U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ENERGY EDUCATION AND WORKFORCE DEVELOPMENT

Building the Basic PVC Wind Turbine

Grades: 5-8, 9-12

Topic: Wind Energy

Owner: Kidwind Project

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Building the Basic PVC Wind Turbine

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We would like to thank the *Wright Center for Science Education* at Tufts University for giving us the time and space to develop a nugget of an idea into something that has proven to be useful to hundreds of teachers.

We would also like to thank Trudy Forsyth at *National Wind Technology Center* and Richard Michaud at the *Boston Office of the Department of Energy* for having the vision and foresight to help to keep the Kidwind Project going! Lastly we would like to thank all the teachers for their keen insights and feedback on making these wind turbine kits and materials first rate!

Basic PVC Wind Turbine Parts List

KidWind sells the *Basic PVC Wind Turbine* but it can easily be built with about $20 worth of parts. For a classroom of 25 kids we recommend having at least three turbines for blade testing. Below is a parts list for this wind turbine.

PVC Pipe & Fittings & Dowels

Head to your local hardware store for PVC pipe and fittings. KidWind also gets fittings from www.PlumbingStore.com. All pipe and fittings are 1″. This turbine has:

- ◊ *(5) 1″ PVC 90° Fittings*
- ◊ *(3) 1″ PVC T Fittings*
- ◊ *(5 ft) 1″ PVC Pipe*
- ◊ *(1) 1″ PVC Coupler*

DC Motor, Wires & Clips

A local electronics shop or *Radio Shack* will have wire, clips and multimeters. There are also a variety of online vendors—www.allelectronics.com. You can use any small DC motor as a generator. One DC motor that works well is the *Motor 500* by PITSCO. We also carry many different kinds at KidWind. You can easily test any motor/generator — spin it with your fingers and see if you get any measurable output if you do that is a good generator. This turbine has:

- ◊ *(1) Motor 500 (Pitsco) (KidWind also sells Wind Turbine Motors)*
- ◊ *(4 ft) 22 Gauge Hook Up Wire*
- ◊ *(2) Clips (Alligator or Banana)*
- ◊ *(1) Simple Multimeter to Record Power Output*

Special Parts

KidWind custom builds hubs for our turbines. For years we used to fashion your own hubs from Tinkertoys. If you want, head to your local toy shop or an online vendor to get yourself a barrel of Tinkertoys. A small junior barrel will run around $20 and has plenty of materials for 10 turbines. When you want something sturdy and tested come to Kidwind.

- ◊ *(1) Hub (Crimping Hub from Kidwind, Tinkertoy or a round piece of wood to attach blades)*

Blade Materials

You can make blades, out of a variety of materials— wood, cardboard, felt, fabric. Students have made blades out of ***styrofoam bowls, pie pans, paper and plastic cups***. Anything you find around the classroom can be made into blades!

- 4″ dowels 3/8″ dia. (or Tinkertoy rods)— attach blades that you make to this.

Tools

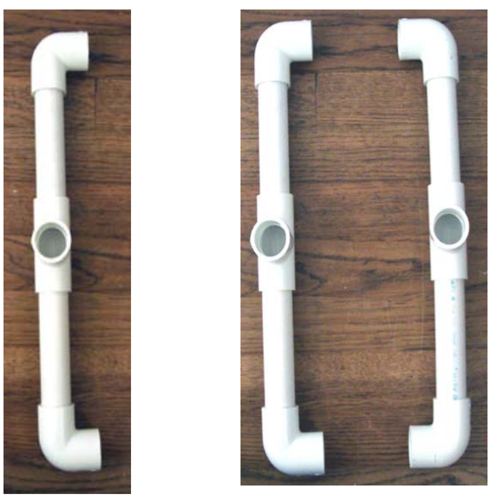
To build this turbine from scratch you'll need at a minimum a drill, ruler, PVC cutter or hacksaw, wire strippers, soldering iron, solder, duct tape, glue.

