Enclosed Vertical Axis Wind Turbines

A Major Qualifying Project

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by

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Abstract
Enclosing vertical axis wind turbines (VAWTs) could increase the efficiency of the turbines; in addition, a wind funneling system may help further benefit the power output. Wind tunnel testing concluded that enclosing VAWTs shows potential to increase efficiency. Additional wind tunnel designs were completed to look for further increases in efficiency through wind funneling.
Executive Summary- Enclosed Vertical Axis Wind Turbines

Enclosed vertical axis wind turbines (VAWTs) may hold the potential to be widely used as small-scale residential turbines. Additionally, wind funneling into wind turbines, particularly structure mounted VAWTs, has the potential to increase the efficiency of sustainable energy solutions.

Goals

The goals of this project were to determine if enclosing VAWTs in an enclosure could increase the efficiency of the turbines and to design a wind funneling system to help further benefit the potential power output. The final product of this design and experimentation will be used to develop a small-scale, one-kilowatt enclosed vertical axis wind turbine to be developed at an affordable price point and sold to homeowners.

Background

Sustainable energy solutions are currently under high development. A system that can produce one-kilowatt of energy operating at 25% time for a product and installation cost of $2000 could yield an eight-year return on investment (ROI). If enclosing a turbine or funneling wind into it could increase the efficiency of the system, the ROI could be significantly reduced. Every increase in efficiency is less energy that needs to come from non-sustainable sources.

Methodology

A number of scale model VAWTs, enclosures, and a testing device were designed and fabricated to test in a wind tunnel. The turbines ranged from two to eight blades and had a variation of blade angles from 30° to 60°. The enclosures varied in orientation of flow entry and exit. Figure 1: Example Turbine, Enclosure, and Testing Setup shows a six blade turbine, enclosure, and assembled testing set up.

Data from combinations of every turbine and enclosure was collected at wind speeds ranging from zero miles per hour to 42 miles per hour. Data analysis included
comparing revolutions per minute to wind speed in order to evaluate the effectiveness of each enclosure-turbine combination at increasing efficiency. Additionally, three variations of wind funneling systems and a torque-monitoring device to estimate potential power were designed for testing inside of the wind tunnel.

Findings

Analysis of the data collected during tests, shows that it is possible to achieve a higher number of rpm's with a range of turbines and enclosures. Figure 2 shows an example of the six blade turbine with four different enclosures.

![Six Blades at 45 Degrees](image)

*Figure 2: Six-blade turbine with four different enclosures*

Summary

Enclosing vertical axis wind turbines shows the potential to increase their efficiency which would not only reduce the turbine’s ROI to a homeowner, but also could decrease emission of eCO₂ into the atmosphere from non-sustainable energy sources.
**Authorship**

We certify that all members of the project team have contributed equally to the completion of this project.
Acknowledgements
Thank you to Don Pellegrino, Neil Whitehouse, and Russ Lang for their help in the lab; and thank you to Julie Eagle for her previous research. Also thank you to Francis X. Reilly Sr. for introducing us to this concept.
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1. Introduction

On a daily basis the world uses many sources of energy that expel carbon dioxide into the atmosphere. It takes years for this gas to dissipate. The increase of carbon dioxide levels has led to an increase of the earth’s average temperature. This effect is commonly known as the “Global Warming Effect”. Alternative energy sources are a viable way to lower the amount of carbon dioxide released. Wind, one of the main alternative energy sources, is a common choice for small scale energy applications.

There are two different kinds of wind turbines, one using a horizontal axis shown in Figure 3: Horizontal Axis Wind Turbine and the other using a vertical axis shown in Figure 4: Vertical Axis Wind Turbine. Enclosing the VAWTs may make it plausible for these to be widely used as small-scale residential turbines. Additionally, wind funneling into wind turbines, particularly structure mounted VAWTs, has the potential to increase the efficiency of sustainable energy solutions.

