Solar Radiation Big Data Analysis to Increase the Efficiency of Solar Panels

National Science Foundation (NSF) Research Experiences for Teachers (RET)

Site at Texas A&M University-Kingsville

Integrating data-driven research in Renewable Energy Across Disciplines (I-READ)

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1. INTRODUCTION

The global transition towards sustainable energy solutions has led to an exponential rise in the adoption of solar photovoltaic (PV) systems. Solar panels, as the backbone of solar energy generation, play a pivotal role in harnessing the abundant and renewable energy from the sun. However, the efficiency and overall performance of solar panels are intrinsically linked to the solar radiation they receive. As such, understanding and harnessing accurate solar radiation data is paramount in optimizing the output and economic viability of solar installations.

The integration of solar radiation data in solar panel engineering and solar energy planning has witnessed significant advancements in recent years. The growing importance of this data has stimulated a multitude of research efforts, aiming to uncover the intricacies of solar radiation patterns and their impact on solar panel performance. This research paper aims to contribute to the existing body of knowledge by conducting a comprehensive investigation into solar radiation data and its significance in enhancing solar panel efficiency. These are the questions we will focus on:

- How can the National Renewable Energy Laboratory (NREL) Solar Position and Intensity (SOLPOS) website help inform us about the amount of solar energy yielded throughout the year?
- How can the NREL SOLPOS website help inform us about solar panel installation angles that yield maximum output?
- How much energy would optimal solar panels provide for a 900 sq ft house?
- How does applying a surface texture to a photovoltaic cell increase the efficiency of the cell?
- How much energy can organic solar cells harvest when used for selective absorbance on a vertical surface such as windows?

MATERIALS

1. NREL’s SOLPOS Calculator

2. Microsoft Excel
3. MATLAB

METHODOLOGY

Preliminary research initially focused on how to use SOLPOS and equations that can be used to calculate solar voltaic output from a solar panel. The formula used to estimate electricity generated from a photovoltaic system is given by E = A x r x H x PR [2], where the inputs are defined as the following:

- E = Energy output from photovoltaic cell (W-hr)
- A = Area of photovoltaic cell (m^2)
- r = Efficiency of photovoltaic cell (%)
- H = Solar irradiance (W/m^2)
- PR = Performance rating
    - Industrial standard = 0.75 [2]

Based on this information, it is apparent that the necessary output from SOLPOS would be Solar Irradiance. SOLPOS gives three different choices for Solar Irradiance - Extraterrestrial Direct Normal, Extraterrestrial Direct Horizontal, and Extraterrestrial Tilted. Since the project focused on determining the maximum output from a solar panel, the Extraterrestrial Tilted Irradiance was used. Furthermore, necessary inputs for SOLPOS including latitude, longitude, date, time interval, time zone, and ambient temperature were also needed and researched. Texas A&M University-Kingsville (TAMUK) Dotterweich Engineering Building was used as a test site for the entire year of 2022. Data was downloaded at 30-minute increments. The solar panel chosen for this project was REC's Alpha series "Black 370" model based on average efficiency versus other competition [3]. This Panel Series Black 370 model has an efficiency of 21.2% [4] and an area of 72 x 40 inches [4]. Once the data from SOLPOS was downloaded, MS Excel was used to perform mathematical routines including solving for output; identifying optimal time and tilt angles that maximize output; and graphing relevant features. Graphs were generated to determine average yields based on hour, day, and month. MS Excel was used to identify the occurrence of maximum zenith angle, tilt angle, and output for non-textured surface. Using MATLAB, a model of multiple reflections with a textured tilted surface was generated and compared to the output of a similarly tilted non-textured surface experiencing the same incident angle. Lastly, the application of organic solar panels on vertical surfaces was investigated by determining the percent of solar radiation that could be transmitted as visible light. Organic solar cells have a property described as selective absorption which means that certain wavelengths are absorbed by the solar cell and others are transmitted. For window applications, visible light would be allowed to pass through while the remaining electromagnetic radiation would be absorbed by the solar cell and converted to electricity. SOLPOS was revisited and data was downloaded for a 90° tilt. The energy that was calculated was then multiplied by .58 (as 42% of solar radiation is visible light [4]) in order to determine a theoretical yield.

RESULTS AND DISCUSSION

Using the basis of a 1.85 m^2 solar panel, we were able to gather data for a solar panel at 0° tilt (horizontal/no tilt), 18.43° tilt, and 33.69° tilt. Looking at the hourly output (Figures 1-3), the maximum energy output would be between 1:00 - 2:00 pm, regardless of the tilt.

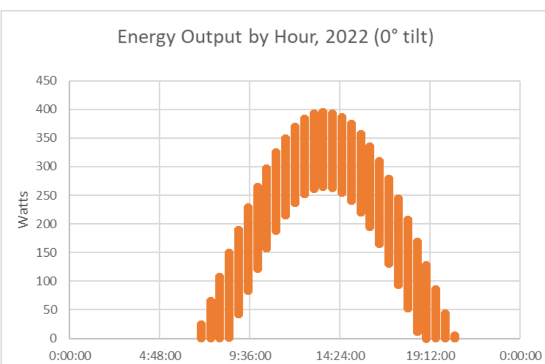


Figure 1: Energy Output by Hour, 2022 (0° tilt)

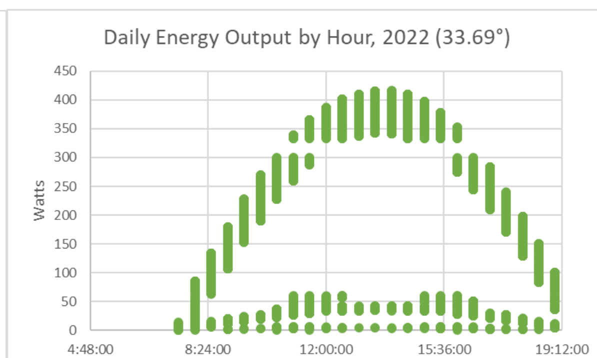


Figure 2: Energy Output by Hour, 2022 (33.69° tilt)

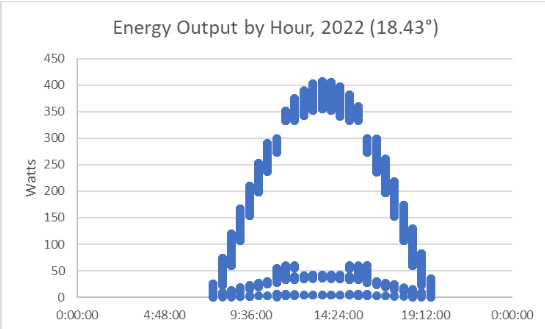


Figure 3: Energy Output by Hour, 2022 (18.43° tilt)

With no tilt (Figure 4), the average solar panel output peaked between June and July. With an 18.43° tilt (Figure 5) the output was steady, albeit comparatively less, from February-September. With a tilt of 33.69° (Figure 6) the highest output was from October-December.

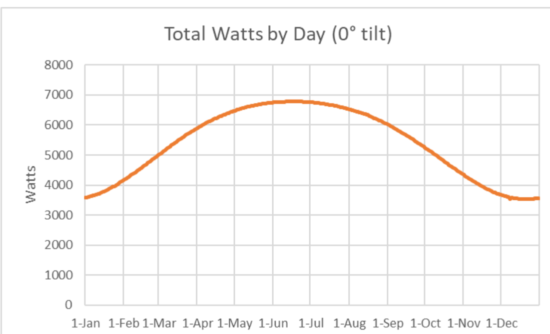


Figure 4: Total Watts by Day, 2022 (0° tilt)

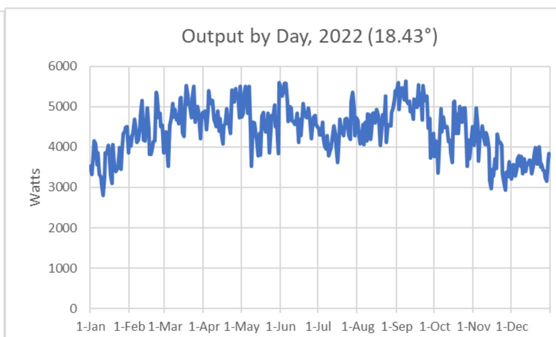


Figure 5: Output by Day, 2022 (18.43° tilt)

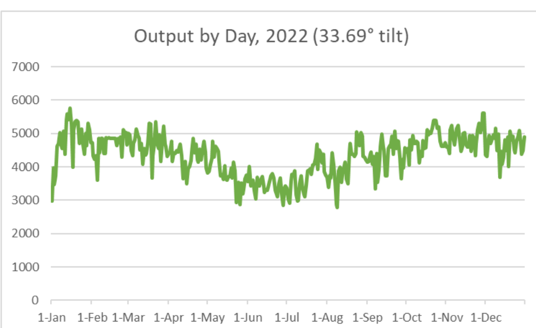
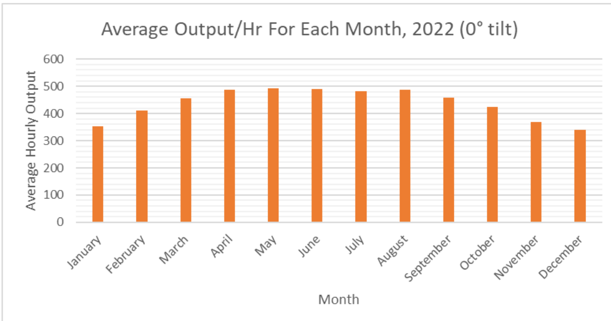


Figure 6: Output by Day, 2022 (33.69° tilt)

Figures 7-9 show the average output per hour for each month during 2022 at the calculated angles. The total average monthly output for a 0° tilt solar panel was 1,964,171.52 W, 18.43° tilt averaged

1,608,814.15 W, and 33.69° tilt averaged 1,588,115.0 W.



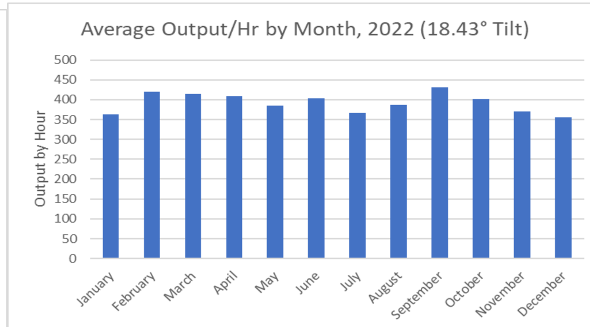


Figure 7: Average Output/Hr for each Month, 2022 (0° tilt)

Figure 8: Average Output/Hr by Month, 2022 (18.43° tilt)

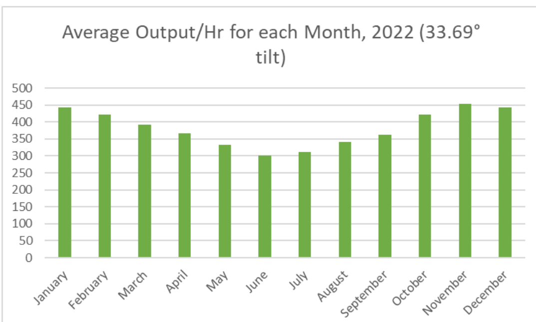
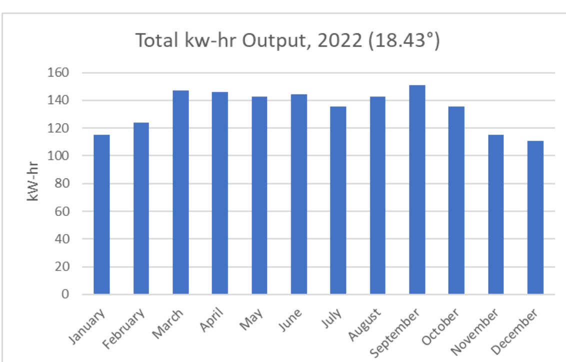


Figure 9: Average Output/Hr for Each Month, 2022 (33.69° tilt)

In order to convey the practical applications for this project, the energy was converted to kW as shown in Figures 10 & 11 for an 18.43° roof. This angle was chosen because it is the minimum angle allowed by Texas Windstorm for asphalt shingles. The average output per solar panel was 134 kW-hrs. If an entire south facing roof of 450 sq. ft. was covered with the allocated solar panels, a total of 11 panels could be utilized. The monthly performance for this setup is shown in Figure 12 and averages out to 1,340.68 kW-hrs per month.



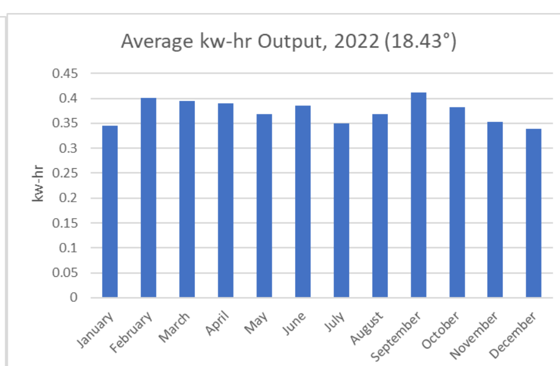


Figure 10: Total kW-hr Output, 2022 (18.43° tilt)

Figure 11: Average kW-hr Output, 2022 (18.43° tilt)

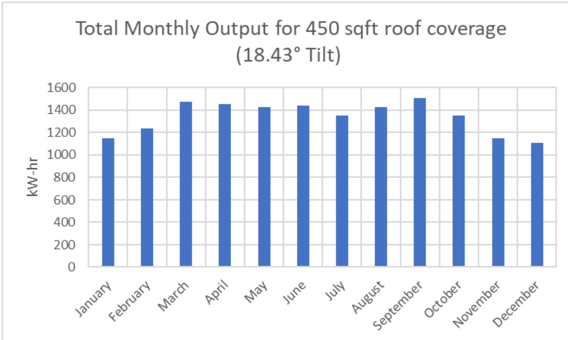
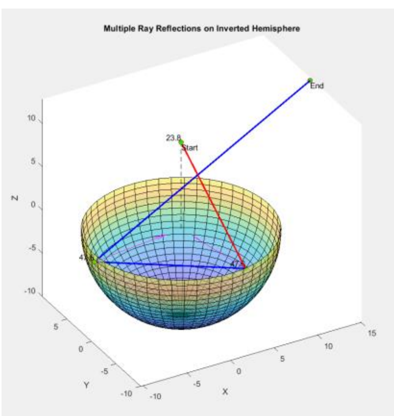


Figure 12: Total Monthly Output for 450 sq. ft. roof coverage (18.43° tilt)

Figure 13 shows a double reflection occurring on a hemispherical cavity generated in MATLAB. The addition of a hemispherical cavity texture on the solar panel could result in a 74% increase in solar voltaic energy (Figures 14 & 15).



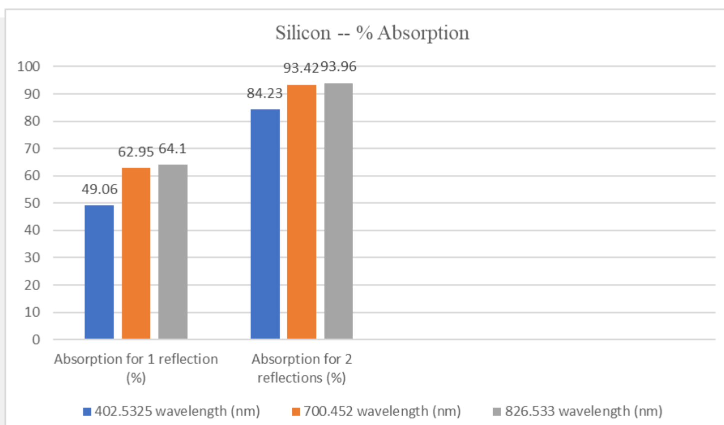


Figure 13: Multiple Ray Reflections on Inverted Hemisphere

Figure 14: Silicon % Absorption

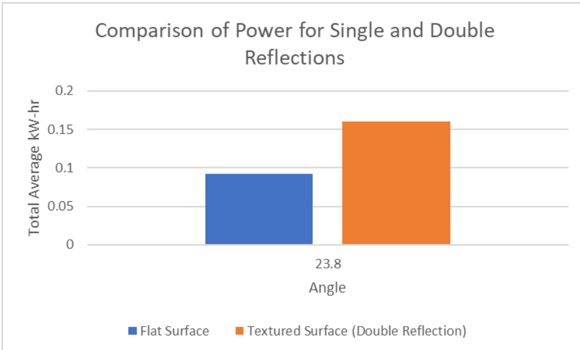


Figure 15: Comparison of Power for Single and Double Reflections

Organic solar cells absorbing all electromagnetic radiation barring visible light generated an average of 0.24 kW-hrs during 2022 when applied to a vertical surface (Figure 16).

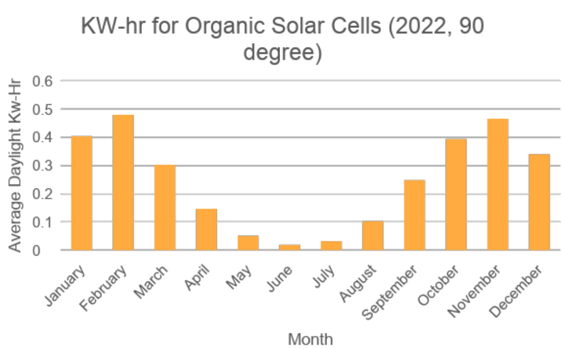


Figure 16: kW-hr for Organic Solar Cells (2022, 90° tilt)

CONCLUSION

The outcome of the research provided user intuition of NREL's SOLPOS calculator including the outputs and how to manage and manipulate the downloaded data sets. We conclude that for the location chosen, the smaller the tilt, the larger the solar output; however, this has limitations in which a solar panel must be titled in order to allow drainage. Regardless of tilt, 1-2 PM generated the greatest output; however, the time of year in which the most energy produced varied widely amongst all tilt angles suggesting further research is necessary. The application of hemispherical cavity surfaces suggests that further practical testing is warranted as is the investigation of other textures. Vertical organic solar cells also show theoretical promise in being able to generate electricity from solar radiation.

POST RESEARCH: CURRICULAR MODULES FOR THE CLASSROOM

1. Curricular Module 1 with TEKS: Jell-O Mold Project

Texas Essential Knowledge and Skills (TEKS): 112.45 Physics, Adopted 2020

P(8) Science concepts. The student knows the characteristics and behavior of waves. The student is expected to:

(C) investigate and analyze characteristics of waves, including velocity, frequency, amplitude, and wavelength, and calculate using the relationships between wave speed, frequency, and wavelength;

(D) investigate behaviors of waves, including reflection, refraction, diffraction, interference, standing wave, the Doppler effect and polarization and superposition; and

(E) compare the different applications of the electromagnetic spectrum, including radio telescopes, microwaves, and x-rays.

Will be cross-curricular with TEKS such as Algebra 1.(A) apply mathematics to problems arising in everyday life, society, and the workplace.

Technology Applications 12.(H) select and use productivity tools found in spreadsheet, word processing, and publication applications to create digital artifacts, including reports, graphs, and charts, with increasing complexity.

Objective: Students in grades 11 and 12 will explore Snell's Law utilizing a Jell-O medium and laser lab/research activity and relate this to innovative research on solar panels.

Standard lab determining index of refraction of acrylic prism.

Students measure the index of refraction of Jell-O.

Use Lead4Ward Instructional Strategies to engage and inquire students about concepts (7).

2. Curricular Module 2 with TEKS: Global Solar Comparison Project

Texas Essential Knowledge and Skills (TEKS): 112.45 Physics, Adopted 2020

P(1) Scientific and engineering practices. The student, for at least 40% of instructional time, asks questions, identifies problems, and plans and safely conducts classroom, laboratory, and field investigations to answer questions, explain phenomena, or design solutions using appropriate tools and models. The student is expected to:

(A) ask questions and define problems based on observations or information from text, phenomena, models, or investigations;

(E) collect quantitative data using the International System of Units (SI) and qualitative data as evidence;

(F) organize quantitative and qualitative data using bar charts, line graphs, scatter plots, data tables, labeled diagrams, and conceptual mathematical relationships;

(G) develop and use models to represent phenomena, systems, processes, or solutions to engineering problems.

Objective: Students in upper high school science courses will utilize online platforms and science resources to conduct data analysis of current and ongoing research; students compare available data on solar energy to determine optimal locations for solar technologies.

Students research necessary geospatial data needed for NREL SOLPOS input for various major cities throughout the world. Students download .txt file and import into Excel as CSV. Students use excel to calculate averages, maximums, minimums and perform conditional formatting to highlight various absolute and relative key data. Data can be analyzed on a daily (sunrise->sunset), weekly, monthly (seasonal), and yearly (longitudinal) to create comparisons. Reasonable calculations using Excel can also be performed.

Extension: Cross-curricular with Environmental Systems 9.(L) Analyze past and present international treaties and protocols such as the environmental Antarctic Treaty System, Montreal Protocol, and Kyoto Protocol.

- Students have an inquiry activity into the Paris Climate Accord to connect their understanding of solar energy data and why it is significant to implement climate change mitigation policies, such as solar panel installations, by making comparisons of carbon dioxide output before and after solar panel implementation.

Use Lead4Ward Instructional Strategies to engage and inquire students about concepts (7).

REFERENCES

1. SOLPOS Calculator at https://midcdmz.nrel.gov/solpos/solpos.html
2. Morales Pedraza, Jorge. (2016). Re: How to estimate the energy production from photovoltaic by using PDF?. (Retrieved from: https://www.researchgate.net/post/How_to_estimate_the_energy_production_from_photovoltaic_by_using_PDF/57842169dc332d4a7a603711/citation/download.)
3. factsheet_rec_alpha_series_en_us.pdf (aeesolar.com)
4. https://sos.noaa.gov/catalog/datasets/climatebits-solar-radiation/#description-data-source
5. https://lead4ward.com/docs/instructional_strategies/playlist_may_2020_21.pdf
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2206864. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Exploration and Investigation of the Impacts of Wind Farms and Hurricanes on Wind Speed Pattern Changes

National Science Foundation (NSF) Research Experiences for Teachers (RET)
Site at Texas A&M University-Kingsville
Integrating data-driven research in Renewable Energy Across Disciplines (I-READ)

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Abstract

Wind speed directly impacts the amount of wind energy that can be harnessed from wind turbines. Data science was used to investigate what influences wind speed to help optimize wind energy generation. This research aimed to analyze wind data to investigate the influence of different factors on wind speed patterns. The study began by collecting meteorological data from the National Solar Radiation Database (NSRDB) and the NOAA Hurricane Track, which were used to identify possible changes in wind speed patterns and correlations with different factors. Two separate wind speed analyses were conducted. One study focused on wind speed changes in Corpus Christi, TX, before and after the landfall of hurricanes. The other study analyzed and compared wind speed patterns at selected locations near the Chapman Ranch and Papalote Creek Wind Farms before and after the wind farm commission dates. Understanding these connections enables informed decisions to promote sustainable energy practices. This research will translate these inquiries into a more localized investigation of renewable energy generation to teach students the importance of using data science to answer research questions.

Keywords: Wind Speed, Wind Farms, Hurricanes, Data Science

1. Introduction

1.1 The Influence of Hurricane Landfalls on Wind Speed in Corpus Christi, TX.

In the past 20 years, 3 major hurricanes have impacted the city of Corpus Christi. Hurricane Hanna, that made a landfall in Corpus Christi, TX on July 25, 2020, at 41m/s under Category 1 (H1)[1]. Hurricane Harvey, which landed on August 26, 2017, at 59 m/s under Category 4 (H4)[1]. Hurricane Harvey was considered one of the most disastrous as residents reported seeing downed trees, buildings with siding ripped off, mangled street signs and broken windows. Hurricane Dolly that landed on July 24,2008 at 43 m/s under Category 2 (H2)[1]. This analysis aimed to determine how the Hurricanes influenced the wind speed in Corpus Christi during a 10-day period of their landfall taken at geographic coordinates (27.76, -97.86 coordinates) [2].

1.2 The Influence of Wind Farms on Wind Speed in Neighboring Cities

This part of the study analyzed and compared wind speeds before and after the wind farm's commission date to discern any significant wind speed changes. The research began with the wind speed analysis for Kingsville, TX. This analysis aimed to determine how the Chapman Ranch Wind Farm influenced wind speed in Kingsville, TX. According to Power-technology.com, the Chapman Ranch Wind Farm was commissioned in October 2017 [3]. Therefore, the wind speed was specifically analyzed for changes before and after this date. Because the wind speed data gathered from NSRDB spanned from 1998 - 2020, the data could only be analyzed three years after the commission date. This yielded moderate results, so a second wind farm and its corresponding location were researched. The Papalote Creek Wind Farm is approximately 38 km East of Mathis, TX, sharing a similar distance and direction as Kingsville from the Chapman Ranch Wind Farm. However, the Papalote Creek Wind Farm was commissioned in November 2009, which yielded more pre and post-data analysis of the wind speed [4].

