WindPitch Wind Turbine Experiment-
How Many Blades Are Best?

EXPERIMENT OVERVIEW

Using the correct number of blades for a given wind condition is important in extracting the maximum electrical power from a wind turbine. In this experiment students gain an understanding of the choices between the numbers of blades that are necessary to produce the most power.

EXPERIMENT OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will learn about how different numbers of blades produce different power outputs from the wind turbine.
- Students will witness how two, three, four and six blades produce different amounts of power for the same wind speed.
- Students will come to understand that:
    - Adding more blades may, or may not, generate more power.
    - More blades cause "drag" by increasing wind resistance and turbulence.
    - Reducing the number of blades may result in higher output power.

SAFETY

Caution must be exercised when using the wind turbine and table fan. Spinning blades can pose a hazard and can cause injury if not careful. DO NOT PLACE YOUR FINGERS, HANDS, ARMS, FACE OR ANY OTHER PART OF YOUR BODY IN THE SPINNING WIND TURBINE OR FAN BLADES!

<u>Wear safety glasses for all experiments</u>

PREREQUISITES

- Read and understand the WindPitch Education Kit instructions including:
  - Component Parts
  - Assembly
  - Blade Installation
  - Blade Pitch Adjustment
  - Electrical Connections

EQUIPMENT

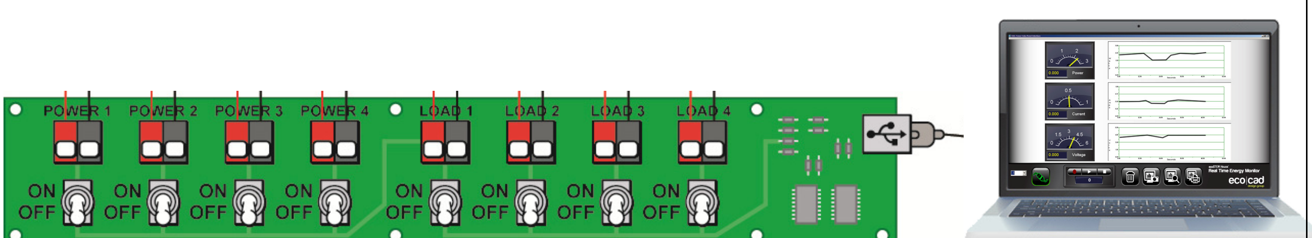
- Control Panel
- Computer running the ecoCAD Real Time Energy Monitoring software
- WindPitch wind turbine with 3 BP-28 profile blades
- Student built flat or profiled blades where available
- Large Table or Floor Fan (at least 16" in diameter with 3 speeds)
- Two (2) 100 ohm fixed resistors
- Printer

EXPERIMENT SETUP

1. The Control Panel should be connected to the computer with the graphic software running to perform the experiment. All the switches should be OFF.

2. Insert a 100 ohm fixed resistor into each **Load 1** and **Load 2** terminals. Polarity does not matter, so the resistor wires can be inserted in any orientation.

3. Attach the WindPitch electrical output terminals to the **Power 1** terminals on the Control Panel. You will need to acquire a length of 2 conductor wire to make the connection between the WindPitch and the Control Panel. Wire the Red terminal on the WindPitch to the Gray or Red terminal on **Power 1** and the Black terminal on the WindPitch to the Black terminal on **Power 1**.



DOING THE EXPERIMENT

2 Blades

1. Setup the WindPitch wind turbine with two (2) BP-44 blades opposite one another on the hub.

2. Adjust the blade pitch angle to 15°.

3. Set the table or floor fan as close to the wind turbine blades as possible. **MAKE SURE THAT THE WIND TURBINE BASE IS SECURE AND CAN'T MOVE. USE A BOOK OR OTHER OBJECT TO HOLD IT IN PLACE BEFORE TURNING THE FAN** ON.

4. Switch ON the wind turbine (**Power 1**) and both 100 ohm resistors (**Load 1 and Load 2**). Since the resistors are in parallel this makes a 50 ohm load.

5. Set the fan to its highest speed setting.

6. Clear the computer screen by clicking on the Trash can icon.

7. Click the Screen Capture icon to record the voltage, current and power being consumed by the 50 ohm resistor load.

8. Stop the fan.

3 Blades

9. Setup the WindPitch wind turbine with three (3) BP-44 blades in a triangular pattern.

10. Switch ON the wind turbine (**Power 1**) and both 100 ohm resistors (**Load 1 and Load 2**). Since the resistors are in parallel this makes a 50 ohm load.

11. Clear the computer screen by clicking on the Trash can icon.

12. Click the Screen Capture icon to record the voltage, current and power being consumed by the 50 ohm resistor load.

13. Stop the fan.

4 Blades

14. Setup the WindPitch wind turbine with four (4) blades – two BP-44 blades opposite one another and two BP-63 blades opposite one another to form a 12, 3, 6 and 9 o'clock pattern.

