AC 2012-3209: DEVELOPMENT OF SMALL WIND TURBINES FOR ISOLATED COLONIA HOMES OF SOUTH TEXAS

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Development of Small Wind Turbines for Low Speed Wind in Isolated Colonia Homes

Abstract

To expose the high school students to renewable energy, a project to build wind turbines exclusively by the high school students was conceived and implemented in a South Texas high school. A key motivation of the project was to make high school students interested in engineering by letting them build a complete system that harnesses wind power. The proposed system converts, stores, and measures all pertinent energy parameters for future usage. Twenty two students worked together as a team and shared all the engineering and budgetary responsibilities. An important societal component was added to the project by identifying the potential of small wind turbines to meet, at least partially, the energy need for isolated, off-grid poor residents in Colonias of South Texas.

A challenge was made to the students; namely, how to supply electricity to poor residents in isolated, off-grid Colonias. They were asked to analyze the need, identify a solution, and finally, deliver it. Important major restrictions for the students included an easy to follow engineering build, $1500 dollar limit for the turbine parts, no outside help, and commercially available parts.

None of the authors were involved in manufacturing the turbine. A total of 22 students, 14 boys and 8 girls, participated in this program. The team had a Team Leader, a girl, and four Team Captains. The team was trained by one of the authors on all science and engineering aspects of wind turbine. Another author trained them in blade carving and aerodynamics. One of the teachers from the high school kept a watchful eye for day to day activities of the students, mostly for safety reasons. Hugh Piggott's book on the subject was given to the students as a guideline.

Final product was a 30' tall tower with three 8' diameter pine wood turbine and 12 Neodymium Iron Boron permanent magnets. The system also included 1200 Watt Whistler power inverter, Xantrex charge controller, and a DC heater as dump load. Four deep cycle Werker 6 VDC output batteries were used to store the wind power to deliver at 12 VDC when needed. Finally, the students also added a HOBO data logger to collect pertinent wind data. Estimated "sweat equity" for the system built was 150 person-hours, a doable effort for Colonia residents.

While the turbine was not able to generate enough power for the lofty goal of electrifying a Colonia home, it was an excellent start for the students to be sensitive to local societal needs and the sense of achievement by developing and delivering an engineering solution to the problem. Students also learnt a lot of about renewable energy and many concerns of the local Colonia residents. Finally, it left a legacy of excitement and hope for the next group of students to further refine the solution. Twenty of the twenty two students, including two who changed their education path to engineering, joined science or engineering degree programs after graduation from this program.

High School Students Erecting Their Wind Turbine, Complete with Data Acquisition System

1. Introduction

Recent emphasis on sustainable energy is based on a number of merits including long term sustainability. Unlike coal and petroleum, wind (and solar) energy will be available even after thousands of years. Even if wind energy has some issues like noise, this type of energy source is more environment friendly than other sources of conventional energy. These include no ozone depletion, limited environmental pollution, relief from dependence on foreign oil, among others. Another significant advantage of wind energy is de facto zero maintenance. Once installed, wind energy can be perpetually used to harness electricity for indefinite length of time except, of course, standard features like regular maintenance, wear and tear, potential damage due accidents and natural disasters, to name a few. Unlike electricity from the commercial grid, home owner need not pay, say $150 dollars a month for converting wind energy assuming again no maintenance cost for wind turbine and inflationary cost adjustment for commercial energy.

An important step in making a shift in the paradigm from conventional to renewable energy is to introduce the advantages of the renewable energy to high school students through hands-on experience. A project plan was developed to build two wind turbines and use them as showcases to local communities. The most important objective of the plan was to make the high school students interested in science, engineering, and renewable energy. They were given appropriate training about the technology, safety, and project management by the authors. A societal component was also added by identifying potential opportunity to electrify Colonia homes where no commercial electricity was available.

Colonias are unincorporated communities along US-Mexico border[1,2] that are characterized by significant poverty and inadequate basic services like potable water, sewage system, and utilities. Hidalgo county, the poorest county in US, has about 400 Colonias[2] and many do not have electric grids. Lack of electricity and building codes has led to inadequate dwellings that compromise health issues and opportunities of education for the children. Non-government organizations (NGO)[3] like Proyecto Azteca[4] and Habitat for Humanity[5] are helping these communities to better their conditions by improving their infra-structure. One such endeavor includes building homes for Colonia residents. Proyecto Azteca, as an example, selects Colonia families to build their two to four bedroom houses with two to three bathrooms. Living areas are typically 800 to 1,000 SF. These homes conform to local building codes and are built in a central park under close supervision. Once completed, they are hauled to the specific lot in the specific Colonia.

While these homes come with necessary electrical connections for lights, fans, ovens, and refrigerator, source of electricity is always a major concern. As stated earlier, many of these isolated Colonias are typically beyond the reach of commercial grids. Innovative source for energy is a necessary requirement for these homes. One such source of energy is some form of sustainable energy. In this investigation, we have explored the option of wind energy. This option is at the system level so that logistics of electricity is totally transparent for the home owner for this turn-key system. Given the educational and economic background for a typical Colonia home owner, it is a necessary condition to make the project successful.

Typical energy use of a Texas home in the Colonias is estimated at 1,000 - 1,500 kilowatt hours a month, the solar and wind potential of the areas where this program was completed (Laredo and Weslaco) had adequate resources of both renewable energies to supply 200 - 500 kilowatt hours per month on the cost scale (less than $700) that we were using. It was not a target of our program to be highly efficient and easily done, rather to provide an energy source for use on the homes that had no services to start with. While sunlight (photovoltaic energy) is more maintenance free and statistically reliable, but costs are 3 - 5 times per peak watt what the equivalent wind power would typically provide. Wind is intermittent and variable, and requires maintenance and monitoring, but does supply nighttime power and is more economical than solar. In this specific project we focused on wind energy and students were made aware of our choice specific to this project.

Since it was noted that many a days in a typical year there may not be continuous wind, energy storage was integral to the system. But for these pilot projects, the low power use of energy stored in the batteries was expected to match the energy input from a single day's operation of the wind turbine. The energy demands were not to be too high, that once the battery level dropped to a set point the inverter would disconnect and save the batteries from too much discharging.

As noted above the focus of this program was not to build the best turbine possible, but to educate students in engineering concepts and teach the tools and techniques to build a working turbine. Objective was to involve the students in a hands-on engineering project and show them some data generated by their designed turbine. The students learned the basics and then were able to pass along this information in the technical manual they subsequently developed. Additionally, they identified local and affordable locations to gather the necessary parts in the manual. It was not that this turbine would necessarily provide all the needs of a Colonia home, it was that it supplied any power controllable by the home owner, that he could use in areas of new infrastructure.

This project is jointly led by the Texas Engineering Experiment Station and the University of Texas, Pan American via a Texas State Energy Conservation Office grant to encourage and educate local high school students in alternative energy. Objectives of this high school student project were two-fold. Firstly, to expose the students to a real life engineering problem that has a societal component. Secondly, to develop an environment friendly, low cost, easy to assemble wind turbine that is suitable and affordable for South Texas Colonia residents.

2. Energy and Power Estimation:

To scope the size of the project for the students, an analysis of the electrical requirements was needed. Typical homes in Colonias, as built by Proyecto Azteca, as an example, have 800 to 1,000 Square Foot (SF) of living space. Energy needs in typical homes in South Texas is about 0.5 KWH per SF for middle class families. Cost of conventional energy is about 12-15 cents per KWH including local taxes. This is true only if the home is connected with a commercial grid. Given the basic needs of Colonia residents[1] with typical annual income in the range of $10,000 to $15,000, air conditioning is a de facto luxury, even if the temperature exceeds 100° F for many weeks in the summer. Given this background, typical need for Colonia homes is estimated in the range of 400 KWh or lower per month. If a wind turbine can be designed to meet this energy need, monthly saving can be on the order of $60 for the home owner. Given their limited income, this is a sizable saving for the family.