2. Methodology

The data for both segments of the study was acquired from the NREL National Solar Radiation Database (NSRDB). The dataset encompasses a time frame from 1998 to 2020, providing consistent 30-minute intervals of wind speed data measurements [2]. This extensive data coverage facilitated statistical analysis, enabling the examination of wind speed patterns and trends.

2.1 The Influence of Hurricane Landfalls on Wind Speed in Corpus Christi, TX.

In addition to the NSRDB, the NOAA Historical Hurricane Tracks provided the dates of hurricane development and landfall, developing Storm Category, and additional wind speed data [1].

Wind and weather data spanning from 2000 to 2020, located at geographic coordinates (27.53, -97.86), were retrieved from the NSRDB [2], as depicted in Figure 1.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	Source	Location II	City	State	Country	Latitude	Longitude	Time Zone	Elevation	Local Time	Clearsky D	Clearsky D	Clearsky G	Dew Point	DHI Units	DNI Units	GHI Units	Solar Zenit	Temperatu	Pressure U	Relative H	Precip
2	NSRDB	674821	-	-	-	27.53	-97.86	-6	21	-6	w/m2	w/m2	w/m2	c	w/m2	w/m2	w/m2	Degree	c	mbar	%	cm
3	Year	Month	Day	Hour	Minute	DHI	DNI	Dew Point	Surface All	Wind Spee	Relative H	Temperatu	Pressure	GHI	Clearsky G	Clearsky D	Clearsky D	Precipitabl	Wind Direc	Global Hor	Global Horizontal	
4	2017	1	1	0	0	0	0	15	0.167	1	100	15	1000	0	0	0	0	2.834	128.7	0	0	
5	2017	1	1	0	30	0	0	15	0.167	1	100	15	1000	0	0	0	0	2.862	128.7	0	0	
6	2017	1	1	1	0	0	0	15	0.167	1	100	15	1000	0	0	0	0	2.891	141.7	0	0	
7	2017	1	1	1	30	0	0	15	0.167	1	100	15	1000	0	0	0	0	2.935	141.7	0	0	
8	2017	1	1	2	0	0	0	15	0.167	1	100	15	1000	0	0	0	0	2.98	153.7	0	0	
9	2017	1	1	2	30	0	0	15	0.167	0.9	100	15	1000	0	0	0	0	3.052	153.7	0	0	
10	2017	1	1	3	0	0	0	15	0.167	0.9	100	16	1000	0	0	0	0	3.125	166.2	0	0	
11	2017	1	1	3	30	0	0	15	0.167	0.8	100	16	1000	0	0	0	0	3.221	166.2	0	0	
12	2017	1	1	4	0	0	0	15	0.167	0.8	100	16	1000	0	0	0	0	3.317	186.4	0	0	
13	2017	1	1	4	30	0	0	15	0.167	0.8	100	16	1000	0	0	0	0	3.404	186.4	0	0	
14	2017	1	1	5	0	0	0	16	0.167	0.8	100	16	1000	0	0	0	0	3.492	213	0	0	
15	2017	1	1	5	30	0	0	16	0.167	0.7	100	16	1000	0	0	0	0	3.545	213	0	0	
16	2017	1	1	6	0	0	0	16	0.167	0.6	100	16	1000	0	0	0	0	3.598	224.4	0	0	
17	2017	1	1	6	30	0	0	16	0.167	0.5	100	16	1000	0	0	0	0	3.61	224.4	0	0	
18	2017	1	1	7	0	0	0	16	0.167	0.5	100	16	1000	0	0	0	0	3.623	209.3	0	0	
19	2017	1	1	7	30	0	0	16	0.167	0.4	100	16	1000	0	0	0	0	3.612	209.3	0	0	
20	2017	1	1	8	0	40	277	17	0.167	0.4	100	17	1000	72	72	277	40	3.601	212.4	0	0	
21	2017	1	1	8	30	64	457	17	0.167	0.7	100	17	1010	161	161	457	64	3.6	212.4	7.7147	5.8989	
22	2017	1	1	9	0	88	481	17	0.167	1	95.82	18	1010	234	252	559	83	3.599	233.1	11.7172	9.0435	
23	2017	1	1	9	30	138	387	17	0.167	1.1	95.83	18	1010	287	341	639	95	3.599	233.1	15.0232	11.6678	
24	2017	1	1	10	0	195	245	17	0.167	1.2	92.02	19	1010	308	422	692	106	3.6	219.3	16.6792	13.0039	
25	2017	1	1	10	30	234	207	17	0.167	1.7	86.48	20	1010	341	493	734	113	3.551	219.3	18.9267	14.7918	
26	2017	1	1	11	0	255	78	17	0.167	2.2	81.96	21	1010	300	553	776	113	3.503	194.2	16.9412	13.2604	
27	2017	1	1	11	30	286	179	17	0.167	2.7	77.07	22	1000	395	598	796	117	3.411	194.2	22.5646	17.6791	

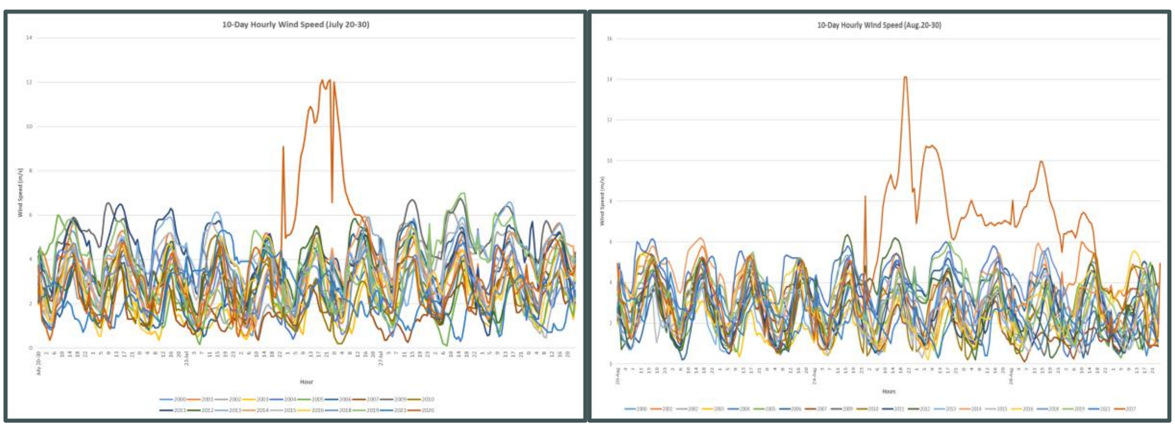
Figure 1: Example of the downloaded raw data from NREL NSRDB.

Utilizing the raw data obtained from the NSRDB, the average wind speed was computed for each year, enabling a year-to-year comparison of average wind speeds, as depicted in figure 2.

Corpus Christi Yearly Wind Speed Average (2000-2021)																						
Month	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Jan	3.44	3.39	3.58	2.93	3.36	3.55	3.42	3.48	3.70	3.28	3.38	3.14	3.23	3.43	3.15	2.89	2.89	3.47	3.39	3.33	3.45	3.19
Feb	3.80	3.73	3.30	3.63	3.54	3.22	3.75	3.06	3.65	4.09	3.22	4.06	3.32	3.39	3.38	3.25	3.33	3.56	3.75	3.29	3.65	3.81
Mar	3.82	3.03	4.02	2.88	3.34	3.18	4.10	3.78	4.44	3.96	3.27	3.79	3.81	3.85	3.52	2.66	3.45	3.78	3.90	3.72	4.01	3.77
Apr	3.46	4.18	4.26	3.48	3.66	3.69	3.94	3.56	4.02	4.45	3.71	4.83	3.87	4.01	3.85	2.91	3.11	3.74	4.13	3.98	3.57	3.94
May	4.04	3.64	4.27	3.69	3.78	3.35	3.78	3.20	3.88	3.56	3.63	4.42	3.45	4.02	3.98	3.71	3.40	3.70	3.88	4.26	3.84	3.85
Jun	3.90	3.14	3.31	2.81	3.32	3.39	2.90	3.06	4.22	3.73	3.38	3.80	3.24	3.32	4.35	2.72	2.71	3.17	4.14	3.59	3.50	3.12
July	3.39	3.30	3.03	2.76	2.75	2.91	2.77	2.54	3.42	3.83	2.93	3.51	3.06	3.34	3.11	3.53	3.83	3.17	2.96	3.74	3.81	2.72
Aug	2.80	3.38	2.68	2.45	2.93	2.64	2.81	2.27	2.53	3.12	2.54	3.24	3.22	2.95	3.08	2.82	2.91	3.88	3.44	3.67	3.08	2.77
Set	3.07	2.69	3.06	2.50	2.34	2.92	2.67	2.28	2.62	2.33	2.71	2.87	2.91	2.83	2.92	2.57	2.43	2.97	2.74	3.48	3.49	2.83
Oct	3.36	3.10	2.76	2.68	3.35	2.90	2.80	2.71	2.67	3.60	2.69	3.11	3.18	2.89	2.84	3.02	2.45	2.73	3.40	3.60	3.19	2.95
Nov	3.45	2.86	2.97	3.32	3.30	3.09	3.20	2.99	2.91	2.72	3.60	3.76	2.70	3.11	3.25	3.07	2.72	2.90	3.33	3.10	2.92	2.89
Dec	3.31	3.10	3.21	3.32	2.99	3.13	3.14	3.36	3.81	3.03	3.32	3.50	3.31	2.87	2.94	3.22	3.24	2.79	3.48	2.91	3.24	3.31

Figure 2: The table with the yearly wind speed average in Corpus Christi, TX from 2000-2021.

The line graphs in figure 3 depict higher wind speeds on the days the hurricanes were in the Corpus Christi area. A wind speed comparison was performed for each hurricane, contrasting the average wind speed with that of all other years.



(a) (b)

Figure 3: Wind speed comparison of the 10-Day period of hurricane landfall.

(a)Hurricane Hanna (b)Hurricane Harvey

2.2 The Influence of Wind Farms on Wind Speed in Neighboring Cities

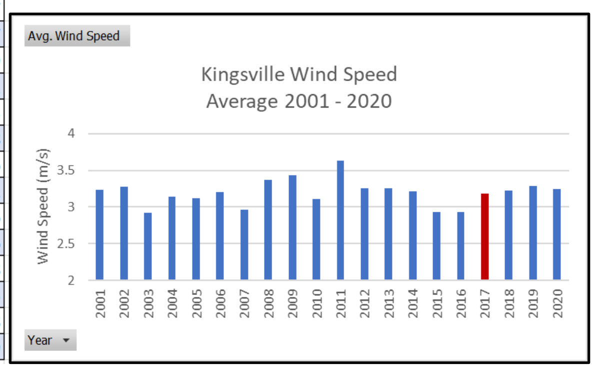
2.2.1 Wind Speed Analysis for Kingsville, TX

The wind speed measurements for Kingsville, TX, were precisely recorded at geographic coordinates (27.53, -97.86) and an elevation of 21 meters [2]. The data in Figure 5 was calculated using approximately 17,000 data points. The analysis began with calculating the average wind speed each year from 2001 to 2020. From there, the standard deviation for each year was calculated to measure the data's spread in relation to the average. Finally, the coefficient of variation was calculated, a ratio of the standard deviation to the average, to see if there was evidence of wind speed stabilization.

Statistical Wind Speed Data for Kingsville, TX

Year	Annual Avg.	Annual StdDev	Annual CoV
2001	3.238110731	1.550408092	0.478800208
2002	3.278493151	1.645797625	0.501998189
2003	2.916689498	1.487158726	0.509879
2004	3.142150501	1.55661013	0.495396427
2005	3.125148402	1.501868988	0.480575254
2006	3.201695205	1.595553279	0.4983464
2007	2.966107306	1.513242241	0.510177847
2008	3.36601776	1.732611283	0.514736227
2009	3.428573059	1.693018882	0.493796939
2010	3.105702055	1.572120328	0.506204491
2011	3.630993151	1.700251149	0.468260633
2012	3.259170082	1.595336794	0.489491728
2013	3.259170082	1.615990377	0.495828796
2014	3.209480594	1.568621676	0.488746272
2015	2.934377854	1.512359497	0.515393576
2016	2.928187614	1.471135179	0.502404686
2017	3.184743151	1.596856962	0.501408398
2018	3.225770548	1.515973789	0.469957105
2019	3.290679224	1.600311202	0.486316378
2020	3.247529599	1.500277062	0.461974869

(a)



(b)

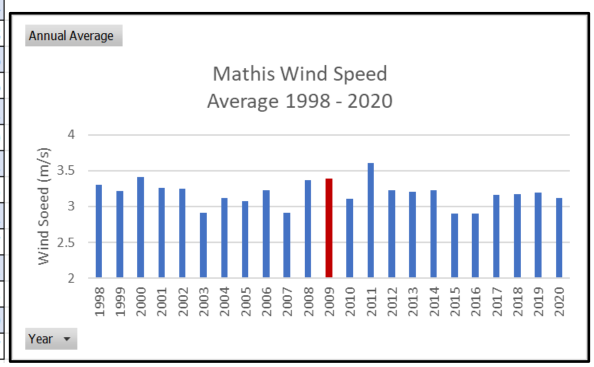
Figure 5: The refined annual wind speed data for Kingsville, TX
(a) The annual average, standard deviation and coefficient of variation
(b) The annual wind speed average (2017 depicts the Chapman Ranch Wind Farm commission year).

2.2.2 Wind Speed Analysis for Kingsville, TX

The wind speed measurements for Mathis, TX, were precisely recorded at geographic coordinates (28.09, -97.82) and an elevation of 44 meters[2]. The data in Figure 6 was calculated using approximately 17,000 data points. The analysis began with calculating the average wind speed each year from 1998 to 2020. From there, the standard deviation for each year was calculated to measure the data's spread in relation to the average. Finally, the coefficient of variation was calculated, a ratio of the standard deviation to the average, to see if there was evidence of wind speed stabilization.

Statistical Wind Speed Data for Mathis, TX			
Year	Annual Avg	Annual StdDev	Annual CoV
1998	3.302522831	1.648673651	0.499216428
1999	3.220125571	1.627493038	0.505412911
2000	3.410166211	1.55756955	0.456743001
2001	3.262363014	1.53069815	0.46919921
2002	3.244657534	1.618412168	0.498792908
2003	2.912665525	1.471616644	0.505247386
2004	3.121129326	1.507565725	0.483019307
2005	3.07658105	1.463305792	0.475627252
2006	3.222671233	1.563201963	0.485064051
2007	2.909965753	1.469740839	0.505071524
2008	3.362869991	1.70467047	0.506909418
2009	3.384646119	1.649661152	0.48739546
2010	3.105821918	1.542827833	0.496753476
2011	3.600336758	1.66409157	0.462204422
2012	3.221670082	1.562252546	0.48492009
2013	3.203544521	1.570616258	0.490274522
2014	3.221478311	1.556712727	0.483229305
2015	2.904486301	1.484446589	0.511087482
2016	2.903660064	1.442728298	0.496865427
2017	3.157340183	1.583793573	0.501622721
2018	3.168327626	1.483373904	0.468188293
2019	3.194189498	1.57680669	0.493648449
2020	3.121715619	1.469616485	0.470772057

(a)



(b)

Figure 6: The refined annual wind speed data for Mathis, TX
(a) The annual average, standard deviation and coefficient of variation
(b) The annual wind speed average (2009 depicts the Papalote Creek Wind Farm commission year).

Figure 7 was generated specifically for the purpose of conducting a t-test statistical analysis. The results of the p-values need to be less than 0.05 to show any evidence of significant change.

Mathis Wind Speed (m/s) Comparision						
	1998 - 2008			2010 - 2020		
Month	Average	StdDev	CoV	Average	StdDev	CoV
Jan	3.074908358	1.564111159	0.509379231	2.902956989	1.612855117	0.556167158
Feb	3.233182891	1.646172918	0.509989328	3.193318966	1.614280353	0.507583545
Mar	3.589485582	1.732971909	0.486007081	3.43998045	1.616768632	0.474996153
Apr	3.805454545	1.622956825	0.429068579	3.588371212	1.570550493	0.442254239
May	3.796896383	1.417527046	0.374598759	3.739406158	1.495309491	0.400076224
Jun	3.596104798	1.374064752	0.388056176	3.367348485	1.324056986	0.398543014
Jul	3.195540078	1.258777248	0.397339304	3.366104594	1.294267605	0.38560807
Aug	2.844250978	1.290785939	0.455904531	3.177107771	1.397748917	0.438897677
Sep	2.559854798	1.283139491	0.501061134	2.759810606	1.24923754	0.453125727
Oct	2.816794966	1.353905697	0.484012865	2.782881232	1.343456362	0.48368465
Nov	2.833693182	1.468839171	0.519731791	2.834690657	1.461419538	0.516282795
Dec	2.890676931	1.617507846	0.559437159	2.813129277	1.617261619	0.577667686

Figure 7: Statistical comparison of the monthly wind speed in Mathis, TX before and after 2009

2.2.3 Wind Direction Analysis for Kingsville and Mathis, TX

The wind direction was also considered towards the end of the investigation. Figure 8 depicts the most prevalent values of wind direction for each year. The data was calculated using the mode for each year for both Kingsville and Mathis, TX.

Kingsville, TX			Mathis, TX	
Year	Wind Direction		Year	Wind Direction
2001	152.1		1998	149.3
2002	158.1		1999	134.1
2003	147.4		2000	136.8
2004	154.8		2001	151.6
2005	141.4		2002	141.6
2006	**158.7**		2003	137.1
2007	137.9		**2004**	**153.6**
2008	140.6		2005	136.2
2009	155.5		2006	149.2
2010	138.8		2007	143.4
2011	158.4		2008	151.1
2012	137.7		2009	134.6
2013	138.3		2010	150.8
2014	148		2011	132.3
2015	147.4		2012	153.4
2016	149.1		2013	133.9
2017	146.7		2014	138.6
2018	153		**2015**	**128.7**
2019	136		2016	132.6
2020	**133**		2017	152.8
			2018	145
			2019	143
			2020	143

(a) (b)

Figure 8: The values of the wind direction that appeared most often for each year.
(a) Wind direction for Kingsville, TX (b) Wind direction for Mathis, TX.

3. Results

3.1 The Influence of Hurricane Landfalls on Wind Speed in Corpus Christi, TX

A two-tailed hypothesis test was conducted to determine whether the sample mean significantly differs from the population mean in both directions. When the reported p-value from a t-test is less than 0.05, the result is considered statistically significant, while a p-value greater than 0.05 indicates an insignificant result.

Figure 9 depicts significant differences in the wind speed on the days the hurricane made landfall in the Corpus Christi area compared to the days when there were no hurricanes. The results from the t-test conducted on the 10-day window for all data showed statistically significant results because most of the p-values were less than 0.05. When the hurricanes made landfall and the p-values were significantly below 0.05, the wind speed stabilized and exhibited no significant changes beyond the 4th day of landfall.

Two Tailed P-Values (Hanna 2020)											
Dates	20-Jul	21-Jul	22-Jul	23-Jul	24-Jul	25-Jul	26-Jul	27-Jul	28-Jul	29-Jul	30-Jul
P-Value	1.237E-15	0.01000736	0.610073513	0.0319823	0.084952579	2.69921E-13	6.364E-06	0.013857906	5.12684E-11	0.461415163	8.04678E-07

(a)

Two Tailed P-Values (Harvey 2017)											
Dates	20-Aug	21-Aug	22-Aug	23-Aug	24-Aug	25-Aug	26-Aug	27-Aug	28-Aug	29-Aug	30-Aug
P-Value	0.600489	0.037443533	0.782612287	0.0024233	0.402448242	1.62753E-09	5.184E-12	5.93475E-16	1.84803E-22	4.80023E-07	0.931148061

(b)

Two Tailed P-Values (Dolly 2008)											
Dates	20-Jul	21-Jul	22-Jul	23-Jul	24-Jul	25-Jul	26-Jul	27-Jul	728/2023	29-Jul	30-Jul
P-Value	0.0115805	6.47E-07	0.001205879	2.672E-13	4.79166E-10	3.63026E-07	4.974E-11	0.003447896	0.142189877	0.021544199	4.96288E-05

(c)

Figure 9: The 10-day table for two-tailed p-values
(a) Hurricane Hanna (b) Hurricane Harvey (c) Hurricane Dolly

In August 2017, Hurricane Harvey occurred. Figure 10 depicts the t-test analysis that was conducted to compare data from August 2017 with data from all other years in the same month. The p-value indicates a significant difference between August of that specific year and all other years.

t-Test: Paired Values Result for the Month of August 2017		
	Variable 1	*Variable 2*
Mean	2.9322192	3.87856183
Variance	0.0742339	3.85502726
Observations	31	31
Pearson Correlation	-0.1910203	
Hypothesized Mean Difference	0	
df	30	
t Stat	-2.5915718	
P(T<=t) one-tail	0.0073079	
t Critical one-tail	1.6972609	
P(T<=t) two-tail	0.0146158	
t Critical two-tail	2.0422725	

Figure 10: The t-test analysis showing the p-value for the month of August 2017 and the average wind speed of all the other years.

3.2 The Influence of Wind Farms on Wind Speed in Neighboring Cities

3.2.1 Wind Speed Analysis for Kingsville, TX

Three figures are presented in this section, focusing on the wind speed analysis in Kingsville, TX, and its relation to the commissioning of the Chapman Ranch Wind Farm.

Figure 11 focuses on the average wind speed analysis in Kingsville, TX, spanning three years before and after the Chapman Ranch Wind Farm commission date. The table illustrates a notable increase in wind speed compared to the three years preceding the commission date. Nonetheless, due to insufficient post-wind farm commission data, predicting a sustained rise in wind speed remains inconclusive.

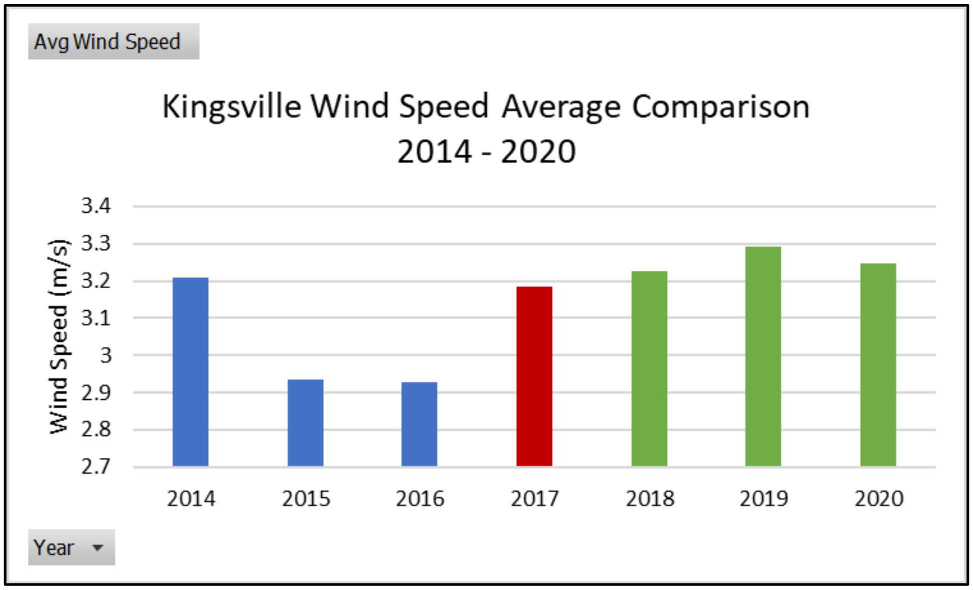


Figure 11: Kingsville, TX annual average wind speed comparison from 2014 - 2020.

In figure 12, the standard deviation exhibits a notable dispersion from the average wind speed. In addition, the wind speed dispersion around the average remains relatively consistent before and after the 2017 commission date, indicating no discernible change in fluctuations.

