

New Jersey and Urban Wind: Perfect Together?

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GSET '09

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Abstract

Wind turbines require high wind speeds that do not naturally occur in urban settings. The annual average wind speed at Rutgers is 4.6 meters per second, and speeds are within the same range in other urban New Jersey areas. In order to increase gross energy output from wind turbines and make wind energy practical in New Jersey, wind "funnels" should be used to concentrate the wind.

Wind energy is viewed as a "clean" source of energy, but due to noise from vibration and variable output, it is considered impractical in urban areas.

To test whether a wind funnel could make wind power practical for New Jersey and other urban areas, we first performed theoretical calculations to estimate the potential increase in efficiency. Based upon the equation of continuity, we theorized that varying the angles of the wind funnel could theoretically increase efficiency up to 562%.

We then designed and built a prototype wind funnel to verify that the theoretical gains in efficiency would be observed in real life. A prototype funnel,

constructed of white pine and nylon tarp, showed a velocity at 167% of the wind velocity without the funnel.

1 Introduction

A major problem with using wind turbines in urban areas is that the turbines require relatively high wind speeds to function efficiently, which are not always present. New Jersey's average wind speed is approximately four meters per second. Many turbines require a start up speed of approximately 3.6 meters per second before they even begin to generate electricity, and, depending on the turbine design, it is possible that the turbine will consume energy at wind speeds below that.

Urban wind turbines face significant criticism because of their noise, lack of aesthetic appeal, cost, and minimal energy output. Previous attempts have been implausible for large-scale production due to the high initial installation cost and use of a large and unsightly turbine. The concept is unique because it does not require modification of a roof. Instead, it redirects airflow over that roof. Our design scheme is both inexpensive and relatively simple to assemble.

Based upon analysis of a prototype, we have shown that the wind velocity increases 167% using a wind funnel.

2 Background

A wind turbine is a rotating machine that converts the kinetic energy in wind into mechanical energy, which is then converted into electricity.

There are three basic parts of a wind turbine. The rotor blades are forced to move by wind, transferring energy to the rotor. The shaft is connected to the center of the rotor, and transfers mechanical rotational energy to an electromagnetic generator. The generator produces current when the shaft spins magnets in a coil of copper wire.

Essentially, a wind “funnel” uses the idea that the wind turbine is in a fixed position, and increases the amount of wind that it would have access to by directing the wind or “funneling” it in the direction of the turbine.

The wind funnel is composed of two eight-foot by five-foot panels. The panels are a white pine framework covered tautly with nylon tarp. The intention is to use the frames to direct wind into the turbine blades. The panels are angled around an elevated structure on the roof with a plywood ramp from the structure to the roof. Where the panels are orientated would vary with location, but they should consistently open to the least obstructed area of the roof so as to maximize wind.

In order to measure the wind speed differences before and after the installation of the wind “funnel”, we used an anemometer. An anemometer is

a small device that measures wind speed using small cups that capture wind and rotate in a circular path. It allowed us to take wind speed measurements and averages for the specific area in which we were testing. If we had used a turbine, it would be situated between the two panels. In our prototype, the anemometer was used instead.



Figure 2.1 Anemometer
Used to measure wind.



Figure 2.2 Anemometer Location
The anemometer, highlighted in pink, is located between the two panels, highlighted in blue.

Our predictions for the results of creating a wind funnel are primarily based on the equation of continuity, a result of mathematician Daniel Bernoulli's work, which states that $AV = k$. A is the cross sectional area at a point in a given duct, V is the average velocity of the fluid at the same point, and k is a constant, the rate of flow of the pipe. Because the equation holds true for any two points in a given duct, it can also be written as $A_1V_1 = A_2V_2$ where A_1 and V_1 are the cross sectional area and average velocity at one point in the duct, and A_2 and V_2 are the cross sectional area and average velocity at another point in the same duct. Theoretically, the wind should enter the funnel with a certain velocity and as the area of the funnel narrows, the velocity increases to maintain the rate of flow.

