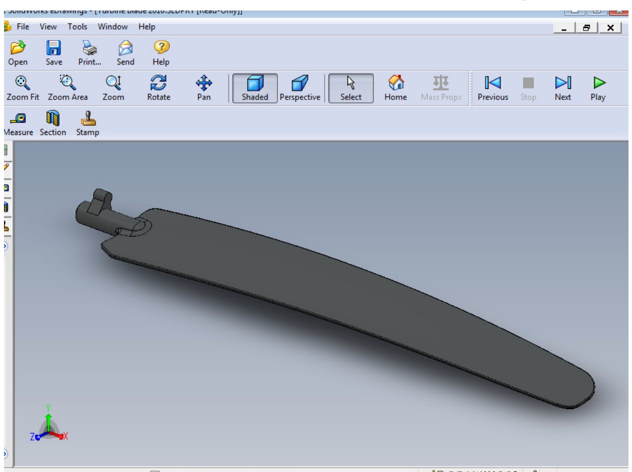
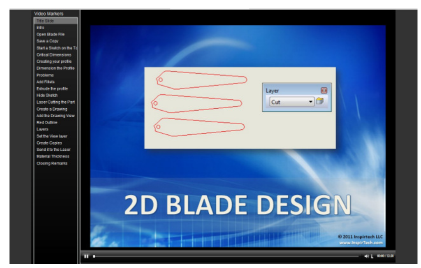
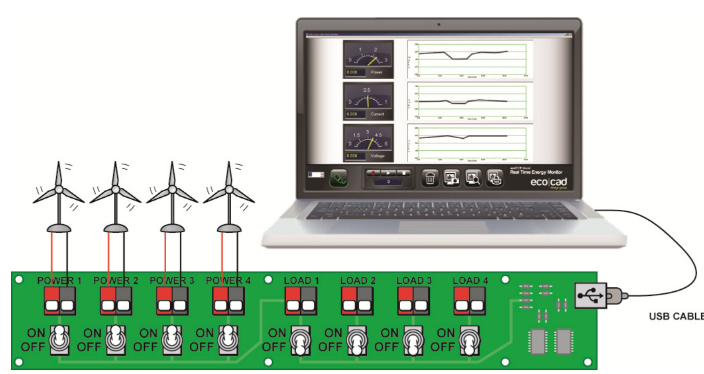
eco|cad Design Group, LLC
www.ecoCadDesignGroup.com
www.ecoStemHouse.com

Experiments for the ecoCAD / InspirTech Wind Turbine Blade Design and Performance Kit

Based on the WindPitch™ Wind Turbine along with Your Custom Blade Designs







WindPitch Experiments for the Blade Design and Performance Kit

eco|cad Design Group, LLC
www.ecoCadDesignGroup.com
www.ecoStemHouse.com

Important Advisory

These plans are presented in "as is" condition.

By using these plans you hold ecoCAD Design Group, LLC and all members, investors, employees and owners harmless from any damages arising from the use of these plans including, but not limited to, the resulting physical implementation of the plans and any tests or experiments done with them.

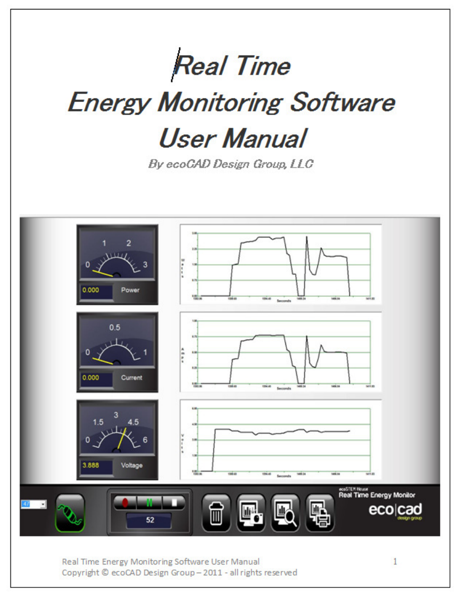
In no case shall ecoCAD Design Group, LLC be liable for any damages or injuries resulting from the use and/or implementations of these plans and/or any tests or experiments done with them.

These plans are not warranted for fitness for any particular purpose. Users of these plans assume all responsibility for their safe and effective use.

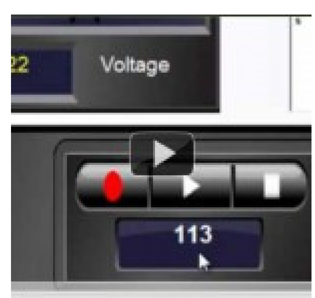
By using these plans you agree to these terms.

eco|cad Design Group, LLC
www.ecoCadDesignGroup.com
www.ecoStemHouse.com

The experiments use the Real Time Energy Monitoring Software. Refer to the *"Real Time Energy Monitoring Software User Manual"* and accompanying video for information on installing and using the software.



User Manual
Refer to the following link to download the manual:
http://www.ecocaddesigngroup.com/downloads/



Video
Real Time Energy Monitoring Software Video
http://www.ecocaddesigngroup.com/videos/

eco|cad Design Group, LLC
www.ecoCadDesignGroup.com
www.ecoStemHouse.com

Table of Contents

Each experiment should take an average of one class period to perform.

The following experiments use the WindPitch Horizontal Axis Wind Turbine (HAWT) along with the blades that come with it.

You are encouraged to also perform these experiments with your own custom blades (either 2D or 3D) in order to determine their performance as compared with the standard supplied blades.

ALWAYS WEAR SAFETY GLASSES

Wear your safety glasses during the preparation for and execution of the experiments

Preliminary Experiment - Measuring Wind Speed

EXPERIMENT OVERVIEW

This experiment demonstrates the proper techniques for measuring wind speed using a La Crosse model EA-3010U handheld anemometer.

Students will become familiar with operating the anemometer alongside a conventional floor fan in order to learn how to correctly measure wind speed for subsequent WindPitch wind turbine experiments.

EXPERIMENT OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will understand how to setup and calibrate the anemometer
- Students will understand how to correctly place the anemometer in front of a floor fan in order to measure the wind speed in meters-per-second.

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>

La Crosse model EA-3010U - Features

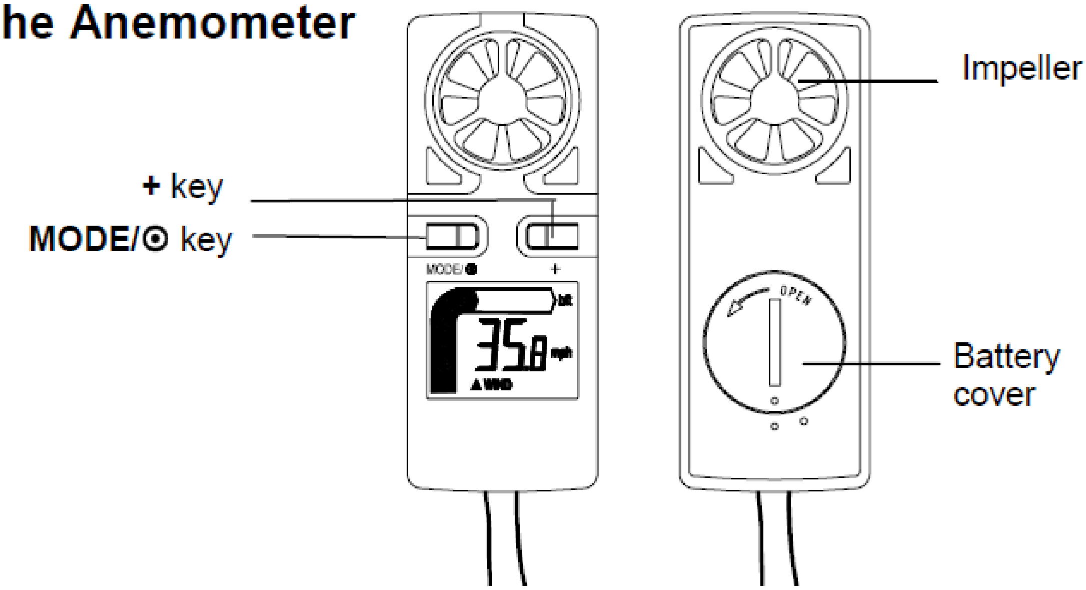
- Wind Speed (mph, km/h, m/s, knots)
- Displays MAX & Average
- Wind Speed Since Power On
- Beaufort Scale Bar Graph (0-12)
- Wind Chill (°F or °C)
- Temperature (°F or °C)
- Backlight with Auto Off
- Battery Saving Auto Off
- Neck Band Included for Easy Carrying

La Crosse model EA-3010U - Specifications

- Maximum measured speed: 67 mph
- Minimum measured speed: 0.44 mph
- Resolution-wind speed: 0.1 for all units
- Temperature measuring range: -21.8 to 138.2 °F (-29.9 to 59 °C)
- Resolution-temperature: 0.2°F (0.1°C)
- Power requirements: 1 CR2032 button cell

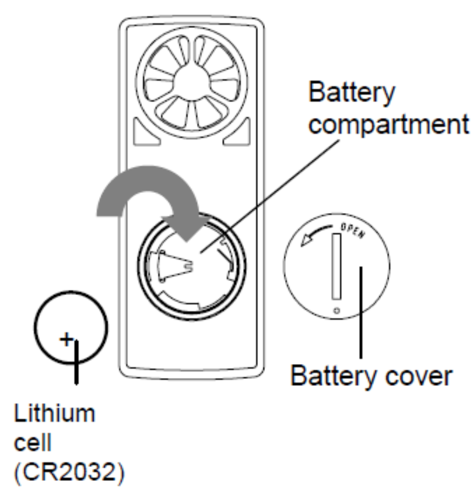
PARTS OF THE INSTRUMENT

The Anemometer



SETTING UP THE INSTURMENT

1. First use a large coin to open the battery cover at the back of the anemometer as indicated above.
2. Checking the correct polarization, insert 1 x 3V (CR2032) lithium cell, positive (+) pole up into the battery compartment and replace the cover.
3. When the battery is inserted, all the segments of the LCD and backlight will light up briefly.



Your anemometer is now operational.

Note:

After inserting the battery, test the anemometer by blowing directly at the Impeller for about 30 seconds. The reading on the LCD should change. If this does not happen remove the battery, wait for 30 seconds, and re-insert the battery.

POWER AND MANUAL SETTINGS

Power ON/OFF:

Press and hold down the **"MODE/⊙"** key for 4 seconds to switch the unit ON or OFF.

Note:

The anemometer is automatically switched OFF when no key is pressed in 34 minutes.

Manual setting

Note:

Before entering the manual setting mode switch off the anemometer. Press and hold down the **"MODE/⊙"** key for about 6 seconds, the speed unit will start flashing on the right side of the LCD when the manual setting mode is entered.

FUNCTION KEYS

The anemometer uses the following keys:

MODE/⊙ key: To toggle between wind speed and temperature/wind chill display
: Power ON/OFF
: To enter the setting mode
: To turn the backlight On

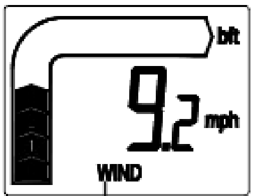
+ Key : To change operation mode
: To change parameters in setting mode
: To turn the backlight On

MEASUREMENT SCALE SETTING

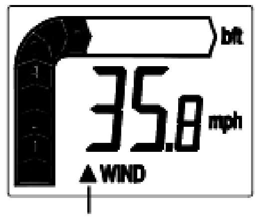
1. After entering the manual setting mode, press **"+"** key to set the measurement scale in Km/h (Kilometers per hour), mph (miles per hour), m/s (meters per seconds) or Kts (Knots).
2. Now press the **"MODE/⊙"** key to confirm and enter the "**°C and °F setting**".

WIND SPEED MODE

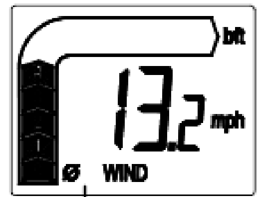
The wind speed mode can be selected to 3 different display modes at any time.



Current wind speed



Maximum wind speed
Since power on



Average wind speed
Since power on

To toggle between current wind speed, maximum wind speed and average wind speed, simply press the **"+"** key:

Beaufort wind scale (bft)

The Beaufort scale is displayed in bar graph (0-12). This is a system for estimating wind force without the use of instruments based on the visible effects of the wind on the physical environment.