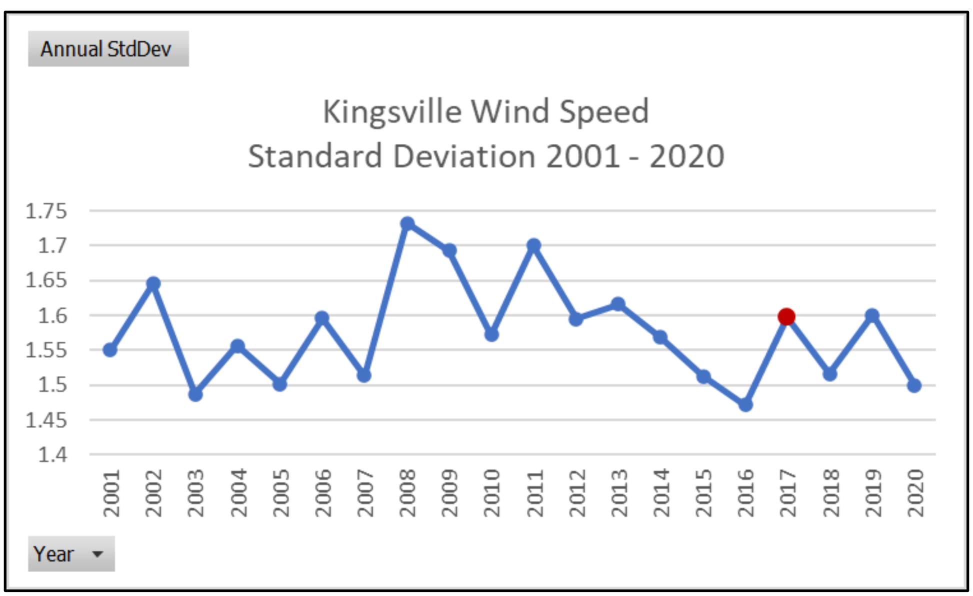


Figure 12: The standard deviation of the wind speed in Kingsville, TX

Figure 13 depicts a reduced coefficient of variation indicating decreased variability in wind speed after 2017, possibly suggesting wind speed stabilization. However, the limited availability of post-commission date wind speed data impedes the verification of this conclusion.

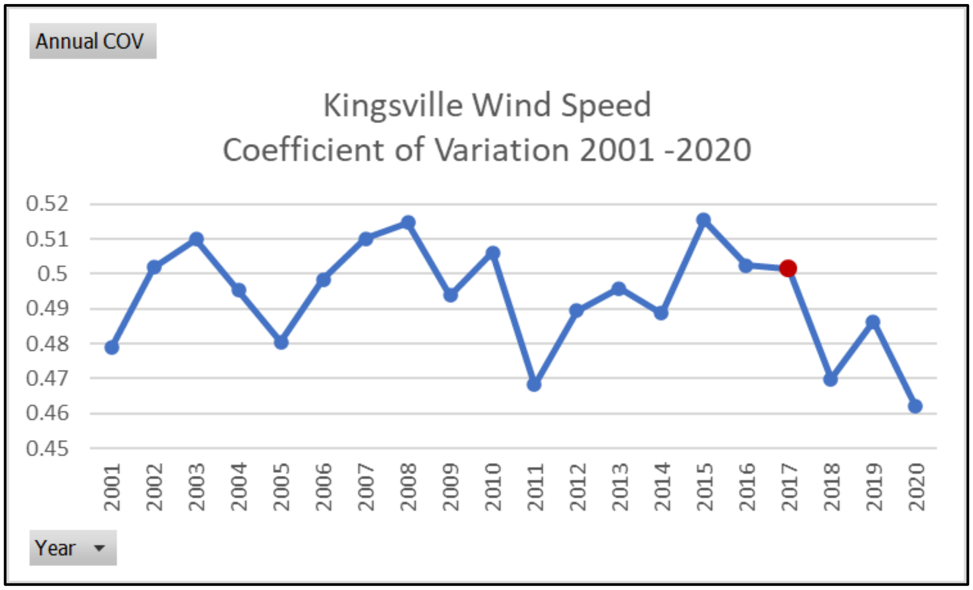


Figure 13: The coefficient of variation of the wind speed in Kingsville, TX

3.2.2 Wind Speed Analysis for Mathis, TX

Figure 14 focuses on the average wind speed analysis in Mathis, TX, spanning five years before and after the Papalote Creek Wind Farm commission date. The table illustrates a notable decrease in wind speed post wind farm commission date, with the exception of 2011. There may be unknown factors that could have yielded a higher average for that year. Furthermore, a t-test analysis was later performed to ascertain the presence of any significant changes, providing further insights into the wind speed trends.

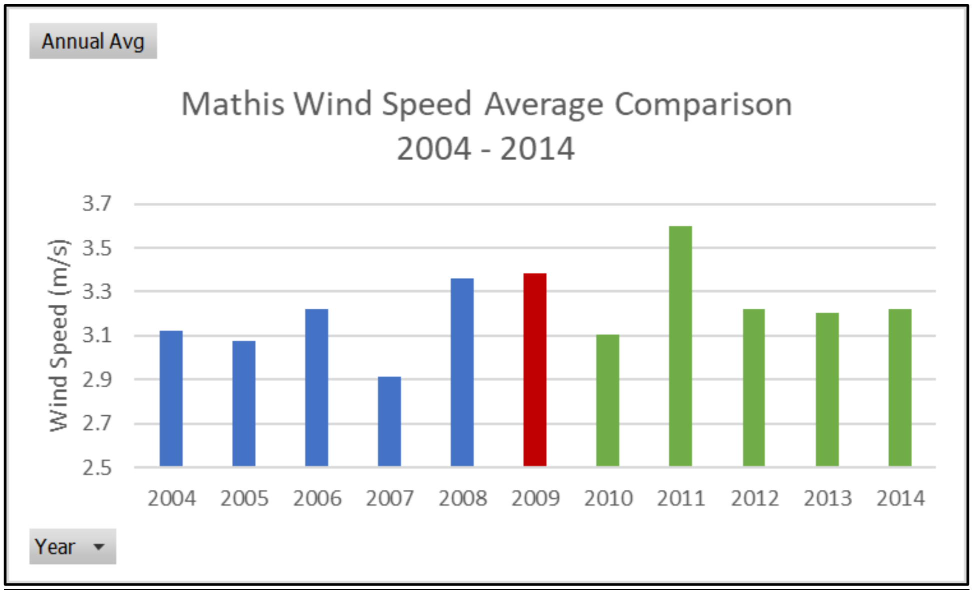


Figure 14: Mathis, TX annual average wind speed comparison from 2004 - 2014.

In figure 15, the standard deviation exhibits a notable dispersion from the average wind speed. The wind speed dispersion around the average remains relatively consistent before and after the 2009 commission date, indicating no discernible change in fluctuations. Furthermore, the standard deviation seems to follow a similar fluctuating pattern in comparison to the averages better seen in figure 6.

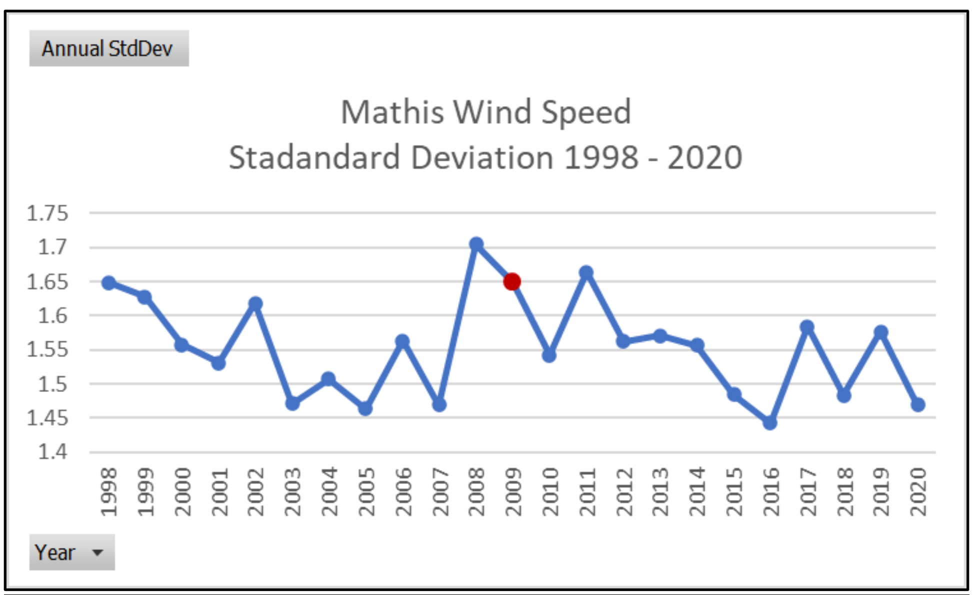


Figure 15: The standard deviation of the wind speed in Mathis, TX

Figure 16 depicts a coefficient of variation with an approximate range of 0.46 to 0.51 (or 46% to 51%). Unlike the wind speed data observed for Kingsville, TX, there is no significant decrease in wind speed variability after 2009, which precludes the possibility of wind speed stabilization.

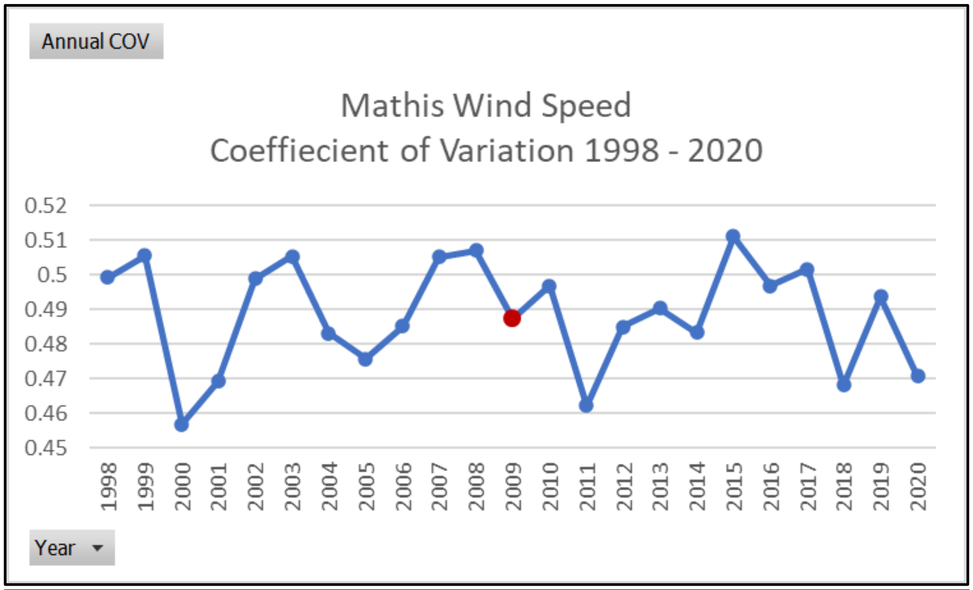
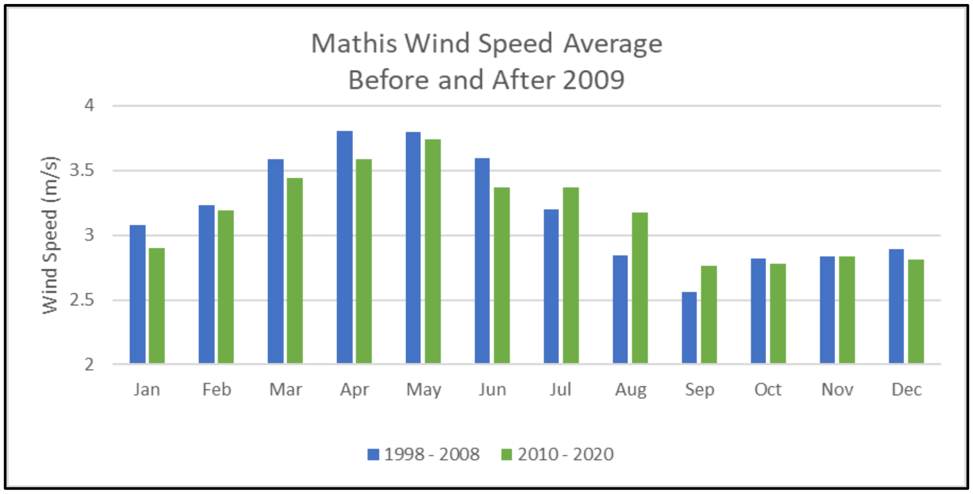
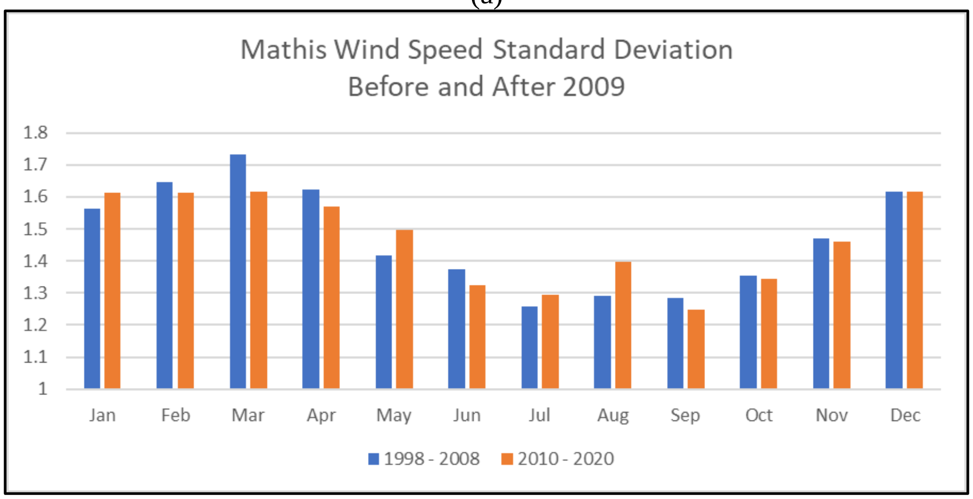


Figure 16: The coefficient of variation of the wind speed in Mathis, TX

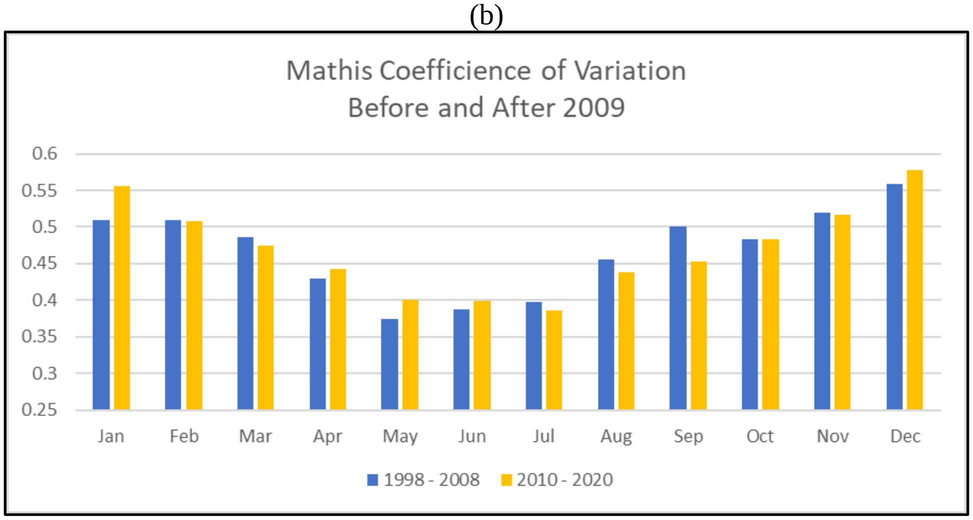
Figure 17 presents side-by-side bar graphs, offering a comparative view of the statistical data before and after the 2009 commission date. While most of the months in figure 17(a) illustrate lower wind speeds after 2009, July, August, and September showed increases. A similar pattern emerged concerning the standard deviation and coefficient of variation, with most months showing a decrease post wind farm commission date, but not all. To draw definitive conclusions on significant changes, a t-test was subsequently conducted.



(a)



(b)



(c)

Figure 17: Statistical comparison of the monthly wind speed in Mathis, TX before and after 2009.

(a) Average (b) Standard deviation (c) Coefficient of variation

Figure 18 verifies what was visually noted in figure 17, that there isn't a significant change in wind speed before and after the wind farm commission date. The p-values obtained for the average wind speed, standard deviation, and coefficient of variation all exceeded 0.05, indicating that the observed changes are statistically insignificant. Specifically, the resulting t-tests yielded a p-value of 0.662800239 for the average wind speed, 0.878464359 for the standard deviation, and 0.810818736 for the coefficient of variation.

t-Test: Mathis Wind Speed Average (Jan - Dec)		
	1998 - 2008	*2010 - 2020*
Mean	3.18640362	3.16375887
Variance	0.17809635	0.11626317
Observations	12	12
Pearson Correlation	0.91632091	
Hypothesized Mean Difference	0	
df	11	
t Stat	0.44806875	
P(T<=t) one-tail	0.33140012	
t Critical one-tail	1.79588482	
P(T<=t) two-tail	0.66280024	
t Critical two-tail	2.20098516	

(a)

t-Test: Mathis Wind Speed Standard Deviation (Jan - Dec)		
	1998 - 2008	*2010 - 2020*
Mean	1.46923	1.46643439
Variance	0.0264801	0.01975221
Observations	12	12
Pearson Correlation	0.92705745	
Hypothesized Mean Difference	0	
df	11	
t Stat	0.15651286	
P(T<=t) one-tail	0.43923218	
t Critical one-tail	1.79588482	
P(T<=t) two-tail	0.87846436	
t Critical two-tail	2.20098516	

(b)

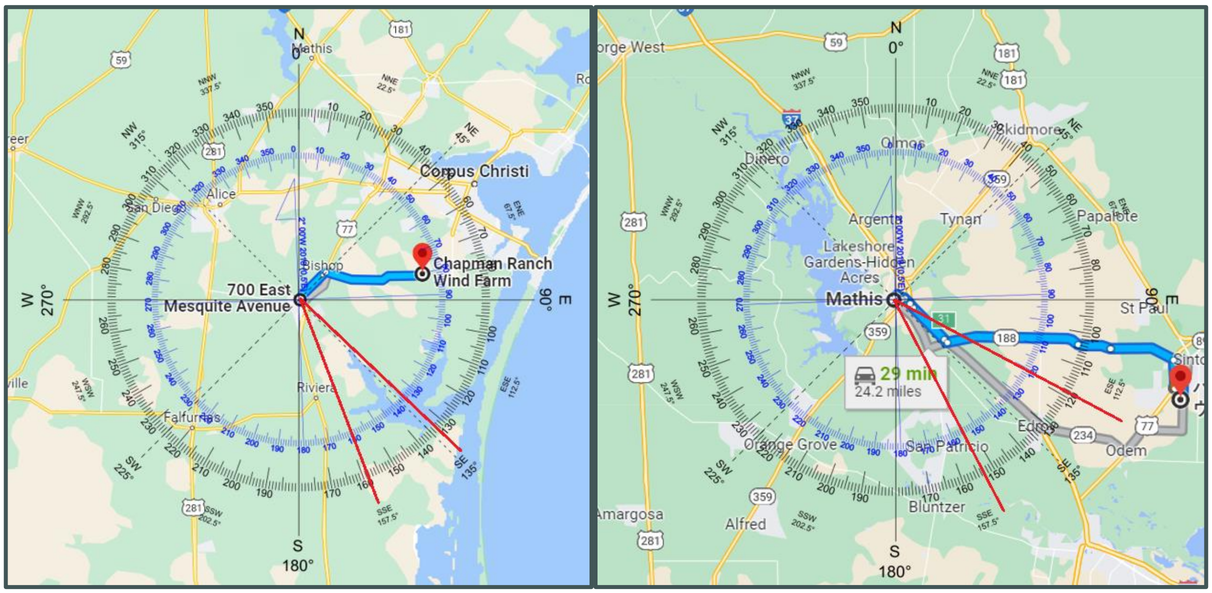
t-Test: Mathis Wind Speed Coefficient of Variation (Jan - Dec)		
	1998 - 2008	*2010 - 2020*
Mean	0.46788216	0.46957391
Variance	0.0034505	0.00381101
Observations	12	12
Pearson Correlation	0.92246946	
Hypothesized Mean Difference	0	
df	11	
t Stat	-0.24519628	
P(T<=t) one-tail	0.40540937	
t Critical one-tail	1.79588482	
P(T<=t) two-tail	0.81081874	
t Critical two-tail	2.20098516	

(c)

Figure 18: Statistical comparison of the wind speed in Mathis, TX before and after 2009.
(a) Average (b) Standard deviation (c) Coefficient of variation

3.2.3 Wind Direction Analysis for Kingsville and Mathis, TX

An analysis of the wind direction was taken because of the results of the t-test. Figure 19 depicts the wind speed blowing in from the southeast for both Kingsville and Mathis, TX. Despite these locations being situated further inland from the wind farms, they are not directly downwind. This observation suggests a strong likelihood that the absence of significant wind speed influence in these areas is attributed to their specific wind direction patterns.



(a) (b)

Figure 19: The values of the wind direction that appeared most often for each year
(a) Wind direction for Kingsville, TX (b) Wind direction for Mathis, TX.

4. Conclusion

This research examined the impact of hurricanes on wind speeds in coastal regions like Corpus Christi, TX, as well as the potential local long-term effects of wind farm development on wind speed. The ensuing comprehensive analysis of wind speed findings offers valuable insights that can inform decision-making towards advancing sustainable energy practices.

The investigation into wind speeds influenced by hurricanes yielded significant and noteworthy results. The current analysis shows significant differences in wind speed on the days the hurricanes made landfall in the Corpus Christi area compared to the years when there were no hurricanes. The results from the t-test conducted on the 10-day window for all three hurricanes showed statistically significant results because most of the p-values were less than 0.05.

However, the investigation results concerning wind speeds influenced by wind farms were inconclusive or less promising. The current analysis reveals no statistically significant change in wind speed before and after the wind farm commission dates. Specifically, the t-test results from the Mathis, TX data yielded p-values greater than 0.05, indicating statistically insignificant results. Wind direction patterns likely contribute to these findings, considering the wind farm's location relative to the prevailing wind direction. Consequently, future wind speed analyses should begin by examining the wind direction at the wind farm under study, followed by selecting a downwind location for further analysis. At present, the study's findings remain inconclusive, demanding further investigation to determine if wind farms indeed exert any substantial influence on wind speeds.

The information learned in these investigations was used to create a lesson module for high school students. Students will use similar skill sets to research and analyze localized investigations focused on renewable energy generation, with the primary objective of emphasizing the significance of employing data science techniques in addressing research questions.

5. Lesson Module

Optimal Placement of Renewable Energy Sources

Learning Standards [5]

STEM TEKS

§130.418 Practicum in STEM

- (2)(A-D) The student applies concepts of critical thinking and problem solving
- (3)(A-F) The student demonstrates leadership and teamwork skills in collaboration with others to accomplish goals and objectives.
- (4)(A-G)The students demonstrate oral and written communication in creating, expressing, interpreting information and ideas, including technical terminology and information.

SCIENCE TEKS

§112.43 Chemistry

- (1)(A-G) The student ask questions and identify problems based on observations of information from text, phenomena, or models.
- (2)(A-C) The student analyzes and interprets data to derive meaning, identify future patterns, discover relationships to develop evidence-based arguments.
- (10)(B) Describe and calculate the relationship among volume, pressure, number of moles, and temperature for an ideal gas.

MATH TEKS

§111.43. Mathematical Models with Applications

- (9)(B) Analyze numerical data using measures of central tendency (mean, median, and mode) and variability (range, interquartile range or IQR, and standard deviation) in order to make inferences with normal distributions.

§111.47. Statistics

- (6)(A-J) Inference. The student applies the mathematical process standards to make inferences and justify conclusions from statistical studies.

Objective

The students use critical thinking and problem-solving skills to analyze and interpret data to derive meaningful insights, identify future patterns, and discover relationships that aid in efficient utilization of renewable electric sources.

Key Terms

- Renewable Energy: Wind Energy, Solar Energy, Wave Energy, Geothermal Energy, Hydropower
- Data Science: Data Analytics, Dynamic Visualization, Data, Statistics, Coefficient of Variation, Standard Deviation, Average
- Measurement: SI Units, Speed (m/s), Temperature (℃), Pressure (Pascals or Bar), Intensity (mW/cm^2), brightness (lumen)

Materials

- Computer (with internet access and Microsoft Excel, Power Point, & Word)
- Weather Station (with set-up and tools)
- Notebook (for documentation and notes)

Research Questions

- *Knowing that good places for wind turbines are where the annual average wind speed is at least 4 m/s* [6].
    - How do weather conditions influence the wind speed?
    - What is the best location on campus to install a small wind turbine?
- *Knowing that solar panels are comprised of photovoltaic cells that react to UV rays and transform them into electricity* [7].
    - How do weather conditions influence UV radiation?
    - What is the best location on campus to install a solar panel?

