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

Mr. Daniel Garza, Mr. Cory Scarborough,
Dr. Mohammad Hossain, Dr. Marsha Sowell, Mr. Lovekesh Singh, and
Mr. Richard Martinez

July 21, 2023

Research Questions

- 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?

Methodology

- Conduct preliminary research on requirements to measure output from a solar panel.
- Determine necessary properties of solar panels in order to conduct analysis.
- Download data from NREL SOLPOS Calculator.
- Use MS Excel to perform mathematical routines including solving for output; identifying maximum time and tilt angle that maximize output; and graph relevant features.
- Use MS Excel to identify the occurrence of maximum zenith angle, tilt angle, and output for non-textured surface.
- Use MATLAB to model multiple reflections within a textured tilted surface and compare output to similarly tilted non-textured surface.
- Analyze solar energy on horizontal and tilted inorganic (e.g., roof applications) and vertical organic (e.g., window applications) solar panels.

Methodology

- Conduct preliminary research on requirements to measure output from a solar panel[2].

Globally a formula **E = A x r x H x PR** is followed to estimate the electricity generated in output of a photovoltaic system.

  - 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

Methodology

- Determine necessary properties of solar panels in order to conduct analysis
  - REC Group Alpha Series chosen for project based on average efficiency versus competition[3].
  - Panel Series Black model – 370
  - Panel Efficiency[4] – 21.2%
  - Area in inches[4] – 72 x 40

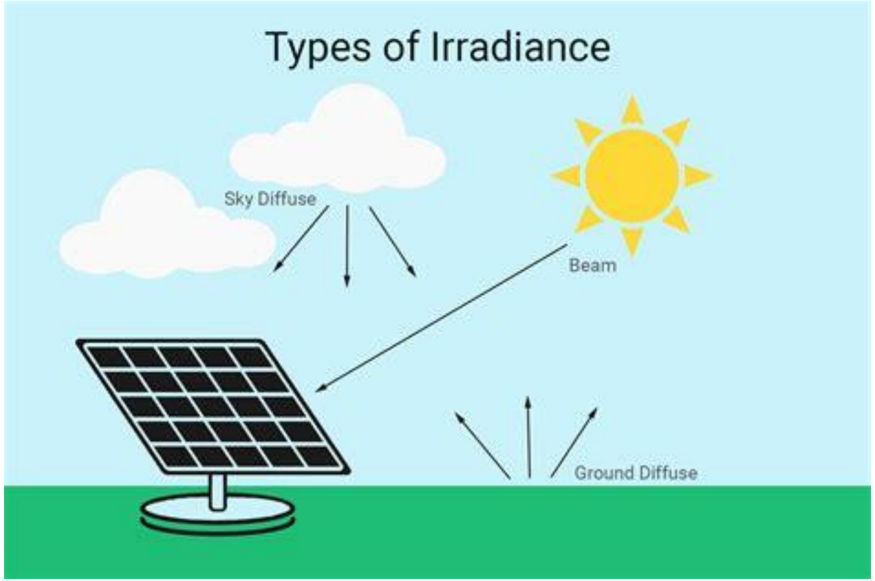
Power Output - P_{MAX} (Wp)	360	365	370	375	380
Watt Class Sorting - (W)	-0/+5	-0/+5	-0/+5	-0/+5	-0/+5
Nominal Power Voltage - V_{MPP} (V)	36.7	37.1	37.4	37.8	38.1
Nominal Power Current - I_{MPP} (A)	9.82	9.85	9.90	9.94	9.98
Open Circuit Voltage - V_{OC} (V)	43.9	44.0	44.1	44.2	44.3
Short Circuit Current - I_{SC} (A)	10.49	10.52	10.55	10.58	10.61
Power Density (W/sq ft)	19.1	19.4	19.7	19.9	20.2
Panel Efficiency (%)	20.6	20.9	21.2	21.4	21.7

MANUFACTURER	MODEL	MAX EFFICIENCY RATING
SunPower	A-series	22.8%
SunPower	X-series	22.7%
Panasonic	EverVolt® Photovoltaic series	22.2%
SunPower	M-series	22%
REC	Alpha series	21.9%
Silfab	Elite series	21.4%
SEG	SIV AC Module Series	21.25%
Silfab	X series	21.1%
Solar World	Sunmodule series	21.1%
S-Energy	SL40-60MCI-370	21.04%

Average = 21.92%

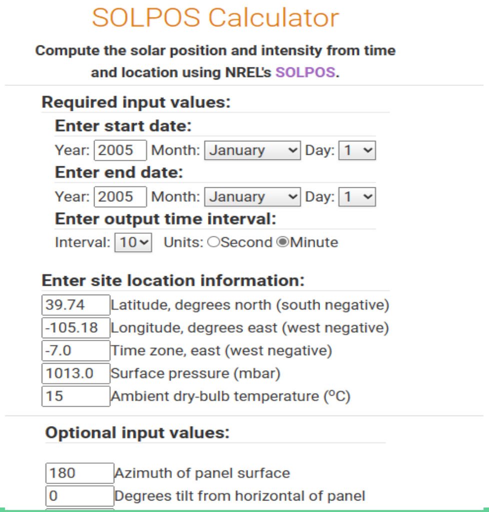
What is Solar Irradiance?

- Three types of solar irradiance:
  - Extraterrestrial Direct Solar Irradiance – The amount of solar energy coming through relative to the horizontal
  - Extraterrestrial Direct Normal Irradiance – The amount of solar energy coming from the vertical
  - Extraterrestrial Tilted Irradiance – The amount of solar energy on a predetermined tilted surface
- For the purpose of the Project the 'Extraterrestrial Tilted Irradiance' was chosen.



Methodology

- Site: TAMUK Dotterweich Building
- Determine necessary inputs for SOLPOS Calculator and download



	A	B	C	D	E
1	Solpos	Start Date	End Date	Time Interval	Temperature
2	Inputs	1/1/2022	12/31/2022	30 minutes	29°C
3	(0° tilt)	Lat	Long	Time zone	Surface Pressure
4		27.525	-98.8825	-5	1011.5
5					
6		Panel Efficiency		Area (m^2)	
7		0.216		1.85	
8					
9	Date	Time	Zenith (refracted)	ETR tilt	Energy Output
10	1/1/2022	8:30:00	88.876	225.2886	
11	1/1/2022	9:00:00	83.2679	379.3431	
12	1/1/2022	9:30:00	77.695	529.9498	
13	1/1/2022	10:00:00	72.3712	67.775	
14	1/1/2022	10:30:00	67.3869	798.8958	
15	1/1/2022	11:00:00	62.8327	911.988	
16	1/1/2022	11:30:00	58.8124	18.626	
17	1/1/2022	12:00:00	55.4456	185.4666	
18	1/1/2022	12:30:00	52.859	1142.8556	
19	1/1/2022	13:00:00	51.172	1179.2478	
20	1/1/2022	13:30:00	50.4756	1194.143	
21	1/1/2022	14:00:00	50.8109	1186.914	
22	1/1/2022	14:30:00	52.1579	1158.32	

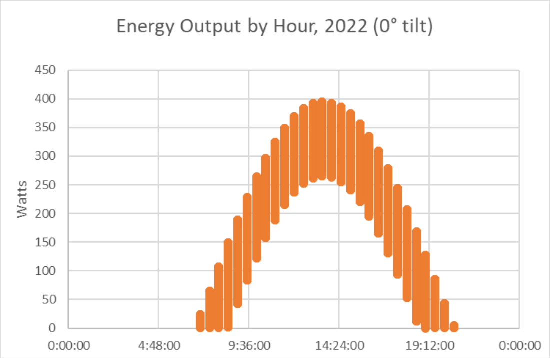
Methodology

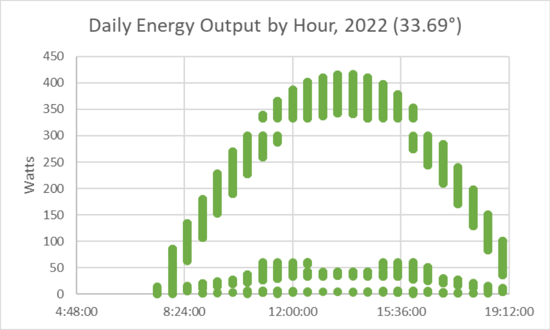
- Use MS Excel to perform mathematical routines including solving for output; identifying maximum time and tilt angle that for gives maximum output; and graph relevant features.

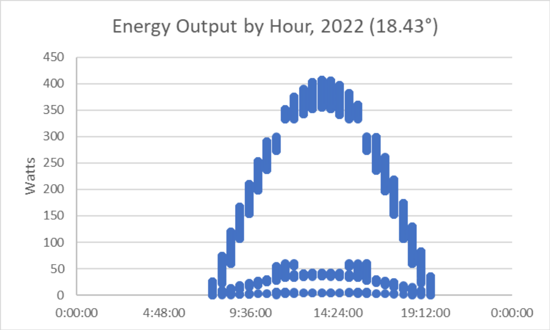
Date	Time	**Energy Output**	Month	Day	Month	Count	Days	Month	Total Monthly Output	Average Monthly Output	Total Hours	Output/Hr
1/1/2022	8:30:00	6751.899342	January	01	January	938	31	January	11501378.19	371012.1996	744	498.6723
1/1/2022	9:00:00	11368.91271	January	01	February	619	28	February	12396727.93	442740.2833	672	658.8397
1/1/2022	9:30:00	15882.59551	January	01	March	744	31	March	14713032.54	474613.9529	744	637.922
1/1/2022	10:00:00	2031.21675	January	01	April	747	30	April	14568911.44	485630.3814	720	674.4866
1/1/2022	10:30:00	23942.90713	January	01	May	775	31	May	14253816.45	459800.5306	744	618.0115
1/1/2022	11:00:00	27332.28036	January	01	June	750	30	June	14436329.87	481210.9957	720	668.3486
1/1/2022	11:30:00	558.22122	January	01	July	775	31	July	13534939.06	436610.9375	744	586.8427
1/1/2022	12:00:00	5558.434002	January	01	August	775	31	August	14285222.57	460813.6313	744	619.3732
1/1/2022	12:30:00	34251.38233	January	01	September	734	30	September	15097931.84	503264.3946	720	698.9783
1/1/2022	13:00:00	35342.05657	January	01	October	707	31	October	13537241.69	436685.2157	744	586.9425
1/1/2022	13:30:00	35788.46571	January	01	November	652	30	November	11505523.32	383517.4442	720	532.6631
1/1/2022	14:00:00	35571.81258	January	01	December	651	31	December	11050359.66	356463.215	744	479.1172

Results: Hourly Peak Analysis for 2022

- Roof analysis, assumed a single 1.85 m^2 solar panel.



