wind turbine, and Vertical Axis Wind Turbines, or VAWTS. HAWTs usually use rotors with blades that resemble aircraft propellers which use similar aerodynamic principles, i.e., the air flow over the **airfoil** shaped blades creates a lifting force that turns the rotor. While HAWTs can have different numbers of blades, three is the most common arrangement. The **nacelle** of a HAWT contains a gearbox and generator. HAWTS are usually placed on towers to take advantage of the higher speed, less turbulent winds high above from the ground, usually 50 to 100 meters up. In order for the turbine to capture the wind, the turbine must face directly into the wind to maximize power generation, so HAWTS require a mechanism for alignment (yawing) so that the entire nacelle will rotate into the wind.

Wind turbines can be used as stand-alone applications, or they can be connected to a utility power grid or even combined with a photovoltaic (solar cell) system. For utility-scale (megawatt-sized) sources of wind energy, a large number of wind turbines are usually built close together to form a wind plant, or **wind farm**. Several large



From: How Stuff Works – http://science.howstuffworks.com

electricity providers in Colorado and elsewhere in the country use wind farms to supply power to their customers. Large wind farms are becoming a familiar site on Colorado's Eastern Plains.

Stand-alone wind turbines are typically used for water pumping or communications. However, homeowners, farmers and ranchers and schools in windy areas can also use wind turbines as a way to cut their electric bills. Small wind systems also have potential as distributed energy resources. **Distributed energy resources** are a variety of small, individual power-generating systems that can be combined to improve the operation of the electricity delivery system.

How Wind Turbines Work

Like old fashioned windmills, today's wind machines (also called wind turbines) use blades to collect the wind's kinetic energy. The wind flows over the blades creating lift, like the effect on an airplane wing, which causes them to turn. The blades are connected to a drive shaft that turns an electric generator to produce electricity.

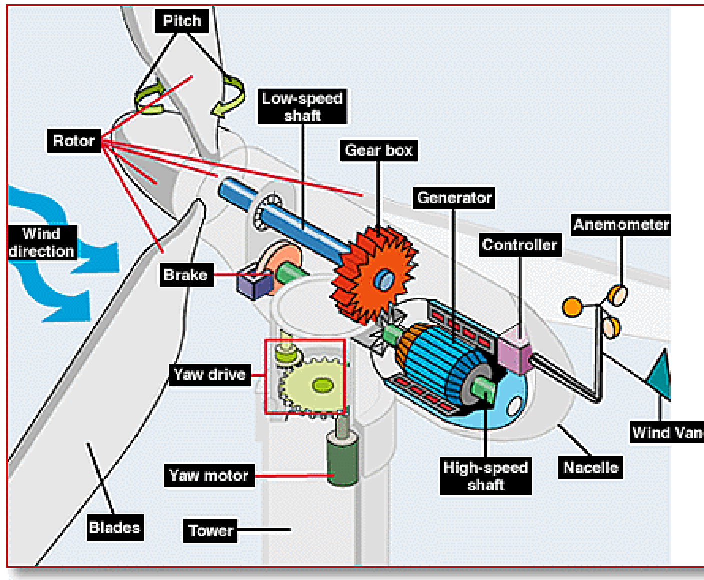


Diagram of Windmill Workings
From: National Renewable Energy Laboratory - www.nrel.gov

Blade Design and Function

Unlike the old-fashioned Dutch windmill design, which relied on the wind's force to push the blades into motion, modern turbines use sophisticated aerodynamic principles to capture the wind's energy most effectively. The two primary aerodynamic forces at work in wind-turbine rotors are **lift**, which acts perpendicular to the direction of wind flow; and **drag**, which acts parallel to the direction of wind flow.

Turbine blades are shaped a lot like airplane wings -- they use an airfoil design. In an airfoil, one surface of the blade is somewhat rounded, while the other is relatively flat. Lift is a pretty complex phenomenon and may in fact require a Ph.D. in math or physics to fully grasp. But in one simplified explanation of lift, when wind travels over the rounded, **downwind face** of the blade, it has to move faster to reach the end of the blade in time to meet the wind travelling over the flat, **upwind face** of the blade (facing the direction from which the wind is blowing).
Since faster moving air tends to rise in the atmosphere, the downwind, curved surface ends up with a low-pressure pocket just above it. The low-pressure area sucks the blade in the downwind direction, an effect known as "lift."

On the upwind side of the blade, the wind is moving slower and creating an area of higher pressure that pushes on the blade, trying to slow it down. Like in the design of an airplane wing, a high lift-to-drag ratio is essential in designing an efficient turbine blade. Turbine blades are twisted so they can always present an angle that takes advantage of the ideal lift-to-drag force ratio. Different blade designs will result in different lift-to-drag ratios and hence generate more or less electricity under the same wind speed regime. Further, voltage is a factor of how fast the blades spin while current is a factor of how much torque the blades create when spinning.

Using the Power of the Wind

Determining the Power in the Wind

We can feel that there is power in the wind just by standing in it. It is estimated that all of the on and off- shore wind that blows generates over 70 TW (terawatts) of power. But how do we know if the wind in our area is sufficient to make wind power generation practical. First, we need to be able to figure out how much power the wind in question actually has.

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

$$\textit{Power in the Wind} = \tfrac{1}{2}\rho A V^3$$

Where:
ρ (pronounced "rho") = density of the air
A = area swept by the blades
V = (velocity) wind speed
Because power depends on the wind speed cubed, wind speed is the single most important factor in determining the power available to a wind turbine. Air density is a variable that cannot be controlled by technology and decreases with increases in elevation. The swept area of the blades (length of a blade squared times pi) is dependent on how long the turbine blades are. Blade length is the one factor in the equation that engineers and designers can control.

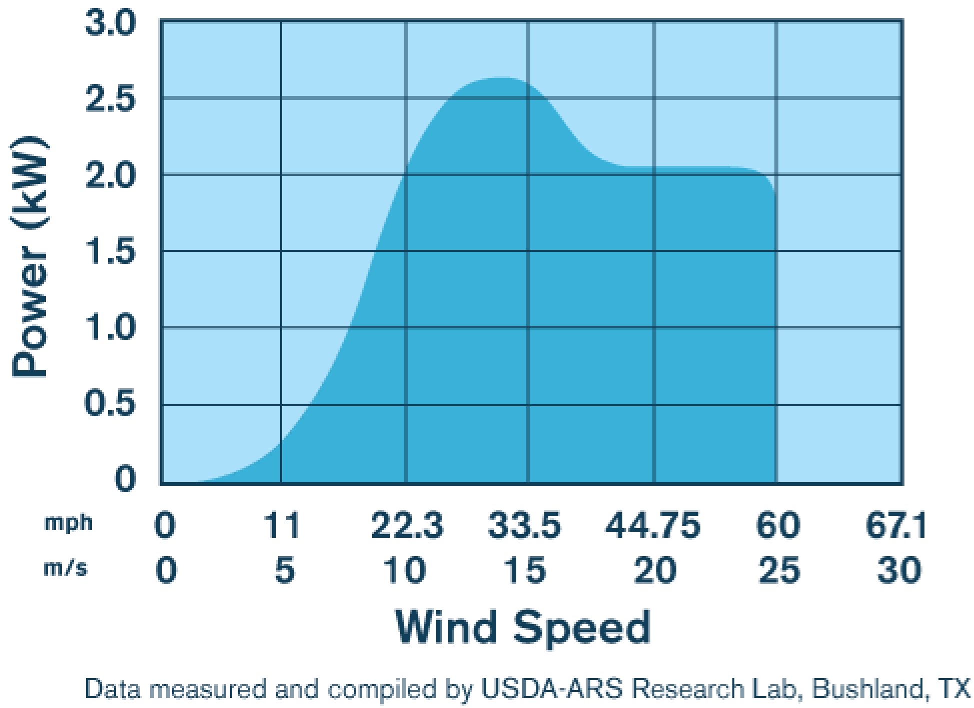
Understanding wind speed

Understanding wind speed is important when working with small wind turbines. Let's start with some of the common terms associated with wind speed as related to wind turbines.

- ***Start-up Speed*** - This is the speed at which the rotor and blade assembly begins to rotate.
- ***Cut-in Speed*** - Cut-in speed is the minimum wind speed at which the wind turbine will generate usable power, usually between 7 and 10 mph for most turbines.
- ***Rated Speed*** - The rated speed is the minimum wind speed at which the wind turbine will generate its designated rated power. For example, a "10 kilowatt" wind turbine may not generate 10 kilowatts until wind speeds reach 25 mph. Rated speed for most machines is in the range of 25 to 35 mph. At wind speeds between cut-in and rated, the power output from a wind turbine increases as the wind increases. The output of most machines levels off above the rated speed. Most manufacturers provide graphs, called "power curves," showing how their wind turbine output varies with wind speed.
- ***Cut-out Speed*** - At very high wind speeds, usually between 45 and 80 mph, most wind turbines stop generating power and shut down. The wind speed at which shut down occurs is called the cut-out speed, or furling speed. Having a cut-out speed is a safety feature which protects the wind turbine from damage. Normal wind turbine operation usually resumes when the wind drops back to a safe level.

One of the most important things to know about wind speed is that the amount of energy which wind can generate is not a one to one relationship. Instead, energy increases by wind speed cubed, so if you double the wind speed, you get eight times the energy. This is one reason that looking at wind maps is so useful. Even a small difference in average wind speed can have a big impact on the amount of energy a wind turbine can generate. It is also one of the reasons why a taller wind tower can make so much of a difference. If the wind speed increases even a few miles an hour by placing the turbine on a taller tower the energy generation potential goes way up. From: http://energybible.com/wind_energy/wind_speed.html

One way to evaluate the potential amount of energy a wind turbine will produce at different speeds is look at a **power curve** graph. This type of chart shows the power output (usually in watts) on one axis and the wind speed on the other. The chart below shows power curve for the Skystream 3.7. The sudden drop off at above 60 mph is caused by a safety cut off. The Skystream 3.7 is rated at 25 mph, which is the wind speed that produces the power at which the turbine is rated (2.4 KW). Once that is exceeded, the turbine begins braking to prevent more power from being produced than the system is rated to handle.



The Power in the Turbine

As it turns out, no wind turbine is 100% efficient. If it were, it would stop the wind! In 1919, a German physicist named Albert Betz figured out that no wind turbine can convert more than 59% of the kinetic energy of the wind into mechanical energy. This is called the **Betz Limit**. Therefore, the maximum efficiency of any wind turbine design can be no greater than 59%. Finding 59% of the calculated power of your turbine will give you the maximum power available from your turbine given the limitations of physics.

The Betz limit is one way to measure an idealized **Coefficient of Power**, or Cp. In the real world, the Cp tells us how well the turbine is actually performing in terms of the percent of kinetic energy being converted to power. The Cp is affected by the Betz limit, but that's not the only factor that influences it. There are also inefficiencies as the power gets converted from the rotor power to the electrical power produced. Typically, there is a mechanical efficiency for the gearbox (if any) and there is an electrical efficiency as the power goes from mechanical power downstream of the gearbox, through the generator and inverters, and then out the wires to the grid.

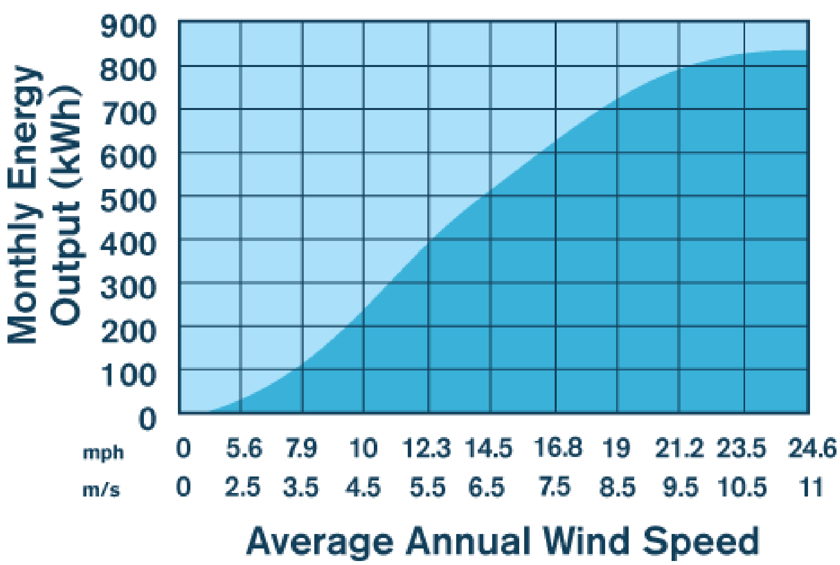
A simpler measure of performance that is often used when studying the performance of wind turbines is the **capacity factor,** the fraction of the actual power compared to the rated power of the turbine. You can see the capacity factor for a number of different kinds of turbines by clicking on any of the locations on the Colorado ALP website at http://www.engr.colostate.edu/ALP/ALP_Sites.htm . It turns out that the turbines in the best wind regimes tend to have capacity factors in the 35-45% range. The capacity factor can be determined at any given moment, but is most often averaged over a year as a way to compare the performance of different turbines in different kinds of wind situations.

This is a good place to review the meaning of your turbine's "**rated power**" or "rated capacity." Rated power is the amount of power the turbine produces when it is operating in its optimum wind speed. For the Skystream 3.7, rated power is reported as 2.4Kw at 29 mph or 13 m/s.
What this means is that the wind has to be blowing at least 29 mph for the turbine to produce this much energy. You will see varying figures for these values for the Skystream on different pieces of literature. The important thing to remember is that it actually takes a pretty substantial wind to get the turbine to produce the rated power. You will remember that the power produced depends very heavily on the speed of the wind. If you look back at the power curve above, you can see how much power is produced at different wind speeds. How much wind actually occurs at your turbine site? Looking at the Wind for Schools website, it is possible to find current, monthly and yearly average wind speeds for the turbine site. At the Colorado Anemometer Loan Program site mentioned above, you can find a year of wind data for over 100 sites in Colorado. This information lets you figure out the capacity factor of your turbine at different wind speeds and this may be very different than the rated power.

The Energy in the Wind

Another curve that is generated with data from the Skystream turbine is an **Energy Curve**. It is useful to know the difference between power and energy in the context of your wind turbine.
Power refers to the potential instantaneous output of a device and is measured in Kilowatts (kW). When you look at your real time Skystream data, you will see measurements of the watts or kilowatts being produced at that moment. **Energy** is a reference to the output of a device over time and is measured in Kilowatt Hours (kWh). When you look at the daily, weekly, monthly or annual data from your turbine, this shows the energy that has been produced over time. Consumers are familiar with Kilowatt Hours because this is how they are billed for electricity they use. In a physics context, energy is the ability to do *work* while power is the rate at which work is done.

The Energy Curve shows the monthly cumulative amount of energy produced by the Skystream turbine that can be expected at different wind speeds. Applying the average annual wind speed and the energy curve provides the data needed to calculate a payback period for your turbine.



http://huskerwindpower.com/skystream/skystreamskystream-specs/

Tip Speed Ratio

The **Tip Speed Ratio** (TSR) is critically important in the design of wind turbine generators. If the rotor of the wind turbine turns too slowly, most of the wind will pass between the rotor blades. If the rotor turns too quickly, the blurring blades act like a solid wall to the wind. Therefore, wind turbines must be designed with optimal tip speed ratios to extract as much power out of the wind as possible. When a rotor blade passes through the air, it leaves turbulence in its wake. If the next blade arrives at this point while the air is still turbulent, it will not be able to extract power efficiently from the wind. If the rotor spins a little more slowly, the air hitting each blade will no longer be turbulent. The tip speed ratio is chosen so that the blades do not pass through turbulent air.

The tip speed ratio is found by dividing the speed of the tips of the turbine blades by the speed of the wind - for example if a 20 mph wind is blowing on a wind turbine and the tips of its blades are rotating at 80 mph, then the tip speed ration is 80/20 = 4.

If your TSR is above 1, lift is making your blades spin faster than the wind speed. If your TSR is below 1, there is a lot of drag going on! Old windmills used to lift weights, grind grain, or pump water probably had TSRs around 1.

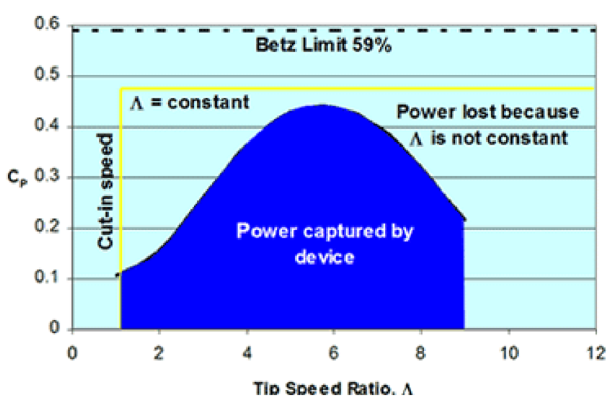
The optimum tip speed ratio depends on the number of blades in the wind turbine rotor. The fewer the number of blades, the faster the wind turbine rotor needs to turn to extract maximum power. A two-bladed rotor has an optimum tip speed ratio of around 6, a three-bladed rotor around 5, and a four-bladed rotor around 3. This formula has been shown to be an accurate way to calculate the optimum TSR for maximum power output. Tip Speed Ratio is symbolized by the Greek letter λ (lambda)

$$\lambda\ (max\ power) = \frac{4\pi}{n} \quad (n = number\ of\ blades)$$

Highly efficient blade design can increase these optimum values by as much as 25-30%, increasing the speed at which the rotor turns and therefore generating more power. A well designed three-bladed rotor can have a TSR of around 6 to 7.

If the tip speed ratio is too low because, for example, the rotor blades are poorly designed, the wind turbine will slow down or stall. If the TSR is too high, the rotor blades will spin very fast through turbulent air, optimal power will not be extracted from the wind, the wind turbine can be stressed to the point of structural failure and more noise and vibrations may be produced.
From: http://www.reuk.co.uk/Wind-Turbine-Tip-Speed-Ratio.htm

Because wind speeds around turbines are not constant, it is not possible to keep a turbine at the optimal tip speed rotation all of the time. The graph below is for a 2-bladed turbine, but it illustrates the potential energy that could be produced at a constant optimum tip speed ratio compared to the actual power produced at different wind speeds.



http://www.reuk.co.uk/print.php?article=Wind-Turbine-Tip-Speed-Ratio.htm

There are several interesting conclusions that can be drawn from considering TSRs. Rotors with lots of blades are generally not a good idea for generating electricity. Lots of blades mean that each blade spends a lot of time in turbulent air at the rpms (revolutions per minute) needed to generate electricity making them very inefficient

for this purpose. People often think more blades are better, but understanding tip speed ratio will help you explain why this is not true.
From:http://cdn.intechopen.com/pdfs/16242/InTech-Wind_turbines_theory_the_betz_equation_and_optimal_rotor_tip_speed_ratio.pdf

How to Find the Tip Speed Ratio

It just takes a few measurements and a little math to figure out the tip speed ratio for your turbine. You will need a **tachometer** to measure the revolutions per minute of your turbine and a wind speed meter or anemometer to measure wind speed. You will also need to know the length of your blade which is the radius of the swept area.

First, determine the speed of the tip of your blade. To do this, calculate the distance the blade travels in one revolution. This is the circumference of the circle inscribed by the blades, found by using the formula $\pi 2r$ or πD. Remember that r is the length of one of the blades. Next, figure out how long it takes the turbine to make 1 revolution. To do this, you will need the information from the tachometer which measure revolutions per minute. You need the inverse of this, or minutes per revolution, and you need seconds rather than minutes, so just take the tachometer data and divide it into the number 60. That will give you how long it takes for a blade to go around one time in seconds.

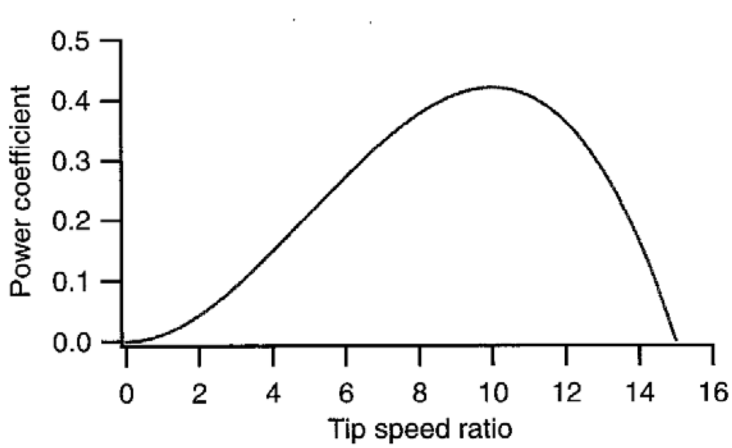
Finally, to calculate **tip speed**, apply the formula for speed, V= Distance/Time, by dividing the circumference by the time it takes to make one revolution.

To find the tip speed ratio, divide the tip speed by the wind speed.

A key point to remember when doing these calculations is that all of the units need to be in the same system. The Skystream 3.7 turbine has a rotor diameter of 3.7 meters. Therefore, all of the other measurements need to be metric if you use this value for your calculations.

Tip Speed Ratio and Coefficient of Power (TSR and Cp)

There is also a relationship between the tip speed ratio and the coefficient of performance of a given turbine. Each turbine has its own specific graph, but in general, the relationship looks like this:

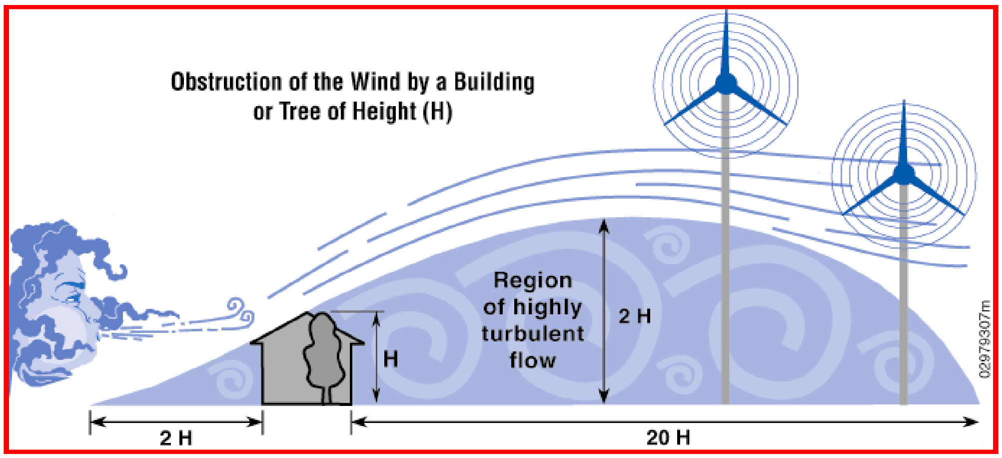


The graph is a good illustration of how the Coefficient of power is not constant, even for an individual turbine. Every turbine will have a different curve and this curve also depends on the aerodynamics of the blades (the amount of lift and drag), the blade shape, and the number of blades on the rotor. Designers will try to keep the turbine at the maximum Cp and at the corresponding tip speed ratio by deciding on the size of the blade required and then varying the rpm with wind speed. All of this demonstrates how many mathematical measurements and design decisions are involved in creating the most efficient wind turbines.

Siting a wind turbine

A small wind energy system may provide an economical source of electricity in areas with fairly steady strong winds and at least one-half acre of open land. Personal impressions of the windiness of a site are often not reliable – it is better to use an objective measure. The most precise information can be obtained by placing an anemometer (a device that measures wind speed) on your site for at least one year.

A faster method is to look up wind data from the Colorado wind resource map and the anemometer loan program. (See the Colorado Wind Resource Maps in Appendix D.) Winds on your site should be at least class 2 (annual wind speeds averaging 9.8 to11.5 mph at 50 meters above ground level) to be suitable for wind generation. In general, the following picture illustrates siting guidelines to be followed for a wind turbine with regard to upwind obstructions:

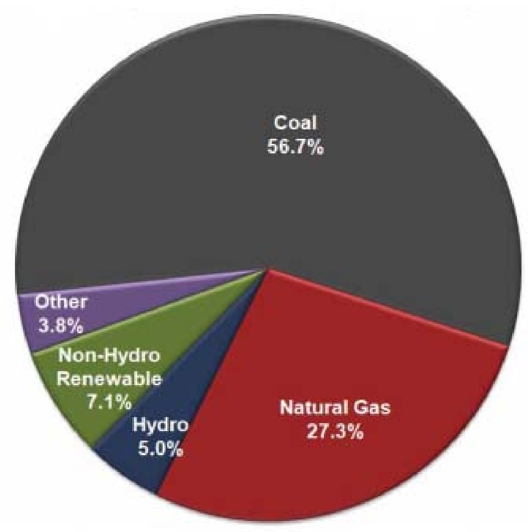


You need to make sure your local zoning codes or covenants allow wind turbines and the fairly tall towers that allow them to catch enough wind to make electricity. You also need to do enough research to learn whether a turbine will pay for itself quickly enough to meet your financial requirements.

Small wind systems designed for individuals, businesses and farm or ranch operators are growing dramatically and evolving rapidly. The industry group, American Wind Energy Association, predicts a thirty-fold increase in the U.S. in the next five years.
While the cost of a wind turbine is steep, the wind energy system will not require further electrical purchases in the future. This allows you to avoid unpredictable future costs of other fuels by paying for wind energy upfront.
From: Colorado State University Extension - www.ext.colostate.edu

Wind and Other Electrical Power Generation in Colorado

Providing the energy we need to live, work, and learn in a comfortable well-lit indoor environment is a challenge. To generate energy like electricity we can take advantage of a variety of different energy sources. In 2009, 57% of Colorado's power was generated at coal-fired power plants. Non-hydro renewable resources represented 7% of the generation mix in 2009. Hydroelectric power also constitutes a portion of Colorado's energy mix (5%). The majority of the hydroelectric power supplied to Colorado is from federally owned dams. Colorado utilities do not generate any power from nuclear sources, though a small amount of nuclear power is imported into the state.



Recent legislation is steering the state toward a more diverse mix of generation resources that will increasingly tap into the state's abundant natural gas and renewable energy sources – primarily wind, solar, and to a lesser extent, biomass, small hydropower, and geothermal. In large part, this is due to the fact that using clean energy sources reduces our emissions of greenhouse gases and the need to withdraw huge quantities of freshwater for generating power.

Colorado Electric Power Mix, 2009
From: 2010 Colorado Utilities Report – www.colorado.gov/energy

Wind Power in Colorado

According to the American Wind Energy Association, as of the fourth quarter 2012, Colorado ranked tenth in the country for wind power capacity with 2,301 megawatts (MW) installed. In 2006, Colorado only had 291 MW of capacity, despite a strong wind resource. The state also ranks high for projects under construction, with 496 MW on the way. Colorado has not only experienced rapid growth in its installed wind capacity, but it has also become home to several wind turbine component manufacturers, including Vestas. Despite recent layoffs due to Production Tax Credit uncertainty, thousands of people are employed in the wind industry in the state. What happened to boost Colorado's growth in the wind industry?

On February 23, 2001, the Colorado Public Utilities Commission (PUC) made an historic decision when it ordered Xcel Energy to undertake good faith negotiations for a wind plant as part of the utility's integrated resource plan. The commission concluded that the wind plant would cost less than new gas-fired generation under reasonable gas cost projections. As a result, a 162-MW wind farm was built in southeast Colorado near Lamar. More wind farms would follow. In November 2004, Colorado voters passed Amendment 37, which created a 10% **Renewable Portfolio Standard** (RPS) by 2015. In 2007, new legislation doubling the RPS passed with bipartisan support. Governor Bill Ritter signed Colorado House Bill 1001 into law in March 2010, establishing a new Renewable Energy Standard for Colorado. In 2015, the Renewable Energy Standard in Colorado increases to 20% (and again to 30% in 2020).

