Evaluation of Airfoils for Small Wind Turbines

Donny R. Cagle, Anthony D. May, Brian D. Vick and Adam J. Holman

WTAMU/Alternative Energy Institute
In cooperation with
USDA-Agricultural Research Service
Bushland, TX

Evaluation of Airfoils for Small Wind Turbines

Donny R. Cagle
WTAMU/AEI
PO Drawer 10
Bushland, TX 79012
dcagle@cprl.ars.usda.gov

Anthony D. May,
PhD Student,
Finance Division,
Price College of Business
University of Oklahoma
admay@ou.edu

Brian D. Vick
USDA/ARS
PO Drawer 10
Bushland, TX 9012
bdvick@cprl.ars.usda.gov

Adam J. Holman
WTAMU/AEI
PO Drawer 10
Bushland, TX 79012
aholman@cprl.ars.usda.gov

ABSTRACT

A new set of blades have been designed, fabricated, and tested at the United States Department of Agriculture-Agricultural Research Service-Conservation and Production Research Laboratory in Bushland, Texas in an attempt to improve the overall performance of small (1-10 kilowatt) wind turbines. The new turbine blades feature more advanced NREL S822 and S823 airfoils, a linear chord distribution, and a near Glauert twist distribution. The blades were fabricated using a hand lay-up method in a single mold. The rotor blades were adapted to a 1.5kW wind turbine for performance and reliability testing. These new blades have demonstrated a lower cut-in wind speed as well as higher energy yield and efficiency than that of the original blades on the 1.5kW wind turbine. Peak coefficient of power for the system was 0.30 for the Bergey blades and 0.41 for new blades. The annual water volume pumped was estimated to double with the new airfoils.

INTRODUCTION

For the past ten years, the USDA-Agricultural Research Service (ARS) Conservation and Production Research Laboratory (CPRL) has been field testing a 3-blade 1.5kW Bergey[1] wind turbine (3.05m diameter) with a 3-phase submersible motor and centrifugal pump for stand-alone water pumping for cattle. Previous studies have shown that the wind electric system has been able to pump enough water from a 73m well to satisfy the water requirements of 80 head of cattle during the fall, winter, and spring. However, only about half the water needed for the 80 head of cattle was pumped by the wind-electric system in the summer low wind months in the Great Plains. An estimate of a 15 blade, 3.05m rotor diameter Dempster mechanical windmill with a piston pump showed it would have pumped enough water to satisfy the water requirements of 80 head of cattle during the entire year (Vick et. al, 1999). A hypothesis was made that the water deficit inherently present for the wind-electric water pumping system during the low wind months could be made up if the system was modified to have a lower cut-in wind speed. In an attempt to improve the overall performance of this wind electric system a new set of blades (*MC Series II* experimental blades) were fabricated and tested on a Bergey 1.5kW wind turbine at USDA-ARS-CPRL near Bushland Texas.

[1] Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S Department of Agriculture and West Texas A&M University.

BERGEY 1.5kW BLADES

The Bergey 1.5 kW blades are 1.37m (4.42 ft) in length. They are made with a pultrusion process in which continuous fiberglass is impregnated with resin and pulled through an airfoil shaped die. The blades are fabricated with a single BW3 airfoil **(Figure 1)** and have a constant chord and no static twist distribution but have pitch weights located near the outboard tip of the blade to allow for some dynamic twisting (**Figure 2)**.

MC SERIES II EXPERIMENTAL BLADES

The goal of this project was to produce blades with more advanced blade and airfoil characteristics in an effort to increase the performance of the Bergey 1.5kW system. This was accomplished by modification of a Havatex 2 kW wind turbine blade. The modified blade served as a model for the production of a mold to produce three functional blades that were built and tested on the Bergey 1.5 kW wind turbine. The final blade design was 0.3m (1ft) longer than the Bergey 1.5kW blade. The *MC Series II* blades incorporated NREL S822 and S823 airfoils **(Figure 1)** for the outboard and inboard sections of the blade respectively. Besides a linear chord taper from root to tip, the blades also incorporated a near Glauert twist distribution. **Figure 3** illustrates the differences in blade geometry between an *MC Series II* blade and a Bergey 1.5kW blade.

Turbine and Tower

The wind turbine used was a three bladed, up-wind horizontal axis machine and was mounted on an 18.3m guyed Rohn 25G lattice tower (**Figure 4).** It features a 3.05m (10 ft) rotor diameter with a direct drive, permanent magnet alternator (PMA) and a horizontal auto-furling tail vain. The turbine was rated at 1500 Watts at a wind speed of 12.5m/s (28 mph) and furled at a wind speed of 13.4m/s (30 mph).

Motor and Pump

The submersible motor used for testing the Bergey 1.5kW original blade set was an off-the-shelf Franklin Electric 1.1kW (1.5hp), 230V, 3-phase AC submersible motor. The submersible motor used for testing the Bergey 1.5kW original blade set was an off-the-shelf Franklin Electric 1.1kW (1.5hp), 230V, 3-phase AC submersible motor. The pump was installed at 87.8m in a 90m well with a static water level of 73m. The submersible motor used for testing the *MC Series II* blades was an off-the-shelf Grundfos 1.1kW, 230V, 3-phase AC submersible motor. The same Grundfos pump used in the Bergey 1.5kW blade testing was used for the *MC Series II* experimental blade testing.

Controls

Another difference in testing was that the original Bergey 1.5kW blade configuration used a controller developed by a cooperative effort between the USDA-ARS and WTAMU-AEI (West Texas A&M University-Alternative Energy Institute) which allowed the user to adjust 4 different frequency settings:

1. low frequency cut-out (30Hz)
2. low frequency cut-in (50Hz)
3. high frequency cut-in (70Hz)
4. high frequency cut-out (78 Hz)

However, the *MC Series II* blades didn't use the same controller for connecting to the motor/pump. Instead, a Campbell Scientific data logger was used to open and close a relay that in turn would connect and disconnect the turbine to the motor/pump. Two frequency settings of 30 and 70 Hz were used to connect and disconnect the turbine. The turbine would only be connected if the frequency was between 30 and 70 Hz. Any frequency above 70Hz or below 30Hz would cause the relay to stay open. A high cut-in/cut-out frequency of 70Hz was chosen because the power measured at 80Hz was witnessed to reach 3kW which greatly exceeds the capacity ratings of the turbine. Both blade configurations had a constant 55μF capacitance added in parallel with each phase of the motor. Capacitance is added to increase the voltage to frequency ratio to ≈ 3.5 so the voltage and current are closer in phase with each other.

