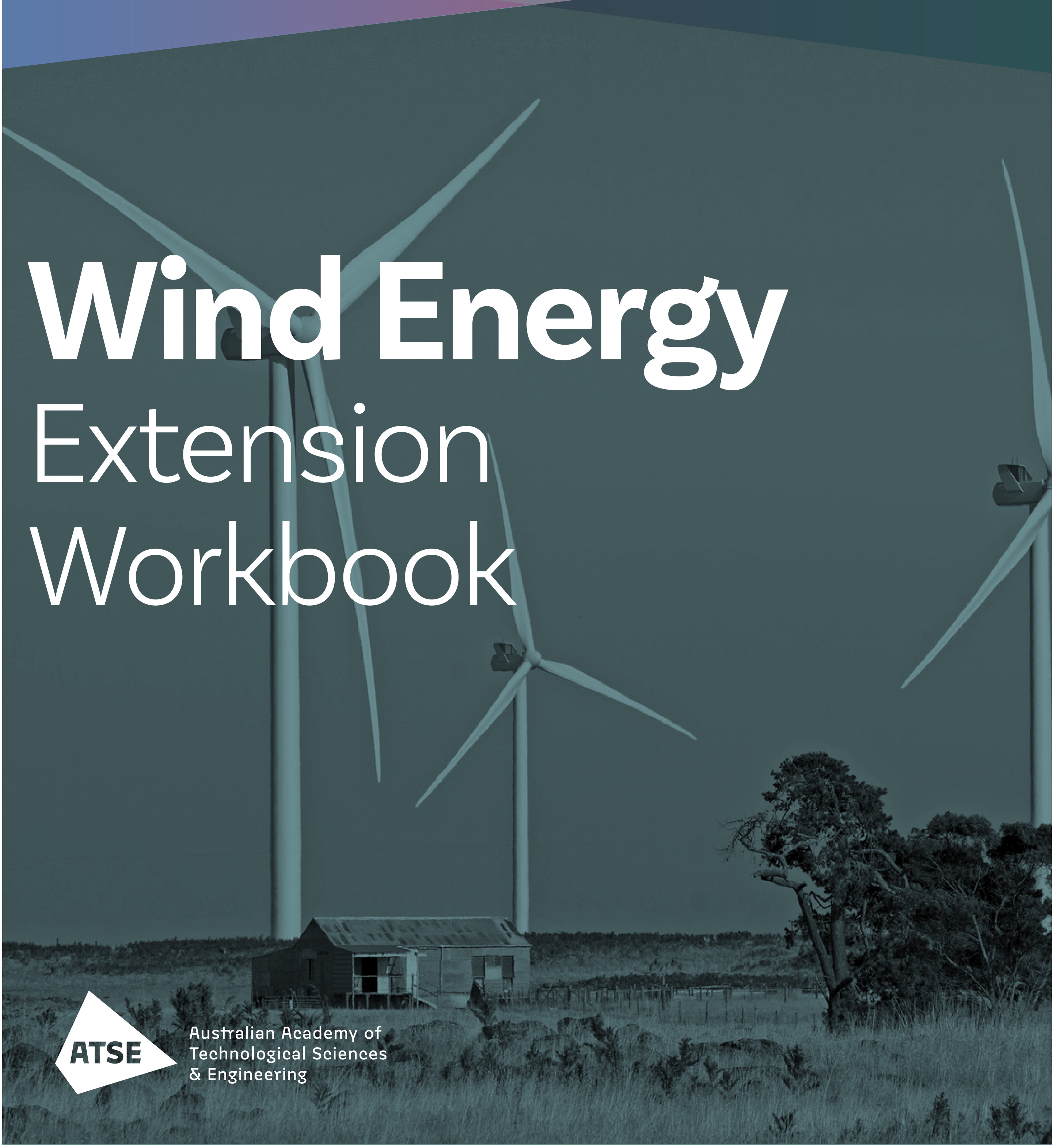
STELR

SCIENCE

8



Wind Energy
Extension Workbook

ATSE
Australian Academy of Technological Sciences & Engineering







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STELR Science — Year 8 Wind Energy
Written and produced by the STELR team at the Australian Academy of Technological Sciences & Engineering.
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SCIENCE TECHNOLOGIES NUMERACY ENGINEERING EXPERIMENTS

STELR is a hands-on, inquiry-based and in-curriculum STEM program designed to be taught so that all students participate in inquiry learning. We also run free webinars for students about careers into STEM, and offer professional development for teachers.

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WIND ENERGY AND POWER

Wind energy is a form of kinetic energy in moving air. Wind power is the rate at which energy is captured and converted into electricity or mechanical work. The power output of a wind turbine is also the rate at which it converts kinetic energy into electricity or mechanical work. The major factor determining power generated is wind speed.

The power of the wind is **proportional to the cube of the wind speed**. This means that:

- If the wind speed were 2 times greater, the power available would be 8 times greater.
- If the wind speed were 3 times greater, the power available would be 27 times greater.

Wind turbines do not produce electricity all the time. Although the wind might be available for as much as 70 % of the time, it is often not strong enough to operate the wind turbine at full capacity. The combination of absence of wind and inadequate wind strength means that even in a good location, the wind turbine — over the course of a year — may only generate about 30 % of the amount it could generate in a constant strong wind.

Factors affecting power

The amount of electrical power produced by a wind turbine doesn't only depend on the speed of the wind, and how smoothly it flows. It also depends on the way the turbine is built. Factors to consider include:

- The length of the blades
- The number of blades
- The shape of the blades
- The weight of the blades
- The angle (pitch) of the blades to the wind
- The height of the tower
- The gears used
- The type of generator used
- The computer system that controls the operation of the turbine and its power output

A good site might have a 35 % capacity factor $(C_p = 0.35)$. This means that the turbines will produce 35% of their capacity on average over a year.

Apart from problems with the wind itself, some of the kinetic energy of the wind is 'wasted', due to the fact some is transformed into heat energy (the gears and shafts get hot) and sound energy (the blades, gears and shafts make some noise as they spin).