Figure 1 shows the typical wind speed[6.7] in Mercedes, Texas, over a year period. Mercedes is centrally located in the Rio Grande Valley and is also the city that contains the school (Science Academy of South Texas) of the participating students. Minimum wind speed is 3 mph and maximum meaningful wind speed is 25 mph. Wind speed distribution is expectedly Raleigh distribution with a mean speed of 5 mph. To take advantage of this wind speed distribution, a wind turbine need be custom made that has a “cut-in” speed of 3 mph and “cut-off” speed of 30 mph.

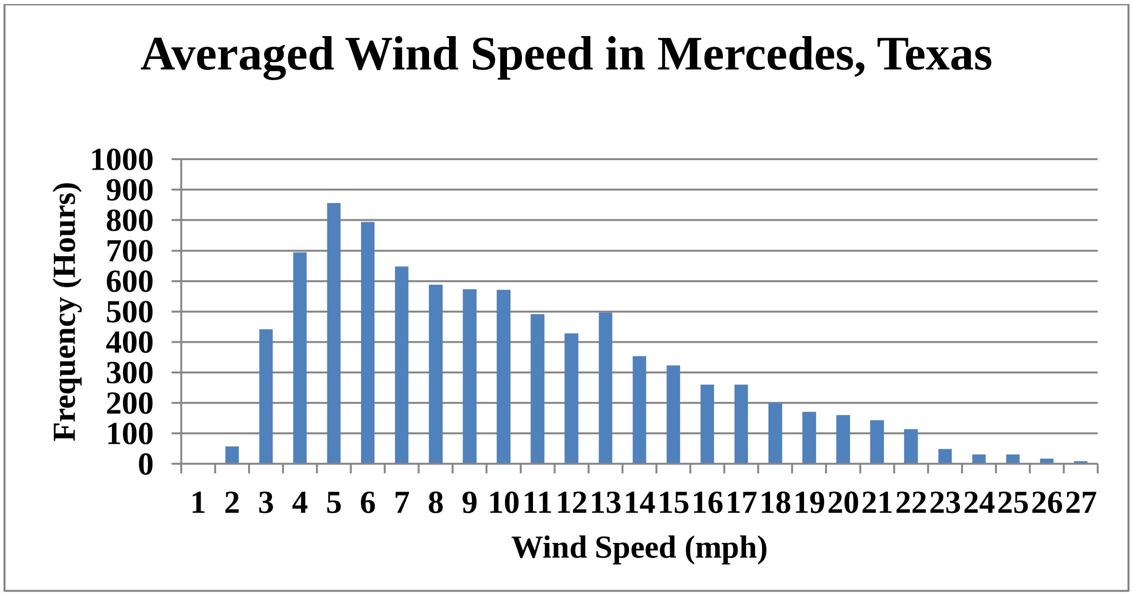


Fig. 1 Typical Wind Speed Distribution in Mercedes, Texas

There are a number of commercial wind turbine manufacturers[9] that have small turbines that cost around $6,000 to $8,000 a piece. Using their rated output for the wind speed, an estimation of energy generation[9] was made for Mercedes as shown in Figure 2. Since their "cut-in" speed is 7 mph, there was no energy available up to this speed. Mercedes also does not have any wind hours at their optimum speed of 30 mph for energy generation. Typical Colonia home was fitted with a refrigerator, Range, TV, washer, microwave, computer, cook top, 10 lights and 4 fans resulting in an average estimated energy usage[8] of 409 KWh. Given the economic situation of the Colonia residents, no air conditioning was assumed. Using local weather pattern during a typical year, this average monthly energy usage was slightly varied month to month as shown in figure 3. It was already noted that due to non-optimized design for the local wind speeds, typical commercial wind turbines[9] are not suited for typical Colonia homes in places like Mercedes in South Texas. This is highlighted in Figure 2 by simply shifting designed wind speeds at a lower wind speed. This dramatically increases the annual energy generation to 5829 KWh from a meager 2380 KWh. This hypothetical change in the design simply increased the monthly energy generation to 486 KWh from 198 KWh over the typical commercial one. This is about the requirement of a typical 1000 SF Colonia home.

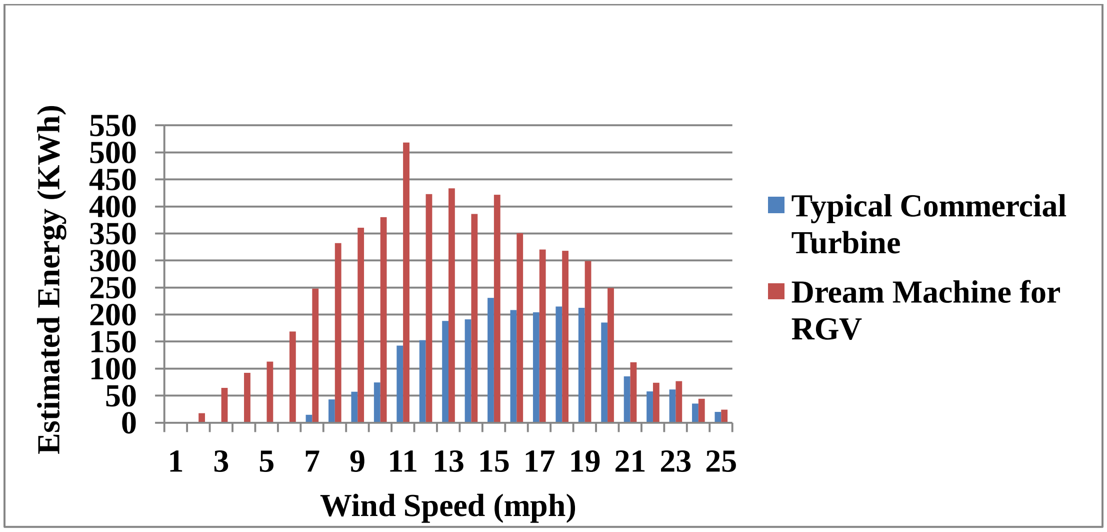


Fig. 2 Estimated Energy Generation of a Commercial Wind Turbine and an Optimized Turbine Specific to Mercedes, Texas.