Criteria

- Use reputable published data (i.e NREL NSRDB)
- Use weather instruments to measure and collect data.
- Filter through the data and refine it to its specific attributes.
- Statistical analysis of the data using excel.
    - Average, Standard Deviation, Coefficient of Variation, T-Test
- Create an excel interface, report, and poster to communicate the results.

Constraints

- Timeline (Create a schedule or gantt chart for project benchmarks)
- Assign specific attributes based on learning standards (i.e. Pressure & Temperature)
- Students must select a minimum 2 attributes to analyze

Lesson Breakdown

Task Duration

Initial set-up ………………………………………………………………………………….…….1 week

- Downloading data from (NSRDB)
    - The instructor can download the data to disseminate to the entire class. https://nsrdb.nrel.gov/data-viewer
- Setting up weather station
    - Students select a location for a weather station set-up based on the instructions provided with the product and renewable energy generation source.
- Determine Attributes
    - The instructor assigns necessary attributes to meet course lesson standards.
    - Students research to select additional attributes that could affect renewable energy generation.
- Excel Tutorials
    - Using Pivot Tables to calculate the Average and Standard Deviation
    - Using simple formulas to calculate Coefficient of Variation
    - Using the data analysis add in on Excel to conduct T-Tests

Statistical Data analysis ……………………………………………………….……………………1 week

- Statistical analysis of the NSRDB data
    - (i.e. Average, Standard Deviation, Coefficient of Variation, T-Test)
- First week of statistical analysis for the weather station
    - Download data front the weather station to analyze the selected attributes.

Weekly weather station data checks ……..…………………..…………..….……. Minimum 1 per week

- Continued statistical analysis for the weather station data throughout the school year
    - Time period for collecting data is up to the instructor's discretion

Conclusion……………………………………………………..………..….………………1 - 2 weeks

- Create an excel interface to depict data analysis
    - Use of Excel Applications
        - Pivot Chart, Slicer Filter, & Developer Tools (Control Buttons)
    - Results (Data Analysis)
        - Statistical Formulas, Calculations, Charts, & Tables
    - Aesthetics
        - Background style, Titles, Labels, Notations, Charts and Tables
- Create the report and poster (the poster is a condensed version of the paper)
    - The report should be done in Microsoft Word, and the poster should be created on a single PowerPoint slide (48" x 38").
        - Title Page
        - Abstract
        - Introduction
        - Methodology
        - Results (Data Analysis)
        - Conclusion
        - Acknowledgment
        - References

Acknowledgement

This material is based upon work supported by the National Science Foundation under Award No. 2206864. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

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Effect of Daylighting on Students' Learning and Classroom Electricity Consumption

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Dr. Hui Shen - Texas A&M University – Kingsville,

Dr. Marsha Sowell - Texas A&M University – Kingsville,

Curtis Davenport - Texas A&M University – Kingsville,

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ABSTRACT

Classrooms are critical areas for learning at all ages. Daylighting is defined as the illumination of buildings, like classrooms, by natural light. Daylighting in classrooms is said to play an important role in students' health, well-being, and overall performance. Recent studies show that daylighting in schools may significantly increase students' test scores and promote improved health and physical development and can be attained without an increase in school construction or maintenance costs (Plympton et al., 2000). This study was meant to examine the effect of daylighting on students' learning as well as its effect on classroom lighting electricity consumption. Correlation analysis was to be used to compare the performance of college students in three classrooms with different daylighting scenarios. Students were also to complete a survey indicating their evaluation of the assignment difficulty level, light comfort level, and room temperature comfort level, among other parameters. Additional data was collected which measured the lighting levels in two rooms for a minimum of 48 hours. Using this data differences in electric lighting consumption were calculated and compared to that when no daylighting methods are utilized.

INTRODUCTION

The objective of this research was to measure the effect of daylighting on students' learning efficiency, correlate it with classroom electricity consumption, and estimate annual electricity savings of a typical educational building. Straightforward activities were designed and implemented to reflect students' learning experience. Multiple metrics were defined from existing literature to evaluate students' learning efficiency. A questionnaire was developed to collect participating students' information and evaluation of the designed activities, lighting environment, daylighting level, etc. after each activity. Supplementary data was collected to then measure the total amount of required electric lighting needed to maintain each location in a work plane at the recommended usable level of 500 lux within what was defined as a typical school day within the hours of 7:30 a.m. to 4:30 p.m.

BACKGROUND

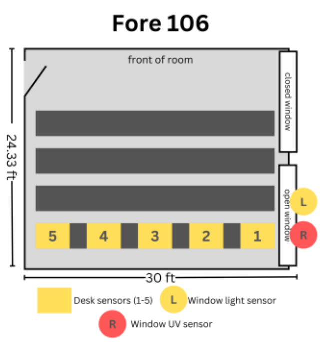
Numerous studies have shown the benefits of daylighting in classrooms. One such study analyzed elementary children in two distinctive classrooms – classrooms with full spectrum lighting compared to classrooms with conventional lighting. Results showed that children in classrooms with full spectrum lighting missed fewer days of school per year as well as increased health affects. A second study at a school district revealed that students with the most daylight in their classrooms progressed significantly faster on their math (20%) and reading tests (26%) compared to students in the least lit classrooms. A third study revealed that students who attended daylit schools outperformed students in non-daylit schools by 5% - 14%. Students in classrooms with the most daylighting were found to have 7% - 18% higher scores than those in with the least. (Plympton et al., 2000)

MATERIALS & METHODS

Non-Human Experimentation

In order to calculate the electricity consumption of the selected rooms for experimentation data was collected for a set period of time in two rooms with different window sizes and orientations. The same materials and experimental setup was used for both.

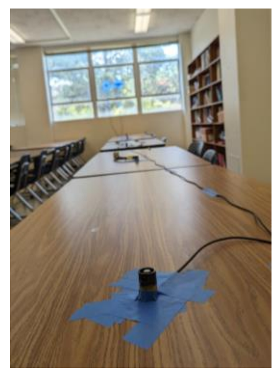
Li-Cor LI-210R photometric sensors were used for measurement of light level on multiple locations within the desk surface as well as the window surface. The sensor detects radiation only within the visible spectrum and has a linear illuminance response up to 100 klux. The sensor has a cosine correction for an angle of incidence up to 80°, a response time of 0.01 ms, and an absolute error of 3%. Additionally, Li-Cor LI-200R, pyranometers were utilized and maintain a spectral response from 280 to 2800 nm, a linear response up to 3000 W/m^2, a cosine correction for an angle of incidence up to 80°, a response time of 0.01 ms, and an absolute error of 3%. The photometers detect radiation only in the visible spectrum (390 to 750 nm) and have a linear illuminance response up to 100 klux. The photometers also have the same cosine correction, response time and absolute error. The Li-Cor LI-210R photometric sensors were connected to an amplifier in order to enhance the signal and convert it to voltage output. Then the voltage output from the amplifier was collected and stored by a HOBO data logger. The figures below show the amplifier, data logger, and the experimental setup in the classrooms. Two classrooms were made use of for this portion of the experimentation, one with a south facing window, as well as another with an east facing window. In the room with the south facing window, Fore Hall Room 106 (FH 106), the HOBO data loggers were programmed to measure and record data from sensors every one-minute from June 30, 2023 (12:50 pm) through July 3, 2023 (10:00 am). Artificial lights to the classroom were turned off and the classroom was secured so that no one entered or disturbed the room while the data was being collected.



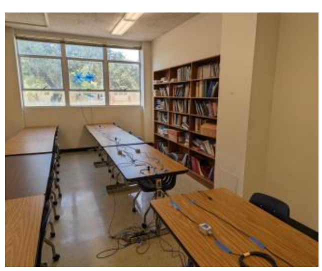
FH 106 South Facing Window

Securing Photometric Sensor and Amplifiers to desk surface

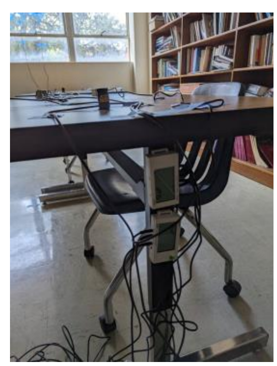
Photometric Sensor and Pyranometers secured to South window



Photometric Sensor secured to desk



Complete Setup



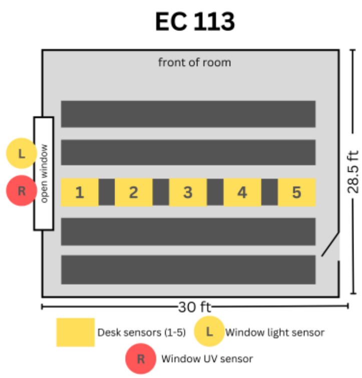
HOBO data loggers

For the window, one photometric sensor and one pyranometer were fastened to the window to collect lighting and radiation information that the window was receiving directly. The room was 30 feet wide and therefore based on the room's width and the availability of photometric sensors, the sensors were placed as can be understood from Table 1, below. The sensors on the work plane were evenly spaced.

Logger	Sensor	Channel	Position	Equation
1st Logger	PH 53	Ch 1	Window	klux= volts x 3.83/0.6
1st Logger	PH 54	Ch 2	3 ft	klux = volts x 3.66/0.06
1st Logger	PH 51	Ch 3	9 ft	klux= volts x 3.9/0.06
1st Logger	PH 52	Ch 4	15 ft	klux = volt x 3.77/0.12
2nd Logger	PY 70	Ch 1	Window	W/m^2 = volts x 12.86/0.02
2nd Logger	PH 56	Ch 2	21 ft	klux= volts x 3.64/0.12
2nd Logger	PH 55	Ch 3	27 ft	klux= volts x 4.05/3.6

Table 1. Sensor placement for south facing window (FH 106)

Similarly for the east facing window, Engineering Complex 113 (EC 113), the HOBO data loggers were programmed to measure and record data from sensors every one-minute but from July 7, 2023 (4:25 pm) through July 10, 2023 (9:00 am). Artificial lights to the classroom were turned off and the classroom was secured so that no one entered or disturbed the room while data was being collected in this room as well.

<table>
<tr>
<td>


EC 113 East Facing Window
</td>
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Photometric Sensor and Pyranometers secured to East window
</td>
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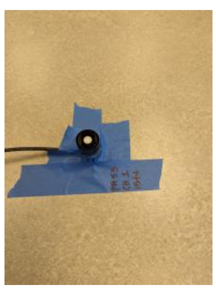
Photometric Sensor secured to desk
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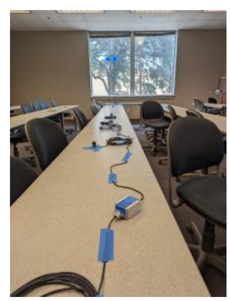
Complete Setup
</td>
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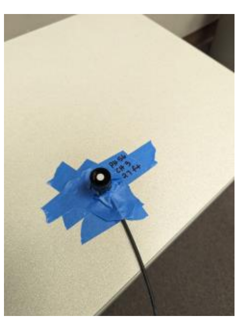
Photometric Sensor secured to desk
</td>
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HOBO data loggers
</td>
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</table>

As in the room with the south facing window, one photometric and one pyranometer were each secured to the window in order to collect data about the UV radiation and lighting level that the window received over the set time. Also, just as with the south facing room, in this east facing room, the room's width was approximately 30 feet and thus the remaining photometric sensors were placed at the same points respective to the window as the first room that experimentation was conducted. The placement of all sensors in EC 113 can be understood in Table 2, below. The sensors on the work plane were evenly spaced.

Logger	**Sensor**	**Channel**	**Position**	**Equation**
1st Logger	PY 70	Ch 1	Window	W/m^2 = volts x 12.86/0.02
1st Logger	PH 51	Ch 2	window	klux= volts x 3.9/0.06
1st Logger	PH 52	Ch 3	3ft	klux = volt x 3.77/0.12
1st Logger	PH 54	Ch 4	9 ft	klux = volts x 3.66/0.06
2nd Logger	PH 53	Ch 1	15 feet	klux= volts x 3.83/0.6
2nd Logger	PH 55	Ch 2	21 ft	klux= volts x 4.05/3.6
2nd Logger	PH 56	Ch 3	27 ft	klux= volts x 3.64/0.12

Table 2. Sensor placement for east facing window (EC 113)

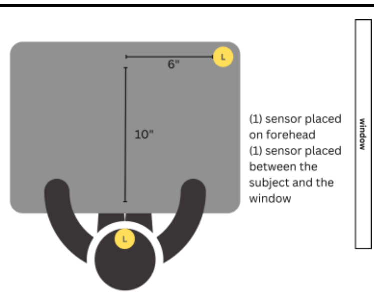
HOBOware software was used to download data from each of the HOBO data loggers onto laptops for analysis. Data was analyzed in both Microsoft Excel as well as Google Sheets in order to determine the average light level, average UV level, Daylight Autonomy (DA) percentage for a typical school day, Useful Daylight Illuminance (UDI) percentage for a typical school day, Glare percentage for a typical school day, as well as the required electrical lighting for both rooms both with the use of daylighting methods as well as relying solely on artificial lighting. Calculations were also made in order to exclude the security lighting that was unable to be shut off in the east facing room (EC 113)

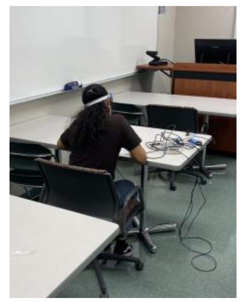
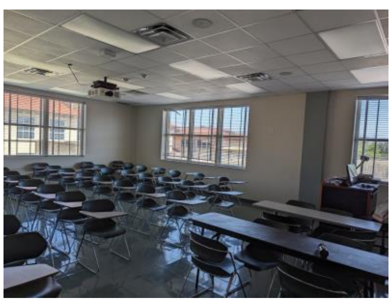
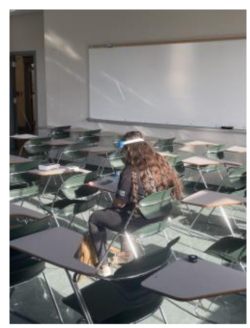
Human Experimentation

In order to achieve analysis of daylighting and its effect on students' learning efficiency, the following portion of experimentation was conducted utilizing student participants. Experimentation was conducted in three different classrooms with different lighting scenarios. Room 1 (south and west facing windows) had a mix of electric lighting and daylight and used primarily daylighting in order to maintain between 400 to 600 lux. Room 2, having no windows at all was used to test participants under purely electric lighting. Room 3 (north and west facing windows) put participants in a setting which relied solely on natural daylight and therefore this room had a variety of light levels. Participants were randomly recruited from a large pool of college-aged individuals.

During the experiment, a participating student chose a desk to sit at and complete a reading activity. Each reading activity was designed with the same parameters – to be easy to implement within the experimentation, to be at an 11th to 12th grade reading level as the participants used were college-aged, followed by a five question quiz with mostly knowledge level questions that related directly to the given reading passage. A photometric sensor was worn by the student participant just above the eyebrows and a photometric sensor was placed on the participant's desk for light level measurement. A PMA2100 Data Logging Radiometer was placed in the room to ensure that a light level of 500lx was maintained within Room 1, as well as to measure overall light level in Rooms 2 and 3. The participant read a short reading passage that was printed on paper and completed a five question quiz, also on paper. The participant had ten minutes maximum to read the reading passage and ten minutes maximum to complete the quiz.

Upon completion of the quiz, the participant was required to complete a survey indicating their evaluation of the assignment difficulty level, light comfort level, room temperature comfort level, as well as which room was their preferred setting, among other parameters. They repeated the experiment, with different reading passages in each of the three rooms with different lighting scenarios. Quizzes were scored in order to determine student's accuracy in each lighting scenario, and their completion times were recorded in order to further determine the student's learning efficiency. In the figures below can be seen the sensor placement on the participant's desk, the sensor that the students wore to collect light data at eye level, as well as each room that was employed for this portion of the experimentation.

 Sensor placement relative to participant	 Wearable Light Sensor

 Room 1 South and West Facing Windows Daylighting Methods Used	 Room 1 Participant Testing
 Room 2 No Windows Pure Electric Lighting Used	 Room 2 Participant Testing
 Room 3 North and West facing Windows ONLY Daylighting	 Room 3 Participant Testing

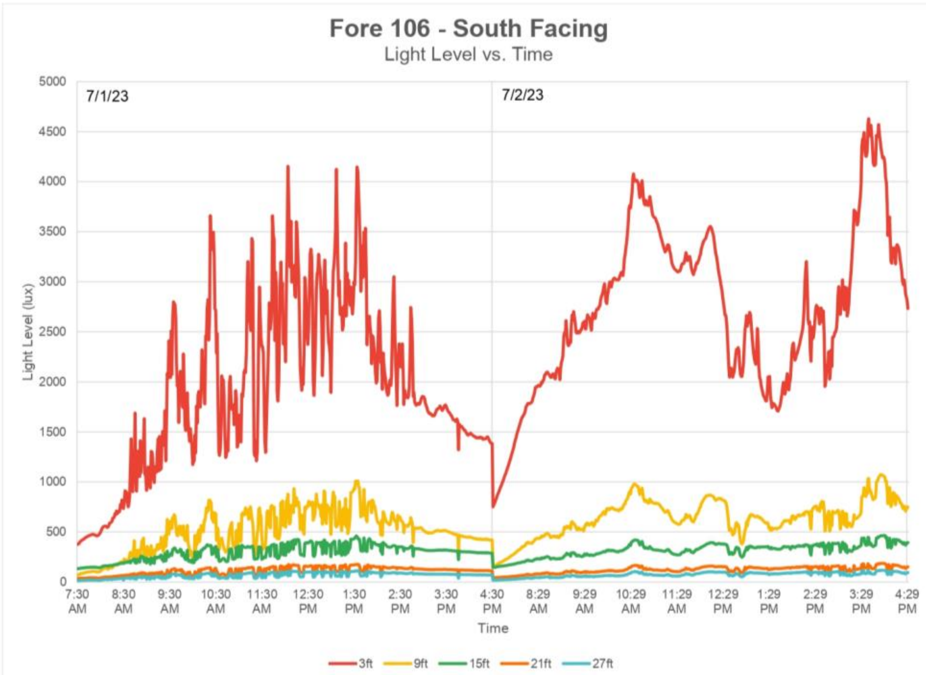
 PMA2100 Dual-Input Data Logging Radiometer	

RESULTS & DISCUSSION

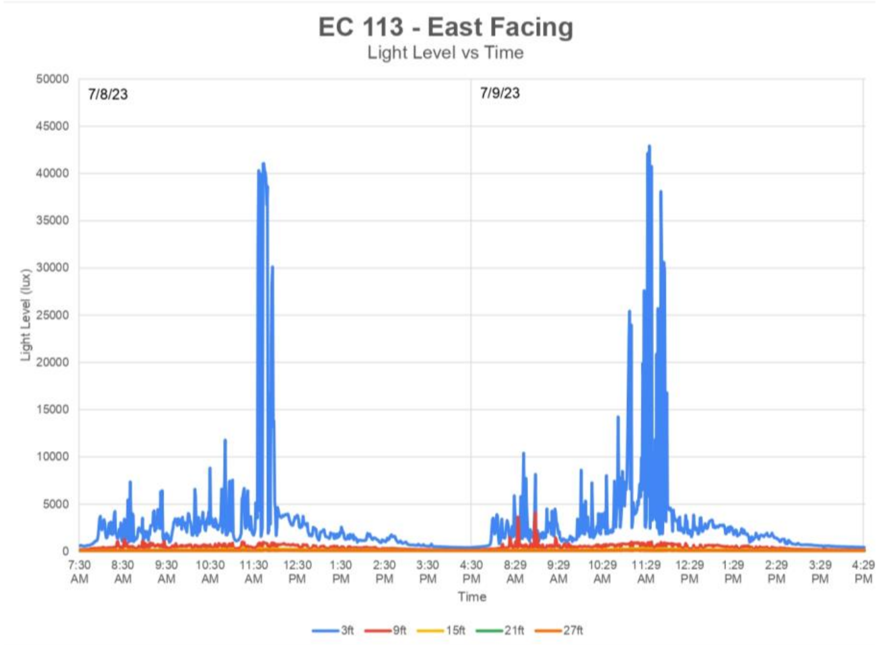
Data from testing was collected and analyzed for any correlation between sensor placement and light intensity levels in non-human testing; and in order to determine if any correlations between student scores and lighting levels in human experimentation exist. It is to be noted that for the south facing room in the non-human data collection portion of this study, the photometric sensor attached to the window malfunctioned during data collection and therefore the data collected from only that node was not usable. All other data was found to be utilizable.

Non-Human Data

Data collected from the two rooms without human participants was used in order to determine the classroom electricity consumption for each room using solely electric lighting and through the use of daylighting methods. For each room, south facing and east facing, only data collected during a time considered a typical school day was analyzed (7:30 a.m. to 4:30 p.m.). The actual light level for each sensor was calculated using their respective multipliers, then converted to lux. Such raw data can be seen in Graph 1 and Graph 2 below for the south facing room and the east facing room respectively.

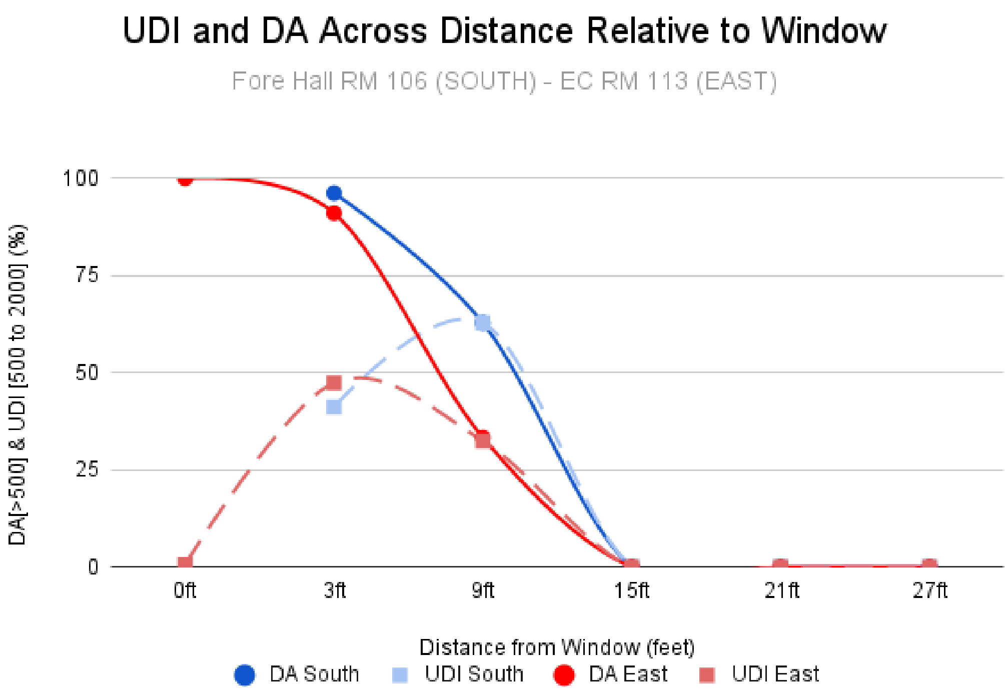


Graph 1. South Facing Room Raw Data



Graph 2. East Facing Room Raw Data

Useful Daylight Illuminance (UDI) and Daylight Autonomy (DA) were calculated for both rooms, FH 106 and EC 113, and graphed to visualize data. UDI is defined as the percentage of time when the work plane illuminances fall between 100 lux and 2,000 lux, but for this study UDI was calculated using the range of 500 lux (the recommended illuminance level for a work space) and 2,000 lux. DA is defined as an annual measure of how often a minimum work plane illuminance requirement can be met by daylighting alone during occupied time, and therefore for this research the minimum illuminance level used in calculations was 500 lux. Glare, meaning when the illuminance level at a work space can be considered too bright to be functional or usable, was also calculated using the illuminance level of 3,000 lux. Graph 3 below compares the UDI and DA for both the room with the south facing window as well as the room with the east facing window. Graph 4 shows the glare as a percentage of time when the room is occupied.