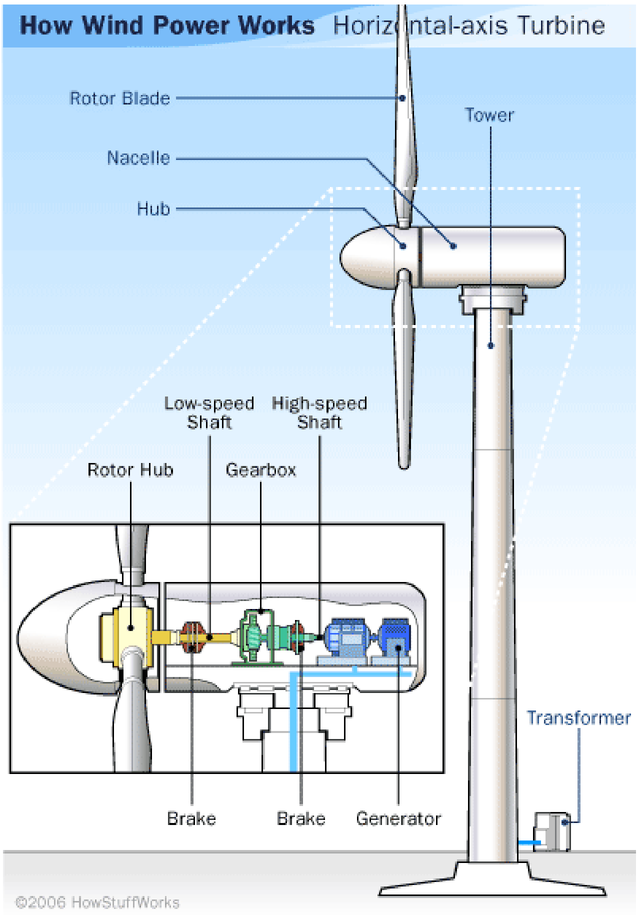


Image: Diagram of a wind turbine (Source: HowStuffWorks)

ACTIVITY 1

Where to place wind farms

What you need

• Nullschool interactive wind map - **earth.nullschool.net**

What to do

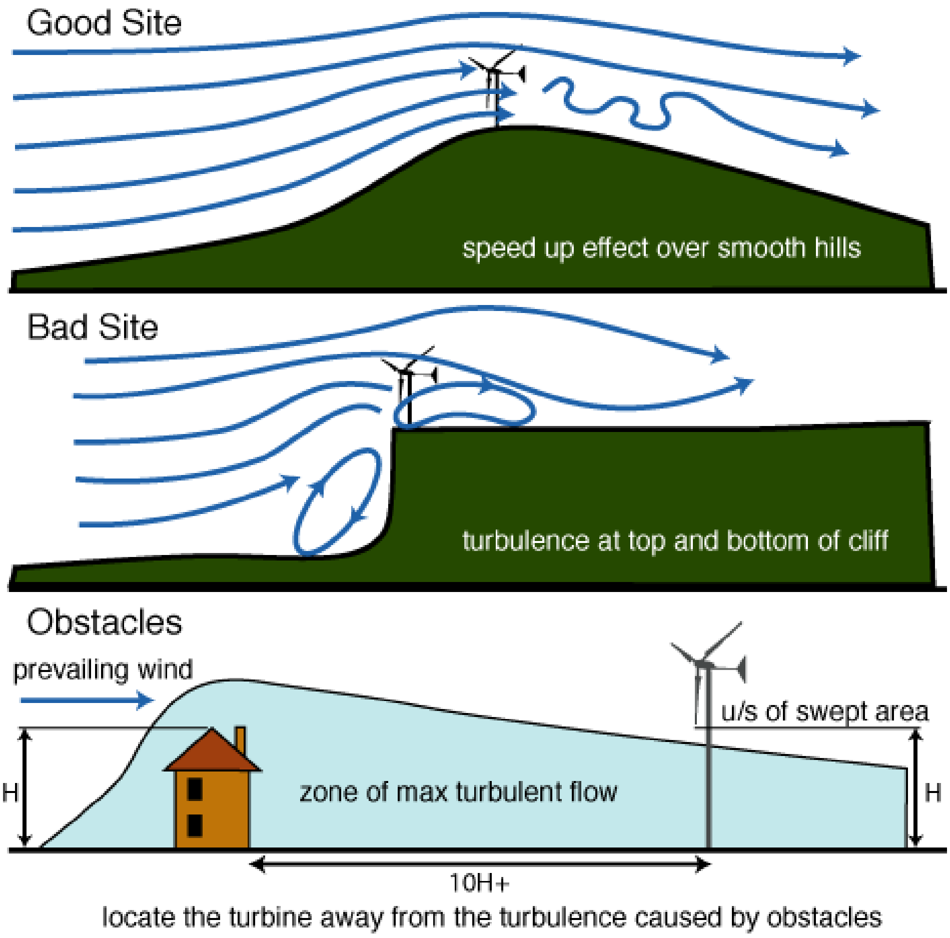
Follow the instructions to perform an investigation using the Nullschool interactive map of wind speeds and patterns in Australia.

Wind turbines are ideally located where there are steady strong winds, though not so strong that they would damage the turbines. More specifically, wind turbines are best located where there are consistently high average wind speeds.

Wind turbines work most effectively when they operate in 'smooth air' (when the air particles are moving parallel to one another).

Ideal sites for wind turbines are:

- Areas with consistently high average wind speeds (greater than 6 m/s)
- Away from obstructions that may cause turbulence, such as rocky outcrops, towers and forests
- At the highest point possible
- Clear space of approximately 10 times the height of local obstacles such as nearby buildings, hills or trees.



Source: https://www.greenspec.co.uk/building-design/small-wind-turbines/

The best place is on top of a smooth hilltop, where the wind increases in speed, and turbulence is at a minimum. Turbines work best in smooth air flow, so they should be placed away from obstructions such as tall buildings or rugged landscapes, which break up the air flow. The higher you go up the stronger the wind, so engineers make turbines as high as they can.