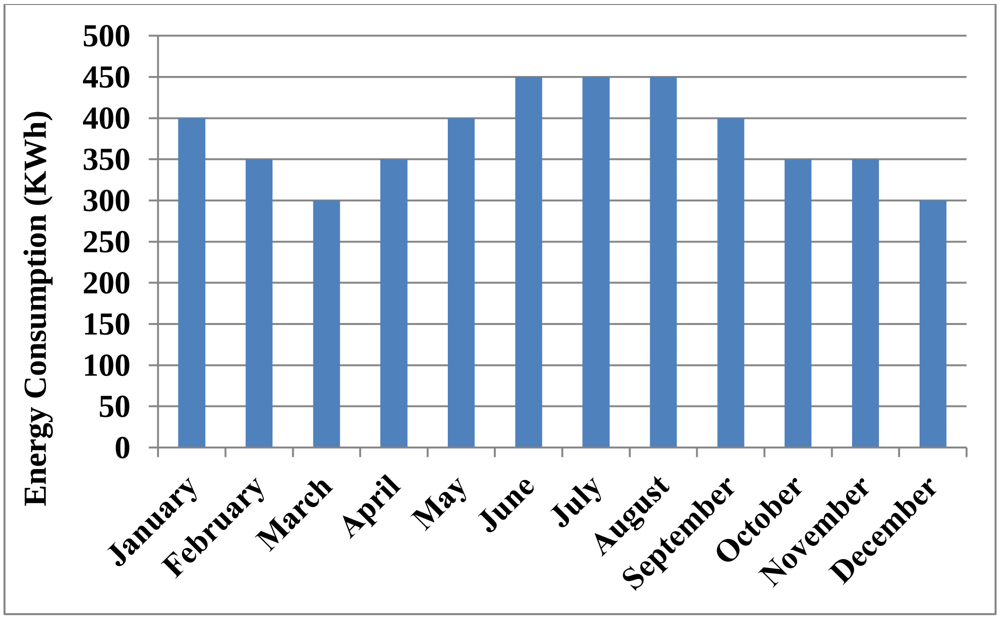


Fig. 3 Estimated Energy Consumption in a 1000 SF Colonia Home

It is noted from figures 2 & 3 that it is possible to design a wind turbine that will optimally deliver adequate energy from the local wind. To do so, it is necessary to re-plot the wind speed on average monthly basis (Figure 4), rather than typical frequency basis shown in Figure 1. It is noted from figures 1 and 4 that we need to address a number of design issues like “cut-in”, “cut-off” and optimal speeds for the turbine. “Cut-in” speed is the minimum speed at which the turbine will start operating is chosen to be 3 mph. “Cut-off” speed is the maximum speed beyond which the turbine blades will be furloughed. At this point the turbine will stop operating for structural integrity and it will be kept in a safe mode. Based on local speed data (Figure 1), it is accepted as 30 mph.

Based on local wind speed data (Figure 1) it was decided that the proposed wind turbine should generate 500 Watt at 10 mph. Using the well-known cubic relation of power with speed and average monthly wind speeds (Figure 4), it was further decided that the proposed wind turbine will have 3 mph, 30 mph, and 10 mph as its “cut-in”, “cut-off”, and optimum speeds. Using a turbine (the “dream machine”) that delivers 500W at 10 mph, the corresponding theoretical energy supplied to a typical 1000 SF Colonia home is shown in Figure 5 on a monthly basis. It is emphasized here that even the “dream” turbine may not be adequate to satisfy all the energy needs of the resident (Figs. 4 & 5). However, it is also true for other alternative energy systems like solar panels. It is just a step towards satisfying most of the basic energy need of a Colonia resident who is outside the electric grids and lives without electricity at this point.

Since wind may not available all the time it is necessary to design and develop an electrical storage system that can support demand during no-wind times. Since this adds both cost and complexity, the storage energy will be limited to about half-a-day at optimal use rate. In reality, alternative energy sources may be necessary in addition to the proposed storage system.

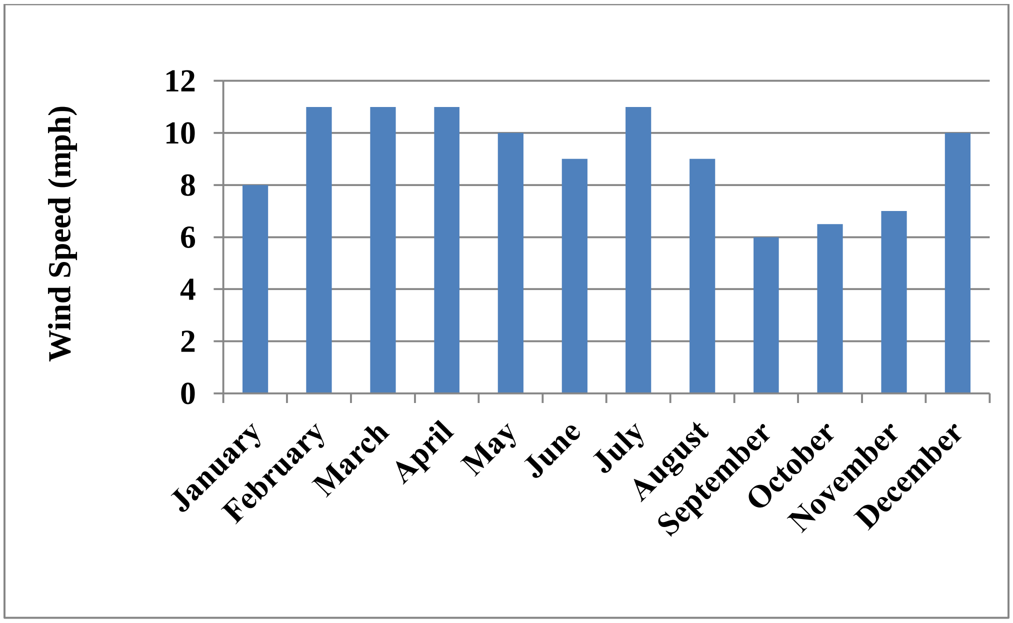


Fig. 4 Wind Speed in Mercedes on Monthly Basis

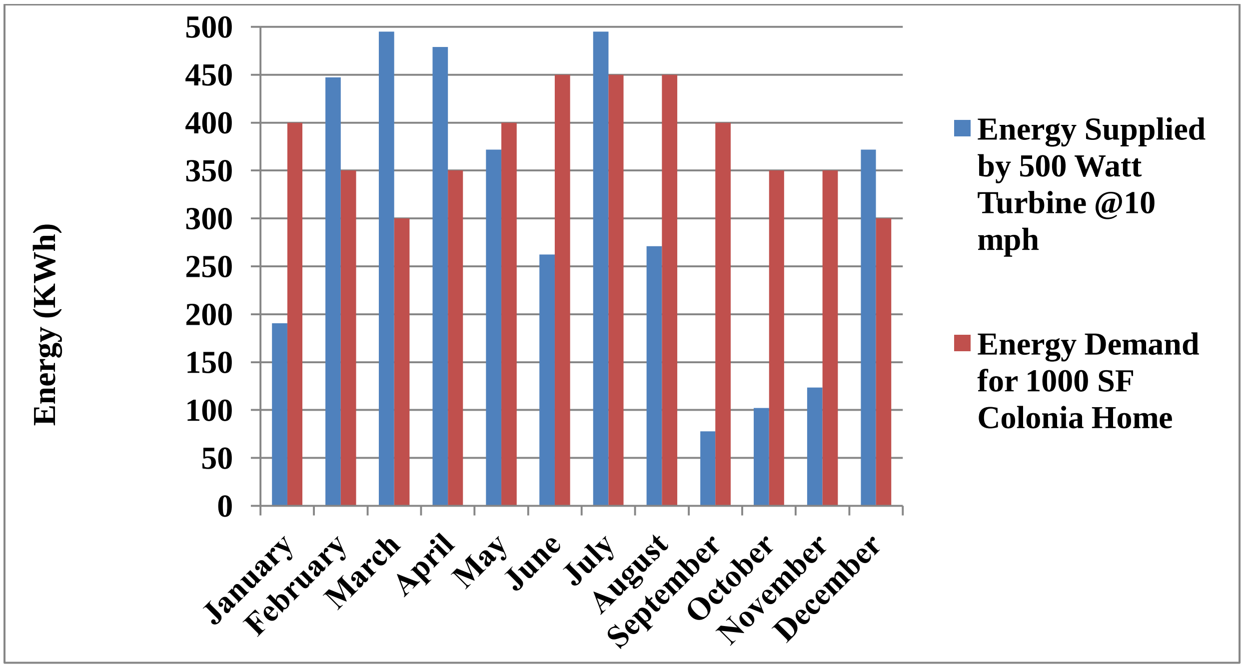


Fig. 5 Energy Demand and Estimated Power Supply for a Typical 1000 SF Colonia Home

3. Team Selection & Training:

To identify and expose high school students to engineering, in general, and alternative energy, in particular, the Science Academy of South Texas[10], was chosen as the target high school that focuses on math and science career fields. The Science Academy, as it is popularly known here, is a nationally recognized Blue Ribbon School known for its excellence in education. Twenty two students, 14 boys and 8 girls, were selected for the program. The team had four groups each with a Captain.