Force	Description	Kts	m/s	Km/h	mph
0	Calm	0	0	0	0
1	Light Air	1	0.5	1.8	1.1
2	Light Breeze	4	2.1	7.4	4.6
3	Gentle Breeze	7	3.6	13.0	8.1
4	Moderate Breeze	11	5.7	20.4	12.7
5	Fresh Breeze	17	8.8	31.5	19.6
6	Strong Breeze	22	11.3	40.8	25.4
7	Near Gale	28	14.4	51.8	32.3
8	Gale	34	17.5	63.0	39.2
9	Strong Gale	41	21.1	75.9	47.2
10	Storm	48	24.7	88.9	55.3
11	Violent Storm	56	28.8	103.7	64.5
12	Hurricane	64	32.9	118.5	73.7

WIND SPEED AVERAGING TIMES

The current wind speed can be measured in average wind speed in a time interval of 2-10 seconds

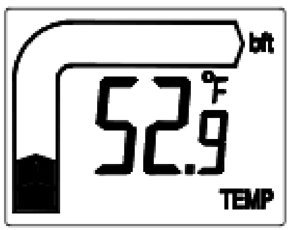
1. Following from the °C and °F Setting, press "+" key to set the desired average time. The range runs from 2 to 10 seconds.
2. Once the desired average time has been chosen, press the **"MODE/⊙"** key to confirm and back to the normal mode.

CENTEGRADE / FARENHEIT SETTINGS

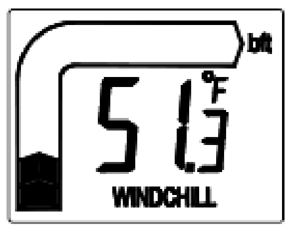
1. Following from the measurement scale Setting °C will be flashing, use the "+" key to toggle °C and °F.
2. Once the desired temperature unit has been chosen, press the **"MODE/⊙"** key to confirm and enter the "**Average time for current speed measurement setting**".

TEMPERATURE MODE

The temperature/ wind chill modes can be selected to 2 different display modes at any time.



Temperature



Wind chill

By pressing the **"+"** key the display will toggle between temperature and wind chill.

Note:

When the temperature is outside the range from –29°C to +59°C, there will be no wind chill measurement.

Wind chill

The anemometer calculates automatically wind chill, which can provide useful information for preparing outdoor activities in cold weather. "Wind chill" provides an indication of how cold it feels given the combined effects of the actual air temperature and the wind speed.

LCD BACKLIGHT

The LCD backlight is automatically switched ON when any one of the 2 function keys are pressed and held down for 2 seconds. The backlight will be switched on for approximately 8 seconds before automatically switching OFF.

EQUIPMENT

- La Crosse model EA-3010U handheld anemometer
- Large 16" to 20" floor fan with 3 way speed control

EXPERIMENT SETUP

Setup the floor fan in an area where it will ultimately be used to provide wind for the WindPitch wind turbine.

DOING THE EXPERIMENT

1. Turn the instrument ON by pushing and holding the **MODE** button for 4 seconds. Release the **MODE** button after turn ON.

2. Set the instrument into Manual Mode by holding the **MODE** button for 6 seconds. You will see a flashing group of letter on the right.

3. Push the Plus (+) key until the **m/s** is displayed then release the MODE button. The display will default to measuring wind speed in meters per second (m/s) in about 6 seconds.

4. Blow on the impeller mechanism for a few seconds and verify that the display indicates wind speed measured in meters per second. The last wind speed reading will remain on the screen until the next reading is taken.

The bar graph on the left side of the LCD that moves up and to the right is the Beaufort Wind Scale reading (bft). It shows in relative terms the general nature of the wind speed based on generalized weather conditions.

The actual wind speed number and the Beaufort numbers are different. For example, a wind speed of 5.8 m/s will generate a bft of 4. Refer to the Table above for wind speed and bft ranges.

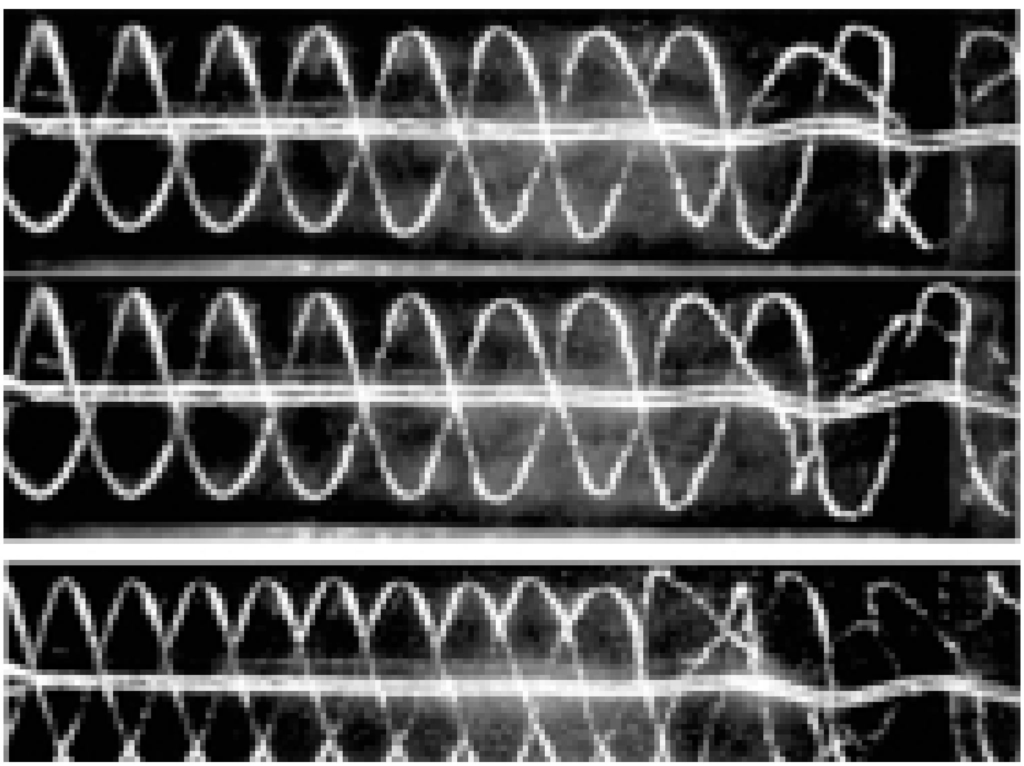
5. Turn the floor fan ON to the highest speed setting.

6. Place the anemometer's impeller at various points in front of the moving air from the fan – left, right and middle – and note the readings you obtain.

7. Place the anemometer's impeller closer to and away from the moving air and note the reading you obtain.

8. Find the spot where you obtain the highest wind speed and note that position as the spot to place the WindPitch wind turbine in subsequent experiments.

The wind pattern out of a standard floor or table fan is not laminar meaning that it is not smooth. In fact, the fan blades act like a boat propeller and create a circular wake of air that is delivered from the front of the fan to the wind turbine. It looks something like the patterns in the illustration below. This is why you need to find the correct spot to place the WindPitch wind turbine in order to "catch" the best "wind wave".



Preliminary Experiment - Measuring RPM

EXPERIMENT OVERVIEW

This experiment demonstrates the proper technique for measuring WindPitch blade revolutions per minute (RPM) using the General Technologies model TA105 infrared laser tachometer.

Students will become familiar with operating the tachometer along with the WindPitch wind turbine and floor fan in order to learn how to correctly measure RPM for subsequent WindPitch wind turbine experiments.

EXPERIMENT OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will understand how to setup and use the laser tachometer to measure RPM.
- Students will understand how to correctly orient the tachometer in front of the WindPitch in order to measure RPM.

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!

Wear safety glasses for all experiments

General Technologies TA105 Features

The TA105 Laser Tachometer and counter can be used to measure the number of rotations per minute (RPM) or total number of rotations or events on any spinning shaft, pulley, wheel, drive belt, fan, or other rotating objects in general - safely, accurately and easily.

Wide measuring range: 2.5 to 99,999 RPM, 2" to 20" reading distance, Min/max and last reading memory recall, <0.5 sec. response time, count function and auto power off.

- Bright and powerful laser optical system allows for easy targeting of rotating shafts, wheels, pulleys, etc., even in bright daylight.
- Measurements can be obtained from safe and comfortable distances between 2 to 20 inches
- The large 5 digits display allows measurements without the need to switch scales or multiply reading ranges
- Comes complete with batteries, reflective tape and soft carrying pouch

Easy To Operate

- Aim the laser beam at reflective tape placed on rotating shafts, pulleys, wheels or objects, depress the switch and read instant RPM displayed on the LCD
- High intensity laser beam not affected by shop or ambient light
- RPM range from 2.5 to 99,999
- 5 Digit Large LCD display
- Auto Ranging
- 0.5 Second sampling time
- Memory recall: Max, Min, Last value
- TOT: Total revolution count
- Resolution: 0.1RPM<1000 RPM, 1.0 RPM>1000 RPM

General Specifications

Display: 5 digits 0.7″ (16mm) LCD, Max. of 99999 display, with measuring unit indicator and Laser On Target indicator

Resolution: ±(0.05%+1 Digit)

Operating Temperature: 32°F to 122°F (0°C to 50°C)

Response time: 0.5 sec. (over 120 RPM)

Range Selection: Auto Ranging

Memory: Max. Value, Min. Value and Last Value stored automatically in memory

Distance to target: 2″ to 20″ (50 mm to 500 mm)

Laser Pointer: Laser Diode, < 1mW output wavelength 630-670 nm, Class II

Power Source: 4 x 1.5 V type AA/UM3 or equivalent

Battery life: Approx. 5 hours.(w/alkaline batteries)

Dimensions: 6.3″x 2.8″x 1.5″ (160 x 72x 37 mm)

Weight: 6.96 oz. (200 g) with battery.

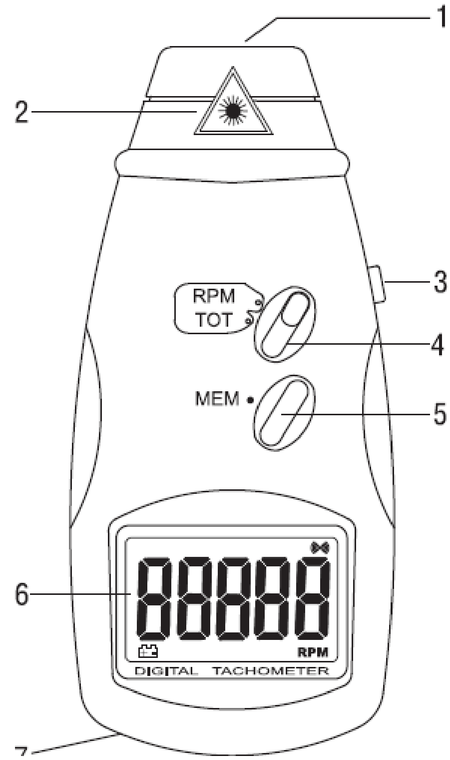
Measurement Specifications

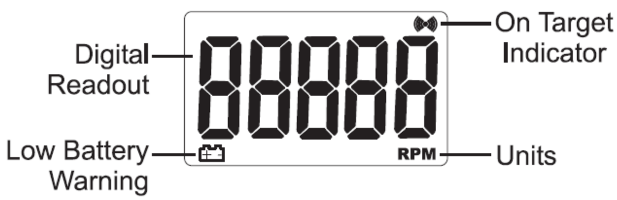
Accuracies are ±(% of reading + number of least significant digits) at 23°C ±5°C ambient temperature, with less than 75% RH.

Function	Range	Acuracy	Resolution
RPM	2.5 to 999.9 RPM	±(0.05%+1 Digit)	0.1 RPM
	1000 to 99,999 RPM		1 RPM
TOT (total revolutions)	1 to 99,999 RPM	±(0.05%+1 Digit)	1 RPM

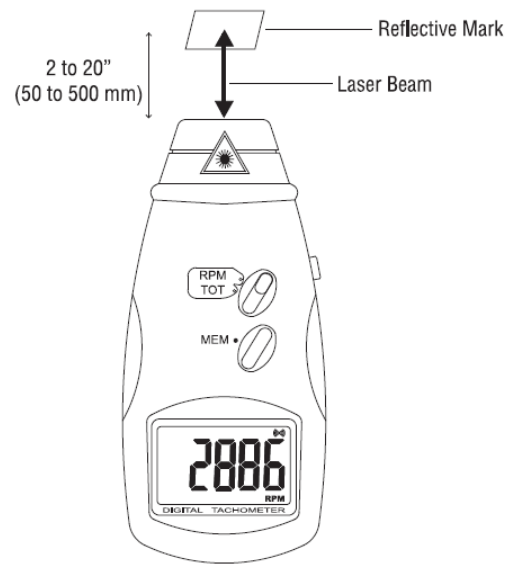
Instrument Description

1) Laser output
2) Laser warning symbol
3) Measurement button
4) Function switch
5) Memory button
6) Digital display
7) Battery compartment cover





General RPM Measurement Techniques



Cut a 1/2" length of the reflective tape and peel off the back to expose the adhesive.