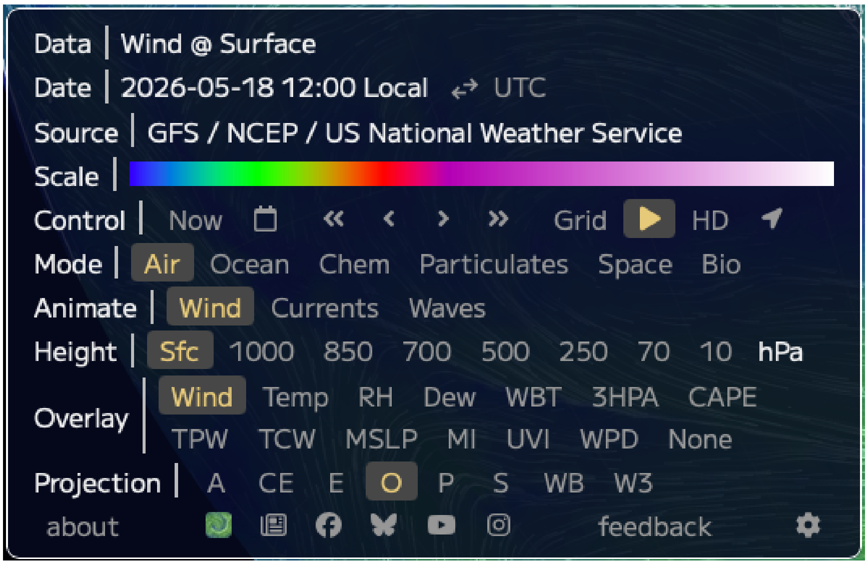
Some wind farms are built offshore in the ocean. These cost more, but winds are generally stronger.

Where in Australia, on land or off the coast, are the best locations for wind farms?

PART 1 - NULLSCHOOL TUTORIAL

Open the website and navigate to Australia - https://earth.nullschool.net

This is a visualisation of global weather condition that is updated every three hours. In the bottom left of the screen are three lines that link to the following menu:



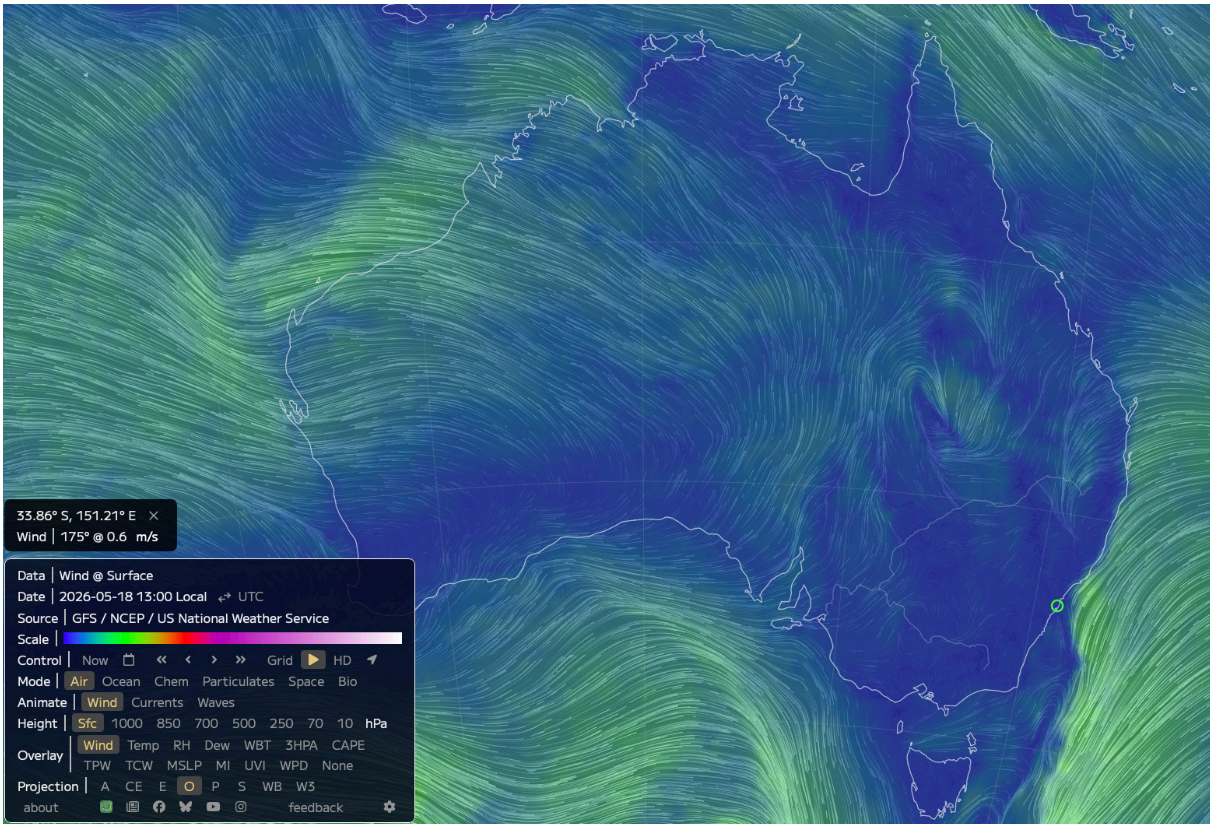
Make sure the **Mode**, **Animate**, **Height**, **Overlay** and **Projection** options are selected as in the image.

As you select an option in this menu, you will notice the title of that function appears in the bottom right corner:

- **Mode** is the primary data category to visualise.
- **Animate** is the dynamic visualisation of global weather and ocean data
- **Height** refers to the atmospheric pressure (hPa is hectopascals) level at which wind, temperature, or other weather data is displayed. As you go higher above the ground, atmospheric pressure decreases and this change can be used to represent height above the ground.
    - Sfc is the Earth's Surface. Wind speed at Sfc is usually measured 10m above the ground.
    - 1000 hPa is approximately 110 metres above sea level
    - 850 hPa is approximately 1500 metres above sea level
- **Overlay** is a visual data layer sitting over the base map (e.g. wind)
- **Projection** is a viewing mode, in this case Orthographic mode shows the Earth as a sphere.