Instrumentation and Data Acquisition System

The data collected on the wind-electric system included:

1. Wind speeds at 10m height (Bergey blades only)
2. Wind speeds at 16.5m height
3. Voltage of wind turbine
4. Current of wind turbine (Bergey blades only)
5 Power of wind turbine
6. Water flow rate
7. Instrumentation and data acquisition system battery voltage
8. Outside air temperature
9 Inside air temperature

One-minute averages of these parameters were collected using a Campbell Scientific Instruments CR21X micro logger and later on a CR23X micro logger. Flow rate was measured using a Hersey model 30 flow meter. Wind speeds were measured using model 014 Met-One cup anemometers. Two anemometers were mounted at heights of 10m and 16.2m on the same tower as the wind turbine. Both anemometers were extended 1.5 meters west of the tower on telescoping pipes. Using the 16.5m anemometer height rather than the hub height (18.5m) results

in an error in wind speed of less than 0.25m/s based on extrapolations of the wind speeds at 10m and 16.5m height to the 18.5m height (Vick, et. al, 1998).

RESULTS

Data collected for both wind-electric water pumping configurations were averaged with a Quick Basic program and tabulated in Microsoft Excel. Wind speeds at 10m (33ft) and 16.5m (54ft) height were tabulated for April 1998 through April 1999. Wind speeds at an 18.5m height were also tabulated for January through December 2003. Average power and flow rate were plotted versus wind speed in 0.5m/s bins. Power for both blade configurations peaked at 1300 Watts. This similarity in peak power was a result of having the same electrical load for the stand-alone configuration. The power curve did, however, shift to the left improving the cut-in wind speed from 6m/s to 5m/s. The power curve is also steeper resulting in the peak power being shifted 2.5m/s to the left when compared to the Bergey blades (**Figure 5)**. This shift in power production from right to left along with maintained peak power output shows an improvement in the efficiency of the system. By installing longer blades on the wind turbine, a greater swept area has been provided by the rotor. To show that this increase in power production is not due entirely to the increase in rotor diameter, non-dimensional units were used to show the efficiency in the form of a coefficient of power (C_p). Results of this analysis indicate a power coefficient of 0.33 at 5.5m/s and further increases to 0.41 at 6.5m/s. This is a 37% improvement in peak power coefficient over the Bergey blades (**Figure 6)**. The flow versus wind speed curve seen in **Figure 7** follows the power curve very well and indicates more water was being pumped at lower wind speeds for the experimental blades than for the Bergey blades.

As previously stated, wind distribution tables were generated for various wind speed heights during two different time periods of interest. A wind distribution table was generated for the year 2003 at a height of 18.5m which is the actual hub height for the wind turbine in this study. This year was chosen because the wind power density for this year was found to be close to that of a normal wind year at a 10m ht for Bushland, Texas. This wind speed distribution was used to project monthly kWh production **(Figure 8)** as well as projected daily water volume **(Figure 9)** for both sets of blades. In addition, the year of April 1998 through April 1999 was chosen because analysis has shown that the wind power density for that time period was significantly low when compared to a normal year, therefore this period was a good time frame to use for predicting how the two blade sets would compare during abnormally low wind months when water would be needed most. **Figures 10 and 11** show energy production as well as flow rate experience a lag during the summer months of 1998. Assuming a demand of 4000 liters per day (close to the equivalent of 80 head of cattle) the Bergey blades fall into a deficit during the low wind months of August while the experimental blades showed to provide about 8700 liters per day or enough water to meet the demand of 170 head of cattle. To further evaluate the capabilities of the experimental blades, a wind speed distribution at a 10m height was tabulated along with corresponding projected daily water yields (**Figure 12)**. This distribution corresponds to the hub height of typical Dempster water pumping wind mill. Results indicate that the experimental blades and the wind mill compete well during the low wind months and can provide enough water to meet the demands of 80 head of cattle. Values for the

Bergey blades were already low for these months at a 16.5m height therefore, values at the 10m height were not presented.

Capacity factors were calculated for each set of blades using the projected energy production values. For wind speeds at a 16.5m height, the capacity factor was improved from 20% to 30%. Capacity factor for an 18.5m height also showed a similar improvement from 22% to 33%. Therefore the capacity factor has been improved by 50%. This increase in capacity factor is primarily a result of the improved cut-in wind speed for the wind turbine as well as the improved efficiency of the rotor. Annual energy production for different annual wind speeds assuming sea level standard day conditions and a Rayleigh wind distribution was also calculated and compared for both sets of blades (**Figure 13**) (Rohatgi et. al, 1994). Energy production for the experimental blades exceeds that of the Bergey blades by 70% at 5m/s and gradually merges as the annual average wind speed approaches 10m/s.

Conclusions

It has been shown by implementation of advanced blade manufacturing techniques such as improved airfoil shapes, variable chord distributions, and variable twist distributions that the overall performance of small wind turbines can be improved significantly. Data from this experimental study indicated a 37% improvement in peak system efficiency due to these changes. The capacity factor of this system showed a 50% improvement. Cut-in wind speed of the wind turbine was successfully reduced from 6m/s to 5m/s which would enable the system to effectively compete with a wind mill of similar rotor diameter. These improvements also imply that the water requirements for 80 head of cattle can be achieved during the low wind months.

ACKNOWLEDGMENTS

We would like to thank Dr. C.Y. Chen (Professor of Engineering Technology at WTA&MU) for providing us the time and opportunity to plan and build our wind turbine blades. We would like to thank Mr. Ken Starcher (WTAMU-AEI) for providing the materials needed to produce the *MC Series II* blades as well as information regarding design and testing. We would like to thank Chase Roberson, Byron Neal and Dr. R. Nolan Clark (USDA/ARS) for providing materials and allowing us to use data collected at USDA/ARS, CPRL in Bushland, Texas.

References

1. 1999. Vick, B.D., Clark, R.N., and Ling, S. One and a Half Years of Field Testing a Wind-Electric System for Watering Cattle in the Texas Panhandle. AWEA Windpower ’99 Proceedings, June 20-24, Burlington, VT, 10pp.