Graph 3. UDI & DA for East and South

Graph 4. Glare for East & South

Once the percentage of time that each individual point within the work plane was within a working range (UDI) was determined then the equation below (equation 1) was used to calculate the electric lighting power that was needed in addition to the daylight received at each point in time of data collection in order to maintain 500 lux at each point on the work plane. The required electric lighting power needed (E_L) to maintain 500 lux at each point in the work plane was calculated for each minute of data collection using the lighting power density (P_L) of 7.6 W/m^2, as that is presumed sufficient to maintain the minimum of 500 lux, the area of the room (A) in m^2, the illuminance set point (E_s of 500 lux), the illuminance from daylight (E_i), and the number of points on the work plane in which data was collected from. The equation would determine if the illuminance from daylight was less than the illuminance set point, and if so determine the amount of electric lighting required to meet the 500 lux set point for each of the five points in the work plane and produce a single result for each minute. Those results were then combined to determine the total required electric lighting power for the entire data collection period.

$$E_L = \frac{P_L \times A}{E_s} \times \frac{\Sigma(E_s - E_i)}{n}$$

Required Electric Lighting Power

EQ 1. Required Electric Lighting Power Equation

Calculations were made for each sensor position on the workplane, for every minute during working hours. The result was then compared to the electric lighting power that was needed when artificial lighting was used alone to maintain 500 lux. Required electric power lighting calculated for both daylighting methods as well as pure electric use are shown below in Table 3 for each room. FH 106, with the south facing window, had an electric lighting power percent savings of 57.4% and EC 113, with the east facing window, had an electric lighting power percent savings of 44.1%. Thus, in terms of electric lighting power consumption, the use of daylighting significantly decreases the required electric lighting power needed to allow for each point within the work plane to be at the working level of 500 lux.

Window Direction	kWh without Daylighting use	kWh with Daylighting use	WWR	Percent Savings
South	4.64	1.98	21.98% 43.96%	57.4%
East	5.43	3.04	22.33%	44.1%

Table 3. Electric Lighting Power Percent Savings for Each Room

Human Data

The intent of this research with regards to the human testing portion of data collection was to combine each participant's accuracy score on their quizzes as well as their reading completion time in words per minute (wpm) into one combined efficiency score in order to be able to compare that determined efficiency score to the various lighting levels. Due to the time constraints and the limited number of participants recruited in the minimal time frame allotted, no definitive results were able to be confidently formed and data was not able to be analyzed thoroughly before the research's completion. In future testing many more participants would be required as well as time to collect and analyze such data, as well as to ensure that a wider range of illuminance levels are used for participant testing purposes.

A very causal data analysis was able to be conducted based on the participants feedback with regards to each lighting scenario and thus it was seen that most participants felt that Room 1, which contained the mix of natural light and artificial light due to using daylighting methods was a "neutral/comfortable" room, or their preferred room, while Room 2 with solely electric lighting was usually seen as "slightly bright" and "very bright", and Room 3, with daylight only was "slightly dim" or "neutral/comfortable". This can be viewed in Table 4 below.

Participant Room Feedback			
Rating	220 Mixed	222 Electric	224 Daylight
Very Dim	0	0	0
Slightly Dim	1	1	6
Neutral	8	3	5
Slightly Bright	2	4	1
Very Bright	2	5	1

Table 4. Participant Illuminance Rating by Room

Through this casual and limited analysis, in terms of participant assessment performance and lighting, on average, most participants performed better on their assessments in classrooms when the lighting was not too dim, as seen in Table 5.. No further relationships could be seen, again due to time constraints, limited participation, as well as limited illuminance ranges during participant testing.

Head Sensors and Grades		
Score	<300	300-1000
100	38.41	61.59
80	35.87	64.13
60	15.11	84.89
40	65.66	34.34
20	90.91	9.09

Table 5. Percentages of Participant Scores Versus Eye Level Illuminance

CONCLUSION

The objective of this study was to measure the effect of daylighting on students' learning efficiency, correlate it with classroom electricity consumption, and estimate annual electricity savings of a typical educational building. Our results in the non human testing indicate that there is indeed an overall significant savings in electric power lighting usage when daylighting is utilized. Our human experiment results, although small in sample size, may also indicate an advantage to student success. The utilization of daylighting will help conserve energy, energy resources, and reduce our carbon footprint ultimately contributing to a more sustainable and eco-friendly environment.

CURRICULUM MODULES

Fifth Grade Mathematics Lesson Module

STANDARDS

Math 5.8(C) – Geometry and Measurement. *The student applies mathematical process standards to identify locations on a coordinate plane. The student is expected to graph in the first* *quadrant or the coordinate plane ordered pairs of numbers arising from mathematical and real-world problems, including those generated by number patterns or found in an input-output table.*

Math 5.9(C) – Data Analysis. *The student applies mathematical process standards to solve problems by collecting, organizing, displaying, and interpreting data. The student is expected to solve one- and two- step problems using data from a frequency table, dot plot, bar graph, stem-and-leaf plot, or scatterplot.*

Science 5.2(C) – Scientific Investigation and Reasoning. *The student uses scientific practices during laboratory and scientific investigations. The student is expected to collect and record information using detailed observations and accurate measuring.*

Analyzing the Effects of Different Lighting Environments on Plant Growth

OBJECTIVE

In this math-based lesson, students will statistically analyze the effects of different levels of lighting on plant growth, learn how to measure light levels using a simple light meter, and explore the relationship between light intensity and plant growth using data collected over a period of time. They will collect data (SCI 5.2C), create graphs, and analyze the results to draw conclusions about the impact of light on plant growth. The simple analysis will be done with a focus on generating data tables and their matching scatterplots **(Math 5.8C)**, as well as a basic statistical analysis **(Math 5.9C)**. From there the students will then draw conclusions based on the visual data and from their various measures of central tendency.

This lesson module can be performed as an end of the year project, or as an end of unit project. It will work best if in conjunction with a photosynthesis lesson or unit in their corresponding science courses.

MATERIALS:

- Potted plants of the same size and type (best to use fast growing ones, ex. sprouts, grasses, etc.)
- Planting soil or potting mix (same type for all plants)
- Planting pots or containers (same size/type for all plants)
- Small measuring cup (for watering precise/exact same amount for all plants)
- Ruler or measuring tape
- Light sources (natural light/window, outside area, counter space, dark closet/cupboard, bright lamp)
- Light meters (phone app also available)
- Data collection sheets
- Graph paper

KEY TERMS

- Scientific method: *a step-by-step process that scientists use to learn new things. This process involves asking questions, doing experiments, collecting data, and drawing conclusions to understand*
- Lux: *unit of measurement used to talk about brightness or how much light there is in a specific location*
- Fluid ounces: *unit of measurement used to talk about the amount of liquid or the volume of something*
- Analyze: *using math and numbers to study and understand information, like data or*

numbers collected from a group of people or things

- Compare: *using numbers and math to see how two or more things are similar or different. It can help you see patterns or differences more clearly*
- Graph: *a way to show and organize data or information in a visual and easy to understand manner*
- Coordinate Plane: *a type of graph where you can locate points using two numbers (coordinate)*
- X-axis: *the horizontal line that helps us find positions and locations on the coordinate plane. How far left or right from the center (origin)*
- Y-axis: *the vertical line that helps us find positions and locations on the coordinate plane. How far up or down from the center (origin)*

LESSON PLAN

INTRODUCTION:

- Begin by discussing the importance of light for plant growth and photosynthesis.
- Explain to students that in this lesson, they will be investigating how different light levels affect plant growth.
- Introduce the concept of measuring light intensity using a light meter or a light intensity app on a smartphone.

PREPARING THE EXPERIMENT:

- Divide students into small groups.
- Provide each group with potted plants and a light meter or a smartphone with the light intensity app.

- Instruct them to place the plants in different locations with varying light levels, such as direct sunlight, partial shade/sunlight, and a dark corner, cabinet with lamp lighting, etc.
- Have students measure the distance between the light source and each plant using a ruler or tape measure.

DATA COLLECTION (spread over weeks or days depending on plant type/growth):

- Instruct students to measure and record the light intensity for each plant daily/weekly, at the same time, for the project's duration.
- Students should also record the plant's height or other relevant growth metrics in their data collection sheets each time.

DATA ANALYSIS:

- Once the data collection is complete, have students compile their measurements and:
    - generate a data table
    - generate a corresponding scatterplot
        - Instruct them to create a line graph/scatterplot with light intensity on the x-axis and plant growth on the y-axis
    - and to calculate the average light intensity for each location
- Guide them in analyzing the data and looking for patterns or trends

CONCLUSION:

- In a class discussion, have students share their findings and observations.

- Encourage them to draw conclusions about how light intensity affects plant growth based on their data and graphs.
- Discuss the importance of controlled experiments and data analysis in scientific research.

EXTENSION (if time allows/if end of year project):

- If time allows, students can explore other factors that might influence plant growth, such as water, temperature, or soil nutrients. They can design experiments to investigate these factors.

ASSESSMENT:

- Evaluate students based on their active participation in the experiment, accurate data collection, graph creation, and thoughtful analysis of the results.
- You can also have students write a brief report summarizing their findings and conclusions.
- Further, you can have students create a scientific poster with their question, methods, data, results, analysis, conclusion, etc. and present as groups.

Note: Safety measures should be observed when using light meters or smartphones outdoors to avoid direct exposure to the sun for extended periods. Also, ensure that plants are cared for properly throughout the experiment.

Sixth Grade Science Lesson Module

Energy Resources, Cost and Conservation

STANDARDS:

6.11(A) Earth and Space. *The student understands how resources are managed and the student is expected to research and describe why resource management is important in reducing global energy.*

6.11(B) Earth and Space. *The student can explain how conservation increased efficiency, and technology can help manage air, water, soil, and energy resources.*

DAY 1

INTRODUCTION:

Objective: to rehearse and practice relevant terms

Vocabulary Pyramid

Click link for Lead4Ward Instructions

(5-10 minutes)

QUICK CONNECTIONS:

The teacher discusses the term 'rank" with students and that students will be researching where the US "ranks" among other countries in energy consumption/use.

Background on Electricity Scavenger Hunt:

- Students use the internet to find the answers to questions.
- Students must cite where they found their answers.
- Time limit 10 minutes max
- Click link for student worksheet

EXTENDED THINKING

Where does electricity come from? (video) (0.51 seconds)

After watching the "Where does electricity come from" video, students (in groups of 3-4) will complete card sorting activity sequencing how coal gets to your home.

Part 1

- Teachers print, cut, and laminate Figure 1 making sets according to class size.
- Link to Figure 1

Part 2

- Figure 2 is to be used by the teacher as a class check/review once all groups have completed the card sort.
- Print, Cut, and Laminate 1 class set.
- Figure 2 https://ohioenergy.org/wp-content/uploads/2019/08oal-Sequence.pdf

DAY 2

QUICK REVIEW:

Teacher reviews previous day's lesson. Review terms from vocabulary pyramid, ask "where did US rank in terms of energy consumption?' Where does the US get the bulk of its energy from (nonrenewable energy/fossil fuels)

BACKGROUND

- Link to display kilowatt power meter on the board for students to see.
- A Kilowatt power meter is a device used for power monitoring of 110 volt plug loads. (Common home electrical outlet)
- The Kill-A-Watt power meter allows measurement of:
    - line voltage (Volts)
    - current (amps)
    - power (Watts)
    - apparent power (VA)

- frequency (Hz)
- power factor (PF)

ANALYZING ENERGY USAGE

Electricity is measured in kilowatt-hours. (KWh)

1 kilowatt = 1000 watts

KWh = watts x hours the appliance is on ÷ 1000

To get kilowatt-hours, take the wattage of the device, multiply by the number of hours you use it and divide it by 1000.

Example:

*0.06 kilowatt **=** 60 watts (common light bulb)*

KWh = kilowatts **x** hours the appliance is on ÷ 1000

To get kilowatt-hours, take the wattage of the device, multiply by the number of hours you use it and divide it by 1000.

*60 watts x 12 hours of usage = 720 ÷ 1000 = **0.72 kilowatt hours (KWh)***

ANALYZING ENERGY COST

The cost of electricity depends on where you live, how much electricity you use, and possibly when you use the electricity.

Schools are "commercial" users of electricity and the current rate for commercial use in Texas is __________ per kWh. (Teacher looks up current kWh rate)

Convert each device watt reading to kilowatts and cost per year and record the results in your table. Here's the formula to figure the electricity cost of running a device:

Wattage x hours used ÷ 1000 x price per kWh = cost of electricity

Example

Convert each device watt reading to kilowatts and cost per year and record the results in your table. Here's the formula to figure the electricity cost of running a device:

Wattage x hours used ÷ 1000 x price per kWh = cost of electricity

60 watts x 12 hours ÷ 1000 x .825¢= 0.594¢ per hour

1. Do you think that electrical devices like phone chargers and printers use electricity and cost money when they are turned OFF? Explain your answer.
2. Using a Kilowatt electricity usage monitor, take the watt reading when the device is turned ON and when the device is turned OFF.

- Video on How a Kilowatt Meter works
- Record your measurements in the Watts Going On Here Data Table.

DAY 3

QUICK REVIEW:

Teacher reviews previous day's lesson.

- We use a kilowatt power meter to measure variables like watts used by small appliances like cell phone chargers when they are ON and OFF.
- Calculations and data collected on the "Watts Going on Here Data Table."

- Double bar graphs are used to show two sets of data on one graph, what 2 sets of data are shown on the worksheet "Watts Going on Here? (ANSWER: Watts used "on" and "off")

GRAPHING

- Click link for Graphing "Watts Going on Here" worksheet.

DAY 4

QUICK REVIEW:

Teacher reviews previous day's graphing lesson.

- What did our graphs look like?
- Were the small appliances using electrical energy when they were in the "off" mode?
- How much money are we spending per year on these appliances that are left plugged in, but off?

INTRODUCTION

What is *energy conservation*? What does it mean to conserve energy? Energy Conservation is the decision and practice of using LESS energy. Turning off the light when you leave the room, unplugging appliances when they're not in use and walking instead of driving are all examples of energy conservation.

- **Energy Conservation Worksheet**
  - Materials needed: student worksheet, PURPLE map color, YELLOW map color.
  - Time: 8-10 minutes
- **Mix and Match Game**
  - The teacher prints, cuts, and laminates cards. Each student receives 1 card.

- Kagan Strategy “Mix Pair Share”
  - The teacher plays classroom appropriate music while students walk around the room with their hand up. When the music stops, students pair up with the students closest to them.
  - One student goes first (student with the longest hair, etc.) and reads their card.
- Teacher writes the following sentence stem on the board for each student to use when they pair up....
  - (*Read the statement on their card)* is an example of (conserving/wasting energy) because.......
    - Example: “*Leaving the lights on in the room when you leave is an example of WASTING energy because no one is using the energy when the room is empty, and the light gives off heat which will require more time to cool the room in the summertime- so energy is being wasted*.”
- When both partners have read their card “high-five” your partner and wait for the teacher's queue to mix pair share again.
- Repeat a few times, making sure that students do not get the same statements.

Day 5

QUICK REVIEW:

Teacher reviews previous day's graphing lesson.

- Why is conserving energy important?
- What does conserving energy look like?

- What does wasting energy look like?

ASSESSMENT

Managing Energy Resources with Technology

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Study the Potential of Converting Food Waste into Renewable Energy in the Backyard

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Industrial Advisor: Enrique Molina

Program Name: NSF RET I-READ Texas A&M University - Kingsville

Abstract

Household food waste has contributed to high levels of greenhouse gas emissions due to waste entering into landfills and not being returned to the soil. Recently, food waste has attracted attention globally to reduce emissions and to conserve and recycle. In the U.S. the estimated food waste at the household consumption level is 32% of purchased food (Ellison et al.,2022). According to the U.S. Department of Agriculture, USDA, 66% of the residential sector's wasted food enters into the landfills. One of the main goals to bring education and awareness to U.S. residents about conserving food waste is by composting in the backyard. The research objective for this project is to study the potential of converting food waste into renewable energy in the backyard through experiments with different combinations of food waste types. The research question is, "How much thermal energy can be generated by a compost tumbler?"

Introduction

According to USDA, in 2018, 35 million tons of food scraps went into landfills. This is approximately 30-33% of the food we buy going out as garbage. The landfills are expensive to open and manage and maintain. Landfills also can contribute to pollution in the form of greenhouse gasses and acidic leachate that can contaminate groundwater. Food waste can be valuable and instead of sending food waste to landfills, we can compost. From an engineering perspective, this valuable food waste is biomass. Can we use biomass as a source of renewable energy?

Composting is the breakdown of organic material that leads to nutrient rich soil. There are many factors that contribute to the rate of decomposition of organic material like the amount of water available, the types of organic waste, the temperature of the environment and the bacteria available just to name a few. The organic waste in landfills cannot turn into compost because there is no way to aerate the material. A byproduct of the composting is heat! Can this heat be used as a natural resource? Possibly! Why would engineers be interested in composting and the heat as a natural resource? Renewable energy is a topic in engineering that allows scientists to consider different methods of obtaining usable energy. Biomass as renewable energy is an avenue that is not very well researched. We need to ask "How much thermal energy can be generated by a simple compost bin?" Then to follow up, "How much of the thermal energy generated can be extracted and used for heating?"

By setting up a simple compost bin, a barrel that rotates, food waste or biodegradable material can be added into the bin with a little bit of dirt/topsoil and water. There are compost bins that can be created at home or there are some that can be store-bought. A bin with fresh materials can be set up with temperature sensors or probes that can be set with a data collection over a few days or weeks at a time. The bin can be rotated manually on a schedule or can be set on a motorized rotation depending on what resources are available that make it possible. One could even add a forced aeration system if technology allows. After the collection of data, the data points can be analyzed so see how much thermal energy can be generated. The optimal combination of variables is unknown to give the highest yield in thermal energy.

Literature Review

Article: *Modelling biomass gasifiers in hybrid renewable energy microgrids; a complete procedure for enabling gasifiers simulation in HOMER.*

- Biomass used as clean technology is not always efficient given the parameters involved in production based on region, resources, facility operational schedules, maintenance and design when using HOMER simulations to re-simulate data to other regions.

Article: *Bioconversion of food waste to energy: A review.*

- Many countries are becoming overwhelmed by increased landfilled consumption as one third of food produced globally is lost along the food chain supply and food waste can be a great resource for production of biofuel through various fermentation processes.

Article: *Food waste matters - A systematic review of household food waste practices and their policy implications.*

- Food waste on the consumer level is being highlighted especially in household practices to help design food waste prevention strategies.

Methodology

Materials:

- 25 gal. Junior Compost Wizard Dueling Compost Tumbler
- Temperature Sensor
- Scale
- Bucket
- Food Waste
- Grass and Leaves
- Top Soil
- Water

<u>Compost Bin #1:</u>
Brown Matter (Carbon):

- Dry Leaves and Small Twigs
- Top Soil Dirt

Greens Matter (Nitrogen):

- Grass Clippings

<u>Compost Bin #2:</u>
Fruit and Vegetable Food Scraps: Onion, Grapes, Tangerines, Watermelon, Cucumbers, Squash, Strawberries, Garden Lettuce, Spinach, Pineapple, Potato Peelings, Rice, Mushrooms, Bell Pepper, Green Beans, Asparagus, Edamame

Compost Bin:
- Bin #1 - Dry leaves, grass clippings, and topsoil
- Bin #2 - Food waste and topsoil

Sensors:

- (TOP) Ch.1 - Food Waste
- (BOTTOM) Ch.2 - Food Waste
- (TOP) Ch. 3 - Grass & Leaves
- (BOTTOM) Ch. 3 - Grass & Leaves
- Ambient Temp Sensor

Collection Parameter:
•5 minute intervals
•4 days

Procedure

- Set the bin, rinse if you have to.
- Stick the temperature probes in the chambers before you put food waste or dirt in the tumbler. Make sure they are secure with tape. We also taped off any of the drain holes, we didn't want to lose water or heat. The sensors we used were HOBO temperature sensors that had a metal tip attached to 6ft long wire.
- Using a scale, weigh out the amount of food waste. We put our waste in a bucket and t bucket on the scale. Ideally we would want to know exactly what kind of food. We mixed a bunch of different types: rice, watermelon, pineapple, oranges, onion, squash just to name a few.
- Place the food waste in the right chamber of the tumbler. We have a dual chamber tumbler. One side will be food waste and topsoil, the other will have the grass, leaves and topsoil.
- Measure out about 2.5 lbs of leaves, and 2.5 lbs of grass and mix into the tumbler. 2.5 lbs was about how much we can fit into the bucket, the material is less dense.
- Measure out about 15 lbs of topsoil to go along with the food waste. Close the chamber.
- Measure out another 15 lbs of topsoil to go into the other chamber of the tumbler. Close the chamber.
- When the materials are in the tumbler chambers, they should take up approximately ⅔ of the chamber.
- Our tumbler was not able to rotate completely because of the wires, so we pushed/pulled it back and forth (approx. 120°) to try to mix as much as possible.

- We then set our data collector to collect temperatures over the next few days at intervals of 5 minutes. Our data collection began at 3 pm on Friday afternoon. The data logger we used was a HOBO logger with 4 channels of input. The information was recorded onto a web-based storage site called HOBOLink.
- We set a separate logger/sensor for our ambient temperature, also a HOBO product.
- We went to “shake” or rotate our compost bin on the following day at 3:50 pm. We also checked our temps and data collectors to make sure our electric components were working properly. Then we went again the following day and everyday after. We took a picture of the logger at the time we rotated the bin.

Results

- Channel 1: Food Waste temperature sensor probe was faulty and recorded at 76.93
- The peak range for temperatures was between 12 PM and 5 PM
- The biggest temperature difference between any bin and the ambient temperature was 53.88°F at 3:58 PM
- The red line (Channel 2) on the graph is higher that the others (Channel 3 and Channel 4) possibly due to water content.

Temperature Data:

Set up date: Friday, Jul 7, 2023

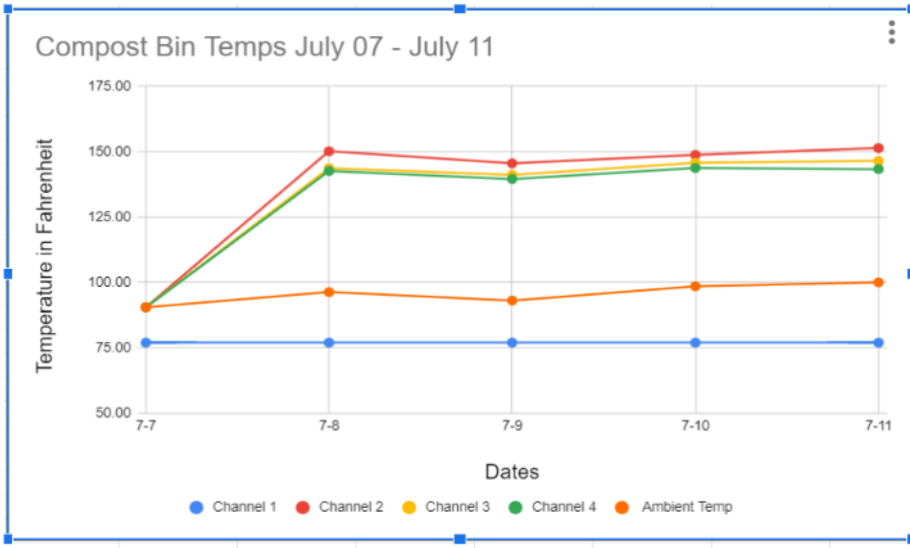
Temperature Data (In Degrees Fahrenheit):

		Probe/Sensor Input Temp. Fahrenheit				Ambient Temp.
Time (PM)	Date	Channel 1	Channel 2	Channel 3	Channel 4	Sensor
3:00	7-7	76.93	90.42	90.42	90.42	90.42
3:58	7-8	76.93	150.12	143.66	142.58	96.24
12:03	7-9	76.93	145.51	141.10	139.51	93.00
4:00	7-10	76.93	148.74	145.70	143.74	98.43
5:07	7-11	76.93	151.35	146.43	143.30	99.96
Average Temerature		-------	137.23	133.46	131.91	95.61

*Assumed materials were at ambient temperature
*Channel 1 - faulty

Channel 1:	Surface temp of Foodwaste
Channel 2:	Internal temp of Foodwaste
Channel 3:	Surface temp of Grass and Leaves
Channel 4:	Internal temp of Grass and Leaves

Temperature Data:



Conclusion

How much thermal energy can be generated by the food waste in a compost bin? The graphs show inconclusive results because the temperature probe in Channel 1 was faulty. Channel 1 shows the same temperature throughout the entire length of time. Also, the data collection was supposed to last 7 days, but due to technical difficulties only recorded data for 2 days. Essentially the data was lost and irrecoverable. Two days is not sufficient data to be able to do much analysis. The measurements that were used as data points were obtained by pictures. Pictures were taken of the sensor every time a member of the team would go out and rotate the barrel to mix up the contents. The pictures were not taken at the same time of the day, so the time interval between readings was not constant. Also not constant were the time intervals between rotations of the bin. A future experiment must be set up to follow up on these results.