PART 2 - INVESTIGATING SYDNEY, AUSTRALIA

The following image shows the approximate location of Sydney:



Using this visualisation, answer the following questions

Question 1.1

What is the approximate latitude (North/South) and longitude (East/West) of Sydney?

Question 1.2

What is the date and time this image was captured?

Question 1.3

What was the speed and direction the wind was coming from in Sydney at this date and time?

PART 3 - INVESTIGATING YOUR LOCATION

Question 1.4

Look up the latitude and longitude of where you are now, and record those below.

Question 1.5

What is the wind speed and direction now where you are? Show your windspeed in km/h.

Question 1.6

What is the wind speed in m/s? You can find this by clicking the windspeed units to change them from the default km/h, or by converting the units if you know how.

Question 1.7

The height of wind turbines above the ground is a critical consideration, because windspeed changes with altitude. Complete the table below based on your current location.

Height (hPA)	Approx. altitude (m)	What is something that goes this high?	Current windspeed (m/s)
1000	100		
700	3,000		
250	10,000		
10	31,000		

Question 1.8

What do you notice happening to the windspeed as the height above sea level increases? Do the changes seem to follow any particular pattern?

Question 1.9 (Challenge)

Why does windspeed increase with altitude?

PART 4 - INVESTIGATING AUSTRALIA'S WINDSPEED

Question 1.10

Using Nullschool, on the map below complete the following:

1. Draw circles around the three areas where the winds are strongest on land.
2. Write in the top wind speeds in m/s for those areas next to each circle.
3. In the bottom left corner of the map, write in a map key:
   a. Name the pen colour you are using, then;
   b. Beside it write 'highest windspeeds' and the date.

Repeat this activity over 3 lessons to map changes in windspeed over time.

Image credit: Google Maps

PART 5 - BUREAU OF METEOROLOGY (BOM) WIND MAP

As you found in Part 4, windspeed around Australia changes regularly. In fact, around the whole globe the windspeed changes daily, but it also follows patterns due to factors such as the seasons.

To help understand the optimum locations for wind farms, average windspeeds over the course of a year need to be taken into account. Just because the windspeed might be high at a particular time of the day or week it does not mean it will be the best place to permanently install a wind farm.

Visit the following link to access Australian average monthly wind velocity maps:

https://www.bom.gov.au/climate/maps/averages/wind-velocity

This map shows the average wind velocity for each month at various heights above the ground all around Australia - blue/purple areas have the highest average speeds and yellow/white areas the lowest.

Question 1.11

Select the current month and a height of 10m. Using another colour pen, add circles and labels for the three areas with the highest average windspeed to your map used in Part 4.

Compare the wind speed data today with the average wind speed information in your map. Did the areas that you circled overlap at all? Explain.

Question 1.12

How do the wind speeds over 3 lessons compare to the averages for the areas?

Question 1.13

Wind turbines need average wind speeds of 6 m/s or more to operate effectively.

Looking at the average wind map for the current month of the year, approximately what proportion of Australia has enough wind to support wind turbines?

☐ Less than 25% ☐ Between 25-50% ☐ Between 50-75% ☐ More than 75%

Question 1.14

If wind speed was the only factor involved in deciding where to build wind farms, we would put them in the areas where the average wind speeds are highest. Looking at the wind map, can you think of reasons why these might not always be good places for wind farms?

ACTIVITY 2

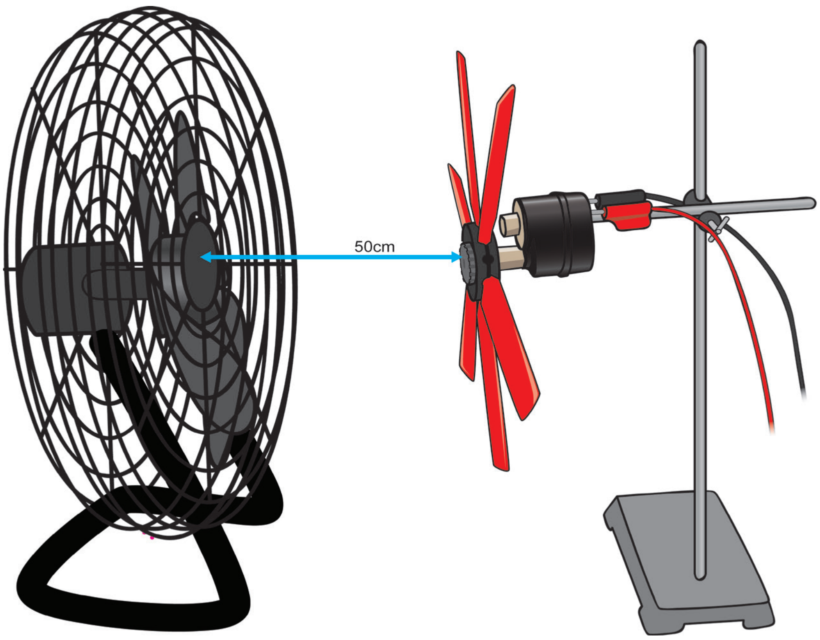
Measuring wind turbine power

What you need

- STELR testing station
- 2 x STELR multimeters
- Sets of blades, red, blue and yellow
- STELR Turbine hub
- STELR wind generator
- Connecting leads
- High-speed electric fan
- Tape measure
- STELR hub protractor

What to do

Set up the wind turbine and high-velocity floor fan 50cm apart. Keep this distance constant throughout the investigation. Secure the STELR wind turbine to the retort stand and make sure that the hub is fitted tightly in the lower socket of the hub.



In the wind energy workbook experiments, we measured the voltage produced by the turbines to determine the optimal blade arrangement.

Electric current flows from higher potential (or voltage) to lower potential (or voltage). This is the potential difference (P.D.) which is being measured across the light globe on the test station. This is not a measure of how much power is being produced – it is a simple way of collecting data which indicates how much energy is being generated (converted) by the wind turbine.

Wind energy is a form of kinetic energy in moving air. Wind power is the rate at which energy is captured and converted into electricity or mechanical work. The power output of a wind turbine is also the rate at which it converts kinetic energy into electricity or mechanical work.