15. Switch ON the wind turbine (**Power 1**) and both 100 ohm resistors (**Load 1 and Load 2**). Since the resistors are in parallel this makes a 50 ohm load.

16. Clear the computer screen by clicking on the Trash can icon.

17. Click the Screen Capture icon to record the voltage, current and power being consumed by the 50 ohm resistor load.

18. Stop the fan.

6 Blades

19. Setup the WindPitch wind turbine with six (6) blades – alternate the blades as 44, 63, 44, 63, 44 and 63.

20. Switch ON the wind turbine (**Power 1**) and both 100 ohm resistors (**Load 1 and Load 2**). Since the resistors are in parallel this makes a 50 ohm load.

21. Clear the computer screen by clicking on the Trash can icon.

22. Click the Screen Capture icon to record the voltage, current and power being consumed by the 50 ohm resistor load.

23. Stop the fan.

<u>Repeat the entire experiment with custom blades of your own.</u>

STUDENT EXERCISES

1. Which number of blades produced the most power?

   2
   3
   4
   6

2. Which number of blades produced the least power?

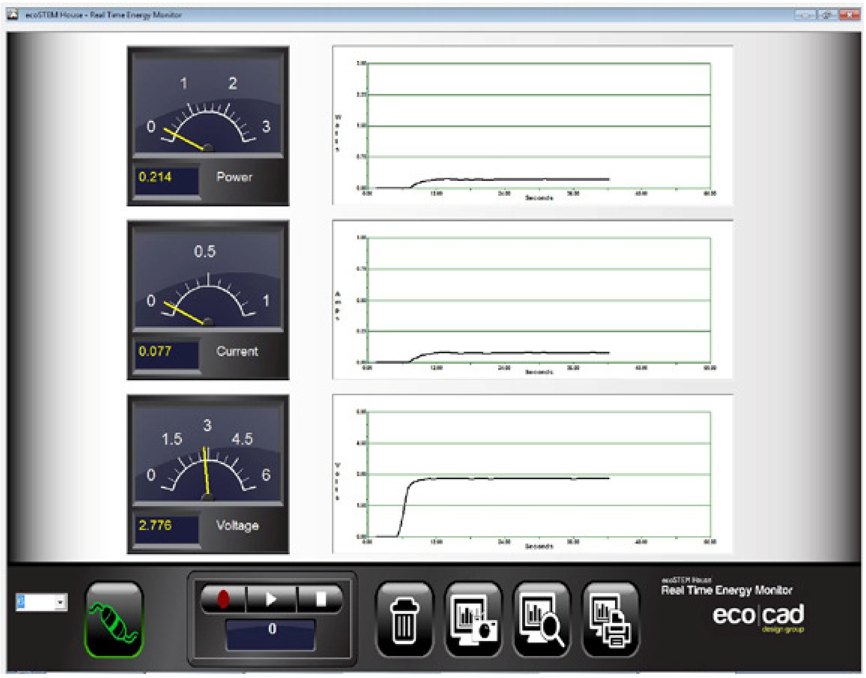
   2
   3
   4
   6

3. Did you expect to see more blades or fewer blades produce the most power? Explain your answer.

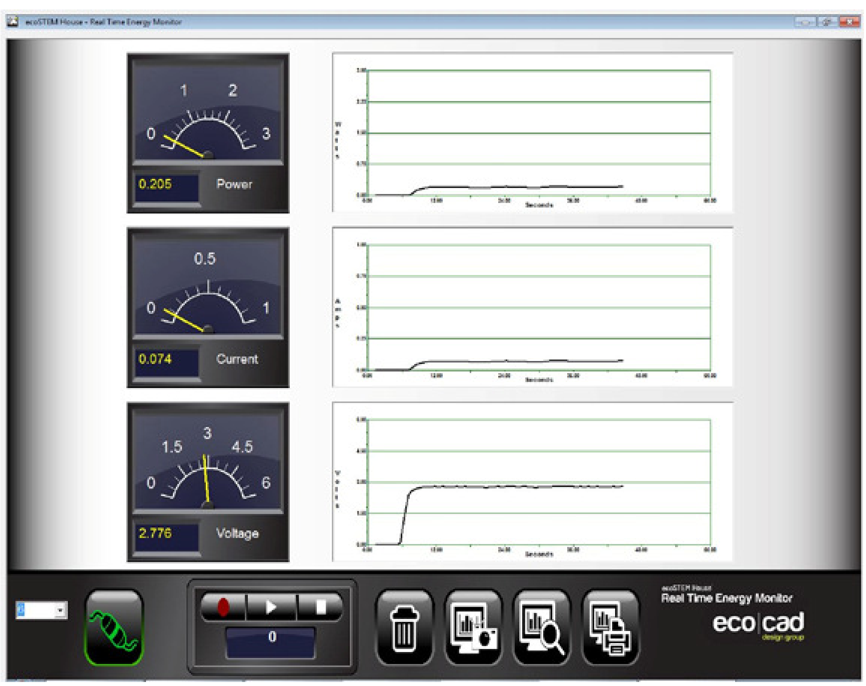
4. Did your expectation prove correct or incorrect? Explain why in either case.