2. 1998. Vick, B.D., Davis, R.G., and Clark, R.N. Field Experience of Using a 1.5Kilowatt Wind Turbine with a Submersible Motor and Pump for Watering Cattle. AWEA Proc. Windpower ’98, Apr. 27 – May 1, Bakersfield, CA, pp. 111-118.

3. 1994. Rohatgi, J.S., Nelson, V. Wind Characteristics. An Analysis for the Generation of Wind Power. ’94, Alternative Energy Institute, West Texas A&M University, Canyon, Texas, p. 154.

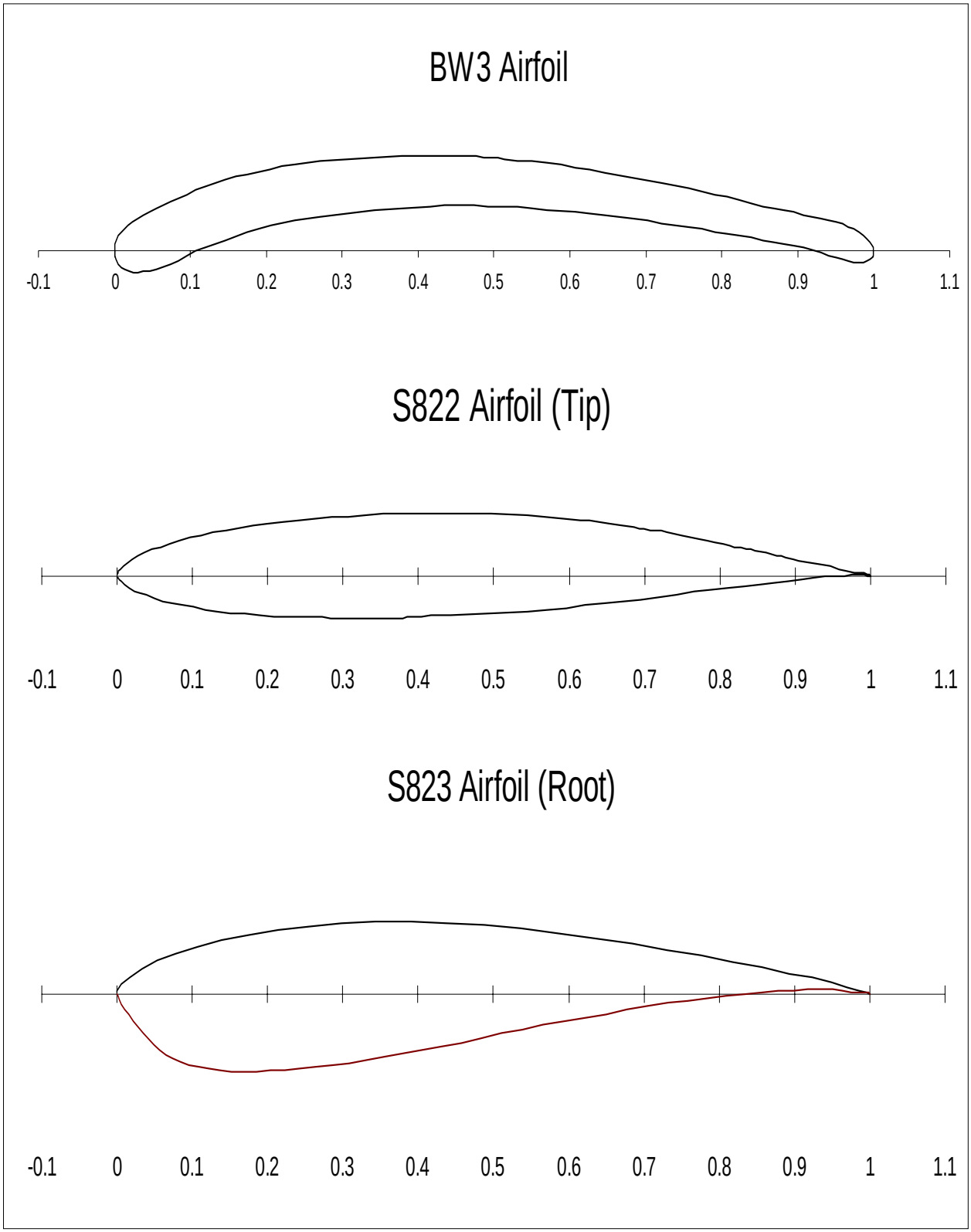

Figure 1: General shape of the Bergey 1.5kW BW3 airfoil (top) and NREL S822 (middle) and S823 (bottom) airfoils. The S822 and S823 airfoils were used for *the MC Series II* Experimental blades.

Figure 2: Bergey 1.5 kW blade with continuous chord airfoil and zero twist distribution

Figure 3: Images showing difference in blade geometry for *MC Series II* Experimental blades and Bergey blades. Note: Difference in length, twist, and variable chord

Figure 4: Bergey 1.5 kW wind turbine with original Bergey 1.5kW blades at USDA/ARS, CPRL in Bushland, Texas.