Attach it to the rotating part or shaft to measure, observing the following recommendations:

- The non-reflective area must always be smaller than the reflective piece of tape.
- If the object or shaft to measure is reflective, it must first be covered with a black tape or painted black before attaching the reflective tape.

Apply a reflective mark or a piece of reflective tape to the rotating object under measurement. Before applying the tape verify that the surface is clean and smooth.

Slide the RPM-TOT function switch to the "RPM" position

Press the measurement button and aim the light beam to the reflective mark or tape on the rotating object.

Verify that the "On Target Indicator" appears on the display, indicating that the instrument is detecting the rotation of the object and the reflective mark on it.

Proceed to read the RPM on the digital display.

Display Hold

The instrument will automatically hold the last reading immediately after the "On Target Indicator" on the display turns off, and hold it while the "Measurement button" is pressed.

MEM function

In every measuring cycle (pressing the measuring button, obtaining a reading, and then releasing the button), the instrument will automatically store in its internal memory the Maximum, Minimum and Last value. To retrieve the values in memory follow the procedure described below:

- With the instrument off press and hold down the "MEM" button to display the Maximum value stored in memory. Display screens will alternate between "UP" (maximum) and the stored maximum reading. Note the value and release the "MEM" button.
- Pressing and holding again the "MEM" button will display the Minimum value stored in memory. Display screens will alternate between "dn" (minimum) and the stored minimum reading. Note the value and release the "MEM" button.
- Pressing and holding again the "MEM" button will display the last reading value stored in memory. Display screens will alternate between "LA" (Last reading) and the stored last reading value. Note the value and release the "MEM" button.

This memory retrieval cycle will keep repeating in the order detailed above.

Note: The values stored in memory will be retained until a new measurement cycle is performed. Removing the batteries or low batteries will cause all values stored in memory to be erased.

TOT (Total revolutions)

- Apply a reflective mark or a piece of reflective tape to the rotating object under measurement.
- Slide the function switch to the "TOT" position
- Press the measurement button and aim the light beam to the reflective mark or tape on the rotating object.
- Verify that the "On Target Indicator" appears on the display, indicating that the instrument is detecting the rotation of the object and the reflective mark on it.
- Proceed to read the total revolutions on the digital display.

EQUIPMENT

- General Technologies TA105 handheld tachometer
- Large 16" to 20" floor fan with 3 way speed control
- WindPitch wind turbine

EXPERIMENT SETUP

Setup the floor fan with the WindPitch in front of it per the photo below.

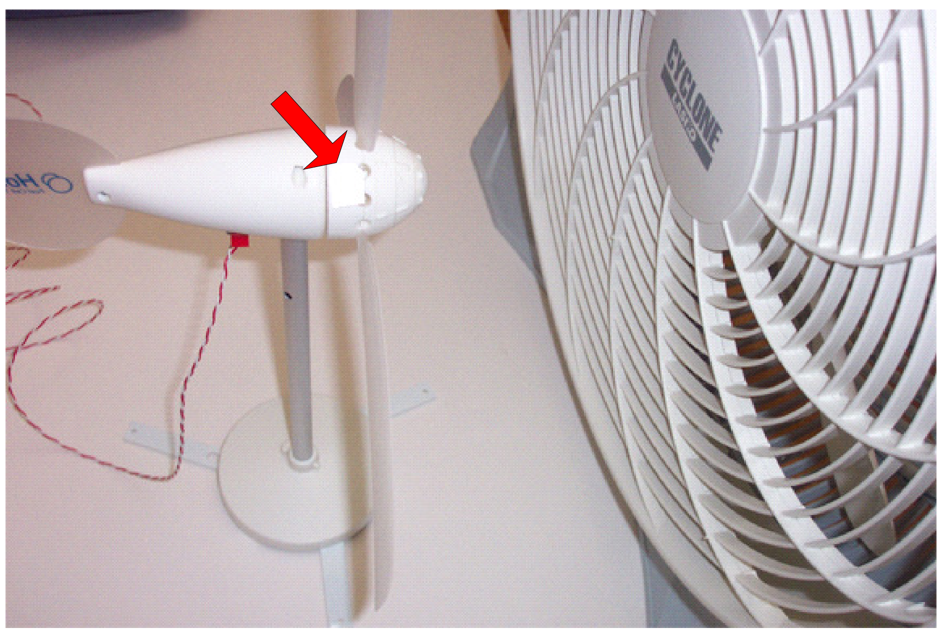
DOING THE EXPERIMENT

1. Set the table or floor fan as close as possible to the wind turbine blades. **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.**

2. Cut a ½" square section of reflective tape and apply it to the side of the WindPitch blade hub just behind the blades.

3. Set the fan to the highest speed setting.

4. On the tachometer set the RPM / TOT button to RPM.



5. Aim the tachometer at the reflective tape and push the square Measurement Button on the side. A red dot will appear on the rotating hub and RPM reading should appear on the display.

6. Test the validity of the RPM reading by changing the fan speed (faster and slower) to see the RPM readings change.

WindPitch Wind Turbine Experiment-
Voltage, Wind Speed and RPM

EXPERIMENT OVERVIEW

This experiment is designed to show the relationship among wind speed, blade revolutions per minute (RPM) and the wind turbine's voltage output at three different fan speeds – fast, medium and slow.

EXPERIMENT OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will learn about the relationship between wind speed, blade RPM and output voltage.
- Students will be shown how to manually plot wind speed against voltage and RPM in graph form.

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!

Wear safety glasses for all experiments

PREREQUISITES

- Be familiar with the operation of the La Crosse anemometer.
- Be familiar with the operation of the General Technologies tachometer.
- 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)
- General Technologies model TA105 infrared laser tachometer
- La Crosse model EA-3010U handheld anemometer.
- Printer

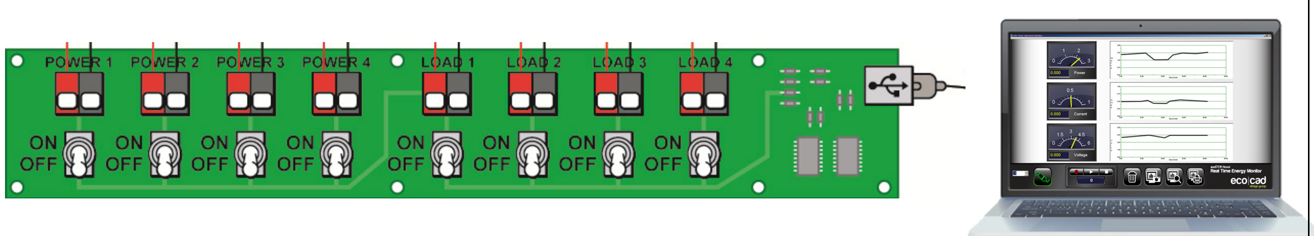
EXPERIMENT SETUP

- Setup the floor fan with the WindPitch in front of it.

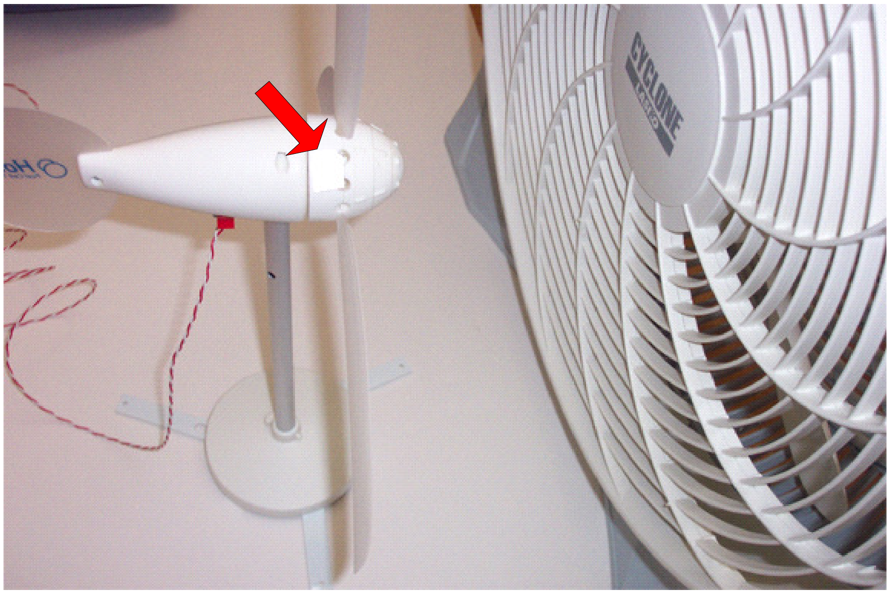
- Adjust the La Crosse anemometer to measure wind speed in meters per second (m/s). Refer to a previous experiment for information.

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

- 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



1. Set the table or floor fan as close as possible to the wind turbine blades. **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.**

2. Cut a ½" square section of reflective tape and apply it to the side of the WindPitch blade hub just behind the blades.

Fast Speed

3. Switch ON the wind turbine (**Power 1**).
4. Set the fan to its highest speed setting.
5. Clear the computer screen by clicking on the Trash can icon.
6. Click the Screen Capture icon to record the voltage reading.
7. Measure and record the wind speed in meters/second.
8. On the tachometer set the RPM / TOT button to RPM.
9. Aim the tachometer at the reflective tape and push the Measurement Button on the side. A red dot will appear on the rotating hub and RPM reading should appear on the display.
10. Measure and record the RPM.

Medium Speed

11. Switch ON the wind turbine (**Power 1**).
12. Set the fan to the medium speed setting.
13. Clear the computer screen by clicking on the Trash can icon.
14. Click the Screen Capture icon to record the voltage reading.
15. Measure and record the wind speed in meters/second.
16. On the tachometer set the RPM / TOT button to RPM.
17. Aim the tachometer at the reflective tape and push the Measurement Button on the side. A red dot will appear on the rotating hub and RPM reading should appear on the display.
18. Measure and record the RPM.

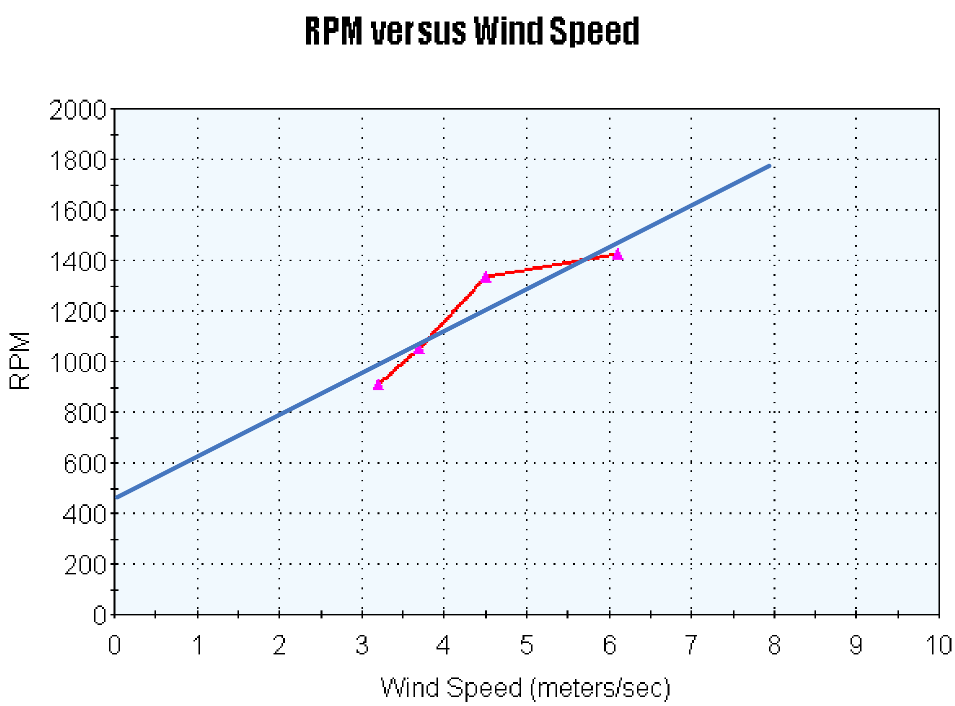
Slow Speed

19. Switch ON the wind turbine (**Power 1**).
20. Set the fan to the slow speed setting.
21. Clear the computer screen by clicking on the Trash can icon.
22. Click the Screen Capture icon to record the voltage reading.
23. Measure and record the wind speed in meters/second.
24. On the tachometer set the RPM / TOT button to RPM.
25. Aim the tachometer at the reflective tape and push the Measurement Button on the side. A red dot will appear on the rotating hub and RPM reading should appear on the display.
26. Measure and record the RPM.
27. Turn off the fan.