Figure 3: Horizontal Wind Turbine (Source: http://jcwinnie.biz/wordpress/?p=2330)
The goals of this project were to determine if enclosing VAWTs in a shroud could increase the efficiency of the turbines and to design a wind funneling system to help further benefit the potential power output. The final product of this design and experimentation will be used to develop a small-scale, one-kilowatt enclosed vertical axis wind turbine to be developed at an affordable price point and sold to homeowners.

This report covers the research done to see if the hypothesis of the team regarding enclosures is supported or not. The report includes examples of other sustainable solutions as well as some VAWTs that are used in the world today.

2. Background

Sustainable energy solutions are currently under widespread and enthusiastic development. This chapter discusses the different types of alternative energy. The discussion of the different types of winds sources can also be found here.

2.1. Types of Alternative Energies

There are many types of alternative energies. This section includes the three main types of sources: hydro, solar, and wind.

2.1.1. Hydro Power

Hydro power is use of water flowing through a turbine connected to a generator which creates electricity. To effectively have hydro power as a source, one needs to have an elevation drop for the water to fall. Usually there is a water reservoir with an intake near the bottom of the dam's wall where it funnels the water toward the turbine that is connected to the generator. After flowing through the turbine it flows back into the river at a much lower elevation then the top of the reservoir (Perlman). An example of a dam is shown in Figure 3: How Hydro Power Works.
2.1.2. Solar Power

Solar power is the collection of the sunlight by a solar panel which converts light energy directly into electricity. Most solar panels are created out of silicon, since it is such a good semiconductor. Solar panels can be arranged in large solar arrays that have the ability to power large areas. The Air Force currently utilizes this form of alternative energy to power Nellis Air Force Base in Nevada. This is also the largest PV array in North America, shown in Figure 4: Nellis Air Force Base Solar Panels (Whitney).

![Figure 5: How Hydro Power Works](http://www.kentuckylake.com/)

2.1.3. Wind Power

Society had been using wind energy as a source of power for the longest time. The use of the windmill to grind grain was first used by the Persians and the Greeks. Now one can find entire fields of wind turbines, such as the Roscoe Wind Farm in Texas, the largest onshore wind farm in the world. Wind Farms can also be found off the coasts of several countries. Europe is growing in their use of wind power, with Denmark leading the charge being the holder of the largest offshore wind farm (Schwartz).

![Figure 6: Nellis Air Force Base Solar Panels](http://www.metaefficient.com/news)
2.2 Types of Wind Sources

This section goes into greater details about available types of wind energies. Also, greater details on how the turbines work will be explained.

2.2.1. Horizontal Axis Wind Turbines (HAWT)

HAWTs are more commonly used for wind farming than for use in households. One of the major concerns of a HAWT is that for it to work best it should be facing into the wind. The big turbines in wind farms usually have motors to help point them into the wind. “Horizontal axis” means that the axis of rotation is parallel to the ground with the blades spinning perpendicular to the ground. Typically these look more like a fan that one could buy in a store for their household. An example of a HAWT is shown in Figure 3: Horizontal Wind Turbine.

2.2.2. Vertical Axis Wind Turbines (VAWT)

The biggest advantage for the VAWT is that no matter from which direction the wind is coming from, the turbine will be capturing the wind and working effectively. This is why in more residential areas where the wind is changing more often VAWTs are more practical. With the vertical axis both of the blades and the axis are perpendicular to the ground or straight up in the air. VAWTs tend to spin considerably faster than HAWTs so a concern of the VAWT is that wildlife, birds and small animals, might fly or get caught in them. An example of a VAWT is shown in Figure 4: Vertical Axis Wind Turbine.

2.3. Enclosing a VAWT and Wind Funneling

The theory behind enclosing a VAWT is that it would increase the flow of the wind into the turbine thus increasing the rotations per minute (RPMs). The idea is that depending on how more efficient the enclosed turbine is working, one could decrease the ROI by a substantial amount. Figure 7: Enclosing a VAWT shows a turbine with an enclosure around it.

Wind funneling is thought to increase the amount of wind going into the enclosed VAWT, thus increasing the RPMs. The more RPMs a turbine has, the more energy it is creating. This translates to lower electricity and gas bills.

