Name: _____ Date: _____

Wind Turbine Worksheet Answers

Problem

What is the problem that you are trying to solve with the design of a wind turbine for a house?

Answers will vary. They should include how to generate electricity for a house using a renewable energy source.

Background Knowledge

See the activity's Introduction/Motivation section for answers.

What are some things that you already know about wind turbines? **Possible answers:**

1. **Wind is a natural renewable energy source that exists because of the sun**
2. **By spacing out many turbines in one area of high wind velocity, engineers are able to harness the energy contained in all that moving air**
3. **When wind contacts the blades of a wind turbine, it transfers some of its energy into spinning the blades**
   - **Engineers use principles of aerodynamics, such as lift and drag, to best design a turbine blade**
   - **Two different kinds of wind turbines are commonly used to harness wind energy — vertical-axis wind turbines (VAWT) and horizontal-axis wind turbines (HAWT)**

Brainstorming Ideas

Before building your wind turbines, designs must first be thought up. Many different designs exist for wind turbines. Some use blades shaped like a fan's blade with a curvature; some might be flat; some look like egg beaters. The possibilities are almost endless. Use the space below to record your group's brainstorming session (ideas, drawings, etc.) for each of the designs of your turbines. You are designing both a vertical-axis and a horizontal-axis wind turbine. Remember no idea or suggestion is "silly."

Design

Use the space below to detail your group's final designs for your two wind turbines. Be specific. Include drawings and dimensions as appropriate. (Note: remember to design your turbines with the blades on the end **opposite** where the hole is drilled in the block.)

Testing and Analysis

Collect and record the following data at each of three fan speeds. Be sure that for each trial you keep the turbine about 6 inches in front of the fan.

		Speed 1 (low)	Speed 2 (medium)	Speed 3 (high)
Voltage produced with HAWT	Trial 1			
	Trial 2			
	Trial 3			
Voltage produced with VAWT	Trial 1			
	Trial 2			
	Trial 3			

1. Calculate the average voltage produced for each turbine at each speed.

Evaluation/Questions

1. Based on the data your group collected, which wind turbine (vertical or horizontal) seems to be the most efficient (that is, which turbine seems to be better at each speed than the other)?

2. Why do you think this type turbine performed better than the other type?

3. The overwhelming majority of wind turbines in use today are horizontal-axis wind turbines. Does this fact seem to agree with your data? Why or why not?

4. One reason why horizontal-axis wind turbines are used more often than vertical-axis wind turbines is because they can be built higher into the air. Why would this allow them to have better performance?

   Turbines located higher above the ground can access greater wind speeds (higher velocity winds are more common at higher elevations) and receive less disruption of wind flow due to nearby buildings and trees.

5. Your engineering firm has been designing an energy-efficient house, and has decided to investigate generating power for the house using a wind turbine. Several factors are under consideration when an engineer decides to build a wind turbine. The table below provides details from a recent study into possible wind turbine placement near the house. Use this information and the following questions to help determine which type of turbine to use and the best place to locate the turbine.

Measurements	Location 1	Location 2	Location 3
Average Wind Speed *10 meters* above the ground	9.3 m/s	11.1 m/s	10.5 m/s
Average Wind Speed *20 meters* above the ground	10.42 m/s	12.43 m/s	11.76 m/s
Average Wind Speed *40 meters* above the ground	11.67 m/s	13.92 m/s	13.17 m/s
Average Wind Speed *60 meters* above the ground	12.37 m/s	14.77 m/s	13.97 m/s
Number of **VAWT** that can fit	2	1	1
Height above ground VAWT can reach	40 m	40 m	40 m
Max power rating for each VAWT at 15 m/s	7.5 kW	7.5 kW	7.5 kW
Efficiency of VAWT	91%	91%	91%
Price to install 1 VAWT	$6,500	$7,500	$7,000
Number of **HAWT** that can fit	3	1	2
Height above ground HAWT can reach	60 m	60 m	60 m
Max power rating for each HAWT at 15 m/s	10 kW	10 kW	10 kW
Efficiency of HAWT	95%	95%	95%
Price to install 1 HAWT	$7,000	$8,000	$7,500

a. Assume that the maximum power output for each turbine occurs at 15m/s. Calculate the power a VAWT and HAWT turbine would generate at ***each site***.