TEACHER NOTES - ANALYZING THE RESULTS

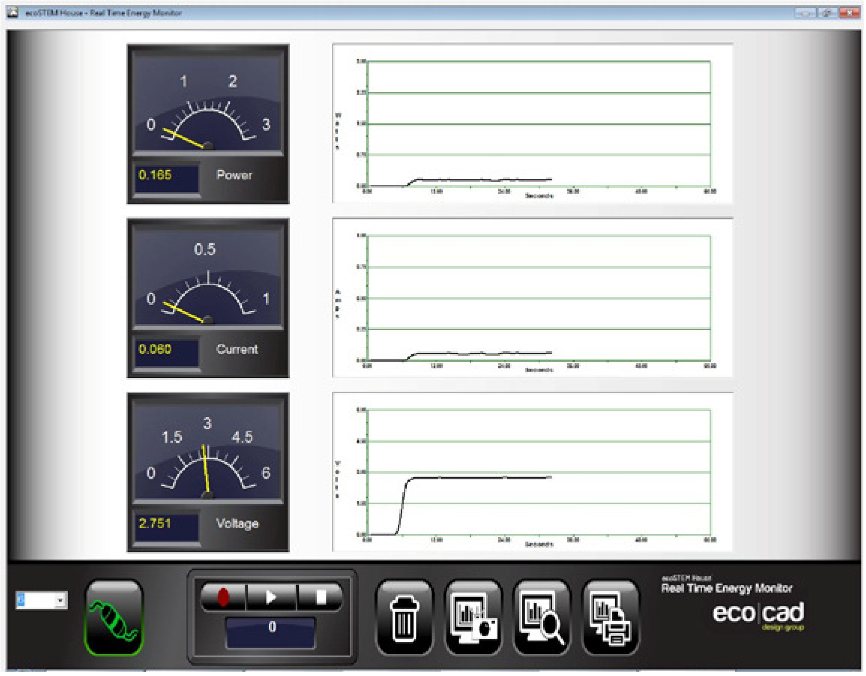
1. First, have the students print out the four (4) screen captures they took in steps 7, 12, 17, 22. Here are our results – your exact results will vary.