Although Colorado has successfully created an attractive business environment for private and public investment and renewable energy companies, the state must address a challenge that is also faced by other states with a great wind resource: how to improve an outdated electrical grid and build the network of transmission lines that will be critical to further large-scale wind development in the state. The uncertain future of production tax credits is also hindering further large and small scale wind developments. From: http://www.windenergyfoundation.org/wind-at-work/case-studies/colorado

Colorado Wind Farms

XCEL ENERGY - COLORADO WIND POWER			
Facility	**Location**	**Capacity**	**In-service Date**
Ponnequin	Weld County (just south of the Wyoming border)	32 MW	1998

Foot Creek III	Wyoming	25 MW	1999
Ridgecrest	Peetz, Colo.	30 MW	2001
Colorado Green	Lamar, Colo.	162 MW	2004
Spring Canyon	Peetz, Colo.	60 MW	2006
Cedar Creek	Grover, Colo.	300 MW	2007
Logan Wind	Peetz, Colo.	201 MW	2007
Peetz Table	Peetz, Colo.	200 MW	2007
Twin Buttes	Lamar, Colo.	75 MW	2007
Northern Colorado Wind	Peetz, Colo.	174 MW	2009
NREL/National Wind Testing Center	Golden, Colo.	9 MW	2010
Cedar Creek II	Weld County, Colo.	251 MW	2011
Cedar Point Wind	Lincoln & Elbert Counties, Colo.	252 MW	2011
Limon Wind I	Lincoln & Elbert Counties, Colo.	200 MW	2012
Limon Wind II	Lincoln County, Colo.	200 MW	2012

From:
http://www.xcelenergy.com/Environment/Renewable_Energy/Wind/Colorado_Wind_Power?stateSelected=true

Economic Impacts of Wind Power Development in Colorado

According to analysis performed by researchers at the National Renewable Energy Laboratory (NREL), 1,000 MW of wind power development in Colorado:

- Generates electricity to power more than 248,000 homes (11.8% of Colorado housing units in 2006)
- Generated approximately 1,700 full-time-equivalent jobs during construction periods with a total payroll of more than $70 million (2008 dollars)
- Supports approximately 300 permanent jobs in rural Colorado areas with a total annual payroll of more than $14 million (2008 dollars)
- Generated $226 million in economic activities from the construction period (2008 dollars)
- Generates $35 million in annual local economic activities (2008 dollars)
- Generates more than $4 million in annual property taxes (2008 dollars)
- Generates more than $2.5 million annually in extra income for farmers and ranchers who lease their land to developers (2008 dollars).

Environmental Impacts of Wind Power

Both proponents and opponents use environmental arguments to support their views about the benefits of wind power. The proponents of wind power point to its non-polluting nature while opponents highlight concerns related to visual impact, sound, effects on wildlife and the intermittent availability of wind.

From: http://www.ewea.org/fileadmin/ewea_documents/documents/publications/WD/wd25-5-focus.pdf

The biggest environmental advantage of wind power is that the power is produced without the use of fossil fuels and therefore does not produce carbon dioxide and other greenhouse gases which have been linked to climate change. Wind is not only a renewable resource, the energy that produces the wind comes from the sun, but there is a lot of it potentially available. The wind energy resource, both on and off shore, has been estimated at 72 TW (terawatts), about five times as much energy as all humans currently use.

From: http://windyearth.blogspot.com/2012/11/the-pros-and-cons-of-using-wind-energy.html

Clearly not all of this can be harnessed, but the point remains that wind is abundant, free and non-polluting.

Let's take a look at the environmental benefits Colorado has experienced from wind power. In 2011, Colorado wind energy production was 4.7 million megawatt hours. Assuming that this replaced the state's traditional electricity power sources, coal and natural gas, over 2.7 million metric tons of CO_2 were eliminated from the atmosphere, the equivalent of taking a half million cars off Colorado's roads, and there were savings of over one billion gallons of water. As a rule of thumb, 1MwH of wind power reduces CO_2 emissions by about 1200 pounds.

From:http://www.environmentcolorado.org/sites/environment/files/reports/Cool%20Breeze%20-%20Colorado%20Wind%20Report%20Final-1.pdf

What are some of the environmental concerns about wind power? One concern is related to aesthetics, or the appearance of wind turbines and wind farms. Because wind turbines need to be exposed to the wind, they are often in high or open places where they are easily seen. Some people like the look of wind turbines; others feel that they negatively affect the "view shed" and do not want to see them in land and seascapes. People also worry about property values when turbines are part of the scenery. However, the Renewable Energy Policy project at the University of Massachusetts studied 25,000 property transactions in the view of wind projects, and compared to similar sites without views of wind turbines, found no evidence of wind power reducing property values.

There is also concern about the "footprint" of wind turbines. There is a change in habitat in areas that have been cleared for wind turbines causing concern about habitat destruction. While the actual base of a turbine is about fifteen square feet, the area around the turbine must be clear of trees. In Colorado this is not as much of an issue as it is in the Eastern U.S. In a wind farm, the turbines must be 2-5 rotor lengths apart to reduce the turbulence that increases wear and decreases performance of each turbine. This translates to a typical spacing of between 500 and 1000 feet between turbines in a full scale farm along a ridge. While this does seem like a lot of land, many uses coexist safely with wind turbines and turbines can be found on school campuses, in towns, along hiking and skiing trails, and in Colorado, on agricultural acreage where farmers plant right up to the bases of turbines.

Sound is another area of concern with wind turbines. Wind turbines are relatively quiet. While the way sound carries depends on terrain and wind patterns, wind turbines should, as a rule of thumb, be about three times the hub height or more from residences. From several hundred
feet away, wind turbines make about as much noise as a refrigerator. Sound is something that people do notice, however, and the siting of wind turbines, and even your school turbine, needs to take the proximity of neighbors into account. The sounds emitted from wind turbines can be mechanical, from internal equipment such as the gearbox, or aerodynamic, from air moving past the rotor blades. Current turbine designs reduce mechanical sound through soundproofing. The aerodynamic sound, often described as a "whooshing" sound, is what can normally be heard. The aerodynamic noise has infrasound, low and normal frequencies. There has been concern about the effects of very low frequency sound on human and animal health and behavior and research continues, although many studies have shown no harmful effects.

From:
http://www.umass.edu/windenergy/publications/published/communityWindFactSheets/RERL_Fact_Sheet_3_Impacts&Issues.pdf and http://www.awea.org/issues/siting/index.cfm

One of the biggest areas of concern around wind turbines is their impact on birds, bats and other wildlife. The Wind Program at NREL carries out research and activities to address the potential effects of wind development on wildlife and identifies corresponding mitigation strategies. As part of this effort, the program supports the work of the National Wind Coordinating Collaborative (NWCC) Wildlife Workgroup (http://nationalwind.org/issues/wildlife.aspx) which is focused on collaborative approaches for understanding and evaluating species- and habitat-specific impacts, mitigation tools, risk assessment, and nocturnal study techniques. The program also collaborates with the Bats and Wind Energy Cooperative http://batsandwind.org. This organization investigates bats and wind turbine interactions.

From: http://www.nrel.gov/wind/environmental_impacts.html?print.

The NWCC summary of research on bird and bat mortality reports that birds are killed by direct contact with wind turbines and that the number varies widely with older, smaller, faster turbines more likely to kill birds. The average is about four birds per megawatt per year. The rate of birds killed by turbines is substantially lower than the rate for most other human caused fatalities such as buildings, windows, pesticides and cats. Most of the birds killed, about three-quarters, are migratory songbirds, causing a spike in bird deaths during the spring and fall. These fatalities are not at such a high rate that the overall populations will be affected. If turbines are placed in areas with abundant prey, raptors are more likely to be killed by turbine blades. Environmental studies done prior to siting wind turbines can help determine migration patterns, abundance of prey species, and preferred bird and raptor habitats to reduce the impact on birds. Overall, bats are more vulnerable to wind turbines than birds. Three migratory, tree roosting species, the Hoary Bat, the Eastern Red Bat, and the Silver-haired Bat, are especially vulnerable. Bat fatalities tend to happen the most during periods of low wind and just before and after storms pass through. One strategy used to reduce bat fatalities is to increase the cut in speed of large turbines so that the turbines are not spinning during the times bats are most active. Birds and other wildlife are also affected by the habitat destruction caused by the building of wind farms. To address wildlife research needs, the NWCC program supports two collaborative efforts. The Grassland Shrub Steppe Species Collaborative (http://www.nationalwind.org/issues/wildlife/gs3c.aspx) currently has two species-specific research projects underway. The first, launched in 2006, is a multi-year effort to study wind turbines in prairie chicken habitat. This project is nearing completion. A second multi-year effort to study the impacts of wind turbines on sage grouse was initiated in 2009.

From: http://www1.eere.energy.gov/wind/pdfs/birds_and_bats_fact_sheet.pdf

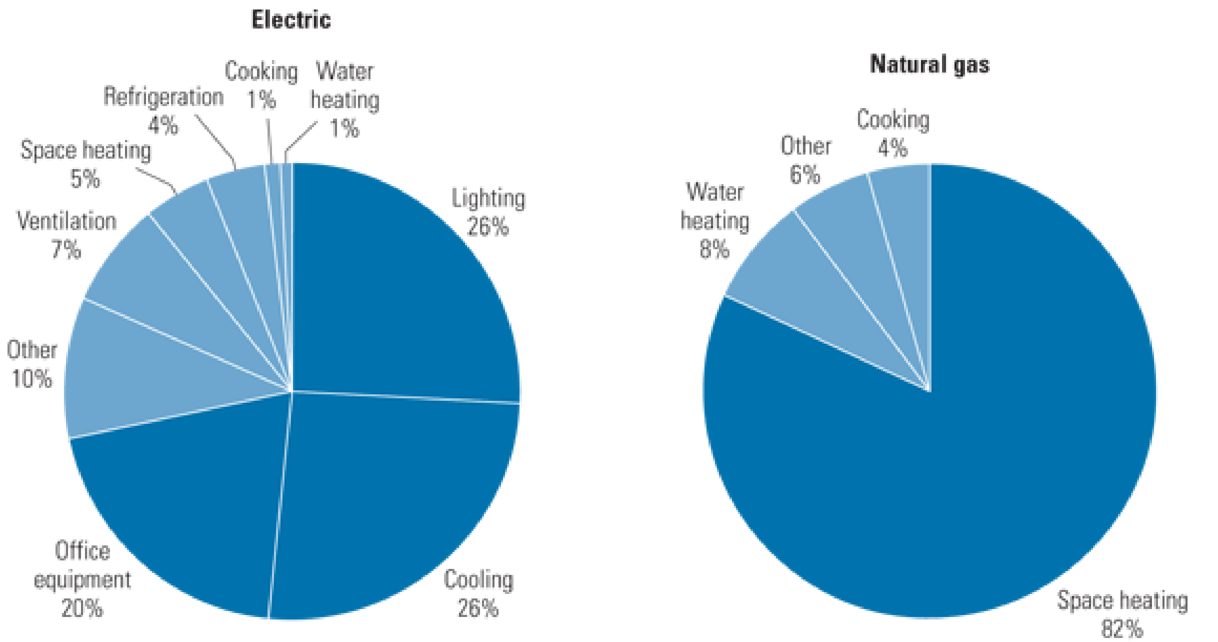
To read more about the effects of wind energy on wildlife, see the Wind-Wildlife Impacts Literature Database (WILD), http://www.nrel.gov/wind/wild.

Colorado Wind for Schools

School Energy Use

Typically, space heating, cooling, and lighting together account for nearly 70 percent of school energy use (see below). Plug loads—such as computers and copiers—constitute one of the top three electricity end uses, after lighting and cooling.

Most of the electricity consumed by educational facilities is used for lighting, cooling, and plug loads such as computers and copiers; most of the natural gas is used for space heating. Each school's energy profile is different, so these charts are not representative of all schools. For example, school buildings in warmer climates will tend to show a larger share of electricity used for space cooling than those in cooler climates.



Courtesy: E SOURCE; from Commercial Building Energy Consumption Survey, 1999 data

Energy intensity in schools varies widely and is influenced by both weather conditions and specific operating characteristics such as building size, classroom seating capacity, and the presence of an on-site cafeteria. On-site energy intensity in schools can range from less than 10,000 Btu per square foot (ft2) to over 500,000 Btu/ft2. Given this large variation and skewed distribution, it can be misleading to assess a school building's performance by comparing its average energy intensity.

From: U.S. Environmental Protection Agency - www.energystar.gov

Getting Data from a School Wind Turbine

The activities in this curriculum call for a number of kinds of data that can be found through the software associated with the Skystream turbine. In Appendix A, you will find several sets of instructions for connecting your turbine to your school computer and sending data from your school computer to the Wind for Schools site in Idaho where it can be shared with all of the Wind for Schools sites around the country as well as any other interested people.

Data is collected on your turbine through two different systems.
SkyView has been developed by Southwest Windpower to be used with the Skystream 3.7 wind turbine. Once installed, SkyView automatically collects data from your wind turbine and saves daily values of energy output which you can retrieve later. Additionally, you can choose to have SkyView export a more expansive data set at different time intervals (i.e.1 second data, 10 second data, etc.) to a .txt file, which you can then open in Microsoft Excel to use for data analysis. SkyView must be open and running to export data to a .txt file.
The Windinterface program was developed for Wind for Schools to allow K-12 schools to upload data from their wind turbines to an online database. This way, data from the Wind for Schools wind turbines across the US would all have a common data storage location allowing teachers to have access to all data to use in the classroom for educational purposes.

Windinterface will only upload data when it is open and running on the same computer which has SkyView installed and is communicating successfully with your wind turbine. If the computer is turned off, hibernating, or Windinterface is simply not open, data will not be collected and transferred to the online database.

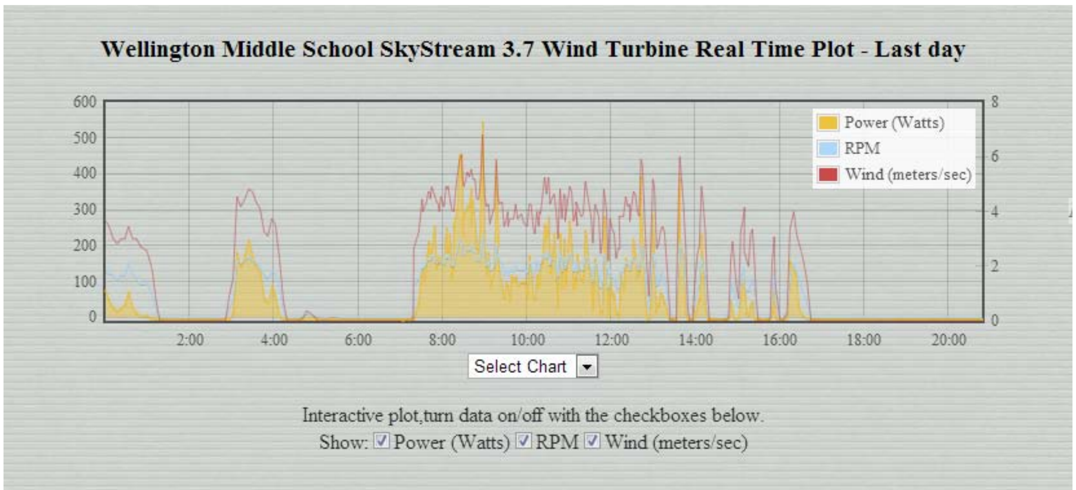
Therefore, someone should be responsible for checking the computer <u>each morning</u> to make sure it is turned on, and Windinterface is running correctly.

Additionally, neither Windinterface nor SkyView will run properly if both are open at the same time. You can only have one program running at a time.

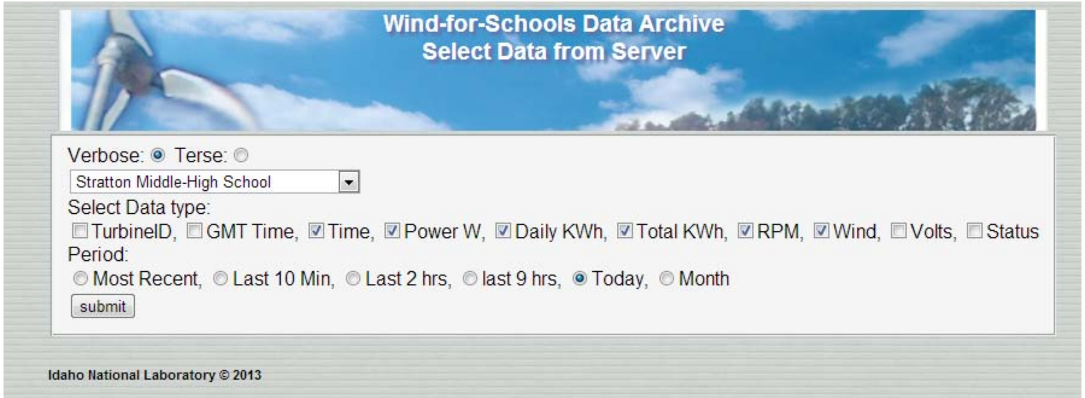
First let's look at the data available through the Wind for Schools site. If you do not have a school turbine, this is also the place you will go to get data to do the activities. The Appendix does have some sample data that has been saved, but real time data is often more engaging.

Follow these steps:

1. Go to the INL Wind for Schools website http://wind-for-schools.caesenergy.org/wind-for-schools/Welcome.html. On the Welcome page, scroll down to see the turbines that are on-line and collecting data for the INL site. Find your school or note which Colorado schools are shown as currently recording data.
2. You will need to go directly to the school site to see all of the data being collected. To find the data from Colorado schools, click on the Wind for Schools tab either at the top of the Welcome page or on the left hand side. Then Click on Colorado in the list on the left hand side of the page.
3. You will see a list of Colorado schools that have connected to the Idaho National Lab website at some time.
4. Click on the list of schools until you find a school (hopefully yours) that shows current readings on the Real Time Data page.
5. On the Real Time Data page, check the current output of your turbine. Use the graph at the bottom of the page to compare power produced over the past day, week, month and year. In which time periods did the turbine produce its rated power? You can also find a table of monthly and yearly averages for power, rpm and wind speed.



6. Click on Turbine Data Av, Data for Month on the left hand side. On the Wind for Schools Data Archive, select your school from the dropdown list, the data you want and the time period you want it to cover. For practice, leave time, power, rpm and wind checked, select Today and submit.



7. After you click submit, and wait, you will get some columns of data. Actually you will get extremely long columns of data. Remember that the computer is updating the data coming from the turbine about 4 times a minute. Just an hour of data collection will have about 240 entries. For many of the activities such as Power in Practice and Theory, where students need data from a range of wind speeds, just scrolling through the data and writing down data that goes with the wind speeds they want will work better than saving very large files and having to scroll through them in Excel.
8. However, there may be times when you do want to save the data files. Then you will place them into an Excel file so you can work with it more easily. There are two ways to do this:
    a. The easy way – click on Download CSV file and open the downloaded file.
    b. The way that lets you use data directly from the SkyView software on your computer as well as from the CAES site - click on select data and copy, open an Excel file and paste. Highlight the first column, click on Data on the top ribbon, and click on Text to Columns. When the Wizard comes up, choose delimited for the file type and click next. On the next screen, uncheck Tab and check Comma and click next. On the next screen, leave General checked and click finish. You may have to make the Date/Time column wider to see the data there.

If you can't see your school, the connection between the turbine and the school or between the school and the CAES site may be broken. Follow the tutorials in Appendix A to reconnect your computer so that your data can be shared.

The Colorado State University Wind Application Center has also started an archived collection of the turbine data from Colorado's Wind for Schools sites. This archived data may be accessed at https://sites.google.com/a/rams.colostate.edu/csu-wac/colorado-wfs-wind-turbine-data-archive. This site will provide a wide variety of data which is especially useful on days when the wind isn't blowing much at your site. This site will also be a reliable source of data for schools that don't have their own turbine.

It is also possible to download data from the SkyView software on your school computer. There is a basic set of data on the Overview page that can be set to retrieve data over a specific period of time and a more complex set of real time data that can be customized under Advanced Diagnostics. The procedure for copying the data into an Excel file is the same as described above. For more specific information about how these two types of software work, see *Using SkyView and Wind Interface for Data Collection* in Appendix A.

References Used to Prepare this Primer

General background

- http://people.bu.edu/noahb/files/wind_turbine_main.pdf#page=1
- http://energybible.com/wind_energy/wind_speed.html

Wind Power

- http://cdn.intechopen.com/pdfs/16242/InTech-Wind_turbines_theory_the_betz_equation_and_optimal_rotor_tip_speed_ratio.pdf

Tip Speed

- http://www.reuk.co.uk/Wind-Turbine-Tip-Speed-Ratio.htm

Colorado State University Anemometer Loan Program

- http://www.engr.colostate.edu/ALP/ALP_Sites.htm

Economic Impact and Wind Economics

- http://www.windenergyfoundation.org/wind-at-work/case-studies/colorado
- BP on Cedar Creek 2 Fact Sheet: http://www.bp.com/liveassets/bp_internet/alternative_energy/alternative_energy_english_new/STAGING/local_assets/downloads_pdfs/Cedar_creek2_fact_sheet_new.pdf
- Denver Business Journal Article about Cedar Creek 2 Wind Farm: http://www.bizjournals.com/denver/news/2011/07/13/475m-wind-farm-dedicated-in-weld.html?page=all
- AWEA’s 10 Steps for Developing a Wind Farm: http://www.awea.org/learnabout/publications/upload/Ten_Steps.pdf
- Wind Energy in Colorado for Rural, Farmer and Ranchers: http://www.coopext.colostate.edu/WR/windbooklet.pdf

Environmental Issues

- http://www.ewea.org/fileadmin/ewea_documents/documents/publications/WD/wd25-5-focus.pdf
- http://windyearth.blogspot.com/2012/11/the-pros-and-cons-of-using-wind-energy.html
- http://www.environmentcolorado.org/sites/environment/files/reports/Cool%20Breeze%20-%20Colorado%20Wind%20Report%20Final-1.pdf
- http://www.umass.edu/windenergy/publications/published/communityWindFactSheets/RERL_Fact_Sheet_3_Impacts&Issues.pdf
- http://www.awea.org/issues/siting/index.cfm
- http://www.nrel.gov/wind/environmental_impacts.html?print
- http://www.nationalwind.org/issues/wildlife.aspx
- http://www.batsandwind.org/
- http://www.nationalwind.org/issues/wildlife/gs3c.aspx
- http://www1.eere.energy.gov/wind/pdfs/birds_and_bats_fact_sheet.pdf

COLORADO STANDARDS

SCIENCE STANDARDS												
Standard	**Grade**	**Grade Level Expectation**	**GLE Number**	**Evidence Outcomes**	**Getting to Know Your Turbine**	**Power in Practice and Theory**	**Tip Top Tip Speed**	**Modeling Efficiency and TSR**	**What Speed Do We Need?**	**Wind Turbine Economics**	**Wind Farm Policy Simulation**	**When The Wind Doesn't Blow**
Earth Systems Science	High School	There are costs, benefits, and consequences of exploration, development, and consumption of renewable and nonrenewable resources	ESS_5	a. Develop, communicate, and justify an evidence-based scientific explanation regarding the costs and benefits of exploration, development, and consumption of renewable and nonrenewable resources								**X**
				b. Evaluate positive and negative impacts on the geosphere, atmosphere, hydrosphere, and biosphere in regards to resource use							**X**	**X**
				c. Create a plan to reduce environmental impacts due to resource consumption								
				d. Analyze and interpret data about the effect of resource consumption and development on resource reserves to draw conclusions about sustainable use			**X**					

Standard	Grade	Grade Level Expectation	GLE Number	Evidence Outcomes	Getting to Know Your Turbine	Power in Practice and Theory	Tip Top Tip Speed	Modeling Efficiency and TSR	What Speed Do We Need?	Wind Turbine Economics	Wind Farm Policy Simulation	When The Wind Doesn't Blow
Physical Science	High School	Energy exists in many forms: mechanical, chemical, electrical, radiant, thermal, and nuclear, that can be quantified and experimentally determined	PSCI_5	a. Develop, communicate, and justify an evidence-based scientific explanation regarding the potential and kinetic nature of mechanical energy		**X**						
				b. Use appropriate measurements, equations and graphs to gather, analyze, and interpret data on the quantity of energy in a system or an object	**X**	**X**			**X**			
				c. Use direct and indirect evidence to develop predictions of the types of energy associated with objects					**X**			
				d. Identify different energy forms, and calculate their amounts by measuring their defining characteristics		**X**			**X**			
Physical Science	High School	When energy changes form, it is neither created not destroyed; however, because some is necessarily lost as heat, the amount of energy available to do work decreases	PSCI_6	a. Use direct and indirect evidence to develop and support claims about the conservation of energy in a variety of systems, including transformations to heat								

Standard	Grade	Grade Level Expectation	GLE Num ber	Evidence Outcomes	Getting to Know Your Turbine	Power in Practice and Theory	Tip Top Tip Speed	Modeling Efficiency and TSR	What Speed Do We Need?	Wind Turbine Economics	Wind Farm Policy Simulation	When The Wind Doesn't Blow
Physical Science	High School	When energy changes form, it is neither created not destroyed; however, because some is necessarily lost as heat, the amount of energy available to do work decreases	PSCI _6	b. Evaluate the energy conversion efficiency of a variety of energy transformations		**X**	**X**					
				c. Describe energy transformations both quantitatively and qualitatively		**X**						
				d. Differentiate among characteristics of mechanical and electromagnetic waves that determine their energy								
				e. Examine, evaluate, question, and ethically use information from a variety of sources and media to investigate energy conservation and loss	**X**							
Life Science	8	Human activities can deliberately or inadvertently alter ecosystems and their resiliency	BIO L_1	a. Develop, communicate, and justify an evidence-based scientific example of how humans can alter ecosystems								
				b. Analyze and interpret data about human impact on local ecosystems								
				c. Recognize and infer bias in print and digital resources while researching an environmental issue							**X**	**X**

Standard	Grade	Grade Level Expectation	GLE Number	Evidence Outcomes	Getting to Know Your Turbine	Power in Practice and Theory	Tip Top Tip Speed	Modeling Efficiency and TSR	What Speed Do We Need?	Wind Turbine Economics	Wind Farm Policy Simulation	When The Wind Doesn't Blow
Life Science	8	Human activities can deliberately or inadvertently alter ecosystems and their resiliency	BIOL_1	d. Use technology resources such as online encyclopedias, online databases, and credible websites to locate, organize, analyze, evaluate, and synthesize information about human impact on local ecosystems							X	
				e. Examine, evaluate, question, and ethically use information from a variety of sources and media to investigate an environmental issue							X	X
Physical Science	8	Identify and calculate the direction and magnitude of forces that act on an object, and explain the results in the object's change of motion	PSCI_1	a. Predict and evaluate the movement of an object by examining the forces applied to it		X	X					
				b. Use mathematical expressions to describe the movement of an object		X	X					
				c. Develop and design a scientific investigation to collect and analyze speed and acceleration data to determine the net forces acting on a moving object					X			
Physical Science	8	There are different forms of energy, those forms of energy can be changed from one form to another – but total energy is conserved	PSCI_2	a. Gather, analyze, and interpret data to describe the different forms of energy and energy transfer		X						