Analysis

Based on the collected data the following table was constructed so that corresponding graphs can be generated from it – your data will be similar but different.

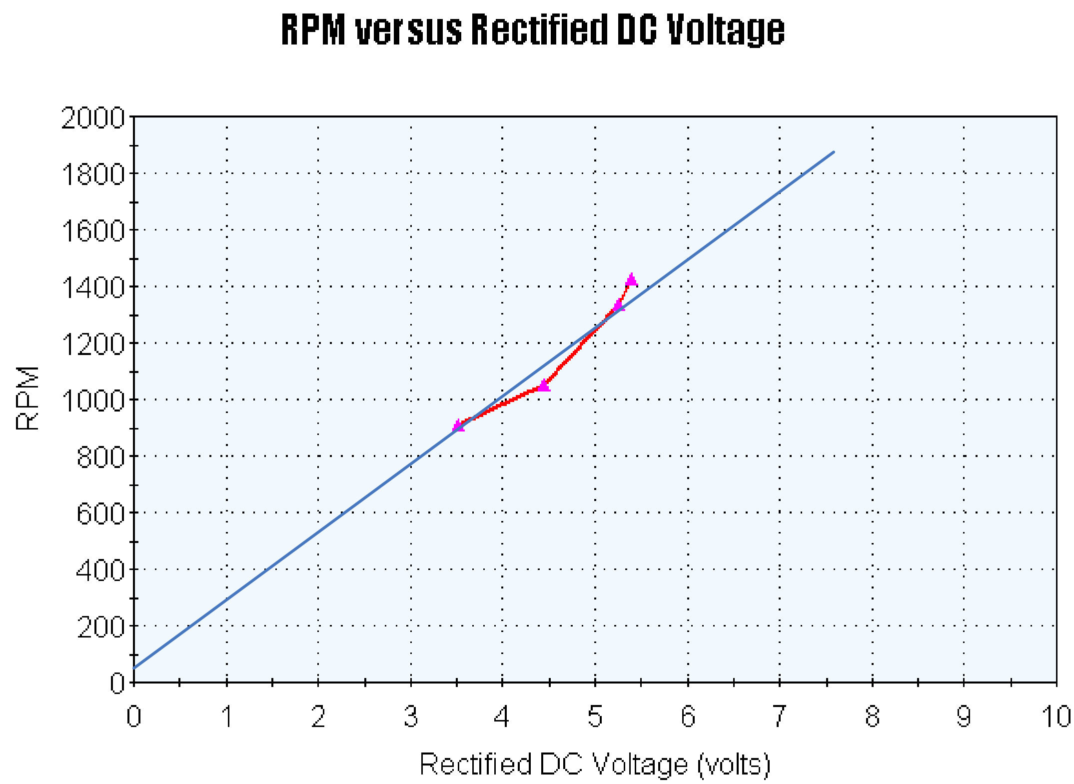
Wind Speed (meters/sec)	RPM	Voltage
6.1	1428	5.391
4.5	1333	5.254
3.7	1052	4.444



As can be seen by the graph the relationship between wind speed and RPM can form a trend line (blue) when the wind is blowing at a reasonable rate of speed, which means that a linear equation can be developed to convert RPM into wind speed as in:

Y = mx + b where **Y** is the RPM value (Y axis)
m is the slope of the line
x is the wind speed (X axis)
b is the RPM value where it intersects the Y axis where the value of wind speed (x) is zero

The same can be done with respect to RPM versus rectified DC voltage by substituting voltage for wind in the x axis.



Certain approximations for wind speed versus RPM as well as RPM versus DC rectified voltage were made to form these graphs. These assumptions **may not** extend well to lower or higher wind speeds; however, the analysis was done in order to approximate the wind turbine's voltage outputs under the measured wind speeds and RPM, and to show how it can be done.

Listed below are two websites that can help explain the above equations in more detail:

http://id.mind.net/~zona/mmts/functionInstitute/linearFunctions/lsif.html

http://www.math.com/school/subject2/lessons/S2U4L2GL.html

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!

Wear safety glasses for all experiments

PREREQUISITES

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

EQUIPMENT

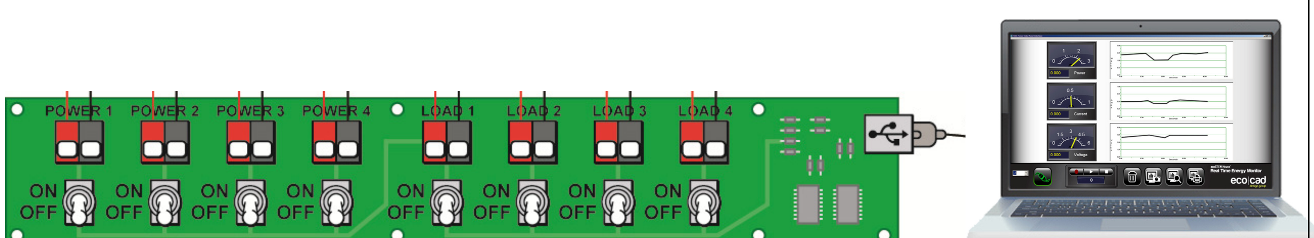
- Control Panel
- Computer running the ecoCAD Real Time Energy Monitoring software
- WindPitch wind turbine with 3 BP-28 profile blades
- Student built flat or profiled blades where available
- Large Table or Floor Fan (at least 16" in diameter with 3 speeds)
- Two (2) 100 ohm fixed resistors
- Printer

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?

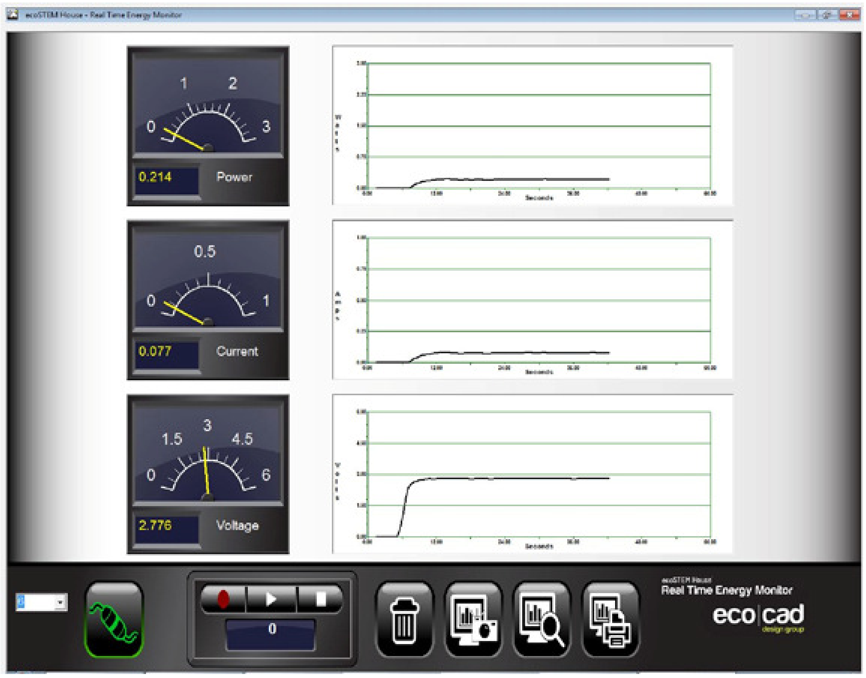
   2
   3
   4
   6

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

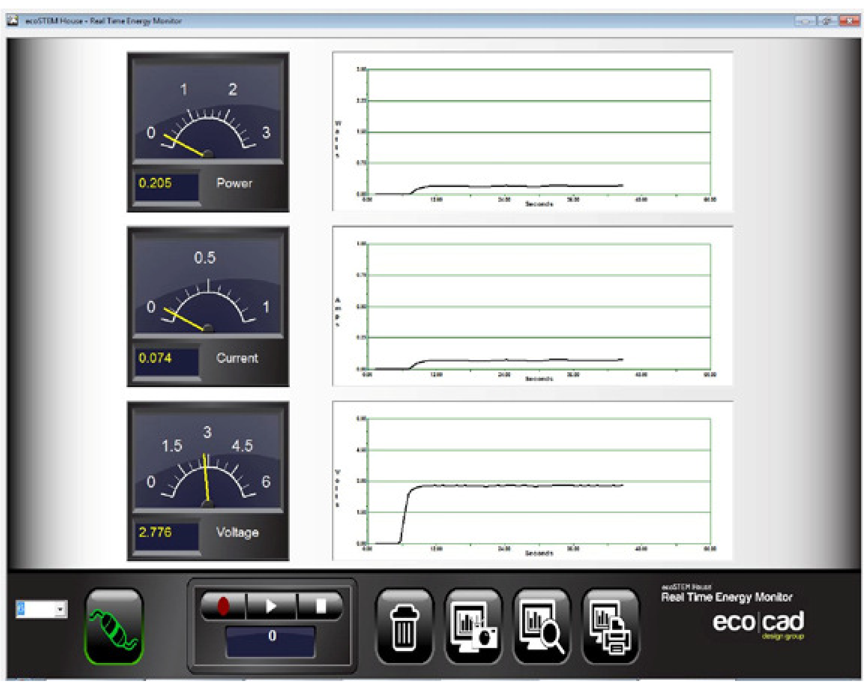
4. Did your expectation prove correct or incorrect? Explain why in either case.

TEACHER NOTES - ANALYZING THE RESULTS

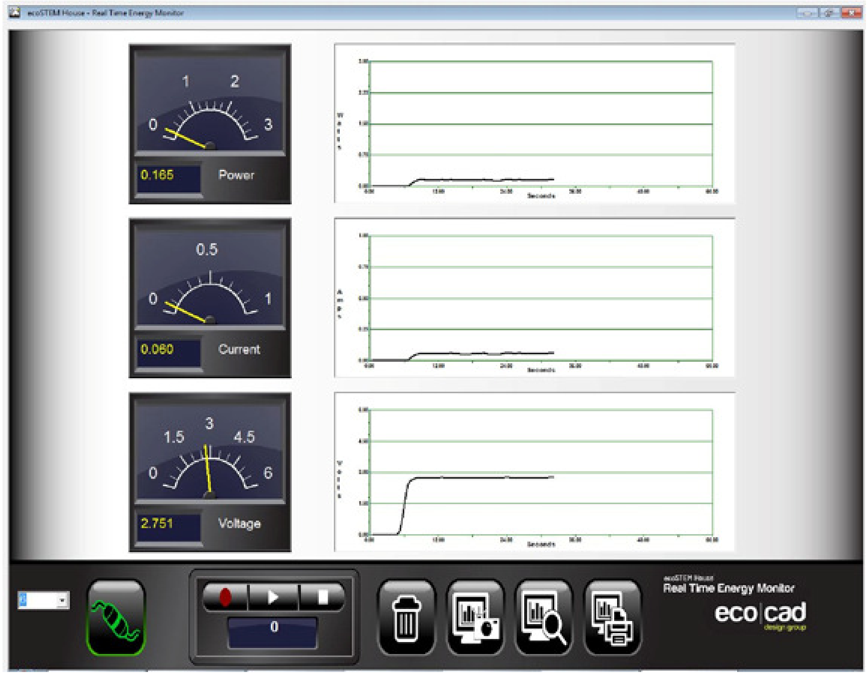
1. First, have the students print out the four (4) screen captures they took in steps 7, 12, 17, 22. Here are our results – your exact results will vary.