Figure 7: Enclosing a VAWT
3. Methodology

In order to test if the addition of an enclosure and wind funneling system to a VAWT can make them more efficient, the following methodology was completed. Components of the design were adapted from previous research where incomplete data was gathered. The methodology includes the design of the testing set up and the procedure used to run the tests. Additional testing procedures have been evaluated for the first designs, and designs of funnel and wind vectoring structures were designed and constructed for further testing. In addition, the next part of the research not only will involve wind funneling systems, but a torque-monitor will be added to the turbine shafts.

3.1. Design and Fabrication

Turbines were designed and then modeled in software named Solidworks. They were fabricated out of Acrylic plastic cut with a laser-cutting machine and molded together with modeling glue. The turbines ranged from two blades up to eight blades with most blades at 45° to tangent. However, different angles relative to their tangent were designed and fabricated in order to test how angles affected efficiency.

A two-blade and 45 degree turbine was designed and created. It can be seen in Figure 8: Two Blades and 45°.

Figure 8: Two Blades and 45°
A three-blade and 45 degree turbine was designed and created. It can be seen in Figure 9: Three Blades and 45°.

A four-blade and 30° degree turbine was designed and created. It can be seen in Figure 10: Four Blades and 30°.
A four-blade and 37.5 degree turbine was designed and created. It can be seen in Figure 11: Four Blades and 37.5°.

![Figure 11: Four Blades and 37.5°](image1)

A four-blade and 45 degree turbine was designed and created. It can be seen in Figure 12: Four Blades and 45°.

![Figure 12: Four Blades and 45°](image2)
A four-blade and 52.5 degree turbine was designed and created. It can be seen in Figure 13: Four Blades and 52.5°.

![Figure 13: Four Blades and 52.5°](image13)

A four-blade and 60 degree turbine was designed and created. It can be seen in Figure 14: Four Blades and 60°.

![Figure 14: Four Blades and 60°](image14)
A five-blade and 45 degree turbine was designed and created. It can be seen in Figure 15: Five Blades and 45°.

![Figure 15: Five Blades and 45°](image1)

A six-blade and 45 degree turbine was designed and created. It can be seen in Figure 16: Six Blades and 45°.

![Figure 16: Six Blades and 45°](image2)
A seven-blade and 45 degree turbine was designed and created. It can be seen in Figure 17: Seven Blades and 45°.

![Image of Seven Blades and 45°](image1.png)

**Figure 17: Seven Blades and 45°**

An eight-blade and 45 degree turbine was designed and created. It can be seen in Figure 18: Eight Blades and 45°.

![Image of Eight Blades and 45°](image2.png)

**Figure 18: Eight Blades and 45°**
Three different enclosure styles were designed and fabricated from designs completed in SolidWorks, fabricated from Acrylic plastic cut with a laser-cutting machine, and then molded together with model glue. These enclosures included: enclosure 2 with two openings which blocked the $90^\circ$ where the turbine was returning into the wind and directed the wind around approximately $260^\circ$ of the turbine and an enclosed top and bottom; enclosure 3 which blocked the $90^\circ$ of the where the turbine was returning into the wind and an enclosed top and bottom; and enclosure 4 which blocked the $90^\circ$ of the where the turbine was returning into the wind and the directed the wind around the opposite $90^\circ$ of the turbine and an enclosed top and bottom. The Enclosures are shown in figures 19 through figure 21.

Enclosure 2 is shown in Figure 19: Enclosure Two Front and Top Views.

![Figure 19: Enclosure Two Front and Top Views](image)
Enclosure 3 is shown in Figure 20: Enclosure Three Front and Top Views.

Figure 20: Enclosure Three Front and Top Views

Enclosure 4 is shown in Figure 21: Enclosure Four Front and Top Views.

Figure 21: Enclosure Four Front and Top Views
Note that all tests completed with the top pictured in Figure 22: Top of an Enclosure.

![Figure 22: Top of an Enclosure](image)

Previous testing had been completed using two through eight blade turbines. These tests used no enclosure and enclosure 1. The results of these tests, indicated that enclosing the wind turbines created shaft alignment vibration under various conditions the following designs and procedures were created to provide more reliable data. The turbine shafts in these test were fixed only at the bottom end of the shaft, and as a result acted as cantilever structures.