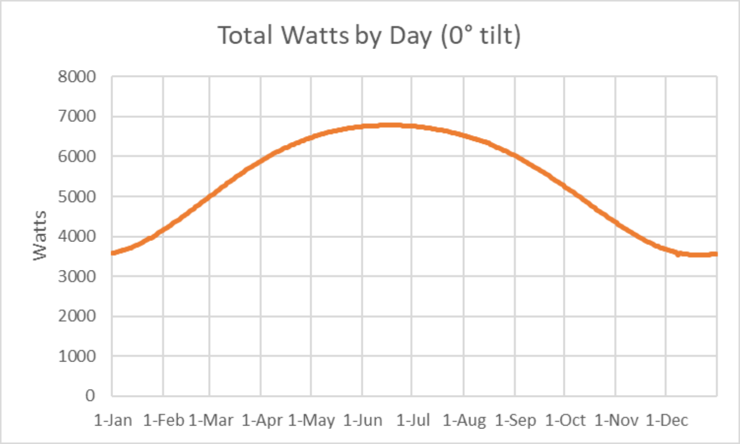


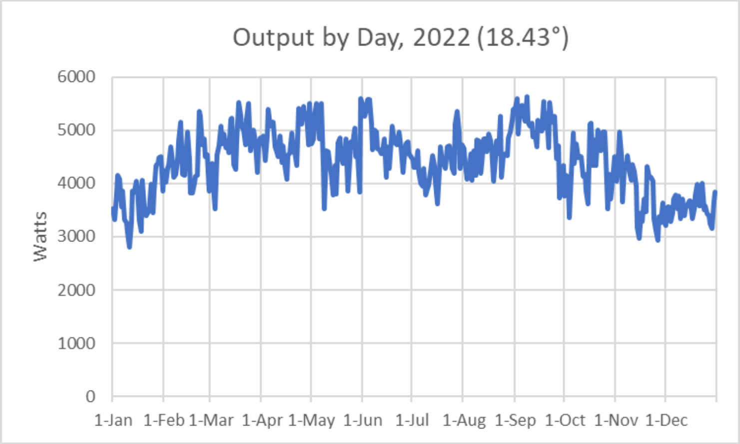


- Maximum output was between 1-2 p.m. regardless of tilt.

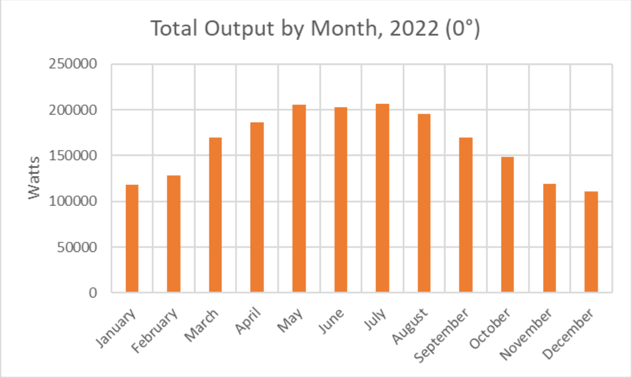
Results: Daily Output Throughout 2022

- With no tilt, average output peaked June-July
- With tilt, average output peaked February-September

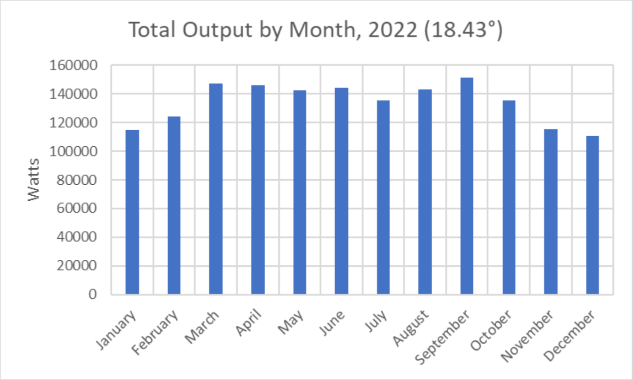


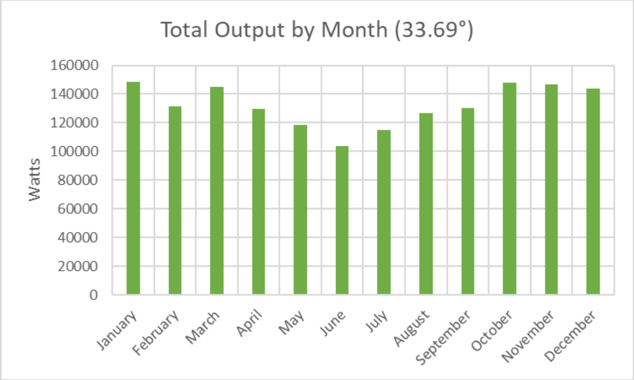


Results: Total Output by Month for 2022



- Average monthly output
  - 0° - 1,964,171.52 W
  - 18.43° - 1,608,814.15 W
  - 33.69° - 1,588,115.0 W

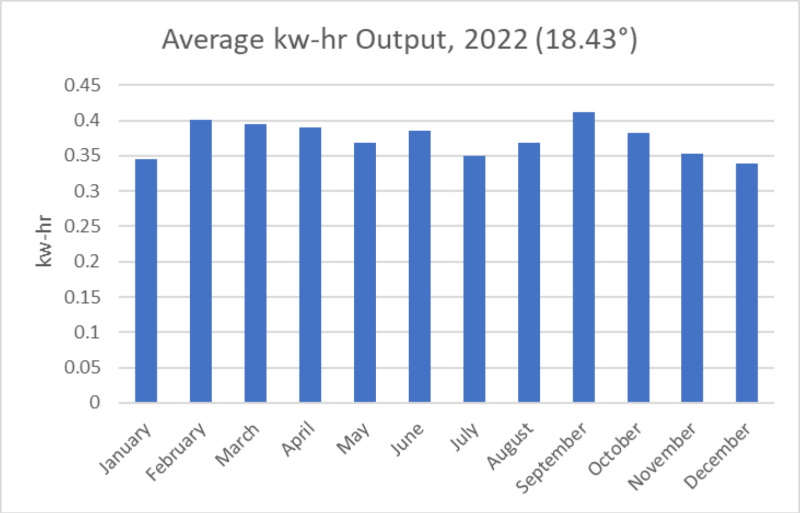


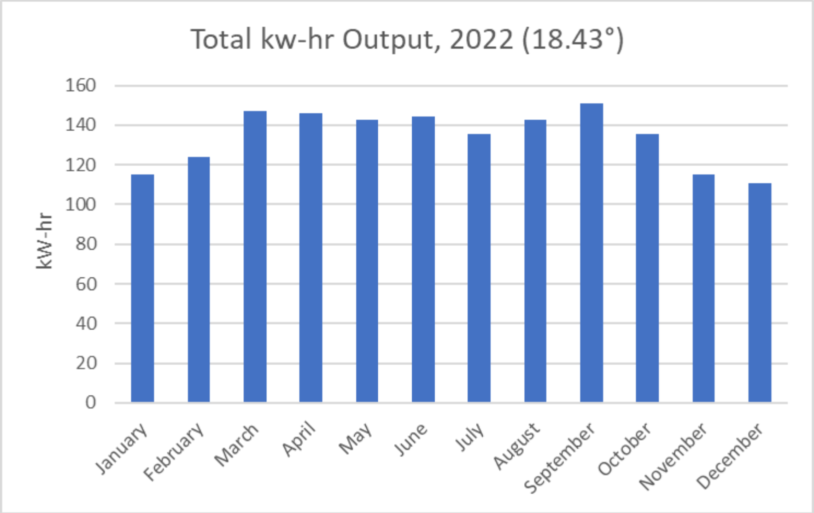


Practical Application

- Kilowatt*Hour (kW-hr) is the standard unit for power consumption.
- Common appliances’ kW-hr usage includes:
    - 1. Ceiling fans – 12 kW-hr
    - 2. Television – 27 kW-hr
    - 3. Lighting (4-5 rooms) – 50 kW-hr
    - 4. Range with Oven – 58 kW-hr
    - 5. Water heater (4 person) – 310 kW-hr

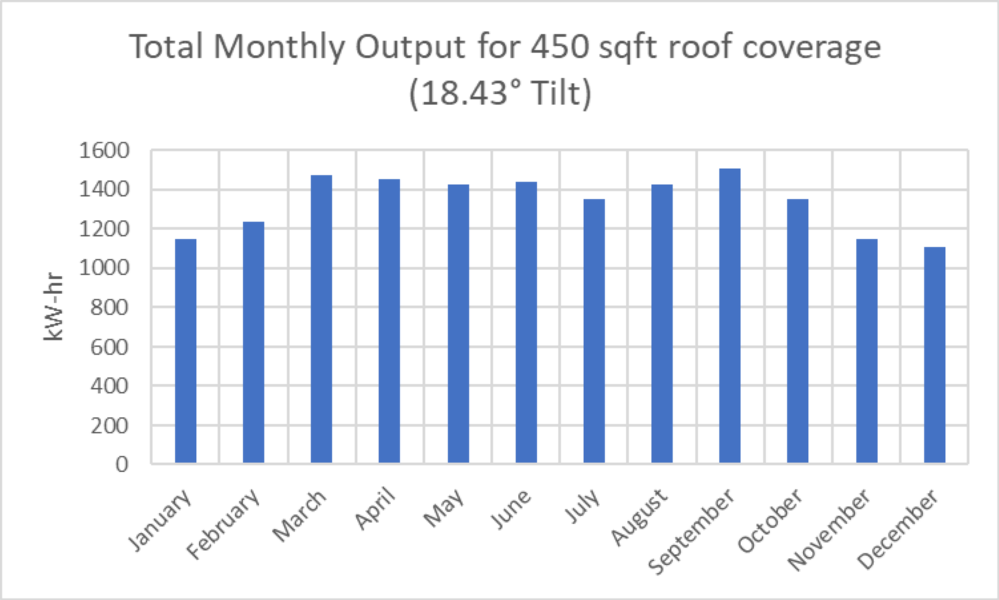
Analysis (Output in kW-hr, per one solar panel, 2022)





Each solar panel produces an average of 0.374 kW-hrs and a total of 134 kW-hrs on average per month.

Analysis (total kW-hrs/day for 450 sq ft roof coverage)



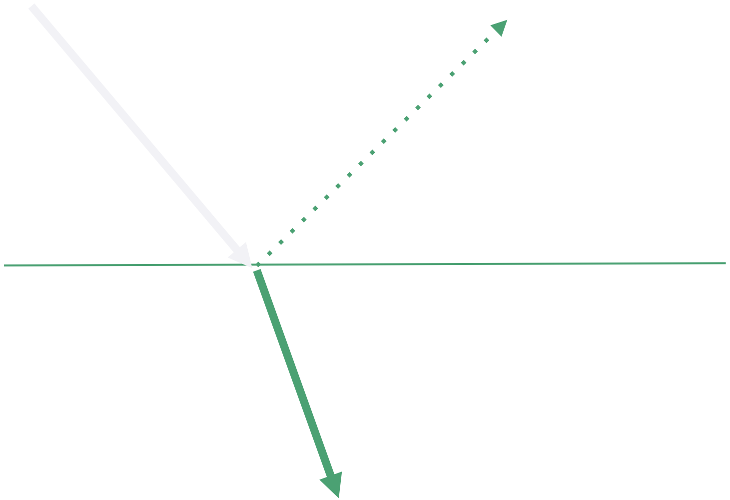
- Assuming a roof has a total southward facing square footage of 450 sq ft (41.8m^{2}), a total of 10 REC Alpha 370 Solar Panels could fit. The total kW-hrs per month averages 1,340.68 kW-hrs.