A full analysis with a calculation of power generated by the model wind turbine can be made by adding an ammeter to measure the current in the circuit. The ammeter would be placed in series with the light globe.

A simple calculation of Potential Difference x Current will give the total power generated:

Power (watts) = Current (amperes) x Potential Difference (volts)

$$P = I \times V$$

Inquiry question

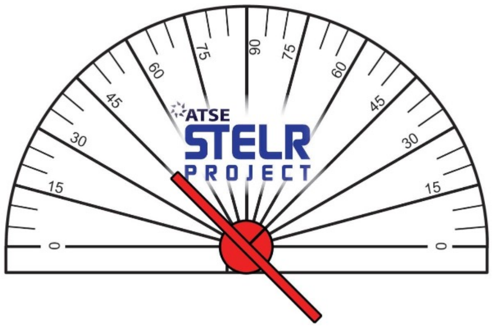
What blade combination will generate the most power?

Question 2.1

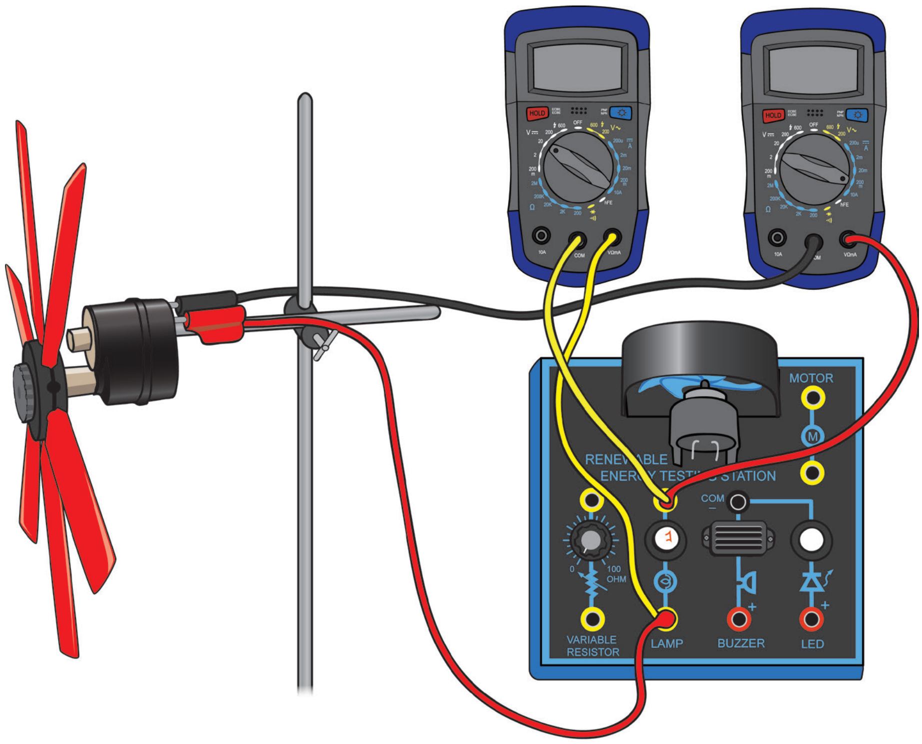
Before you start, predict what you think will be the combination of blades that will generate the most power from the wind turbine. **This will be your hypothesis.**

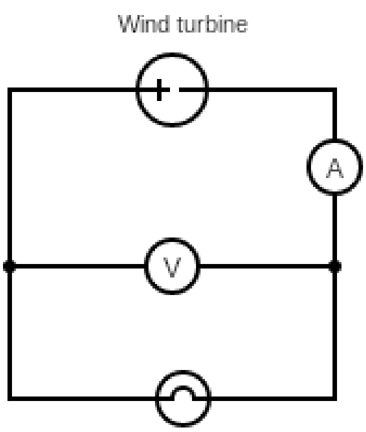
Setup

Using the STELR protractor, set the blade angle to 45°. Keep this angle consistent throughout the investigation.



Set up the turbine, testing station and multimeters as shown in the diagram below. Have one multimeter connected to the lamp in parallel. Set this meter to DC (⎓) voltage or 2V depending on your STELR multimeter model. Connect the second multimeter in series with the lamp and turbine. Set this meter to A or milliamps (mA) depending on your STELR multimeter model.





In this experiment, you will be testing each of the three different blade lengths, set at 45° with different numbers of blades in the turbine hub.

When testing each blade configuration, make sure you record voltage (V) and milliamps (mA). The product of these values will give you power in milliwatts (mW)

Question 2.2

Fill in the table with your results for blades set at 45°.

Blade length (mm)	Number of blades	Voltage V (V)	Current I (mA)	Electrical power P (mW)
75	2			
	3			
	4			
	6			
100	2			
	3			
	4			
	6			
150	2			
	3			
	4			
	6			

Question 2.3

Draw a graph of your results by plotting the results for number of blades on the x-axis and power on the y-axis.

Use a different colour line or line style for each of the different blade lengths and include a key.

VARIABLES

When conducting any experiment, it's important to consider the types of variables involved:

- Independent variable — the variable you change to see what difference it makes;
- Dependent variable — the variable you measure to see if/how it changes when you change the independent variable;
- Controlled variables — other factors that you keep constant, so that they don't have any impact on the dependent variable.

Question 2.4

Identify which of the following variables are independent, dependent and controlled:

power | length of blades | distance between fan and wind turbine | angle of blades

fan setting | number of blades | angle of wind turbine to fan

Independent variables:
Dependent variables:
Controlled variables:

Question 2.5

Was the prediction you made at the start of this experiment (your hypothesis) correct? Were you surprised with the results? Suggest a reason why the prediction was or was not correct.

Question 2.6

List the variables that were kept the same while you performed the experiment.

Question 2.7

List the variables that were changed while you performed the experiment.

CONCLUSIONS

Inquiry question

What is the best arrangement for the STELR model wind turbine hub to produce the most electrical power? (Recommend the length blade, number of blades and blade angle).

Extension question

What do you think will happen to the performance/power of the turbine if you combine different blade sizes instead of controlling this variable to a single size at a time? How much more complicated would this experiment be to include multiple sizes in the same test?