Building the Basic PVC Wind Turbine

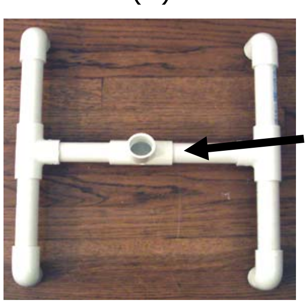
This is the first wind turbine developed at KidWind. The idea was adapted from a design we found at the www.otherpower.com website.

Rugged and cheap to build, this device will allow you to perform a variety of experiments and wind demonstrations quite easily.

These instructions will show you how to build this PVC turbine, how to make blades for your wind turbine, how to use a multimeter to record electrical data and some basic wind energy science.



(2) Identical Base Sides



Sides joined together.

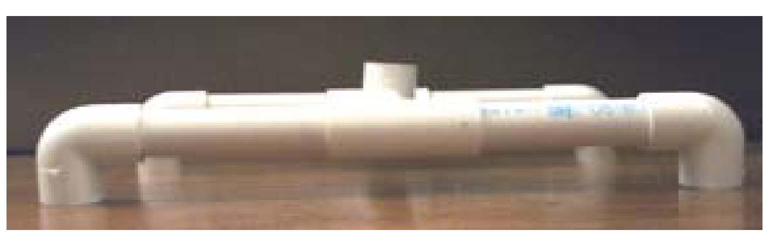
Make sure to drill a hole in this PVC tee so you can get the wires out!

Building the PVC Tower Base

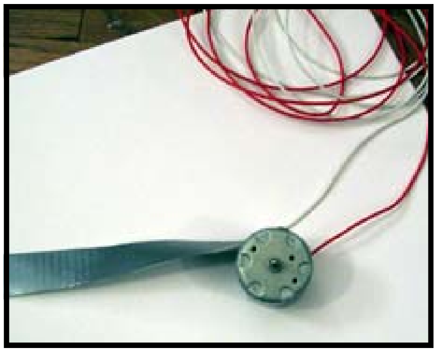
1. Using (4) 90° PVC fittings, (2) PVC tees and (4) 6" PVC pipe sections construct the two sides of the PVC turbine base. Make sure in this step to use the PVC tees that **DO NOT** have a hole drilled in them.

2. Fit the parts together without using glue (PVC glue is really nasty stuff). To make them fit snuggly tap them together with a hammer or bang them on the floor once assembled.

3. Next connect the two sides using the PVC Tee with the hole. The hole will allow you to snake the wires from the DC motor out.



Building the Rotor & Hub

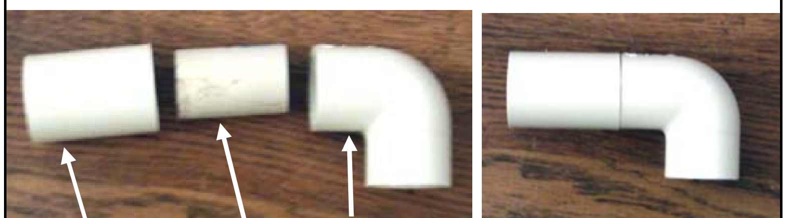


1. You will need to solder some wires (4′ long) to your DC motor. Wrap a piece of duct tape around the outside of the motor. This piece of tape should be about 1/2″ wide and 18″ long. This will help the motor fit securely into the PVC coupler.

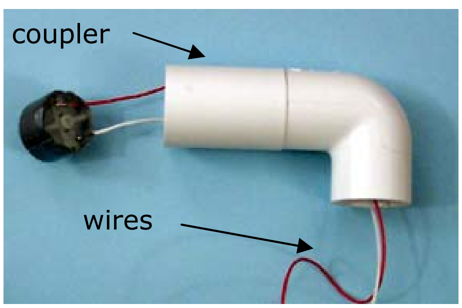
2. For this step use (1) PVC 90° fitting, (1) PVC coupler, (1) 3″ piece of PVC pipe and the DC motor. The best DC motors will be close to 1″ in diameter so they fit tight in the coupler.