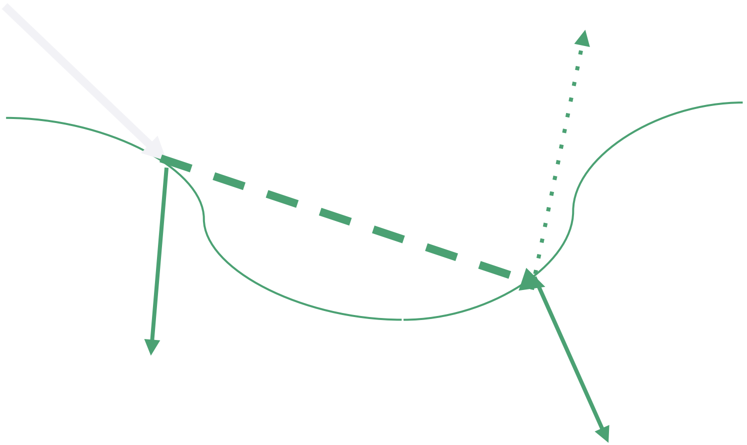
Summary: Roof Applications

- Regardless of tilt, the highest daily output by hour occurred between 1-2 p.m. throughout the year.
- With no tilt, the months showed largest monthly output were June-July. The average monthly output was 5.37 kW-hr
- With a tilt of 18.43 degrees, monthly output between February-September was relatively steady. The average monthly output was 4.492 kW-hr.
- With a tilt of 33.69 degrees the output was highest during October-December.The average monthly output was 4.563 kW-hr.

Texture and Multiple Reflections

- Multiple reflections can increase the absorption of solar panels thereby improving effectiveness.



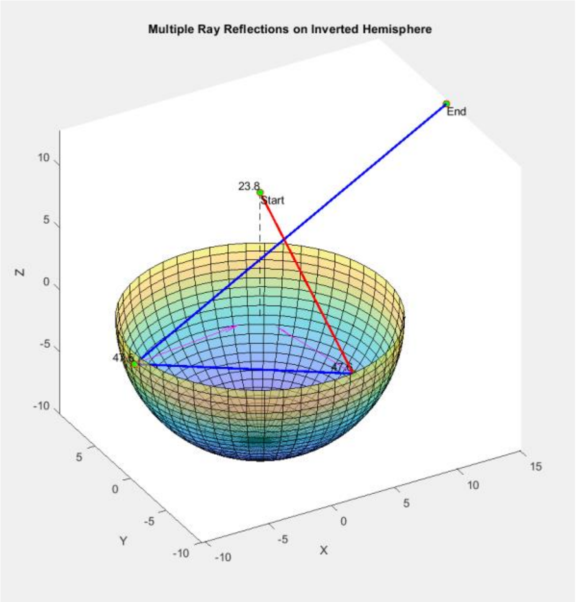


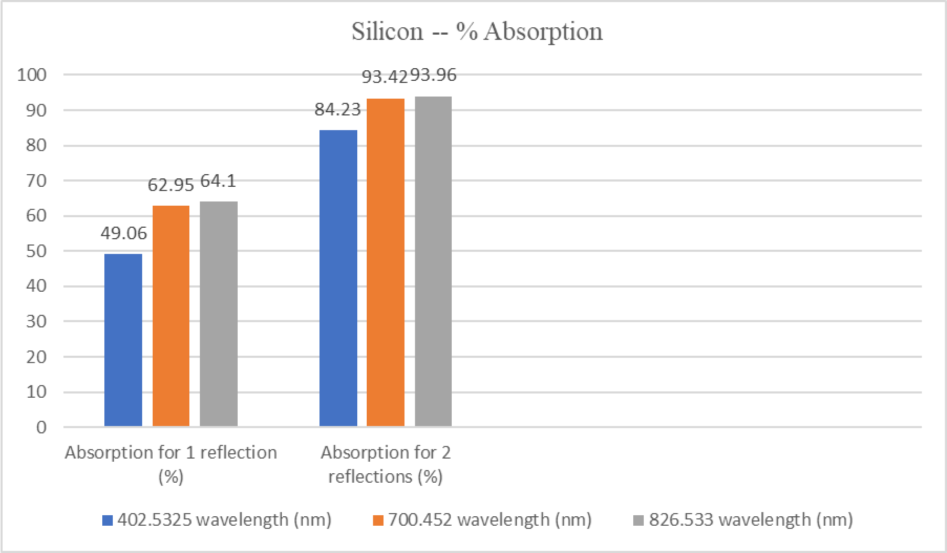
Identification of Optimal Incident Ray for Multiple Reflections

- Minimum legal roof pitch for shingle roofs in Texas is 18.43°. Average solar panel installation is between 30-35°. An average legal roof angle of 33.69° was used.
- MS Excel was used to identify occurrence of maximum solar output and corresponding zenith angle.
- The zenith angle yielding maximum solar output (407W) occurred on March 31st, 2022 at 1:30. The zenith angle was 23.8 degrees.

Methodology

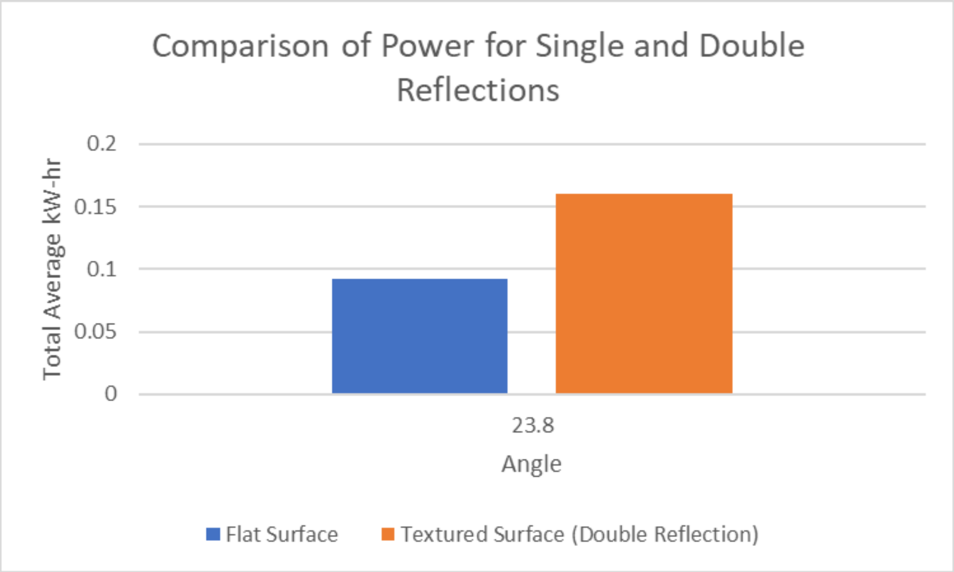
- Use MATLAB to model multiple reflection within a textured tilted surface and compare output to similarly tilted non-textured surface.





Analysis

- By instilling a textured surface, two reflections were obtained for various angles. The presence of a texture increased the energy production an average of 74%.

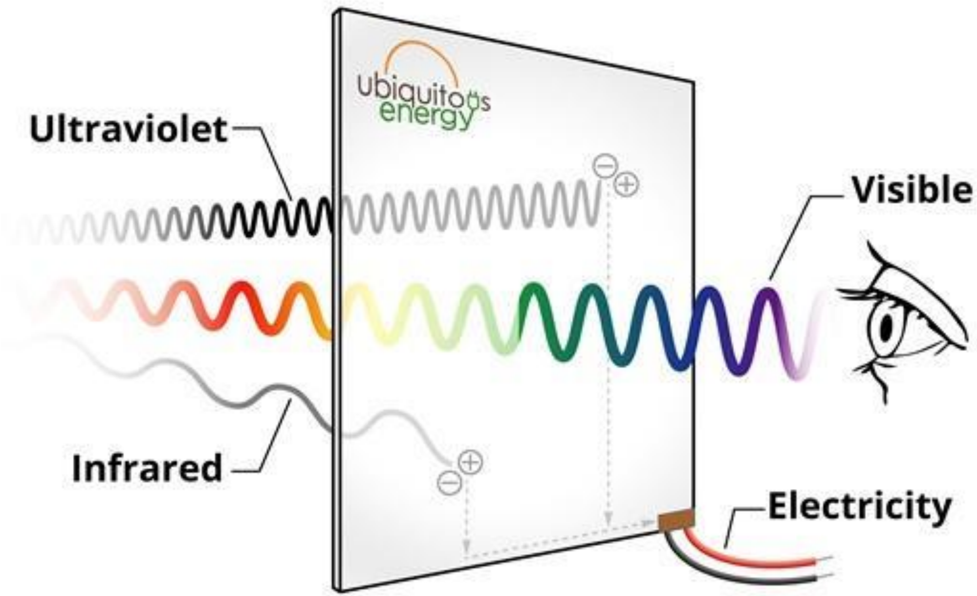


Organic Solar Cells

- Organic solar cells, despite being generally less efficient, offer a number of benefits over inorganic solar cells.
    - 1. cheap and easy manufacturing
    - 2. transparency
    - 3. selective absorption

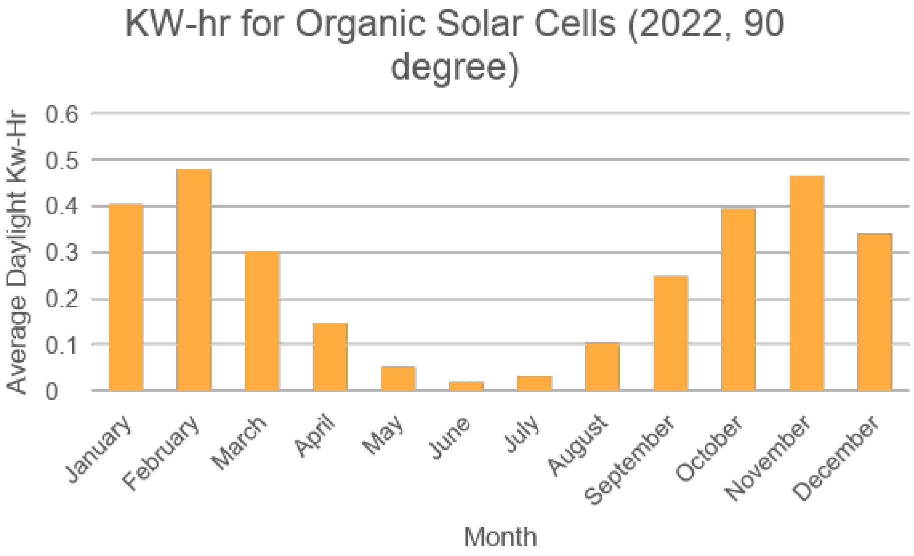
Organic Solar Cells on Windows

- Selective absorbance on windows allows users within a house to look outside without allowing anyone on the inside to look in.



