

The Effect of Changes in Air Pressure and Temperature on Wind Energy Production

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Section I: Research Topic

Research focus

This study assesses how weather conditions, namely temperature and barometric pressure, affect the amount of energy produced by wind turbines in Union Township. The variance of weather patterns in the Great Lakes Region prompted this study. Fluctuating weather conditions could cause wind turbines to produce more or less energy. All data was collected at a constant wind speed of 10 miles per hour. Data was collected and analyzed over a 60 day period.

Hypothesis

At a constant wind speed of 10 miles per hour, temperature and barometric pressure directly correlate with the amount of energy produced by the wind turbines collectively.

Null hypothesis

At a constant wind speed of 10 miles per hour, temperature and barometric pressure have no impact upon the amount of energy produced by the wind turbines collectively.

Section II: Background Information

Air pressure, temperature, and wind

Air pressure, temperature, and wind all have an effect on one another. Changes in wind, atmospheric pressure, or temperature will alter how the atmospheric elements behave. These dynamics are a necessity in the Earth's atmosphere and contribute to the weather activities experienced on a daily basis.

Air pressure is exerted at every angle and applies to all matter. Simply, it is the pressure exerted by the weight of the air above it. This force against surfaces is caused by the constant collision of gas molecules. Air pressure is measured with a mercury barometer, which was invented in 1643 by a former student of Galileo, Torricelli (Lutgens & Tarbuck, 2007). He described the atmosphere as, "a vast ocean of air that exerts pressure on us and all things about us (Lutgens & Tarbuck, 2007, p. 169)." To measure the force that is air pressure, Torricelli closed one end of a glass tube, filled it with mercury, and then turned the tube over into a dish of mercury. With this method, he found that the mercury in the tube flowed out into the dish until the weight of the mercury column was equalized by the pressure from the ground to the top of the atmosphere; when the pressure increases, the mercury rises in the tube and vice versa. Inches of mercury is a term commonly used to measure air pressure, referring to the length of the column of mercury.

Inches of mercury is not the only measurement of air pressure, but it is the unit of measure used in this study. Few refinements have been made to the mercury barometer, but it remains the standard instrument used to measure air pressure to this day. Aneroid barometers are also common and the instrument used in this study to measure air pressure. The word 'aneroid' means without liquid. Instead of using mercury, an aneroid barometer has a metal chamber that

is partly evacuated and is responsive to changes in air pressure. When air pressure increases the chamber condenses and decreases cause it to enlarge. Within the aneroid barometer is a sequence of levers that interpret the compressions and expansions of the metal chamber and transfers them to a dial that reads the measurements as inches of mercury. At sea level, standard air pressure is 29.92 inches of mercury (Lutgens & Tarbuck, 2007).

Temperature is defined as a measure that describes how warm or cold something is in respect to standard measure; a measure of the kinetic energy produced by molecules or atoms. Particles of an object or substance move faster when it gains energy, causing the temperature to rise and vice versa. Temperature is measured by a thermometer, broken down to meters of therms. These instruments can measure temperature electronically or mechanically. In this study an electronic thermometer was utilized. The unit of measure for temperature used in this study is degrees Fahrenheit. This scale was developed by Gabriel Daniel Fahrenheit in 1714 (Lutgens & Tarbuck, 2007, p. 87). Measurements are based on fixed points with the scale being defined by using the ice point, 32 degrees Fahrenheit, and the steam point, 212 degrees Fahrenheit (Lutgens & Tarbuck, 2007).

Wind is the horizontal movement of air, resulting from differences in air pressure. Wind speed can be measured in a variety of fashions. Often times this measurement is obtained using an instrument called a cup anemometer. Using this device, wind speed can be read from a dial similar to that of a speedometer of a vehicle. Aerovanes can be used to measure wind speed in replacement of using a wind vane and a cup anemometer (Lutgens & Tarbuck, 2007). Wind speed is measured using miles per hour (mph) throughout this study.

Air pressure, temperature, and wind are inter-related, thus, changes in any of these elements will affect the others. The surface of Earth is heated unequally which creates constant

pressure differences. As a result, solar radiation is the prime source of energy for wind.

Roughness of the Earth's surfaces cause friction, resulting in variations in air movement. Earth is continually rotating, causing the Coriolis Effect. If these forces did not exist, air would flow directly from high to low pressure areas, but because these features do exist, wind is regulated by an amalgamation of forces. These forces include the pressure-gradient force, friction, and the Coriolis Effect (Lutgens & Tarbuck, 2007).