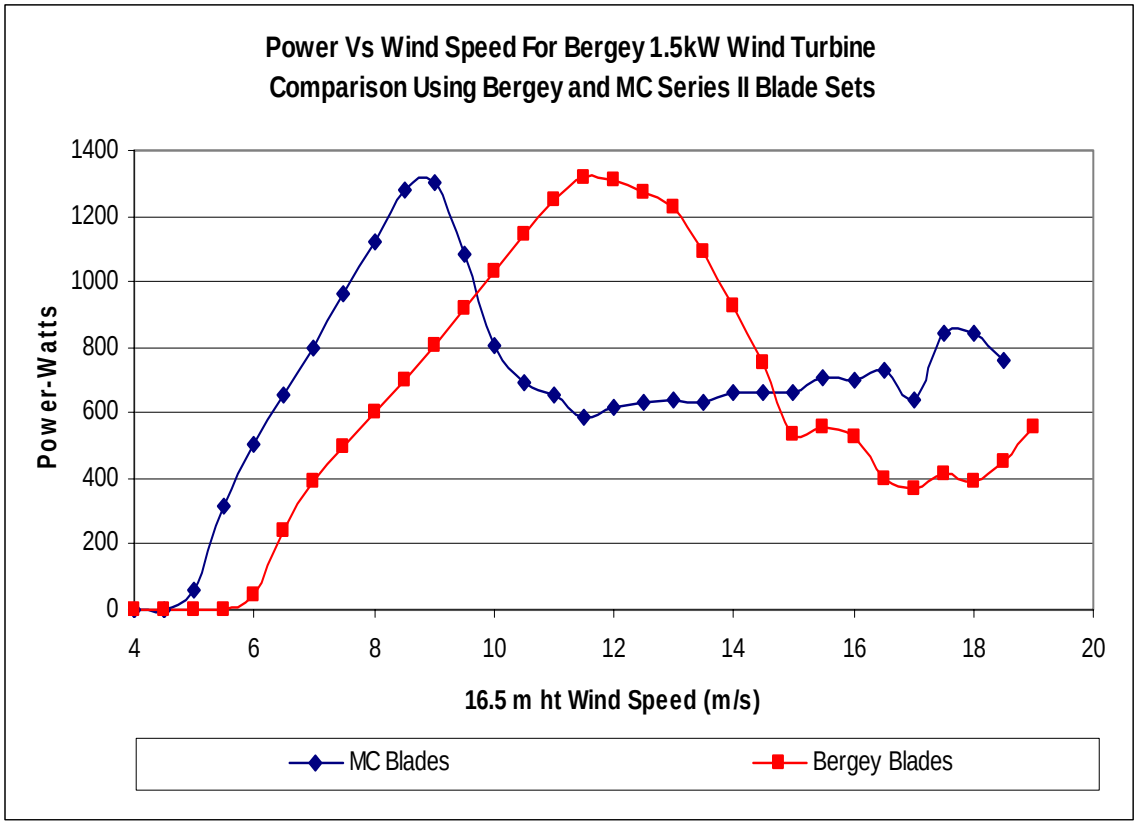

Figure 5: Power curve comparing power performance of *MC Series II* Experimental blades and Bergey blades. Note: Power curve shift to the left for Experimental blades.

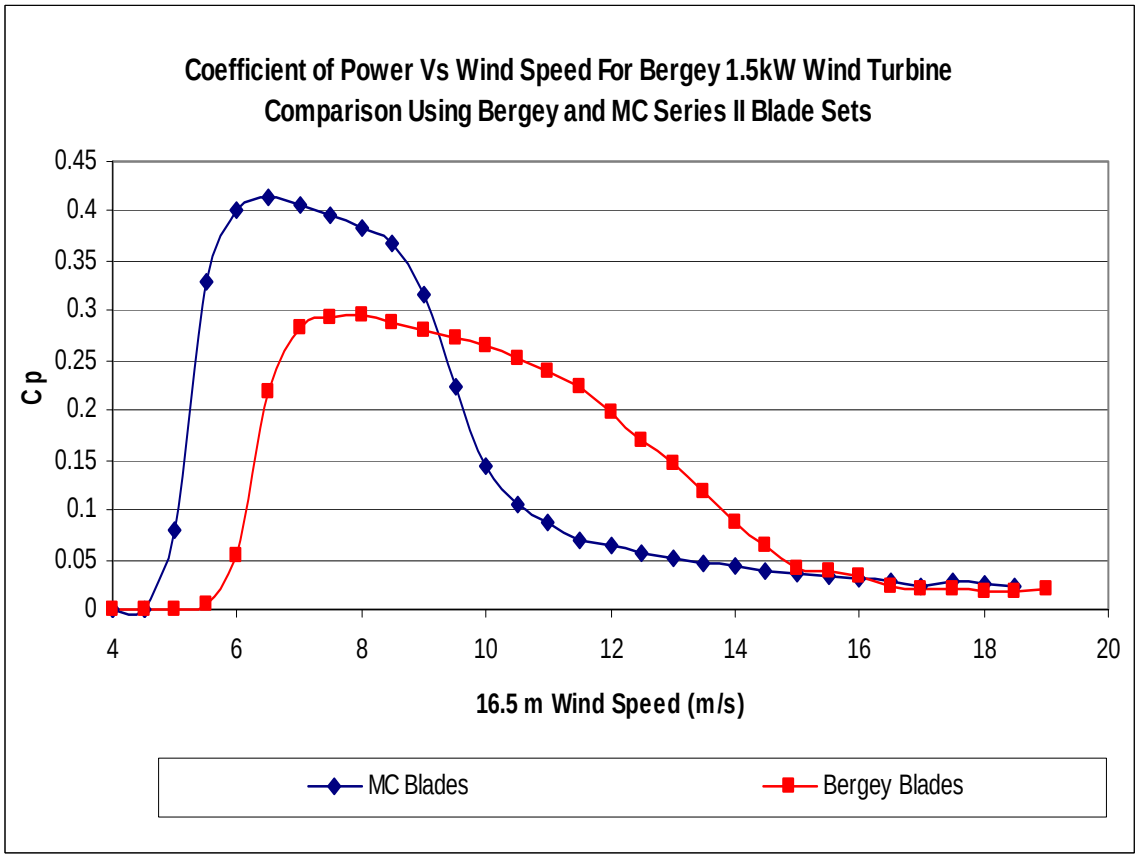

Figure 6: Coefficient of power curve illustrating improved system efficiency for lower wind speeds. Experimental blades have greater peak Cp at a lower wind speed than Bergey blades. Note: Cp is maintained above 0.3 from 5.5m/s to 9m/s.