In this future experiment, the food waste must be categorized by type and weighed individually. The temperature sensors must not interfere with the rotation of the bin. Rotation of the compost bin must be standardized, for example, the rotation must be on a set schedule. This is where the benefit of a motor for rotation must be taken into consideration. The rotation by motor will take more ingenuity. This trial run gives a basic experimental model to try to improve on.

Taking this experience to the classroom and having students carry out this methodology may yield better performances of the experimental procedure, the expectation is that each experiment will be better than the previous one.

Learning Development Module

TEKS Applied

- Cross-Curricular TEKS applied in both Lesson Modules
  - Principles of Applied Engineering
  - Environmental Systems
  - Biology
  - Mathematics
  - English/Writing

[1] Learning Module: *Compost - Generating Thermal Energy*

Lesson objective: Students will attempt to measure how much thermal energy can be generated by a compost tumbler.

Brief overview of learning module [1]:

1. Students will explore the connection between engineering and renewable energy.
2. Students will learn how to set up a compost bin.
3. Students will gather materials (food waste, grass, leaves, topsoil, water).
4. Students will measure and graph the changes in temperature over a 3 week period.

Lesson Plan for Learning Module [1] High School Principles of Engineering Students

- Using PBL (Project Based Learning), students will maintain an engineering notebook that has details over the project. Students will record everything that happens along the way in the duration of the project.
- Students will consider different designs for the compost tumbler and will be encouraged to research what has been done already.
- Students will build their tumblers and experience using cutting tools and power tools.
- Students will aim to record temperatures for 5 days.
- As an extension, on day 5, students will be asked to insert a coffee can with water into the compost bin. They will record the temperature of the coffee can over a period of 8 hours.
- After having several days of data and temperature changes of the water, students should be able to calculate the heat transfer using the heat capacity equation: $Q=mc\Delta T$
- Students will be asked to evaluate their projects and discuss flaws in the design and or data collection.
- Students will write a reflection and put together a presentation.
- Variations of the project:
  - Size of the water reservoir
  - Improvements on design (vertical bin vs horizontal bin)
  - Power output calculations
  - C:N ratios comparisons

    - Alternative methods of aerating
- If students really enjoyed the project, they could consider careers or studies in:
    - Microbiology
    - Biochemistry
    - Environmental Science
    - Environmental Engineering
    - Civil Engineering

5E Lesson Plan - RET-IREAD Learning Module [1]:

Teacher: Andy Hernandez
Date:
Subject / grade level: Principles of Applied Engineering, Grades 9-10
Materials: • Compost bins/barrels (store bought or diy) • Temperature Sensors • Temperature logger • Weight Scale • Bucket • Food Waste • Grass and Leaves • Top Soil • Water
Essential Standards and Clarifying Objectives (TEKS): (1) The student demonstrates professional standards/employability skills as required by business and industry. The student is expected to: (A) demonstrate knowledge of how to dress, speak, and conduct oneself in a manner appropriate for the profession; (B) show the ability to cooperate, contribute, and collaborate as a member of a group in an

effort to achieve a positive collective outcome;

(C) present written and oral communication in a clear, concise, and effective manner;

(D) demonstrate time-management skills in prioritizing tasks, following schedules, and performing goal-relevant activities in a way that produces efficient results; and

(E) demonstrate punctuality, dependability, reliability, and responsibility in performing assigned tasks as directed.

(3) The student presents conclusions, research findings, and designs using a variety of media throughout the course. The student is expected to:

(A) use clear and concise written, verbal, and visual communication techniques;

(B) maintain a design and computation engineering notebook;

(E) use the engineering documentation process to maintain a paper or digital portfolio.

(6) The student thinks critically and applies fundamental principles of system modeling and design to multiple design projects. The student is expected to:

(A) identify and describe the fundamental processes needed for a project, including the design process and prototype development and initiating, planning, executing, monitoring and controlling, and closing a project ;

(9) The student demonstrates the ability to function as a team member while completing a comprehensive project. The student is expected to:

(A) apply the design process as a team participant;

(B) assume different roles as a team member within the project;

(E) demonstrate communication skills by preparing and presenting the project.

Lesson objective(s): To investigate how much thermal energy can be generated by a compost by taking temperatures of heat generated by the compost.

Language objective(s): Students will learn how soil organisms recycle organic wastes through composting. Students will observe soil organisms in a compost sample, then fill a compost bin with organic wastes and observe and write a reflection piece about the decomposition of the organic wastes into humus during the school year.

Differentiation strategies to meet diverse learner needs:

- Copy of Classroom Notes
- Visual Aids
- Videos
- Vocabulary/Journal Notes
- Project-Based Learning
- Task Selection
- Peer Feedback
- Socratic Sessions
- Students can choose media platform for presentation

ENGAGEMENT

- Show a video of different types of energy.
- Hot Seat Vocabulary!
- Show a video of compost providing burnable gas
- Have a pre-lesson discussion
    - Ask the students to ponder where electricity comes from.
    - Ask students what countries use the most energy
    - Ask the students if they know where energy will come from in the future.
    - Ask students if they know how much food waste goes to landfills
    - Can we repurpose some of that food waste? (YES!)
    - How much energy can we recover? (Heat)
- Vocabulary Activity: Students will be given a list of vocabulary words with visual pictures and be asked to get in groups of 4 to categorize the following list into exhaustible vs. inexhaustible energy.

  https://docs.google.com/document/d/1M2kiUA_EtITcEO3BxWQ4hpQttRnriTNsqqsQzUEtjV8/edit?usp=sharing

EXPLORATION

Questions:

- What is renewable energy?
- What is Biomass?
- What are three methods of composting?
- What kinds of materials should go into a compost pile?
- Is moisture required in composting?
- What is the C:N ratio? What happens if the C:N ratio is too high or too low?
- What happens during the thermophilic stage of composting?
- What is the temperature of a typical compost pile in the thermophilic stage?
- Reflection Piece-What are the limitations of the project?
- What variables contribute to composting?
- What is the ultimate source of energy for Planet Earth?

Renewable Energy Vocabulary:

Petroleum, Fossil Fuels, Biomass, Renewable Energy, Non-renewable Energy, Compost, ΔQ, Specific Heat, Watt, Hydroelectricity, Chemical Energy, Newton-meter, British Thermal Unit, Exhaustible Energy, Sustainable Energy, Efficiency, Mechanical Energy, Wind Turbine, Electricity, Wind Farm, Wind Energy, Potential Energy, Climate Change, Joule, Power, Solar Energy, Law of Conservation of Energy, Work, Inexhaustible Energy, Hydrogen, Photovoltaic Cell, Geothermal Energy, Natural Gas, Nuclear Energy, Kinetic Energy, Greenhouse Effect, Greenhouse Gases, Conservation, Power Grid, Bio Energy, Hydropower, Geothermal Power, Tidal Power, Marine Energy, Recycle

Biomass/Composting Vocabulary:

Organic Matter, Compost, Decomposition, Aerobic, Anaerobic, Microbes, Aeration, C:N Ratio, Mesophilic, Thermophilic, Food Waste, Bio Energy

EXPLANATION

- Direct Teach/Lecture
- List higher order thinking questions which teachers will use to solicit *student* explanations and help them to justify their explanations.
- Parallel teaching: Students take notes on math equations and organizing notebook

ELABORATION

- Describe how students will develop a more sophisticated understanding of the concept.
- What vocabulary will be introduced and how will it connect to students' observations?
- How is this knowledge applied in our daily lives?
- Generic Procedure for students:
    - Using PBL (Project Based Learning), students will maintain an engineering notebook that has details over the project. Students will record everything that happens along the way in the duration of the project.
    - Students will consider different designs for the compost tumbler and will be encouraged to research what has been done already.
    - Students will decide on a design to build their tumblers and experience using cutting tools and power tools. Students may opt to buy a tumbler.
    - Students should try to insulate the bin to get optimum changes in temperature.
    - Students will decide what materials (combination of) to put into the tumbler. Students should aim to give a good reason why they chose the combination of materials they did.
    - Students will place sensors into compost.
    - Students will decide how to aerate the compost.
    - Students will aim to record temperatures for 5 days.
    - As an extension, on day 5, students will be asked to insert a coffee can with water into the compost bin. They will record the temperature of the coffee can over a period of 8 hours.
    - Students should be able to graph temp vs time on an Excel sheet. They should be able to lay out a table to use for their graph.
    - After having several days of data and temperature changes of the water, students should be able to calculate the heat transfer using the heat capacity equation: $Q=mc\Delta T$
    - Students will be asked to evaluate their projects and discuss flaws in the design and or data collection.

- Students will write a reflection and put together a presentation.
- Variations of the project:
    - Size of the water reservoir
    - Improvements on design (vertical bin vs horizontal bin)
    - Power output calculations

EVALUATION

- Students will choose format/media for a presentation that walks them through the project.
- Students will reflect and evaluate project/data
- Students will maintain a notebook with all sections: 1) Objective/Problem, 2) Brainstorming/Research, 3) Solution (on paper), 4) Build a Prototype, Test Prototype and take Data, 5) Conclusion/Evaluation, 6) Presentation.
- Optional* Formal Multiple Choice, T/F, Short Answer Assessment

Lesson Plan for Learning Module [2]

[2] Learning Module: ***Compost - A Scientific Investigation***

Lesson objective(s):

1. Students will learn that trash is composed of two types of waste: organic and inorganic.
2. Learn that decomposers such as fungi, microorganisms, and insects are important in the decomposition of organic waste.
3. Practice asking scientific questions.
4. Gain experience designing an experiment to answer a question by composting in a jar.

Brief overview of learning module [2]:

In this four-part inquiry-based activity:

1. Students will practice using the scientific method while learning about decomposition, exploring how some types of garbage will decompose while others will not.
2. Students can then go on to design their own experiment to test different variables affecting the rate of decomposition.
3. The extension activity will consist of students learning about decomposition on a larger scale by setting up a compost bin outside near the classroom garden.
4. Students will then graph the change in temperature of the compost from the bin and will use the compost in the garden to compare & contrast regular soil vs. compost soil to determine growth rate differences in the lima beans planted. Students will record results in a journal.

Lesson Plan
AE Unit: Composting
2023-2024

Subject / Grade Level: Adaptive Education, Science (Biology, Chemistry, Physics, Environmental Science), Grades 9-12

1. Objective

- TEKS

§112.37 Environmental Systems
(2) Scientific processes. The student uses scientific methods during laboratory and field investigations. The student is expected to:
(A) know the definition of science and understand that it has limitations, as specified in subsection (b)(2) of this section;
(B) know that scientific hypotheses are tentative and testable statements that must be capable of being supported or not supported by observational evidence. Hypotheses of durable explanatory power which have been tested over a wide variety of conditions are incorporated into theories;
(E) follow or plan and implement investigative procedures, including making observations, asking questions, formulating testable hypotheses, and selecting equipment and technology;
(F) collect data individually or collaboratively, make measurements with precision and accuracy, record values using appropriate units, and calculate statistically relevant quantities to describe data, including mean, median, and range;

(6) Science concepts. The student knows the sources and flow of energy through an environmental system. The student is expected to:
(B) describe and compare renewable and non-renewable energy derived from natural and alternative sources such as oil, natural gas, coal, nuclear, solar, geothermal, hydroelectric, and wind;
(C) explain the flow of energy in an ecosystem, including conduction, convection, and radiation;
(D) investigate and explain the effects of energy transformations in terms of the laws of thermodynamics within an ecosystem; and
(E) investigate and identify energy interactions in an ecosystem.

§112.34 Biology

(12) Science concepts. The student knows that interdependence and interactions occur within an environmental system. The student is expected to:
(A) interpret relationships, including predation, parasitism, commensalism, mutualism, and competition, among organisms;
(B) compare variations and adaptations of organisms in different ecosystems;

(C) analyze the flow of matter and energy through trophic levels using various models, including food chains, food webs, and ecological pyramids;
(D) describe the flow of matter through the carbon and nitrogen cycles and explain the consequences of disrupting these cycles; and
(E) describe how environmental change can impact ecosystem stability.

§111.43	Mathematical Models with Applications

(1) Mathematical process standards. The student uses mathematical processes to acquire and demonstrate mathematical understanding. The student is expected to:
(A) apply mathematics to problems arising in everyday life, society, and the workplace;
(B) use a problem-solving model that incorporates analyzing given information, formulating a plan or strategy, determining a solution, justifying the solution, and evaluating the problem-solving process and the reasonableness of the solution;
(C) select tools, including real objects, manipulatives, paper and pencil, and technology as appropriate, and techniques, including mental math, estimation, and number sense as appropriate, to solve problems;
(D) communicate mathematical ideas, reasoning, and their implications using multiple representations, including symbols, diagrams, graphs, and language as appropriate;
(E) create and use representations to organize, record, and communicate mathematical ideas;
(F) analyze mathematical relationships to connect and communicate mathematical ideas; and
(G) display, explain, and justify mathematical ideas and arguments using precise mathematical language in written or oral communication.

2. Materials

- 6 clear jars
- At least one "set" of trash:
  - an apple core
  - a piece of plastic
  - two leaves from outside
  - a piece of bread
  - a piece of tin or aluminum foil
  - a piece of paper
- Soil, enough to fill six jars (from outside, not store-bought)
- 1 Experiment Data Workbook and science notebook
- Composter
- Temperature Sensor

3. Exploration

<u>Vocabulary-Scientific Terms:</u>

- **organic waste:** waste from organisms or their life processes that can easily be broken down
- **inorganic waste:** waste not from organisms, or from organisms that existed millions of years ago, that cannot be easily broken down
- **decompose:** to separate or resolve into components or elements
- **decomposer:** an organism, usually a bacterium or fungus, that breaks down the cells of dead plants and animals into simpler substances
- **full-loop life cycle:** a life cycle for a material that never comes to an end. Examples are organic waste like food scraps or lawn trimmings that are composted and turned back into the soil from which they came.
- **linear life cycle:** a life cycle for a material that comes to an end. For example, plastic is made from fossil fuels mined from the Earth, but its life cycle will end in a landfill.
- **compost:** a mixture of decayed or decaying organic matter used to fertilize soil
- **microorganism:** Micro = small, Organism = living thing. A living thing so small that it can only be seen with a microscope. These include bacteria, protozoans, and certain algae and fungi.

<u>Questions:</u>

- What is renewable energy?
- What is Biomass?
- What are three methods of composting?
- What kinds of materials should go into a compost pile?
- Is moisture required in composting?
- What is the temperature of a typical compost pile in the thermophilic stage?

4. Engagement

Introduction

1. Present the objects (leaves, paper, apple core, bread, plastic, foil) to the students. Allow students to carefully observe, touch, and pick up the objects. Have students discuss and then answer the following questions in their science notebooks along with their observations:
    a. What do you notice about these objects? Record initial observations of each object. Make sure they include size (length, width, and height), color, shape, and a simple sketch
    b. Is there anything that two or more objects have in common?
    c. Is there anything that makes some of these objects different?

2. Introduce the scientific practice of planning and carrying out an investigation. Explain that scientists conduct investigations to understand how the world works, and that the students will be conducting an investigation to see how the objects change. With this experiment, we will all be answering the same question and using the same procedure, but everyone will be creating their own hypothesis.

3. Have students write down the question they are answering in their science notebooks or data workbooks. The question this experiment is answering is "How do you think these objects will change over time?"

5. Direct instruction

Procedure - Part One

1. Set up the experiment. Place each trash item in a clean, empty mason jar and place the item against the glass to monitor it over time.

2. Students will fill each jar to within 1 inch from the top with soil that is from outside to ensure that it contains the bacteria and microorganisms necessary for decomposition.

3. Objects will be left in the soil for seven weeks. Question: "How do you think these objects will change over time?" Use this question to guide writing their hypothesis. Students will record their hypothesis in their science notebooks.

4. Add a few tablespoons of water to the jar, and keep the lid off. Continue adding water to each jar as necessary to keep the soil moist but not soaked over the next seven weeks.

5. Each week students will record their observations for each trash item in their science notebooks. They should note the color, shape, and size of all the objects, and even include a sketch.

6. At the end of seven weeks record final observations. Students should observe a tremendous difference in some jars between the first and last week.

7. The next step for students is to analyze their data. Using the information they have gathered over the past seven weeks, they will choose to either accept or reject their hypothesis. Was their prediction correct? What evidence do they have to support this? Students can record their analysis in their science notebooks.

8. Finally, for a conclusion, students will summarize what happened over time to each piece of trash. Encourage them to draw conclusions about different types of trash. Ask the students:
   - Which pieces of trash changed the most? Why?
   - Which didn't decompose at all? Why?

- What made these pieces different?

6. Guided teaching

Wrap-Up

1. Introduce the word "decompose" and ask for the meaning. After going over the definition, ask students if any of their objects decomposed.

2. Revisit the fact that not all of their objects decomposed. Why do they think this is? Define the terms organic and inorganic waste, and ask students for some other possible examples of each. What are the differences between organic and inorganic waste?

3. Discuss what causes decomposition to occur. Name some decomposers and explain why they are important. *(Bacteria, fungi, beetles, ants, flies. All of these organisms eat decaying animal and plant matter, returning nutrients back into the earth. It may appear that matter breaks down by itself, but in reality we just cannot see all of these organisms hard at work. Without them dead matter would never convert back into nutrients and Earth's ecosystems would not function properly.)*

4. What takes longer to break down – organic or inorganic waste? Why? *(Organic waste is made of matter that was very recently alive, like plants and animals. Inorganic matter is made of matter that was not alive, or was alive millions of years ago, like minerals and petroleum. Inorganic matter takes longer to break down because it is not decomposed by other organisms. It is left to break down on its own with the help of the sun and water, which takes a very long time, sometimes thousands of years.)*

5. What are the benefits of composting for the environment? *(It returns essential nutrients back into the soil. If organic waste is landfilled, it permanently removes those nutrients from the earth.)*

6. What can we do at home to help organic trash complete its life cycle? *(Compost!)*

7. What can we do at home to keep inorganic trash from piling up in landfills? *(Use less products made of non-recyclable materials, and recycle or compost everything we can.)*

Procedure - Part Two

Once students have a basic handle on the concept of decomposition and how to set up the jars, they will be able to design an experiment to answer another question.

1. Start by having students generate questions about their results. *A simple way to ask students to generate questions is to ask them "what do you wonder?"* Have students discuss with groups and record their questions, and then share them with the class and write them on the board.

2. Next, go through the questions to pick out the ones that a second experiment could answer. Some examples are below:
    - Does temperature matter? What if it's warmer or colder?
    - Does the substrate matter? What if we tried soil from a different place?

- What if we moistened the soil with something other than water?
- Do different types of organic matter decompose faster? Slower?

3. Have a class vote to choose one of these questions to answer with an experiment.

4. Have students design the experiment. This is a good point to define the terms “variable” and “control.” In the first experiment, the question was ‘how do you think the objects will change over time,’ so it was comparing all of the objects to each other. If the question is about how the parameters of the decomposition jar changes the rate of change, then there must be a control to compare to the variable. For example, if a group is testing how temperature affects the rate of decomposition, they may use three jars: one that is warmed up (variable), one that is kept in the fridge (variable), and one that is left at room temperature (control). As students design their experiments, be sure they are including a control and a variable if appropriate.

5. Carry out and analyze the experiment(s). Be sure to include a hypothesis, analysis, and a conclusion. After students have their results, as a class, have a discussion over their findings.

7. Closure and assessment

Extension-Part Three

The extension activity will consist of students learning about decomposition on a larger scale by setting up a compost bin outside near the classroom garden. Students will gather materials such as dirt, soil, and water along with the following Brown Matter (Carbon) and Green Matter (Nitrogen) from the following chart to add into the compost bin.

Part Four

Students will then graph the change in temperature of the compost from the bin weekly using a HOBO Data Logger/Temperature device during a two-week period until the components of the tumbler turns into compost. Once the mixture turns into compost, students will use the compost in the garden to compare & contrast regular soil vs. compost soil to determine growth rate differences in the lima beans planted. Students will record results in a journal.

Assessment

- Completion of Journal entries (check-points)
- Experiment Data Workbook (GRADE)
- Classroom Vocabulary and Notes
- Participation as a Grade
- Mini-Quizzes on Videos and Nearpod Assignments

Differentiation strategies to meet diverse learner needs:

- Copy of Classroom Notes
- Visual Aids
- Videos
- Vocabulary/Journal Notes
- Project-Based Learning
- Peer Feedback
- Hands-on Activities
- Color/drawing in Journal or writing options

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Optimization of Wind Farm Layouts Through Wind Turbine Coordination

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RET Site: Integrating Data-Driven Research in
Renewable Energy Across Disciplines (I-READ)

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July 21, 2023

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Abstract

This research project explores the impact of turbine coordination techniques within a wind farm using small-scale turbine structures. Theoretical analysis and experimental data were utilized to optimize power production and reduce fatigue loads in wind energy systems. Comparing baseline wind speed data to wake effect data revealed convergence to the baseline indicating subsiding of the wake effect. Voltage data analysis demonstrated distinctive regions within the power curve, showcasing the turbine's operational efficiency and power generation capabilities across varying wind speeds. The findings contribute valuable insights to the advancement of wind energy technology and its integration into a sustainable energy landscape. Staggered turbine layouts were identified as beneficial for maximizing power production and minimizing fatigue due to wake effects, extending the lifespan of turbines. This research project offers a beneficial method of analyzing turbine coordination techniques and wake effects using small-scale wind turbine analysis. The study's results provide valuable guidance for optimizing wind energy systems and promoting renewable energy exploration in STEM education.

Introduction

Fossil fuels as the main energy sources in current society are not sustainable and will be exhausted in the foreseeable future due to limited resources, rapid consumption, climate change, global warming , etc. [1]. Renewable energy sources have emerged as promising alternatives to traditional fossil fuels in the global pursuit of sustainable and eco-friendly power generation. Among these naturally replenishing options are solar energy, geothermal energy, wind energy, hydropower, and biomass fuels. Over time, society has evolved into one with exponentially increasing energy demands. Therefore, the transition to renewable energy remains essential for a sustainable future.

As of 2021, renewable energy sources accounted for only 12.4% of total energy consumption in the United States [2]. Wind energy, one of the prominent renewable sources, constituted 27% of all renewables in the same year [2]. Wind is the movement of air, caused by the uneven heating of the Earth by the sun and the Earth's own rotation [3]. These winds are influenced by various natural features in the environment, including mountains, valleys, lakes, oceans, forests, plains, farmlands, and cities.

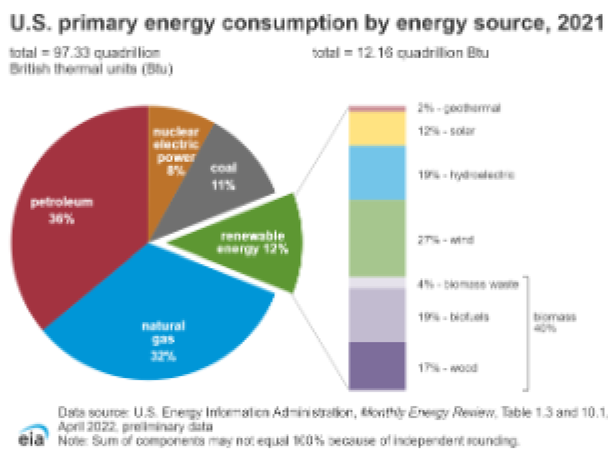

Figure 2: Displays US energy consumption for 2021.

Humans have manipulated the wind for various purposes throughout history, from using them for sailing and grinding grain in windmills to gathering water. In recent times, wind currents have been harnessed to generate electricity using wind turbines. The optimization of wind turbines and their coordination within wind farms has been a subject of extensive research. The cornerstone of wind energy technology lies in wind turbines, which play a pivotal role in capturing wind resources and converting them into electrical energy. Wind farms accounted for about 30 percent of all new power generating capacity added in the United States in 2007.[4] As wind farms continue to expand and turbines become larger and more powerful, the need to optimize their performance becomes increasingly critical.

This paper focuses on investigating the impact of turbine coordination techniques within a wind farm using small scale turbine structures, with an emphasis on strategies to optimize power production, reduce fatigue loads, and enhance overall performance. Among all kinds of factors affecting wind farm layout design, the authors only consider the following factors based on the scope of this study: (1) baseline wind speeds of the upstream turbine, (2) subsidence of wake effect and (3) optimal power production taken as a percentage of max voltage output. Analysis of the effectiveness of coordination methods due to wake effects aims to contribute valuable insights towards the advancement of wind energy technology and its integration into a greener, more sustainable energy landscape. A second primary goal of this research project is to build middle and high school student interest in the fields of science, technology, engineering, and mathematics (STEM). The focus is on researching wind turbines and developing a series of curriculum modules that can be implemented in classrooms and shared with students. The hope is that these modules will be disseminated to other teachers throughout our area, state, country, and the world. The mission is to foster an enduring interest in discovery through science among the next generation, encouraging them to explore the wonders of renewable energy and its potential in shaping a sustainable future.