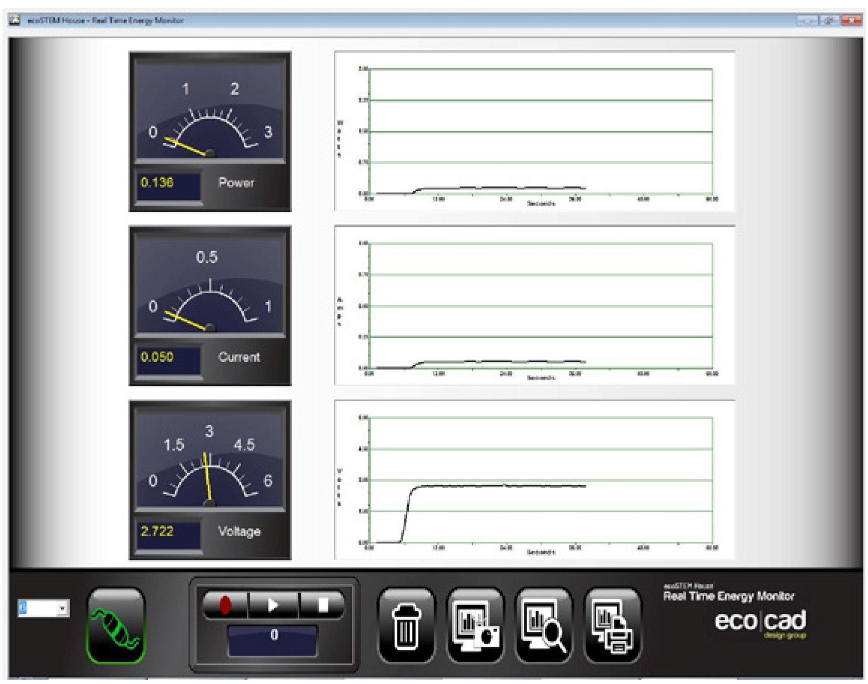
Step 7 2 Blades Power = 0.214 watts



Step 12 3 Blades Power = 0.205 watts



Step 17 4 Blades Power = 0.165 watts



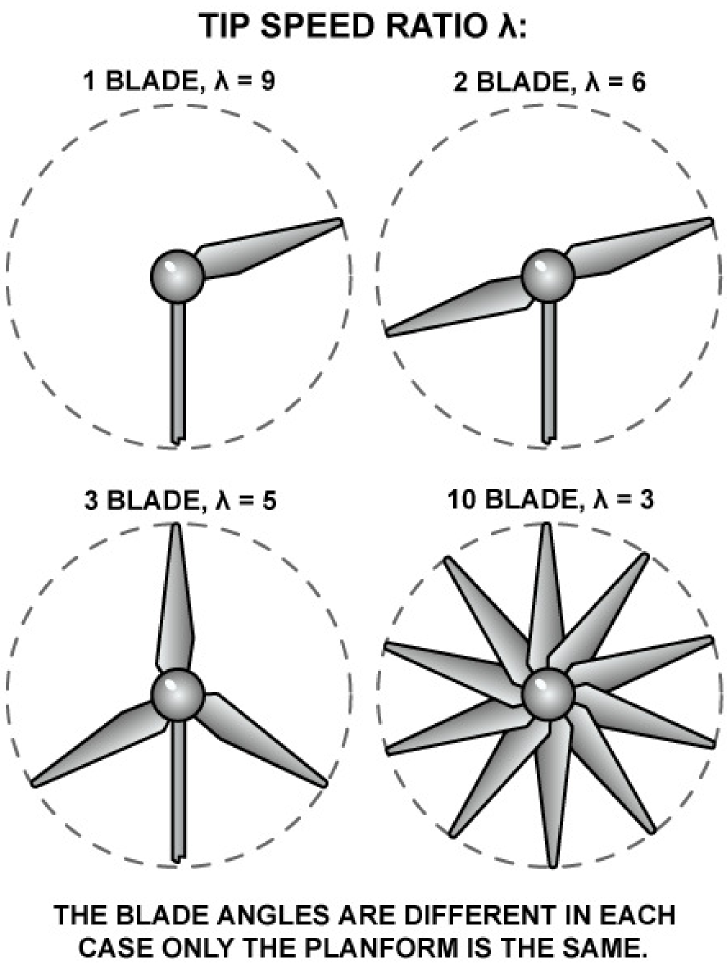
Step 22 6 Blades Power = 0.136 watts

- 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.

WindPitch Wind Turbine Experiment-Adjusting Blade Pitch

EXPERIMENT OVERVIEW

Adjusting the blade pitch for a given wind speed and load is critical to the wind turbine's power output. In this experiment students adjust a group of three blades in triangular pattern at three different blade angles (pitch) to measure the wind turbine's electrical output power at each pitch setting.

EXPERIMENT OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will learn about how blade pitch alone produces different power outputs from the wind turbine.
- Students will come to understand that increasing blade pitch using only one fan speed and one resistive load may decrease the wind turbine's power output.

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!

Wear safety glasses for all experiments

PREREQUISITES

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

EQUIPMENT

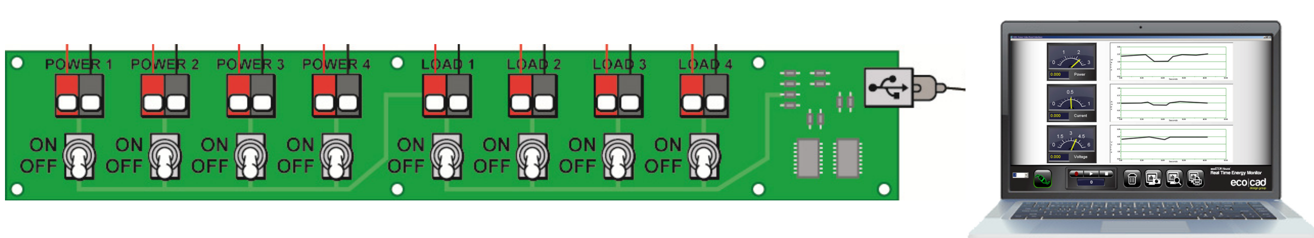
- Control Panel
- Computer running the ecoCAD Real Time Energy Monitoring software
- WindPitch wind turbine with 3 BP-28 profile blades
- Student built flat or profiled blades where available
- Large Table or Floor Fan (at least 16" in diameter with 3 speeds)
- Two (2) 100 ohm fixed resistors
- Printer

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

15°

1. Setup the WindPitch wind turbine with two (3) BP-28 blades.

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 variable resistor.

8. Stop the fan.

30°

9. Adjust the blade pitch angle to 30°.

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. Set the fan to its highest_speed setting.

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

13. Click the Screen Capture icon to record the voltage, current and power being consumed by the variable resistor.

14. Readjust the variable resistor to full resistance (full clockwise).

15. Stop the fan.

45°

16. Adjust the blade pitch angle to 45°.

17. 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.

18. Set the fan to its highest speed setting.

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

20. Click the Screen Capture icon to record the voltage, current and power being consumed by the variable resistor.

21. Readjust the variable resistor to full resistance (full clockwise).

22. Stop the fan.

Repeat the entire experiment with custom blades of your own.

STUDENT EXERCISES

1. Which blade pitch angle produced the most power?

   15^0
   30^0
   45^0

2. Which blade pitch angle produced the least power?

   15^0
   30^0
   45^0

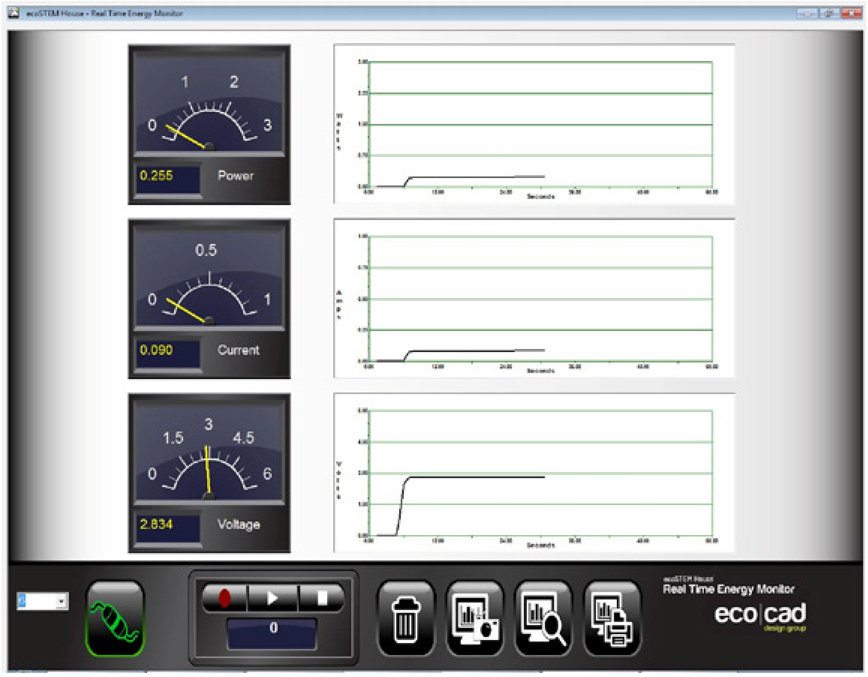
3. At what blade pitch setting did you expect to see the most power produced? Explain your answer.

4. At what blade pitch setting did you expect to see the least power produced? Explain your answer.

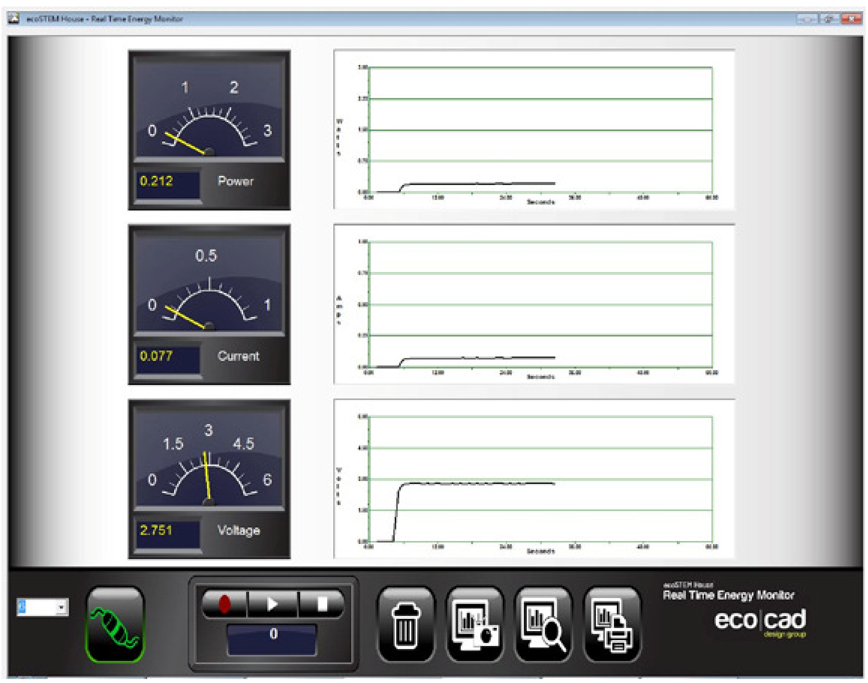
5. Would changing the fan wind speed affect the results differently? Explain why you think it would or would not.

TEACHER NOTES - ANALYZING THE RESULTS

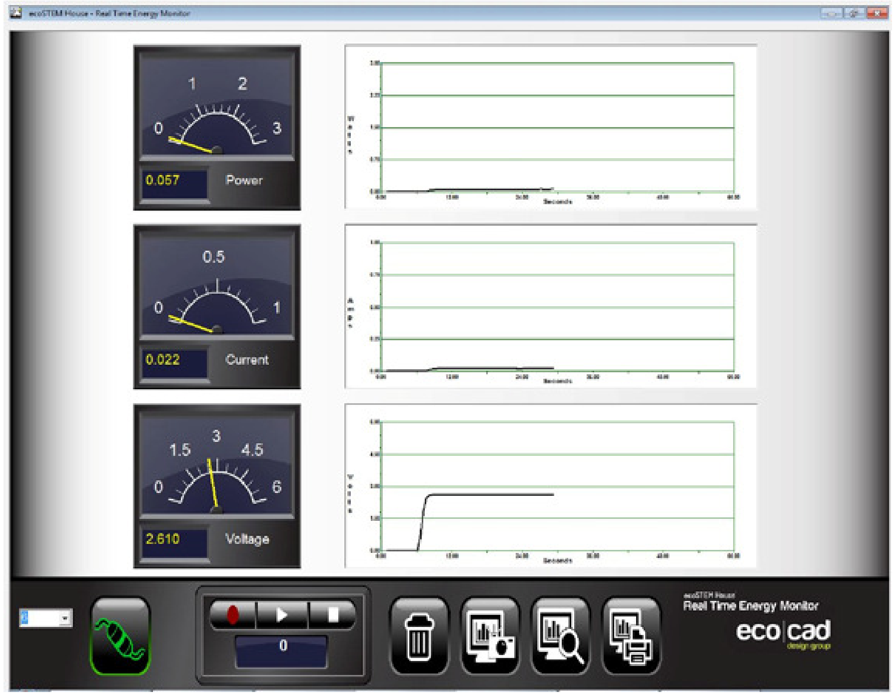
1. First, have the students print out the three (3) screen captures they did in steps 7, 13 and 20. Here are our results – your exact results will vary.