Application of Organic Solar Cells on Windows

- SOLPOS Calculator was reused at 90 degrees.
- According to NOAA 43% of solar radiation is visible light.



The average expected kW-hr output for a vertical organic solar cell is 0.24 kW-hr throughout the year.

Curriculum Modules

Curriculum Module 1 TEKS: Jell-O Mold Project

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;

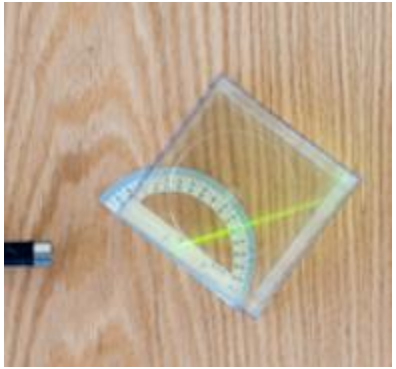
Will be cross-curricular with TEKS such as Algebra 1.(A) apply mathematics to problems arising in everyday life, society, and the workplace;

And 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.

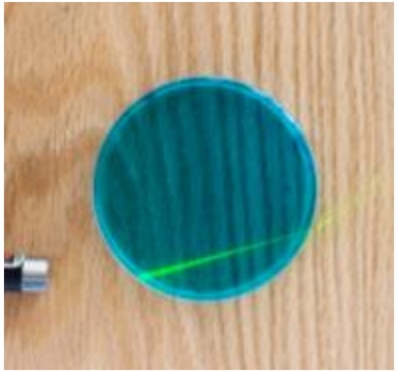
Jell-O Mold Project

Project 1/3

<u>Objective:</u> Students 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 jello.
- Use Lead4Ward Instructional Strategies to engage and inquire students about concepts (7)



Jell-O Mold Project

Project 2/3

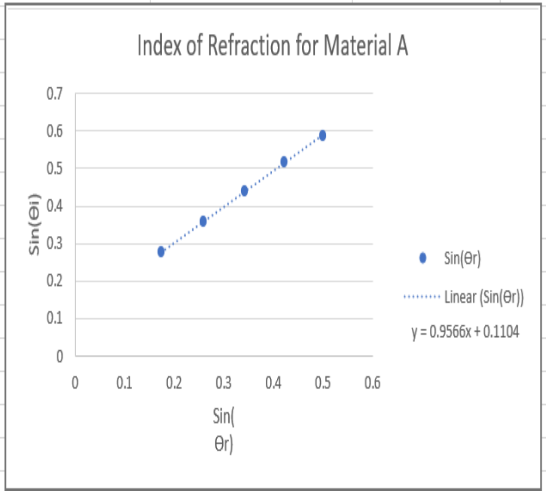
Objective: Students will explore Snell's Law utilizing a Jell-O medium and laser lab/research activity and relate this to innovative research on solar panels.

- Students use excel to calculate trigonometric functions, plot data, and determine the index of refraction of the acrylic prism and jello

=RADIANS(A3)

Angle of Incidence (θi)	Angle of Refraction (θr)	θi (radians)	θr (radians)	Sin(θi)	Sin(θr)
10	16	0.174532925	0.27925268	0.173648178	0.275637356
15	21	0.261799388	0.366519143	0.258819045	0.35836795
20	26	0.34906585	0.453785606	0.342020143	0.438371147
25	31	0.436332313	0.541052068	0.422618262	0.515038075
30	36	0.523598776	0.628318531	0.5	0.587785252

=SIN(C5)

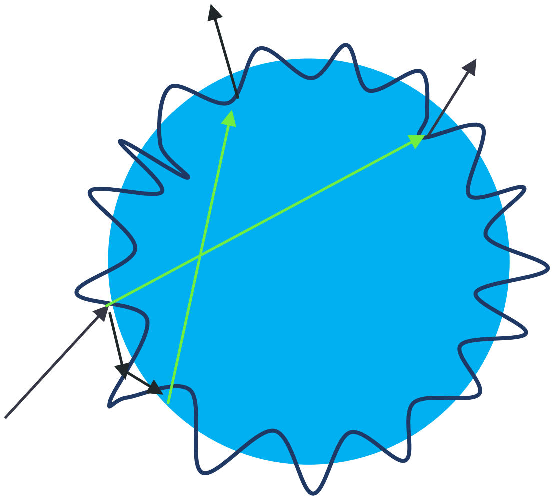


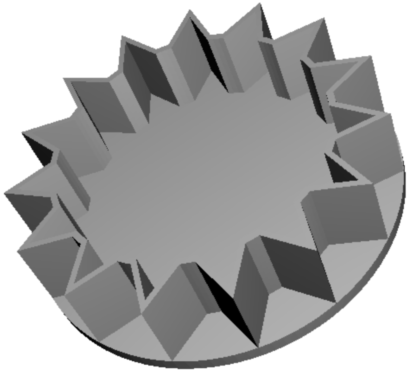
Jell-0 Mold Project

Project 3/3

<u>Objective:</u> Students will explore Snell's Law utilizing a Jell-O medium and laser lab/research activity and relate this to innovative research on solar panels

- Teacher will present a Jell-O block with a texture formed from a prefabricated mold.
- Students will reconduct the refraction lab and make observations about the total refracted rays.
- Discussion on how the texture could improve solar cell efficiency.
- Use different color Jell-O blocks with different color lasers. Discuss why color changes/disappears once certain lights enter gelatin.





Curriculum Module 2 TEKS: Global Solar Comparison Project

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

Global Solar Comparison Project

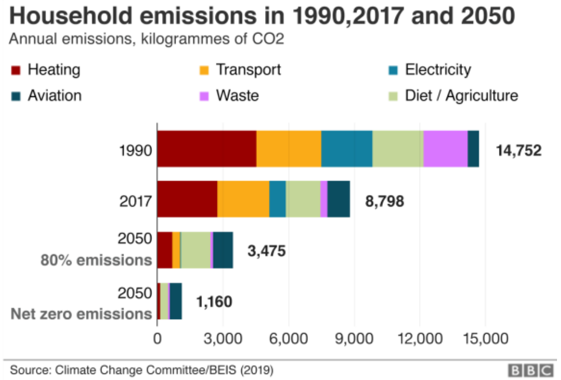
- Objective: Students will utilize online platforms and science resources to conduct data analysis of current and ongoing research; students compare available data on solar energy to determine optimal locations for solar technologies.
- Students research necessary geospatial data needed for NREL SOLPOS 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.

Date	Time	Zenith (ref	Azimuth ar	Cos incide	Cos zenith	Day angle	Equation c	Solar Time - LST		Boolean1	Boolean2	
1/1/2005	0:00:00	98.9658	248.6801	-0.1558	-0.1558	0	-3.5232	-93.1072		Yes	yes	zenith above average
1/1/2005	0:10:00	98.9658	248.6807	-0.1558	-0.1558	0	-3.5263	-93.1104		Yes	yes	azimuth below maximum
1/1/2005	0:20:00	98.9658	248.6814	-0.1558	-0.1558	0	-3.5301	-93.1141		Yes	yes	
1/1/2005	0:30:00	98.9658	248.682	-0.1558	-0.1558	0	-3.5334	-93.1174		Yes	yes	
1/1/2005	0:40:00	98.9658	248.6827	-0.1558	-0.1558	0	-3.5366	-93.1206		Yes	yes	
1/1/2005	0:50:00	98.9658	248.6833	-0.1558	-0.1558	0	-3.5399	-93.1239		Yes	yes	
1/1/2005	1:00:00	98.9658	248.684	-0.1558	-0.1558	0	-3.5431	-93.1271		Yes	yes	

Global Solar Comparison Project

- <u>Objective:</u> Students 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.
- 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.

(8)



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://ubiquitous.energy/

6. https://www.exploratorium.edu/snacks/laser-jello

7. https://lead4ward.com/docs/instructional_strategies/playlist_may_2020_21.pdf

8. https://www.bbc.com/news/science-environment-49499521

Acknowledgements

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 author(s) and do not necessarily reflect the views of the National Science Foundation.

Questions?

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

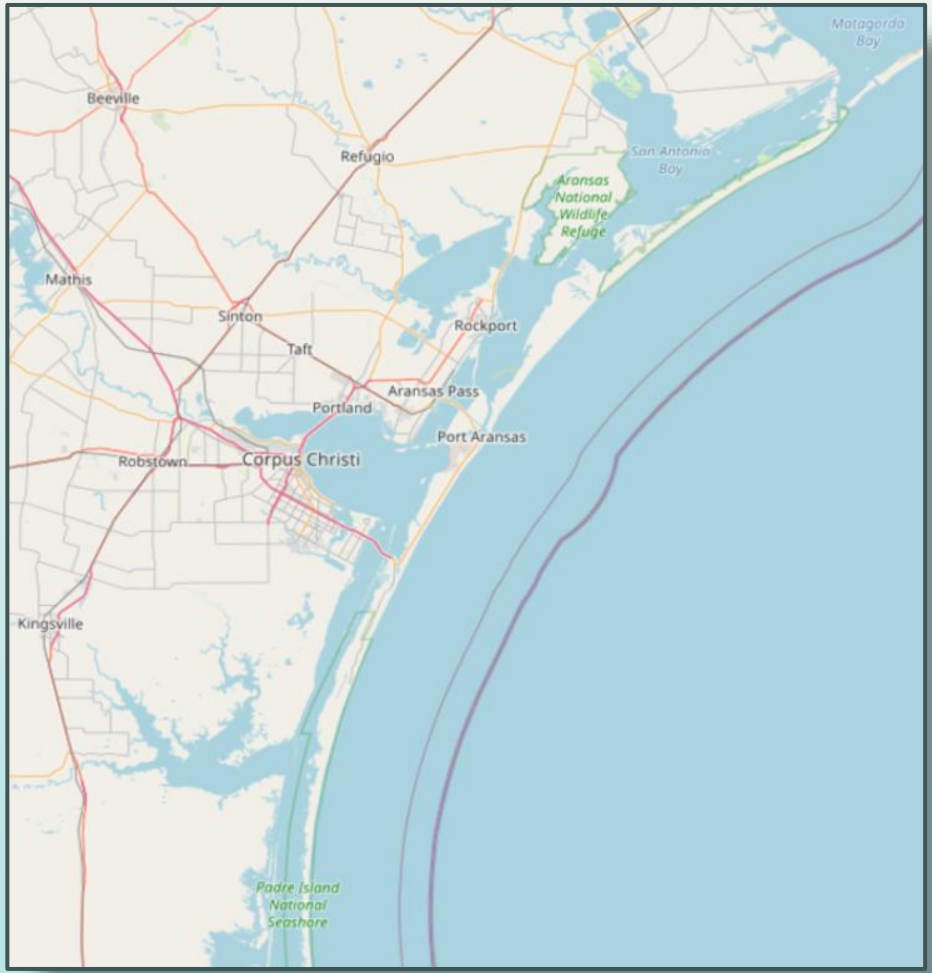
National Science Foundation (NSF) Research Experiences for Teachers (RET) Site at Texas A&M University-Kingsville
Integrating data-driven research in Renewable Energy Across Disciplines (I-READ)

CCISD Teacher Participant: Charife Calpo
Research Faculty Mentor: Dr. Hua Li
Student Mentor: Erick Martinez-Gomez

KISD Teacher Participant: Christina Gonzales
Curriculum Faculty Mentor: Dr. Marsha Sowell
Industrial Advisor: Kevin Rees, P.E

Background Information

- 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.
    - How long hurricanes affect the wind speeds in coastal regions like Corpus Christi, TX.
    - Whether wind farm development has any local long-term effects on wind speed.
- By understanding these connections, we can make 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.