Standard	Grade	Grade Level Expectation	GLE Number	Evidence Outcomes	Getting to Know Your Turbine	Power in Practice and Theory	Tip Top Tip Speed	Modeling Efficiency and TSR	What Speed Do We Need?	Wind Turbine Economics	Wind Farm Policy Simulation	When The Wind Doesn't Blow
Physical Science	8	There are different forms of energy, those forms of energy can be changed from one form to another – but total energy is conserved	PSCI_2	b. Develop a research-based analysis of different forms of energy and energy transfer								
				c. Use research-based models to describe energy transfer mechanisms, and predict amounts of energy transferred		**X**						
Earth Systems Science	6	Earth's natural resources provide the foundation for human society's physical needs. Many natural resources are nonrenewable on human timescales, while others can be renewed or recycled	ESS_3	a. Research and evaluate data and information to learn about the types and availability of various natural resources, and use this knowledge to make evidence-based decisions								**X**
				b. Identify and evaluate types and availability of renewable and nonrenewable resources	**X**				**X**			**X**
				c. Use direct and indirect evidence to determine the types of resources and their applications used in communities					**X**			
				d. Research and critically evaluate data and information about the advantages and disadvantages of using fossil fuels and alternative energy sources								**X**

MATH STANDARDS												
Standard	**Grade**	**Grade Level Expectation**	**GLE Number**	**Evidence Outcomes**	**Getting to Know Your Turbine**	**Power in Practice and Theory**	**Tip Top Tip Speed**	**Modeling Efficiency and TSR**	**What Speed Do We Need?**	**Wind Turbine Economics**	**Wind Farm Policy Simulation**	**When The Wind Doesn't Blow**
Data Analysis, Statistics and Probability	High School	Statistical methods take variability into account, supporting informed decision-making through quantitative studies designed to answer specific questions	DASP_1	a. Formulate appropriate research questions that can be answered with statistical analysis								
				b. Determine appropriate data collection methods to answer a research question								
				c. Explain how data might be analyzed to provide answers to a research question					**X**			
	High School	Visual displays and summary statistics condense the information in data sets into usable knowledge	DASP_3	a. Identify and choose appropriate ways to summarize numerical or categorical data using tables, graphical displays, and numerical summary statistics (describing shape, center and spread) and accounting for outliers when appropriate		**X**						
				b. Define and explain how sampling distributions (developed through simulation) are used to describe the sample-to-sample variability of sample statistics								
				c. Describe the relationship between two categorical variables using percents		**X**						

Standard	Grade	Grade Level Expectation	GLE Number	Evidence Outcomes	Getting to Know Your Turbine	Power in Practice and Theory	Tip Top Tip Speed	Modeling Efficiency and TSR	What Speed Do We Need?	Wind Turbine Economics	Wind Farm Policy Simulation	When The Wind Doesn't Blow
Number Sense, Properties and Operations	High School	Formulate, represent, and use algorithms with real numbers flexibly, accurately, and efficiently	NSPO_2	a. Use appropriate computation methods that encompass estimation and calculation		X	X	X				
				b. Use technology to perform operations (addition, subtraction, multiplication, and division) on numbers written in scientific notation		X	X	X				
				c. Describe factors affecting take-home pay and calculate the impact (PFL)								
Shape, Dimension and Geometric Relationships	High School	Attributes of two- and three-dimensional objects are measureable and can be quantified	SDGR_1	a. Calculate (or estimate when appropriate) the perimeter and area of a two-dimensional irregular shape								
				b. Justify, interpret, and apply the use of formulas for the surface area, and volume of cones, pyramids, and spheres including real-world situations								
				c. Solve for unknown quantities in relationships involving perimeter, area, surface area, and volume		X		X				

Standard	Grade	Grade Level Expectation	GLE Number	Evidence Outcomes	Getting to Know Your Turbine	Power in Practice and Theory	Tip Top Tip Speed	Modeling Efficiency and TSR	What Speed Do We Need?	Wind Turbine Economics	Wind Farm Policy Simulation	When The Wind Doesn't Blow
Shape, Dimension and Geometric Relationships	High School	Attributes of two- and three-dimensional objects are measureable and can be quantified	SDGR_1	d. Apply the effect of dimensional change, utilizing appropriate units and scales in problem-solving situations involving perimeter, area, and volume								
Number Sense, Properties and Operations	8	Formulate, represent, and use algorithms with real numbers flexibly, accurately, and efficiently	NSPO_2	a. Add, subtract, multiply and divide rational numbers including integers positive and negative fractions and decimals		**X**		**X**				
				b. Apply computational methods to solve multi-step application problems involving percentages and rational numbers		**X**		**X**				
Patterns, Functions and Algebraic Structures	8	Linear functions model situations with a constant rate of change and can be represented algebraically, graphically, and using tables	PFAS_1	a. Convert from one representation of a linear function to another, including situations, tables, equations (slope-intercept form), and graphs								
				b. Use representations of linear functions to analyze situations and solve problems								

Standard	Grade	Grade Level Expectation	GLE Number	Evidence Outcomes	Getting to Know Your Turbine	Power in Practice and Theory	Tip Top Tip Speed	Modeling Efficiency and TSR	What Speed Do We Need?	Wind Turbine Economics	Wind Farm Policy Simulation	When The Wind Doesn't Blow
Patterns, Functions and Algebraic Structures	8	Linear functions model situations with a constant rate of change and can be represented algebraically, graphically, and using tables	PFAS_1	c. Identify the dependent and independent variable in real-world situations					X			
				d. Identify and interpret the slope(rate of change) and y-intercept in graphs, in tables, and from equations in slope-intercept form								
				e. Model and graph two linear equations in slope-intercept form on the same coordinate plane and interpret the point of intersection as the solution to the system of equations								
	8	Graphs and tables can be used to distinguish between linear and nonlinear functions	PFAS_3	a. Given a table or graph determine if the function is linear		X			X			
				b. Explain the properties of linear functions in tables and graphs								

Standard	Grade	Grade Level Expectation	GLE Number	Evidence Outcomes	Getting to Know Your Turbine	Power in Practice and Theory	Tip Top Tip Speed	Modeling Efficiency and TSR	What Speed Do We Need?	Wind Turbine Economics	Wind Farm Policy Simulation	When The Wind Doesn't Blow
Number Sense, Properties and Operations	7	Formulate, represent, and use algorithms with integers and positive rational numbers flexibly, accurately, and efficiently	NSPO_2	a. Simplify numeric expressions using the order of operations								
				b. Add, subtract, multiply, and divide integers		X	X	X				
				c. Use mental math and estimation strategies to solve problems involving percents								
				d. Solve problems involving percent of a number, discounts, taxes, simple interest, percent increase, and percent decrease		X						
	7	Proportional reasoning involves comparisons and multiplicative relationships among ratios	NSPO_3	a. Use ratio relationships to solve for a missing value in a proportion			X					
				b. Model proportional relationships with bar models, ratio tables, and similar figures								
				c. Explain the difference between a ratio, rate, and unit rate								
				d. Estimate and compute unit cost of consumables (to include unit conversions if necessary) sold in quantity to make purchase decisions based on cost and practicality (PFL)								

Standard	Grade	Grade Level Expectation	GLE Number	Evidence Outcomes	Getting to Know Your Turbine	Power in Practice and Theory	Tip Top Tip Speed	Modeling Efficiency and TSR	What Speed Do We Need?	Wind Turbine Economics	Wind Farm Policy Simulation	When The Wind Doesn't Blow
Shape, Dimension and Geometric Relationships	7	Proportional reasoning is used to make indirect measurements	SDGR_2	a. Describe the relationship between the circumference and diameter of a circle		X	X					
				b. Read and interpret scales on maps								
				c. Use proportions to convert from one set of units to another within customary and metric systems using standard units of measure for length, weight, capacity and time		X	X					
Number Sense, Properties and Operations	6	Formulate, represent, and use algorithms with positive rational numbers flexibly, accurately, and efficiently	NSPO_2	a. Model and compute the addition, subtraction, multiplication and division of positive fractions, decimals, and combinations of fractions and decimals		X	X	X				
				b. Solve multi-step word problems involving fractions, decimals and whole numbers		X	X	X				
				c. Estimate sums, differences, products and quotients of rational numbers using common fractions, common decimals, and whole numbers								

Standard	Grade	Grade Level Expectation	GLE Number	Evidence Outcomes	Getting to Know Your Turbine	Power in Practice and Theory	Tip Top Tip Speed	Modeling Efficiency and TSR	What Speed Do We Need?	Wind Turbine Economics	Wind Farm Policy Simulation	When The Wind Doesn't Blow
Number Sense, Properties and Operations	6	Formulate, represent, and use algorithms with positive rational numbers flexibly, accurately, and efficiently	NSPO_2	d. Compare and round positive numbers from thousandths through millions								
Shape, Dimension and Geometric Relationships	6	Standard units provide common language for communicating measurements	SDGR_2	a. Connect metric prefixes to place value								
				b. Measure to the nearest sixteenth of an inch								
				c. Select and use appropriate units to accurately measure length, weight, capacity and time in problem-solving situations		X	X	X				
				d. Use a protractor to measure angles to the nearest degree				X				

SOCIAL STUDIES												
Standard	**Grade**	**Grade Level Expectation**	**GLE Number**	**Evidence Outcomes**	**Getting to Know Your Turbine**	**Power in Practice and Theory**	**Tip Top Tip Speed**	**Modeling Efficiency and TSR**	**What Speed Do We Need?**	**Wind Turbine Economics**	**Wind Farm Policy Simulation**	**When The Wind Doesn't Blow**
Geography: Develop spatial understanding, perspectives, and personal connections to the world	High School	Use different types of maps and geographic tools to analyze features on Earth to investigate and solve geographic questions	GEOG_1	a. Gather data, make inferences and draw conclusions from maps and other visual representations								**X**
				b. Create and interpret various graphs, tables, charts, and thematic maps								**X**
				c. Analyze and present information using a variety of geographic tools and geographic findings in graphs, tables, charts, and thematic maps								
				d. Locate physical and human features and evaluate their implications for society						**X**	**X**	
Geography: Develop spatial understanding, perspectives, and personal connections to the world	High School	Explain and interpret geographic variables that influence the interactions of people, places, and environments	GEOG_2	a. Apply geography skills to help investigate issues and justify possible resolutions involving people, places and environments.							**X**	
				b. Identify, evaluate, and communicate strategies to respond to constraints placed on human systems by the physical environment								

Standard	Grade	Grade Level Expectation	GLE Number	Evidence Outcomes	Getting to Know Your Turbine	Power in Practice and Theory	Tip Top Tip Speed	Modeling Efficiency and TSR	What Speed Do We Need?	Wind Turbine Economics	Wind Farm Policy Simulation	When The Wind Doesn't Blow
Geography: Develop spatial understanding, perspectives, and personal connections to the world	High School	Explain and interpret geographic variables that influence the interactions of people, places, and environments	GEOG_2	c. Explain how altering the environment has brought prosperity to some places and created environmental dilemmas for others								
				d. Research and interpret multiple viewpoints on issues that shaped the current policies and programs for resource use							**X**	**X**
				e. Explain how information and changing perceptions and values of places and environment influence personal actions							**X**	
				f. Define sustainability and explain how an individual's actions may influence sustainability								

ACTIVITIES

Activity Table of Contents

Activity One: Getting to Know Your Turbine

Grade Level
6-12

Objectives
Students will gain the background knowledge needed to understand the operation of their school turbine.

Overview
Students will use a "Spec Sheet" to learn the basic characteristics of the Skystream 3.7 turbine used in the Wind for Schools program.

Materials

- Skystream 3.7 Spec Sheet

Estimated Cost (per group)
$0

Computer required?
Only for research on Elaboration questions

Duration
1 class period

Primer References

- How Wind Turbines Work
- Using the Power of the Wind: Determining the Power in the Wind
- Understanding Wind Speed
- The Power in the Turbine
- The Energy in the Wind

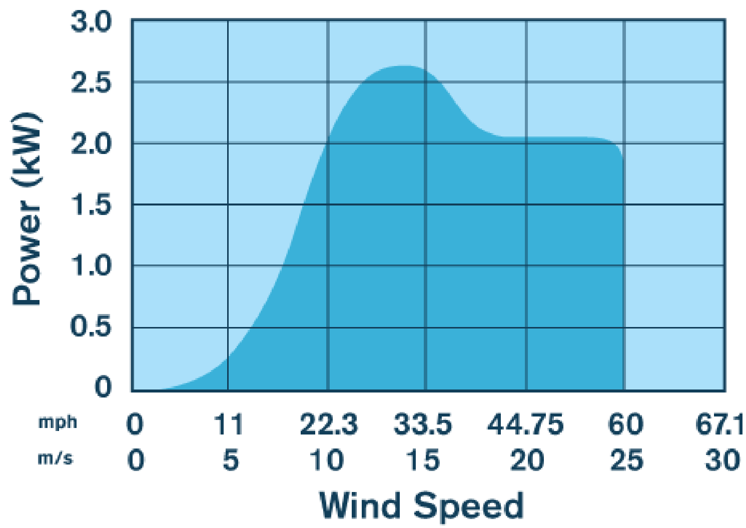
Engagement

- You may look at your school wind turbine every day, but how much do you really know about it?
- What can you expect it to do?
- How much wind does it take for it to produce energy?
- Why on some of the windiest days is it not turning?

Exploration
Find the Skystream 3.7 brochure below and use it to become familiar with your turbine by answering the following questions.

1. What is the rotor diameter in feet and meters?
    a. Bonus question: Why is this model called the Skystream 3.7?
2. What is the swept area? Draw a picture of what you think swept area describes.
3. What is the rated speed?
4. What is rpm?
5. What does "rated speed" mean?
6. What wind speed is the cut in speed? What happens at the cut in speed?
7. What is the rated wind speed? What does this tell you?
8. What is the maximum tip speed? What is tip speed?

9. What is the rated capacity of the Skystream 3.7 in KW? In watts? What does this mean?
10. This is the power curve for the Skystream 3.7 (the top graph on the left hand side of the sheet.) Label the cut in speed, the rated speed, where braking begins to occur and the cut out speed.



Data measured and compiled by USDA-ARS Research Lab, Bushland, TX

1. The graph on the lower left hand side is the Energy Curve for the Skystream 3.7. What can you learn from this graph and how might this information be important?
2. How high is your turbine tower?

Elaboration/Extensions

To get more information about the functions of different parts of the turbine, the process for installing the turbine and a number of manuals and fact sheets, go to the CSU Wind Application Center website at https://sites.google.com/a/rams.colostate.edu/csu-wac/clients/resources

1. The Skystream 3.7 has a passive yaw control. What is "yaw" and how does a passive yaw system work?
2. Braking also occurs passively on this turbine, that is, no electrical power is required for the braking system to work. Research how braking occurs on this turbine.
3. When you look at your school data, sometimes you will see a negative number under the power produced. What causes this negative reading?

References

- The Skystream Spec sheet may be found on-line at http://www.windenergy.com/sites/all/files/3-CMLT-1338-01_REV_J_Skystream_spec_.pdf
- Product manuals and other materials from the manufacturer are available at the Skystream 3.7 website http://www.windenergy.com/products/skystream/skystream-3.html#upclose

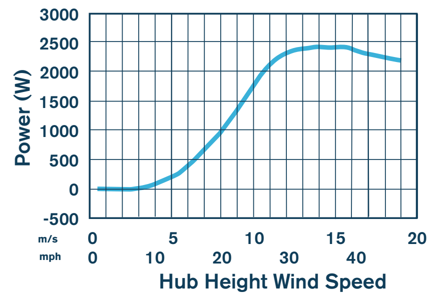
SKYSTREAM 3.7®

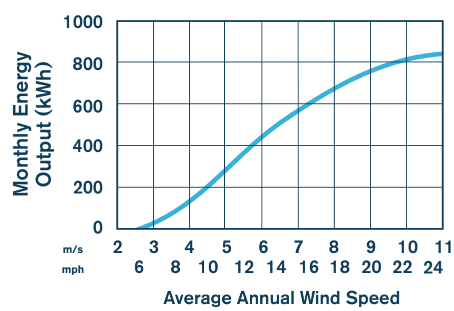
by Southwest Windpower

Take Control of Your Energy Needs

Designed for homes and small businesses, the Skystream 3.7® converts wind into clean electricity you can use. It's the first compact, user-friendly, all-inclusive wind generator (with controls and inverter built in) designed to provide quiet, clean electricity in very low winds.

Skystream 3.7 can help offset a household or small business's total energy needs.[1] And because it operates at a low RPM, Skystream is as quiet as the trees blowing in the wind.





Technical Specifications

Rated Power	2.1 kW at 11 m/s
Nominal Power	2.4 kW at 13 m/s
Rotor Diameter	12 ft (3.72 m)
Weight	170 lb (77 kg)
Swept Area	115.7 ft^2 (10.87 m^2)
Type	Downwind rotor with stall regulation control
Direction of Rotation	Clockwise looking upwind
Blades	(3) Fiberglass reinforced composite
Rotor Speed	50 - 330 rpm
Maximum Tip Speed	216.5 ft/s (66 m/s)
Alternator	Slotless permanent magnet brushless
Yaw Control	Passive
Grid Feeding	120/240 VAC Split 1 Ph, 60 Hz 120/208 VAC 3 Ph compatible, 60 Hz (Check with dealer for other configurations)
Battery Charging	Battery Charge Controller kit available for battery charging systems
Braking System	Electronic stall regulation with redundant relay switch control
Cut-in Wind Speed	6.7 mph (3.0 m/s)
User Monitoring	Wireless 2-way interface
Survival Wind Speed	140 mph (63 m/s)
Warranty	5 year limited warranty

FIVE YEAR WARRANTY

SOUTHWEST WINDPOWER™
(928) 779-9463
www.windenergy.com

[1] Actual savings is based on wind speed at the site and monthly energy consumption.
[2] Power performance testing by WINDTEST, Kaiser-Wilhelm-Koog, Germany November 14, 2008 - March 22, 2009. With Combined Standard Uncertainty. Reference air density: 1.22 kg/m3.

Printed on recycled paper with vegetable inks using 100% new wind energy.

3-CMLT-1338-01 REV J 7-12

Activity Two: Power in Practice and Theory

Adapted from

Boise State Wind Energy Teacher Resources
http://coen.boisestate.edu/windenergy/wfs/teacherresources/

Grade Level

6-12

Objectives

- Students will create graphs of wind turbine and efficiency data.
- Students will be able to calculate the theoretical power in the wind that blows through a turbine and compare it to actual data captured from a Wind for Schools turbine.
- Students will be able to calculate the efficiency of the study turbine.
- Students will be able to draw and support conclusions based on data.

Overview

Students will learn to determine the amount of theoretical, mathematically calculated, power in the wind reaching a turbine and compare it to the actual production of the school turbine. Students will use the data to determine the efficiency of the school turbine. They can then use this information to discuss the positives and negatives of the school wind turbine.

Materials

- Calculators
- Graph paper
- Internet connection
- Activity sheets

Estimated Cost of Materials

$0

Computer Required?

Yes

Duration

2 class periods

Primer References

- What is Wind and What is Wind Energy?
- How Wind Turbines Work: Blade Design and Function
- Using the Power of the Wind: Determining the Power in the Wind
- Understanding Wind Speed
- The Power in the Turbine
- The Energy in the Wind
- Getting Data from a School Wind Turbine

Engagement

- The wind seems like it blows much of the time in most places. Yet only some places are suitable for wind power production. Think about all the wind that blows past a turbine.
- Does all of it produce energy? How can the amount of energy produced by the wind be maximized?

- If we could use all of the power in the wind that came into a turbines swept area, what would happen? Is there such a thing as too much wind?
- These are important questions for wind engineers.
- How good a job of converting wind kinetic energy (the energy of moving air) to electrical energy does your Wind for Schools turbine do?

Exploration/Investigation

Warm-Up

Before you start closely analyzing your turbine and its output, study the relationship between wind speed and the power produced by looking at the data collected by your turbine.

1. Look at the data from your school over the past month and pick out 5-6 readings that show a wide range of different wind speeds. Record your wind speed in meters/second.
   If you can't find m/s data, convert miles per hour to meters per second by multiplying mph X .44704.
2. Make a table of watts produced and wind speed.
3. After you get a table of values, use them to graph the wind speed vs the watts. The wind speed is your independent variable and the watts produced are the dependent variable.

What do you notice? Is there a one to one relationship or does increased wind speed greatly increase the watts produced?

Instructor Note: Real data tends to be quirky and this is especially true of turbine data. Have students find places where there are several readings at the same wind speed. Use the value that occurs most frequently. Even that may not be entirely accurate! This is another good place to talk about the theoretical power curve versus the observed curve.

Part 1

You have seen that the data collected from your turbine shows you how much power is being produced at different wind speeds. In this activity, you will calculate the amount of power that would theoretically be produced at that wind velocity if all of the wind could be converted to power. How much of that power is your turbine really producing? What is the efficiency of your turbine?

The power in the wind is determined by the following equation:
Power (W) = $\frac{1}{2}\rho AV^3$
Where:
ρ (pronounced "rho") = density of the air
A = area swept by the blades
V = (velocity) wind speed

In the Warm-Up activity, you noticed that more wind equals a lot more power. Look at the equation for power. Can you tell why?

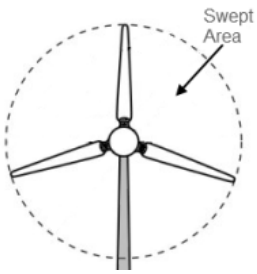
Power depends on the wind speed <u>cubed</u>, making wind speed the single most important factor in determining the power available to a wind turbine. If the wind speed doubles, how much does the power increase?
Air density is a variable that cannot be controlled by technology and decreases as elevation increases.
The swept area of the blades depends on the length of the turbine blades.

As you see from the equation above, there are several values you need to find or calculate in order to find the power in the wind.

1. The first value that you need to find for this calculation is the air density. This value varies based on temperature, humidity, and importantly for our work, altitude. Altitude is something we need to pay attention to in CO! To get an approximate value for the air density value at your location, go to http://www.engineeringtoolbox.com/standard-atmosphere-d_604.html
   Scroll down to U.S. Standard Atmosphere Air Properties in SI Units. Find your altitude to the closest 1000 feet in the first column. Go across to Density (ρ), the fifth column over. The value is listed in 10^{-1} kg/m^3 so move the decimal point one place to the right to convert to kg/m^3. The standard value at sea level is 1.22. Determine ρ for your location. Record this value in column 4 in your worksheet.

   Don't forget that you have just retrieved a value in SI units. Why did you have to collect your wind data in meters per second? Don't forget to collect your other values in the same system.

2. Next calculate the area swept by the turbine.



http://www.thebetterplanet.com

   You can see that this just means the area of the circle inscribed by the blades of the turbine. The formula for the area of a circle and the radius of the circle (remember the 3.7 tells you something) are all you know to figure this out. Record the diameter and radius of your turbine in columns 5 and 6 and the value of the Swept area in column 7 of your chart. Check the Skystream brochure. How close is your value to the one they report in their literature?

3. Finally, check the wind speed reported in your turbine data and record that in column 8.

4. At the same time you look at the wind speed, record the turbine name, date and time and power produced on the worksheet.(columns 1,2,3 and 11) If you are using data from the CAES website, the turbine updates data every 30 seconds. Watch the data for a couple of minutes and see how it changes. Column 11 is your observed power.

5. Remember that the formula uses wind velocity cubed. Cube your m/s value, enter in column 9.

6. Use the formula Power (W)= $\frac{1}{2}\rho AV^3$ to calculate the power of the wind passing through the turbine. Record this value in Column 10.

7. Next , look back at the data you wrote down in column 11. How much power is your turbine is actually producing?
   Note: If the reference wind speed is less than 8 mph(3.5m/s), the data will be erratic and not very useful. Why?

8. Calculate the efficiency of your turbine or , in other words, what percent of the kinetic power of the wind is it converting to mechanical energy?(Observed power/ calculated power x 100)

9. Let's see if your turbine efficiency is different at different wind speeds. Using the table you made in the first part of this activity, enter the data for each wind speed into the Efficiency worksheet. Calculate the efficiency at different wind speeds and then graph your results using the wind speed as the independent variable and efficiency as the dependent variable.

Part 2 More About Efficiency

As it turns out, no wind turbine is 100% efficient. If it were, it would stop the wind! In 1919, a German physicist named Albert Betz figured out that no wind turbine can convert more than 16/27 or approximately 59% of the kinetic energy of the wind into mechanical energy. This is called the **Betz Limit**. Therefore, the maximum efficiency of any wind turbine design can be no greater than 59%. You'll find out more about how this works when you work with tip speed ratios in the next lesson.

1. Find 59% of the calculated power of your turbine which will give you the maximum power available given the limitations of physics. (Maximum theoretical power). Enter in column 14.
2. Then calculate what percentage of this maximum power is actually being produced by your turbine. Enter this value in column 15.

The Betz limit is one way to measure an idealized **Coefficient of Power**, or Cp. In the real world, the Cp tells us how well the turbine is actually performing in terms of the percent of kinetic energy being converted to power.

A simpler measure of performance that is often used when studying the performance of wind turbines is the **capacity factor,** or the fraction of the actual power compared to the rated power of the turbine. (See Activity One for the rated power for the Skystream 3.7) If the actual power generated at some wind speed is 10 kW and that the turbine is rated 100 kW (at its rated wind speed), then the capacity factor would be 10/100 = 10%. You can check out any of the locations on the Colorado ALP website at http://www.engr.colostate.edu/ALP/ALP_Sites.htm to see the capacity factor for a number of different kinds of turbines. Turbines in the best wind regimes tend to have capacity factors in the 35-45% range.

3. In the Capacity Factor section of your worksheet, calculate the capacity factor at the same wind speeds you used in the previous section.

Explanation/Class Review:

1. How does wind speed affect power production?
2. What did you notice about wind speeds at your turbine site?
3. What variable can be controlled to increase the amount of power converted to electricity?
4. Is your turbine equally efficient at all wind speeds?
5. If no, at which speeds does it function best?
6. If not all of the energy in the wind passing by the turbine is converted to electricity, what happens to the rest of it?
7. Were you surprised at the efficiency of the turbine?
8. What factors do you think effect the efficiency of your turbine?
9. What does the value in column 15 tell you?
10. Does the efficiency of the turbine based on the maximum possible power production change at different wind speeds?
11. What about the capacity factor? Does it vary at different wind speeds? Do you think that this is a useful value to evaluate your turbine?
12. How do you feel about the level of efficiency of your turbine?
13. Given the efficiency of your turbine and the amount of power being produced, make a good argument pro or con for the value of the turbine to your school.

Elaboration/ Extensions

1. We know that wind power has some positive environmental effects. But how does the efficiency of a wind turbine compare to the efficiency of another renewal resource such as solar or hydropower? How does it compare to a plant generating electricity with coal? Do a web search to find out more about the efficiencies of different power generation systems.

If efficiencies are close to the same value, what other factors might help us decide which sources to develop and use?

2. If you enjoy advanced math, some of the References show how the Betz Limit is calculated.

Instructor Notes:

1. You can have students work in group of two to collect data and discuss results.
2. To get wind turbine data, you can get data directly from your school turbine. Convert the text file you get from the SkyView software into an excel spreadsheet. See Appendix B for instructions on how to do this. Or give students the raw data and have them do it. You will need data from a long enough period of time to show a variety of wind speeds to reveal differences in efficiency at different speeds.
   If your school sends data to the CAES site, students can follow instructions in Appendix C to go download data to get wind speed and power readings from the last week or month. This makes a very long file, so have them scroll through and record samples of data rather than try to print.
   If your school does not have a turbine, select a school from the Wind for Schools list and use their data following the same directions a school with a turbine would use to access the CAES data. Students may want to look at the Wind for Schools welcome page to find a school that is close to them or that seems to be in a windy area. Hint: Try Kansas!
3. It can't be emphasized too often that real data can be erratic! If the power produced produces and efficiency greater than the Betz Limit, have students scan the data at the same wind speed to see if the value they are using is typical. Gusts of wind produce spikes in reported power that may not be accurate. Find a section where there are 4 or 5 readings at the same wind speed and use the watts value that appears most often. Try comparing data between schools.
4. Remember that all of these sites are using Skystream 3.7 turbines so the measurements are the same. However, to be a bit more precise, have students find the air density for the location they are using if it is not similar to their own.