Step 7 Blade Pitch = 15° Power = 0.255 watts



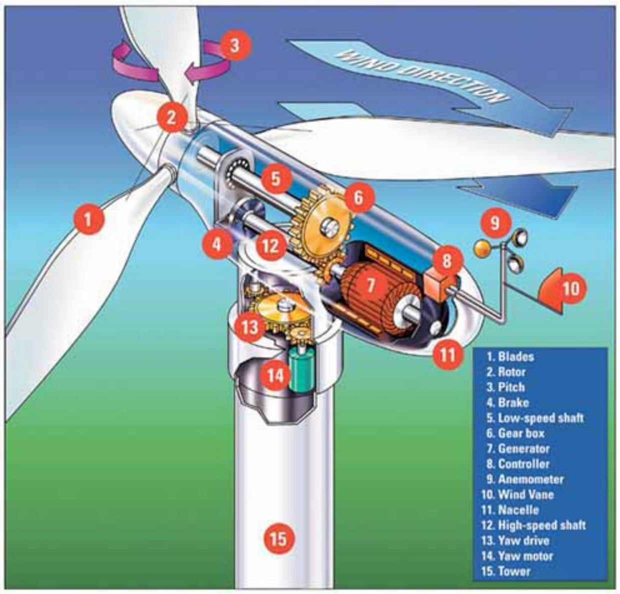
Step 13 Blade Pitch = 30° Power = 0.212 watts



Step 20 Blade Pitch = 45° Power = 0.057 watts

- Explain to the students that increasing the blade pitch angle is really like trying to "grab" more air.
- When the fan speed is set to its highest setting, increasing the pitch angle only creates more resistance for the blades to turn. This is because the wider blade pitch is churning up the fast moving air creating more turbulence at greater pitch angles, which causes the blades to loose lift and slow down.
- This is why the power drops off as the blade angle is increased, because more turbulence is created. If the students don't understand the concept of turbulence or lift, have them look it up on the Internet. Look for the Bernoulli Principle that describes both.
- A larger blade pitch works better (produces more power) when the wind is slower. This allows the blades to capture more air without as much turbulence.
- Suggest doing the experiment over again, but this time with the fan speed set at medium and low speeds. The results may change significantly.

Understanding the Wind Power Equation



EXPERIMENT OVERVIEW

This is not an experiment but rather an explanation of the wind power equation.

In preparation to perform the Power and Efficiency experiment, students will become familiar with the wind power equation and how wind speed, blade area and other factors influence the electrical power output of the WindPitch wind turbine.

EXPERIMENT OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will understand the primary elements of the wind power equation.

THE WIND POWER EQUATION

The wind power equation is expressed as follows:

$P = 0.5*\rho*A*V^3*E$

Where:

P = Power in Watts
ρ= Air Density in Kg/m^3 (about $1.225 Kg/m^3$ at sea level, less higher up)
A = Rotor Swept Area in $m^2 = \pi r^2$ (r= radius or blade length)
V = Wind Speed in m/s (cubed)
E = Efficiency in percent

The following is a general explanation of each variable and what it means to the output power from any given wind turbine.

- **P** The symbol "P" stands for electrical power in watts. This is measured by the electronics on the Control Panel and displayed on the PC software.

- **0.5** After the equal (=) sign the "0.5" value is a close approximation of the Betz Limit, which implies that the maximum amount of power that can be derived from the wind amounts to about one-half of the power in the wind itself. Refer to the following page for more information on the Betz Limit.

- **ρ** The lower case Greek symbol rho (ρ) represents the air density in kilograms per meter squared (Kg/m^2). While it is a minor contributor to the overall wind power level it can make a significant difference if the wind turbine is at a very high altitude like on a mountain peak where the air density is low. Refer to the next page for a convenient means to determine air density.

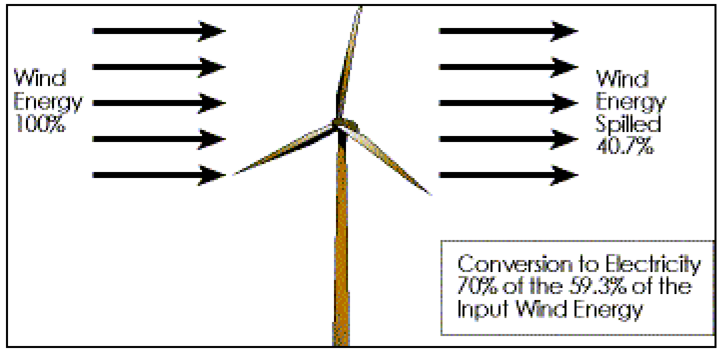
- **A** The rotor swept blade area is a significant contributor to wind turbine power production. As the equation indicates the power (P) varies as the square of the swept area. This means that doubling the amount of swept area will (theoretically) quadruple (P x 4) the output power. Conversely, halving the rotor swept blade area will reduce the output power to one-forth (P / 4).

It should be mentioned that the rotor swept blade area DOES NOT mean increasing the number of blades. It only means the circular area that is swept by the rotating blades themselves – be it 2, 3, 4, 6 or even 1 blade.

- **V** The wind speed itself determines a large part of the power production. As the equation indicates the power (P) varies as the cube of the wind speed. This means that doubling the wind speed will (theoretically) multiply the power by eight times (P x 8). Conversely, halving the wind speed will reduce the power output to one-eight (P/8) of the previous wind speed value.

- **E** Wind turbine efficiency is expressed by the symbol E. Efficiency can be expressed as a multitude of sub-variables that are beyond the scope of this writing; however, it can take in things like blade design, wind resistance and turbulence, wind turbine tower height, wind flow around the blades and tower and other factors some of which are explained next along with the Betz Limit.

BETZ LIMIT



Albert Betz was a German physicist who in 1919 concluded that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. To this day this is known as the **Betz Limit** or **Betz' Law**. This limit has nothing to do with inefficiencies in the generator, but in the very nature of **wind turbines** themselves.

Wind turbines extract energy by slowing down the wind. For a wind turbine to be 100% efficient it would need to stop 100% of the wind - but then the rotor would have to be a solid disk and it would not turn and no kinetic energy would be converted. On the other extreme, if you had a wind turbine with just one rotor blade, most of the wind passing through the area swept by the turbine blade would miss the blade completely and so most of the kinetic energy would remain with the wind and not be transferred to the wind turbine's electrical generator.

REAL WORLD WIND TURBINE EFFICIENCIES

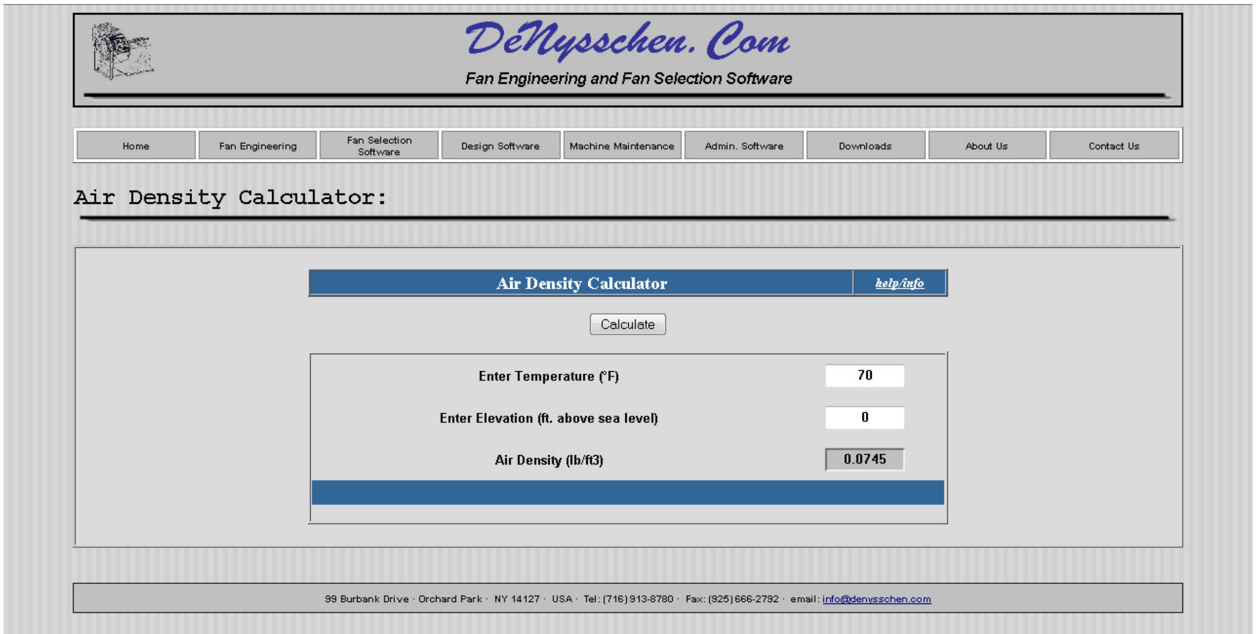
According to the Betz Limit the theoretical maximum **power efficiency** of *any* design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). Once you also factor in the engineering requirements of a wind turbine - strength and durability in particular - the real world limit is well below the Betz Limit with values of 0.35-0.45 common even in the best designed wind turbines.

By the time other ineffiencies in a complete wind turbine system are taken into account - e.g. the generator, bearings, power transmission and so on - only 10-30% of the power of the wind is ever actually converted into usable electricity. (see the graphic above from the Iowa Energy Center, USA.)

Horizontal axis wind turbines (**HAWT**) theoretically have higher power efficiencies than vertical axis wind turbines (**VAWT**) however wind direction is not important for a VAWT and so no time (or power) is wasted *"chasing"* the wind. In turbulent conditions with rapid changes in wind direction more electricity will be generated by a VAWT despite its lower efficiency.

DETERMINING AIR DENSITY

Here's a website to compute air density at your altitude and temperature
http://www.denysschen.com/catalogue/density.asp



WindPitch Wind Turbine Experiment-
Output Power and Efficiency

EXPERIMENT OVERVIEW

This experiment will determine the efficiency factor (E) of the WindPitch wind turbine based on wind speed and RPM using both a 100 ohm and 50 ohm load.

EXPERIMENT OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will learn about how blade pitch alone produces different power outputs from the wind turbine.
- Students will come to understand that increasing blade pitch using only one fan speed and one resistive load may decrease the wind turbine's power output.

WIND POWER EQUATION PREREQUISITE

Students must be familiar with the Wind Power Equation that precedes this experiment.

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!

Wear safety glasses for all experiments

PREREQUISITES

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

EQUIPMENT

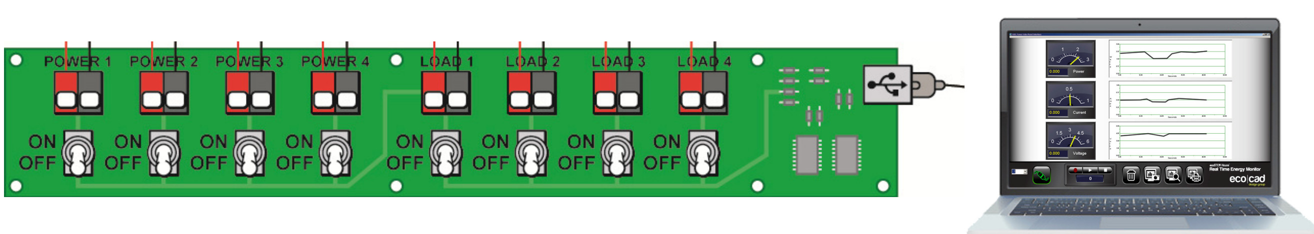
- Control Panel
- Computer running the ecoCAD Real Time Energy Monitoring software
- WindPitch wind turbine with 3 BP-28 profile blades
- Student built flat or profiled blades where available
- Large Table or Floor Fan (at least 16" in diameter with 3 speeds)
- General Technologies model TA105 infrared laser tachometer
- La Crosse model EA-3010U handheld anemometer.
- 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.

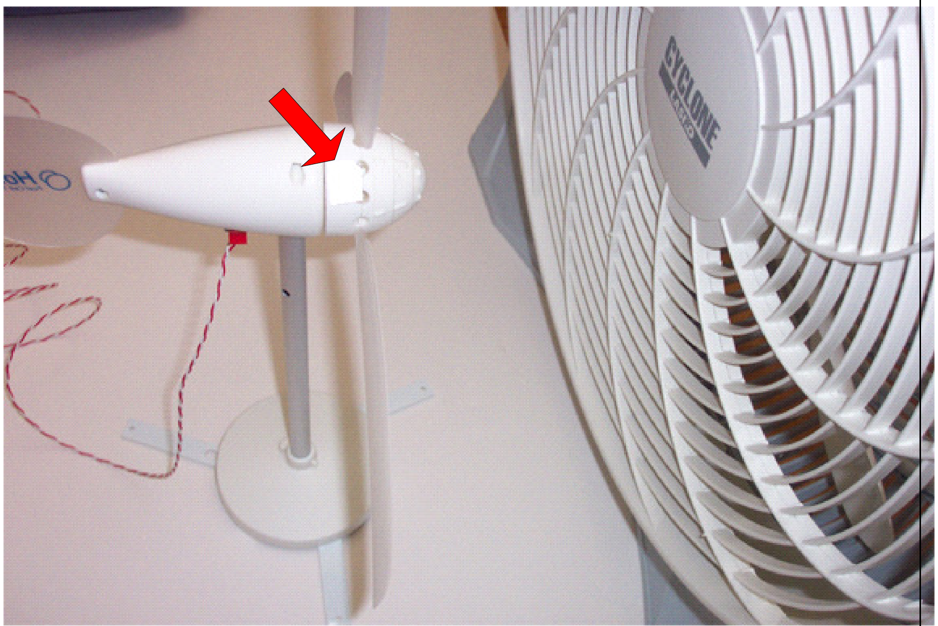
2. Insert a 100 ohm resistor into both the **Load 1** and **Load 2** terminals. Polarity does not matter.