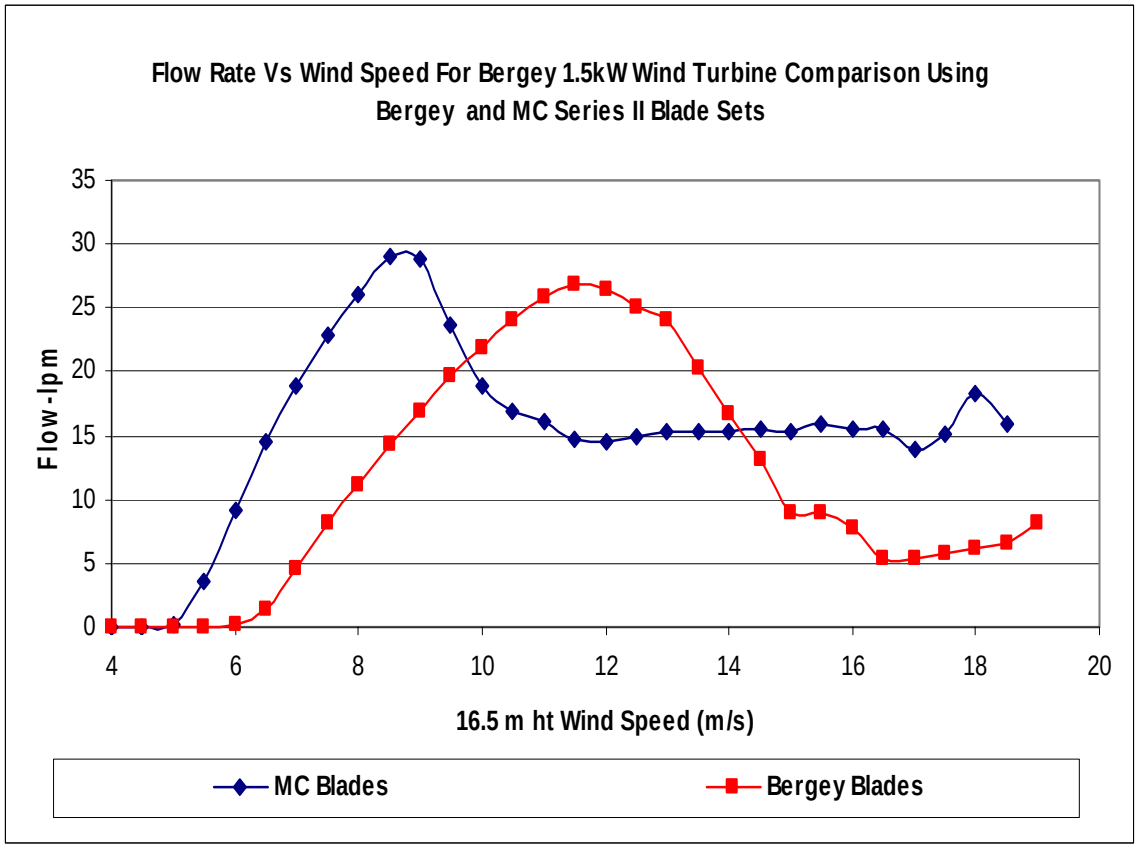

Figure 7: Flow curve comparing water pumping performance of *MC Series II* Experimental blades and Bergey blades. Note: Flow curve shift to the left for experimental blades.

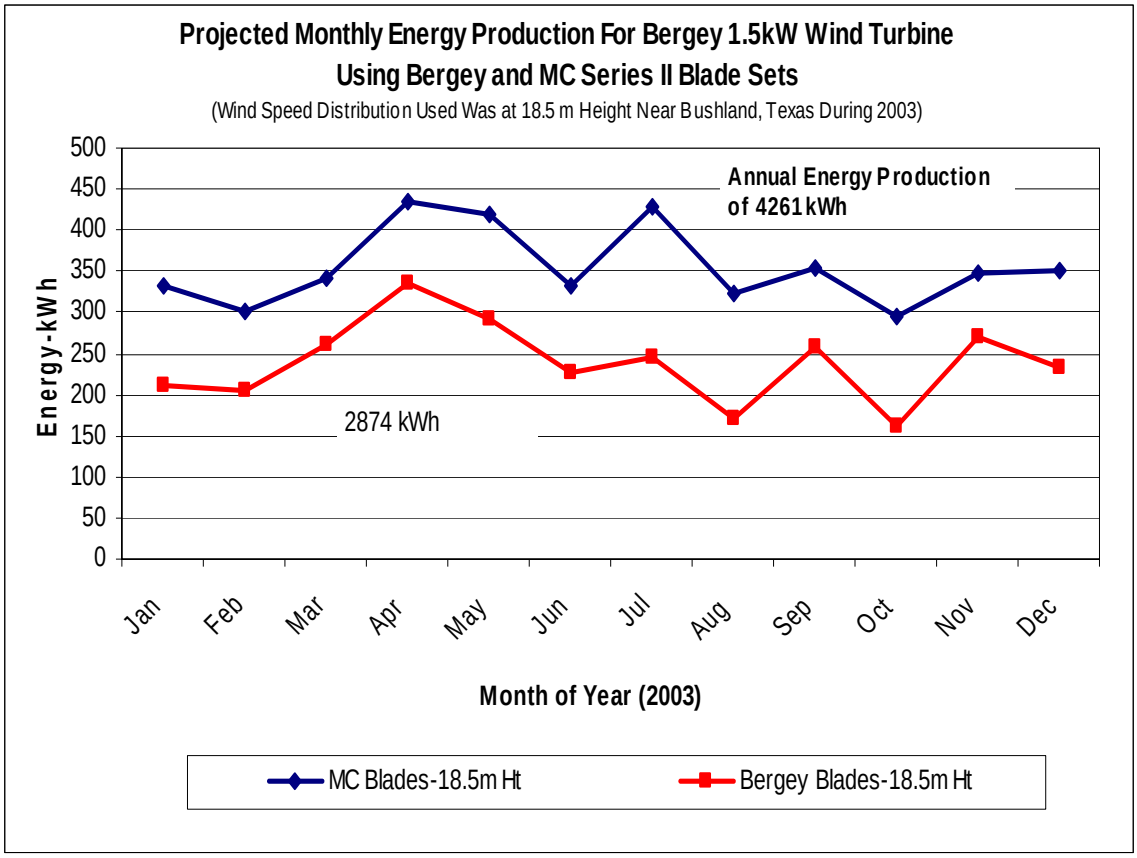

Figure 8: Line chart illustrating projected monthly energy production during the year 2003. Note: Wind speed collected at 18.5m height near Bushland, Texas.