P=W/t

(Hint: First find the maximum power that each type of turbine could produce at 15 m/s.)
Students should use the average wind speed for the turbine at its maximum height. According to the chart, the maximum height for a VAWT is 40 m and the maximum height for a HAWT is 60m.

$$\textbf{\textit{VAWTs:}}\ \frac{7.5kW}{15m/s} = \frac{0.5kW}{m/s}$$

$$Site\ 1 = 11.67\frac{m}{s} * \frac{0.5kW}{\frac{m}{s}} = 5.84\ kW$$

$$Site\ 2 = 13.92\frac{m}{s} * \frac{0.5kW}{m/s} = 6.96\ kW$$

$$Site\ 3 = 13.17\frac{m}{s} * \frac{0.5kW}{m/s} = 6.59\ kW$$

$$\textbf{\textit{HAWTs:}}\ \frac{10kW}{15\ m/s} = \frac{0.667kW}{m/s}$$

$$Site\ 1 - 12.37\frac{m}{s} * \frac{0.667kW}{\frac{m}{s}} = 8.25\ kW$$

$$Site\ 2 - 14.77\frac{m}{s} * \frac{0.667kW}{\frac{m}{s}} = 9.85\ kW$$

$$Site\ 3 - 13.97\frac{m}{s} * \frac{0.667kW}{m/s} = 9.32\ kW$$

b. Using the efficiency ratings given, determine the actual power output of one turbine of each kind at each site.

$$P * \eta = P_{actual}$$

VAWTs:

$$Site\ 1 - 5.84\ kW * .91 = 5.31\ kW$$
$$Site\ 2 - 6.96\ kW * .91 = 6.33\ kW$$
$$Site\ 3 - 6.59\ kW * .91 = 6.00\ kW$$

HAWTs:

$$Site\ 1 - 8.25\ kW * .95 = 7.84\ kW$$
$$Site\ 2 - 9.85\ kW * .95 = 9.36\ kW$$
$$Site\ 3 - 9.32\ kW * .95 = 8.85\ kW$$

c. If we can expect the wind to be blowing about 7.5% of the time at the average speed, how much power can we expect each turbine to produce at each site?

$$VAWTs:$$
$$Site 1 - 5.31\ kW * .075 = 0.398\ kW$$
$$Site\ 2 - 6.33\ kW * .075 = 0.475\ kW$$
$$Site\ 3 - 6.00\ kW * .075 = 0.450\ kW$$

$$HAWTs:$$
$$Site\ 1 - 7.84\ kW * .075 = 0.588\ kW$$
$$Site\ 2 = 9.36\ kW * .075 = 0.702\ kW$$
$$Site\ 3 - 8.85\ kW * .075 = 0.664\ kW$$

d. How much energy (in kW-hours) would be generated at each site in one year?

$$E = P * t$$

$$1\ year = 365\ days * 24\frac{hours}{day} = 8760\ hours$$

$$VAWTs:$$
$$Site\ 1 - 0.398\ kW * 8760hrs = 3486.5\ kWh$$
$$Site\ 2 - 0.475\ kW * 8760hrs = 4161.0\ kWh$$
$$Site\ 3 - 0.450\ kW * 8760\ hrs = 3942.0\ kWh$$

$$HAWTs:$$
$$Site\ 1 - 0.588\ kW * 8760hrs = 5150.9\ kWh$$
$$Site\ 2 - 0.702\ kW * 8760hrs = 6149.5\ kWh$$
$$Site\ 3 - 0.664\ kW * 8760hrs = 5816.6\ kWh$$

e. If we would like to generate 5900 kWh of energy per year from our wind turbine, which turbine and site would you recommend and why.

We recommend installation of a HAWT at site 2 because the estimated energy generated in one year by a HAWT at site 2 would be about 6149 kWh, which exceeds our goal.

6. Wind turbines are often built as a means to produce energy from a renewable energy source. Wind power offers several advantages over energy generated from non-renewable energy sources such as fossil fuels. One of the biggest benefits is that wind power is a clean energy, meaning it does not produce any emissions that are bad for the Earth's environment, climate and animals. One disadvantage to using wind power is that it costs more to generate energy from wind than from burning fossil fuels. Can your group think of three other disadvantages of wind power?

   Possible example answers:
   - The wind does not always blow, so the turbine will not continuously be generating electricity. This means to effectively use wind power you need additional/supplementary means of generating electricity when the wind is not blowing, a battery system to store energy for when the wind is not blowing, or the ability to go with less/no electricity for periods of time.
   - The wind turbines themselves can be detrimental to birds and bats. Wind turbines are also noisy and this limits where they can be placed.
   - The installation of wind turbines can also take up farm land or land that could be beneficially used for another purpose.
   - Wind turbines often are not running at 100% since wind speeds fluctuate (too low, too high).

7. Where would you recommend for your firm to locate a wind turbine to generate power for the house? How would the turbine affect the individuals and the environment? Write a short persuasion piece to help your firm understand the advantages of using wind power in this area.