A shaft to mount the turbines on was designed in SolidWorks and fabricated out of ¼ inch steel axil shaft. This shaft was securely attached to the top of the wind turbine at the top by a stabilization mount and bearing which was designed in SolidWorks and fabricated out of cylindrical stock aluminum. The other end of the shaft was securely mounted to an anemometer, which could record the revolutions per minute on a data logger and computer programming. This set up was designed to hold the wind turbine and enclosure securely in the middle of the wind turbine. A complete example set up can be seen in Figure 23: Turbine Set Up.

### 3.2. Testing

Before testing of the previously mentioned setups could be completed a calibration of the wind tunnel had to be complete. All testing was completed in a wind tunnel with a 24-inch by 24-inch cross section with in a rectangular testing segment. In order to confirm
accuracy of the data relative to wind speeds a three-cup anemometer was used to measure the wind speed within the testing segment of the wind tunnel at the give output in hertz provided on the tunnel’s display.

Each turbine was first tested without an enclosure, then with enclosure 2, enclosure 3, and then enclosure 4. The procedure was to place the completed set up, shown in Figure 18: Turbine Set Up, inside the wind tunnel and begin the test at 42 miles per hour and step the wind speed down in even increments every 30 seconds until a wind speed of zero was reached.

![Figure 23: Turbine Set Up](image)

Once this was completed the turbine would be changed and the test then completed with that turbine. Once every turbine was tested with an enclosure, the enclosure was changed and every turbine was tested with the next enclosure.

### 3.3. Further Design

Designs were completed in SolidWorks of a wind funneling system to be used in conjunction with the previously constructed testing equipment in order to test for further efficiency gains.

Designs were completed for a torque-measuring device to be used with the previously constructed testing equipment in order to test for further efficiency gains. Images of these designs can be seen in detain in the results section of the report.
4. Findings

This section outlines our results and findings from our research. It outlines the data collected and designs created. It then suggests further research, which could build off the data collected and analyzed. Blade area was found to be the most promising variable to follow because of the clarity of results seen.

4.1. Enclosures vs. No Enclosures

A comparison of the differences of each turbine shows that regardless of blade number, area, or angle any turbine tested can be made more efficient when enclosed.

Figure 24: Two Bladed Enclosure Comparison shows that all the enclosures tested will increase the efficiency of the two-blade turbine tested.

Figure 25: Three Bladed Enclosure Comparison shows that all the enclosures tested will increase the efficiency of the three-blade turbine tested.
Figure 26, Figure 27, Figure 28, Figure 29, and Figure 30 shows that all the enclosures tested will increase the efficiency of the five different four-blade turbine tested.
Figure 29: Four Bladed 52.5 Degree Enclosure Comparison

Figure 30: Four Bladed 60 Degree Enclosure Comparison

Figure 31: Five Bladed Enclosure Comparison shows that all the enclosures tested will increase the efficiency of the five-blade turbine tested.
Figure 32: Six Bladed Enclosure shows that all the enclosures tested will increase the efficiency of the six-blade turbine tested.

![Six Bladed Enclosure Comparison](image)

Figure 33: Seven Bladed Enclosure shows that all the enclosures tested will increase the efficiency of the seven-blade turbine tested.

![Seven Bladed Enclosure Comparison](image)
Figure 34: Eight Bladed Enclosure Comparison shows that all the enclosures tested will increase the efficiency of the eight-blade turbine tested.

A comparison of the differences of each enclosure shows how the enclosures affected the complete data set of each enclosure.
Figure 35: No Enclosure Turbine Comparison shows a comparison of all the data collected for each turbine with no enclosure.
Figure 36: Enclosure Two Turbine Comparison shows a comparison of all the data collected for each turbine with enclosure 2.

![Enclosure 2](image)

Figure 36: Enclosure Two Turbine Comparison

Figure 37: Enclosure Three Turbine Comparison shows a comparison of all the data collected for each turbine with enclosure 3.