The four groups had the responsibilities of Turbine, Alternator, Tower, and MOS (Monitoring Operating System). Additionally, there was a Team Leader, a girl. The first three teams were identified and divided into these groups to ensure the design and manufacturing of the key wind turbine components. The remaining group (MOS) provided overview of the project by keeping track of all purchases, making sure that the interfaces of the components are seamless, and helping out any group needing some additional emergency help. The Team Captain tracked each group's progress and helped resolve major issues.

Students were trained in fundamentals of project management and wind turbine technology by one of the authors (D. Schneider) using the following training modules (Fig. 6):

Curriculum Modules
Formation of Teams and Selection of Team Leader
#1 – Introduction to Wind Energy
#2 – Engineering Program Management/Safety
#3 – Blade Design/Power Extraction & Torque
#4 – Blade Carving Workshop
#5 – Magnetics and Electricity
#6 – Batteries/Rectifiers/Inverters
#7 – Mechanical Structures/Tower Design
#8 – Data Analysis

Installation of Turbine

Fig. 6 Curriculum Modules for Designing Wind Turbine

While the basic learning modules were the same as above, the approach used was challenge based[11,12]. As an example students were challenged to come up with an energy solution in an isolated campground. While the discussions were open and students were encouraged to come up with other ideas like solar, the discussions were channeled towards wind energy by emphasizing complexity of material issues and logistics/demography of Colonias. Since students were responsible for manufacturing their own turbines, training on safety issues was a big part of the overall training. Complexity of the aerodynamic behavior of the turbine blades were turned into a fun exercise by one of the authors (K. Starcher) by teaching and training them about aerodynamics, angle of attack, and wood carving, among others. Overall design was based on the popular book on the subject by Hugh Piggott[13].

The students worked for one academic year (mid-August to first week of June) to complete the project of building two wind turbines. They worked every other day for an hour and half. The time included both training and work time. They also came to the school every other Saturdays, on the average, to finish some of their work, for four to five hours. Occasionally, some of the students worked an hour between 4 and 5 PM. It may be noted that these time included a lot of learning and not limited to build the system alone. The fun part was their involvement in the project as evidenced in their comments[14] during the year end project summary.

One critical objective of the project for the student was to deliver a project report based on their academic year (actually 9 months) long experience. Purpose of this report was many folded including documentation of their own work, a starting document for the next group for the next year, and a potential document for Colonia residents to do the job themselves. Idea was to write it in simple language by a high school student, rather than by a professional engineer.

4. Manufacturing Highlights:

Based on the design details stated above, a manufacturing approach was developed to build a 500 Watt wind turbine. One of the important objectives was to motivate high school students into real life project like this. Apart from making them interested in science and engineering through exposure to a real life engineering project, the other objective was to make them sensitive to a social need and their role in solving a real life problem that impacted so many people of their own community.

While taller towers are always preferable for harvesting wind energy, other priorities of this student led project came into play. They included tower cost, easier maintenance, limited overall budget, design simplicity, etc. The standard pipe joint length being 21 feet, 30 feet pole was used to include the 8 feet diameter turbine. This tower size is also recommended in the manual [13] since it satisfies the need for a manageable tower height that delivered adequate performance. While it is a proven survivable, buildable, and rugged length, it can also be lifted and/pulled down with minimal crew. Again for safety reasons, we always used more students than needed.

The turbine's three 8' blades were made from treated pine wood (4' long X 6' wide X 1.5' thick). Three blades were used for the turbine. Understanding the aerodynamics and actually building the blades with one as a spare were both a challenge and fun for the students. While students built all blades (Figure 7, middle), initial training was given by one of the authors (K. Starcher). The blade design is from what has worked well in 20 years of running this type turbine, with ease of start up in light winds, and suitable performance in high winds, and well as being able to be hand carved by anyone following the basic plans. The basic airfoil shape, a NACA 4415 style is easy to replicate and with a flat bottom has an easy to create face and upper surface [15]. The built in twist along the blade length keeps the inflow angles close to the $12^0 – 14^0$ angle of attack that is desirable. Students cut 2X6 lumbers to approximate lengths and put tracing marks of blade geometry with a pencil. Next they performed re-saw operations on a band-saw to obtain the rough shape. Final aerofoil shape (NACA 4415) was carved out using a block-plane and contour/ profile templates.

Balancing was performed just as the manual[13] suggested, making the center of gravity of each blade as close alike as possible (using the rolling pin method, figure 7, left, to find the center of gravity) and then the dynamic balance was done once the rotor was added to the alternator. This was done by trial and error, and adding appropriate weight to the blades to avoid any bias to a specific blade. All these steps were spelled out very well in the manual and the students improved and refined these methods to explain them to future locals that build this unit.

There was not a perfect match of Reynolds numbers to the turbine rotor. The increased blade width as it neared the rotor center accounted for this. Lower Reynolds at the root were compensated by the thicker / wider blade cross-section, and thinner narrower sections at the tip, to allow for the different type conditions to be expected at each of these blade areas. That was designed into the building methodology and the pattern matching required of the blade construction process.

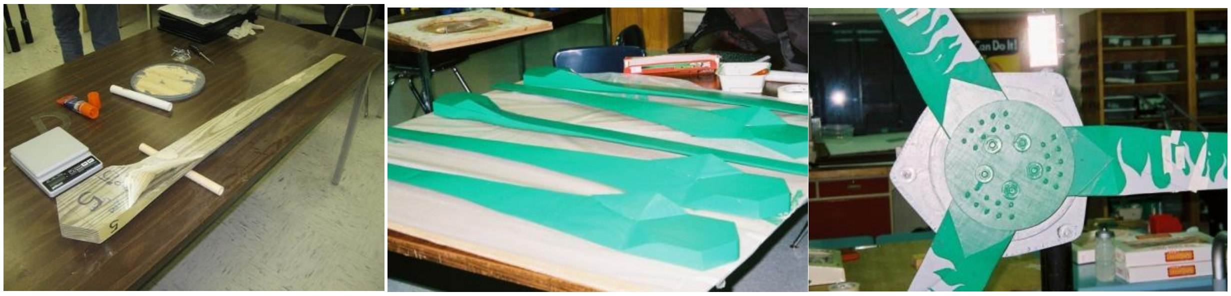
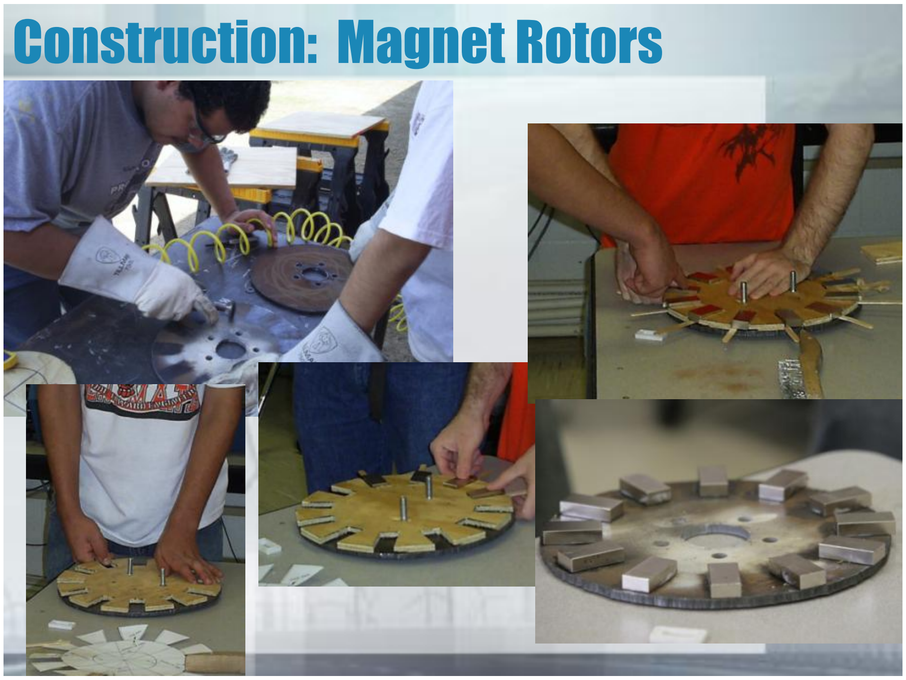