In order to fully understand the pressure-gradient force there needs to be an understanding of the Ideal Gas Law.

$$PV=nRT$$

is the mathematical equation describing the Ideal Gas Law. P is pressure, V is volume, n is the amount of substance of gas, R is the gas constant, and T is for temperature. Thus, pressure and volume are equivalent to the amount of a gas present, the gas constant, and air temperature (Lutgens & Tarbuck, 2007).

The pressure-gradient force is the main driving force of wind. This unbalanced force generates winds as a consequence of horizontal pressure variances; air moves from higher pressure areas to lower pressure areas. The differences in pressure are what cause air to move or blow and air moves at a higher speed with greater differences in air pressure. On a weather map, there are lines that connect areas equivalent in air pressure (isobars) and the spacing of them demonstrates changes in air pressure over a specified distance (gradient). The direction in which pressure moves and the rate at which pressure changes in a specific site is controlled by pressure gradient. Pressure-gradient force gets air moving, but is not the only force affecting wind. Direction, speed, and friction are other forces which significantly alter airflow (Lutgens & Tarbuck, 2007).

Coriolis Effect and friction are factors that contribute to sustainable pressure systems. Without these forces, pressure systems would be unable to sustain themselves causing relatively still air with occasional calm breezes. Pressure-gradient force indicates that wind intersects isobars directly at right angles, but this is not exactly how air moves. The Coriolis Effect is an apparent force resulting from the Earth's rotation. Wind, along with all other free-moving matter, appears to be deflected to the right of their path of motion in the Northern Hemisphere and in the Southern Hemisphere it is directed to the left of its path. The Coriolis Effect is strongest at the Earth's poles, grows weaker toward the equator, and only affects the direction of wind, not its speed. However, increased wind speeds increases the Coriolis Effect. Friction is a force that strongly influences airflow within a couple of miles to the Earth's surface. Pressure-gradient force is resisted by friction in order to balance airflow. Although pressure-gradient force, the Coriolis Effect, and friction greatly affect wind, the primary cause of wind is the uneven heating of the Earth's surface (Lutgens & Tarbuck, 2007).

Residential scale wind turbines

Union Township Hall of Isabella County, MI has three wind turbines installed on site for energy production and a study fellowship with Central Michigan University. Two of the three turbines are *Skystream 3.7* model horizontal-axis wind turbines (HAWT). The third turbine is a *Windspire* standard model vertical-axis wind turbine (VAWT). This section will explain the features of these two models.

Skystream 3.7 is a residential scale wind turbine manufactured by Southwest Windpower. They are most commonly used for individual homes or small businesses within a residential area. HAWT must be facing the wind in order to begin capturing energy because the rotor system, this

includes the blades and the hub that connects them to the shaft of the turbine, and the electricity generator are at the top of the tower mechanism (Jain, 2011).

Skystream 3.7 turbines were designed specifically for residential use; they feature low noise production and an innovative blade style to increase efficiency, particularly at low wind speeds. These turbines also weigh approximately 205 pounds with three blades and can withstand speeds up to 140 mph. *Skystream 3.7* have a cut-in speed of 8 mph, but average wind speeds of 10-12 mph is recommended for optimal energy production. Cut-in speed is the wind speed at which turbines will begin rotating and producing power, this is critical information for turbine site selection. These mechanisms are designed to have an extensive running life and come with a 5 year warranty. *Skystream 3.7* comes with *Skyview*, allowing users to view energy production and monitor system health and performance (Southwest Windpower, 2011). See Figure 2.1 in the Appendix for an enriched view of *Skystream 3.7*.

Windspire standard model wind turbines are a subtype of vertical-axis wind turbines (VAWT) classified as a low-speed Giromill or H-rotor VAWT. These unique turbines are designed and manufactured by Windspire Energy Inc., formerly Mariah Windpower (Windspire Energy Inc., 2010). VAWT function in a different manner than HAWT, mainly because blades of the turbine run parallel to the main shaft or axis of rotation. These turbines are viewed as easier to maintain than HAWT because the main components of the turbine mechanism are on ground level as opposed to HAWT that have these components at the top of the tower (Jain, 2011).

Windspire standard models are extremely quiet and have an aesthetically pleasing, innovative, low-profile design on which Windspire Energy Inc. takes great pride, making these turbines appealing for personal residence or commercial business use. All *Windspire* turbines are

manufactured in the USA. The *Windspire* installed at Union Township was manufactured in a Michigan based plant that was previously a part of the automobile industry (Union Township, n.d.). *Windspire* turbines have a unique blade style containing three sets of tall, slender airfoils that are designed to harness wind as the blades are rotating around the vertical axis. These mechanisms are 30 feet tall, weigh approximately 624 pounds and can withstand wind speeds up to 105 mph. With a cut-in speed of 8.5 mph, *Windspire* turbines perform optimally with average speeds of 11 mph. Much like the *Skystream 3.7*, the *Windspire* has a 5 year warranty and a performance monitoring system (Windspire Energy Inc., n.d.). Figure 2.2 in the Appendix exhibits the *Windspire* located at Union Township Hall.