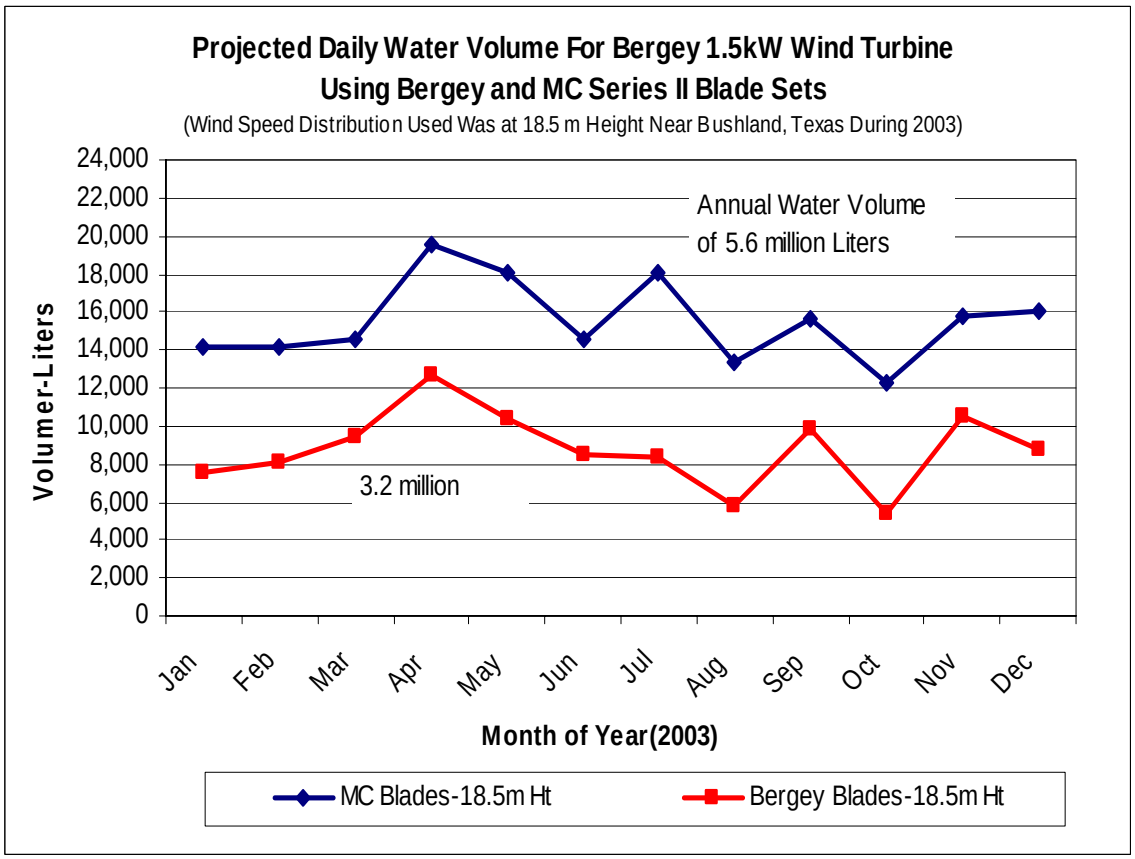

Figure 9: Line chart illustrating projected daily water volume during the year 2003. Note: Wind speed collected at 18.5m height near Bushland, Texas.

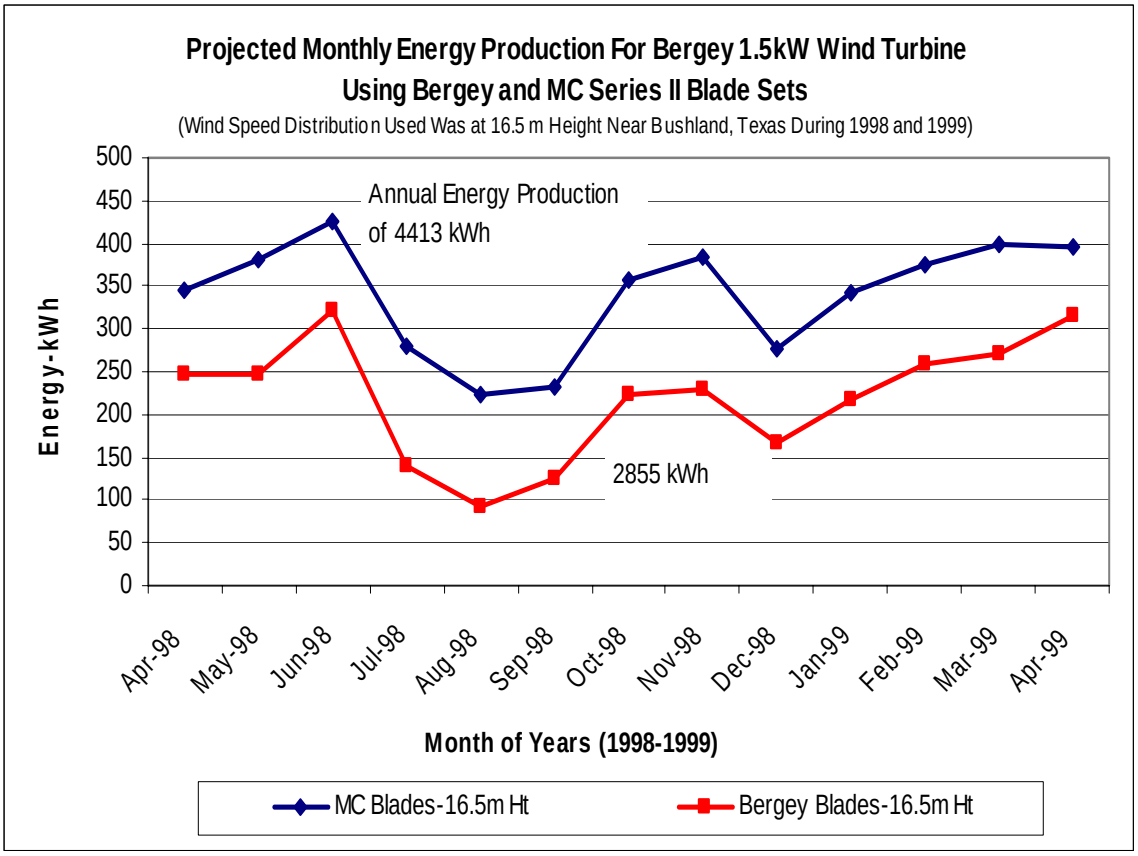

Figure 10: Line chart illustrating projected monthly energy production during the year of 1998-1999. Note: Wind speed collected at 16.5m height near Bushland, Texas.