ACTIVITY 3

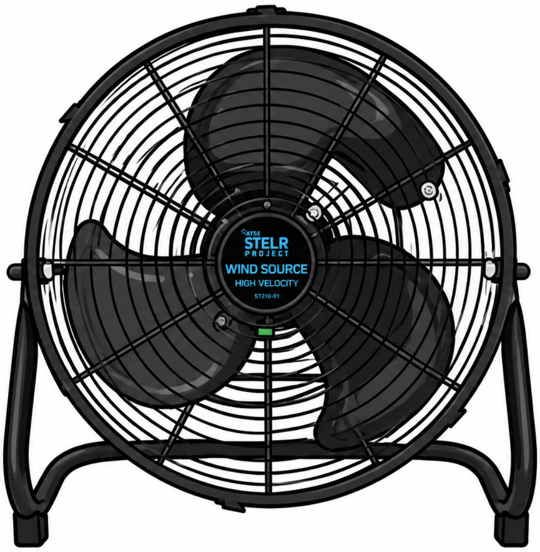
STELR fan speed map

What you need

- STELR High Velocity Fan
- STELR Anemometer
- Retort stand, boss head and clamp
- Tape measure or metre ruler
- Tape

What to do

Setup the STELR high-velocity floor fan and measure the wind speed along the vertical and horizontal axis to create a map of the wind speed coming from the fan.

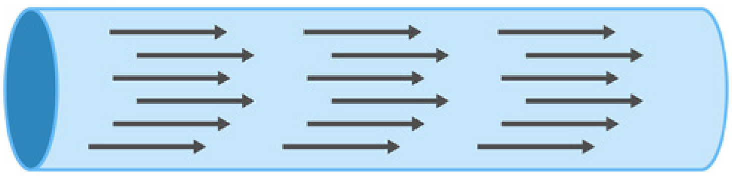


As we have learnt in an earlier section, wind turbines are ideally located where there are steady strong winds, though not so strong that they would damage the turbines. More specifically, wind turbines are best located where there are consistently high average wind speeds.

Wind turbines work most effectively when they operate in 'smooth air' (when the air particles are moving parallel to one another - also called **laminar flow**) and where there is minimal turbulence. Turbulence refers to regular and chaotic fluctuations in wind velocity and pressure.

To operate the STELR wind turbine efficiently, the behaviour of the air coming from the fan or other wind source needs to be considered. When using the STELR high velocity floor fan, the turbine should be placed somewhere within the path of smooth air being produced by the fan, and the place where the wind speed is fastest.

LAMINAR FLOW



TURBULENT FLOW

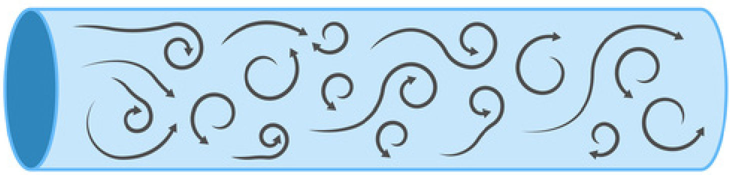


Image source: https://toptec.pk/laminar-flow-vs-turbulent-flow/, last visited 20/5/2026

Inquiry questions

1. What speed is the wind produced by a high velocity floor fan?
2. Can we map the speed of wind generated by the fan?
3. What is the position in front of the fan that produces the least turbulent wind with the greatest speed?

Question 3.1

Before you start, predict the distance from the fan that you think will produce the least turbulent wind with the greatest speed. **This will be your hypothesis.** Explain why you think this.

Question 3.2

What are the variables? List all the factors that you think could have an effect on the results of this experiment.

Question 3.3

Identify which of the following variables are independent, dependent and controlled:

Anemometer used | distance between fan and anemometer

distance between anemometer and table/bench top | fan setting | wind speed recorded by anemometer

Independent variables:
Dependent variables:
Controlled variables:

TASK - MAPPING WIND SPEEDS

You are to measure the wind speed along a vertical and horizontal grid to map the wind speed created by a STELR fan.

These measurements will produce a wind speed map which will assist you in determining the most efficient position to situate your STELR model wind turbine.

Results

Record all your results from this task in the tables below.

Vertical offset

Vertical offset (cm)	Distance from fan (cm)					
	0	10	20	30	40	50
+20						
+10						
0	X					
-10						
-20						

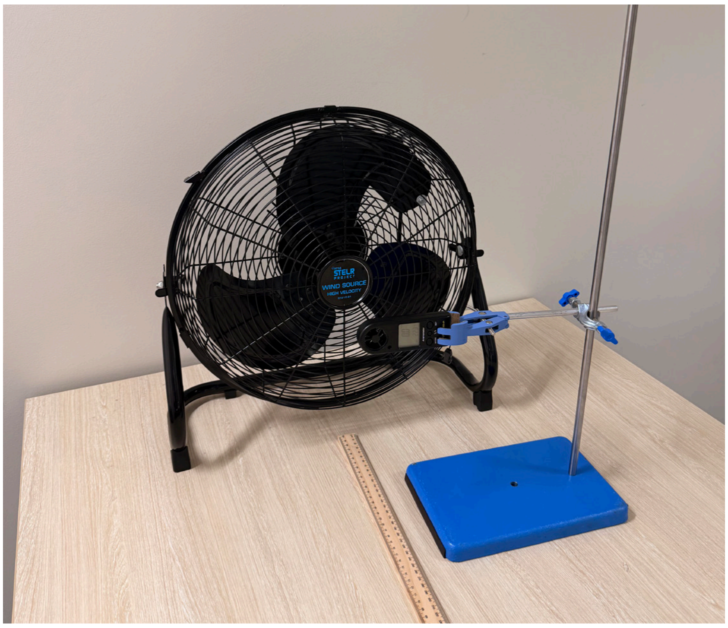
Horizontal offset

Horizontal offset (cm)	Distance from fan (cm)					
	0	10	20	30	40	50
+20						
+10						
0	X					
-10						
-20						

PART 1 - VERTICAL OFFSET

Setup

Place the STELR high-velocity floor fan on a table or elevated surface and connect to power. Place a 1m ruler at the base of the fan and mount the STELR anemometer in the clamp of a retort stand as shown in the image below.