Literature Review

Wind turbines are often installed in dense clusters, mainly due to the limited number of quality sites, as well as the need to reduce the cost of transmission lines and maintenance.[5] As wind turbines extract energy from the wind , they consequently retard the wind field behind the turbine.[6] Lack of layout construction often places downstream turbines in the wake of upstream turbines. Turbine function in the wake region of upstream turbines causes the following issues: (i) reduction in the turbine service life due to increased turbulence intensity in the incoming flow [7, 8], and (ii) greater aerodynamic interactions leading to reduced power production.[9]

A knowledge of the terminology is essential to understanding the equations and their relevance to data sets. A portion of essential terms regarding wind turbine analysis have been defined here:

1. **Velocity Deficit:** The velocity deficit is a critical parameter in wind analysis, representing the reduction in wind speed caused by the presence of the wind turbine. The velocity deficit decreases with increasing separation distance between up and downstream

turbines. It provides valuable information about the wake effect and the influence of the wind turbine on the surrounding flow.

2. **Axial Induction Factor:** The axial induction factor is a dimensionless parameter used to estimate the reduction in wind speed caused by the wind turbine. An axial induction factor of 0.25 would mean the wind turbine is capturing approximately 25% of the approaching wind's kinetic energy.
3. **Entrainment Constant:** The entrainment constant is another dimensionless parameter used to model the wake effect. It represents the rate at which surrounding air is entrained (pulled through) into the wake behind the wind turbine. Typically, the larger the entrainment constant, the larger the wake radius can become.
4. **Thrust Coefficient:** The thrust coefficient is a dimensionless parameter used to evaluate the aerodynamic efficiency of the wind turbine. It is calculated as the ratio of the rotor's tangential force to the available kinetic energy in the wind. The thrust coefficient varies with the wind speed and the wind turbine's characteristics.
5. **Surface Roughness:** The surface roughness is a measure of the roughness of the terrain over which the wind is flowing. It can significantly influence the wind flow and turbulence, especially near the ground.

These terms collectively contribute to the understanding of the wake effect caused by the wind turbine and how it affects the wind speed at different distances behind the turbine.

A theoretical analysis was performed using equations based on the one that was developed by Jensen (1983) [10], later improved by Katic, Hojstrup, and Jensen(1986) [6] and Frandsen [11], and as demonstrated by Chen et.al (2013,15). [12, 13]

The following equations and graphics adapted from Chen et.al (2013). [13]

The wind speed *U(x)* in front of the blade of the downstream turbine can be calculated using *Equation (1)*:

$$U(x) = U_0(1 - U_{def} \times (A_{overlap}/A)), \tag{1}$$

where U_0 is the wind velocity of the free stream in front of the upstream turbine blades. A is the blade swept area and $A_{overlap}$ is the overlap area between the wake generated by turbine 'a' and turbine 'b' as shown in the red area in *Figure 2*.

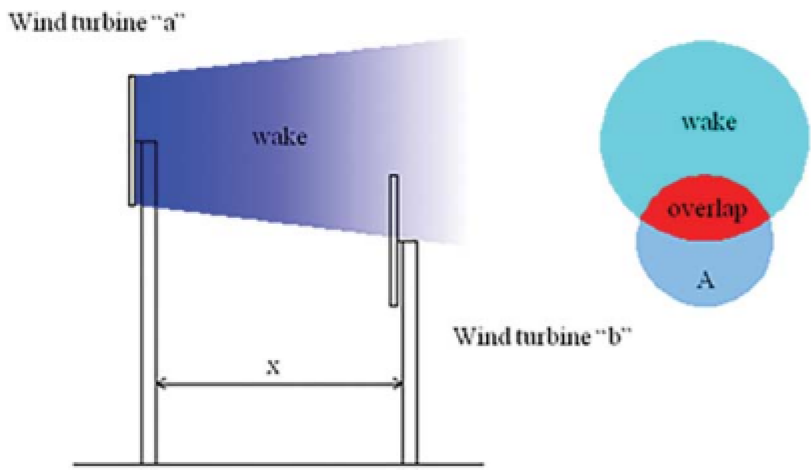

Figure 2: Scheme of a wake model with different height wind turbines.

U_{def} is the velocity deficit at distance x after turbine 'a', which can be calculated using *Equation (2)*:

$$U_{def} = \frac{2a}{\left(1+\alpha\frac{x}{r_r}\right)^2}. \tag{2}$$

In *Equation (2)*, a is the axial induction factor related to the thrust coefficient of *Equation (3)*:

$$C_T = 4a \times (1 - a). \tag{3}$$

r_r represents the radius of the turbine's blade. α is the entrainment constant related to the wind turbine that generates the wake, and can be calculated using *Equation (4)*. In *Equation (4)*, z is the wind turbine hub height, and z_0 is the surface roughness length:

$$\alpha = \frac{0.5}{ln\left(\frac{z}{z_0}\right)}. \tag{4}$$

And the wake radius (r_1) at distance x after it being generated can be calculated using *Equation (5)*:

$$r_1 = \alpha x + r_r. \quad (5)$$

Chen et.al goes on to define the formula necessary for when a wind turbine is covered by multiple wakes. However, those calculations will be beyond the scope of this research.

The blade swept area and wake area when considering overlap, were assumed to be circular. Therefore, the area of the overlap was calculated using *Equation (6):*

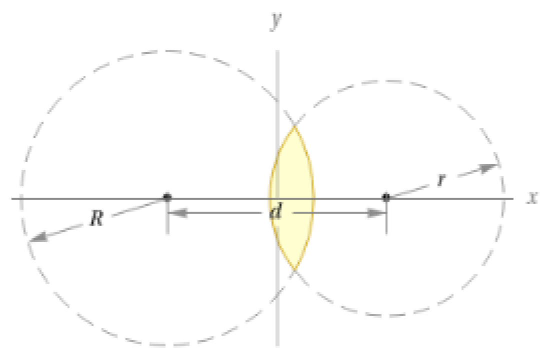

Figure 3. Schematic of the overlap area of the downstream blade swept area and the wake area.

$$A = r^2 cos^{-1}\left(\frac{d^2+r^2-R^2}{2dr}\right) + R^2 cos^{-1}\left(\frac{d^2-r^2+R^2}{2dR}\right) - \frac{1}{2} \times \sqrt{(d + r - R)(d - r + R)(- d + r + R)(d + r + R)} \quad (6)$$

Where r is the radius of the blade swept area of the downstream turbine, R is the radius of the wake area, and d is the distance between the foci of each circular area as seen in *Figure 3*.

Theoretical Data and Analysis

Using the aforementioned equations, this study has produced theoretical data showing: (1) the speed of the wind post interaction with the upstream turbine depicting subsidence of the Wake effect, (2) Wind speeds in front of the blade of the downstream turbine when staggered in horizontally overlapped regions, and (3) wind speeds in front of the blade of the downstream turbine when adjusting Hub height and and accounting for the vertically overlap regions. The data can be used for further analysis and modeling to optimize wind turbine placement and improve the overall performance of wind energy systems.

The graph in *Figure 4* shows that as wind moves downstream from a wind turbine, the wind speed at a given point tends to recover due to mixing with the ambient wind. This phenomenon is known as wake recovery. In the figure, as the separation distance increases (x [m]), the Wind

Speed at Turbine 'b' (U(x)) is expected to increase due to the wake recovery effect. The recovery rate may not be linear, and it will vary depending on factors such as wind turbine characteristics, ambient wind speed, atmospheric stability, and surface roughness.

To determine the exact relationship between Wind Speed at Turbine 'b' and the separation distance, we would need to perform a more detailed analysis, potentially using wake models or computational fluid dynamics (CFD) simulations. Nevertheless, the figure can provide an initial understanding of how Wind Speed behaves concerning the separation distance for this specific dataset.

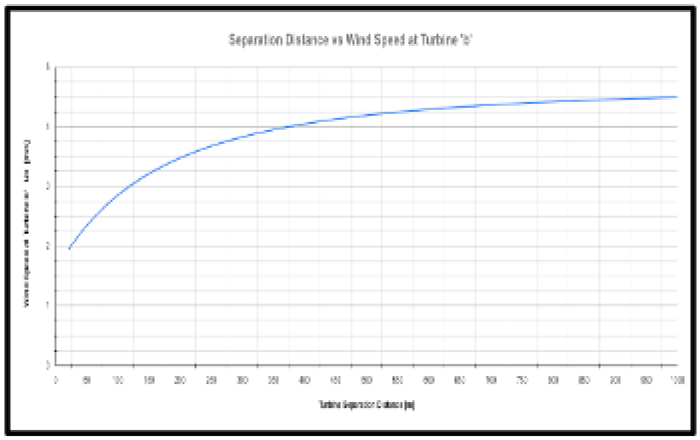

Figure 4. Parameters used:

U_0 Wind Speed (m/s)	4.69	Blade Radius (m)	22
Surface Roughness (m)	0.05	Overlap	100%
Axial Induction Factor	33%	Hub Height 'a'/'b' (m)	100
Turbine Separation Distances (m) 20 - 1000 in 20 meter increments			

Theoretical data displayed in *Figure 5* was gathered to investigate how the wind speed at turbine 'b' (*U(x)*) is affected by the overlap area ($A_{overlap}$ [m^2]) between the blade swept area and the wake radius area. The data is provided for different separation distances (50m, 100m, 200m, 400m, and 600m) between turbine 'a' and point 'b' downstream.

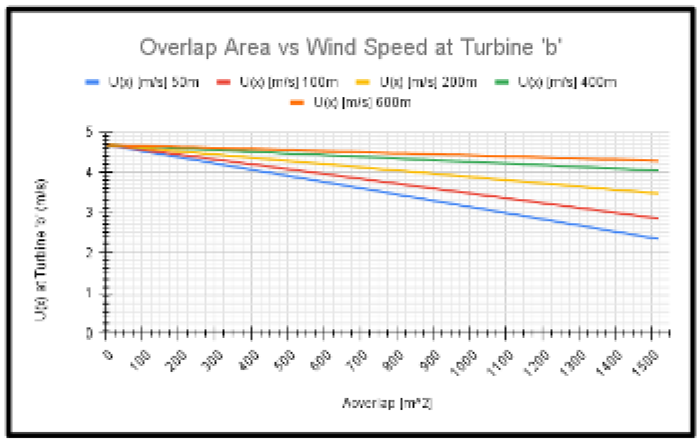

Figure 5: Parameters used:

U_0 Wind Speed (m/s)	4.69	Blade Radius (m)	22
Surface Roughness (m)	0.05	Hub Height 'a'/'b' (m)	100
Axial Induction Factor	33%		
Separation Distance (m)	50, 100, 200, 400, and 600		
Overlap was 0 - 100% in increments of 2% (from 0 to 1520.53 m^2)			

Key observations of the graph include: (1) As the overlap area increases, the wind speed at turbine 'b' decreases: This is expected since a larger overlap area indicates a greater impact of the wind turbine's wake on the downstream turbine 'b', leading to a reduction in wind speed. (2) The effect of overlap area is more significant at closer distances: The reduction in wind speed due to increased overlap area is more pronounced at shorter separation distances (e.g., 50m) compared to longer distances (e.g., 600m). This seems to be because the wake of the wind turbine has a more substantial influence on nearby points than those farther downstream. These findings emphasize the importance of managing the wake effect of wind turbines in wind farm layouts to optimize overall energy production and turbine efficiency. By carefully considering turbine placement and spacing, the impact of wake effects can be mitigated, leading to improved wind farm performance.

The objective of the hub height analysis shown in *Figure 6* was to understand how changes to the hub height of turbine 'b' would impact the wind speed at its blades. Turbine 'a's hub height and initial speed were held constant. Systematic adjustments were then made to the hub height of turbine 'B', ranging from 36.0m to 164.0m in 4-meter increments. Account was taken for the natural wind speeds turbine 'B' would experience when its hub height was lower or higher than turbine 'A's. Wind speeds were added or subtracted at increments of 0.2m/s for every 22m increase or decrease in turbine 'B's hub height relative to the initial hub height and wind speed at turbine 'A'. This assumption was based on the expectation that wind speed would naturally increase with higher hub heights.

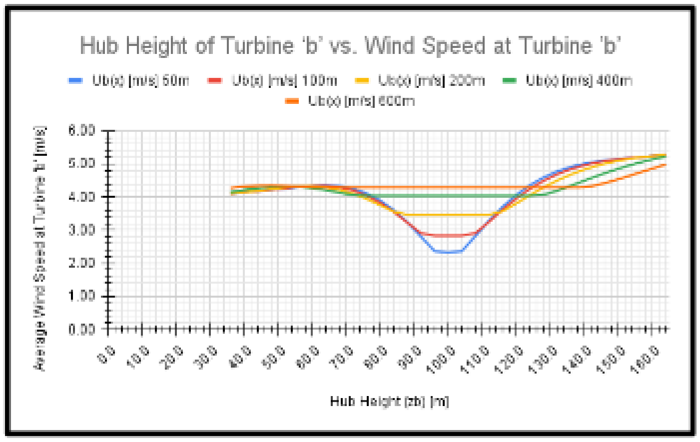

Figure 6: Parameters used:

U_0 Wind Speed (m/s)	4.69	Blade Radius (m)	22
Surface Roughness (m)	0.05	Separation Distance (m)	100
Axial Induction Factor	33%	Hub Height 'a' (m)	100

Separation Distance (m) 50, 100, 200, 400, and 600
Hub Height 'b' (m) 36 to 164 in 4 meter increments
Overlap was calculated as Hub height 'b' increased
While U_0 was held constant, it was assumed that wind speed of turbine 'b' would be affected by changes in wind speed due to height at a factor of 0.2m/s per 22m of hub height change.

The aim was to gain insights into how changes in hub height can affect wind speeds for a downstream wind turbine, considering both the wake effect and the influence of naturally flowing winds. The findings suggest that variations in hub height may be more beneficial when space is limited and turbines need to be placed closer to one another. Advantages in this instance were observed for a lower upstream turbine height coupled with a higher downstream turbine height. However, further research would be necessary to determine whether placing a larger hub height turbine closer to an upstream turbine can cause more fatigue to the tower of the downstream turbine due to its position within the wake of the upstream turbine.

Methodology

Having a final goal of creating modules that can be used by teachers with students in the classroom, researchers ideally sought out materials that could be cost-effective, size effective, and useful for lessons that would promote student understanding of the concepts being taught. The following materials were used during experimentation.

Figure 7. Wind Kit

1. Wind turbine kit
    a. Stores energy by charging a battery during rotation.
    b. Rotor blades can be placed in various locations.
    c. Rotor blades can be adjusted to capture more or less wind.
    d. Can measure measure voltage output
    e. Purchased here: [Thames & Kosmos Wind Power V4.0 STEM Experiment Kit]
2. Anemometer (measure wind speed)
3. Multimeter (measure voltage)
4. Wind source (RIDGID 1625 CFM 3-Speed Portable Blower Fan)
    a. Other wind sources are available but it may be prudent to mention that a standard box fan was not sufficient to produce wind speeds necessary to conduct the research in this paper.

Experimentation

Part 1: Measurement of Baseline Average Wind Speeds

The first objective was to gather baseline wind data using a grid array placed on two tables. The grid array can be seen in *Figure 8*. Each column was spaced 10in apart, and each row was spaced 18in apart. The wind source was positioned 31in away from position 1B. Measurements of the wind turbine blade radius and hub height were carefully recorded. An anemometer was positioned at a height matching the center of the wind source and used to measure wind speed. Wind speed data was collected at grid array positions 1B

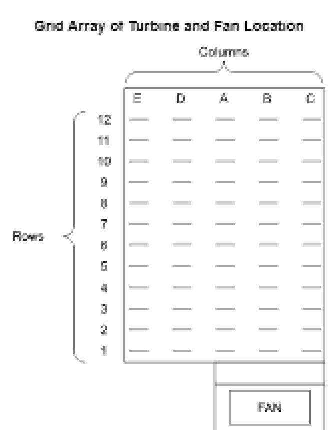

Figure 8. Grid Array of turbine, fan, and anemometer locations for gathering data.

through 12B, 1A through 12A, and 1C through 12C. Data was collected at each grid position manually allowing the fan to blow for 30 seconds to establish a baseline wind speed. Afterward, data was collected at each location in 15-second intervals. At each grid position, four data points were recorded and then averaged to obtain the average wind speed at that specific position on the grid. Care was taken to ensure that the anemometer was consistently aligned at the same location for each grid position and that the wind source remained stationary. *Table 1* contains exact measurements from the center of the fan to each grid location and the angle of displacement.

Displacements and Angles from Center of Fan										
Row Position	Column Position									
	E		D		A		B		C	
	Displacement (m)	Angle (°)	Displacement (m)	Angle (°)	Displacement (m)	Angle (°)	Displacement (m)	Angle (°)	Displacement (m)	Angle (°)
1	1.10	134.06	0.94	122.83	0.83	107.88	0.79	90.00	0.83	72.12
2	1.46	121.48	1.34	112.20	1.27	101.63	1.24	90.00	1.27	78.47
3	1.86	114.12	1.78	106.62	1.72	98.49	1.70	90.00	1.72	81.51
4	2.29	109.44	2.22	103.24	2.17	96.71	2.16	90.00	2.17	83.29
5	2.72	106.24	2.67	100.99	2.63	95.55	2.62	90.00	2.63	84.45
6	3.17	103.92	3.12	99.39	3.08	94.72	3.07	90.00	3.08	85.28
7	3.61	102.18	3.57	98.19	3.54	94.11	3.53	90.00	3.54	85.89
8	4.06	100.82	4.02	97.26	4.00	93.64	3.99	90.00	4.00	86.36
9	4.51	99.73	4.47	96.52	4.45	93.27	4.45	90.00	4.45	86.73
10	4.96	98.84	4.93	95.92	4.91	92.97	4.90	90.00	4.91	87.03
11	5.41	98.09	5.38	95.41	5.37	92.71	5.36	90.00	5.37	87.29
12	5.87	97.46	5.84	94.99	5.82	92.50	5.82	90.00	5.82	87.50
Table 1: Displacements from Fan Center and Angle of Displacement to Anemometer Testing Position. Hub Height is 0.455m (18in), Blade Radius 0.385m (15.2in)										

Table 1: Displacements from Fan Center and Angle of Displacement to Anemometer Testing Position. Hub Height is 0.455m (18in), Blade Radius 0.385m (15.2in)

Part 2: Measurements of Wake Effect Wind Speed Averages

A wind turbine was placed at location 1B, representing the upstream turbine. The anemometer was set at position 2B and aligned with the hub height of the upstream turbine, to represent the downstream turbine. The wind source was started and after allowing it to blow continuously for 30 seconds, wind speed data was collected at positions 2B through 12B with four data points acquired at 15-second intervals for each position.

Part 3: Measurements of Average Voltage

To collect voltage data, a multimeter was connected to the battery terminals on the back of turbine 'a'. Turbine 'a' was then positioned at location 1B in the grid array. The wind source was started and a constant wind speed was established. Four data points of voltage readings were then collected for turbine 'a', with each data point taken after 15 seconds, and the average voltage was calculated for each position of turbine 'a' along the grid array. The data collection process was conducted for positions 1B through 12B.

After obtaining the voltage data for turbine 'a', data was obtained for turbine 'b', placed in the wake of turbine 'a'. For this segment of the experiment, turbine 'a' was returned to position 1B. The multimeter was then connected to turbine 'b'. Once the wind source established a constant speed, voltage data for turbine 'b' was recorded at positions 2B through 12B, 2A through 8A, 2D through 8D, and 2E through 8E. The same data collection method employed for turbine 'a' was applied to turbine 'b'.

Analysis

Part 1 - Baseline Wind Speed Data Analysis

The baseline wind speed data reveals a consistent pattern of decreasing wind speeds with increasing displacement from the wind source (*Figure 9*). The position of the columns in relation to the fan plays a significant role in determining the wind speeds they experience. Column B, being in front of the fan, registers the highest wind speeds, while columns A and C, off-center from the fan, observe slightly lower initial wind speeds. As wind from the source Propagates, there is a noticeable convergence of wind speeds at the 4 M mark. These observations highlight the importance of position and proximity to the wind source when considering wind speed measurements in experimental setups.

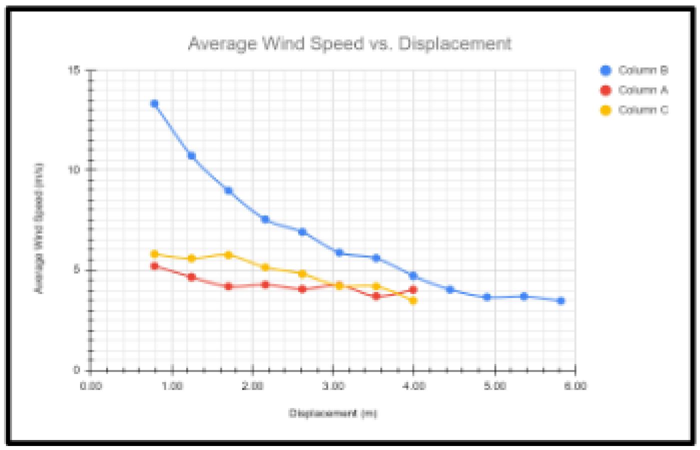

Figure 9: Displays the average wind speed readings of the blower only. Readings taken for locations 1A to 8A (blue), 1B to 12B (red), and 1C to 12C (yellow).

Part 2 - Comparison of Baseline Data to Wake Effect Data

From the comparison of the Baseline wind speed data (anemometer only readings) for column 1B through 12b to the wake effect data of turbine 'b' in the wake of turbine 'a', it can be seen that The wind speeds in the wake of turbine 'a' (B column) are lower than the corresponding Baseline wind speeds. *Figure 10* shows that at position 1.24m, the wake effect of turbine 'a' has a substantial impact on turbine 'b's wind speed, resulting in a significant drop from the Baseline value. This indicates that turbine 'b' is well within the wake zone of turbine 'a' at this position. Further down the grid array (positions 2.16m to 5.82m), there seems to be a slight convergence of the wake effect data towards the Baseline wind speed data as seein figure 8. This convergence may indicate a subsiding wake effect, where the impact of turbine 'a's wake on turbine 'b' lessens. The data suggests that the wake effect extends to the downstream direction and may be subsiding between the 4 to 5m position, emphasizing the importance of considering wake effects in wind turbine placement and array design.

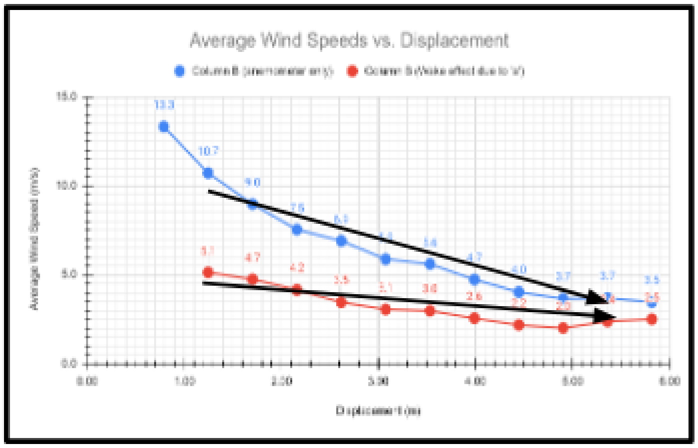

Figure 10: Baseline anemometer wind speed readings compared to anemometer readings taken in the wake effect of Turbine 'a'. Change in gradient and convergence to baseline shows subsiding of the wake effect as distance from the fan increases.

Part 3 - Analysis of Voltage Output

The voltage curve resulting from wind speed readings at various locations exhibits distinctive regions that are typically found within a power curve of wind capture machines, such as windmills. *Figure 12* shows that turbine 'b', situated in the wake-affected area, displayed significant differences in voltage production corresponding to wind speeds at different grid array

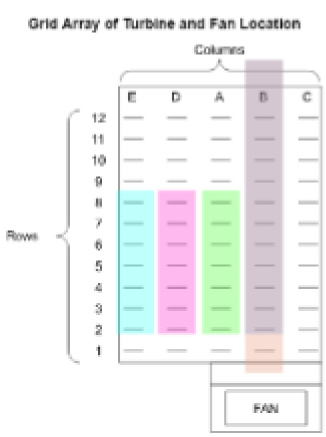

Figure 11. Grid Array of Turbine and anemometer locations for voltage data.