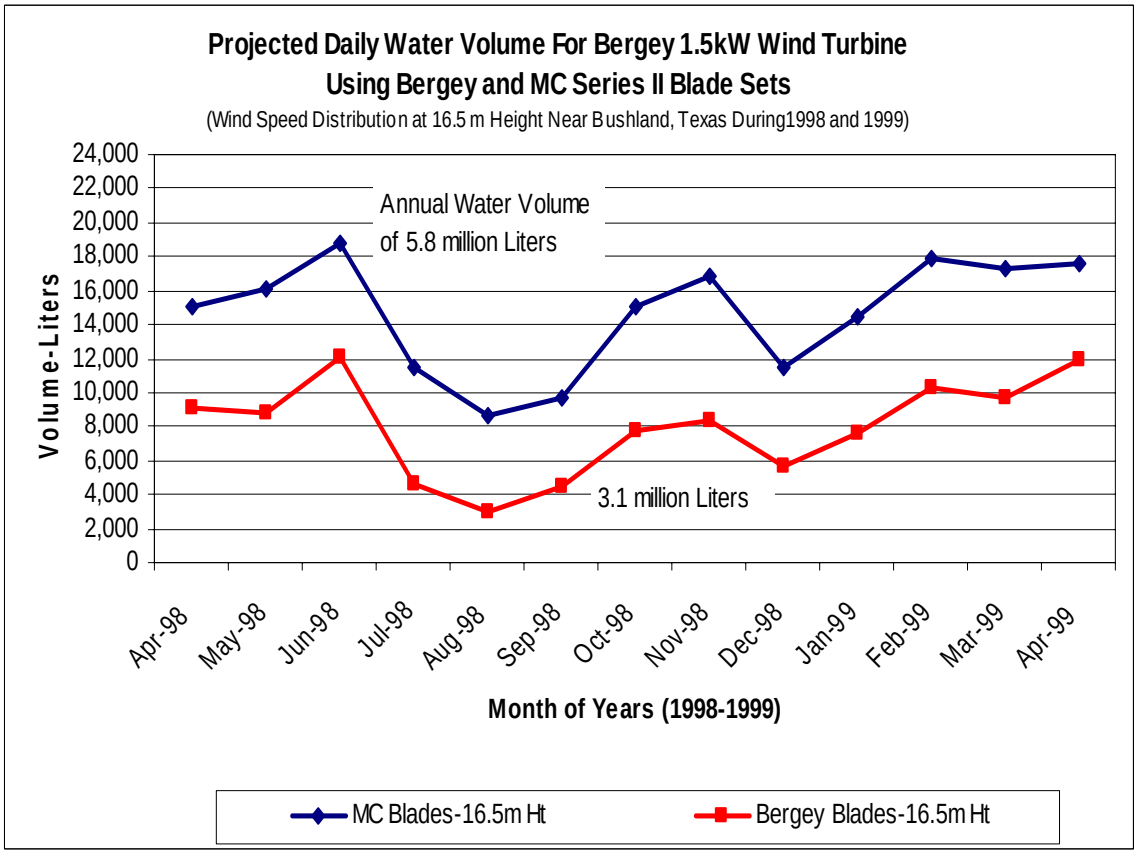

Figure 11: Line chart illustrating projected daily water volume during the year 1998-1999. Note: Wind speed collected at 16.5m height near Bushland, Texas.

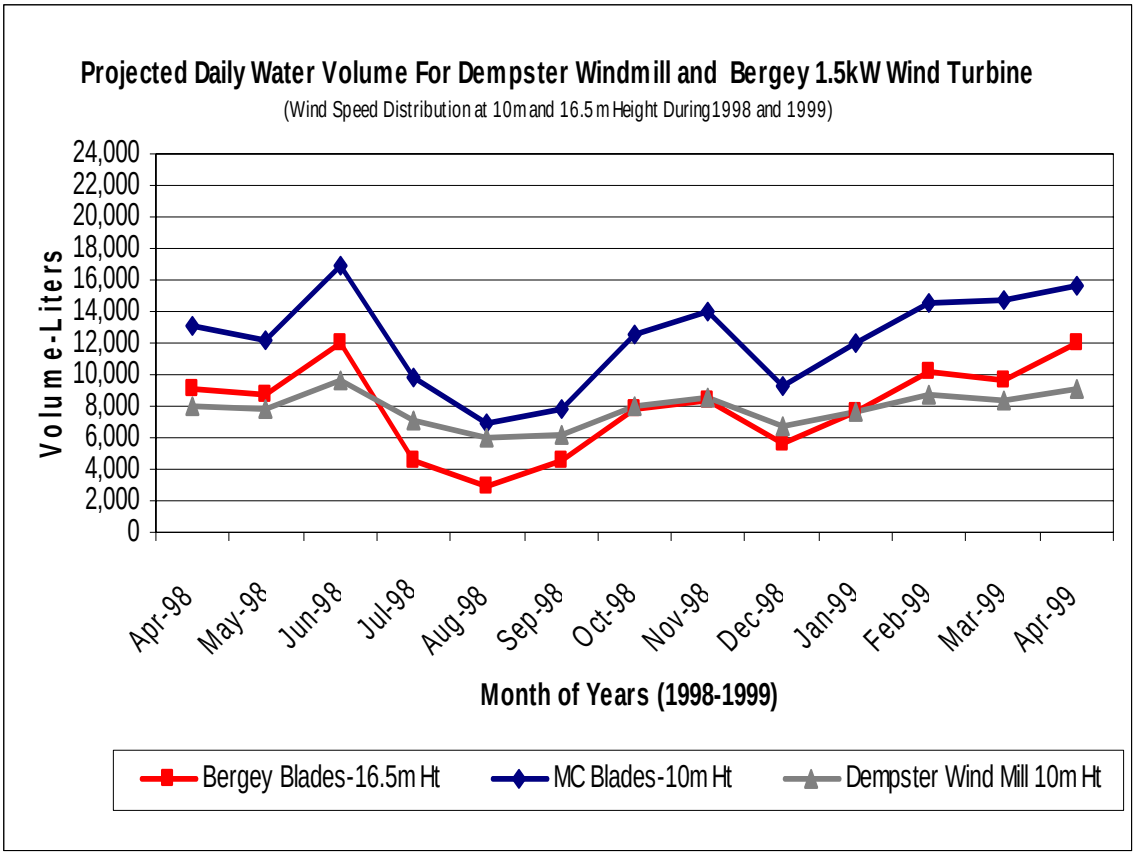

Figure 12: Line chart illustrating projected daily water volume during the year 1998-1999. Note: Wind speed collected at 10m and 16.5m height near Bushland, Texas.