Step 1

Position the anemometer 10cm in front of the fan using the 1m ruler, and set the height of the anemometer to be equal to the centre of the fan cage (where the STELR logo is). Turn the fan onto its highest setting and record the windspeed in m/s using the table provided.

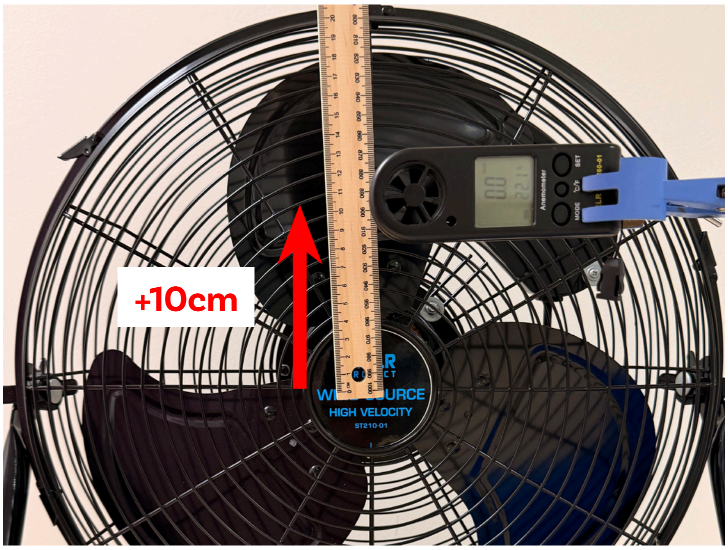
Step 2

Continue to measure the windspeed in m/s at intervals of 20cm, 30cm, 40cm and 50cm while still at the height of the centre of the fan cage. Record your results in the table provided.

Step 3

Adjust the height of the anemometer so that it is 10cm above the centre of the cage (+10cm) and move the anemometer so that it is 0cm distance from the fan cage. Turn the fan to the highest setting again and measure the windspeed in m/s. Record your results in the table provided.

Note: Data collection didn't start from 0cm distance when in the centre of the fan's height because there are no blades moving the air in that location.

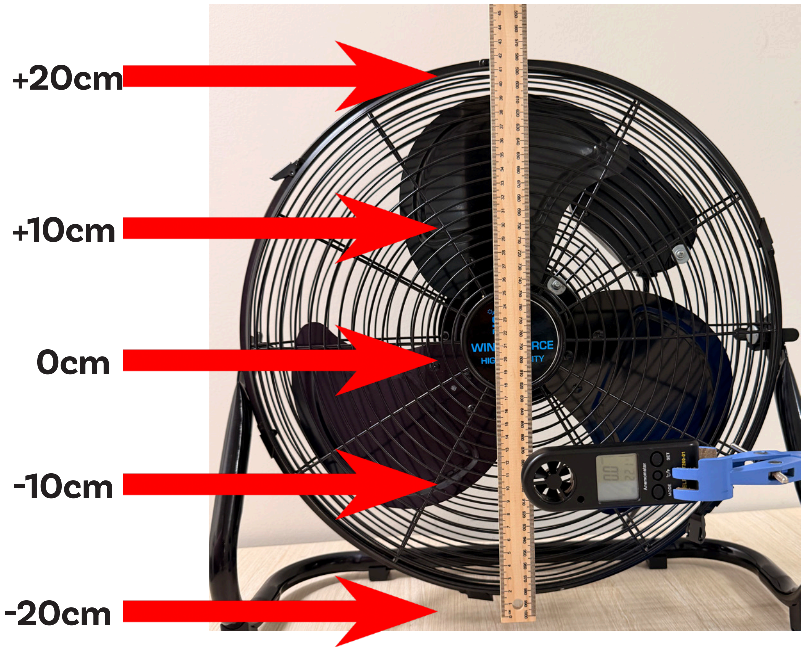


Step 4

Repeat step 3 by moving the distance the anemometer is from the fan in increments of 10cm, from 10cm up to 50cm away.

Step 5

Repeat steps 3-4 at heights of 20cm above the centre of the cage (+20cm), and below the centre of the cage at -10cm and -20cm. Record your results in the table provided.