Fig. 7 Building and Assembling Turbine Blades

The turbine's rotor had two sets of 12 Neodymium Iron Boron rare earth magnets. These permanent magnets had dimensions of 2"X1"X0.5". Handling and positioning the strong rare earth magnets were both tricky and dangerous. A 12"X12" plywood was used for this purpose and exact positions for the magnets were properly marked and cut before the magnets were put in the slots (Fig. 8). Magnets were handled carefully, typically, with thick gloves to ensure safety.



Construction: Magnet Rotors

Fig. 8 Construction of Magnetic Rotors

To make and assemble the components, all the typical tools available in a typical high school engineering workshop were used. This included, among others, carpentry shop, welding shop, manufacturing shop, molding shop, and assembly shop. Another key resource was computer aided design software (Autodesk Inventor) and a few students were trained in the software. Typical tools used regularly included various saws (Saber, Band, Scroll, etc.), sander, drill, soldering guns, clamps, vices, hot gun, etc.

Ten sets of coil each with 80 turns of 15 gauge wire were used to make the stator that ultimately delivered charging current to 12V batteries. Students built a coil winder (Fig. 9, top left) to consistently build the 10 stators each with 80 turns.

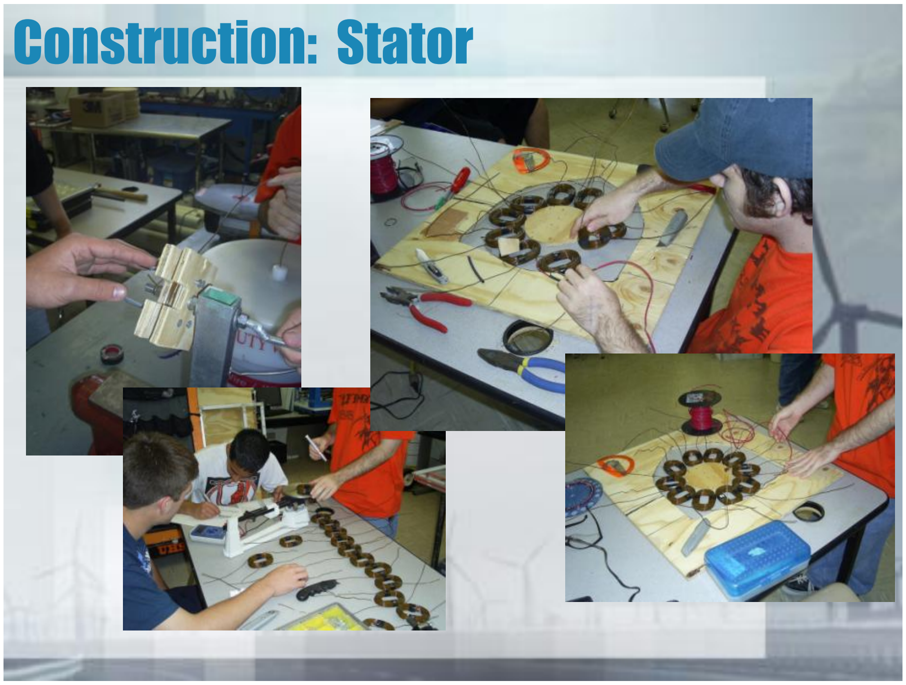


Fig. 9 Coil Winder (Top Left) and Building of the Stator

Since wind will not be blowing all the time, it is important to store electrical energy when there is more energy generated than being used. This is done by using a bank of batteries. Total capacity of a battery is known in terms of time at a given ampere for the stated DC voltage. Typical capacity of a 6 volt battery is 110 minutes at 75 Amperes. Time estimation is made on a number of assumptions like no loss, resistive loads, etc. Assuming 120 Volt as supply, the 320 Watts will draw 2.6 Amperes of alternating current (AC). Assuming 100% inversion efficiency, no other losses, as well as resistive loads, etc, the DC amperage requirements at 12 volts is 26.6 amperes direct current (DC). Each battery is rated at 137 Ah (DC) for 6 volts (DC); two batteries in series will deliver 137 Ah at 12 volts. A series/parallel configuration of the 6 volt cells will deliver 274 Ah at 12 volts (DC). The proposed load has a need of 26.6 amperes (DC). Therefore, the fully charged battery will be able to supply electrical energy for about 10.3 hours (=274 Ah/26.6 A). Thus the four 6 volt batteries may be used in 2X2 array to deliver 12 volt for about 10 hours for a load of 320 Watts. This will allow to power eight 40 Watt fluorescent lights or a combination of fan and lights totaling 320 Watts of power. Obviously, these numbers are optimistic and mostly for estimation purpose only.

As discussed above, storage of the energy as DC in a set of batteries is an important design issue. Once the battery is fully charged, it should not be charged further to prevent any damage of the battery. At that point, the additional energy that cannot be stored in the batteries needs to be diverted to an energy dump load via a charge controller. The dump load, in our case, was simply a resistor (a DC water heater element) that was adjacent to the energy storage package.

A furling system (Fig 10) was required as a part of the design. The purpose of the system was to deliver power at low optimum speeds (3 mph to 15 mph) and ensure safety at higher speeds beyond 20 mph. This furling system was another challenge for the students to understand and implement. It was made using three steel pipes and a 3'X2'exterior plywood with 3/8" thickness.

At low speed the furling system turns the blades into the wind to maximize wind power. As the wind speed increases beyond the critical value of about 10 miles per hour, the tail tends to move the blades away from the optimal angle of attack ($12^0 – 14^0$) to reduce the impact of the load of the wind force. Beyond the cut-off speed of the wind (30 mph), the tail end effectively folds the blades so that there is no impact of wind force on the blades and no useful generation of wind power. At that time, the turbine is expected to be brought down to avoid any structural damage. In case of emergency like high winds, four adults should be able to bring down the wind turbine safely.

Fig. 10 Furling System Being Checked for Operation and Safety

Students built all the components and sub-components. They also did the base preparation and hoisting the 30' pole. Finally, they did all the tests and checks. While students did not do welding of the furling, it was also possible to be done by them. Welding was done by a certified employee of the high school. As a part of this project, total labor hours, we call it "sweat equity", was estimated as150 person-hour. The idea was to use this many hours by the Colonia owner to build the wind turbine with appropriate resources, supervision, and training.

Preparation and securing the tower (Fig. 11) with the turbine was another major task. Identification and selection of the site was a task by itself to guarantee free laminar flow for the turbines using DOE Small Wind Turbine Site Guidelines[16]. Two cubic feet of cement (Fig. 11) went into the base of the tower itself.

The turbine tower was constructed from a 30 feet 3" OD steel pipe with 2.5" pipe fitted in the end to support the turbine head and provide the ability of the head to track the wind direction. The turbine head was welded to a 1' 3" OD pipe which slid over the 2'6" OD pipe on the top. The base was constructed from 2" angle steel that was fitted onto bolts embedded in the concrete base.