3. Arrange the pieces as they look in the image to the right. Push them together to form a solid piece. On a large wind turbine this is called a **nacelle** it holds the generator, gear boxes, and other equipment.

Nacelle Construction



coupler 3" piece 90° fitting



Make sure the wires come out the bottom!

4. Insert the wires attached to the DC motor through the nacelle. They should come out of the 90° PVC fitting. The motor will rest in the coupler.

Notice the motor is straight and not pushed all the way in!

5. Insert the motor into the coupler. It should fit **very** snuggly. If it is too loose or tight adjust by wrapping or unwrapping duct tape around the outside. As the motor is pushed on frequently by students, it must be TIGHT! You can glue this in to make it secure.

Motor secured into the coupler. STRAIGHT!

6. Insert the motor making sure that it is straight and not too far in. If it looks cockeyed straighten it out as it will cause your hub and blades to wobble while spinning.

7. Once the motor is secured attach the hub you have decided to use. Press the hub onto drive shaft. It should fit very snuggly.

Crimping Hub sold by KidWind — FANTASTIC!!!

Nacelle complete with Tinkertoy Hub!

Attaching the Tower to the Base

1. Snake the motor wires down the tower and through the hole in the PVC tee at the base of the wind turbine.
2. Attach the nacelle to the top of the tower.
3. Insert the bottom of the PVC tower into the tee at the center of the turbine base.
4. It should look just like the wind turbine to the right!
5. Assure that the PVC pipe is seated tightly into the fittings by tapping together with a hammer or by banging on the floor.
6. Do not to use any glue so that once finished you can take it apart and store it away for next year!
7. Attach alligator clips to the wires coming out of the turbine to help to hook your turbine up to a multimeter!

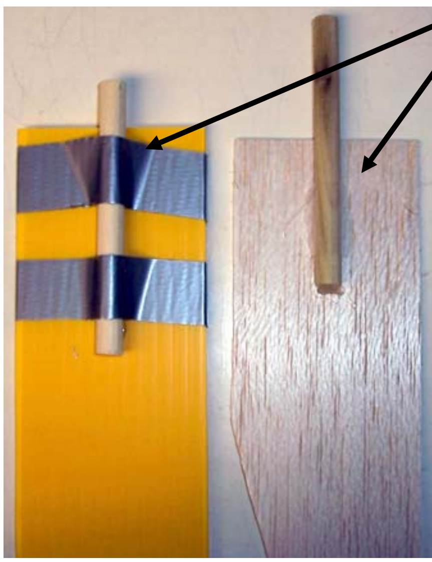
SUCCESS!!
Wind Turbine Completed!

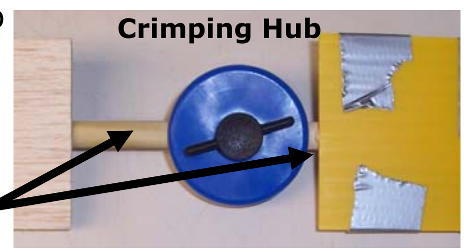
Building & Attaching Blades

Caution!!

Never make blades using metal or any sharp edged material as these could cause injury during testing. Blades tend to spin very fast (400-600 RPM) and they can easily cut people if they have sharp edges.