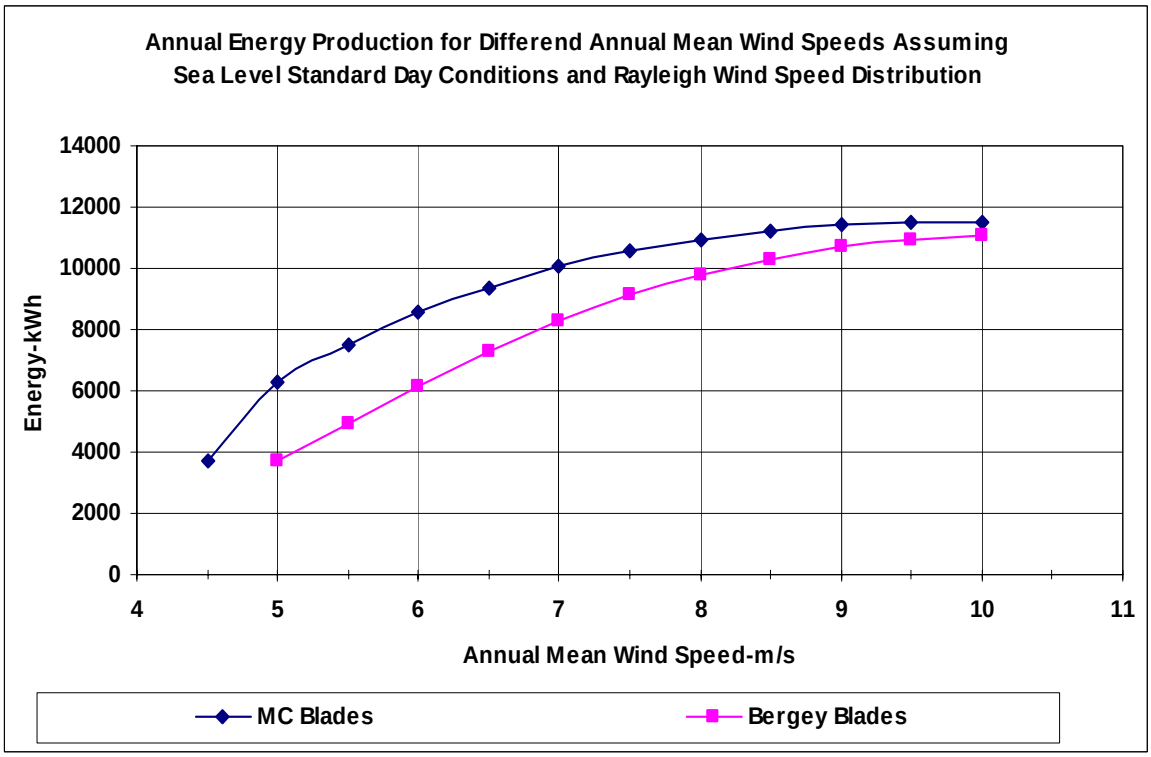

Figure 13: Annual energy production assuming Sea Level Standard Day conditions and Rayleigh wind probability distribution.

SMALL WIND SESSIONS

Main Page | Session List

Simply click on a button to play the presentation or view supplemental material.
To exit a presentation, simply close the browser window which will bring you back to this page.

Small Wind Systems Technical and Market Developments

Small wind systems can and will play a significant role in growing the wind energy business but to do so requires successful market strategies and technology to address both the residential and the small commercial markets. This session explored examples of recent technical advancements in small wind technology that can improve performance and reduce cost and examples of market strategies for bringing small wind systems into the mainstream.

Moderator: Charles Newcomb, Regional Director - Great Plains, Entegrity Wind Systems Inc.

Alicen Kandt, Mechanical Engineer, National Renewable Energy Laboratory
Making the Economic Case for Small Scale Distributed Wind

Louis Rigaud, General Director, Halus Power Systems
Wind Turbines for Projects under 2 MW

Donny Cagle, Research Technician, Alternative Energy Institute, West Texas A&M University
Evaluation of Airfoils for Small Wind Turbines

Byron Neal, Agricultural Engineer, U.S. Department of Agriculture / Agricultural Research Service
Speed Control of a Small Wind Turbine Using Electrical Loading

Play Presentation

Printable Slides

Final Papers

These sessions require Adobe Flash Player and Adobe Reader to view. If you do not have recent versions of Adobe Flash Player or Adobe Reader, you can download the latest versions by clicking on the logos below. **You will need to be connected to the internet to download the player.**
These sessions are best viewed in Internet Explorer 5.0 or higher.

For technical assistance with this DVD-ROM please contact
Content Management Corporation support: support@cmcgc.com or 1-888-711-1138

powered by Content Management Corporation

SMALL WIND SESSIONS

Main Page | Session List

Simply click on a button to play the presentation or view supplemental material.
To exit a presentation, simply close the browser window which will bring you back to this page.

Small Wind Systems Technical and Market Developments

Small wind systems can and will play a significant role in growing the wind energy business but to do so requires successful market strategies and technology to address both the residential and the small commercial markets. This session explored examples of recent technical advancements in small wind technology that can improve performance and reduce cost and examples of market strategies for bringing small wind systems into the mainstream.

Moderator: Charles Newcomb, Regional Director - Great Plains, Entegrity Wind Systems Inc.

Alicen Kandt, Mechanical Engineer, National Renewable Energy Laboratory
Making the Economic Case for Small Scale Distributed Wind

Louis Rigaud, General Director, Halus Power Systems
Wind Turbines for Projects under 2 MW

Donny Cagle, Research Technician, Alternative Energy Institute, West Texas A&M University
Evaluation of Airfoils for Small Wind Turbines

Byron Neal, Agricultural Engineer, U.S. Department of Agriculture / Agricultural Research Service
Speed Control of a Small Wind Turbine Using Electrical Loading

Play Presentation

Printable Slides

Final Papers

These sessions require Adobe Flash Player and Adobe Reader to view. If you do not have recent versions of Adobe Flash Player or Adobe Reader, you can download the latest versions by clicking on the logos below. **You will need to be connected to the internet to download the player.**
These sessions are best viewed in Internet Explorer 5.0 or higher.

For technical assistance with this DVD-ROM please contact
Content Management Corporation support: support@cmcgc.com or 1-888-711-1138

powered by Content Management Corporation