![Enclosure 3](image)

Figure 37: Enclosure Three Turbine Comparison
Figure 38: Enclosure Four Turbine Comparison shows a comparison of all the data collected for each turbine with enclosure 4.

While the general overview of data presented in these figures makes it apparent that enclosing a VAWT will increase its efficiency the combination of the data makes it hard to form any real trends. Comparison of other factors such as blade area may prove to be more useful.

4.2 Blade Area

Evaluating the blade area VAWTs used for testing shows the potential to increase the efficiency of the turbines. An evaluation using the median value of rpm yielded the following findings.
Figure 39: No Enclosure Blade Area vs. RPM Graph shows that blade area appears to have a large effect on any non-enclosed VAWT's rpm's.

![No Enclosure Blade Area Vs. RPMs](image)

**Figure 39: No Enclosure Blade Area vs. RPM Graph**

Figure 40: Enclosure 2 Blade Area vs. RPM Graph shows that blade area appears to have a minimal effect on any VAWT in enclosure 2.

![Enclosure 2 Blade Area Vs. RPMs](image)

**Figure 40: Enclosure 2 Blade Area vs. RPM Graph**
Figure 41: Enclosure 3 Blade Area vs. RPM Graph shows that blade area appears to have little effect on a VAWT with an area between 30in^2 and 90in^2 at 45° to tangent and a wind speed below 40MPH in enclosure 3.

![Enclosure 3 Blade Area Vs. RPMs](image)

*Figure 41: Enclosure 3 Blade Area vs. RPM Graph*

Figure 42: Enclosure 4 Blade Area vs. RPM Graph shows that blade area appears to have variable effects on rpm with varying wind speeds.

![Enclosure 4 Blade Area Vs. RPMs](image)

*Figure 42: Enclosure 4 Blade Area vs. RPM Graph*

The different blade areas associated with the turbines proved to have the biggest effect when they were not within an enclosure. When the turbines were placed within an enclosure the blade areas seemed to matter less when analyzing the number of rpms produced. Enclosure 2 provided the most promising results because very similar results
were yielded at each wind speed regardless of blade area. This is promising for testing with the torque monitoring set up because it may be possible for the VAWTs with greater areas to produce more torque at the same rpms as the turbines with lower blade areas.

4.3. Torque-Monitoring Device

Figure 43: Torque-Monitoring Device Front and Back shows the torque-monitoring device fabricated to test the differences in torque produced between different blade areas.

4.4. Wind Funneling Testing Device

Figure 44: 30 Degree Wind Funneling Device shows the completed designs for the wind funning device with a 30° opening.
Figure 45: 45 Degree Wind Funneling Device shows the completed designs for the wind funning device with a 45° opening.

Figure 45: 45 Degree Wind Funneling Device

Figure 46: 60 Degree Wind Funneling Device shows the completed designs for the wind funning device with a 60° opening.

Figure 46: 60 Degree Wind Funneling Device
5. Summary

Enclosing vertical axis wind turbines shows the potential to increase their efficiency which would not only reduce the turbine’s ROI to a homeowner, but also could decrease emission of eCO$_2$ into the atmosphere from non-sustainable energy sources.

Comparison of blade area may be the best way to continue with research because of the trends seen. It will be possible to test if a greater blade area will yield a greater torque with the relatively similar rpm's.
Works Cited


Appendix A

This Appendix contains data collected during testing of the various turbines and shrouds. The following terminology was used.

Enclosures
E0 or bank name where the enclosure name would be: no enclosure
E2: 260 degrees “back” and 90 degree “front”
E3: 90 degrees “front”
E4: 90 degrees “front and 90 degrees “back”

Offsets
100 degrees for E2 is closest to wind tunnel controls
100 degrees for E3 is opposite wind tunnel controls
Note: A 100 degrees of set put the wind coming directly into the opening of each enclosure.

S1,S2: refers to which shaft was used. This report used only data gather while using S2 which was securely supported at both ends.

Note: View Electronically and use zoom function to view data
Table 1: No Enclosure Data

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Note: Additional columns and data points may be present in the table.