Energy production

Wind turbines are used to harness wind and convert it into electricity. The way in which these machines turn wind into power is a simple process. Blades of wind turbines are used to capture energy from the blowing wind by rotating around a rotor. The rotor of a turbine is connected to the main shaft of the machine, and in turn spins a generator which creates electricity. Electricity produced by wind turbines can be used for a single home or business or be connected in a grid of wind turbines to provide energy for multiple infrastructures (Jain, 2011). Figure 2.3 in the Appendix displays a detailed description of the inner-workings of a wind turbine.

Watts (W), kilowatts (kW) and kilowatt-hours (kWh) are the measurements utilized to express the amount of electricity produced by wind turbines. 1,000 W of electricity is a kW and kWh is a measurement equivalent to 1,000 watt hours. In this study, kW is the measurement of electricity used. In order to better understand exactly how much energy is equivalent to these measurements, it is best to analyze everyday use of energy.

In 2010, the monthly average energy use in Michigan was 681 kWh per household; the US average per household was 958 kWh (United States Energy Information Administration, 2011). To further put these figures into perspective, a 30 W light bulb used for one hour will use 30 Wh or .03 kWh. In order to determine energy usage of an appliance you multiply the wattage of the appliance by the hours used per day and divide it by 1,000 to get the daily kWh consumption (United States Department of Energy, 2011).

Section III: Union Township Wind Energy Research

Research objectives

This study aims to determine whether changes in air pressure and temperature affect the amount of energy produced by wind turbines at Union Township Hall. Varying weather conditions inherent in the Great Lakes Region may contribute to an increase or decrease in wind turbine energy production. The effects of air pressure and temperature are aspects of wind energy for which little research exists.

Materials

The materials used to conduct this study were hardware and software necessary for weather and power production data collection. At Union Township Hall there is an anemometer and weather station located 825 feet away from the wind turbines that reaches 58 feet high. Figure 3.1 in the Appendix displays an image of the weather station's location in relation to the turbines. The weather station measures weather data such as temperature, wind speed, wind direction, and barometric pressure. Davis Vantage Vue virtual weather station collects data once every minute. The virtual weather station logs the data and is stored on a computer at Union Township Hall. Stored weather data is accessed through Microsoft Excel spreadsheets.

Power data collected is performed in a similar manner to that of weather data. AcquiSuite A8810 data acquisition server collects power production data. A Dent Power Scout 18 power meter then reads data and is logged by Obvious Power Data Logger on a computer at Union Township Hall. Data is recorded every minute. This data can then be accessed through Obvious Building Manager Online and opened as a Microsoft Excel spreadsheet.

Procedures

Barometric pressure, temperature, and power production data was collected to analyze the possible effects on power production. Data was collected at a constant speed of 10 miles per hour which is enough speed to ensure that the turbines are producing power this resulted in 60 days of collection. After all data was compiled it was entered into Microsoft Excel in order to create graphs to display the data. On the x-axis temperature is displayed and on the y-axis barometric pressure is displayed. Data is separated into six graphs with 10 days represented on each graph. Every datum was put into a category based on the amount of power produced at that particular point. Data is represented with several different shapes and sizes in accordance with power production. A correlation equation was applied to all six sets of data and to all data together in Microsoft Excel.

Research findings

Correlation coefficients were utilized in this study to assess results. Correlation was used to compare both barometric pressure and temperature to power production in order to determine the relationship between the factors. The closer to 1 or -1 a correlation is, the stronger the relationship between the two sets of variables. A strong correlation is 0.80 or -0.80 or higher, whereas a correlation below 0.50 or -0.50 is considered weak. The analysis of barometric pressure and power production data and temperature and power production data collected, in Microsoft Excel, resulted in correlations of -0.064 and -0.016; both are weak correlations. Correlation was used to analyze each set of data separately as well. The results are as follows:

Time period	Correlation between barometric pressure and power production	Correlation between temperature and power production
April 30-May 9	-0.083	-0.023
May 10-May 19	-0.113	-0.070
May 20-May 29	-0.237	0.027
May 30-June 8	-0.142	0.210
June 9-June 18	0.164	0.040
June 19-June 29	0.131	-0.167
Total	-0.064	-0.016

Results are displayed in graphs as Figures 3.2-3.7 in the Appendix. The results of this study are inconclusive and the null hypothesis is accepted.