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

1. Set the table or floor fan as close as possible to the wind turbine blades. **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.**



2. Cut a ½" square section of reflective tape and apply it to the side of the WindPitch blade hub just behind the blades.

3. Setup the WindPitch wind turbine with two (3) BP-28 blades.

4. Adjust the blade pitch angle to 15^{o}.

5. Switch ON the wind turbine (**Power 1**) and the first 100 resistor (**Load 1**).

6. Set the fan to its highest speed setting.

7. Measure and record the wind speed in meters/second.

8. On the tachometer set the RPM / TOT button to RPM.

9. Aim the tachometer at the reflective tape and push the Measurement Button on the side. A red dot will appear on the rotating hub and RPM reading should appear on the display.

10. Measure and record the RPM.

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

12. Click the Screen Capture icon to record the power being consumed by the 100 ohm resistor load.

13. Switch ON the second 100 ohm resistor (**Load2**). Now both resistors are in parallel and the total resistance is 50 ohms.

14. Measure and record the wind speed in meters/second.

15. On the tachometer set the RPM / TOT button to RPM.

16. Aim the tachometer at the reflective tape and push the Measurement Button on the side. A red dot will appear on the rotating hub and RPM reading should appear on the display.

17. Measure and record the RPM.

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

19. Click the Screen Capture icon to record the power being consumed by the 50 ohm resistor load.

20. Turn the fan OFF.

Analysis

The power is nearly the same for both the 100 ohm load and 50 ohm load. However, in our tests the speed of the wind turbine blades (not the wind speed generated by the fan, which remained the same) has decreased with the added load. This may reveal differences in the wind turbine's ability to generate power based on the fixed wind speed of the fan.

Power (watts)	RPM / load	Wind Speed (m/s)
0.094	1052 (100 ohms)	3.33
0.092	952 (50 ohms)	2.75

To determine the efficiency factors for the above two sample start with the following equation for wind turbine power:

$$P = 0.5*\rho*A*V^3*E$$

where:

P = Power in Watts

ρ= Air Density in Kg/m^3 (about $1.225 Kg/m^3$ at sea level, less higher up)

A = Rotor Swept Area in $m^2 = \pi r^2$ (r= radius of the rotor)

V = Wind Speed in m/s (cubed)

E = Efficiency in percent

Based on a blade length of 6 inches (radius = 0.1542 meters) it can be stated that the Rotor Swept Area equals $0.0073\ m^2$. It can also be stated that the measurements were taken exactly at sea level so the air density is $1.22 Kg/m^3$.

Solving for efficiency (E) we have:

$$E = P / (0.5*\rho*A*V^3)$$

<u>1052 RPM & 100 ohm load</u>

$E = 0.094 / (0.5 * 1.225 * 0.0073 * 3.33^3)$

$E = 0.094 / 0.165$

$E = 0.56\ \%$

<u>952 RPM & 50 ohm load</u>

$E = 0.092 / (0.5 * 1.225 * 0.0073 * 2.75^3)$

$E = 0.092 / 0.093$

$E = 0.98\ \%$

By the formula above, the power output is increased by the cube of the wind speed, so performing this and the other experiments with lower and higher wind speeds will result in different efficiencies.   You are encouraged to do so.

Another factor to be considered in terms of power generation is torque.

For a DC motor the torque is proportional to the magnetic field cut by the motor coils, and the strength of the magnetic field is proportional to the current passing through the coils. Thus the motor torque is proportional to the input current. However, the motor torque of the motor is inversely proportional to the rotational speed of the motor.

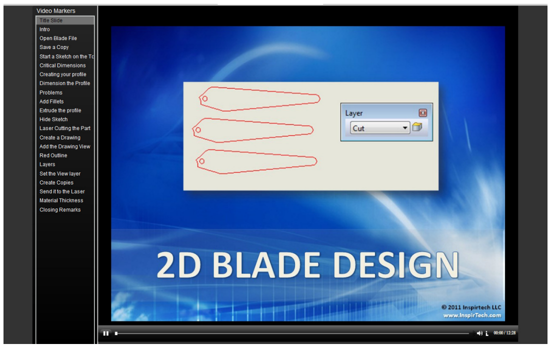
The same theories that apply to a motor also apply to the WindPitch 3-phase alternator. Thus, when more load (50 ohms versus 100 ohms) is applied to the alternator, the alternator's torque increases. With the wind force applied to the alternator being kept constant the rotation speed is reduced to compensate for the increased load.

More about torque can be found at the following websites:

http://www.physics.uoguelph.ca/tutorials/torque/Q.torque.intro.html

http://auto.howstuffworks.com/auto-parts/towing/towing-capacity/information/fpte4.htm

WindPitch Wind Turbine Experiment-
Experimenting with Your Own Blades



EXPERIMENT OVERVIEW

This experiment will test short and long custom designed blades that students create with the ***InspirTech* "*Wind Turbine Blade Design and Performance Kit*"** software along with fabricating the blades on either a 3D printer or laser cutter, as appropriate.

EXPERIMENT OBJECTIVES

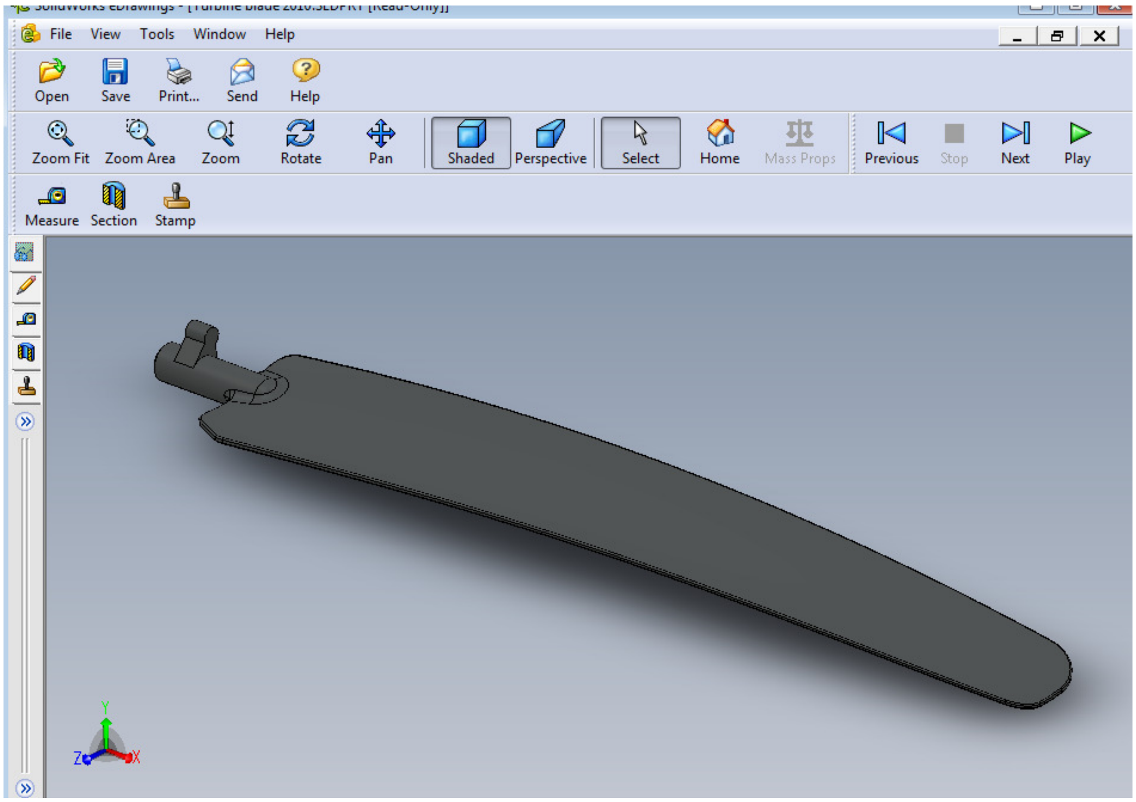
- Students will use the Scientific Process to perform the experiment.
- Students will apply the knowledge they've gained in the previous experiments and apply it to their custom designed blades.
- Students must have successfully completed all the previous experiments using the WindPitch wind turbine and the supplied blades.
- Students must have designed their own short and long 2D or 3D blades.
- Students must have the equipment, or locate same, to fabricate their own custom blades.

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!

Wear safety glasses for all experiments

SHORT AND LONG CUSTOM BLADES



- The following experiment use custom blades of two general lengths, short and long, that students design and build, or have built for them.

- The custom blades designed using the "***InspirTech* "*Wind Turbine Blade Design and Performance Kit*"** software can be of the 2D "flat" or 3D "profiled" variety.

- The experiment is a compilation of the previous WindPitch experiments; therefore, all the previous experiments should have already been successfully performed before this one.

- The experimental results are purposely left general in nature, since the specific blade lengths and other characteristics like shape and type (2D versus 3D) are not known.

- **<u>The student should build "at least" six (6) long and six (6) short blades.</u>**

PREREQUISITES

- Be familiar with the operation of the La Crosse anemometer.
- Be familiar with the operation of the General Technologies tachometer.
- Read and understand the WindPitch Education Kit instructions including:
  - Component Parts
  - Assembly
  - Blade Installation
  - Blade Pitch Adjustment
  - Electrical Connections

EQUIPMENT

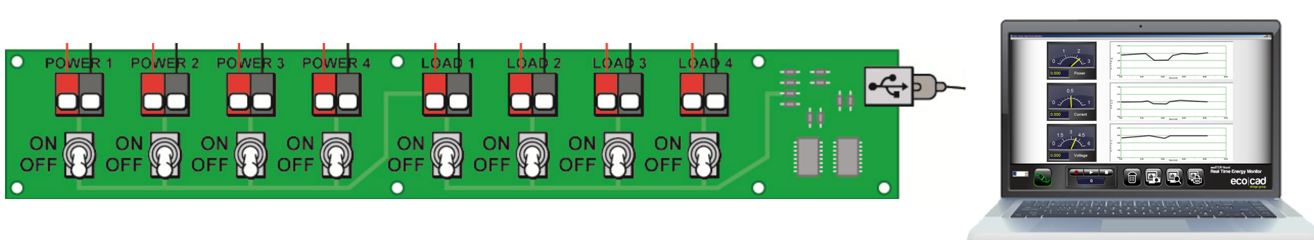
- Control Panel
- Computer running the ecoCAD Real Time Energy Monitoring software
- WindPitch wind turbine with six (6) long and six (6) short custom blades
- Large Table or Floor Fan (at least 16" in diameter with 3 speeds)
- General Technologies model TA105 infrared laser tachometer
- La Crosse model EA-3010U handheld anemometer.
- 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.

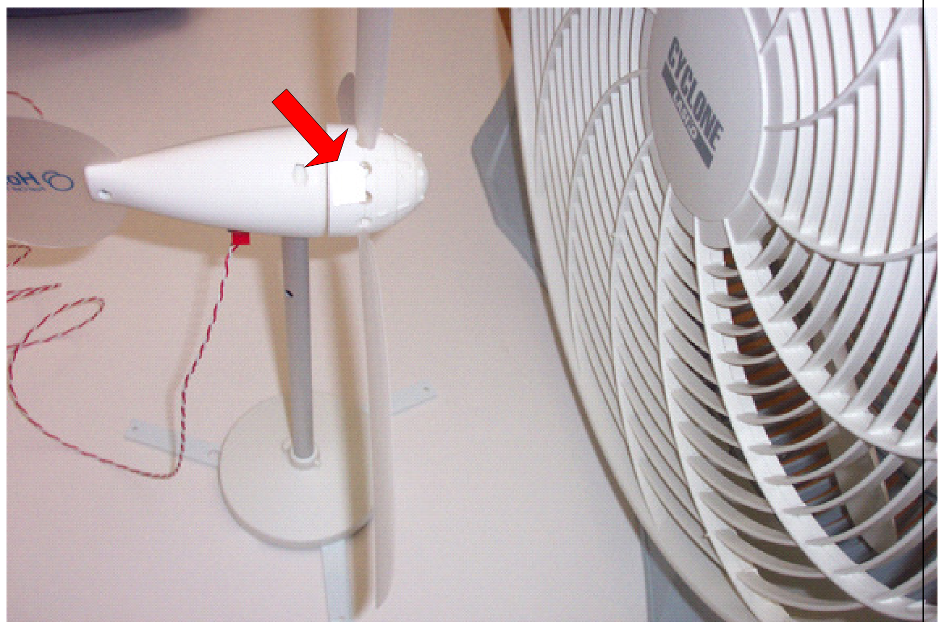
2. Insert a 100 ohm resistor into both the **Load 1** and **Load 2** terminals. Polarity does not matter.