References/Related Articles

Wind Turbine Power Calculations
http://www.raeng.org.uk/education/diploma/maths/pdf/exemplars_advanced/23_wind_turbine.pdf

Calculation of Wind Power
http://www.reuk.co.uk/print.php?article=Calculation-of-Wind-Power.htm

Wind Energy Math
http://www.mmpa.org/Uploaded_Files/ab/ab5c7c5c-79d9-48bd-b64d-833001b7e230.pdf

Colorado Anemometer Loan Program Website
http://www.engr.colostate.edu/ALP/ALP_Sites.htm

Activity 2 How efficient is your turbine?

1. Turbine location	2. Date	3. Time	4. Rho	5. Blade D (m)	6. Blade R (m)	7. Swept Area m²	8. Wind speed m/s (V)	9. V cubed	10. Calc. Power (w)	11. Observ. Power (w)	12. % Energy Produced to Power Observ./Calc. X100	13. Betz Limit	14. Maximum theoretical power	15. Actual % Efficiency Observ/Maximum theoreticalX100
			0.82									59%		
			0.82									59%		
			0.82									59%		
			0.82									59%		
			0.82									59%		
			0.82									59%		
			0.82									59%		
			0.82									59%		
			0.82									59%		
			0.82									59%		
			0.82									59%		

Notes:

Calc.= Calculated Power

Observ. = Observed Power

Expec. = Expected Power

Rated= Turbine's Rated Power

Capacity Factors

1. Turbine location	2. Date	3. Time	4. Observ.	5. Rated	6. Capacity Factor

Activity Three: Tip Top Tip Speed

Adapted from

KidWind, "Wind Energy Math Calculations"

Grade Level

6-12

Objectives

- Students will be able to explain the importance of the tip speed ratio to turbine performance.
- Students will use a tachometer to measure revolutions per minute.
- Students will be able to calculate tip speed and tip speed ratio.

Overview

It might seem that the faster your turbine turns the more power it generates. But is this actually the case? Your Skystream turbine blades appear to turn very quickly. A large wind farm turbine's blades appear to turn much more slowly. Which is producing more power? The speed at which the blades travel helps to determine the tip speed ratio and being able to calculate a tip speed ratio allows us to maximize the power generated by a wind turbine.

How does the speed at which the turbine is spinning relate to the power produced? Clearly, if the blades spin too slowly, a lot of the potential power will blow right through the turbine. If the blades spin very fast, they can create a solid wall and no wind can blow through, producing no power. When fast-moving wind can blow through a fast spinning turbine, the turbulence created in the wind stream by one blade will interfere with the travel of the next blade if it arrives too quickly. In order to design a turbine that gets the maximum power from the wind, the best "tip speed ratio" must be determined. In other words, there is a speed of the blade tips that should be matched to the speed of the wind for the best results.

Materials

- Your school turbine
- Tachometer
- Wind speed meter
- Activity Sheets

Estimated cost (per group)

$50 for one tachometer and one wind speed meter

Computer needed?

Yes

Duration

2 class periods (One class period to collect and analyze outdoor data and one for computer data calculations, discussion and research.)

Primer References

- Using the Power of the Wind: Tip Speed Ratio
- How to Find Tip Speed Ratio
- Tip Speed Ratio and Coefficient of Power

Engagement

- Is it true that the faster your turbine spins, the more power the turbine generates?
- Is the highest wind always the best for power generation?

Exploration

Finding the Tip Speed Ratio of your school turbine

Part 1 –Using data gathered at your site

The tip speed ratio is the ratio of the tip speed of the turbine blade to the speed of the wind.

$$\text{Tip Speed Ratio}(\lambda) = \frac{\text{Tip Speed of blade}}{\text{Wind Speed}}$$

1. Find out how far the tip of the turbine blade travels in one revolution.
   This distance is the circumference of the circle traced by the tip of the blade.
   Circumference = $\pi 2r$ or πD
2. Sadly, the tachometer in your kit cannot determine RPM (revolutions per minute) on the actual turbine. You can get this from your turbine data or go outside and see if you can find a strategy for estimating the RPM of your turbine. When you get a value, you need its inverse, or minutes per revolution, and you need seconds rather than minutes, so just take the RPM value and divide it into the number 60. That will give you how long it takes for a blade to go around one time in seconds.

3. Speed = Distance (circumference) divided by time (for one revolution). Calculate the speed of the tips of your turbine.

4. Use your wind speed meter to determine the wind speed that is moving your turbine blades at this speed.

5. Determine the Tip Speed Ratio by dividing the tip speed by the wind speed. Remember that the units in your calculations all need to be in the same system.

6. Observation and data collection has shown that this formula is an accurate way to find the optimum TSR for maximum power output:

   $$\lambda \text{ (max power)} = \frac{4\pi}{n} \quad \text{(n = number of blades)}$$

   λ = Tip speed Ratio or TSR

   What is the optimum TSR for your turbine using this formula?

7. Research using some of the sites listed in the References below to find out how the optimum tip speed ratio can be increased.

Part 2 –Using Data from Your Wind for Schools site

1. Record the date and time of your data set.

2. Record the RPM of your turbine.

3. Record the wind speed.

4. Calculate the circumference of the circle traveled by your turbine blades. (Hint: Is this different than the value you found in Part 1?)

5. Calculate the tip speed based on this data.

6. Calculate the tip speed ratio based on this data.

7. Look at some of the past month's data for your turbine. Pick two different wind speeds. Record the RPM associated with each wind speed. Repeat steps 2-6 to calculate the tip speed ratios at those speeds. Does the tip speed ratio change with changing wind speeds?

8. At what wind speed, is the TSR value optimal?

Explanation
Class Discussion

1. What exactly does the tip speed ratio describe?
2. Why is this ratio important?
3. What happens at the optimum TSR? What is happening if the TSR is less than the optimum value? What is happening if it is higher than the optimum value?
4. Do you think the TSR of your turbine is a constant value? Why or why not?
5. The optimal or optimum tip speed ratio predicted by the formula used earlier can be increased by making some changes to the turbine. What are some of the changes you learned about?

Elaboration/Extension

1. How does the tip speed of a large wind turbine compare to the speed of the Skystream turbine? The Cedar Point Wind Farm in Limon, CO uses Vestas v90 turbines. The rotor on this turbine has a diameter of 90 m. At the nominal wind speed of 12m/s (the lowest speed at which the turbine produces the rated power), the rotor turns at 16.1 RPM. Using your Tip Speed Ratio worksheet, calculate the Tip Speed and the Tip Speed Ratio for this turbine. How do the values compare to those of the smaller turbine? To look at more of the technical specifications of the Vestas v90 3.0MW turbine, see page 14 of the brochure at http://www.vestas.com/Files/Filer/EN/Brochures/Vestas_V_90-3MW-11-2009-EN.pdf

Instructor Notes

For a discussion of the higher level math used in calculating the Betz Limit, Power Coefficient and Optimal TSR, see
http://www.raeng.org.uk/education/diploma/maths/pdf/exemplars_advanced/23_wind_turbine.pdf

References

http://www.windynation.com/articles/wind/tip-speed-ratio-how-calculate-and-apply-tsr-blade-selection
Warning: we did not calculate TRS as they did, but the rest of the information is useful

Optimal Rotor Tip Speed Ratio
http://mragheb.com/NPRE%20475%20Wind%20Power%20Systems/Optimal%20Rotor%20Tip%20Speed%20Ratio.pdf

Calculating the Tip Speed Ratio of your Wind Turbine
http://www.mmpa.org/Uploaded_Files/2c/2c48c69c-303d-4fc7-8d88-2153190d1fcc.pdf

A whole collection of tip speed ratio problems and handouts
http://www.energyforeducators.org/lessons/TipSpeedRatio/tip_speed_ratio_lesson_plan.pdf

Find a Coefficient of Power to TSR graph here
http://www.reuk.co.uk/print.php?article=Wind-Turbine-Tip-Speed-Ratio.htm

Tip Speed Ratio - Observed Data								
Turbine Location	Date	Time	Rotor Circumference	RPM	Time for 1 Revolution	Tip Speed	Wind Speed m/s	Tip Speed Ratio

Tip Speed Ratio - Turbine Data

Turbine Location	Date	Time	Rotor Circumference	RPM	Time for 1 Revolution	Tip Speed	Wind Speed m/s	Tip Speed Ratio

Activity Four: Modeling Power Efficiency and Tip Speed Ratios

Adapted From
KidWind "Wind Turbine Blade Design" and "Building the Basic PVC Wind Turbine"

Grade Level
6-12

Objectives
Students apply concepts learned about what makes an efficient wind turbine to building a model turbine and using data collection skills and mathematics knowledge to determine the efficiency of their model.

Overview
Students will work in teams to build what they believe will be the most efficient model wind turbine in the classroom. They will calculate and measure power and tip speed ratio and design experiments to explore the variables that can affect turbine efficiency.

Materials
For each group of 3-4 students

- Wind turbine kit (hub, dowels, generator, holder)
- Materials for making turbine blades – poster board, foam core board, balsa wood, etc.
- Scissors or exacto knives for cutting blade materials
- Strong Tape or hot glue
- Tachometer
- Multimeter
- Box Fan
- Wind Speed Meter
- Masking tape
- Activity Worksheets

Estimated Cost (per group)
$150 per group if premade kits are used.

Computer required?
None, unless worksheets are done on the computer. They can also be printed out.

Duration
Two to three 40-45 minute class periods to build turbines, carry out experiments and discuss results

Primer References

- What is Wind and What is Wind Energy?
- How Wind Turbines Work: Blade Design and Function
- Using the Power of the Wind: Determining the Power in the Wind
- Understanding Wind Speed; the Power in the Turbine
- The Energy in the Wind; Tip Speed Ratio
- How to Find Tip Speed Ratio
- Tip Speed Ratio and Coefficient of Power
- Getting Data from a School Wind Turbine

Engagement

Usually scientists and engineers will use models to explore larger, real time phenomenon. You have been collecting data and analyzing it to explore the efficiency of your school turbine as well as larger wind farm turbines and now you will apply the principles you learned about turbine efficiency to try to build a highly efficient wind turbine model. Based on what you learned in the two previous activities, your team will try to build the most efficient wind turbine in the class.

- What characteristics contribute to maximum power generation?
- What should your blades be like; how many, what size, shape and pitch?
- What other factors should you consider?

Exploration/Investigation

Using your wind turbine kit, design a turbine that will produce the greatest amount of power at the highest degree of efficiency.

Super Power

1. With your team, draw a blueprint of the wind turbine you plan to build.
2. Once you are satisfied with your design, get the construction materials and carefully cut out your blades and firmly attached them to the dowels that will go into your hub.
3. Measure the length of your blades and record your turbine radius and diameter on the worksheet.
4. Find and record the air density for your location.
5. Measure the wind speed at the tape mark with the fan set at setting 3.
6. Calculate the energy your turbine can potentially produce.
7. Place the hub on the turbine and place it at the test site.
8. Connect the generator to the multimeter.
9. Record volts and milliamps produced at each fan setting and calculate power produced at each setting. Remember you are most likely measuring milliamps when you take your readings and do your calculations.

Instructor Note: In order to measure current (amps) with the multimeter in this kit, a resistor must be placed in series with the multimeter and turbine. There are small 50 Ω resistors in the kit that can be incorporated into the circuit using an alligator clip. The literature in the kit also explains how to calculate power using volts and resistance.

Tip Top TSR

Can engineers increase the TSR of a wind turbine? Experiment with some possible factors.

1. Determine the RPM of your turbine using the tachometer. You and your partner will need to work together to do this. Place a small square of reflective tape near the tip of one blade. Find a spot where you can aim the laser light directly at the square. Turn on the tachometer and make sure it is aimed in the spot you chose. This will be near the edge of the blades. One person will turn on the tachometer and watch the screen. The other will call out "reading' every 10 seconds and record what the holder says. When you have 60 seconds of readings, average them to get an rpm reading. The readings may vary widely but the averaging should help give a useable value.
2. Measure the wind speed.
3. Calculate the TSR for your turbine. What does the TSR tell you about your design?
4. Think of another variable to test. If necessary, look back at some of the references you consulted in the Tip Top Speed activity. Remember to only change one feature at a time when you are testing for differences!

Explanation

1. Which classroom turbine produced the most power? What about its design made it work so well?
2. Which design should theoretically have been the most efficient? Was it? Why or why not?

3. Compare class Tip Speed Ratios. Did turbines with longer blades produce more power than those with shorter blades? Would you expect them to? Why? If they didn't, why not?
4. Does the TSR change with the length of the blades? What other factors affected TSR?
5. Does a larger TSR lead to more power produced? Should it? Why or why not?
6. Which factors seem to have the most effect on optimizing TSR?
7. What factors are designed into real wind turbines to bring TSR as close to optimal as possible?

Extension

Work with other groups in your class to design a wind farm using several of your model turbines. Calculate the efficiency and the power produced by the farm. Does putting turbines together in a farm format increase the overall efficiency of production?

Instructor Notes

Set up a test area with a box fan placed 18 inches from the turbines. Use tape to mark a spot where all turbines will be placed for testing.

References

KidWind has lots of materials about blade design. This activity has some god hints about blade design variables to try.
http://learn.kidwind.org/sites/default/files/blade_design2.pdf

Another good resource available at the KidWind site is a turbine Performance Calculator that actually allows students to put in their data and have results calculated for them.
http://learn.kidwind.org/challenge/web/turbine_performance_calculator

KidWind also has a good overall primer on wind energy, turbines, farms and on electricity concepts. There is a useful section on wind farms and model wind farms including how to wire models in series and parallel and a good discussion on the "wind park effect."
http://learn.kidwind.org/sites/default/files/learn_wind.pdf

Using the Tachometer

Your kit includes a very basic tachometer that turns out only to work within 6 feet of the spinning object you are timing so it will not work for measuring the RPM of your school turbine. There may be a larger scale tachometer available through one of your high school science teachers.

1. To use the tachometer, first put the battery in. Press the TEST button to see if it comes on.
2. Place a 1/2 inch piece of reflective tape on one of the blades, near the outer edge.
3. Find a spot where the laser beam that does the counting can be aimed fairly straight and level at the blade with the tape. The easiest way to do this is to have the blade pointing straight down in front of the turbine tower and aim straight at the tower and brace the instrument on the turbine. This will help you keep it in the same position when you are measuring.
4. Start the turbine. Aim at the edge of the spinning "wheel", staying level with the spot you noted on the tower and press the TEST button. You may have to hold it for a while or press it on and off before data starts to show.
5. Once you get a reading, have a partner call out "Reading" every 10 seconds and record the reading. You will find that the readings may be very erratic. Repeat 3 times.
6. You will notice that the readings go up and down, but that there will be a period of time when the same value stays on the screen. Over the course of 3 trials, you may find that this value is fairly close in all three trials. If that is the case, average these 3 together.
7. If you have widely spaced, jumpy data, you may want to throw out your outliers and average the 3 or 4 values that are closer together for each trial. Then average the 3 trial averages to get an estimated RPM.

This is a good chance to discuss experimental error with the class.

Activity 4 Modeling Power and Efficiency

Team name - Rotor description	Volts produced	Current produced mA	Power Produced mW	Power Produced W	Rho	Blade radius m	Swept Area m²	Wind speed m/s (V)	V cubed	Calc. Power (w)	Observ. Power (w)	% Energy Produced to Power Observ./Calc. X100
					0.82							
					0.82							
					0.82							
					0.82							
					0.82							
					0.82							
					0.82							
					0.82							
					0.82							
					0.82							
					0.82							
Notes:												
Calc.= Calculated Power												
Observ. = Observed Power												

Modeling Tip Speed Ratio

Team name	Rotor Diameter m	Rotor Circumference m	RPM	Time for 1 Revolution	Tip Speed	Wind Speed m/s	Tip Speed Ratio

Activity Five: What Speed Do We Need?

Adopted/ Revised From
NEED - Wind for Schools Curriculum
KidWind – Can Wind Power Your Classroom?

Grade Level
6-12

Objectives
- Conduct an electricity audit of the classroom using a power monitor
- Compare the current and potential electricity output of the school wind turbine to the classroom's electricity needs

Overview
Students use a power monitor to estimate the energy used by all appliances and lights in the classroom and use the wind turbine's power curve to determine if that demand can be met through wind energy.

Materials (per group)
- Power monitor (Kill-a-watt or similar)
- Flicker checker
- Anemometer or anemometer mobile app

Estimated Cost of Materials
$45 per group

Computer Required?
No

Duration
1 class period

Primer References
The Energy in the Wind
School Energy Use
Getting Data from a School Wind Turbine

Engagement
1. Do you think our school wind turbine can power our school? Our classroom?
2. Where does the electricity generated by our wind turbine go when school is closed?
3. What powers the classroom when the wind isn't blowing?
4. How fast does the wind need to blow to power our classroom?

Investigation
Now we're going to measure how much electricity our classroom uses and see if our wind turbine can generate that amount:
1. Divide the class into small groups and hand out listed materials.
2. Ask each group to use the power monitor to measure the wattage of each appliance in the classroom.
3. Each group should also count the number of light fixtures and light bulbs in the classroom.

4. When counting light fixtures, have the students use flicker checkers to determine if they have magnetic (inefficient) or electronic (efficient) ballasts.
5. Each group should also measure the current wind speed near the turbine using either an anemometer or anemometer mobile app.
6. Data should be recorded in their activity sheets and the activity sheets should be completed.

Class Review

1. Ask the class to share the results of their electricity audit and anemometer readings as well as their answers to the activity sheet questions.

Elaboration

Now that we have seen the relative power of your school's wind turbine:

1. Have students read the Primer References for this lesson.
2. If the current wind speed was insufficient to power the classroom, what would you turn off to meet wind energy that is currently being generated? Why?
3. Is the relationship between wind speed and power linear or nonlinear? Why?

Instructor Notes

- Show students how to measure watts using the power monitor and how to use the flicker checker based on the sheets below.

Extensions and Variations

- Calculate the electricity needs of your bedroom at home. What would the average wind speed need to be to power your bedroom for a month? Your living room? Your home?

References/For More Information

- http://www.need.org/needpdf/WindForSchools.pdf
- http://learn.kidwind.org/sites/default/files/Lesson%205.pdf

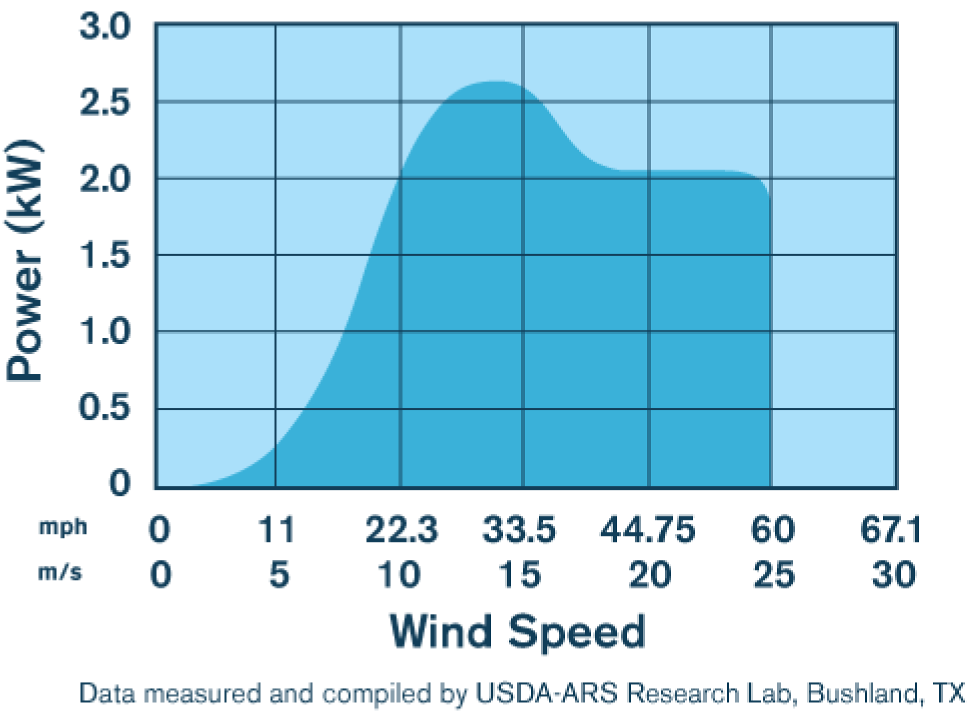
What Speed Do We Need?

Appliance	On now?	Watts - on	Watts - off	Hours on/ day	kWh/ month - on	kWh/ month - off	kWh/ month - total
*Ceiling light fixtures can be assumed to use 43 watts when on if electronic ballasts are present and 117 watts when on if magnetic ballasts are present. For a more accurate determination of wattage, teachers can remove the lens from a sample fixture, identify the number and type of lamps, and multiply volts times amps as listed on the ballast nameplate for the number and type of lamps in the fixture.							
Current wind speed near wind turbine (mph)							

Questions

1. How many watts are being used right now in the classroom? Convert this to kilowatts.

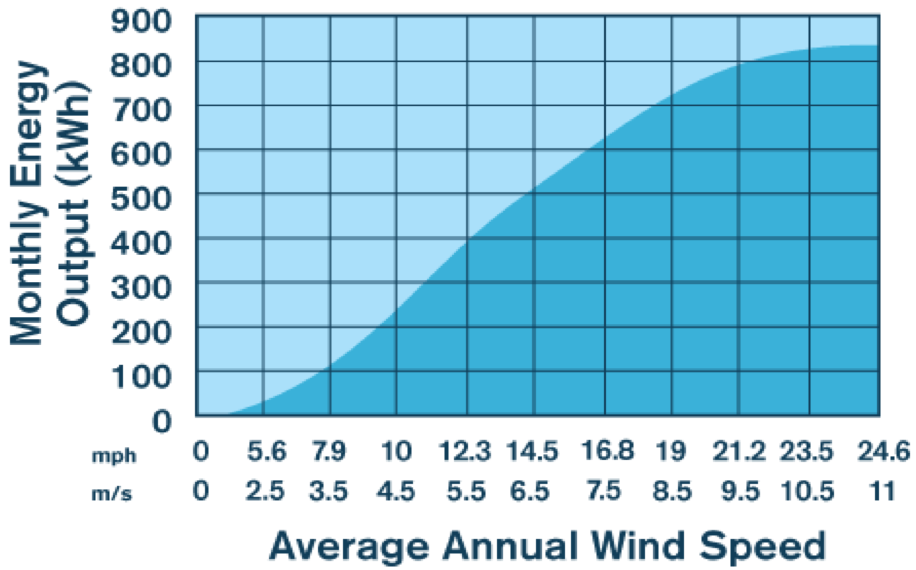
2. Using the power curve below, what does the wind speed need to be (mph) to generate this many kilowatts?



[Source: http://huskerwindpower.com](http://huskerwindpower.com)

3. Is the current wind speed near your school's turbine sufficient to meet your current needs for electricity in the classroom?

4. Using the energy curve below, what does the average wind speed need to be to supply one month's worth of electricity for your classroom?



Source: http://huskerwindpower.com

5. Using your historical wind speed data, is it fair to assume that your classroom's electricity use is offset by what is generated from your turbine? If every classroom in the school had similar electricity demands, how many classrooms could be powered by your turbine?

Using a Flicker Checker

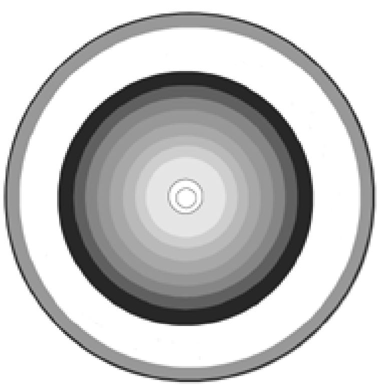
A fluorescent bulb produces light by passing an electric current through a gas using a ballast. The ballast is an electromagnet that can produce a large voltage between the two parts. It is this voltage that gives the electrons of the gas molecules the energy inside the tube. A magnetic ballast has an iron ring wrapped with hundreds of turns of wire. The current from the electrical outlet runs through the wire in the ballast. The wire also is a resistor to some degree, so there is some heat produced. There is also a little heat given off by the gas.

A fluorescent bulb with a magnetic ballast converts about 40 percent of the electricity into light and 60 percent into heat. An electronic ballast has a microchip, like that found in a computer, instead of the coils of wire. This ballast is about 30 percent more efficient in turning electrical energy into light than a magnetic ballast. Some heat is produced in the gas, but not in the ballast itself.

The reason that the Flicker Checker can tell the difference between the magnetic and electronic ballasts is because of the way the current is delivered to the gas. In any outlet in the United States that is powered by an electric company, the electricity is sent as alternating current— it turns on and off 60 times each second. Because the light with the magnetic ballast has wires attached to the outlet, it also turns on and off 60 times per second. The microchip in the electronic ballast can change that frequency. Light bulbs with electronic ballasts are made to turn on and off between 10,000 and 20,000 times each second.

Using the Flicker Checker

Spin the black and white Flicker Checker on a flat surface located beneath your overhead fluorescent light and away from direct, natural light. Any tabletop should do! If you see smooth, grey rings on the Flicker Checker, the fluorescent fixture contains electronic ballast. If you see a checkered pattern with hints of color that move from ring to ring, the fixture contains a magnetic ballast. Other indicators of magnetic ballasts; a flickering effect, a buzzing sound and poor quality light. This suggests you have lighting that wastes energy.



Example of a flicker checker showing smooth grey rings typical of electronic ballasts

Flicker checking showing the checkered pattern typical of magnetic ballasts

From: National Energy Education Development (NEED) Project – www.need.org

Using a Power Monitor

Power monitors have various functions that allow you to check different aspects of electricity usage. For testing energy use, the most important ones are Watts (W) and kilowatt hours (kWh). The Watts function measures the instantaneous draw (how much electricity a device is using), whereas the kWh gives the measure of electricity usage over time. For example, a 1,000 watt electric heater running for one hour will use one kWh of electricity.

For the purpose of this lesson, the Watts function can be accessed on a Kill-a-Watt EZ power monitor by:

1. plugging the monitor into an electrical outlet
2. plugging an appliance into the monitor
3. Hitting the “Up” button four times until the “Watt” function is displayed.

This can be done both when the appliance is turned on and when it is off (to measure “phantom loads”.

Many power monitors also allow for electricity use to be converted into cost. While a default value (i.e. $0.10 per kWh) may be pre-entered on a power monitor, monitor users should enter the rate they are charged by their local utility to get the most accurate cost estimates from the monitor.

Functions of less relevance for energy efficiency include Volts (your reading should be close to 120.0, the standard voltage in US electrical outlets), Amps (the measure of the flow rate of electric current), and HZ/PF (60 hertz cycles per second is the standard for alternating current in US electrical outlets).

Special cases
Some appliances such as fans, space heaters, and hair dryers have multiple settings. Read the wattage of these types of appliances as you change the settings for a fun experiment.

Other appliances may have large fluctuations in their draws when actively on. For example, a hair dryer ranged from 240 to 1,000 watts when on high. Still other appliances have such a low draw that they may not immediately register. These may include LED nightlights and carbon monoxide detectors. The electricity usage of these is so small that it may not be worth capturing even over a longer period. It’s most important to get accurate readings for the appliances that use the most electricity such as refrigerators or large screen televisions.

Some appliances such as computers and printers use significantly different amounts of energy when “on” depending on whether they are actively “on” or passively “on”. Computers are actively “on” when being used or not in sleep mode. Printers are actively on when printing, not standing by.