1. To make blades, carve or cut different shapes and sizes out of a variety of materials (wood, cardboard, felt, fabric) and hot glue or tape them to the dowels. Students have made blades out of ***styrofoam bowls, pie pans, paper and plastic cups***. Anything you find around the house or classroom can be made into blades!
2. Before testing check that the blades are securely attached to the dowel. If not secured properly, they may detach or deform as you test your turbine in high winds. We recommend using a combination of tape and hot or regular glue.
3. Insert the dowels into holes on the crimping hub. It is important to tighten the hub when inserting the blades so that they do not come out at high speed.
4. When attaching the blades to the hub consider a few important questions;
   - How close is the root of your blade to the hub? What do you think is optimal?
   - Are your blades about the same size and weight? Blades that are not balanced will cause vibrations that can reduce the efficiency of your turbine..
   - Are the blades equally distributed around the hub? If not you can also have a set up that is out of balance.
   - Have you secured the hub after you inserted the blades? If not they can fly out at high speed!
   - Want to know how fast your blades are spinning then get one of these—*Hangar 9 Micro Tachometer*.





Pie plate used to catch the wind. As the crimping hub can be separated into two parts you can try different creative ways to attach blades to the hub. One of the best blades we ever saw was made from a pizza pie box!

Again, **DO NOT USE** sharp metal or very hard plastic to make blades as blades can spin at very high speed (500RPM) and could cause injury.

SAFETY & BLADE TESTING AREA

- **It is important to wear safety goggles when constructing and testing blades.**
- **NEVER make blades using metal or any sharp edged material as these could cause injury while spinning fast during testing.**

SETUP FOR TESTING

Safely set up your testing area like the picture below. It is important to clear this area of debris and materials.

Stand In Front or Behind Turbine

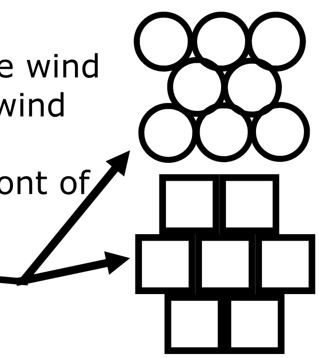
Make sure the center of the fan matches up with the center of the wind turbine. You may need to raise your fan with some books or a container.

Some things to note about fan wind that reduces the efficiency. Fans create;

- *Highly Turbulent & Rotational Wind*— Blades may spin better one direction than another
- *Highly Variable Wind Speed* - Wind speed is about 10-13 MPH on high for a $20 circular fan. Wind speeds near the middle will be much different than the edges.
- *Limited Diameter*— Blades bigger than fan will not “catch” more wind—they will just add drag and slow down your blades.

How to Clean Up Wind?

Want some more “professional wind”? You can try to build a simple wind tunnel. Lots of plans can be found online (search term:classroom wind tunnel) and at www.kidwind.org. One simple way to make more laminar—smooth, straightened—flow is to build a honeycomb in front of your fan using milk cartons, 2” PVC pipe or some other material.



Going Outside?

While you can use your wind turbine outside, you must make sure that you face it into the into wind. This is because this turbine is not designed to YAW (or rotate) to face the wind. If the wind shifts, and the turbine cannot rotate, winds will hit the blades from the sides causing stress and inefficiency.

For a wind turbine that can yaw check out the Kidwind Yawing PVC turbine on our website (http://www.kidwind.org).

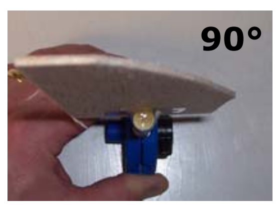
Some Blade Building Tips

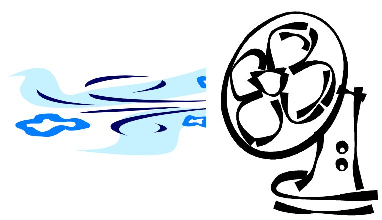
KidWind model wind turbines are designed for use in science classes, or as a hobby or science fair project. Their purpose is to give students an affordable way to perform various blade design experiments quickly. **Efficient blades are a key part of generating power from a wind turbine. Sloppy or poorly-made blades will never make enough energy to do anything. It takes time and thought to make good blades!**

An important concept to keep in mind when making turbine blades is drag. Ask yourself, **"Are my blades creating too much DRAG?"**. Your blades are probably catching the wind and helping to spin the hub and motor drive shaft, but consider the ways that their shape or design might be slowing the blades down as well. If they are adding **DRAG** to your system it will slow down and in most cases low RPM means less power output.