Fig. 11 Preparation of the Base for the 30' Tall, 100 lbs Wind Turbine

To raise this 30' tall and 100 pounds tower, an electric winch was attached to guy wire in the plane of the hinge base, and strung over a step ladder (fig 12) to provide the initial lifting moment. The students raised the tower twice. The first raise was without the turbine head mounted on the tower to allow the guy wire positioning. The wires were taut when the tower was vertical as required. Once this was completed, the positioning of the four guy wires was finalized. At that point the turbine head was attached to the tower and power wires were strung through the tower pipe to the base to ensure completion of all electrical connections. The second raise was then made with the turbine head installed and electrical connections completed. This completed the installation of the turbine.

Fig. 12 Students Erecting the 30’ Tall Wind Turbine

Following (Fig. 13) is the comparison of a typical commercial[9] and home-made wind turbines built by the students. It may be noted that this comparison is for overview and information only since the student turbine includes only the material cost and nothing beyond that. Apart from the labor, all the resources were supplied by the school and there was no question of any sort of profit.

Parameter	**Skystream 3.7**	**Student Turbine**
Weight	**170 lbs**	**100 lbs**
Rotor Diameter	**12'**	**8'**
Number of Blades	**3**	**3**
Blade Material	**Fiber Reinforced Composite**	**Treated Pine Wood**
Alternator	**Permanent Magnet**	**Permanent Magnet**
Cut-in Wind Speed	**8 mph**	**6 mph**
Rated Wind Speed	**20 mph**	**10 mph**
Survival Wind Speed	**140 mph**	**30 mph**
Tower Height	**33'-110'**	**30'**
Yaw Control	**Passive**	**Furling system**
Data Acquisition	**None**	**HOBO Data Logger**

Braking System	Electronic Stall Regulation	Mechanical Furling System
Cost	$12,000	$1,500

Fig. 13 Comparison of the Student Turbine with A typical Commercial Wind Turbine

5. Data Analysis:

Close to 12,000 data points were collected one on a once every five minutes basis for the turbine bus voltage in volts and instantaneous current in amperes from January 6 to February 16 of 2010. Additionally, 60,000 data points were collected one on a once per 20 second for wind speed in mph during January 6 and January 20 of 2010. A HOBO data logger was continually collecting data and was downloaded once a month. For our purpose, data analysis is restricted to a typical January day (using the January 6, 2010 data set). Figure 14 shows the wind speed data between 3:30 PM of January 6 and January 7, 2010. These are instantaneous wind speeds sampled every five minutes between 3:30 PM of January 6 and 7 of 2010. Average speed for the day was 8.1 mph. It is noted from Figure 4 that the average monthly wind speed is 8 mph for Mercedes. This data reflects a typical January day. Expectedly, wind mostly blows during afternoons and slows down significantly during early mornings. While early morning wind speed drops to below 5 mph for several hours, the speed picks up as high as 20 mph and above, occasionally hitting 25 mph. While this is not the best wind month for this area, this is a good representation of the average wind speed for the area as is clear from Figure 4.

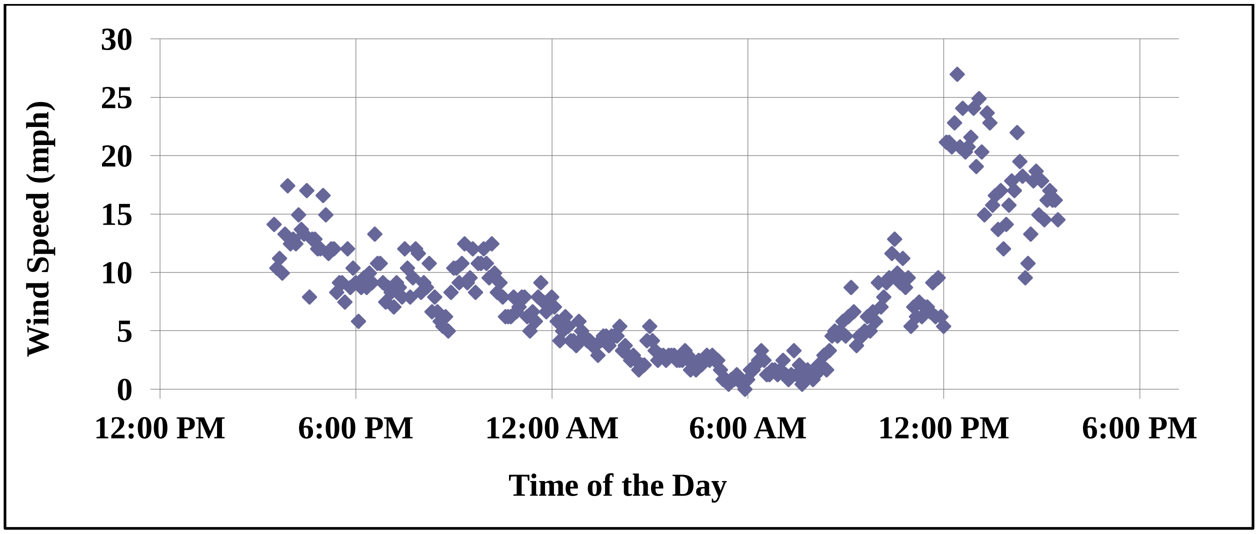


Fig. 14 Wind Speed Data during 3:30 PM of January 6 & 7, 2010

Since the students used batteries in conjunction with a charge controller, the bus voltage was held at a minimum of 12 VDC. However, the current varied significantly (Fig. 15) between 0 and more than 17 Amperes during this period. Expectedly, the current dropped to zero when the turbine was not moving. As the wind speed increased current started flowing and for high speeds of 15 mph and above, the current increased to 8 amperes and above. At higher speeds, the current was as high as 14 amperes and more.

Figure 16 shows the corresponding instantaneous power generation by the wind turbine on January 6 1nd 7 of 2010 over 24 hour periods. Since each data point was collected at 5 minutes interval, these numbers were multiplied by 12 to reflect hourly power output. No power reflects the idle time for the turbine, typically in the early morning. High power is generated during afternoon high winds.