It is best to capture the cycling of these active and passive stages over a representative period of time as is done with refrigerators and water heaters. A less accurate means of calculating wattage when “on” would be to record the most common wattage (active or passive) or take the average of the active and passive wattages if they are not too far apart.

Activity Six: Wind Turbine Economics

Grade Level
7-12

Objectives
- Determine the cost of installing wind turbine at your school
- Use math to determine what the savings a school wind turbine provides to a school

Overview
Youth will use a worksheet to determine what the actual and projected costs that would in incurred for the installation of a wind turbine at a school. A possible extension is to look a wind farms in Colorado and determine the economic costs of building and maintaining a wind farm.

Materials (per group)
- Worksheet (see attached)
- Skystream technical specifications worksheet (http://www.skystreamenergy.com/products/skystream/skystream-3.7) or Specifications worksheet for another wind turbine
- Access to DSIRE Website for federal, state and local rebate information (www.dsireusa.org)

Estimated Cost of Materials
$0

Computer Required?
Yes

Duration
35-50 minutes

Primer References
- Wind Power in Colorado
- Colorado Wind Farms
- Economic Impacts of Wind Power Development in Colorado

Engagement
This activity is ideally conducted after "What Speed Do We Need" since in that lesson students should have learned that the school wind turbine is insufficient to provide the school's electricity needs and won't generate any electricity at all if the wind doesn't blow.

1. What sort of savings is the school seeing from having the wind turbine?
2. How long does it take to pay off a wind turbine?
3. What does this look like on the scale of an entire wind farm?

Investigation
Let's determine the economic benefit of the school turbine.

Wind for Schools Turbine Worksheet
1. In order to calculate the total annual potential energy, we need to know the capacity of the turbine and the total hours in a year. To determine the capacity of the turbine, use this link or print the handout at this link: http://www.skystreamenergy.com/products/skystream/skystream-3.7.

2. Determine the annual average predicted energy by multiplying the turbine's capacity factor for your location by the total annual potential energy.
    a. The capacity factor can be determined by looking up the nearest site from CSU's Anemometer Loan Program at: http://www.engr.colostate.edu/ALP/
    b. Alternatively, and to keep students from accidentally finding the predicted kWh when looking up the capacity factor, use a default of 30% noting that this will vary based on your location's wind regime.
3. The total cost to the school can be estimated using an approximate total cost of the turbine plus cost of installation and total local fees minus the incentive available. In order to determine the available incentives, go to www.dsireusa.org and check with your local utility.
4. To determine the annual avoided costs, multiply the annual average predicted energy by the cost of electricity (dollars/kWh).
5. The avoided costs for twenty years can be calculated by multiplying the annual avoided costs times 20.
6. Assuming that the cost of electricity and wind speeds are constants, students will finally calculate the total number of years to recover costs by dividing the total costs to the school after incentives by the annual avoided costs.

Class Review
Now that we have a better idea about the economics of the wind turbine at our, answer the following questions:

Wind for School Turbine Questions
Obviously, cost of electricity and wind speeds are not constants.
1. What if the cost of electricity has a flat increase of 4% indefinitely?
2. What about maintenance costs?
3. What if the cost of electricity goes up slower or faster than 4%?

References/For More Information

- Wind Energy in Colorado: A Practical Guide for Farmers and Ranchers About Producing Energy from Wind
- http://www.landsward.nau.edu/windforschools.html
- http://www.agmrc.org/media/cms/WIND_REPORT_Final_A97037D9FC0B8.pdf

Wind Turbine Economics	
Skystream 3.7 Turbine on 33 Foot Tower	
Capacity of Turbine (kW): (*Hint* Nominal Power)	
Hours in a Year:	8,760
Total Annual Potential Energy (kWH):	
Capacity Factor (% of time generating):	30.0%
Annual Average Predicted Energy (kWH):	
Cost of Turbine Installed:	$25,000
Incentives Available	
Federal:	$ 7,500
State:	
Local:	
Total Cost to the School after Incentives:	
Cost of Electricity (cents/kWH):	$ 0.11
Annual Avoided Costs:	
Avoided Cost Over 20 Years:	
Total Cost to the School after Incentives:	
Annual Avoided Costs:	
** Assumption that the cost of electricity and wind speed **NEVER CHANGES**	
Total Number of Years to Recover Costs:	
Questions:	
Obviously, cost of electricity and wind speeds are not constants.	
What if the cost of electricity has a flat increase of 4% indefinitely?	
What about maintenance costs?	
What if the cost of electricity goes up slower or faster than 4%?	

Activity Seven: Wind Farm Policy Simulation

Grade Level
7-12

Objectives
- Learn about the various stakeholders in wind development
- Consider the roles of decision makers in large infrastructure projects
- Consider multiple view points

Overview
Youth will role play as various stakeholders in their community to determine how they would approach the locating of a utility-scale wind farm in their community.

Materials (per group)
- Playing card
- Instructions on role playing and community hearing
- Read an article about existing wind farms: http://www.bizjournals.com/denver/news/2011/07/13/475m-wind-farm-dedicated-in-weld.html?page=all

Estimated Cost of Materials
$0

Computer Required?
Yes

Duration
2 or more class periods

Primer References
- Wind Power in Colorado
- Colorado Wind Farms
- Economic Impacts of Wind Power Development in Colorado
- Environmental Impacts of Wind Power

Engagement

1. Who might be interested in the development of a wind farm in your community? Make a list of the stakeholders.
2. What might be a stance that the various stakeholders' might take?
3. Who would be promoting the wind farm? Who might be discouraging the wind farm?

Investigation
1. Assign youth groups and stakeholder topic areas. (See topic cards below). All groups should conduct research to determine what their stance will be for the community hearing. Each group should read the short description about their stakeholder and use the goal of each stakeholder to best fit the argument they will be attempting to make at the community hearing.
2. The goals are not necessarily to be shared, except amongst the members of the group.
3. Youth should conduct research related to their assigned perspective.

Class Engagement
At the community hearing, the community commissioner group will be listening to the various stakeholders and make a determination about how the community will proceed. The commission group of students can either do research beforehand or listen to the various other presentations and justify its decision as its work.

References/For More Information

- Wind Energy in Colorado: A Practical Guide for Farmers and Ranchers About Producing Energy from Wind
- http://www.landsward.nau.edu/windforschools.html
- http://www.agmrc.org/media/cms/WIND_REPORT_Final_A97037D9FC0B8.pdf

Wind Company

You represent the company that is developing the wind farm. Likely, you are a large corporation with huge investments in energy resources. You have expansive capital.

Goal: Win over those in the community that have political power or control over regulations governing wind development.

Landowners

You represent a landowner. Landowners own the land where the turbines might be built, which is likely currently used for ranching or farming. You might have a connection or legacy with the land and want to keep it in agricultural production, but you have the potential of earning money from the wind development.

Goal: Ultimately, you want to make the best financial decision for you personally and you want to maintain your standard of life. You might need to do some research to determine how much money you could receive from wind development.

Conservation

You are part of a conservation group that protects wildlife for its own sake and/or for the benefit of hunting.

Goal: You want the populations of birds, bats, and other wildlife to not be negatively impacted by the development.

Wind Power Purchaser

You represent a company that purchases power and distributes it to end consumers. You have to meet the state and federal power regulations and continue to keep end consumers satisfied.

Goal: Strike a balance between buying power as inexpensively as possible and making sure you can always have power available.

Neighbors—Pro

You represent neighbors and community members that see this as a benefit to the community. You know that it will increase the community's tax base and provide additional employment opportunities.

Goal: You would like to see it built so more money goes to the local school and there are more jobs.

Neighbors—Con

You represent neighbors and community members that see this as a detriment to the community. You believe this wind farm will be an eye sore, may be noisy, will decrease property values, and you believe it might be harmful wildlife.

Goal: You want to squash this project.

Industry Group

You represent the wind industry and its employees. You believe in wind energy's ability to create jobs, increase energy independence, diversify the country's energy portfolio, provide a clean source of electricity, and offer a renewable alternative to fossil fuels. You would like to see an increase in wind initiatives wherever feasible.

Goal: See that this wind farm is built.

County Commissioner

You represent the decision-making body that will determine if this initiative will proceed.

Goal: Make a decision that will be benefit the community as a whole without alienating your voting base for the next election.

Activity Eight: When the Wind Doesn't Blow

Adopted/ Revised From
N/A

Grade Level
6-12

Objectives

- Brainstorm options for meeting electricity needs without sufficient wind to power a turbine
- Research costs and benefits of the different options
- Present a given option as a group
- Vote on the options presented to come to class consensus

Overview
Students conduct a web quest to learn about energy efficiency and conservation, storage, and renewable and non-renewable forms of energy. They then create mock budgets to promote various solutions to bridge our demand for electricity with the intermittent supply of wind and solar.

Materials (per group)

- Internet access
- Stickers (2 per student)

Estimated Cost of Materials
$5

Computer Required?
Yes

Duration
2 class periods (assuming web quest is conducted as homework)

Primer References: Wind and Other Electrical Generation in Colorado

Engagement
This activity is ideally conducted after "What Speed Do We Need" since in that lesson students should have learned that the school wind turbine is insufficient to provide the school's electricity needs and won't generate any electricity at all if the wind doesn't blow.

1. What powers the classroom when the wind isn't blowing?
2. What are some options for making sure school electricity demand is met when the wind isn't blowing?
3. What are some options for making sure the U.S. electricity demand is met when the wind isn't blowing?

The third question should result in a list of options named by the students, to include the following:

1. **Reduce our electricity demand** through energy conservation and efficiency
2. **Use other sources of energy** to generate backup electricity
3. **Store electricity** from wind and solar in batteries or otherwise for later use
4. **Expand the grid** to incorporate more renewable energy systems from across the country
5. **Charge more** for electricity produced by sources other than wind and solar
6. **Ration electricity** based on intermittent supply of wind and solar

Investigation
Now we're going to learn how to conduct unbiased research in order to understand the advantages and disadvantages of different energy sources:

1. Divide the students into groups, assigning each group to one of the options listed above.
2. Read the students each of the following paragraphs and ask them to detect bias:

   "A new solar photovoltaic array was constructed in Colorado yesterday. The panels were an expensive local solution to global warming, which itself has not been proven. It remains to be seen how much electricity is actually generated by the panels and whether the neighbors object to the "new look" of their community."

   "A new solar photovoltaic array was constructed in Colorado yesterday. The panels were tastefully installed to match the surrounding environment and will reduce energy costs for participating customers. "This technology benefits everyone – the customers, the environment, the economy, and the community", said Joe Schmidt, a local solar installer.

3. Explain to the students that their research should be unbiased and that they should cite a minimum of four unbiased websites in their presentations.
4. Hand out the lesson's List of Suggested Websites to all students to use in their research. This table is a mere starting point for research and is not intended to be comprehensive.
5. Each group should prepare a 5-10 minute PowerPoint presentation to present to the class that includes the following (charts, graphs, and other visuals encouraged); citations should be placed on each slide as applicable:

   a. What is the current status of your approach – is it used widely or is it still being researched?
   b. What are the advantages and disadvantages of your approach, including factors such as feasibility, cost, and environmental impact?
   c. What are the main barriers to implementing your approach?
   d. What stakeholder groups would favor your approach? Who would oppose it?
   e. Could your approach work independently of any other approaches or would it need to be supplemented by other approaches?
   f. What does your approach need to become more widespread?

Class Review
Now we're going to compare the advantages and disadvantages of different approaches to meeting electricity demand in the face of intermittent renewable resources in order to come up with a shared vision for our energy future:

1. Each group should make their presentation.
2. After all the presentations are made, list the various approaches and ask the students to put stickers next to their top two choices. A student can put both of his/her stickers next to the same choice if so desired.
3. Tally the votes and discuss as a class.

Elaboration
Students should at least read "Colorado Boosts its RPS to 30% by 2020" and "A Plan to Power 100 Percent of the Planet with Renewables".

1. Is a 30% Renewable Portfolio Standard too high, too low, or just right.
2. Do you think we can power the plant with 100% renewables? Why or why not?

Instructor Notes

- Reports do not have to be done in PowerPoint – they can also be done as oral reports, with posters, etc. If using a poster, voting stickers can be stuck directly to them.

Extensions and Variations

- Debate the advantages and disadvantages of the different approaches to meeting electricity demand.

References/For More Information

- See below.

When The Wind Doesn't Blow: List of Suggested Websites

Source	Website	Topic	Description
U.S. Energy Information Administration	http://www.eia.doe.gov/kids/	All	Comprehensive overviews of each energy source
U.S. Energy Information Administration	http://www.eia.gov/cfapps/state/state_energy_profiles.cfm?sid=CO	All	Colorado energy production, consumption, cost data
U.S. Department of Energy	http://apps1.eere.energy.gov/states/state_specific_information.cfm/state=CO	All	Colorado-specific energy information under "Energy Summary" and "Energy Statistics"
U.S. Energy Information Administration	http://www.eia.gov/todayinenergy/detail.cfm?id=4310	Energy Storage	Overview of various technologies – advanced information
California Energy Commission	http://energyquest.ca.gov/story/index.html	All	Student-friendly overviews of each energy source
Sandia National Labs	http://www.sandia.gov/ess/tech_batteries.html	Energy Storage	Overview of various technologies – advanced information
Scientific American	http://www.scientificamerican.com/article.cfm?id=solution-to-renewable-energy-more-renewable-energy	Intermittency of renewable energy	Article on the potential for a mix of renewable energy sources to provide reliable electricity
Washington State University Extension	http://energyexperts.org/EnergySolutionsDatabase/ResourceDetail.aspx?id=912	Backup power	An Ask an Expert question with detailed response describing backup power options for renewable energy
U.S. Energy Information Administration	http://www.eia.doe.gov/oiaf/ieo/index.html	Non-renewables	Energy reserve data for non-renewable resources
Midwest Energy News	http://www.midwestenergynews.com/2013/02/05/midwest-grid-operator-expands-south-to-last-frontier-for-renewables/	Expanding the grid	A news article covering costs and benefits of expanding transmission
NY Times	http://www.nytimes.com/2009/10/20/science/earth/20fossil.html?_r=0	External cost of fossil fuels	Describes health care and environmental costs of fossil fuels not accounted for in electric rates

GLOSSARY

Glossary of Wind Energy Terms

A

Air Density
The mass per unit volume of Earth's atmosphere, can be thought of as the number of air particles in a given volume of air. This decreases with altitude. It is an important value in aeronautics and in calculating wind power. It is symbolized by the Greek letter rho.
Air Foil
The aerodynamic cross section of a body such as a wing that creates lift as it moves through the air. Airfoils typically have teardrop shape.
Anemometer
An instrument for measuring the force or velocity of wind; a wind gauge.
Appliance
A device for converting one form of energy or fuel into useful energy or work.
Audit (Energy)
The process of determining energy consumption, by various techniques, of a building or facility.
Availability factor
The percentage of time that a wind turbine is able to operate and is not out of commission because of maintenance or repairs, typically greater than 98% for most modern wind turbines.
Average Cost
The total cost of production divided by the total quantity produced.
Average Wind Speed (or Velocity)
The mean wind speed over a specified period of time.
Avoided Cost
The incremental cost to an electric power producer to generate or purchase a unit of electricity or capacity or both.

B

Ballast
A device used to control the voltage in a fluorescent lamp.
Battery
An energy storage device composed of one or more electrolyte cells.
Battery Energy Storage
Energy storage using electrochemical batteries.
Betz Limit
The Betz limit says that the best compromise between completely stopping the wind (100% capture) and letting all the wind go by (0% capture) is 59.6% (or 16/27) of the energy in the wind. Practically this means that the most efficient wind turbine would convert about 59% of the available energy in the wind to mechanical energy.
Blades
The aerodynamic structures that capture the energy of motion on a turbine. Most commercial wind turbines have three blades.
Braking system
The mechanism that slows a wind turbine shaft speed down to safe levels, electrically or mechanically, often using magnets.
Bird Mortality
Mortality from bird collisions with the turbine blades, towers, power lines, or with other related structures, and electrocution on power lines. Bat Mortality describes deaths to bats.

C

Capacity Factor
A measure of the productivity of a wind turbine, calculated by the amount of power that a wind turbine produces over a set time period, divided by the amount of power that would have been produced if the turbine had been running at full capacity during that same time interval (its rated capacity). Most wind turbines operate at a capacity factor of 25% to 40%. Capacity factor depends on the quality of the wind at the turbine and higher capacity factors imply more energy generation.
Carbon Dioxide
A colorless, odorless noncombustible gas with the formula CO_2 that is present in the atmosphere. It is formed by the combustion of carbon and carbon compounds (such as fossil fuels and biomass), by respiration, which is a slow combustion in animals and plants, and by the gradual oxidation of organic matter in the soil.
Climate Change
A term used to describe short and long-term effects on the Earth's climate as a result of human activities such as fossil fuel combustion and vegetation clearing and burning.
Coefficient of Power
A measurement of how efficiently the wind turbine converts the energy in the wind into electricity. Calculated by dividing the electricity produced by the total energy available in the wind at that speed.
Controller
A device that starts up the turbine generator at wind speed of about 8 to 16 mph and shuts off the generator at about 65 mph.
Cut-in Speed
The wind speed at which the turbine blades begin to rotate and produce electricity. For the Skystream turbines this is about 8 mph or 3 m/s.
Cut-out Speed
The wind speed at which the turbine automatically stops the blades from turning and rotates out of the wind (or furls) to avoid damage to the turbine. For the Skystream, this is around 60 mph or 25 m/s.

D

Distributed Energy Resource or distributed generation
The use of multiple smaller, more dispersed generation facilities to produce power, rather than larger, centrally located power plants.
Downwind Wind Turbine
A horizontal axis wind turbine in which the rotor is downwind of the tower.
Drag
Resistance caused by friction in the direction opposite to that of movement (i.e., motion) of components such as wind turbine blades.

E

Efficiency
Under the First Law of Thermodynamics, efficiency is the ratio of work or energy output to work or energy input, and cannot exceed 100 percent. The efficiency of wind turbines is measured by dividing the amount of energy produced by the total amount of energy available in the wind. In other words, how good of a job does a turbine do in converting potential power to actual power?
Electricity Generation
The process of producing electricity by transforming other forms or sources of energy into electrical energy; measured in kilowatt-hours.
Electricity Grid
A common term referring to an electricity transmission and distribution system.
Electric Rate

The unit price and quantity to which it applies as specified in a rate schedule or contract.

Electric Rate Schedule

A statement of the electric rate(s), terms, and conditions for electricity sale or supply.

Electric Power Transmission

The transmission of electricity through power lines.

Electronic Ballast

A device that uses electronic components to regulate the voltage of fluorescent lamps.

Emission(s)

A substance(s) or pollutant emitted as a result of a process.

Energy

The capability of doing work; different forms of energy can be converted to other forms, but the total amount of energy remains the same. In electrical generation, energy is the amount of power produced over time. A measure of energy is kilowatt hours.

Energy Audit

A survey that shows how much energy you use in your house or school. It will help you find ways to use less energy.

Environment

All the natural and living things around us. The earth, air, weather, plants, and animals all make up our environment.

F

Fluorescent Light

The conversion of electric power to visible light by using an electric charge to excite gaseous atoms in a glass tube.

Furling

Turning the blades of a wind turbine away from the direction of the wind to prevent it from turning to rapidly.

G

Gear Box

Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speed of the shaft to the speed required for the generator to produce electricity. Some of the wind's power is lost due to friction in the gearing system.

Generator

A device that converts mechanical energy to electrical energy.

Global Warming

A popular term used to describe the increase in average global temperatures due to the greenhouse effect.

Greenhouse Effect

A popular term used to describe the heating effect due to the trapping of long wave (length) radiation by greenhouse gases produced from natural and human sources.

Greenhouse Gases

Those gases, such as water vapor, carbon dioxide, tropospheric ozone, methane, and low level ozone that are transparent to solar radiation, but opaque to long wave radiation, and which contribute to the greenhouse effect.

Grid

A common term referring to an electricity transmission and distribution system.

Grid-Connected System

Independent power systems that are connected to an electricity transmission and distribution system (referred to as the electricity grid) such that the systems can draw on the grid's reserve capacity in times of need, and feed electricity back into the grid during times of excess production. The Wind for Schools turbines are connected to the grid.

H

Horizontal-Axis Wind Turbines
Turbines in which the axis of the rotor's rotation is parallel to the wind stream and the ground.
Hub
The central part of the wind turbine, which supports the turbine blades on the outside and connects to the low-speed rotor shaft inside the nacelle.

I

Intermittent Generators
Power plants, whose output depends on a factor(s) that cannot be controlled by the power generator because they utilize intermittent resources such as solar energy or the wind.
Inverter
A device that converts direct current electricity (from for example a wind turbine) to alternating current for use directly to operate appliances or to supply power to a electricity grid.

K

Kilowatt (kW)
A standard unit of electrical power equal to one thousand watts, or to the energy consumption at a rate of 1000 Joules per second.
Kilowatt-hour
A unit or measure of electricity supply or consumption of 1,000 Watts over the period of one hour
Kinetic Energy
Energy available as a result of motion that varies directly in proportion to an object's mass and the square of its velocity.

L

Lift
The force of a moving fluid (in this case air) that goes perpendicular to the blade. This movement creates an area of low pressure which causes the blade to move upward.

M

Mechanical energy
Energy created by physical movement , rotation, or revolution of an object or system
Megawatt
One thousand kilowatts, or 1 million watts; standard measure of electric power plant generating capacity.
Megawatt-hour
One thousand kilowatt-hours or 1 million watt-hours.

N

Nacelle
The cover for the gear box, drive train, generator, and other components of a wind turbine.
Net Metering

The practice of using a single meter to measure consumption and generation of electricity by a small generation facility (such as a house with a wind or solar photovoltaic system). The net energy produced or consumed is purchased from or sold to the power provider, respectively.

Nonrenewable Fuels

Fuels that cannot be easily made or "renewed," such as oil, natural gas, and coal.

NREL

The National Renewable Energy Laboratory (NREL) is the U.S. Department of Energy's primary national laboratory for renewable energy and energy efficiency research and development. Located in Golden, Colorado. http://www.nrel.gov

O

Off-Peak

The period of low energy demand, as opposed to maximum, or peak, demand.

On-Site Generation

Generation of energy at the location where all or most of it will be used.

P

Payback Period

The amount of time required before the savings resulting from your system equals the cost of the system.

Peak Power

Power generated that operates at a very low capacity factor; generally used to meet short-lived and variable high demand periods.

Peak Shifting

The process of moving existing loads to off-peak periods.

Phantom Load

Any appliance that consumes power even when it is turned off. Examples of phantom loads include appliances with electronic clocks or timers, appliances with remote controls, and appliances with wall cubes (a small box that plugs into an AC outlet to power appliances).

Pitch

The angle between the edge of the blade and the plane of the blade's rotation. Blades are turned, or pitched, out of the wind to control the rotor speed.

Potential Energy

Energy available due to position or stored energy.

Power

Energy that is capable or available for doing work; the time rate at which work is performed, measured in horsepower, Watts, or Btu per hour. Electric power is the product of electric current and electromotive force (volts).

Power (Output) Curve or Wind Power Curve

A plot of a wind energy turbine’s power output versus wind speed.

Power Generation Mix

The proportion of electricity distributed by a power provider that is generated from available sources such as coal, natural gas, petroleum, nuclear, hydropower, wind, or geothermal.

R

Rated Power

The power output of a device under specific or nominal operating conditions. For wind turbines, this is the amount of power the turbine produces when it is operating in its optimum wind speed.

Rated Speed

The rated speed is the minimum wind speed at which the wind turbine will generate its designated rated power. For example, a "10 kilowatt" wind turbine may not generate 10 kilowatts until wind speeds reach 25 mph. Rated speed for most machines is in the range of 25 to 35 mph.

Renewable Energy

Energy derived from resources that are regenerative or for all practical purposes cannot be depleted. Types of renewable energy resources include moving water (hydro, tidal and wave power), thermal gradients in ocean water, biomass, geothermal energy, solar energy, and wind energy.

Rotor

Comprises the spinning parts of a wind turbine, including the turbine blades and the hub.

RPM

Revolutions per minute **RPS** (renewables portfolio standard)

A policy set by federal or state governments that a specified percentage of the electricity supplied by electricity generators must be derived from a renewable source.

S

Shaft

The rotating part in the center of a wind turbine or motor that transfers power. . A low-speed shaft is turned by a rotor at about 30 to 60 rpm and is connected by gears to a high-speed shaft that drives the generator.

Swept Area

In reference to a wind energy conversion device, the area through which the rotor blades spin, as seen when directly facing the center of the rotor blades.

T

Tachometer

A device that measures revolutions per minute.

Tip Speed

The speed that a wind turbine blade travels when it makes one revolution.

Tip Speed Ration (TSR)

The ratio of tip speed to wind speed. An optimum tip speed ratio is needed for maximum turbine efficiency. TSR is symbolized by the Greek letter lambda.

Tower

The base structure that supports and elevates a wind turbine rotor and nacelle.

Transmission

The process of sending or moving electricity from one point to another; usually defines that part of an electric power provider's electric power lines from the power plant buss to the last transformer before the customer's connection.

Turbine

A device for converting the flow of a fluid (air, steam, water, or hot gases) into mechanical motion.

U

Upwind Face

The side of the blade facing in or toward the direction from which the wind blows.

V

Vertical-Axis Wind Turbine (VAWT)

A type of wind turbine in which the axis of rotation is perpendicular to the wind stream and the ground.

Volt

A unit of electrical force equal to that amount of electromotive force that will cause a steady current of one ampere to flow through a resistance of one ohm.

W

Watt
The rate of energy transfer equivalent to one ampere under an electrical pressure of one volt. It is the product of Voltage and Current (amperage).
Watt-hour
A unit of electricity consumption of one Watt over the period of one hour.
Wattmeter
A device for measuring power consumption.
Wind Energy
Energy available from the movement of the wind across a landscape caused by the heating of the atmosphere, earth, and oceans by the sun.
Wind Power Class
A system to rate the quality of the wind resource in an area, based on the average annual wind speed. The scale ranges from 1 to 7, with 1 being the poorest wind energy resources and 7 representing exceptional wind energy resources.
Wind Power Plant or Wind Farm
A group of wind turbines interconnected to a common power provider system through a system of transformers, distribution lines, and (usually) one substation. Operation, control, and maintenance functions are often centralized through a network of computerized monitoring systems, supplemented by visual inspection.
Wind Resource
The wind energy available for use based on historical wind data, topographic features, and other parameters.
Wind Resource Assessment
The process of characterizing the wind resource, and its energy potential, for a specific site or geographical area.
Wind Rose
A diagram that indicates the average percentage of time that the wind blows from different directions, on a monthly or annual basis.
Wind speed
The rate at which air particles move through the atmosphere, commonly measured with an anemometer.
Wind Speed Profile
A profile of how the wind speed changes with height above the surface of the ground or water.
Wind Turbine
A term used for a wind energy conversion device that produces electricity; typically having one, two, or three blades.
Wind Vane
Measures wind direction and on a wind turbine communicates with the yaw drive to orient the turbine properly with respect to the wind.
Wind Velocity
The wind speed and direction in an undisturbed flow.

Y

Yaw
To rotate around a vertical axis, such a turbine tower. The yaw drive is used to keep a turbine rotor facing into the wind as the wind direction changes.