Some tips on improving blades:

- **SHORTEN THE BLADES** - Wind turbines with longer blades do make more power. While this is also true on our small turbines it is often difficult for students (and teachers) to make large, long blades that don't add lots of drag and inefficiency. See what happens when you shorten them a few centimeters.
- **CHANGE THE PITCH** - Students commonly set the angle of the blades to around 45° the first time they try to use the turbine. Try making the blades flatter towards the fan (0° - 5°) . Pitch dramatically affects power output, so play with it a bit and see what happens. Finding a way to **TWIST** the blades (0° near the tips and around 10° - 20° near the root) can really improve performance.





- **USE FEWER BLADES** - To reduce drag try using 2, 3 or 4 blades.
- **USE LIGHTER MATERIAL** - To reduce the weight of the blades use less material or lighter material.
- **SMOOTH SURFACES** - Smooth blade surfaces create less drag. Try removing excess tape or smoothing rough edges to reduce drag.
- **FIND MORE WIND** - Make sure you are using a decently sized box or room fan with a diameter of at least 14"-18".
- **BLADES VS. FAN** - Are your blades bigger than your fan? If the tips of your blades are wider than the fan you're using, then they're not catching any wind– they are just adding drag!
- **BLADE SHAPE** - Are the tips of your blade thin and narrow or wide and heavy? The tips travel much faster than the root and can travel faster if they are light and small, which means that if you have wide or heavy tips you may be adding lots of drag.

What can you do with your turbine?

Factors that Affect Power Output

How much power is your wind turbine producing? The weightlifter turbine uses simple machines (pulleys, wheels) to transform the energy in the wind to lift heavy objects. There are two factors that determine how much power your turbine is producing: (1) How much weight it can lift, and (2) How fast the weight is lifted. Look at the next page to learn more about power in the wind and how to get the most out of your turbine. Once you have read through the materials, start experimenting! What factors can you change to increase the power output of your turbine?

Here are a few ideas for starters.

- *Wind Speed*
- *Blades*
- *Diameter of driveshaft, adding gears, etc.*

Wind speed is an easy one. Take your turbine and place it in front of a fan at three different distances. How does the power output change? Why does it change? Make a graph and discuss. Think about this in relation to the Power in the Wind equation.

Blade Design

An entertaining group of experiments involves blade design. The blades on modern turbines "capture" the wind and use it to rotate the shaft of a generator. The spinning shaft of the generator spins magnets near wires and generates electricity. The WeightLifter turbine does not produce electricity, but works in much the same way to convert wind into power. How well you design and orient your blades can greatly impact how much power your turbine produces.

The ideal blade setup for the weightlifter turbine may be different than the ideal blade setup for an electricity producing turbine. When producing electricity, the goal is to make the rotor spin as fast as possible to spin the generator faster. When lifting weights, however, your blades need to provide lots of torque (muscle) not just speed. It can really pay off to experiment with your blades until you find a setup that provides lots of torque and speed.

Experiments with blades can be simple or very complicated, it depends on how deep you want to explore. Some variables you can test with blades include:

- *Blade Length*
- *Blade Number*
- *Blade Pitch*
- *Blade Shape*
- *Blade Materials*
- *Blade Weight*

If you are doing this for a science fair or project you should focus on just one these variables at a time as your results can get confusing quite quickly.

See page 10 for some great ideas for experimenting with your WeightLifter wind turbine.

Power in the Wind — A simple look

If a large truck or a 250lb linebacker was moving towards you at a high rate of speed you would move out of the way right?

Why do you move? You move because in your mind you know that this moving object has a great deal of ENERGY as a result of its **mass** and its **motion**. And you do not want to be on the receiving end of that energy.

Just as those large moving objects have energy so does the wind. Wind is the movement of air from one place on earth to another. That's the motion part.