Recommendations for further study

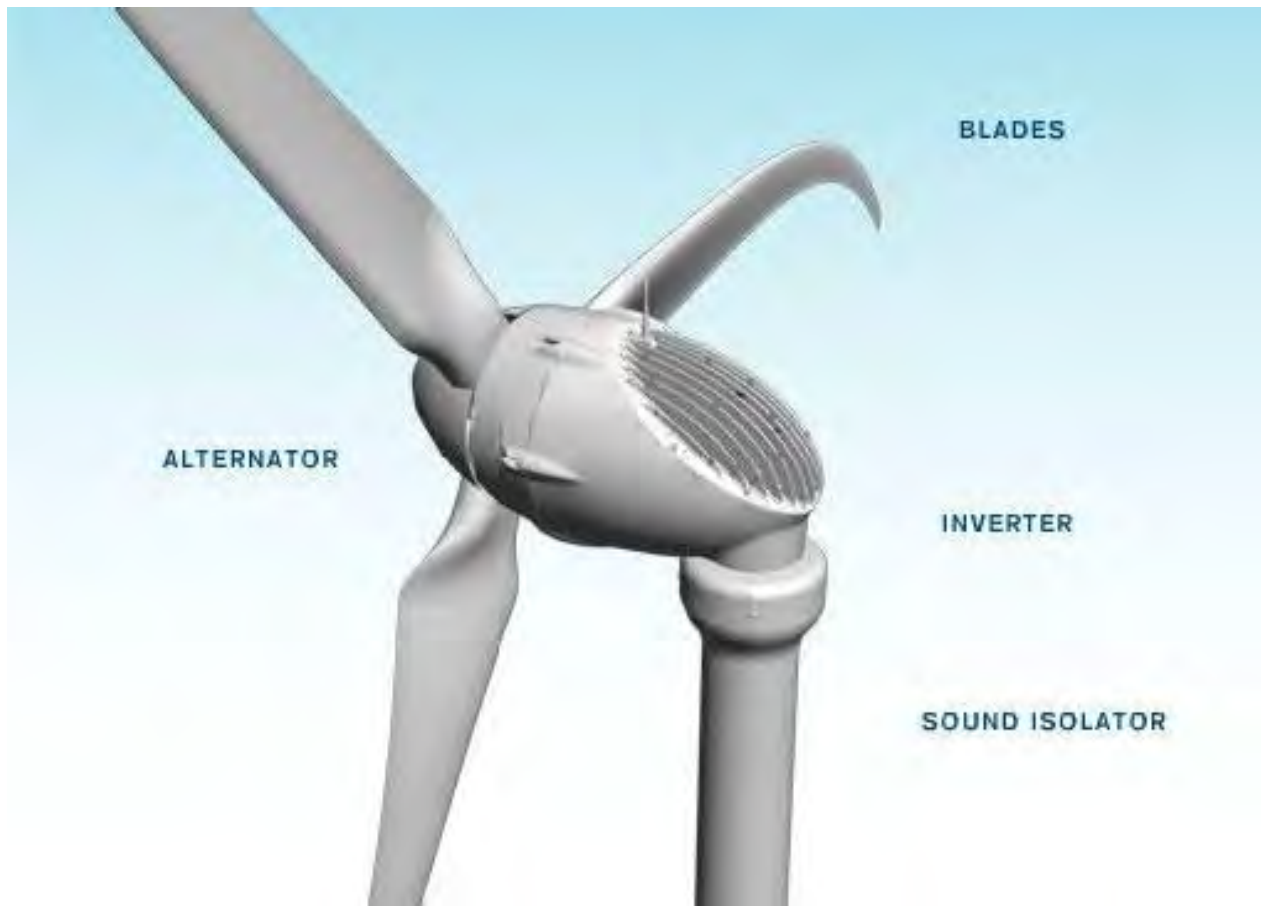
This study shows that, for the period of this study, air pressure does not appear to have a relationship with power production by wind turbines at Union Township Hall. It would be beneficial to look at other weather-related factors that could potentially effect power production. One of these factors is wind direction in relation to each turbine. It would also be interesting to find out if there is a difference in power production in relation among all four seasons. Comparing the extreme seasons, summer and winter, would be noteworthy as well.

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Appendix

Figure 2.1



Skystream 3.7: Skystream up close

Source: <http://www.windenergy.com/products/skystream/skystream-3.7#upclose>

Figure 2.2



Windspire at Union Township Hall

Source: http://uniontownshipmi.com/images/pdf_service/Wind%20Brochure.pdf

Figure 2.3



How wind turbines work

Source: <http://www.alternative-energy-news.info/images/technical/wind-turbine.jpg>

Figure 3.1



Anemometer and weather station in relation to wind turbines

Source: Woody Woodruff, Union Township Zoning Administrator