From:
U.S. Department of Energy – www1.eere.energy.gov,
http://www.miseagrant.umich.edu/downloads/research/projects/Wind-Energy-Glossary.pdf
http://www.seic.okstate.edu/owpi_old/Stakehld/landownr/OK_glossary.pdf

APPENDICES

Appendices Table of Contents

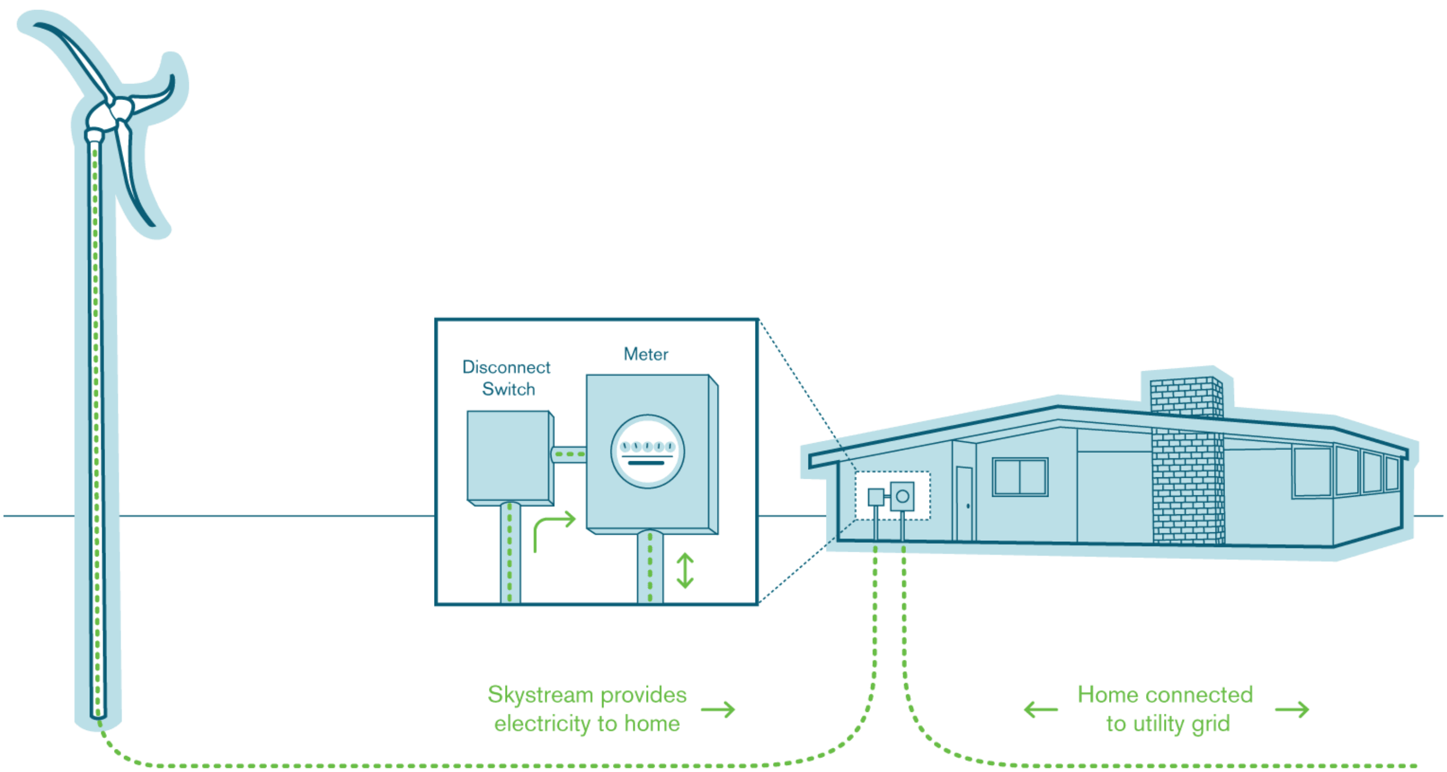
Appendix A: Parts and Installation of the Skystream 3.7 Turbine

Southwest Windpower Skystream 3.7 Wind Turbine

The Wind for Schools program uses the Skystream 3.7 wind turbines which were manufactured by Southwest Windpower in Flagstaff, Arizona. The WfS programs choose the Skystream turbine for several reasons:

- Southwest Windpower offered Skystreams at a 30% discount to WfS host schools
- The Skystream is one of the few (if not the only) small, gird-connected turbine that is IEEE 1547.1 and UL 1741 certified
- The data acquisition system for the Skystream is configured to allow connection to the Center for Advanced Energy Studies at Idaho National Laboratory. Data from WfS host school turbines are available for public use from the CAES site.
- The turbine comes with a five-year limited warranty. The expected life of the turbine is 20 years.
- Note: Southwest Windpower stopped operations in 2013.

Skystream is an innovative technology that converts energy in the wind into utility grade electricity. Electricity is sent down the tower into the building for immediate use. Any excess energy is sent into the grid spinning the meter backwards.* With "Net-metering", the energy going into the grid can be used at a later date at retail value.



The Skystream is a popular residential wind turbine. It was designed in partnership with the U.S. Department of Energy's National Renewable Energy Laboratory. The turbine generates electricity that feeds back into the electrical system of the building on the customer's side of the electric service, so it offsets the electricity used in the building.

The Skystream 3.7 has a rotor diameter of 3.7 m (12 feet). At the rated wind speed of 29 mph, the turbine generates 2.4 kW of electric power.

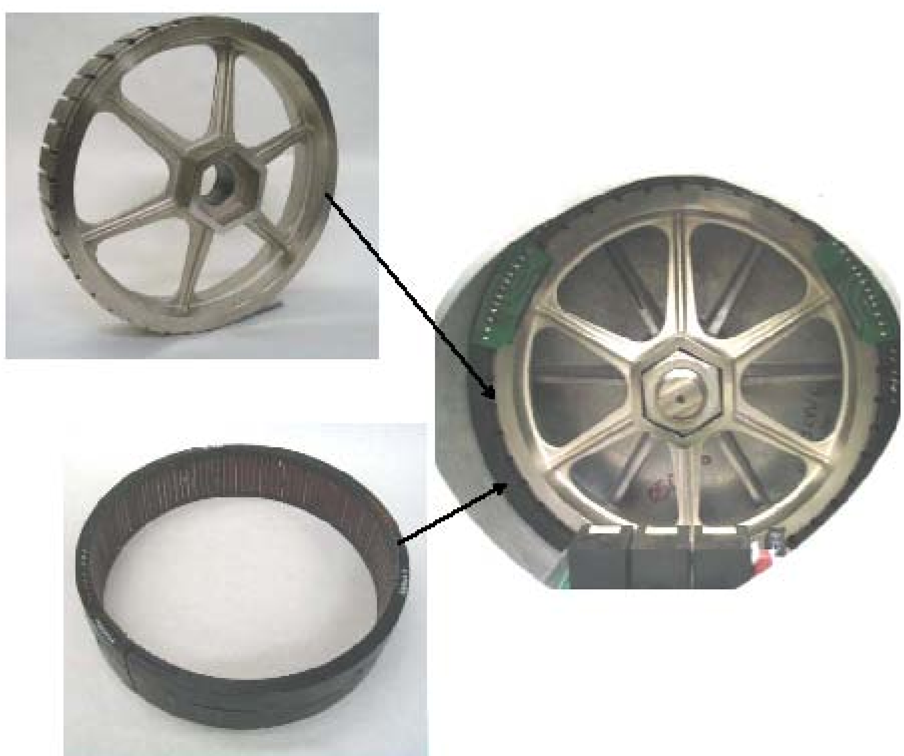
Some of the key design elements are the integrated inverter that is built into the nacelle so a separate inverter is not required.

Wiring for the turbine is run up through the core of the tower. For the Colorado Wind for Schools program, the default tower is a 45 foot monopole tower that tilts up with the use of a gin pole.

The turbine is a downwind design so that the blades of the turbine are downstream from the nacelle, which is quieter and inherently better at finding the wind direction than upwind designs.

The inverter constantly monitors the turbine and the electrical connection to assure that the electric energy generated by the turbine synchs with the frequency and voltage of the building's electrical system. The inverter actually draws about 5-7 watts to operate the monitoring system. Because of this, the turbine will not generate electricity when the electrical grid to the building is down. The inverter is UL 1741 certified which means that it meets UL standards for islanding protection, frequency synchronization, flicker, and the ability to withstand surges.

The alternator includes of 42 sets of powerful rare earth magnets. The motion of the rotor within the stator generates electricity, but there is no transmission or mechanical braking required. The only moving part is the stator hub. The inverter senses the need for braking and uses the repelling action of the magnets to slow the turbine, much like the regenerative brakes on a hybrid vehicle (but in reverse). Once the winds are strong enough to get the turbine up to speed, the inverter keeps the speed of the turbine between 300 and 340 rpm.

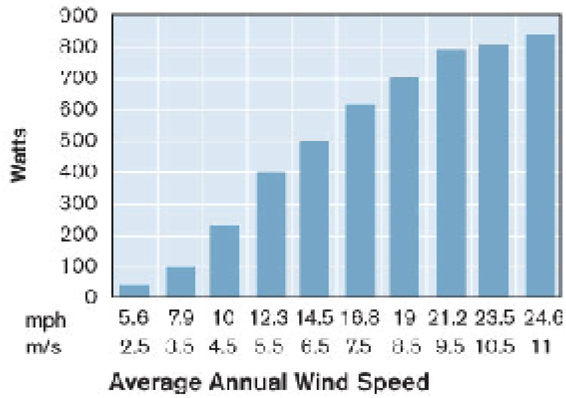


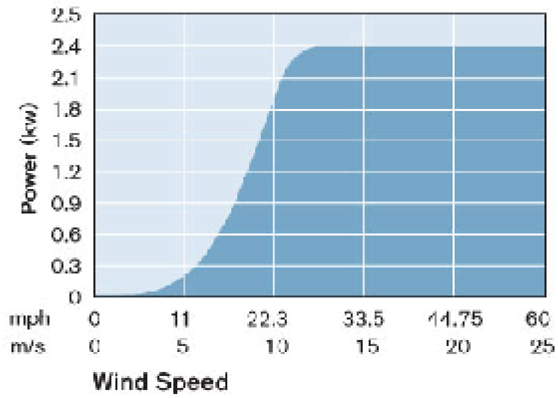
The blades are constructed from two halves of compression molded fiberglass. The curve of the blade helps to more efficiently capture the energy in the wind and to reduce the sound of the blades as they move through the air.

Because of the many features incorporated in the turbine and blade design, the Skystream emits about 45-55 db at 50 feet from the base of the tower. Background sound level is usually between 30 and 45 dB. Because sound perception at a receptor is measured on a logarithmic scale, a perceived doubling of sound is represented by a difference of 10 dB. Much of the sound generated by the turbine is masked by the wind itself. Sound decreases significantly with distance from the source. Doubling the distance from the turbine decreases the sound level by a factor of four. For example, sound level readings at 50 feet from the turbine hub drop by a factor of 4 at 100 feet.

The Skystream is quiet because:

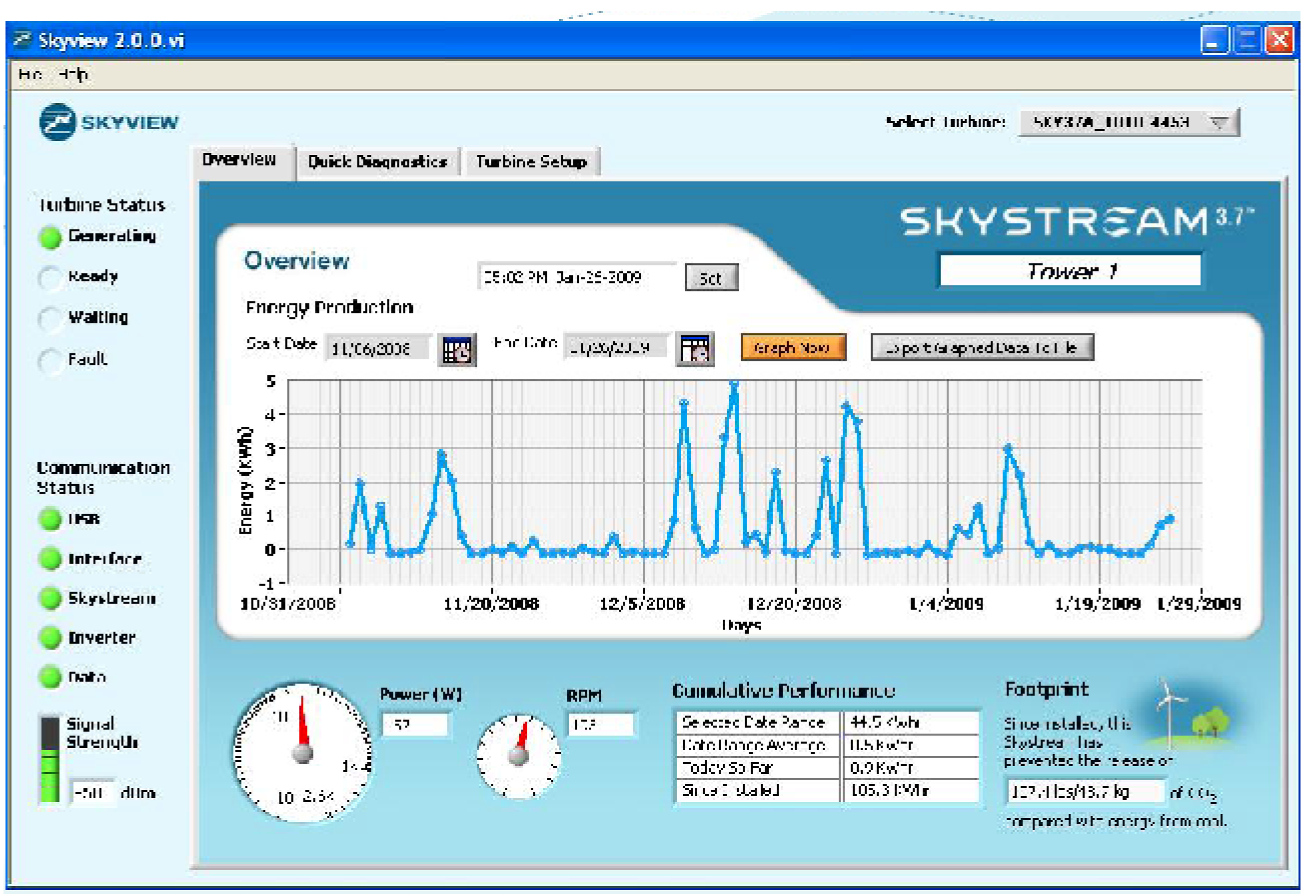
- Airfoils are specifically designed for low noise
- Very low max RPM – about 320
- Slot-less alternator technology
- Electronically stall regulation prevents loud sound in high wind
- Swept blade design reduces tower shadow induced sound





It's important to understand that this turbine is built to supply power to homes and buildings directly. As long as there is at least 4 kW of electricity being used by the school (very likely), a Skystream connected to the school's electrical system won't generate enough electric power to go onto the utility grid.

In a Class 2 or 3 wind and proper siting, the Skystream is expected to generate an average of 200-400 kWh per month.



The Skystream has a built in 2.4 Ghz wireless radio that sends performance data to a desktop computer with a wireless receiver. A software package called Skyview is included with the turbine. With the software, schools can track the generation of the turbine and download data for use in the classroom. This data can also be sent to a site at the Center for Advanced Energy Studies at Idaho National Laboratory to compare with other schools.

Introduction – Skystream 3.7™

The first small wind generator designed specifically for utility-connected residential use, Skystream 3.7™ from Southwest Windpower lets Americans harness wind energy and take control of their energy bills like never before.

Specifically for Grid-Connectivity

Skystream 3.7™ is specifically designed for utility-connected home and business use. In certain states consumers can take advantage of "net-metering" or the sale of unused energy back to the power grid.

Low Cost

Skystream 3.7™ costs approximately $12,000 to $15,000 to purchase and install, although costs vary significantly depending on your site. The generator itself costs $5,400. Depending on the tower and installation costs, wind speed average, rebates and local electricity costs, Skystream 3.7 can pay for itself in as quickly as 5 years.

All-in-One Solution

Skystream 3.7™ offers a simple, all-in-one solution to harnessing wind energy on a residential scale. Different from all other technologies, Skystream 3.7™ is the first all-inclusive wind generator with the controls and inverter built in.

Energy Production in Exceptionally Low Wind

Designed for very low winds, Skystream 3.7™ begins producing power in an 8 mph (3.5 m/s) breeze with full output achieved at 23 mph (10.3 m/s).

Low Profile

Skystream 3.7™ can be mounted on a 35 foot (10.6 meters) tower. This means a vast number of households on one acre or larger lots will now have access to residential, utility-connected wind energy. Towers up to 110 feet (33.5 meters) are available. A site assessment is important to determine the best tower height for your site.

Exceptionally Quiet Operation

Skystream 3.7™ is exceptionally quiet. In fact, Skystream's sound is unrecognizable over trees blowing in the wind. The sound pressure level generated by Skystream is in the range of 40-50 decibels which is quieter than background noise in a home or office.

Award-Winning Technology

Skystream 3.7™ was awarded a 2006 Best of What's New award from the editors of Popular Science and was included in TIME magazine's 2006 Best Inventions.

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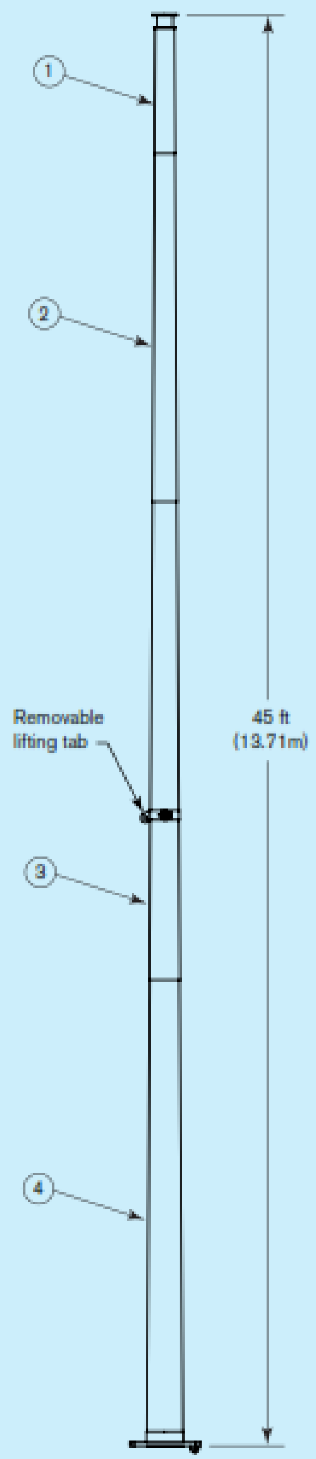
Side View



SKYSTREAM™

45-19 (45 ft/13.71 m) Tilt-Up Segmented Monopole Tower - NEW

Similar to the existing 45 ft Segmented tower, our most popular monopole tower has been re-engineered for easier installation. Tower ships in nested segments for easier shipping. Features include re-designed hinge-plate for ease of tilt up, handholds for maneuvering. With proper siting, this tower is appropriate for sites that may need a lower tower to meet zoning codes.

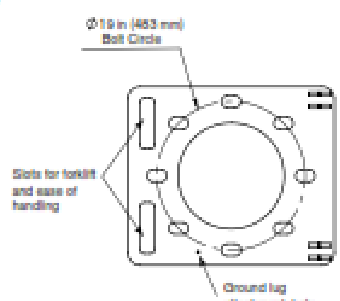
Technical Specifications

Model	45-19 Skystream Tower
Part Number	With Land Skystream 3.7: part # 1-SSL-240-45-19-S With Marine Skystream 3.7: part # 1-SSM-240-45-19-S
Foundation	Mat/Pier
Foundation Bolts	42 in Anchor rods - bolt kit part # 3-CMBP-3048-01
Height	45 ft (13.71 m)
Bolt Circle	19 in (483 mm)
Type	Sectional monopole
Construction	Galvanized tubular steel
Number of Sections	4
Shipping	Nested
Weight	

Section	Weight lb (kg)	Length ft (m)
1	58 (26)	4.38 (1.33)
2	161 (73)	13.18 (4.02)
3	341 (155)	17.52 (5.34)
4	581 (264)	17.52 (5. 34)
Total Weight = 1141 lb (518.6 kg)		

Installation Tools	Gin pole - part # 2-TWS-200 Hinge plate - part # 2-TWS-300

Bottom View



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928.779.9463
www.skystreamenergy.com

Makers of Skystream™ / AIR / Whisper

SKYSTREAM 3.7™

www.skystreamenergy.com

Skystream 3.7™ Frequently Asked Questions

What is Skystream 3.7™?

Skystream 3.7™, developed by Southwest Windpower in collaboration with the U.S. Department of Energy's National Renewable Energy Laboratory (NREL), is the newest generation in residential wind technology. Skystream 3.7™ has a 1.8 kW rating and is the first fully integrated small wind generator specifically designed for the utility-connected market. Skystream 3.7™ is designed for homeowners looking to reduce or eliminate their monthly electric bills. Skystream 3.7™ is a down-wind (wind hits the blades on the downwind side of the tower) direct drive (gearless or no transmission) permanent magnet wind generator. Skystream 3.7™ uses an innovative 12 ft rotor and produces approximately 400 kWh per month in a 12 mph wind. The initial prototype has been operating at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) in Colorado for almost two years and has undergone extensive performance, reliability and duration testing in accordance with internationally accepted testing standards.

What will it cost and how long will it take to pay for itself?

Skystream 3.7™, installed, costs approximately $12,000 to $15,000, depending on tower height and installation expenses. Price includes the generator, operation controls and inverter. Skystream 3.7™ is has tower height options available to accommodate a location's wind resource. Skystream 3.7™ is capable of producing energy at a fraction of the cost of other small wind, solar photovoltaics or reciprocating engine technology. Depending on the installed price, average wind speed, local cost of electricity and state rebates, Skystream 3.7™ can pay for itself in as little as 5 years.

What makes this product unique?

Skystream 3.7™ is the first all-inclusive wind generator with controls and inverter built-in. Skystream 3.7™ was designed for very low winds, reaching rated power at just over 23 mph. In addition to the innovative technology, Southwest Windpower invested heavily in tooling to reduce component cost. Doing so makes it possible to sell Skystream 3.7™ at a very low price. Its full 1800 watts is achieved at 20 mph with a maximum rotor speed of 325 RPM. Because of the exceptionally low RPM, the machine operates nearly sound free. Skystream 3.7™ can be installed on a range of tower heights from 35 ft to 110 ft. The optional 35 ft freestanding (no guy wire) tower looks much like a standard light pole. A visually aesthetic shape played a key role in the design to show that a wind generator is not only a clean source of energy but pleasing to the eye.

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Who can install this system?

Southwest Windpower recommends installing Skystream 3.7™ at sites with the following criteria:

- Adequate wind resource: Minimum average wind speed for Skystream 3.7™ is 10 mph. Ideal sites have 12 mph average wind or greater.
- Site free from obstructions: Clean, unobstructed wind is best for Skystream 3.7™. The top of the tower should be a minimum of 20 feet above any surrounding object within a 300 foot radius. Although the machine can be installed on smaller lots of land, properties of one acre or more are typically ideal as they will more likely have unobstructed wind.
- Suitable zoning: Tower installation must comply with local zoning regulations. It is also advisable to make sure there are no HOA (Home Owner Association) regulations that prohibit the use of towers.
- Interconnection with utility: Local utility must allow for interconnection. The 1979 federal PURPA act requires small systems can connect to the electrical grid; but homeowners should consult their local utility.
- Electricity cost of $0.10/kWh or greater: Consumers should consult with their local utility or look at their electric bill.

Where can this system be purchased?

Skystream 3.7™ will be distributed through Southwest Windpower's 20 year-old dealer network. Please visit our website to locate your local distributor.

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Installation

The typical installation used for the Colorado Wind for Schools program is a 45 foot segmented monopole tower. (see above)

After the turbine location is sited and permitted, a trencher or backhoe is used to build a 2 foot deep trench from the tower foundation back to the building and the electrical connection.

For the most common foundation design a backhoe (left) is used to excavate for the tower foundation. In softer soils, a pier foundation may be needed and a 30" hole must be bored with a drill rig (below).

The preferred foundation design is a round, shallow pill-shaped design. The anchor bolts are arranged in a pattern and supported on a stanchion. Concrete is then poured around the bolt assembly, finished, and allowed to harden for 28 days to allow the concrete to reach its full strength.

The tower is assembled on the ground and the turbine is attached to the end of the tower. The blades are assembled onto a hub and attached to the turbine. The tower is lifted into place through the use of a removable hinge plate and gin pole.

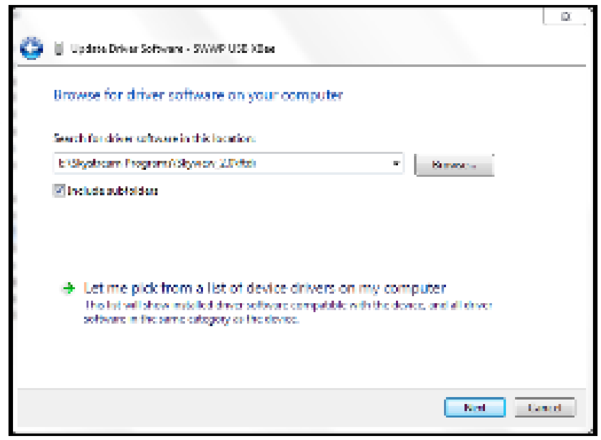
The tower is then leveled and bolted in place.

Appendix B: Managing and Troubleshooting Your Turbine Data Software

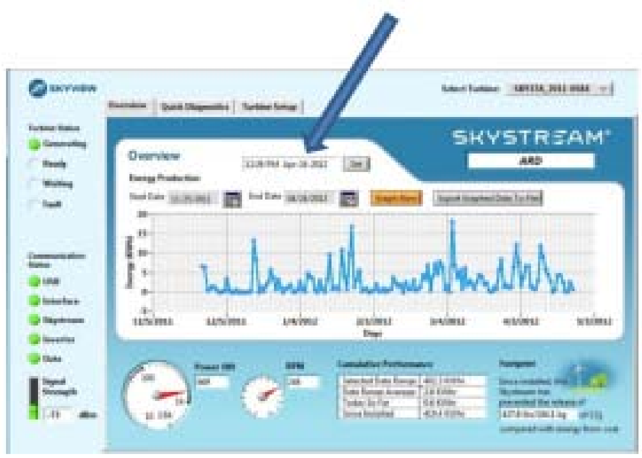
SkyView and WindInterface Installation Tutorial

These instructions are to install WindInterface, allowing your turbine to report data to the Wind for Schools Skystream wind Turbine Database.

4. Identify a computer which can be designed for the use of collecting and uploading data. It should always be turned on, and must be located within sight of your wind turbine.
5. Install SkyView
    a. Plug the X-bee wireless communicator into a USB port.
    b. Open Device Manager (Start→ Control Panel → Hardware & Sound → Device Manager).
    c. Find the SWWP USB XBee device, under ‘Ports (COM & LPT). It should have a yellow exclamation point next to it. Right click and choose ‘Update Software’.
    d. Browse to find the ftdi folder within the SkyView 2.0 folder from you SkyView installation disk or download. Click Next.
    e. In the next window, choose ‘Install Anyway.’
    f. When the update has finished, there should be a yellow exclamation point next to ‘USB Serial Port.’ Right click and choose ‘Update Software.’ Follow the remaining steps in parts d and e.

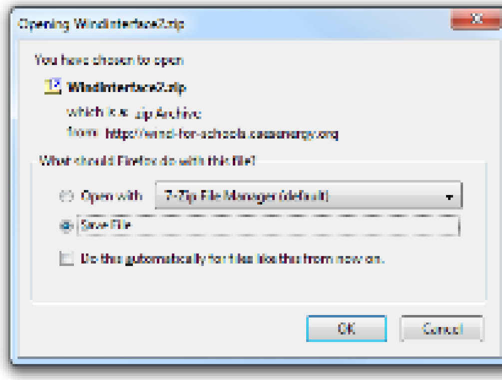


    g. From your SkyView installation disc or download, open the file called ‘SkyView_setup.’ Go through all the prompts, and restart your computer when asked.
    h. Skyview should now be installed on your computer. Open the program to set the date and time and to ensure it is communicating properly with your wind turbine.
    i. Close SkyView.