Data Collection

National Solar Radiation Database

- Location (Corpus Christi, Kingsville, Mathis; Texas)
- Data sets available (1998 - 2020)
- Attributes (Wind speed, Wind Direction, etc.)
- Data points (30 minute intervals)

NOAA Historical Hurricane Tracks

- Dates of hurricane development and landfall
- Developing Storm Category
- Wind speed

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 Dolly (H2), 2008
- Hurricane Harvey (H4), 2017
- Hurricane Hanna (H1), 2020

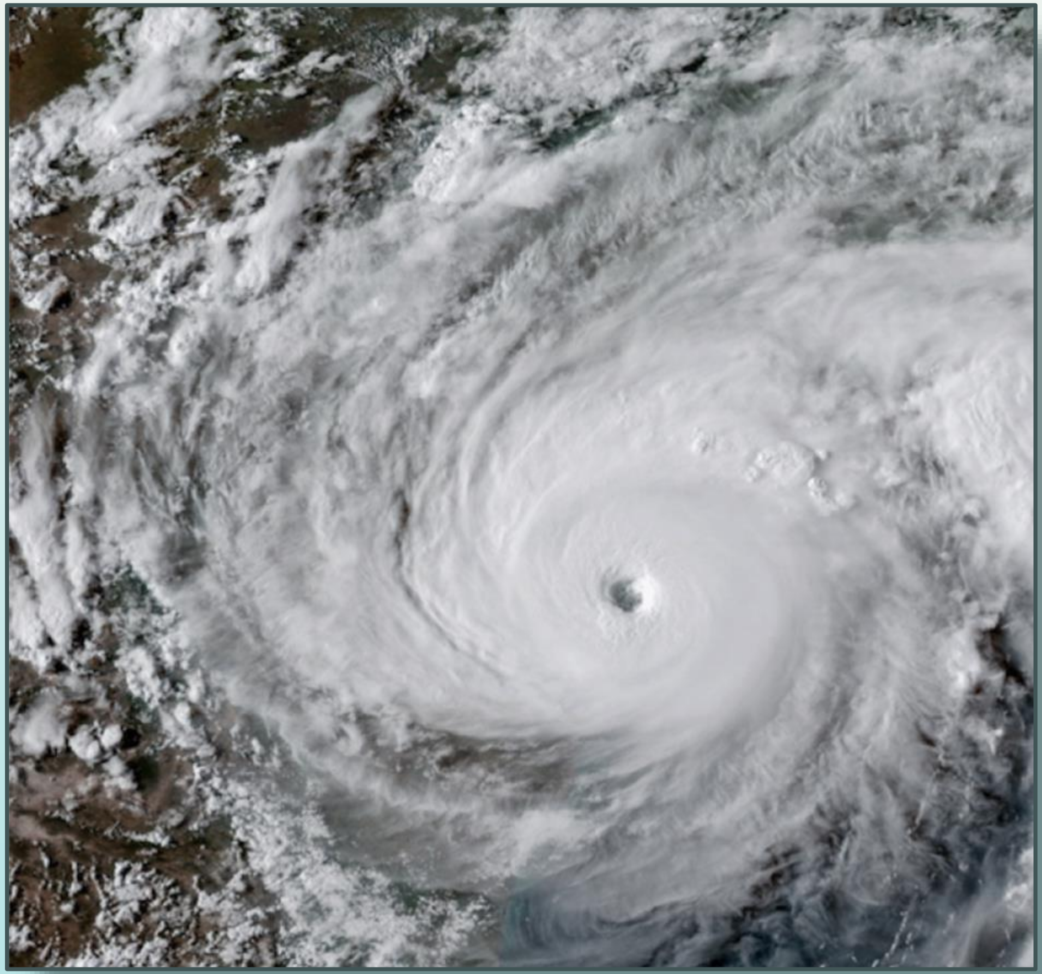
This analysis aimed to determine how the Hurricanes influenced the wind speed in Corpus Christi during a 10-day period of their landfall.

Hurricane Information

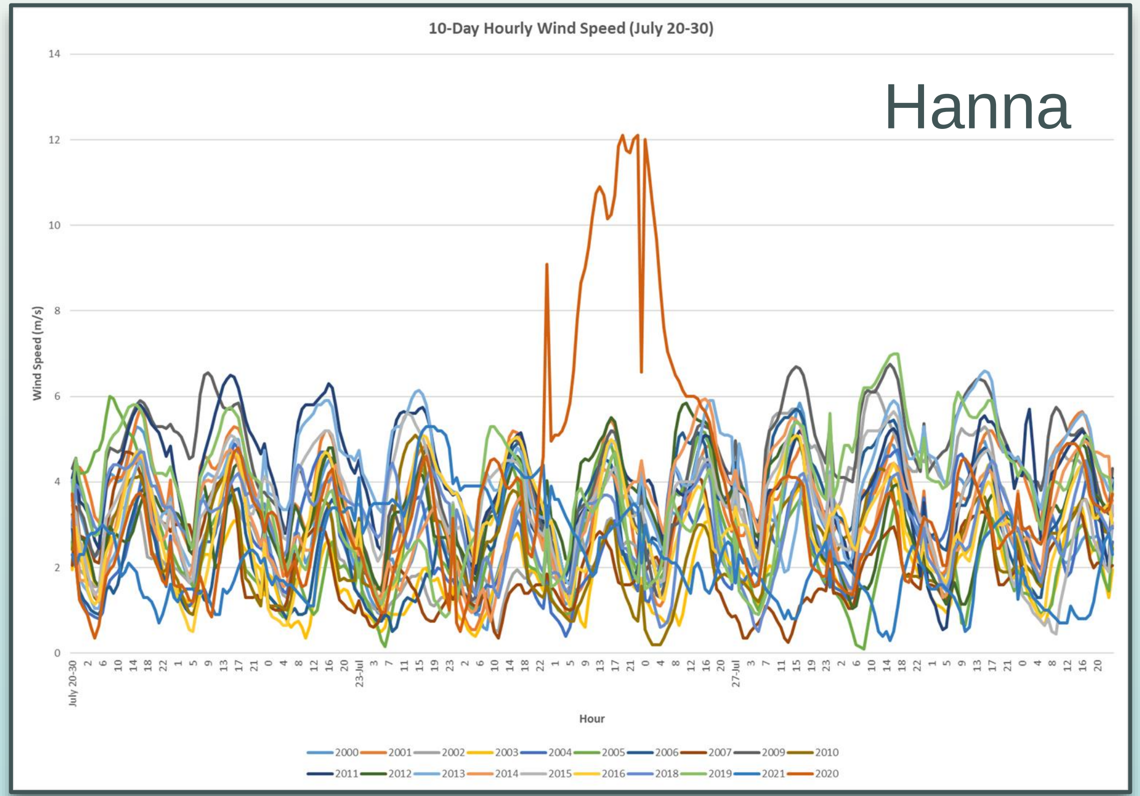
- <u>Hurricane Hanna</u>
  -July 25, 2020,
  -at 41m/s, Category 1 (H1)

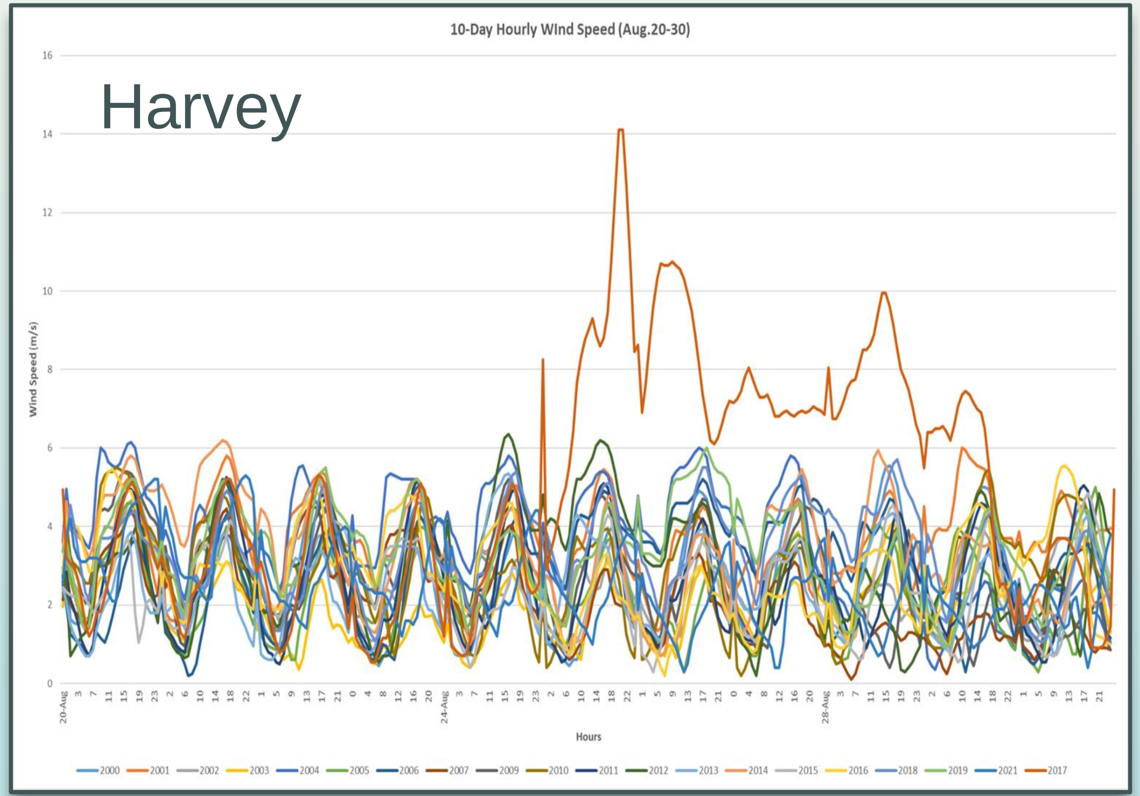
- <u>Hurricane Harvey</u>
  -August 26, 2017,
  -at 59 m/s Category 4 (H4)

- <u>Hurricane Dolly</u>
  -July 24, 2008
  -at 44m/s, Category 2 (H2)



10-Day Hourly Wind Speed Average





- The data sets were taken from National Solar Radiation (NSR) Database at geographic coordinates of 27.76, -97.43.
- The line graphs show that the wind speed is higher on the days the hurricanes were in the area.