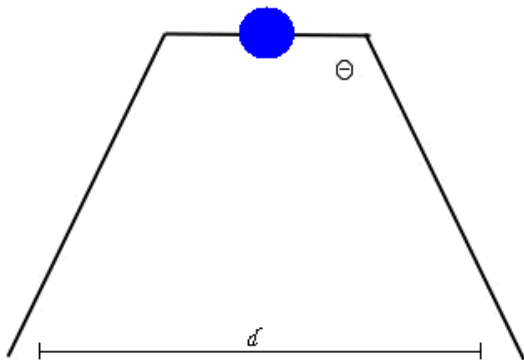


Figure 2.3 Angle θ of “Wings”
*Distance “d” between the wings
 The anemometer’s location is indicated by the blue circle.*

In our predictions for increase in wind speed we assessed three different angle measures (indicated by θ) between the “funnel” walls and the structure on which the anemometer was placed.

Since the panels are fixedly at eight feet long and five feet tall, the only thing that varies is the distance between them,

based upon the angles, and this affects the volume.

Design ‘Wing’ Angles	Original Velocity	New Velocity	Percent Increase
120°	1.2 m/s	4.4 m/s	365%
135°	1.2 m/s	5.72 m/s	477%
150°	1.2 m/s	6.75 m/s	562%

Table 2.1 Velocity Comparison

The largest angle we assessed gave the largest increase in wind velocity.

The velocity predictions after the installation of the wind funnel, along with calculations of air volume and mass, can be used to calculate the theoretical transfer of kinetic energy from the wind to the wind turbine. Our computations will be compared to our actual recorded data.

Design ‘Wing’ Angles	Original Kinetic Energy	New Kinetic Energy	Percent Increase
120°	63.4 J	167.3 J	263%
135°	63.4 J	285.4 J	450%
150°	54.7 J	342.0 J	625%

Table 2.2 Energy Comparison

The largest angle we tested gave us the biggest increase in kinetic energy. The amount of kinetic energy flowing through the “funnel” is a key factor in how much energy a wind turbine can produce.

3 Design Decisions

Our wind “funnel” was primarily constructed from white pine and nylon tarp. The biggest factor affecting our design decisions was cost. The materials we chose were reasonably priced while still retaining stability. The funnel was

constructed for under a hundred dollars. Wood was the most expensive component of the design, but at about eight dollars for eight feet of lumber, white pine was by far the most cost-effective choice. Alternatives such as PVC or aluminum pipe were considered, but dismissed as cost prohibitive. Using aluminum in place of lumber would have required hundreds of dollars.

Wood is stable, strong, easy to use for construction, and fairly inexpensive. As the ease of assembly was a functional requirement for our wind funnel, we hoped to build it in approximately three hours.

The initial design included a top piece with a half-parabolic shape made of tarp that would further increase the volume of air funneled into the wind turbine. This design piece was later excluded because of potential difficulty of assembly. It was not possible to find a material to provide a curved frame for the tarp that was both inexpensive and strong enough to hold the tarp in the curved shape.

Nylon tarps are a cheaper way to cover the frames than, for example, plywood.

The major risk is that the tarps would lose the kinetic energy of the wind to vibration, so the tarps were kept taut to minimize that risk.

Two frames were built; each was five feet tall and eight feet long, with cross braces on the corners to prevent skew. They were composed of white pine. The frames were angled out from a rooftop protrusion in order to funnel wind. We included wooden supports along the frames to provide a larger base that would brace the “funnel” against strong gusts of wind.

Included in the design is a four foot length of plywood to create a ramp from the roof top to the elevated anemometer. This decision is in order to make use of all available wind, including that below the level of the turbine blades.

The nine foot by nine foot tarps we used were approximately five dollars each, while the two foot by four foot piece of plywood used for the ramp was around four dollars. Using all plywood to cover the frames would have raised costs significantly.