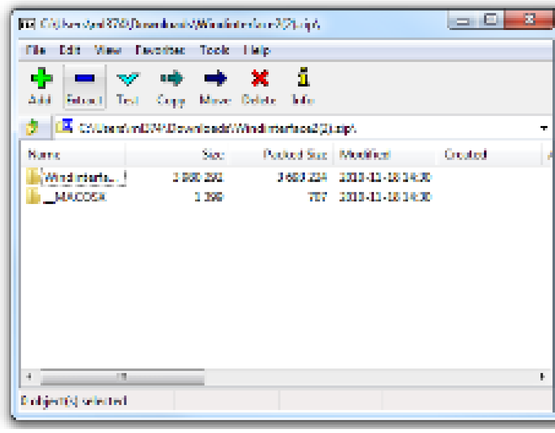
6. Contact Mark McKay with Idaho National Laboratory at mark.mckay@inl.gov with the following information:
    a. School name
    b. School address
    c. SkyStream location (lat, long)
    d. Contact information for a teacher or school tech at the school
    e. SkyStream serial number
    f. Zigbee system ID

        i. Open Command Prompt.
        ii. Type ‘cd Desktop\Windinterface2\resources’. Press enter.
        iii. Type ‘dir’. Press enter.
        iv. Type ‘skzcmd-z’. Press enter.
        v. A ‘%’ should appear. After this type ‘zls’. Press enter.
        vi. The serial number of your wind turbine should appear here in the format ‘SKY37A_XXXX_XXXX’. Confirm this serial number.
        vii. Also, your Zigbee System ID should be listed before that in the format XXXXXXXX-XXXXXXXX. Take note of the last 8 digits.
        viii. Type ‘end’. Press enter.

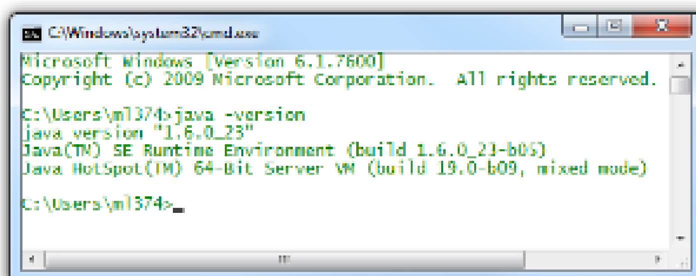


    g. Static IP of the computer communicating with the SkyStream
        i. Open Command Prompt.
        ii. Type: ‘ipconfig’. Press enter.
        iii. The IP (or IPv4) address will appear as a series of numbers following the pattern xxx.xxx.xxx.xxx.

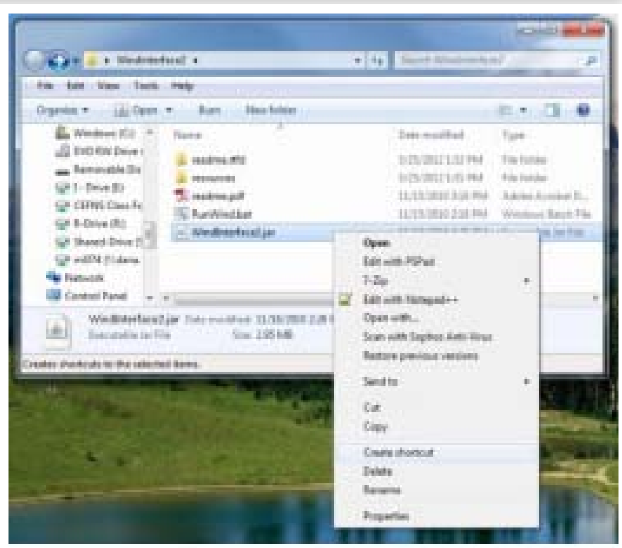
4. Install WindInterface



    a. Go to http://wind-for-schools.cesenergy.org/downloads/install/Windinterface2.zip.
    b. Chose ‘Save File’.
    c. When file has finished downloading, double click to open the zip file.
    d. In the following window click ‘Extract’ (or go to ‘File’ → ‘Extract’).
    e. Select the Desktop as the location for your files to be extracted.

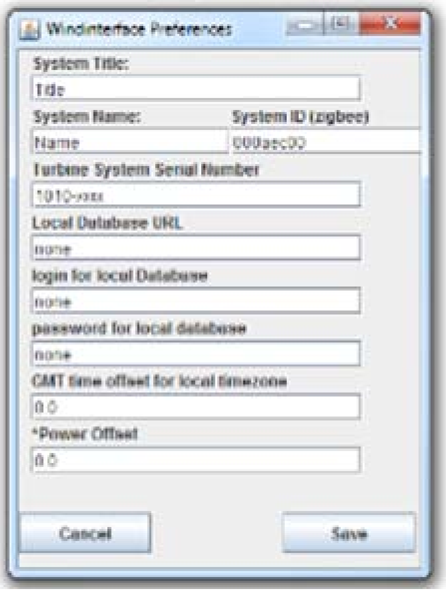


5. Install Java
    a. Click START
    b. Type ‘cmd’ into the search bar at the bottom of the menu to open Command Prompt.
    c. Type ‘java-version’ into Command Prompt.
    d. This will tell you which version of Java is installed on your computer. If you are using version 1.6 or better, skip to step 7.
    e. If you do not have version 1.6 installed, go to http://java.com/en to download the newest version of Java for free.



6. Open WindInterface2 folder which was extracted to your desktop.
7. Right click the WindInterface2.jar file and choose ‘Create shortcut’.
8. Drag and drop the WindInterface2.jar shortcut to your desktop.
9. Set up WindInterface.

a. Open WindInterface using the shortcut on your desktop, which was created earlier.
b. Click the ‘S’ and choose ‘Yes’ to open the WindInterface Preferences menu, and fill in all fields.

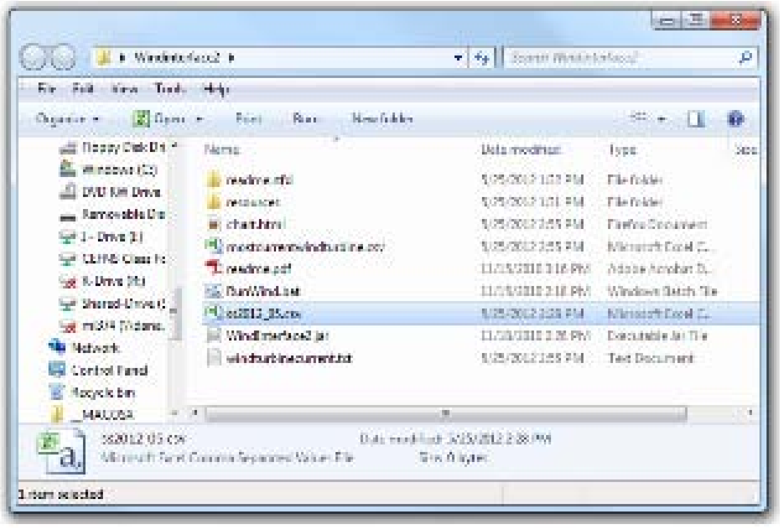


i. System Title: choose a title for your turbine
ii. System Name: enter the passcode you chose earlier in step 4f.
iii. System ID (zigbee): enter the 8 digit Zigbee System ID found in step 10h
iv. Turbine System Serial Number: enter the last 8 digits of your turbine’s erial number in the format XXXX-XXXX, found in step 10g
v. Local Database URL: leave as none
vi. Login for Local Database: leave as none
vii. Password for Local Database: leave as non
viii. GMT time offset for local timezone: enter 7 for Colorado
ix. Power Offset: leave as 0.0

c. Click ‘Save’
d. Click the X in the upper left corner to close the program. Then re-open and verify settings have been saved (title, date and time).

10. At this point, your turbine should be communicating. If working properly, the circle in the lower right corner of WindInterface should be green, and there should be a non-zero number after ‘Total Energy’.
11. When WindInterface is running and the status light is green, you are successfully archiving data and uploading it to Idaho National Lab’s online database. These archives can be found as .csv files in the

WindInterface 2 folder which was extracted to your desktop.



12. Add WindInterface to the startup menu
    a. Right click the WindInterface shortcut on your desktop and choose ‘create shortcut’.
    b. Click START. Click ALL PROGRAMS. Click STARTUP.
    c. Drag and drop the second shortcut to the startup folder.
    d. Open WindInterface using this shortcut to ensure it works properly.
13. Go to http://wind-for-schools.caesenergy.org/wind-for-schools/Welcome.html to see the data being reported from your wind turbine.

Appendix C: Getting Data from the Wind for Schools Data Library

Using SkyView and WindInterface for Data Collection

The Basics

Skyview: This program was developed by Southwest Windpower to be used with the SkyStream 3.7 wind turbine. One installed, SkyView automatically collects data from your wind turbine and saves daily values of energy output which you can retrieve later at any time. Additionally, you can choose to have Skyview export a more expansive data set at different time intervals (i.e.: 1 second data, 10 second data, etc.) to a .txt file, which you can then open in Microsoft Excel to use for data analysis. Skyview must be open and running to export data to a .txt file.

Windinterface: This program was developed for Wind for Schools to allow K-12 schools to upload data from their wind turbines to an online database. This way, data from wind turbines across the US installed through Wind for Schools, could all have a common data storage location so teachers have access to all data to use in the classroom for educational purposes.

WindInterface will only upload data when it is open and running on the same computer which has SkyView installed and is communicating successfully with your wind turbine. If the computer is turned off, hibernating or WindInterface is simply not open; data will not be collected and transferred to the online database. **Therefore, someone should be responsible for checking the computer each morning to make sure it is turned on, and WindInterface is running correctly.**

Additionally, neither WindInterface nor SkyView will run properly if both are open in the same time. You can only have one program running at a time.

SkyView

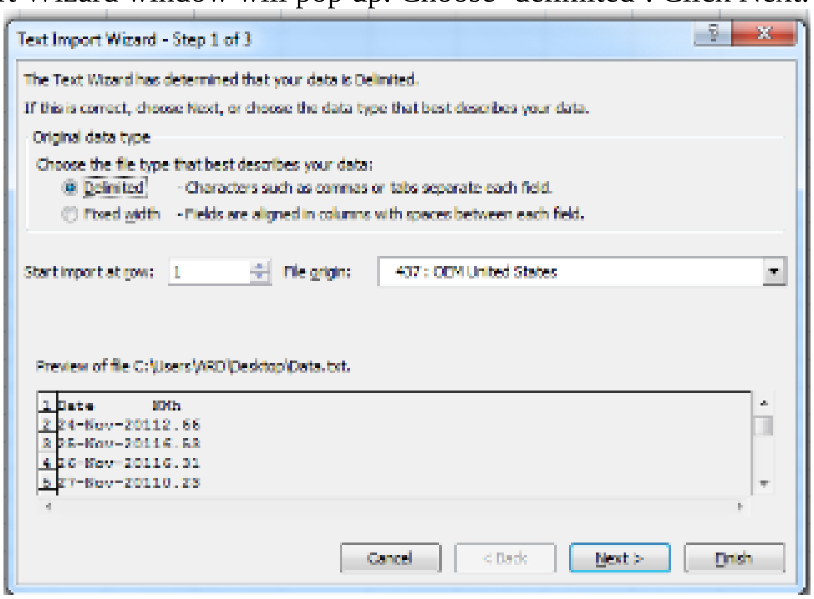
Windinterface

How to capture data

SkyView: There are two options for capturing data from SkyView. First, on the main screen you can choose a time period you wish to review. SkyView will automatically produce a graph of energy production during the choosen time period. You can then export the data from that time period to a .txt file. This .txt file can then be opened in Microsft Excel. This option will only show you daily energy production during the time period you selected.

1. Choose the time period for which you would like to see data. Once SkyView has retreived the data and produced a graph, click Export Graphed Data to File. Choose a name for the file and save the .txt file on your desktop.

2. When you are ready to open the .txt file, first open Microsoft Excel.
3. Click File → Open.
4. Open the .txt file from your desktop by choosing the file name you created earlier. You may need to change the file type to 'All Files' in the dropdown menu.
5. The Text Import Wizard window will pop up. Choose 'delimited'. Click Next.

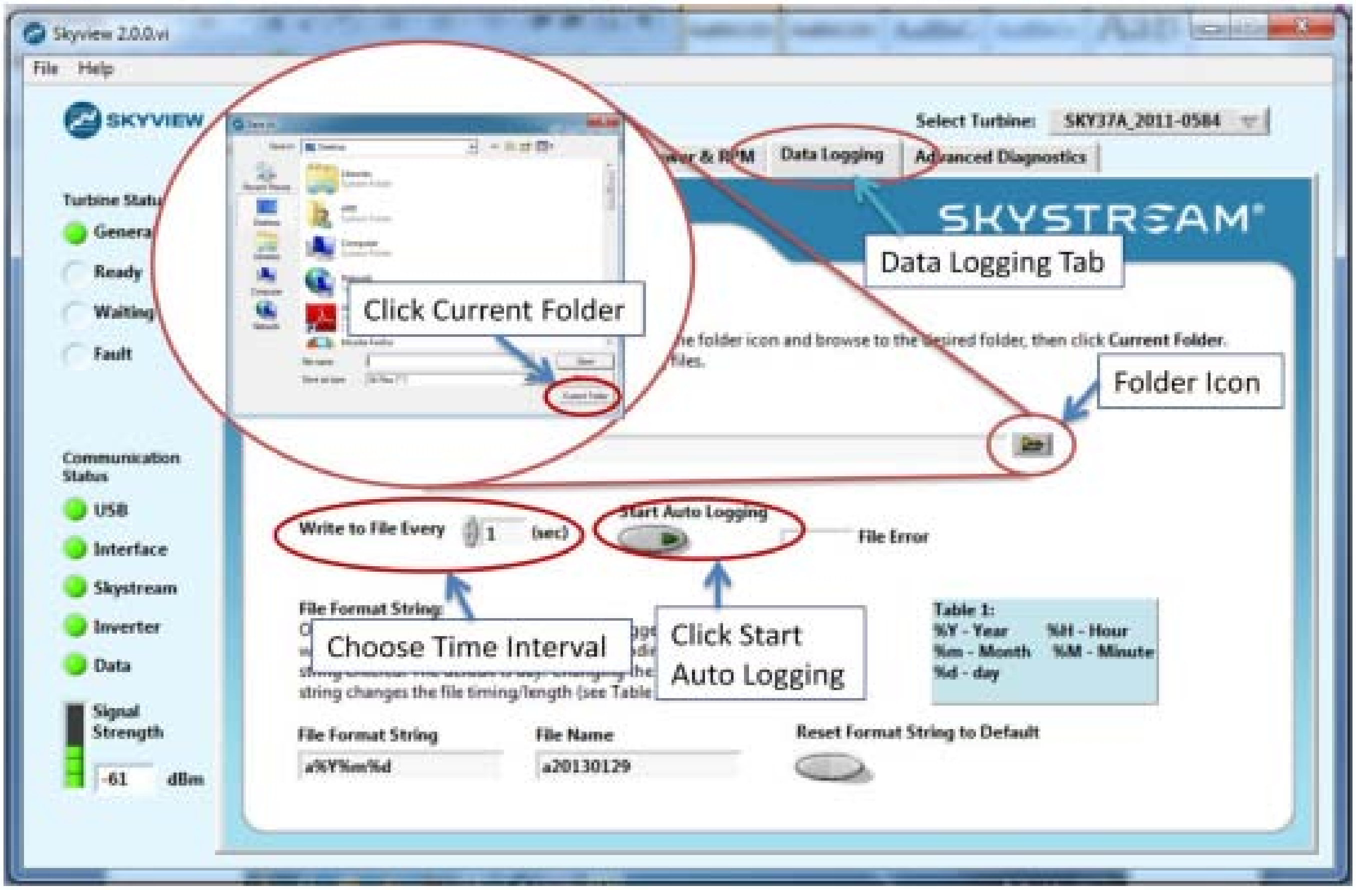


6. Select Tab, Comma and Space as the delimiters. Click Next. On the next screen, simply click Finish.
7. The data should appear as two columns, date and kWh (energy).

The second option to collect data using SkyView is more complicated but will allow you to export a more expansive data set at shorter time intervals to a .txt file. You cannot, however, obtain historical data.

1. File → Advanced Diagnostics.
2. Click on the Data Logging Tab.
3. To choose where the data will be saved, click on the folder icon. Choose the desktop. Click Current Folder. You do not need to choose a name – it will be created automatically.
4. Choose your time interval in the box "Write to file every ____ seconds. (10 seconds will give you a good resolution without an overwhelming amount of data.)

5. Click Start Auto Logging to begin collecting data. A .txt file will automatically appear on your desktop. At this point, SkyView will begin exporting data to the .txt file. Allow it to run as long as necessary to collect the appropriate amount of data for your purposes.
6. To open the .txt file in Microsoft Excel, follow steps 2 through 7 above.



WindInterface: To open data from WindInterface, follow the directions provided in the document entitled, “How to capture data from Wind For Schoosl CAES energy site.”

How to use the data in your classroom

KidWind and NEED have both developed ideas for ysing the data collected from you SkyStream wind turbine in the classroom. The documents entitled ‘Can Wind Power Your Classroom/” and ‘NEED Wind Energy Curriculum’ include their ideas for implementing this curriculum.

Other Ideas

There are mnay ways to teach about wind energy in your classroom beyond using the data. I encourage you to check out these websites for more ideas of lessons, discussions, and activites you can lead in your classroom.

- KidWind: www.kidwind.org
- NEED: www.need.org
- Colorado Wind for Schools: www.engr.colostate.edu/wac/
- Arizona Wind for Schools: ses.nau.edu (click on Wind for Schools)

Contact Information

If you have any questions or encounter any issues, please contact Mike Kostrzewa at michael@rams.colostat.edu.

Appendix D: Sample Turbine Data from the Wind for Schools Site

INL Wind for Schools Data Library

Turbine: Gilpin County School: 03/01/2013 Idaho National Laboratory © 2010

Day & time	PowerW	DailyKWh	TotalKWh	RPM	Wind	Volts
3/1/2013 15:00	405	3922.842642	3392128	196	6	169.4
3/1/2013 14:59	1201	3919.467655	3392117	284	9	239.9
3/1/2013 14:59	1201	3919.467655	3392117	284	9	239.9
3/1/2013 14:58	934	3909.459362	3392094	267	7	227.3
3/1/2013 14:58	934	3909.459362	3392094	267	7	227.3
3/1/2013 14:58	934	3909.459362	3392094	267	7	227.3
3/1/2013 14:56	450	3901.67606	3392071	208	6	182.6
3/1/2013 14:56	450	3901.67606	3392071	208	6	182.6
3/1/2013 14:56	450	3901.67606	3392071	208	6	182.6
3/1/2013 14:56	450	3901.67606	3392071	208	6	182.6
3/1/2013 14:52	28	3897.926075	3392045	107	3	96.5
3/1/2013 14:52	28	3897.926075	3392045	107	3	96.5
3/1/2013 14:52	28	3897.926075	3392045	107	3	96.5
3/1/2013 14:52	28	3897.926075	3392045	107	3	96.5
3/1/2013 14:52	28	3897.926075	3392045	107	3	96.5
3/1/2013 14:52	28	3897.926075	3392045	107	3	96.5
3/1/2013 14:52	28	3897.926075	3392045	107	3	96.5
3/1/2013 14:52	28	3897.926075	3392045	107	3	96.5
3/1/2013 14:50	46	3897.692743	3392044	115	3	101.5
3/1/2013 14:50	46	3897.692743	3392044	115	3	101.5

Idaho National Laboratory © 2010

Turbine: Wellington Middle School: 05/15/2013 Idaho National Laboratory © 2013

Day & time	PowerW	DailyKWh	TotalKWh	RPM	Wind
5/15/2013 16:17	0	600.3976	2239120	0	0
5/15/2013 16:16	0	600.3976	2239120	0	1
5/15/2013 16:16	1022	600.3976	2239109	282	9
5/15/2013 16:13	1169	591.881	2239027	288	9
5/15/2013 16:13	1169	591.881	2239027	288	9
5/15/2013 16:13	1169	591.881	2239027	288	9
5/15/2013 16:13	1169	591.881	2239027	288	9
5/15/2013 16:13	1169	591.881	2239027	288	9
5/15/2013 16:13	1169	591.881	2239027	288	9
5/15/2013 16:12	1673	582.1393	2239013	329	10
5/15/2013 16:12	1459	568.1977	2239003	309	10
5/15/2013 16:11	2069	556.0394	2238990	334	10

5/15/2013 16:11	1642	538.7978	2238979	327	9
5/15/2013 16:10	1043	525.1146	2238967	286	8
Day & time	PowerW	DailyKWh	TotalKWh	RPM	Wind
5/15/2013 16:09	590	513.0563	2238951	231	7
5/15/2013 16:08	944	508.1396	2238937	278	8
5/15/2013 16:08	944	508.1396	2238937	278	8
5/15/2013 16:08	0	500.273	2238935	6	0
5/15/2013 16:07	0	500.273	2238935	0	0
5/15/2013 16:07	0	500.273	2238935	0	0
5/15/2013 16:06	0	500.273	2238935	0	0
5/15/2013 16:06	0	500.273	2238935	0	0
5/15/2013 16:05	0	500.273	2238935	0	0
5/15/2013 16:05	0	500.273	2238935	0	0
5/15/2013 16:04	0	500.273	2238935	0	0
5/15/2013 16:04	0	500.273	2238935	0	0
5/15/2013 16:03	0	500.273	2238935	0	0
5/15/2013 16:03	0	500.273	2238935	0	3
5/15/2013 16:02	1220	500.273	2238911	289	9
5/15/2013 16:02	1220	500.273	2238911	289	9
5/15/2013 16:01	524	490.1064	2238902	223	6
5/15/2013 16:01	331	485.7397	2238891	198	5
5/15/2013 16:00	0	482.9814	2238891	0	0
5/15/2013 16:00	0	482.9814	2238891	0	0
5/15/2013 15:59	0	482.9814	2238891	0	0
5/15/2013 15:59	0	482.9814	2238891	0	0
5/15/2013 15:58	0	482.9814	2238891	0	0
5/15/2013 15:58	0	482.9814	2238891	0	0
5/15/2013 15:57	0	482.9814	2238891	0	0
5/15/2013 15:57	0	482.9814	2238891	0	0
5/15/2013 15:56	-8	482.9814	2238891	0	0
5/15/2013 15:55	2044	483.0481	2238890	335	13
5/15/2013 15:55	2044	483.0481	2238890	335	13
5/15/2013 15:55	2458	466.0148	2238876	330	14
5/15/2013 15:54	666	445.5316	2238867	238	8
5/15/2013 15:54	507	439.9816	2238859	220	7
5/15/2013 15:53	333	435.7566	2238851	200	5
5/15/2013 15:53	0	432.9816	2238851	0	0

Turbine: Mesa County Valley: 04/23/2013 Idaho National Laboratory © 2013

Day & time	PowerW	DailyKWh	TotalKWh	RPM	Wind	Volts
4/9/2013 5:25	341	1547.202	139072	189	6	163.2
4/9/2013 5:24	382	1544.36	139062	192	6	165.2
4/9/2013 5:24	382	1544.36	139062	192	6	165.2
4/9/2013 5:24	60	1541.177	139058	119	3	105.3
4/9/2013 5:24	86	1540.677	139058	127	4	111.6
4/9/2013 5:23	203	1539.961	139056	158	5	139.6
4/9/2013 5:23	93	1538.269	139055	129	4	112.8

4/9/2013 5:22	701	1537.494	139042	236	7	200.4
4/9/2013 5:22	701	1537.494	139042	236	7	200.4
4/9/2013 5:21	387	1531.652	139038	193	6	166.8
4/9/2013 5:21	342	1528.427	139030	187	6	160.9
4/9/2013 5:20	697	1525.577	139020	239	7	205.6
4/9/2013 5:20	951	1519.769	139011	261	8	221.8
4/9/2013 5:19	1070	1511.844	139003	273	8	229
4/9/2013 5:18	481	1502.927	138984	214	6	185.9
4/9/2013 5:18	481	1502.927	138984	214	6	185.9
4/9/2013 5:18	481	1502.927	138984	214	6	185.9
4/9/2013 5:17	1051	1498.919	138975	281	8	240.3
4/9/2013 5:17	2167	1490.161	138965	308	13	245.4
4/9/2013 5:16	514	1472.102	138947	214	7	183.7
4/9/2013 5:16	2281	1467.819	138938	316	11	255.2
4/9/2013 5:15	2708	1448.811	138918	328	14	258.1
4/9/2013 5:14	21	1426.244	138909	103	3	91.7
4/9/2013 5:14	116	1426.069	138908	135	4	118.6
4/9/2013 5:14	1624	1425.103	138903	318	9	265.9
4/9/2013 5:13	1624	1411.569	138892	313	10	261.4
4/9/2013 5:12	1945	1398.036	138863	329	10	271.9
4/9/2013 5:12	1945	1398.036	138863	329	10	271.9
4/9/2013 5:12	560	1381.828	138853	225	6	194.7
4/9/2013 5:11	139	1377.161	138850	146	4	127.4
4/9/2013 5:10	302	1376.003	138842	184	6	160
4/9/2013 5:10	302	1376.003	138842	184	6	160
4/9/2013 5:10	302	1376.003	138842	184	6	160
4/9/2013 5:09	530	1373.486	138837	220	6	190.9
4/9/2013 5:08	795	1369.07	138828	250	8	214.4
4/9/2013 5:08	795	1369.07	138828	250	8	214.4
4/9/2013 5:06	1317	1362.445	138804	300	9	253.6
4/9/2013 5:06	1317	1362.445	138804	300	9	253.6
4/9/2013 5:06	1317	1362.445	138804	300	9	253.6
4/9/2013 5:06	1317	1362.445	138804	300	9	253.6
4/9/2013 5:06	745	1351.47	138793	248	7	213.9
4/9/2013 5:05	527	1345.261	138786	223	6	193.7
4/9/2013 5:05	1641	1340.87	138781	317	9	264.8
4/9/2013 5:04	432	1327.195	138771	205	6	180.2
Day & time	PowerW	DailyKWh	TotalKWh	RPM	Wind	Volts
4/9/2013 5:04	332	1323.595	138766	189	6	163.5
4/9/2013 5:03	1780	1320.828	138745	328	10	275.3
4/9/2013 5:03	1780	1320.828	138745	328	10	275.3
4/9/2013 5:01	1154	1305.995	138721	279	9	236.1
4/9/2013 5:01	1154	1305.995	138721	279	9	236.1
4/9/2013 5:01	714	1296.378	138714	235	7	200.9
4/9/2013 5:00	494	1290.428	138694	213	6	185.1
4/9/2013 5:00	494	1290.428	138694	213	6	185.1
4/9/2013 5:00	494	1290.428	138694	213	6	185.1
4/9/2013 4:59	663	1286.312	138689	236	7	203.6