Statistical Analysis of the Wind Speed

T-Test Results

- A two-tailed hypothesis test is to show weather the sample mean is significantly greater than and significantly less than the mean numbers.
- If a p-value reported from a t-test is less than 0.05, then that result is said to be statistically significant. If a p-value is greater than 0.05, then the result is insignificant.

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

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

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

Statistical Analysis of the Wind Speed

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

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

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

- There are 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.

Statistical Analysis of the Wind Speed

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

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

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

Interesting Fact:

When the hurricanes made landfall and the P-Values were significantly below 0.05, the wind speed stabilized and exhibited no significant changes on the 4th day after the landfall.

T-TEST for the Wind Speed

The p-value reported from this t-test is less than 0.05, then that result is said to be statistically significant.

T-Test for the Daily Wind Speed for August 2017

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	

The Influence of Wind Farms on Wind Speed in Neighboring Cities

Chapman Ranch Wind Farm's influence on wind speed in Kingsville, TX

- The Chapman Ranch Wind Farm was commissioned in October 2017[5].
- Wind speed was specifically analyzed for changes before and after this date.

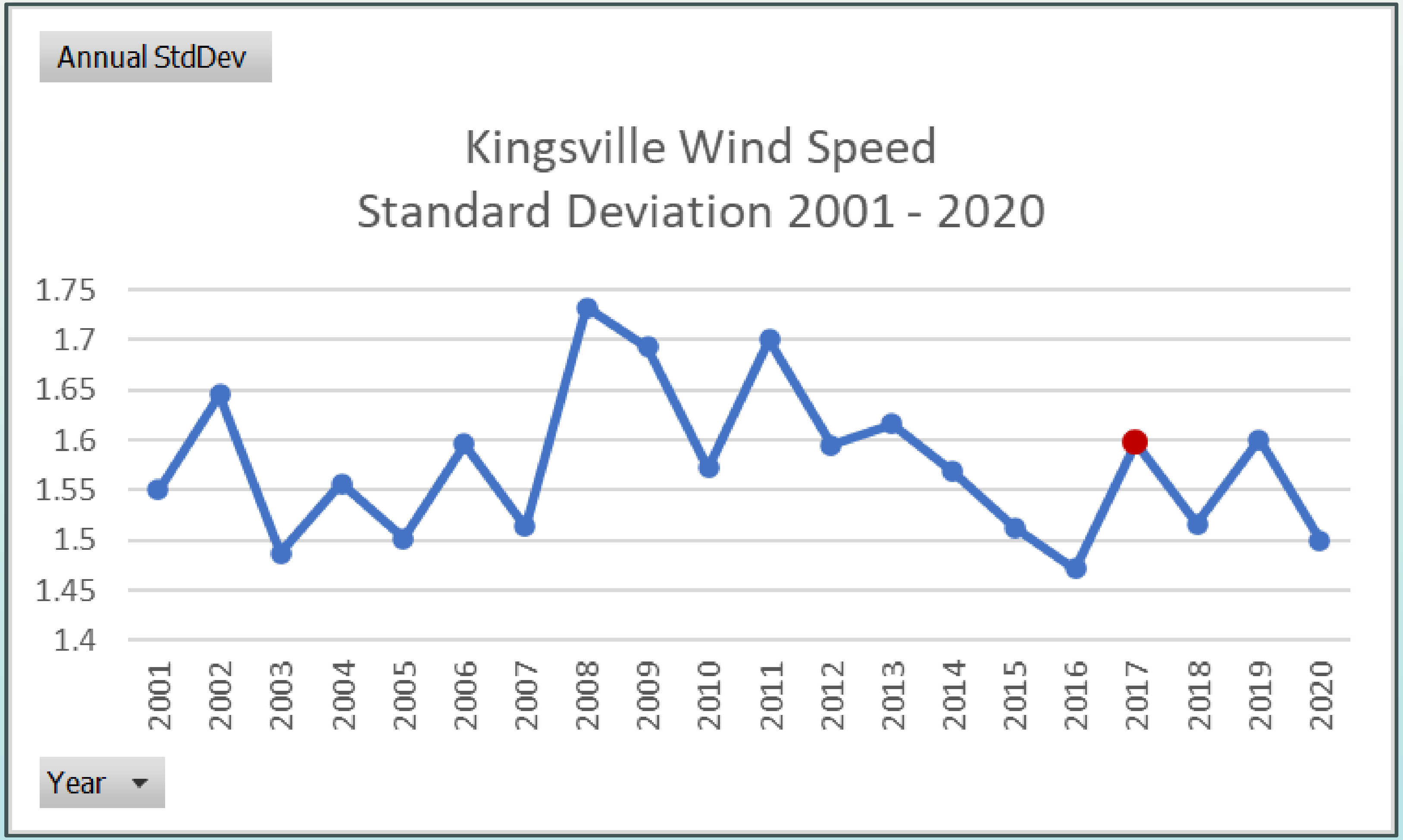
Wind Speed Analysis - Kingsville, TX

Average

- Refined wind speed averages over a 20 year period.
- Focuses in on the average wind speed 3 years before and after 2017.

Standard Deviation

- A measure of the spread of the data is in relation to the mean over a 20 year period.
- The lower standard deviations indicate more consistency.



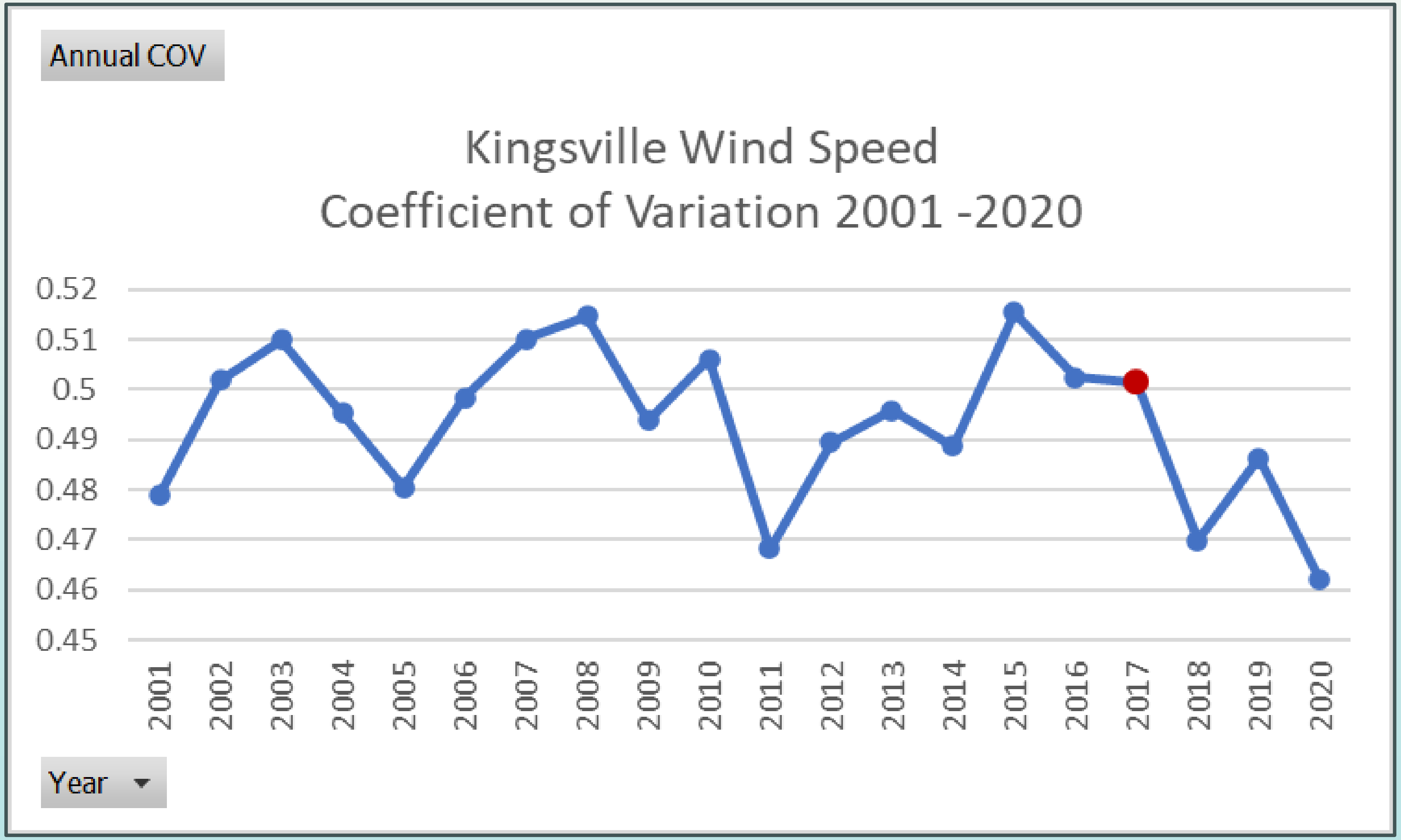
Wind Speed Analysis - Kingsville, TX

Coefficient of Variation

- The ratio of the standard deviation to the mean.

Coefficient of Variation Formula = $\frac{\text{Standard Deviation}}{\text{Mean}}$

- Results seem to show less variability after 2017.
- This could indicate possible wind speed stability.
- Not enough post wind speed data to verify this conclusion.



The Influence of Wind Farms on Wind Speed in Neighboring Cities

Papalote Creek Wind Farm’s influence on wind speed in Mathis, TX

- The Papalote Creek Wind Farm was commissioned in November 2009[6].
- This yielded more pre and post-data analysis of the wind speed.