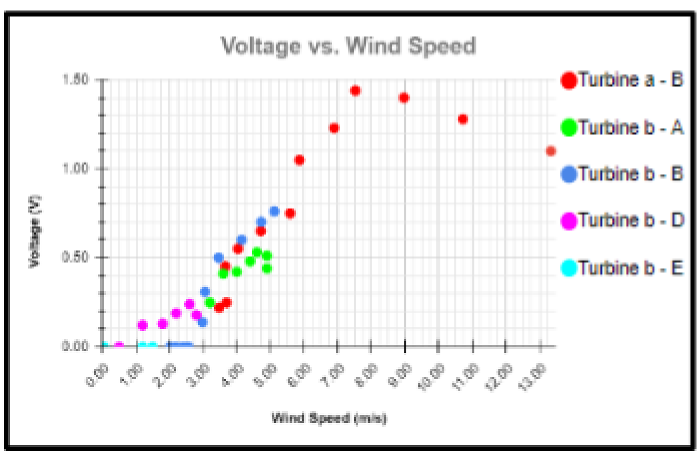

Figure 12: Displays an initial voltage response to wind speed followed by a linear increase which leads to a voltage plateau indicating the turbine has reached a maximum voltage output.

locations. The startup region, characterized by low wind speeds influenced by the wake effect, is represented by data from turbine 'b' when placed in columns B, D and E as the turbine requires a minimum wind speed to initiate power production. Within this region, the power output is minimal as the blades begin to rotate. A linear increase region is also observed, which includes data from turbine 'b' in columns A and B, along with low-speed data from turbine 'a'. Within this region, power output escalates linearly with wind speed, and the turbine operates most efficiently. Beyond the linear increase region, the power curve reaches a saturated region, represented by turbine 'a' data points for high-speed winds, where power output levels off and reaches its maximum capacity. The voltage data graph (*Figure 12*) reveals that at an average wind speed of 7.53 m/s, turbine 'a' achieves its peak voltage output of 1.44 volts, representing the maximum output for the small-scale wind turbine. The turbine here operates at full power within this region, and further increases in wind speed have little impact on power output. Subsequently, the voltage exhibits a small linear decline, potentially due to energy losses resulting from the vibrations caused by the turbine rotating at high velocities. The observed voltage curve highlights the turbine's power performance across different wind speeds, providing valuable insights into its efficiency and power generation capabilities.

Conclusion

This research project aimed to investigate turbine coordination techniques within a wind farm using small-scale turbine structures. Theoretical analysis, based on equations and wake models, provided valuable insights into wind speed behavior and the influence of turbine wake effects. The experimental data collected from the wind turbine kit corroborated the theoretical findings, showing a consistent pattern of decreasing wind speeds with increasing displacement from the wind source. Furthermore, the comparison of baseline wind speed data to wake effect data revealed that wind speeds in the wake of turbine 'a' showed a convergence to baseline readings indicating subsidence of the wake effect further from the wind source.

The voltage data analysis demonstrated distinctive regions within the power curve, including the startup region, linear increase region, and saturated region. turbine 'b' data points fell into the startup and linear increase regions, while turbine 'a' data points occupied the saturated region, showcasing the turbine's operational efficiency and power output across varying wind speeds.

Based on the heat map (*Table 2*) and wind speed data analyses, data suggests that a staggered layout (*Figure 14*) would be ideal for downstream turbines to maximize power production and minimize fatigue due to the wake effect which will ensure sustained structural integrity and extend the lifespan of turbines.

Heat Map of % of Maximum Voltage for Turbine 'b' in wake of Turbine 'a'				
	Column			
Row	E	D	A	B
2	0.00	0.00	30.56	52.78
3	0.00	0.00	35.42	48.61
4	0.00	8.47	36.81	41.67
5	0.00	9.03	33.33	34.72
6	0.00	13.19	29.17	21.53
7	0.00	16.67	28.47	9.72
8	0.00	12.50	17.36	0.00

Table 2: Heat map - Green = Low % of max voltage, Yellow = mean % of max voltage, and Red = High % of max voltage

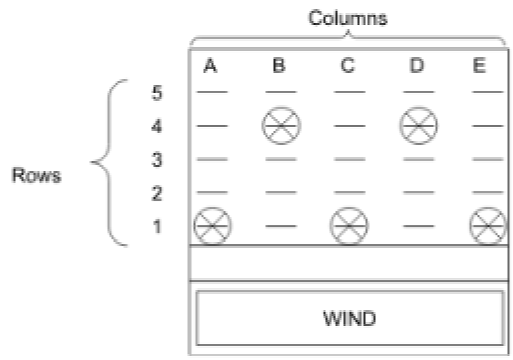

Figure 13: Staggered array of optimal turbine locations for power production and fatigue reduction.

This research project demonstrated a beneficial method of analyzing turbine coordination techniques, wake effects, and power generation capabilities through both theoretical and experimental means using small scale wind turbine analysis. The findings contribute valuable insights to the advancement of wind energy technology and its integration into a sustainable energy landscape. Moreover, the development of curriculum modules aims to inspire the next generation of students to explore the wonders of renewable energy and its potential for a greener future. Students will learn to implement carefully planned turbine placements and use scientific equipment to gather data. Teacher and student collaboration in research such as this will lay the foundation for further advancements in wind energy technology and its crucial role in the transition towards renewable energy sources.

Learning Modules

High School Learning Modules

Wind Turbine Investigations: Exploring Physics Principles

General Physics Standards for Scientific Processes

- P.1 Scientific processes. The student conducts investigations, for at least 40% of instructional time, using safe, environmentally appropriate, and ethical practices. These investigations must involve actively obtaining and analyzing data with physical equipment, but may also involve experimentation in a simulated environment as well as field observations that extend beyond the classroom.
- P.2 Scientific processes. The student uses a systematic approach to answer scientific laboratory and field investigative questions.
    - P.1(A) demonstrate safe practices during laboratory and field investigations
    - P.1(B) demonstrate an understanding of the use and conservation of resources and the proper disposal or recycling of materials
    - P.2(A) know the definition of science as specified in chapter 112.39, subsection (b)(2) of 19 TAC
    - P.2(B) know that scientific hypotheses are tentative and testable statements that must be capable of being supported or not supported by observational evidence
    - P.2(C) know that scientific theories are based on natural and physical phenomena and are capable of being tested by multiple independent researchers. Unlike hypotheses, scientific theories are well established and highly reliable explanations, but may be subject to change
    - P.2(D) design and implement investigative procedures, including making observations, asking well defined questions, formulating testable hypotheses, identifying variables, selecting appropriate equipment and technology, evaluating numerical answers for reasonableness, and identifying causes and effects of uncertainties in measured data
    - P.2(E) demonstrate the use of course apparatus, equipment, techniques, and procedures, including multimeters (current, voltage, resistance), balances, batteries, dynamics demonstration equipment, collision apparatus, lab masses, magnets, plane mirrors, convex lenses, stopwatches, trajectory apparatus, graph paper, magnetic compasses, protractors, metric rulers, spring scales, thermometers, slinky springs, and/or other equipment and materials that will produce the same results
    - P.2(F) use a wide variety of additional course apparatus, equipment, techniques, materials, and procedures as appropriate such as ripple tank with wave generator, wave motion rope, tuning forks, hand-held visual spectroscopes, discharge tubes with power supply (H, He, Ne, Ar), electromagnetic spectrum charts, laser pointers, micrometer, caliper, computer, data acquisition probes, scientific calculators, graphing technology, electrostatics kits, electroscope, inclined plane, optics bench, optics kit, polarized film, prisms, pulley with table clamp, motion detectors, photogates, friction blocks, ballistic carts or equivalent, resonance tube, stroboscope, resistors, copper wire, switches, iron filings, and/or other equipment and materials that will produce the same results
    - P.2(G) make measurements with accuracy and precision and record data using scientific notation and International System (SI) units

- P.2(I) communicate valid conclusions supported by the data through various methods such as lab reports, labeled drawings, graphic organizers, journals, summaries, oral reports, and technology-based reports
- P.2(J) express relationships among physical variables quantitatively, including the use of graphs, charts, and equations

- P.3 Scientific processes. The student uses critical thinking, scientific reasoning, and problem solving to make informed decisions within and outside the classroom
  - P.3(D) research and describe the connections between physics and future careers
  - P.3(E) express, manipulate, and interpret relationships symbolically in accordance with accepted theories to make predictions and solve problems mathematically
  - P.3(A) analyze, evaluate, and critique scientific explanations by using empirical evidence, logical reasoning, and experimental and observational testing, so as to encourage critical thinking by the student

THE FOLLOWING IS SAMPLE EQUIPMENT THAT MAY BE USED FOR EACH INVESTIGATION:

Wind Turbine Investigations: Exploring Physics Principles

Wind Turbine Investigation #1

Investigating Wind Speed Changes and Wake Effects in a Wind Farm

Physics Standards:

- P.4(A) generate and interpret graphs and charts describing different types of motion, including investigations using real‑time technology such as motion detectors or photogates
- P.4(B) describe and analyze motion in one dimension using equations and graphical vector addition with the concepts of distance, displacement, speed, average velocity, instantaneous velocity, frames of reference, and acceleration

Objective:
Students will measure wind speeds before and after a wind turbine within a model wind farm, calculate the difference, and analyze the implications of wake losses on energy production using physics concepts.

Materials:

1. Anemometer (wind speed measuring device)
2. Model wind farm setup (constructed with miniature wind turbines, play windmills, etc)
3. Measuring tape or ruler
4. Stopwatch or timer

Procedure:

1. **Introduction:**
    - Provide the students with a detailed explanation of wind turbine farms, while emphasizing the physics principles involved in harnessing wind energy.
    - Introduce the concept of wake losses, which occur due to the interaction between wind turbines within a wind farm, resulting in reduced energy output.
    - Discuss the importance of understanding and mitigating wake effects for optimizing wind farm efficiency.
2. **Model Wind Farm Setup:**
    - Set up a model wind farm with multiple wind turbines, windmills, or fan blades arranged in a specific layout to replicate the spacing and positioning of a real wind farm.
    - Ensure the model wind farm allows for unobstructed wind flow, like actual wind farm conditions.
3. **Wind Speed Measurement:**
    - Instruct students to measure wind speeds at predetermined locations within the model wind farm, representing positions before the wind turbine.
    - Prior to turbine operation, students should use an anemometer to measure and record the wind speed at each location.
    - Take multiple measurements at each location to calculate an average wind speed, ensuring accuracy.
4. **Activating the Wind Turbines:**
    - Allow the wind turbines, windmills, or fans within the model wind farm to spin with the generated airflow, simulating their operation and the generation of energy from wind flow.

- Allow sufficient time for the turbines to reach a steady state, ensuring consistent conditions for data collection.

5. **Wind Speed Measurement After Turbines:**
    - Instruct students to measure wind speeds again at the same predetermined locations within the model wind farm, this time representing positions after the wind turbine.
    - Using the anemometer, students should take multiple measurements at each location and calculate an average wind speed.
6. **Data Analysis and Conclusion:**
    - Calculate the difference in wind speed before and after the turbines at each location within the model wind farm.
    - Guide students in analyzing the results, emphasizing physics concepts such as conservation of energy and the Bernoulli principle.
    - Discuss the implications of the measured wind speed differences, relating them to wake losses and reduced energy production in real wind farms.
    - Some possible engaging questions to discuss:
        1) Did the wind speed decrease or increase behind the turbines compared to before (considering multiple iterations are performed)?
        2) How does the difference in wind speed relate to wake losses?
        3) How might the measured wind speed differences impact the energy production of a real wind farm?
7. **Discussion on Wake Losses:**
    - Engage students in a discussion about the physics principles underlying wake losses and their impact on wind farm efficiency.
    - Encourage students to propose physics-based strategies for minimizing wake losses, such as optimizing turbine spacing and orientation based on fluid dynamics principles.
    - Discuss the role of advanced computational modeling and experimentation in wind farm design and optimization.
8. **Extensions and Further Exploration:**
    - Challenge students to investigate additional factors influencing wake losses, such as wind direction, turbulence, and blade designs using physics principles like fluid dynamics.
    - Have students research and present case studies of real-world wind farms, analyzing wake effects and the engineering solutions employed to mitigate them.
    - Discuss the environmental and economic impacts of wind farm efficiency, considering concepts like renewable energy integration, power generation, and sustainability.

Remember to provide clear instructions, safety guidelines, and emphasize the scientific rigor of the experiment, encouraging students to apply their understanding of physics principles throughout the process.

Wind Turbine Investigations: Exploring Physics Principles

Wind Turbine Investigation #2

Investigating Conservation of Energy Using Wind Turbine Analysis

Physics Standards:

- P.4(B) describe and analyze motion in one dimension using equations and graphical vector addition with the concepts of distance, displacement, speed, average velocity, instantaneous velocity, frames of reference, and acceleration
- P.6(A) investigate and calculate quantities using the work‑energy theorem in various situations
- P.6(B) investigate examples of kinetic and potential energy and their transformations
- P.6(D) demonstrate and apply the laws of conservation of energy and conservation of momentum in one dimension

Objective:

Students will learn about the conversion of wind energy into kinetic energy by exploring the relationship between wind speed and the kinetic energy of the moving air. They will investigate how the design of the wind turbine's rotor affects the capture and conversion of kinetic energy.

Materials:

1. Anemometer (wind speed measuring device)
2. Model wind farm setup (constructed with miniature wind turbines, play windmills, etc.)
3. Measuring tape or ruler
4. Stopwatch or timer
5. Tachometer

Procedure:

1. **Introduction:**
   - Provide the students with a detailed explanation of wind turbine farms, while emphasizing the physics principles involved in harnessing wind energy.
   - Introduce the concepts of translational kinetic energy and rotational kinetic energy which are seen in the wind and rotor blades of a wind turbine.
   - Discuss the importance of understanding and optimizing energy conversion for wind farm efficiency.
2. **Model Wind Farm Setup:**
   - Place the wind turbine at a fixed distance from the box fan.
   - Measure the distance from the base of the turbine to the highest blade.
3. **Wind speed and kinetic energy measurements:**
   - Vary the fan speed to produce different wind speeds. For each wind speed, use the anemometer to measure and record the wind speed.
   - Use the tachometer to measure the rotational speed of the wind turbine's blades. Record the corresponding rotational speed for each wind speed.

4. **Calculation of translational kinetic energy:**
   - Calculate the kinetic energy of the moving air using the measured wind speed values. The kinetic energy (KE) can be calculated using the formula:

$$K = \frac{1}{2} m_{air} v_{wind}^2$$

     Since the mass of air is difficult to measure directly, it can be assumed to be constant throughout the experiment. To estimate the mass of the air, you can multiply the density of air by the volume of air between the fan and the swept area of the wind turbine at a given moment. This approach assumes that the air can be approximated as a uniform fluid with a constant density.
5. **Calculation of Rotational kinetic energy:**
   - Students calculate the rotational kinetic energy of the wind turbine using the measured rotational speed data and the moment of inertia of the turbine blades. They can use the formula:

$$K_{rot} = \frac{1}{2} I_{blades} \omega_{turbine}^2$$

     Since students are not familiar with finding moments of inertia for complex or irregularly shaped objects, treating the wind turbine blades as rods is a reasonable simplification. While the blades of a wind turbine are not exactly rod-shaped, this approximation can provide a reasonable estimation of the moment of inertia for educational purposes. It allows students to understand the concept of moment of inertia and its role in rotational motion without getting bogged down in complex calculations.
6. **Graphing the data:**
   - Create a graph with wind speed on the x-axis and kinetic energy on the y-axis.
   - Plot the data points representing the measured wind speed and corresponding calculated kinetic energy values.
7. **Inferences from the graph:**
   - Analyze the graph and draw inferences. Some possible inferences:
     1. As wind speed increases, the kinetic energy of the moving air increases. This demonstrates the relationship between wind speed and kinetic energy.
     2. The graph may show a quadratic relationship, indicating that kinetic energy is proportional to the square of the wind speed.
     3. Students can compare the kinetic energy values for different wind speeds to observe the impact of wind speed on the energy available for conversion in the wind turbine.
8. **Comparison and analysis:**
   - Students compare the calculated wind kinetic energy with the calculated rotational kinetic energy. They can plot these energies on a graph or simply compare the values. Some points for analysis include:
     1. Difference in magnitude: Students can observe that the wind kinetic energy is typically higher than the rotational kinetic energy of the turbine. This difference

is due to various factors, including the inefficiencies of the turbine system, losses in the conversion process, and the limited capture area of the turbine blades.

2. Efficiency considerations: Students can discuss the reasons for the energy losses in the conversion process, such as frictional losses in the turbine's mechanical components, aerodynamic losses, and electrical losses in the generator and transmission.
3. Design improvements: Students can brainstorm and discuss possible design improvements that could enhance the efficiency of the wind turbine system. For example, they can explore blade design modifications, optimizing the turbine's components, or incorporating more advanced technologies to improve energy capture and conversion.

Remember to provide clear instructions, safety guidelines, and emphasize the scientific rigor of the experiment, encouraging students to apply their understanding of physics principles throughout the process.

Wind Turbine Investigations: Exploring Physics Principles

Wind Turbine Investigation #3

Investigating Rotational Motion Concepts Using Wind Turbine Analysis

Physics Standards:

- P.4(A) generate and interpret graphs and charts describing different types of motion, including investigations using real-time technology such as motion detectors or photogates
- P.4(B) describe and analyze motion in one dimension using equations and graphical vector addition with the concepts of distance, displacement, speed, average velocity, instantaneous velocity, frames of reference, and acceleration
- P.4(D) calculate the effect of forces on objects, including the law of inertia, the relationship between force and acceleration, and the nature of force pairs between objects using methods, including free-body force diagrams
- P.4(C) analyze and describe accelerated motion in two dimensions, including using equations, graphical vector addition, and projectile and circular examples
- P.5(D) identify and describe examples of electric and magnetic forces and fields in everyday life such as generators, motors, and transformers
- P.7(A) examine and describe oscillatory motion and wave propagation in various types of media

Objective:

Students will delve into the principles of rotational motion by examining the dynamics of wind turbine blades. They will explore topics such as angular velocity, angular acceleration, and torque. By studying the rotational motion of the blades, they will understand how the wind's force translates into rotational energy.

Materials:

1. Anemometer (wind speed measuring device)
2. Model wind farm setup (constructed with miniature wind turbines, play windmills, etc.)
3. Measuring tape or ruler
4. Stopwatch or timer
5. Tachometer

Procedure:

1. **Introduction:**
    - Provide the students with a detailed explanation of wind turbine farms, while emphasizing the physics principles involved in harnessing wind energy.
    - Introduce the concepts of angular speed, average angular acceleration, and torque as related to wind turbines.
    - Discuss the importance of minimizing load forces while maximizing rotation speed for optimal power production.
2. **Model Wind Farm Setup:**
    - Place the wind turbine at a fixed distance from the box fan.
    - Measure the distance from the base of the turbine to the highest blade.

3. **Measurement of Angular Velocity and Angular Acceleration:**
    - Students can measure the angular velocity of the wind turbine blades using a tachometer. They can position the tachometer close to the rotating hub or axis of the turbine blades and measure the rotational speed in revolutions per minute (RPM).
    - By recording the time it takes for the blades to complete one revolution, students can calculate the angular velocity (ω) in radians per second. Angular velocity (ω) can be calculated using the formula:

$$\omega = \frac{2\pi}{T}$$

    - Students can also calculate the average angular acceleration (α) of the turbine blades by measuring the change in angular velocity over a given time interval. Angular acceleration (α) can be calculated using the formula:

$$\alpha = \frac{\Delta\omega}{\Delta t}$$

4. **Measurement of Torque and Force:**
    - Students can explore the torque exerted on the turbine blades by the wind. They can measure the length of the blades from the axis of rotation using a meter stick, providing the length (r) in meters.
    - Since torque (τ) is the product of force (F) and the perpendicular distance (r) from the axis of rotation, students can approximate torque as τ = F * r. They can assume that the force exerted by the wind acts perpendicular to the blades.
5. **Simplifying Assumptions:**
    - Students can assume that the wind flow is constant and that the turbine blades are experiencing uniform wind speed across their entire length.
    - Students can also assume that the wind force acts perpendicularly to the blades, neglecting any variations caused by turbulence or non-uniform airflow.
6. **Graphing and Analysis:**
    - Students will create graphs to analyze the relationship between various parameters.
        1. Angular velocity vs. time
            a. This graph can provide insights into how the wind speed affects the rotational motion of the turbine blades.
            b. They can observe how the angular velocity increases as the wind speed increases.
        2. Torque vs. wind speed
            a. This graph can help students understand how the wind force translates into torque on the turbine blades.
            b. They can investigate the relationship between wind speed and the torque generated by the wind.
    - From the graphs, students can draw inferences such as:
        1. The slope of the angular velocity vs. time graph represents the angular acceleration of the blades. Students can determine how different wind speeds affect the acceleration of the blades.

2. The slope of the torque vs. wind speed graph provides insights into how changes in wind speed influence the torque exerted on the blades. They can observe whether the relationship is linear or nonlinear.

Remember to provide clear instructions, safety guidelines, and emphasize the scientific rigor of the experiment, encouraging students to apply their understanding of physics principles throughout the process.

Middle School Learning Modules

Investigating Wind Speed Changes Around a Wind Turbine

Note: Lesson Made for a Middle School Elective with no TEKS, however the lesson aligns with these highschool standards

Principles of Applied Engineering TEKS:

- §127.743
    - (2) The student investigates the components of engineering and technology systems. The student is expected to:
        - (D) describe how technological systems interact to achieve common goals;
        - (F) conduct and present research on emerging and innovative technology; and
        - (G) demonstrate proficiency in the engineering design process.
    - (3) The student presents conclusions, research findings, and designs using a variety of media throughout the course. The student is expected to:
        - (A) use clear and concise written, verbal, and visual communication techniques;
        - (B) maintain a design and computation engineering notebook;
        - (D) use industry standard visualization techniques and media; and
        - (E) use the engineering documentation process to maintain a paper or digital portfolio

Objective:
Students will measure wind speeds before and after a wind turbine to observe and calculate the difference, gaining an understanding of the impact of the turbine on the wind flow.

Materials:
An anemometer (wind speed measuring device)
Wind turbine
Measuring tape or ruler
Stopwatch or timer
Data recording sheets (or notebooks)

Procedure:

1. **Introduction:**
    - Introduce the concept of wind turbines and their role in generating electricity from wind energy.
    - Explain that wind turbines can affect wind flow due to the creation of wakes behind the turbine.

2. **Experiment Setup:**
    - Set up the wind turbine in an open area where the wind can flow freely. If needed, utilize a wind source, like a fan, to create wind flow onto the turbine.
    - Place the anemometer at a set distance in front of the turbine (e.g., 18 inches) and measure and record the initial wind speed.
      Note: Ensure that the anemometer is facing directly into the wind.

3. **Wind Speed Measurement:**
   - Allow the wind turbine to rotate freely until it reaches a steady state.
   - Use the anemometer to measure and record the wind speed at the same distance behind the turbine as before.
   - Take multiple measurements at different time intervals (e.g., every 30 seconds) and calculate the average wind speed.
4. **Data Analysis:**
   - Calculate the difference between the wind speed measured before and after the turbine.
   - Guide students in discussing and interpreting the results.
   - Ask questions such as:
     1. Did the wind speed decrease or increase behind the turbine compared to before?
     2. Why do you think there is a difference in wind speed?
     3. How might the wind turbine affect the energy output or performance of the wind farm?
5. **Conclusion and Application:**
   - Engage students in a discussion about the impact of the wind turbine on wind flow and the concept of wake losses.
   - Ask students to consider how the measured wind speed difference could affect the performance of other turbines in a wind farm.
   - Discuss the importance of optimizing wind turbine placement and design to minimize wake losses and maximize energy production.
     Note: You can modify the experiment by using different-sized wind turbines or varying the distances between the anemometer and the turbine.
6. **Extensions and Further Exploration:**
   - Encourage students to research and discuss different strategies employed in wind farms to mitigate wake losses and improve energy output.
   - Note: Implement additional wind turbines and allow students to arrange a layout to optimize energy output and minimize wake losses.
   - Have students design and conduct additional experiments to investigate factors that affect wake losses, such as varying wind speeds, turbine spacing, or blade angles.
   - Ask students to explore real-world examples of wind farms and their impact on energy production in different geographical locations.

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