4/9/2013 4:59	147	1280.787	138686	141	4	125.5
4/9/2013 4:58	670	1279.562	138682	234	7	199.5
4/9/2013 4:57	582	1273.978	138677	224	7	192.1
4/9/2013 4:57	226	1269.128	138671	168	5	147.9
4/9/2013 4:56	293	1267.245	138670	182	5	159.3
4/9/2013 4:54	1912	1264.803	138638	331	10	274.7
4/9/2013 4:54	1912	1264.803	138638	331	10	274.7
4/9/2013 4:54	1912	1264.803	138638	331	10	274.7
4/9/2013 4:54	1912	1264.803	138638	331	10	274.7
4/9/2013 4:54	1912	1264.803	138638	331	10	274.7
4/9/2013 4:53	961	1248.87	138631	273	8	232.9
4/9/2013 4:53	703	1240.862	138624	245	7	212.3
4/9/2013 4:52	427	1235.003	138616	227	5	198.1
4/9/2013 4:51	155	1231.445	138614	151	4	132.9
4/9/2013 4:51	155	1231.445	138614	151	4	132.9
4/9/2013 4:51	155	1231.445	138614	151	4	132.9
4/9/2013 4:50	457	1230.153	138612	208	6	180.6
4/9/2013 4:50	436	1226.345	138608	205	6	176.8
4/9/2013 4:49	1404	1222.712	138603	305	9	257.1
4/9/2013 4:48	1118	1211.012	138579	283	8	240.6
4/9/2013 4:48	1118	1211.012	138579	283	8	240.6
4/9/2013 4:48	1118	1211.012	138579	283	8	240.6
4/9/2013 4:47	387	1201.695	138572	199	6	173.9
4/9/2013 4:47	79	1198.47	138570	127	4	113.4
4/9/2013 4:46	481	1197.812	138569	212	6	184.6
4/9/2013 4:45	836	1193.804	138556	258	7	222.2
4/9/2013 4:45	836	1193.804	138556	258	7	222.2
4/9/2013 4:45	1024	1186.837	138539	276	7	238.1
4/9/2013 4:45	1024	1186.837	138539	276	7	238.1
4/9/2013 4:44	1803	1178.304	138532	329	10	275.8
4/9/2013 4:43	124	1163.279	138526	137	4	120.4
4/9/2013 4:43	622	1162.245	138524	231	7	198.5
4/9/2013 4:42	174	1157.062	138521	156	4	136.3
4/9/2013 4:42	59	1155.612	138520	117	4	104.2
4/9/2013 4:41	548	1155.12	138509	221	7	190.7
4/9/2013 4:41	548	1155.12	138509	221	7	190.7

SkyView Sample Data

Basic Daily Report
Wellington School

Date	KWh
05-Jan-2011	1.79
06-Jan-2011	1.10
07-Jan-2011	1.54
08-Jan-2011	0.00
09-Jan-2011	6.72
10-Jan-2011	1.11

11-Jan-2011	-0.14
12-Jan-2011	-0.00
13-Jan-2011	0.79
14-Jan-2011	3.24
15-Jan-2011	0.61
16-Jan-2011	1.45
17-Jan-2011	7.11
18-Jan-2011	4.09
19-Jan-2011	1.94
20-Jan-2011	0.23
21-Jan-2011	6.09
22-Jan-2011	4.38
23-Jan-2011	1.47
24-Jan-2011	8.48
25-Jan-2011	2.75
26-Jan-2011	5.09
27-Jan-2011	3.18
28-Jan-2011	-0.05
29-Jan-2011	2.20
30-Jan-2011	0.03
31-Jan-2011	11.04
01-Feb-2011	7.25
02-Feb-2011	-0.00
03-Feb-2011	6.00
04-Feb-2011	4.69
05-Feb-2011	10.04
06-Feb-2011	5.30
07-Feb-2011	1.16
08-Feb-2011	1.51
09-Feb-2011	-0.00
10-Feb-2011	0.02
11-Feb-2011	0.17
12-Feb-2011	3.89
13-Feb-2011	5.89

Partial Sky View Advance Diagnostics
Wellington School

Log Time	watt-hours	Voltage In	Current out	Line Frequency	RPM	Windspeed (ref)	TargetTSR
2010:10:08:15:01:34.074	117029	251.2	177	6.43	303	9	6.75
2010:10:08:15:01:35.293	117029	272.2	195	8.9	333	9	6.25
2010:10:08:15:01:36.543	117030	258.6	185	7.81	316	9	6.75
2010:10:08:15:01:37.777	117030	239.5	169	5.62	289	9	6.75
2010:10:08:15:01:39.293	117031	260.6	186	7.73	318	9	6.75
2010:10:08:15:01:40.855	117031	262	196	12.91	336	10	5.25
2010:10:08:15:01:42.355	117033	265.9	195	11.22	334	11	5.75
2010:10:08:15:01:43.933	117034	261.4	193	10.5	330	12	6.25
2010:10:08:15:01:45.012	117035	252.7	179	7.32	307	10	6.5
2010:10:08:15:01:46.543	117035	251.6	178	6.84	305	9	6.5
2010:10:08:15:01:47.777	117035	246.1	203	20.56	348	12	2.25

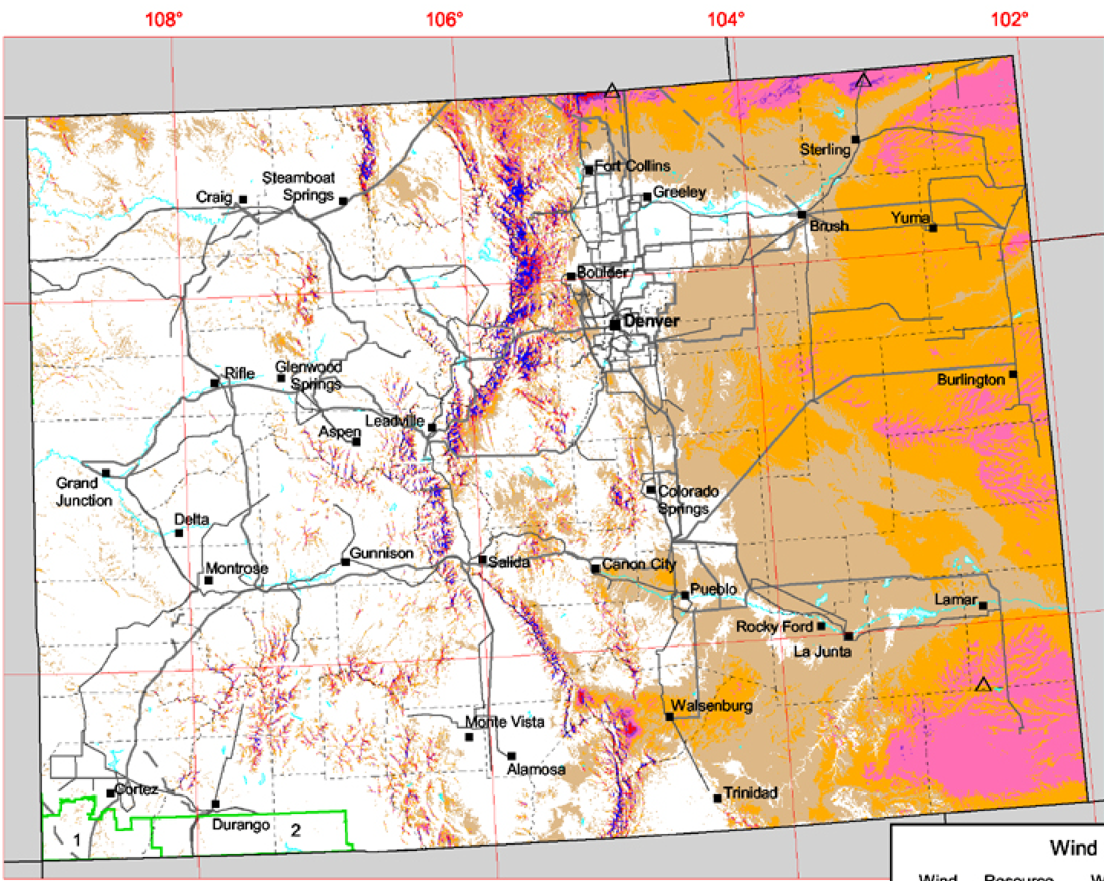
2010:10:08:15:01:49.012	117037	268.7	192	8.29	328	11	6.75
2010:10:08:15:01:50.262	117037	265	189	7.73	323	10	6.75
2010:10:08:15:01:51.762	117038	230.9	200	22.27	343	15	2.5
2010:10:08:15:01:53.293	117039	4.2	0	0.07	0	10	7
2010:10:08:15:01:54.824	117039	0	0	0.08	0	2	7
2010:10:08:15:01:56.356	117039	0	0	0.08	0	1	7
2010:10:08:15:01:57.887	117039	0	0	0.08	0	0	7
2010:10:08:15:01:59.434	117039	0	0	0.09	0	0	7
2010:10:08:15:02:01.074	117039	0.4	0	0.08	0	0	7
2010:10:08:15:02:02.621	117039	0.8	0	0.08	0	0	7
2010:10:08:15:02:04.121	117039	1.2	0	0.08	0	0	7

Notes:

Students may wonder why when the wind is not blowing; there is a negative reading in the watts produced column. The turbine is wired to the electrical system of the school and through that, to the power grid. The turbine requires a small amount of power to run its data functions and to maintain the electromagnets needed for braking. Therefore, the turbine draws a small amount of power to maintain its basic functions when it is not producing power on its own.

The CSU Wind Application Center is beginning to archive data from the Wind for Schools Data Library so you will be able to find data to use, even when your turbine is not producing any data itself. Find this archive at https://sites.google.com/a/rams.colostate.edu/csu-wac/colorado-wfs-wind-turbine-data-archive .

Appendix E: Wind Resource Maps

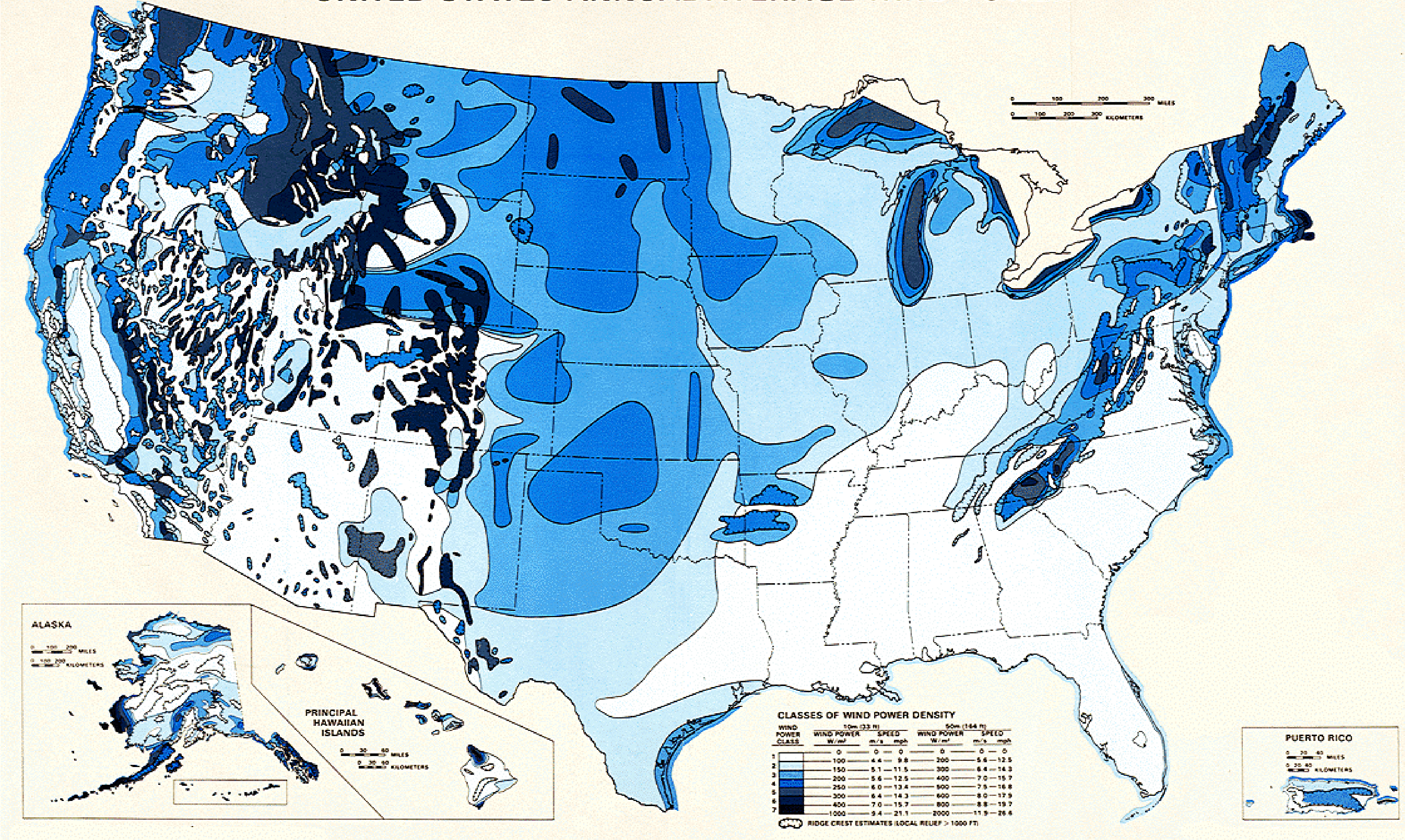


Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m ^{2}	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
1	Poor	0 - 200	0.0 - 5.9	0.0 - 13.2
2	Marginal	200 - 300	5.9 - 6.7	13.2 - 15.0
3	Fair	300 - 400	6.7 - 7.4	15.0 - 16.6
4	Good	400 - 500	7.4 - 7.9	16.6 - 17.7
5	Excellent	500 - 600	7.9 - 8.4	17.7 - 18.8
6	Outstanding	600 - 800	8.4 - 9.3	18.8 - 20.8
7	Superb	> 800	> 9.3	> 20.8

[a] Wind speeds are based on a Weibull k of 2.0 at 1500 m elevation.

UNITED STATES ANNUAL AVERAGE WIND POWER



Appendix F: School Energy Bills

Nov 27, 2009 1

Customer Bill

ABC Elementary School
Anytown, USA

Your Electric Company

Billing and Payment Summary

Account # 000-1234 2 **Due Date: Jan 02, *2010*** 3

Total Amount Due: $ 7,462.61 4

To avoid a Late Payment Charge of 1.5% please pay by Jan 02, 2010.

Previous Amount Due:	$ 8,152.93
Payments as of Nov 27:	$ 8,152.93

Meter and Usage

Current Billing Days: 34

Usage History

Billable Usage

Schedule 130	*10/23 - 11/26*	12
Total kWh	12192	
Dist Demand	61.0	10
Demand	57.0	
Schedule 130	*10/23 - 11/26*	
Total kWh	69888	
Dist Demand	272.0	10
Demand	259.0	

Measured Usage 5

Meter: 000-1234	*0/23 - 11/26*	
Current Reading	4147	
Previous Reading	4020	
Total kWh	12192	6
Current Reading	.60	
Demand	57.60	11
Multiplier: 96		
Meter: 111-4567	*0/23 - 11/26*	
Current Reading	51746	
Previous Reading	51382	
Total kWh	69888	6
Current Reading	1.35	
Demand	259.20	11
Multiplier: 192		

Explanation of Bill Detail

Your Electric Company		**1-800-123-4567**	
Previous Balance	**8,152.93**		
Payment Received	**8,152.93**		
BALANCE FORWARD		**0**	
Non-Residential Service (Schedule 130)		***10/23 - 11/26***	
Distribution Service			
Basic Customer Charge		**86.52**	
Distribution Demand		**206.29**	
13 **Electricity Supply Service (ESS)**			
ESS Adjustment Charge		**83.93 CR**	
Electricity Supply kWh		**214.94**	
ESS Demand Charge		**558.85**	7
Fuel Charge		**353.81**	
Sales and Use Surcharge		**2.68**	8
Non-Residential Service (Schedule 130)		***10/23 - 11/26***	
14 **Distribution Service**			
Basic Customer Charge		**86.52**	
Distribution Demand		**919.87**	
Electricity Supply Service (ESS)			
ESS Adjustment Charge		**374.243 CR**	
Electricity Supply kWh		**909.41**	
ESS Demand Charge		**2,539.36**	7
Fuel Charge		**2,058.15**	
Sales and Use Surcharge		**13.38**	8
TOTAL CURRENT CHARGES		**7,463.61**	9
TOTAL ACCOUNT BALANCE		**7,463.61**	4

For service emergencies and power outages, call 1-800-123-4567.

Mailed on Nov 28, 2009

Please detach and return this payment coupon with your check made payable to Your Electric Company.

Bill Date Nov 27, 2009 1

Payment Coupon

Amount Enclosed

Please Pay by 01/02/2010 3
$ 7,463.54 4

Account # 000-1234 2

Send payment to:

ABC Elementary School
123 Main Street
Anytown, USA 98765

Your Electric Company
PO BOX 123456
Anytown, USA 98765

01166005000 0000000009368 6868686 0001234 11272007

ABC Elementary School
Anytown, USA

NOTE: The bill you received on or around Friday, Nov. 2 was calculated using estimated usage instead of the actual meter reading. This invoice reflects your actual meter reading. If your new amount due is more than what was indicated on your previous bill, please remit payment for the difference. If it is less, and you've already paid, the difference will be credited to your account and shown on your next bill. We apologize for the inconvenience.

1 Account Number	2 Billing Date	3 Next Meter Reading	4 Next Billing Date
000-12345678	Nov 15, 2009	Dec 3, 2009	Dec 4, 2009

Visit our web site at www. yourgascompany.com

If you have any questions call 1-800-000-0000

Credits & Charges Since Your Last Bill

Payments Received - Thank You	$1,302.60 CR	5
Outstanding Balance	$0.00	

Current Charges

General Service

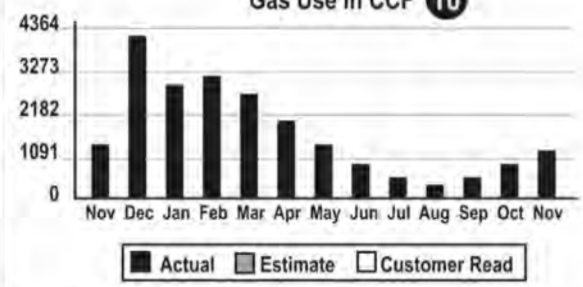
Delivery	6	282.14
Gas Supply	7	1,377.91
Total Current Charges		**$1,660.05**
Total Account Balance	8	**$1,660.05**

For Gas Leaks, call 1-800-123-4567

Monthly Usage Comparison

Heating Degree Days For This Billing Period	2007	9	2008	NORMAL
	160		51	138

Gas Use in CCF 10



Billing Period and Meter Readings

Date	Read Type	Reading	
October 30, 2007	Actual	70320	11
October 01, 2007	Actual	68985	

CCF used in 29 days: 1335 12
Meter Number 123456 13

Please pay by Dec 10, 2009, To Avoid A Late Charge of 1.5% Per Month

EnergyShare has helped Virginians pay heating bills of all kinds. You can help by adding $1, $2, $5, $10, $15, or $20 to your gas bill payment. 14

Please make checks payable to Your Gas Company and return this portion with your payment. Thanks!

YOUR GAS COMPANY
PO Box 123456 Anytown, USA 98765

PREVIOUS BALANCE	**$0.00**	
Total Current Charges	**$1,660.05**	**Pay By Dec 10, 2009** 15
Total Account Balance	**$1,660.05**	
Account # 000-12345678	Amount Enclosed	16

ABC Elementary School
123 Main Street
Anytown, USA 98765

Your Gas Company
PO BOX 123456
Anytown, USA 98765

0116600500000000000093686868686860012345678

Sample Bill Explanation Key

1. Bill Mailing Date
2. Customer Account Number
3. Payment Due Date
4. Total Amount Due
5. Meter Readings By Date in Kilowatt-hours (Note that there are two meters on this bill)
6. Actual Kilowatt-hours Consumed
7. Cost of the Electricity Consumed
8. Sales and Use Surcharge
9. Total Current Charges
10. Demand. This is a measurement of the rate at which electricity is used. The monthly demand is based on the 15 minutes during a billing period with the "highest average" kW use. Demand charges are designed to collect some of the generation and transmission-related costs necessary to serve a particular group or class of customers.
11. Actual Demand for the meter
12. Schedule 130. A rate class that determines how much is paid per kWh of usage and kW demand.
13. Electricity Supply Service. Customers are billed for the electricity supply and the delivery of the electricity. The supply charge reflects the cost of generating the electricity at the power plant.
14. Distribution Service. The delivery charge reflects the cost of delivering the electricity from the power plant to the customer.

Sample School Natural Gas Bill Explanation

1. Customer Account Number
2. Date of the Bill
3. Date of Next Meter Reading
4. Date of the Next Bill
5. Last Payment Received
6. Charge for Delivering the Natural Gas to the School
7. Charge for the Natural Gas
8. Total Amount Due
9. Comparison of Heating Degree Days. Degree day is a quantitative index that reflects demand for energy to heat or cool buildings. This index is derived from daily temperature observations at nearly 200 major weather stations in the contiguous United States. The heating year during which heating degree days are accumulated extends from July 1st to June 30th. A mean daily temperature (average of the daily maximum and minimum temperatures) of 65°F is the base for both heating and cooling degree day computations. Heating degree days are summations of negative differences between the mean daily temperature and the 65°F base.
10. Graph of Actual Gas Used by Month for the Last Year
11. The Actual Meter Readings for the Month
12. The Volume of Gas Used in CCF
13. The Meter Number
14. EnergyShare Fund. Most utilities have a fuel fund for needy customers; paying customers can contribute any amount to the fund and note it here.
15. Due Date of Payment
16. Amount Enclosed by Customer

Appendix G: List of Materials

The following list is solely intended to give teachers ideas of the types of items used in the lesson plans. Colorado State University Extension does not endorse any particular brands, and the list is not exhaustive. **Disposables are not included in this list.**

Lesson Plan(s)	Item	Possible Source
Top Speed Tip Speed	Tachometer	CyberTech Digital Photo Laser Tachometer Non Contact Amazon (Warning: these are not designed to measure rpm on an outdoor turbine)
	Wind Speed Meter (anemometer)	GM8908 LCD Digital Wind Speed Temperature Measure Gauge Anemometer Amazon (Warning: Comes on a very slow boat from China)
Modeling Power Efficiency and Tip Speed Ratios	Wind turbine kit	Basic Wind Experiment Kit - KidWind http://store.kidwind.org/wind-energy-kits/complete-kits/basic-wind-experiment-kit Wind turbines can also be built from easily available materials See 4-H *Power of the Wind* for ideas http://www.4-h.org/resource-library/curriculum/4-h-the-power-of-the-wind/
	Multimeter	These are included in the Basic Wind Kit and can also be purchased from Harbor Freight, KidWind and on Amazon.
	Box fan	Local hardware and big box stores
	Extra alligator clips for measuring amperage	2 per kit Elenco TL-6 Standard Alligator Lead Set, 10-Piece
	Tachometer, Wind Speed Meter	See above
	Scissors or exacto knives, blade materials, strong tape or hot glue, masking tape	Local stores
What Speed Do We Need?	Power Monitor	Kill-a-watt or similar (P3 International P4400 Kill A Watt Electricity Usage Monitor Home Depot, Amazon
	Flicker checker	Osram Sylvania 800-544-4828 (these are free if you request them)

Appendix H: Additional Resources

Videos
Several videos are available to support teachers in delivering most lesson plans from this curriculum. In particular, look for videos on how to use the tachometer and the wind speed meter. To access these videos, visit: www.ext.colostate.edu/energy/k12.html

Kit Materials
Kits have been made available to schools that attended the training that accompanies this curriculum. Kits may be borrowed from the CSU Wind Application Center by contacting Michael Kostrzewa at michael@engr.colostate.edu or 970.491.7709. Teachers interested in purchasing materials to carry out the lesson plans can use "Appendix D: List of Kit Materials" as a reference.

Wind Content
The following websites were used during the content development of this curriculum and provide more in-depth resources for wind energy information:

General background

- American Wind Energy Association
  - http://www.awea.org/learnabout/publications/factsheets/index.cfm
- Boston University
  - http://people.bu.edu/noahb/files/wind_turbine_main.pdf#page=1
- Colorado Anemometer Loan Program has measured the wind resource at over 100 sites in Colorado. This site can give you a great overview of the wind resource at each area, including an average wind speed for at least a year.
  - http://www.engr.colostate.edu/ALP/ALP_Sites.htm]
- Energy Bible
  - http://energybible.com/wind_energy/wind_speed.html
- National Renewal Energy Lab (NREL) Wind Power Basics
  - http://www.nrel.gov/learning/re_wind.html

Wind Power, Efficiency, Tip Speed Math Resources

- Calculation of Wind Power
  - http://www.reuk.co.uk/print.php?article=Calculation-of-Wind-Power.htm
- Tip Speed and Tip Speed Ratio
  - http://www.reuk.co.uk/Wind-Turbine-Tip-Speed-Ratio.htm
- Tip Speed Ratio Video
  - http://www.youtube.com/watch?v=ejRt-PtQOIk
- Wind Energy Math
  - http://www.mmpa.org/Uploaded_Files/ab/ab5c7c5c-79d9-48bd-b64d-833001b7e230.pdf
- **W**ind Power Engineering Toolbox
  - http://www.engineeringtoolbox.com/wind-power-d_1214.html
- Wind Power theory, Betz limit and optimal TSP
  - http://cdn.intechopen.com/pdfs/16242/InTech-Wind_turbines_theory_the_betz_equation_and_optimal_rotor_tip_speed_ratio.pdf
- Wind Turbine Power Calculations

  - http://www.raeng.org.uk/education/diploma/maths/pdf/exemplars_advanced/23_wind_turbine.pdf

Economic Impact

- Wind Energy Foundation
  - http://www.windenergyfoundation.org/wind-at-work/case-studies/colorado
- Wind Feasibility for Livestock Operations – good econ data on payback
  - http://www.agmrc.org/media/cms/WIND_REPORT_Final_A97037D9FC0B8.pdf

Wind and the Environment

- University of Massachusetts Fact Sheets
  - http://www.umass.edu/windenergy/publications/published/communityWindFactSheets/RERL_Fact_Sheet_3_Impacts&Issues.pdf
- Wind Power and the Environment: Benefits and challenges
  - http://www.ewea.org/fileadmin/ewea_documents/documents/publications/WD/wd25-5-focus.pdf
  - http://windyearth.blogspot.com/2012/11/the-pros-and-cons-of-using-wind-energy.html

Wildlife

- Bats and Wind Energy Cooperative
  - http://www.batsandwind.org/
- National Wind Coordinating Collaborative (NWCC) Wildlife Workgroup
  - http://www.nationalwind.org/issues/wildlife.aspx
  - http://www1.eere.energy.gov/wind/pdfs/birds_and_bats_fact_sheet.pdf
- NREL
  - http://www.nrel.gov/wind/environmental_impacts.html?print,
  - NREL Wind Wildlife Impacts Literature Database http://www.nrel.gov/wind/wild

Resources for Teachers

- 4-H Power of the Wind
  - http://www.4-h.org/resource-library/curriculum/4-h-the-power-of-the-wind/
- Boise State University
  - http://coen.boisestate.edu/windenergy/wfs/teacherresources/
- CSU Clean Energy Curriculum for Middle and High Schools
  - http://www.ext.colostate.edu/energy/k12.html
- KidWind Windwise
  - http://learn.kidwind.org/windwise
- National Energy Education Development(NEED)
  - http://www.need.org/curriculum-guides
- Wind Powering America (DOE)
  - http://www.windpoweringamerica.gov/schools_teaching_materials.asp

Wind for Schools

- Colorado State University Wind Application Center

    - https://sites.google.com/a/rams.colostate.edu/csu-wac/
- Northern Arizona University Wind Application Center
    - http://nau.edu/CEFNS/Centers-Institutes/Sustainable-Energy-Solutions/Education/Wind-for-Schools/Wind-Energy---Curriculum-Resources/
- CAES (Center for Advanced Energy Studies) Wind for Schools site
    - http://wind-for-schools.caesenergy.org/wind-for-schools/Wind_For_Schools.html

For more information on Colorado State University's energy programming, please visit:
www.ext.colostate.edu/energy