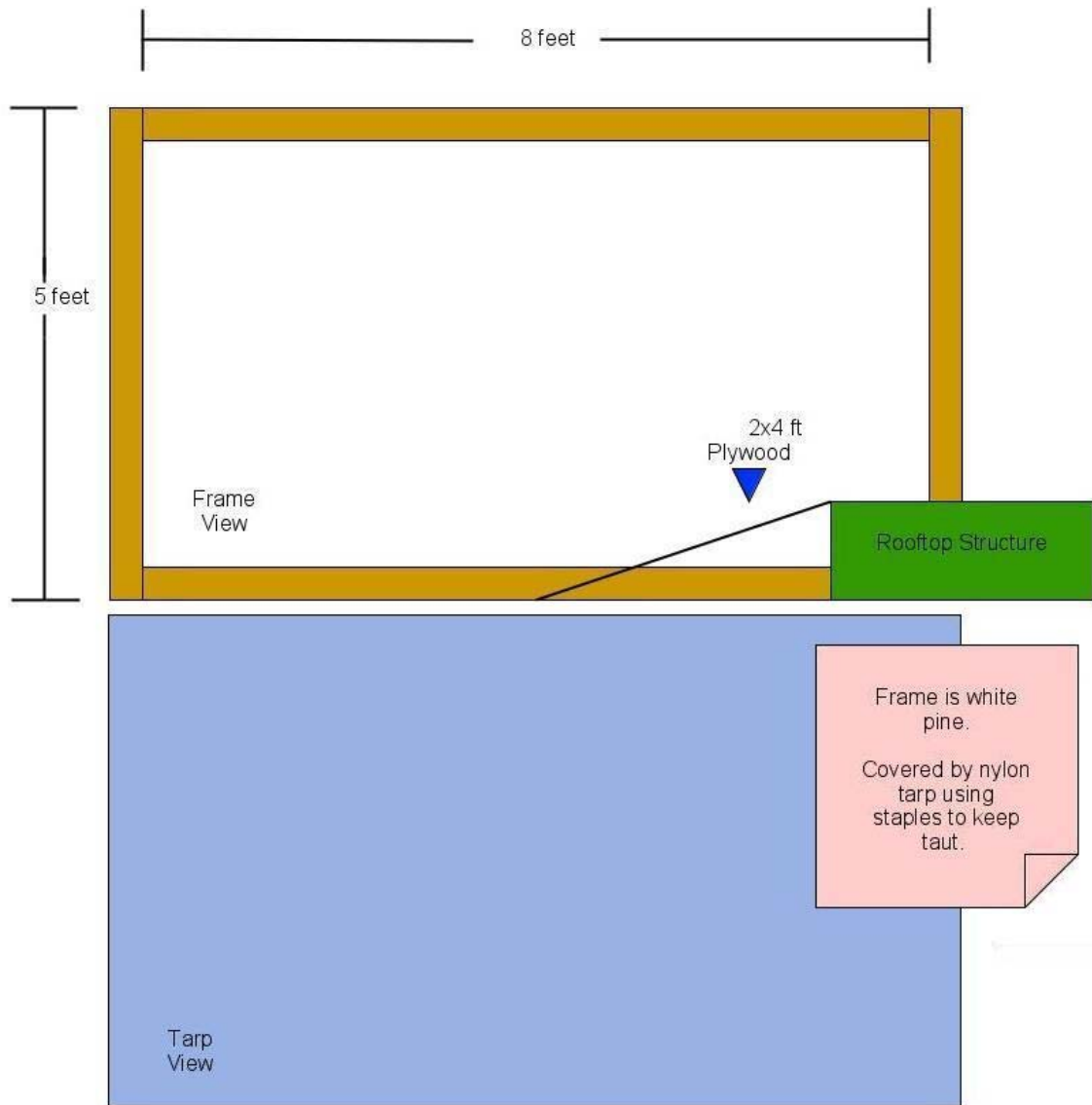


Figure 3.1 Funnel Design Concept

Each frame is eight feet by five feet.

The tarps are stapled over the frames.

There is two foot by four foot ramp made of plywood.