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

1. Set the table or floor fan as close as possible to the wind turbine blades. **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.**



2. Cut a ½" square section of reflective tape and apply it to the side of the WindPitch blade hub just behind the blades.

3. Using the anemometer measure and record the wind speed in meters / second where the WindPitch will be placed in front of the fan.

Part 1 – Short Blades

2 Short Blades

4. Setup the WindPitch wind turbine with two short blades opposite one another on the hub.

5. Adjust the blade pitch angle to 15^{o}.

6. 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.

7. 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.

8. Set the fan to its highest speed setting.

9. Aim the tachometer at the reflective tape and push the Measurement Button on the side. A red dot will appear on the rotating hub and RPM reading should appear on the display.

10. Measure and record the RPM.

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.

3 Short Blades

14. Setup the WindPitch wind turbine with three (3) short blades in a triangular 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. Aim the tachometer at the reflective tape and push the Measurement Button on the side. A red dot will appear on the rotating hub and RPM reading should appear on the display.

17. Measure and record the RPM.

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

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

20. Stop the fan.

4 Short Blades

21. Setup the WindPitch wind turbine with four (4) short blades opposite one another to form a 12, 3, 6 and 9 o'clock pattern.

22. 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.

23. Aim the tachometer at the reflective tape and push the Measurement Button on the side. A red dot will appear on the rotating hub and RPM reading should appear on the display.

24. Measure and record the RPM.

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

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

27. Stop the fan.

6 Short Blades

28. Setup the WindPitch wind turbine with six (6) short blades.

29. 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.

30. Aim the tachometer at the reflective tape and push the Measurement Button on the side. A red dot will appear on the rotating hub and RPM reading should appear on the display.

31. Measure and record the RPM.

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

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

34. Stop the fan.

Part 2 – Long Blades

2 Long Blades

35. Setup the WindPitch wind turbine with two long blades opposite one another on the hub.

36. Adjust the blade pitch angle to 15^{o}.

37. 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.

38. 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.

39. Set the fan to its highest speed setting.

40. Aim the tachometer at the reflective tape and push the Measurement Button on the side. A red dot will appear on the rotating hub and RPM reading should appear on the display.

41. Measure and record the RPM.

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

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

44. Stop the fan.

3 Long Blades

45. Setup the WindPitch wind turbine with three (3) long blades in a triangular pattern.

46. 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.

47. Aim the tachometer at the reflective tape and push the Measurement Button on the side. A red dot will appear on the rotating hub and RPM reading should appear on the display.

48. Measure and record the RPM.

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

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

51. Stop the fan.

4 Long Blades

52. Setup the WindPitch wind turbine with four (4) long blades opposite one another to form a 12, 3, 6 and 9 o'clock pattern.

53. 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.

54. Aim the tachometer at the reflective tape and push the Measurement Button on the side. A red dot will appear on the rotating hub and RPM reading should appear on the display.

55. Measure and record the RPM.

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

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

58. Stop the fan.

6 Long Blades

59. Setup the WindPitch wind turbine with six (6) long blades.

60. 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.

61. Aim the tachometer at the reflective tape and push the Measurement Button on the side. A red dot will appear on the rotating hub and RPM reading should appear on the display.

62. Measure and record the RPM.

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

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

65. Stop the fan.

STUDENT EXERCISES

1. Which number of blades produced the most power overall?

2 short	2 long
3 short	3 long
4 short	4 long
6 short	6 long

2. Which number of blades produced the least power overall?

2 short	2 long
3 short	3 long
4 short	4 long
6 short	6 long

3. Which number of blades produced the most RPM?

2 short	2 long
3 short	3 long
4 short	4 long
6 short	6 long

4. Which number of blades produced the least RPM?

2 short	2 long
3 short	3 long
4 short	4 long
6 short	6 long

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

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

7. Would decreasing the fan's wind speed produce more power for specific blade numbers and length? Explain why you think so (or not).

TEACHER NOTES - ANALYZING THE RESULTS

- Most of the material for this experiment has been covered in previous experiments.
- Refer to the previous experiments for background on how to advise the students on their results.
- Ask the students what changes they would make to their custom blade designs to create more power from the WindPitch wind turbine.
- Use this and the other experiments to continually test and validate new results.

Worldwide Wind Power Installations

Using the wind to generate clean, efficient and "cheap" electricity has been the dream of many people and industries for at least 100 years. However, until very recently the ability to achieve these three goals was elusive, mainly because fossil fuels were so plentiful and relatively inexpensive. Now with the threat of "global warming" along with the attendant pollution caused by the burning of fossil fuels, renewable energy technologies are making inroads into providing commercially attractive power sources.

While solar power is a great choice for localized electricity generation, wind power is certainly the choice for grid-based power generation. Modern wind generators, and the wind farms that host them, can provide large cities like San Francisco and even entire rural states with sufficient power to operate homes and businesses, alike.

It has been correctly claimed that if our mid-western states like North and South Dakota were to build mega-wind farms this flat, barren and constantly windy territory could become the "Saudi Arabia of the United States" in terms of grid-based wind energy generation.

For sometime now counties such as Germany, Spain and Denmark (in order of the percentage of use of wind power) have supplemented their existing fossil and nuclear power generation by the use of wind power. The United States is behind in similar programs; however, it is on a course to catch up at some point in the near future. We will briefly explore these and other examples of wind power usage beginning with the primary types of wind turbines in use today.

Wind Energy Technologies

While old-fashioned windmills are still seen in many rural areas for pumping water, modern wind turbines are divided into two major categories: horizontal axis turbines (HAWT) and vertical axis turbines (VAWT).

Horizontal axis turbines like the one pictured above are the most common turbine configuration used today. They consist of a tall tower atop which sits a fan-like rotor that faces into or away from the wind. Most horizontal axis turbines built today have two or three blades, although some have fewer or more blades.   The newer, larger and more powerful horizontal axis turbines have blades that are longer then the wings of a 747-jet airliner! Plus, they are the most efficient in terms of energy production, to date.

Vertical axis turbines fall into two major categories: Savonius and Darrieus, however neither turbine type is in wide use today. The Darrieus turbine was invented in France in the 1920s. Often described as looking like an eggbeater, this vertical axis turbine has vertical blades that rotate into and out of the wind. Using aerodynamic lift, these turbines can capture more energy than drag devices like the Savonius which offer no lift due to their flat blade structure.

The basic "theoretical" advantages of a vertical axis machine are that the generator and gearbox can be placed on the ground and, thus, do not require a tower. Plus, you do not need a mechanism to turn the blades into the wind as you do with a horizontal axis machine. That said, the disadvantages of a Darrieus turbine far outweigh its advantages. First of all, wind speeds are much lower and more turbulent close to the ground so the overall power generating efficiency is not very impressive. Plus this type of turbine needs a push to get started and must also have a wide network of guy wires to hold it in place, which occupy valuable farm land that can't be used for grazing or planting. Finally, when the main bearings or other parts need maintenance the whole machine must be torn down. That's why the Darrieus turbine pictured here has been out of service for many years, rusting away on a hill above the St. Lawrence Seaway in Canada.

First invented in Finland, the Savonius turbine is S-shaped if viewed from
ype VAWT turns relatively slowly, but yields a high
for grinding grain, pumping water, and many other
otational speeds are not good for generating

Some practical electrical applications forSavonius wind turbines still exist, however, like the one pictured here on the left. When there is a need for a small amount of electricity and solar panels are not practical due to climate or lots of trees, etc. a home-built Savonius wind turbine will do nicely. This one in particular provides the user with enough electrical power to open and close a gate to the driveway entrance as well as power safety lights.

Wind Farms

There are many today who think of harvesting the wind as if it were a crop. In reality, wind is a like a crop since it has value to the wind farmer who cultivates it as well as to the consumer he services with the electricity the wind farm generates. Unlike editable crops, however, the wind crop does not need to be tilled, fertilized or spayed with pesticide to grow healthy and strong. At the same time there is inherent risk in establishing and maintaining an economically healthy wind farm. Here are some examples of new and potentially successful wind farms.

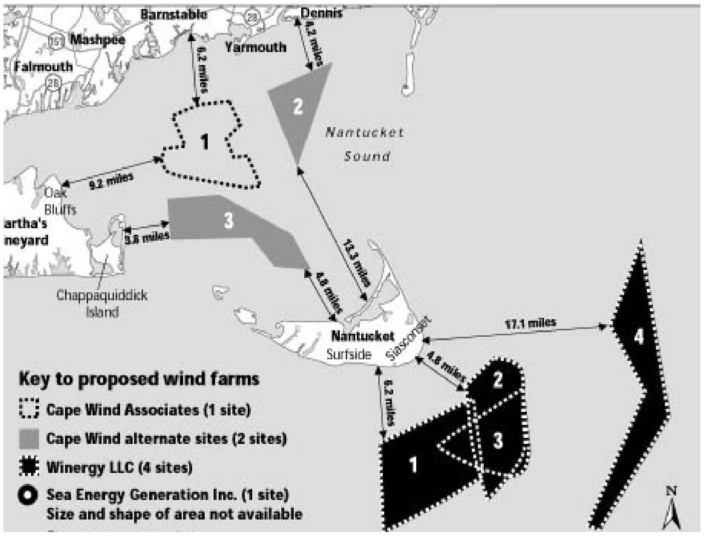
Native American Wind Farms

The Rosebud Sioux Tribe Wind Turbine Project is the first large-scale Native American-owned and operated wind turbine in the country. It is located on the Rosebud Sioux reservation in south-central South Dakota. The project had been stalled as funding and energy sales issues were addressed, but with a long term contract with ***Native*****Energy,** complementing a long term sales option retained by the Tribe for a portion of the wind turbine, the Rosebud Sioux Tribe has now proceeded with final construction financing and has placed the first turbine order. If successful, many more turbines will be constructed and put into operation.

Wind Farms as a Tourist Attraction

"Windmill Tours" of Palm Springs, California has hit upon a unique and fun way to learn about wind power. As the ad says ..."Travel through a forest of towering windmills on electric-powered vehicles. Feel the energy as the giant blades WHOOSH overhead. Your skilled guide will take you inside this working wind farm comprised of turbines modernized to efficiently contribute to a cleaner and safer environment. As you travel along the 90-minute adventure, you realize the environmentally friendly power propelling experience was created by the air you are breathing".

Wind Farms At Sea – United States



One of the more unique and controversial newly planned wind farms will be located on our East Coast off Nantucket Island, which is near Cape Cod, Massachusetts. Cape Wind Associates of Boston has proposed building the country's first offshore wind farm in Nantucket Sound. The 130 wind turbines are to be placed in a 24-square-mile area on Horseshoe Shoal, and some of the 417-foot tall turbines would be visible from Nantucket, Martha's Vineyard and various points along the Cape's south coast from Mashpee to Dennis. As popular as these areas are to the summer vacation tourist trade, let alone the local year-round residents, it will be interesting to see if this plan succeeds in the long run.

Wind Farms at Sea – Denmark

In the summer months of 2002 the world's largest offshore wind farm on the Danish west coast was built and put into operation. The sea-based wind farm is sited 14 to 20 kilometers into the North Sea, west of Blåvands Huk, and represents the first phase of a large-scale Danish effort to produce non-polluting electricity from these offshore wind turbines. The "Horns Rev" project, as it is called, has a total capacity of 4000 megawatts and must be established in full before 2030.

Historically, wind power capacity has been developed on land, but it has become increasingly difficult to obtain the required permits for turbine sites. With its available coastline, interest has been directed toward coastal areas with shallow water depths between 15 and 50 feet that have the possibility of locating the turbines far enough away from the coast that they are visually neutral, something the Nantucket Sound project is criticized for ignoring.

Content Credits

The following individuals and organizations are recognized here for their contributions to this section.

The U.S. Department of Energy - http://www.eere.energy.gov
Wind Mill Tours - http://www.windmilltours.com
http://wireo.ises.org/wire/independents/imagelibrary.nsf/H/O?Open&0000316A

Photo Credits

Darrel Dodge
Lance Turner
Intertribal Council On Utility Policy
Cape Wind Associates LLC