What is air though? Air is a mixture of gas molecules. It turns out that if you get lots of them (and I mean lots of them) together in a gang and they start moving pretty fast they can definitely give you, a sailboat or a windmill a serious push. Just think about hurricanes, tornadoes or a very windy day!

Why aren't we scared of light winds while we stay inside during a hurricane or wind storm? The velocity of those gangs of gas molecules have a dramatic impact on whether or not we will be able to stay standing on our feet. In fact, in just a 30 mph gust you can feel those gas molecules pushing you around.

Humans have been taking advantage of the energy in the wind for ages. Sailboats, ancient wind mills and their newer cousins the electrical wind turbines, have all captured the energy in the wind with varying degrees of effectiveness. What they all do is use a device such as a sail, blade or fabric to "catch" the wind. Sailboats use energy to propel them through the water. Wind mills use this energy to turn a rod or shaft.

A simple equation for the ***Power in the Wind*** is described below. This equation describes a the power found in a column of wind of a specific size moving at a particular velocity.

P = Power in the Wind (watts)
ρ = Density of the Air (kg/m3)
r = Radius of your swept area (m2)
V = Wind Velocity (m/s)
Π = 3.14

$$P = 1/2\ \rho\ \Pi\ r^2\ V^3$$

From this formula you can see that the size of your turbine and the velocity of the wind are very strong drivers when it comes to power production. If we increase the velocity of the wind or the area of our blades we increase power output.

The density of the air has some impact as well. Cold air is more dense than warm air so you can produce more energy in colder climates (as long as the air is not too thin!).

The sample equation to the right shows how much power there is in a column of wind coming out of your average household box fan.

How much power is there coming off a regular circular house fan?

V = 5 m/s (meters per second)
ρ = 1.0 kg/m3 (kilograms per cubic meter)
R = .2 m
A = .125 m2 ($A = \Pi r^2$)

Power in the Wind = ½ρAV^3

Power = (.5)(1.0)(.125)(5)3
= 7.85 Watts

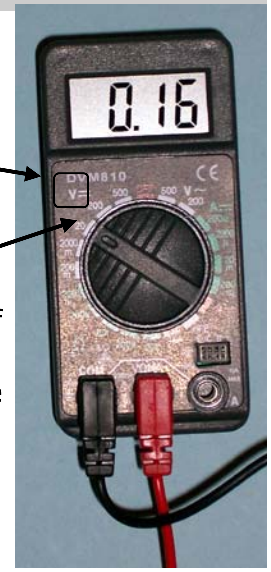
There are 7.85 watts coming out typical house fan. Can our little turbines capture all of this power?

How to use the Multimeter

Small DC motors like the one you're using do not produce much power when spun slowly (see power output sheet). As a result, our electrical output will be limited and even a great set of blades in high winds might only be able to light an LED. To accurately measure our production you should use a multimeter. If you are interested in lighting bulbs and creating more electricity you may want to check out the *Geared Turbine* at the Kidwind Website (http://www.kidwind.org).

Power (Watts) = Voltage (V) x Current (A) <—- **Watch Your Units**

Make sure you are recording volts and amps (not milli or microvolts unless you want to!) If your readings are higher than 1— 2 watts you have done something wrong!



Voltage

1. Attach the wires from the generator to the multimeter.

2. To check the voltage select DC Volt (V) and choose a the whole number setting at 20 volts.

Set at 20 DC Volts

3. Place your turbine out in the wind or in front of a fan and let it run up to speed. It is normal for the readings to fluctuate. Power output is often unsteady because the wind is inconstant or your blades are not balanced.

4. A set of very well designed blades may make around 1 –2 volts Typical blades will be in the 0.4 - 0.8 volt range.

5. When measuring voltage you are calculating how fast the DC generator is spinning. The faster it spins the higher the voltage. As there is no load on the generator it has very little resistance so it can spin very fast. If you look closely when you attach a load (bulb, pump) the RPM may drop as will your voltage.