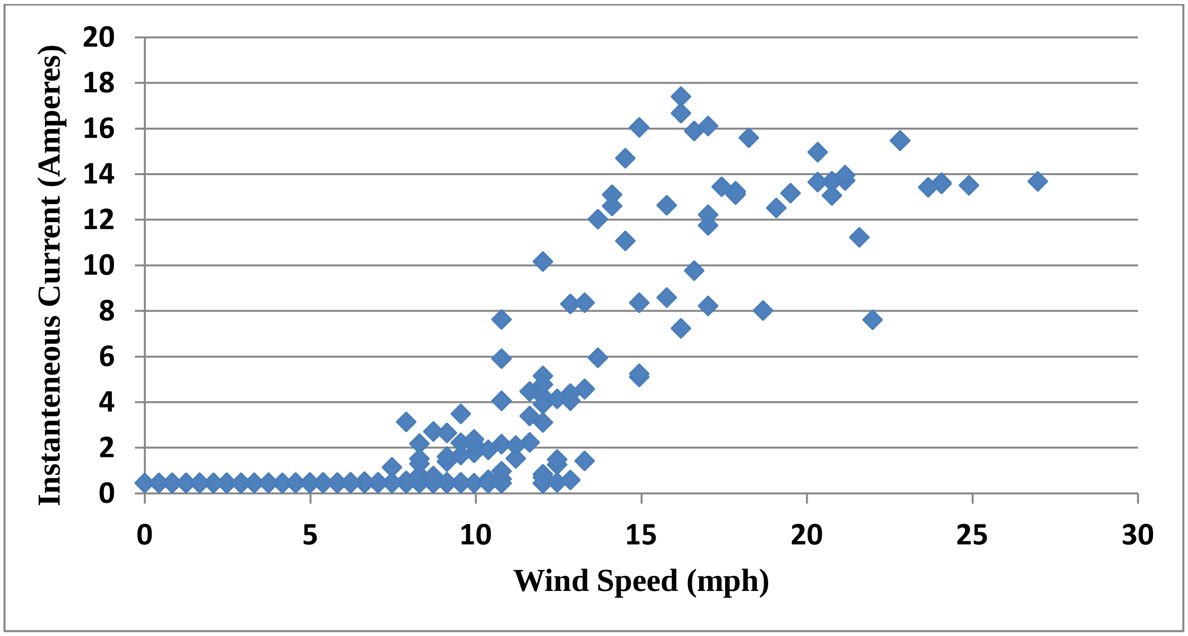


Fig. 15 Instantaneous Current at Various Wind Speeds from the Wind Turbine

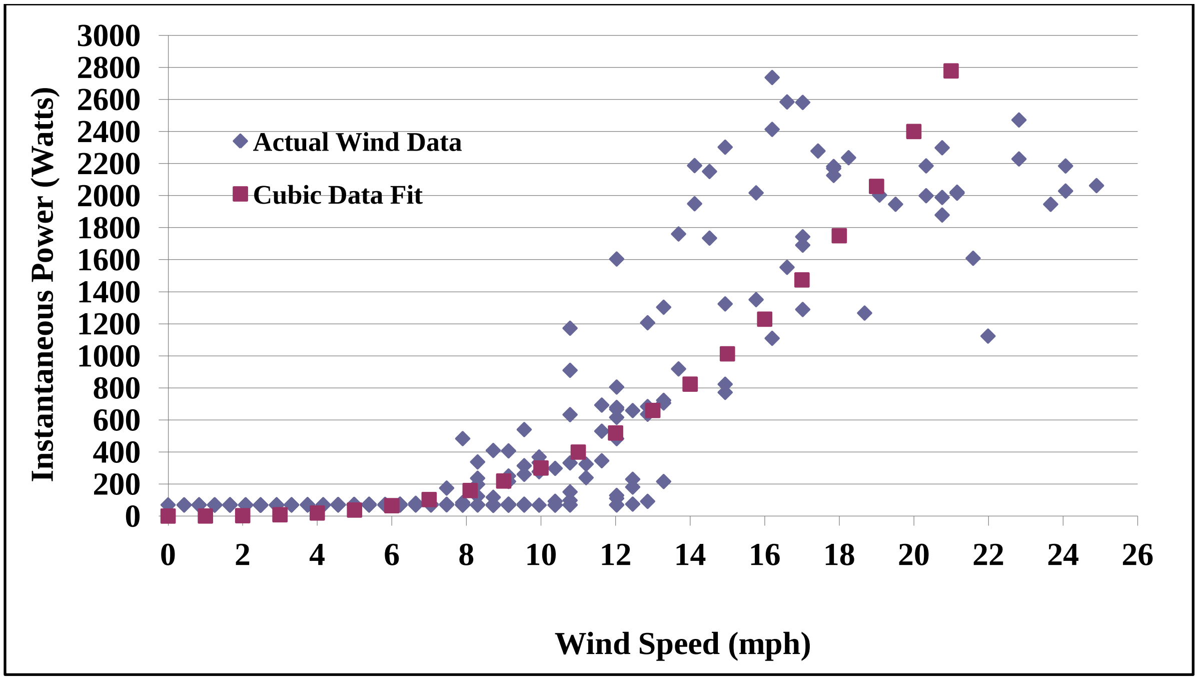


Fig. 16 Instantaneous Wind Power on A Typical January Day Over 24 Hours

It may be noted from figure 16 that there is significant scatter in the graph and the scatter increases significantly with wind speed. This is due to the highly nonlinear nature of the parameters of interest (namely current or power) and averaging method used in getting and plotting the data. While the wind data has been collected every minute, current, and hence power has been averaged every five minutes. Since there is significant change in wind data during the averaging five minute time, there is a wide swing in instantaneous power computation. To ensure this understanding, we made a cubic fit (power = 0.3*mph^3) for the wind data as shown in figure 14. In this theoretical, rather empirical, estimate there is no scatter and it clearly shows the well-known cubic dependence of power with wind speed. This validates both wind data and empirical fit. This cubic fit also clarifies the nonlinear nature of the scatter with increasing wind speed since change in power is now square of wind speed. Final observation from the figure 16 is the cut-in speed for the turbine as 6 mph. This is slightly higher than the proposed cut-in (3 mph) for the region (Fig. 1). However, it is lower than that (8 mph) for the commercial machine Skystream 3.7 as noted above (Fig. 13).

Based on this wind data for the day (Fig. 14), it was estimated that the hourly average instantaneous power was 421.4 Watts for the day. This hourly average power corresponds to the average speed of 8.1 mph for the day. It may be noted that these averages were independent averages for wind speed and instantaneous power and reflect the highly nonlinear nature of their relationship. This average hourly power, in turn, gives a 10.1 KWh of the energy for the day. Assuming this is a typical January day (Figure 4), the monthly average energy for January is estimated as 313.5 KWH for the month with 31 days. This is less than 80% of the energy required (400 KWh) for a 1000 SF Colonia home (Figure 3).

From figure 16, further calculations were made for power at optimum speed of 10 mph as was the objective (Fig. 4). From data fit, the rated capacity is 300 Watts corresponding to the wind speed of 10 mph. This is again below our rated capacity of 500 Watts at 10 mph "dream machine". Nevertheless, from figure 16, it is noted that the student turbine delivers 2.4 KW at 20 mph. This is better than the commercial turbine with 1.8 KW at 20 mph.

It was clear from the data and subsequent calculations that the wind turbine did not meet expectations of the design (the "dream machine") to meet the energy requirement of a typical Colonia home. Nevertheless, this was a promising beginning. Students were still excited and optimistic. They themselves came up with a number of ideas to make the next generation wind turbines to ensure that they will be successful next time. Some of their ideas included:

- Lighter, better turbine blades using fiber glass reinforced composites
- Longer blades
- Taller tower
- More efficient rotor and motor

The key issue was the excitement among the students and the attitude to win. Their commitment and involvement in the project was really impressive. Post surveys from the students showed that the students liked the project and more than 90% of them wanted to pursue a career in science and engineering.

6. Educational Outcomes:

While we were interested to make the high school students interested and excited we also set a number of measurable parameters to gauge our success. This included both formal and informal tools. The most critical parameter was a 39 page word document [17] entitled Building a Wind Turbine written by the students without limited editorial help from the authors. Table of Contents included Safety, Materials List, Blades, Tower, Carriage, MOS (Management and Operating System), and Alternator. This document included detailed material lists, Autodesk Inventor engineering drawings, figures and pictures, and step by step detailed manufacturing process, among others.

Additionally, we held a final program review at the end of the project when we talked to the students about what they learned. Their narratives[14] were captured by one of the authors (J. Konecny) as private communication. From the perspective of the authors, a report was sent to the Texas State Energy Conservation Office compiled by D. Schneider [18].

Cooperative Group Dynamics

While these students had worked together before, they have not had to cooperate in a group this size (22 students) or a project of this scope. The students learned how to deal with both internal customers (the dynamics of their own team interactions, and the interactions with the other technical teams on the project) and external customers (the metal shop teacher and class as their main “subcontractor” and the Hidalgo County Commission for approval of the site location). Every student that voiced an opinion included this as a real positive for the experience.