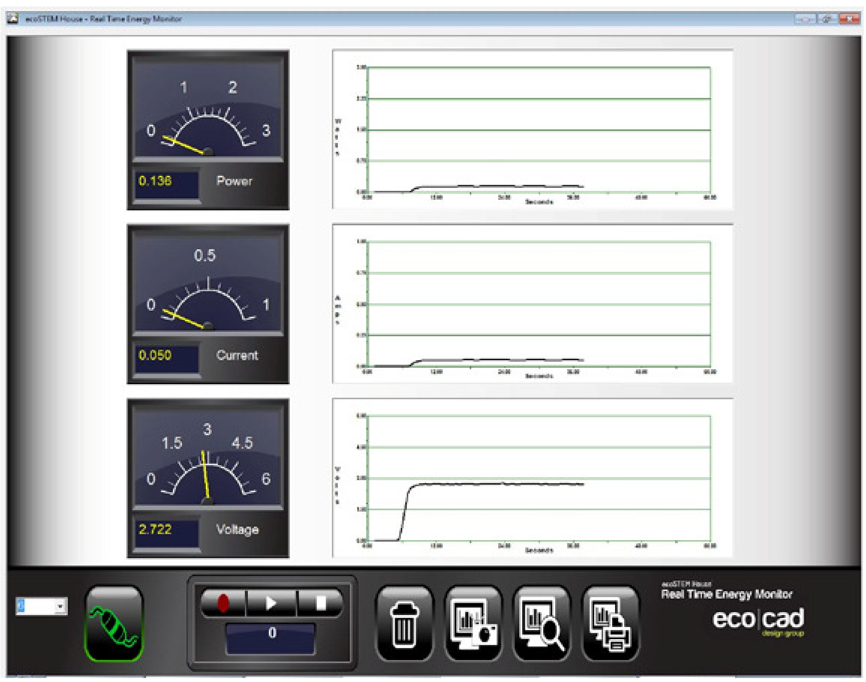
Step 7 2 Blades Power = 0.214 watts



Step 12 3 Blades Power = 0.205 watts



Step 17 4 Blades Power = 0.165 watts



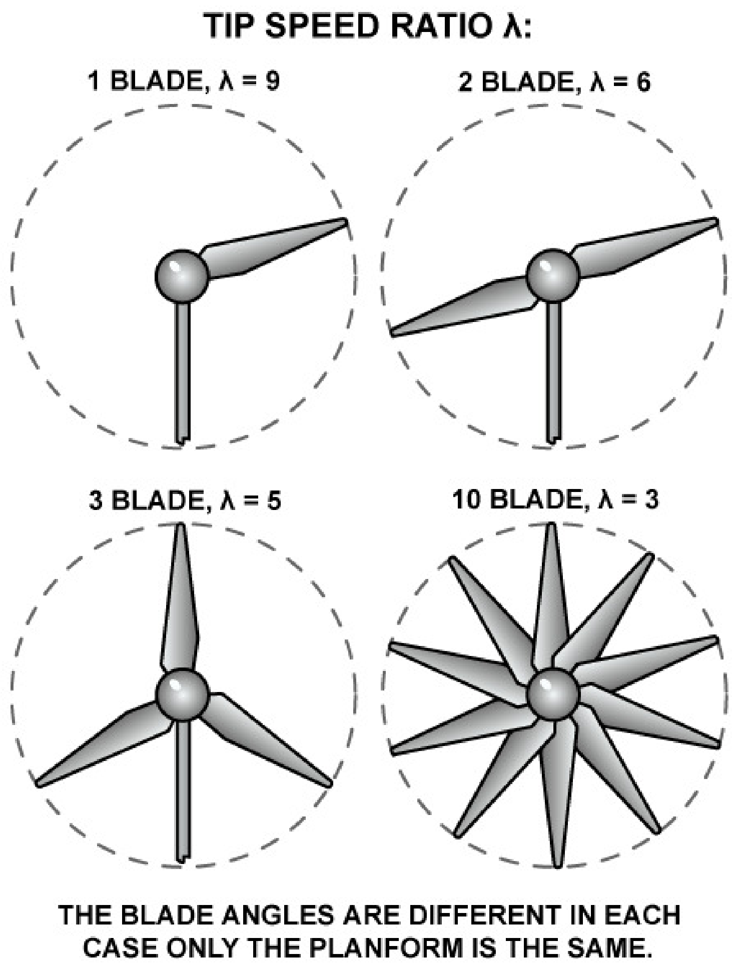
Step 22 6 Blades Power = 0.136 watts

- It maybe counter intuitive to see that the power output decreases with the increasing number of blades, but explain to the students that this is [mainly] due to the extra drag or wind resistance created by the extra blades. You can perform this experiment again with slower fan speeds to obtain different results.

- In order to harvest more output power with increasing wind speeds, the number of blades should be less and the length and width of the blades should be smaller.

- Energy in low wind speed is small; therefore, more blade area will harvest more of the wind power as we see here. However, at high wind speeds, longer blades result in a longer time to complete one full revolution at the tip of the blade. Shorter blades result in shorter time to complete one revolution and thus results in higher rotation speed for higher output power from the alternator.

- The Tip Speed Ratio parameter of the turbine relates to this:



- The **tip speed ratio** λ (lambda) or **TSR** for wind turbines is the ratio between the rotational speed of the tip of a blade and the actual velocity of the wind.

- If the velocity of the tip is exactly the same as the wind speed the tip speed ratio is equal to one. A higher tip speed ratio generally indicates a higher efficiency but is also related to higher noise levels and a need for heavier, stronger blades.

$$\text{Tip speed ratio} = \frac{\text{Tip speed of blade}}{\text{Wind speed}}$$

- It has been shown [empirically] that the optimum tip speed ratio for maximum power output occurs at…

$$\lambda_{\text{max power}} = \frac{4\pi}{n}$$

where *n* is the number of blades.

- Therefore, it is in your interest to repeat this experiment with shorter blades, since shorter blades will rotate faster thus achieving a greater TSR and more output power from the wind turbine.

- Credit for portions of this analysis goes to Wikipedia (http://en.wikipedia.org/wiki/Tip_speed_ratio).

Odd Wind Turbine Blade Examples

Three bladed turbines are not a magic number as these photos point out.

The 98 meter diameter (longer than a football field), two-bladed NASA/DOE Mod-5B wind turbine was the largest operating wind turbine in the world in the early 1990s. Built in the 1980's and like the Spruce Goose of the 1940's it, too, is an exaggerated example of what can be done with a particular technology along with no useful commercial outcomes.

Photo credit: Wikipedia.

The NASA Mod-0 research wind turbine at Glenn Research Center's Plum Brook station in Ohio tested a one-bladed rotor configuration. Its odd looks probably contributed to its lack of popular acceptance even though its one blade may have proven effective for its design goals. A single blade turbine like this will produce the highest Tip Speed Ratio.

Photo credit: Wikipedia.