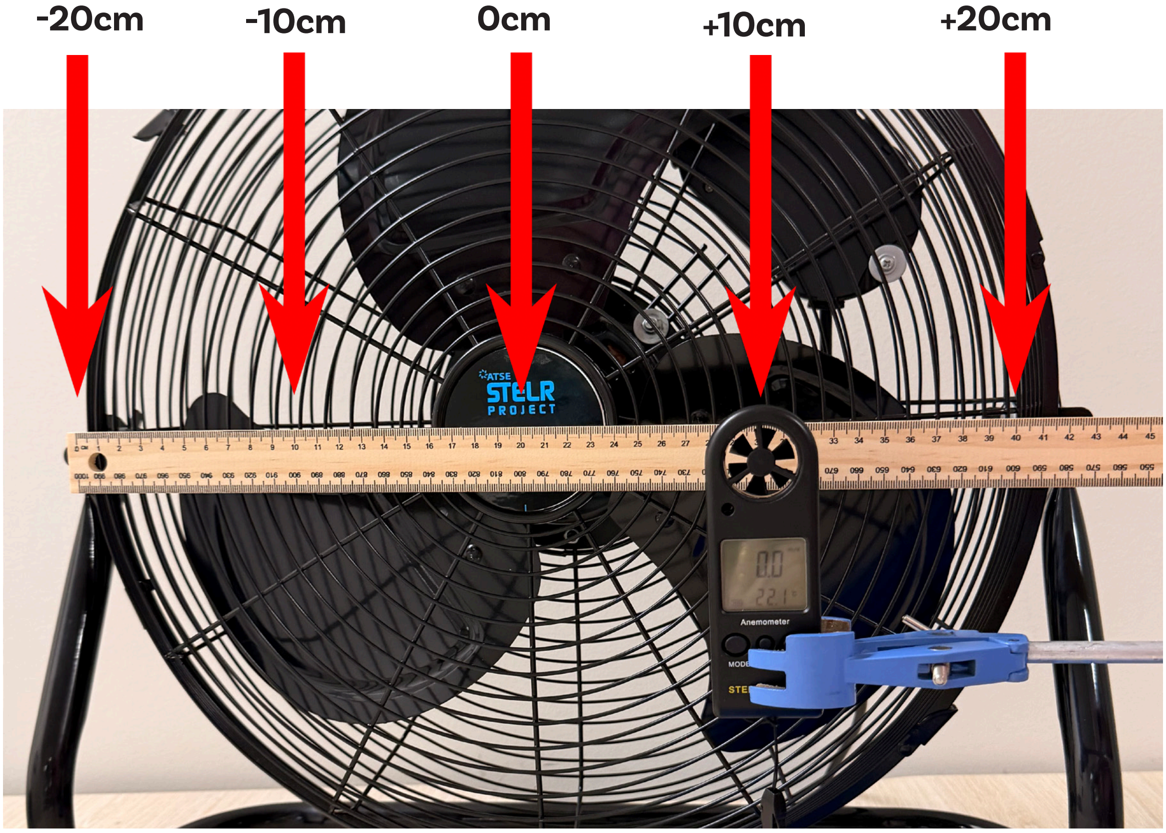


Step 6

Confirm that all the boxes in the table for vertical offset are filled in, taking measurements for any that may be missing.

PART 2 - HORIZONTAL OFFSET

We will now repeat the steps in part 1 to measure the wind speed across the front of the fan horizontally



Step 1

Set the anemometer height back to the centre of the fan cage (where the STELR logo is). Place the anemometer 10cm to the right of the centre of the fan (+10cm). Turn the fan onto the highest speed and measure the windspeed at 10cm intervals from 0cm up to 50cm. Record your results in the table provided.

Step 2

Repeat this process at 20cm to the right of the fan's centre (+20cm), as well at 10cm to the left (-10cm) and 20cm to the left (-20cm).

Step 3

Copy your results from the vertical offset table into the horizontal offset table for 0cm offset (or measure them again to see if anything has changed).

Step 4

Confirm that all the other boxes in the table for horizontal offset are filled in, taking measurements for any that you may be missing.

PART 3 - ANALYSIS

Examine the range of wind speeds in m/s you have collected. Results may vary but you can expect wind speeds from 1.0 m/s to 5.0 m/s in your table.

To visually represent this data, use a colour code to correspond with each class of wind speed. For example:

Windspeed (m/s)	0-1	1-2	2-3	3-4	4-5	5+
Colour	Purple	Blue	White	Yellow	Orange	Red

Vertical offset

Vertical offset (cm)	Distance from fan (cm)					
	0	10	20	30	40	50
+20						
+10						
0						
-10						
-20						

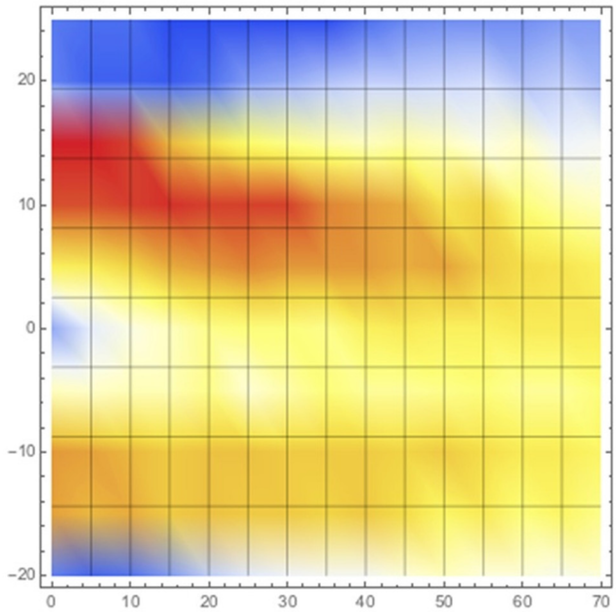
Horizontal offset

Horizontal offset (cm)	Distance from fan (cm)					
	0	10	20	30	40	50
+20						
+10						
0						
-10						
-20						

Sample data

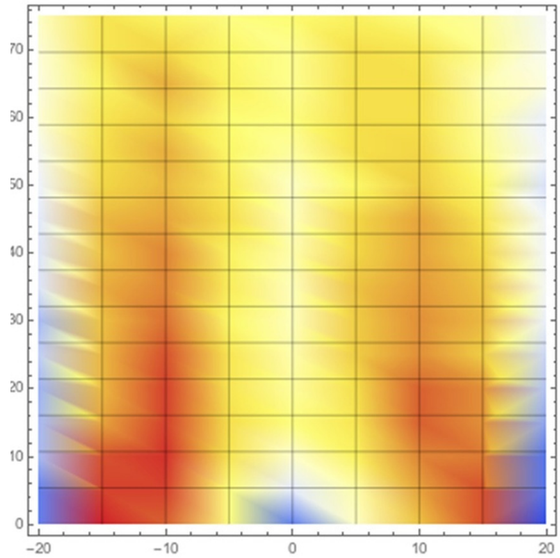
The following image shows the a sample distribution of wind speed data collected for the STELR fan on the highest setting. The STELR fan is included to help you visualise what this data represents:

Side-on view (vertical offset)



Wind speed scale (m/s)

Top-down view (horizontal offset)



Question 3.4

Examining your results, how do they compare with this sample data? List some of the similarities and differences you observe.

Question 3.5

Was the prediction you made at the start of this experiment correct? Were you surprised with the speed variations produced by your fan? Suggest a reason why the prediction was or was not correct.

Question 3.6

Complete the table below summarising your findings for the highest velocity air and where this is located in front of the fan.

Highest wind speed (m/s)	Distance from fan (x) (cm)	Vertical offset (y) (cm)

Conclusion

Using the results from all of your wind turbine investigations, make a statement regarding the optimal turbine configuration and position for a fan to generate the maximum power.