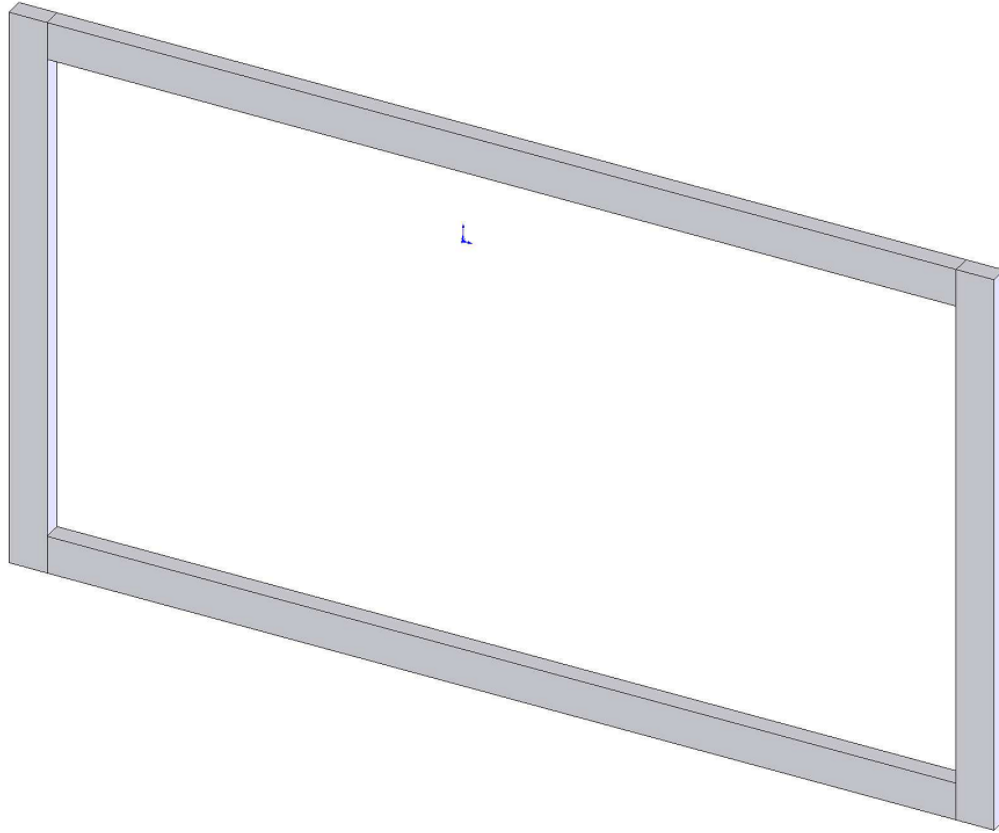


Figure 3.2 Frame

A scale drawing indicating the dimensions of the frame concept in 3D.

Our funnel design needed to increase wind speed enough to boost the efficiency of a small wind turbine while remaining inexpensive. The “funnel’s” “V” shape helps eliminate wind turbulence caused by numerous buildings and structures in urban areas by forcing the air into a more laminar flow.

The wind funnel was built using approximately eighty dollars. Nylon tarp, white pine, screws, plywood, and staples are all affordable to those looking to use wind turbines in urban settings.

4 Experimental Design

For our actual design tests, we chose to test wind speed changes using an angle of one hundred fifty degrees between the “funnel” wall and the anemometer. This angle provided the largest predicted increase in wind speed. The volume of air flowing through the “funnel” and the net kinetic energy within increased in a direct relationship with the velocity.

Design ‘Wing’ Angles	Inner Cross Sectional Area	Outer Cross Sectional Area	New Volume
120°	.56m ²	4.95 m ²	6.6m ³
135°	.56m ²	6.44 m ²	6.6m ³
150°	.56m ²	7.59 m ²	5.7m ³

Table 4.1 Area and Volume

Our experimental design involved two anemometers. One was inside the funnel, and one was not. The anemometer outside the funnel was used as a control in order to determine the wind speed in the absence of a funnel.

5 Design Analysis

Predicted Wind Speed Change	1.2 m/s to 6.75 m/s	562% Increase
Actual Wind Speed Change	1.2 m/s to 2 m/s	167% Increase

Table 5.1 Wind Speed Change

A percent error analysis revealed 70.3% error. This is an acceptable amount of error. The fact that the velocity increased shows proof of concept.

Many of our predictions were extremely optimistic. In a real world environment, the impact of other forces makes it impossible to transfer all of the kinetic energy contained in the wind. Many factors, including friction against the “funnel” walls and wind turbulence, affect the outcome of our results but are difficult to accurately model and predict. The prototype illustrates the potential of low cost wind funnels.