Wind Speed Analysis - Mathis, TX

Average

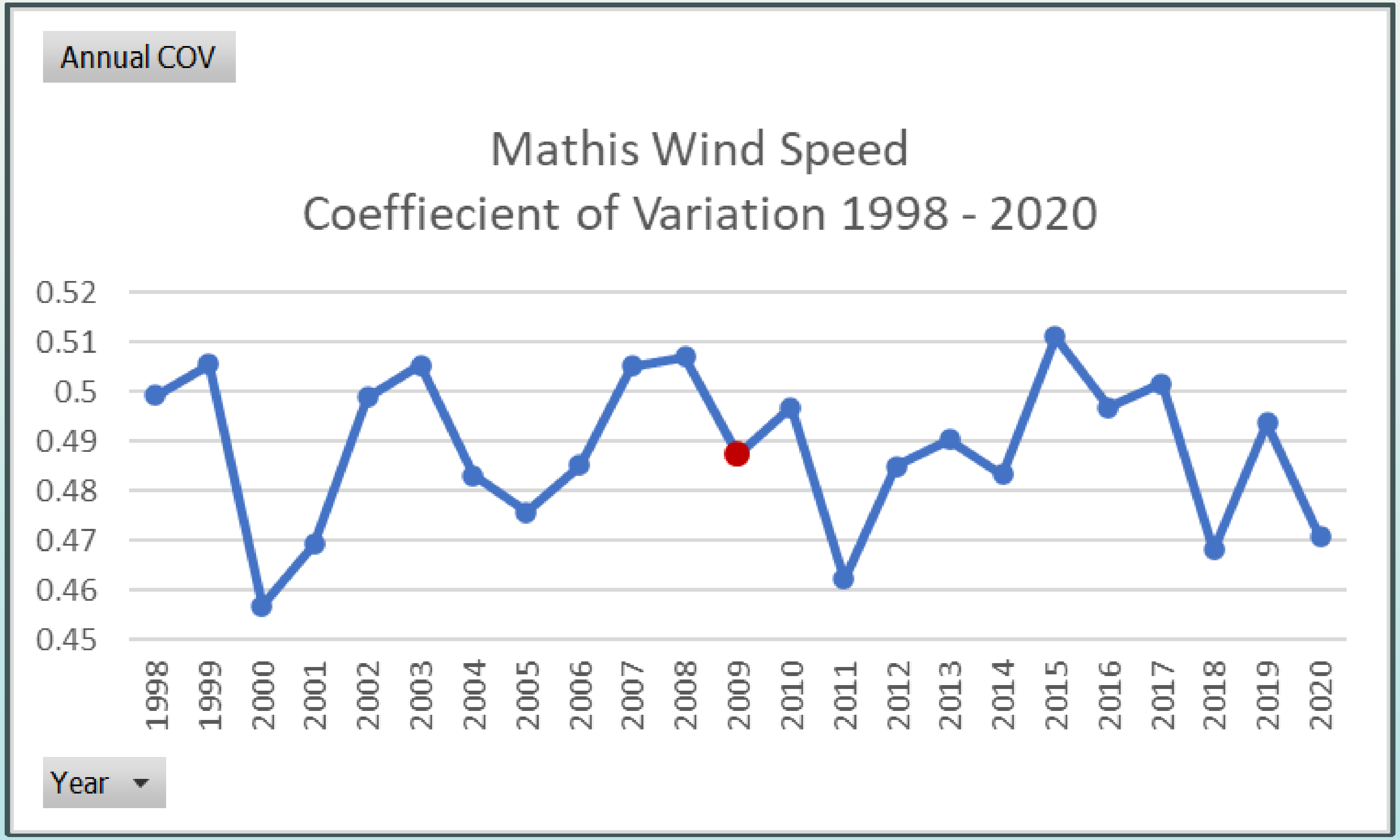
- Refined wind speed averages over a 20 year period.
- Focuses in on the average wind speed 5 years before and after 2009.

Standard Deviation

- A measure of the spread of the data is in relation to the mean over a 20 year period.
- The lower standard deviations indicate more consistency.

Coefficient of Variation

- Results seem do not show a change in variability after 2009.



Wind Speed Analysis - Mathis, TX

Wind Speed Comparison

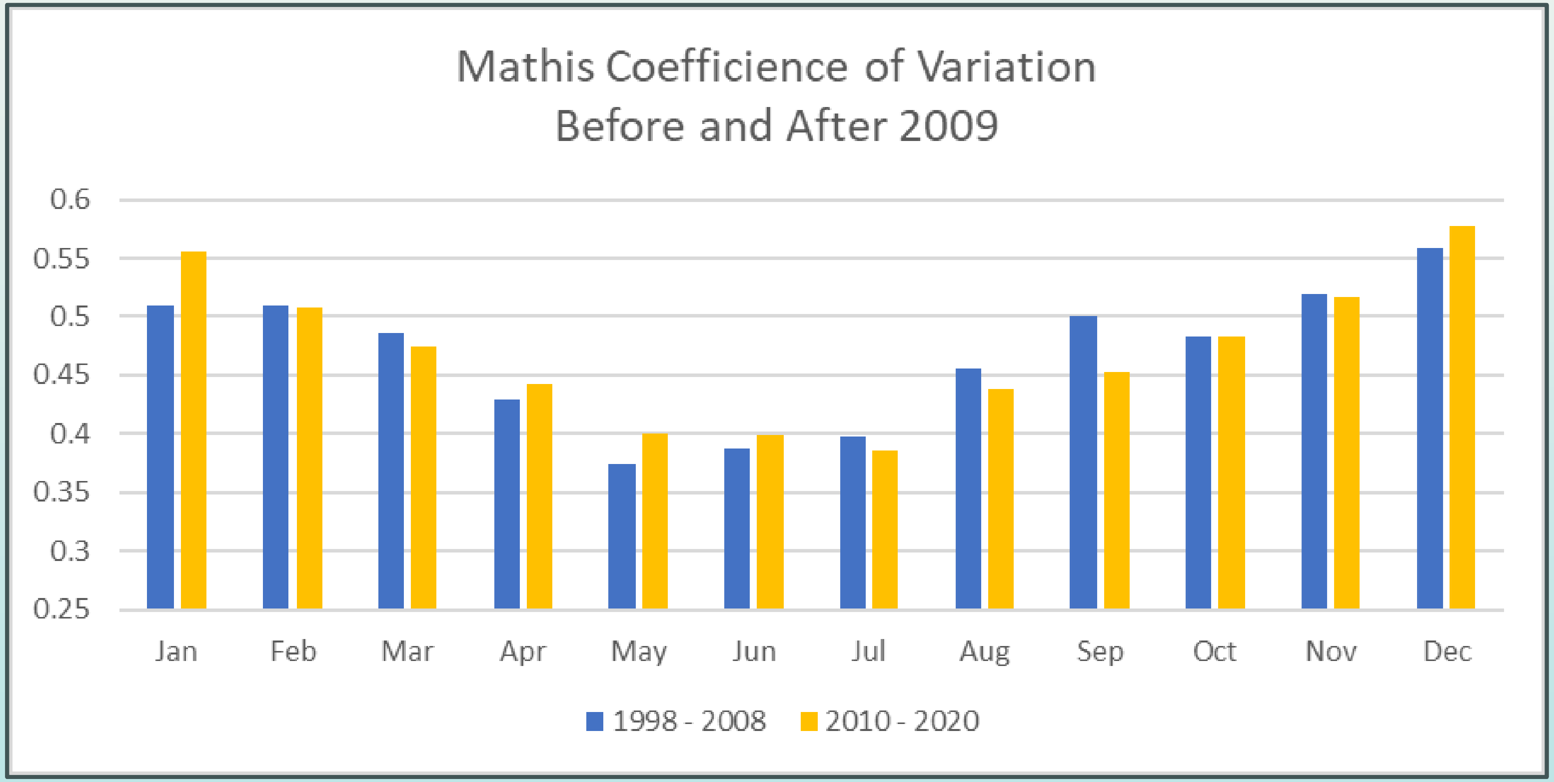
T-Test Results

- Average
  p-value = 0.662800239
- Standard Deviation
  p-value = 0.878464359
- Coefficient of Variation
  p-value = 0.810818736

The current analysis shows no significant change in wind speed before and after the wind farm commission dates.

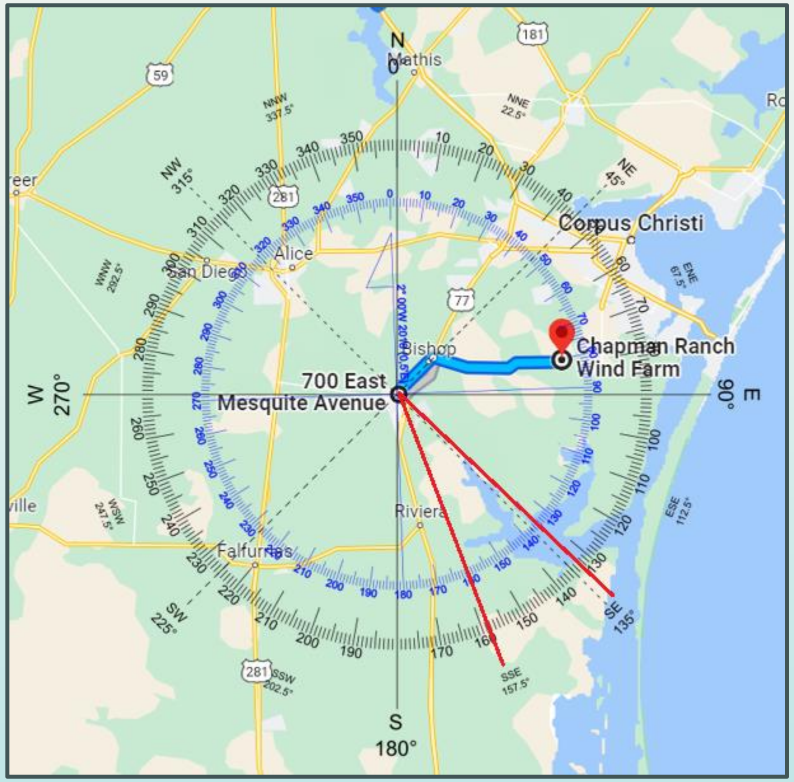
T-Test resulted in statistically insignificant results because the p-values were greater than 0.05.

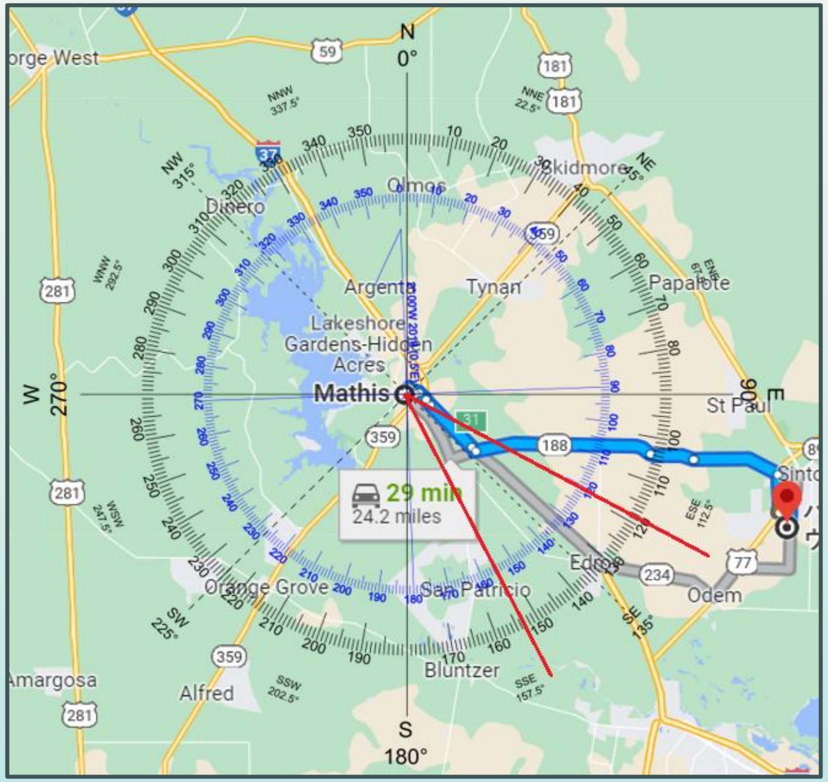
Further investigation would need to be conducted to see if wind farms show any true influence on wind speeds.