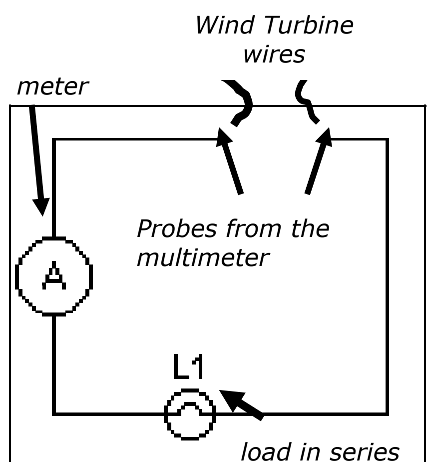
Amperage

1. To get a more accurate picture of the power output of your turbine measure amperage as well. To accurately measure the amperage you must hook up your multimeter differently.

2. Place a load (a resistive object - small bulb, resistor, pump etc.) in series with the meter so that the generator is "loaded" and has to do work.

3. A set of very well designed blades will make around 0.1 amps (100 milliamps) with this motor. Typical blades will be in the .02-.05 amp (20 – 50 milliamp) range. This will vary based on your resistive load.

4. When measuring amperage you are gauging how many electrons are being pushed through the wire by the turbine. This relates to the torque your blades are generating.



To accurately record current you need to put a load in series. In this picture you can see the load (bulb) between the connection with the meter and the turbine.

DON'T FORGET TO TURN OFF THE METER WHEN YOUR ARE DONE OR THE BATTERY WILL DIE!!

PVC Wind Turbine FAQ

Why are the dowels flying out of the hub?
You need to get a Crimping Hub from Kidwind or secure them better to the hub.

Why won't the rotor spin when I put my turbine in front of the fan?
Check the orientation of the blades. Are your blades oriented in the same direction? Are they flat? Are they hitting the tower? Look at some pictures of old and new windmills to get some ideas about how to orient your blades.

Why does the turbine slow down when I attach it to load (pump, bulb, motor)?
Loading the generator forces it to do work. This makes it harder to push electrons through the circuit. The more load you add the harder it is for the generator to turn and the more torque you must generate from the blades. The only way to do this is to make bigger blades or relocate your wind turbine to a place with higher wind speeds.

Why are the readings on my multimeter all over the place?
Your readings may be fluctuating because the wind coming out of your fan is fluctuating. This can also be caused by your blades not spinning smoothly or changing shape as they spin. Additionally, if your blades are not balanced, evenly distributed, or are producing unequal amounts of drag your readings will be irregular.

What are the best blades?
That is for you to figure out! Lots of testing and playing will get you closer to your answer.

Is a fan a good wind source to test with?
Well, it is the best we've got, unless you have a wind tunnel handy! The wind that comes out of a fan has a great deal of rotation and turbulence. It isn't very smooth. While it will still make your turbine spin it is not exactly like the wind outside. To see this turbulence, hold a short piece of thread in front of a fan and move it from the center out. It should head out straight all the time...does it?

Can I take my turbine outside? Can I leave it there?
You can certainly take, use and test your wind turbine outside. But unless you have a yawing turbine it will not track the wind and may not perform optimally. To make it work well you will have to continually face it into the wind. It is not a good idea to leave your turbine outside for too long. It is designed for basic lab tests and not to endure the rigors of the outdoor environment!

Based on the power in the wind equation it seems that longer blades should make more power. On my turbine this is not true!! WHY??
The blades on your turbine may be bigger than the diameter of the fan. If that is the case, the extra part is only adding drag so your blades will slow down. Additionally if you design large blades poorly they will have lots of drag near the tips and slow down. This will negate any positive effect of the added length. Also short blades spin faster than long ones, so if you are just recording voltage they will seem better. Try short blades with a load in series and see if they have enough torque to spin. Many cases they do not!