A 167% increase in energy using an eighty dollar device supports the theoretical concept of wind funnels increasing the output of urban wind turbines.

In addition, July is on average the least windy month at Rutgers. More dramatic changes would be expected at higher speeds.

6 Related Work

Andrew Joseph Schembri and Joseph Paul Schembri patented a funnel wind turbine in which the building constitutes a funnel as well as the lower portion of the wind turbine. The turbine features four outwardly extending “wings” that

direct airflow into the turbine. We found this design to be impractical for urban use, as the cost of redesigning the roof of the building would be too expensive and only add more cost to the installation of wind turbine. The large size of the turbine is also unsightly in urban settings.

Our design is much more practical than Schembri's funnel because no roof redesigning is necessary. Our funnel merely sits on top of the building's existing roof without causing any damage. Unlike our design, the Schembri Funnel Wind Generator features funnel walls attached to the wind turbine structure, adding weight to it.

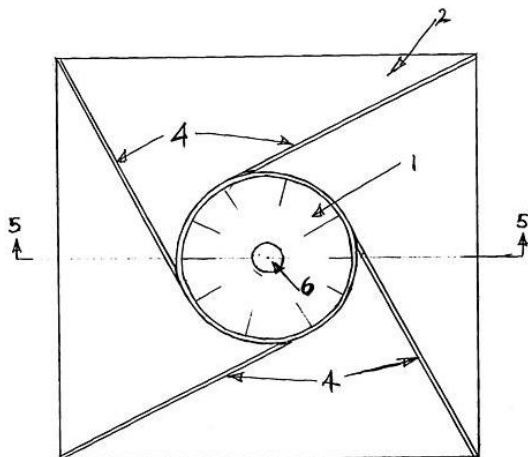


Figure 6.1 Schembri Wind Funnel
The design spans an entire roof and contains four “wings”.

The main design disparity, however, is that the Schembri “funnel” design is much larger than ours, as it is meant to cover the entirety of the roof it sits on. It must be integrated with the roof. This allows the funnel and generator to be much larger than our design and makes the contraption more capable of capturing wind energy from all

directions. This also brings up the resurfacing problems of vibrational noise and aesthetic appeal. Our goal is to primarily improve the efficiency of much smaller turbines that could possibly be mounted on residential homes or apartment buildings.

7 Conclusion

From our experiments it is clear that the wind “funnel” provides an increase in wind speed, which translates into an increase in wind turbine efficiency. On the scale of our experiment the change in wind speed is minor; however, percentage-wise, it was a significant improvement, and larger scale efforts would logically show more dramatic changes in velocity with the same percent increases.

In a more windy location, such as on top of a building in New York City where average wind speeds are 5.4 meters per second, the 167% increase in wind speed induced by our funnel design would result in a wind speed of 9.5 meters per second. This end result is considerably higher than the common wind turbine start up speed of 3.6 meters per second.

The wind “funnel” provides an option to people residing in areas that have wind speeds that border those necessary to efficiently run a wind turbine. Wind speeds passing through the funnel are consistently higher.

This proof of concept could extend to larger scale efforts as a feasible way of increasing wind turbine output in urban settings.

8 Acknowledgements

We would like to thank the 2009 Governor's School of Engineering and Technology (GSET) program for providing us with the opportunity to explore exciting new topics in engineering, as well as to complete this project. In particular, we would like to thank Thien Win, Jessica Silva, James Winka, and Sean Hemmings, our project mentors, and Caleb Williams, our project advisor. We would also like to recognize the NJ Governor's School of Engineering and Technology (Donald M. Brown, Director, and Blase Ur, Program Coordinator), the Rutgers University School of Engineering (Dr. Yogesh Jaluria, Outgoing Interim Dean, and Dr. Thomas Farris, Dean), and the NJ Governor's School Board of Overseers for organizing this program. Finally, this program would not have been possible without the generous contributions from our sponsors: Rutgers University, the Rutgers University School of Engineering, the Motorola Foundation, Morgan Stanley, PSEG, Silver Line Building Products, and the families of the 2001-2008 program alumni.

9 References

1. A.J. Schembri and J.P. Schembri. 'Funnel Wind Generator,' www.wipo.in, 1998.