Improvement in the Science Academy Curriculum

Two of the authors (D. Schneider and K. Starcher) taught the students some fundamental engineering topics like wind energy, aerodynamics, magnetic and electricity, electric machines, mechanical structures, and project management, as noted in figure 6. In spite of the basic nature, the students learnt adequately about these topics due to reinforcement through immediate hands-on approach and collaborative team effort. This was evidenced from their end-of-the-course[14] narratives like “engineering experience”, “learned so much”, “something that nearly no one gets to experience in high school”, “learned to deal with deadlines and bureaucracy”, etc.

During the project, the students created Autodesk Inventor drawings of all the components and created assembly instructions that were provided to their subcontractor (the school welding shop) to complete all the welding for the wind turbine components. Almost universally, the units of measure were missing from the drawings, which created the opportunity for the welding shop teacher to teach the students about the critical nature of technical communication and the adverse impacts that poor communication abilities can have on project schedule. While all the issues were resolved in a somewhat timely manner, the Science Academy faculty went back to the curriculum and discovered that the IED (Introduction to Engineering Design) curriculum had neglected to include information on units of measure and how to include that on diagrams. This change to the curriculum will improve the student’s communication for the coming year.

Students Completely Engaged

The teachers continually commented towards the end of the year, and especially after the semester was over, that the students involved in this project had absolutely no “Senioritis.”

The teachers felt that the engagement was remarkable and completely outside their previous experience. Part of the engagement resulted from the tower winch failure at the Science Academy turbine (the first turbine) in front of the whole school in their first attempt! These students had a real need to prove to the rest of the student body that they could do this successfully and did so within 72 hours in their second attempt. Additionally, the students were intensely interested in the project and recognized its value to them. They recognized that this was something unique and that they were going to see it through to the end. Great feelings of the students were reflected in many narratives[14] they shared at the end of the project. These included phrases like “event in my life”, “learned a lot”, “honored to be a part of this project”, “Saturdays (sic) works were great”, “class should be continued”, “very positive experience”, etc.

Real World Experiences

One student at the final program review remarked[14] “I really didn’t know what to expect. This project let me know what I really wanted to do – What the real world really means.” Similar sentiments were echoed by all the students that the experience really prepared them for involvement in real-world projects. The faculty commented that this project will do more for the success of these students in their college career than most other programs that they have seen. Just the ability to conceptualize a plan and then execute it will allow them to compete very favorably against other students that have not had this type of experience. Another observation by the faculty was that the project was really interdisciplinary. The students had to work in both the mechanical and electrical domains and were able to directly observe the interaction between the two at the design level. As a result, many improvements on process and the actual product were documented.

Safety Awareness

This experience highlighted the need for a deliberate safety process for the students performing the project. The team had a requirement to appoint safety managers for each group and to develop a strong safety plan covering all aspects of the project from planning, component assembly, tool safety, safety equipment, and site supervision.

Time Management and Communication

Lack of communications skills were a large contributor to the schedule delays that the students experienced. Not so much that they had problems communicating within team members, but external communication was a challenge. In fact, a winch failure that the students experienced can be directly attributed to a lack of understanding how to specify pipe and tubing purchases. Since the specification (e.g. the communication of the requirement from the team to the vendor) the students developed resulted in the tower being ½ inch more in diameter than the design called for, which increased the overall weight of the tower. Thus, the students became keenly aware of the vocabulary necessary to effectively communicate with vendors and subcontractors (e.g. the school welding shop).

The students also let the communications problems contribute to schedule delays. Since part of effective communication strategies is to ensure that the receiver of the information clearly understands the intent of the communication, it was incumbent on the team members to follow-up with the vendors and subcontractors to ensure that their providers understood both the technical and delivery requirements that the teams established. This failure prevented the team members from recognizing that a schedule issue due to material delivery or fabrication was taking place. All the students commented at the final program review on how much this project raised their awareness of the importance of communication in a technical career.

Career Goals

Out of the twenty two students involved in the program, only two did not intend to pursue a technical or scientific career. One student planned to pursue a political science degree at Georgetown University in Washington DC, so the team was willing to acknowledge a worthwhile course of action on his part; the other was planning a military career.

7. Conclusions:

A targeted outreach program was conceived and implemented for a team of high school students to get them interested and involved in science and engineering, in general, and wind energy, in particular.

A challenge based methodology was adopted to train a team of 22 the high school students (14 boys and 8 girls) about design of a wind turbine.

This was a hands-on engineering project for 22 senior high school students. They completed it in time (one academic year) and in budget ($1,500 dollars). Apart from learning the fundamentals of wind turbine, they learnt many important aspects of an engineering project like team work, communications, budget control, time management, safety, documentation, etc.

The two wind turbines students made are in operation, one at their own high school and the other one (Figure 17) in a local public park (San Juan, Texas). Since the turbines did not produce enough power, it was decided not to install them in Colonia homes. However, data collection is going on for research purposes.

Fig 17. Operational Wind Turbine in San Juan, Texas, Public Park

Even if the wind turbine was unable to achieve the lofty goal of electrifying a Colonia home, it was a good step in the right direction. The system gave the students a sense of achievement, an understanding of a societal need, and, finally, useful continuous data from their wind turbines.

20 of the 22 students followed their careers in science and engineering. Two of these students actually changed their minds to engineering from non-science major.

Based on the success of the project, we will be looking for further funding to implement the project in other schools also, if possible.

8. Acknowledgements:

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References:

1. Texas Department of Housing and Community Affairs
   Office of Colonia Initiatives
2. http://www.sos.state.tx.us/border/colonias/faqs.shtml
3. http://en.wikipedia.org/wiki/Non-governmental_organization
4. www.proyectoazteca.com
5. www.rgv-habitat.org
6. http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~SelectStation~USA~TX
7. www.3tier.com
8. http://www.rockymountainpower.net/content/dam/rocky_mountain_power/media/Efficiency_Environment/energyUsageCalculator.swf
9. http://greenboxusa.com/Default.aspx?tabid=1122&CategoryID=19&List=0&SortField=ProductName%2cProductName&Level=a&ProductID=916
10. http://www.stisd.net/scitech.html
11. Desegregated Learning: An Innovative Framework for Programs of Study, with A.A. Fuentes, S. Crown, J. Kypuros, and H. Mahdi, J. New Directions for Teaching and Learning**,** No. 108, Winter 2006, pp. 17-32, Jossey-Bass.
12. Challenge-Based Instruction: The VaNTH Biomechanics Learning Modules, with Ronald Barr, Sean Brophy , Marcus Pandy , Anthony Petrosino , and Robert Roselli,on-line journal "Advances in Engineering Education," Fall 2007, Vol. 1, No. 1.
    URL: http://advances.asee.org/vol01/issue01/04.cfm
13. How to Build A wind Turbine by Hugh Piggott, May 2003
14. Private Communications, Compilation of Science Academy Student Comments on Wind Turbine Project, Compiled by James Konecny, June 2011

15. “Post-Stall Wind Tunnel Data for NACA 44XX Series Airfoil Sections - A Subcontract Report,” Naik, D.; Ostowari, C.; SERI/STR-217-2559 (Solar Energy Research Institute/ SERI Technical Report)
16. Small Wind Electric Systems: A U.S. Consumer’s Guide, National Renewable Energy Laboratory, Department of Energy, August 2007.
17. Building a Wind Turbine, Texas A&M in partnership with Science Academy of South Texas, 2009-2010.
18. Education-Centered Border Wind Energy Final Report to the Texas State Energy Conservation Office, Dean Schneider, Texas Center for Applied Technology, Texas Engineering Experiment Station, August 2011.