Wind Direction - Kingsville & Mathis, TX

Year	Wind Direction
2001	152.1
2002	158.1
2003	147.4
2004	154.8
2005	141.4
2006	**158.7**
2007	137.9
2008	140.6
2009	155.5
2010	138.8
2011	158.4
2012	137.7
2013	138.3
2014	148
2015	147.4
2016	149.1
2017	146.7
2018	153
2019	136
2020	**133**





Year	Wind Direction
1998	149.3
1999	134.1
2000	136.8
2001	151.6
2002	141.6
2003	137.1
2004	**153.6**
2005	136.2
2006	149.2
2007	143.4
2008	151.1
2009	134.6
2010	150.8
2011	132.3
2012	153.4
2013	133.9
2014	138.6
2015	**128.7**
2016	132.6
2017	152.8
2018	145
2019	143
2020	143

- The wind blows from the southeast for both Kingsville and Mathis, TX.
- While both locations are located further inland, they’re not directly downwind from their respective wind farms.
- Future analysis would consider the wind direction at the wind farms before examining a particular location.

Classroom Lesson Module

Optimal Placement of Renewable Energy Sources

Learning Standards

Cross Curricular Lesson

STEM TEKS

§130.418 Practicum in STEM (2)(A-D), (3)(A-F), (4)(A-G)

Science TEKS

§112.43 Chemistry (1)(A-G),(2)(A-C),(10)(B)

Math TEKS

§111.43. Mathematical Models with Applications (9)(A-F)

§111.47. Statistics (6)(A-J)

STEM
Science | Technology | Engineering | Math

Main 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.

Research Questions

Knowing that good places for wind turbines are where the annual average wind speed is at least 4 m/s[3]*.*

How do weather conditions influence the wind speed?

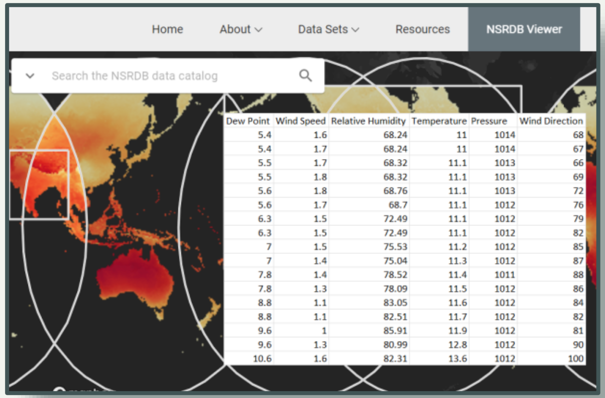
What is the best location on campus to install a small wind turbine?

Knowing that solar panels are comprised of photovoltaic cells that react to UV rays and transform them into electricity[4]*.*

How do weather conditions influence UV radiation?

What is the best location on campus to install a solar panel?

Lesson Criteria & Constraints



Dew Point	Wind Speed	Relative Humidity	Temperature	Pressure	Wind Direction
5.4	1.6	68.24	11	1014	68
5.4	1.7	68.24	11	1014	67
5.5	1.7	68.32	11.1	1013	66
5.5	1.8	68.32	11.1	1013	69
5.6	1.8	68.76	11.1	1013	72
5.6	1.7	68.7	11.1	1012	76
6.3	1.5	72.49	11.1	1012	79
6.3	1.5	72.49	11.1	1012	82
7	1.5	75.53	11.2	1012	85
7	1.4	75.04	11.3	1012	87
7.8	1.4	78.52	11.4	1011	88
7.8	1.3	78.09	11.5	1012	86
8.8	1.1	83.05	11.6	1012	84
8.8	1.1	82.51	11.7	1012	82
9.6	1	85.91	11.9	1012	81
9.6	1.3	80.99	12.8	1012	90
10.6	1.6	82.31	13.6	1012	100

Criteria

- Use reputable published data (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 Timeline

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

- Downloading data from (NSRDB)
- Setting up weather stations
- Determine Attributes
- Excel Tutorials

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

- Statistical analysis of the NSRDB data (Average, Standard Deviation, Coefficient of Variation, T-Test)
- First week of statistical analysis for the weather station

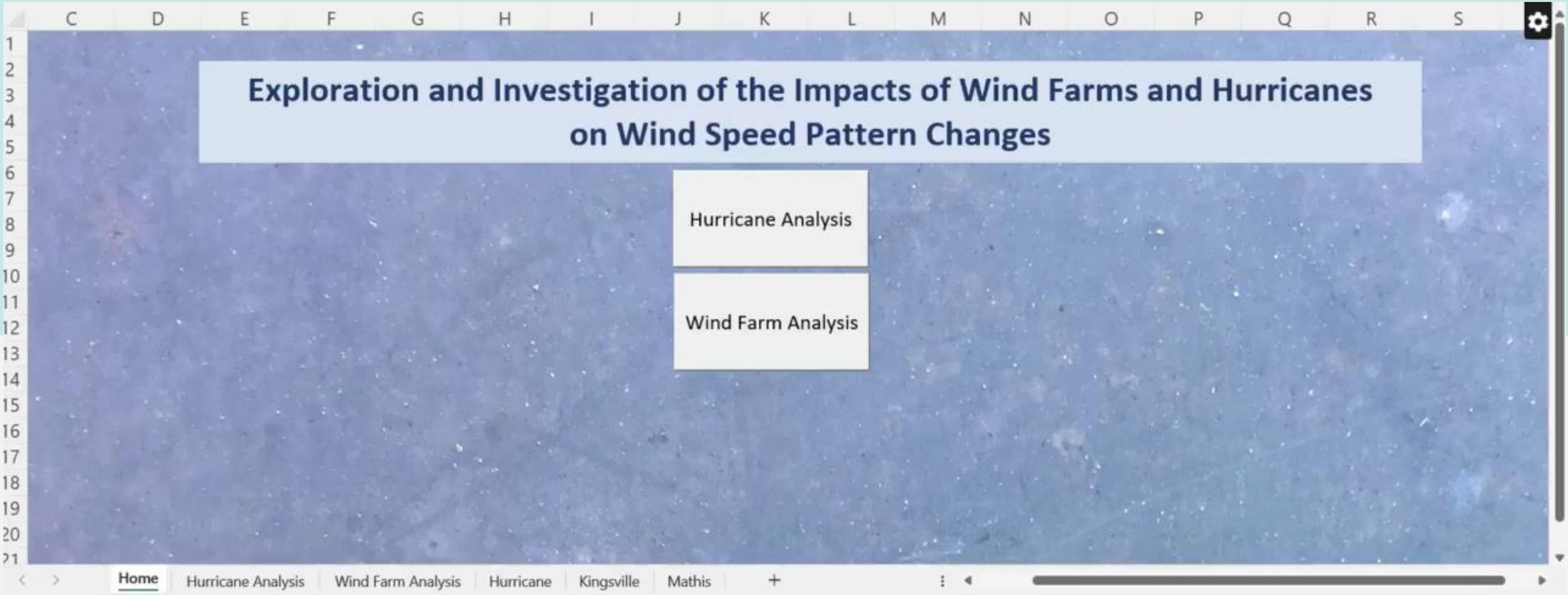
Weekly weather station data checks ……..……………………………………. Minimum 1 per week

- Continued statistical analysis for the weather station data throughout the school year.

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

- Create the interface, the report, and the poster

Interface



Exploration and Investigation of the Impacts of Wind Farms and Hurricanes on Wind Speed Pattern Changes
Hurricane Analysis
Wind Farm Analysis
Home
Hurricane Analysis
Wind Farm Analysis
Hurricane
Kingsville
Mathis

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

[1] NSRDB. (n.d.). Nsrdb.nrel.gov. https://nsrdb.nrel.gov/data-viewer

[2] Historical Hurricane Tracks. (n.d.). Coast.noaa.gov. https://coast.noaa.gov/hurricanes/#map=4/32/-80

[3] Where wind power is harnessed - U.S. Energy Information Administration (EIA). (n.d.). www.eia.gov. https://www.eia.gov/energyexplained/wind/where-wind-power-is-harnessed.php#:~:text=Good%20places%20for%20wind%20turbines

[4] How Do Solar Panels Work. (n.d.). Performance Services. Retrieved July 14, 2023, from https://www.performanceservices.com/resources/how-do-solar-panels-work/#:~:text=Energy%20Conversion

[5] Carmen. (2021, November 30). Power plant profile: Chapman Ranch Wind, US. Power Technology. https://www.power-technology.com/marketdata/power-plant-profile-chapman-ranch-wind-us/

[6] The Papalote Creek Wind Farm Project Project. (n.d.). Power Technology. https://www.power-technology.com/projects/papalotecreekwindpro/

Effect of Daylighting on Students' Learning and Classroom Electricity Consumption

Teacher Participants: Arianna Arevalo- Ricardo ISD
Stacey Canales- Driscoll ISD
Faculty Mentors: Dr. Hui Shen, Dr. Marsha Sowell
Curtis Davenport (Student Mentor)
Ralph Pitzer, P.E. (Industrial Advisor)
Texas A&M University – Kingsville

Shining a Light on Student Success: The Impact of Daylighting on Academic Performance and Electrical Energy Usage

Background

- **Daylighting** refers to the use of natural light to illuminate indoor spaces, and has been shown to have significant benefits for human health and productivity.
- By improving the quality of light in educational settings, we can help to create a more conducive learning environment.

Background: Key Terms

Daylighting – the illumination of buildings by *NATURAL* light

Lux – the SI unit of illuminance, equal to one lumen per square meter.

500 lux is the recommended level for work spaces

Daylight Autonomy (DA) – an annual measure of how often a minimum work plane illuminance requirement can be met by daylight alone during occupied time.

Useful Daylight Illuminance (UDI) – the percentage when the workplane illuminances fall between 100 lux-2,000 lux of the occupied time.

Window to Wall Ratio (WWR) – measure of the amount of window area there is on a building relative to the total amount of exterior wall area.

Background

Case #1	Case #2	Case #3
Full Spectrum vs Conventional Lighting	"Most Daylighting" classrooms vs "Least Daylighting" classrooms	Daylighting Schools vs Non-Daylighting Schools
Results:	**Results:**	**Results:**
Full Spectrum: ❑ Missed fewer days ❑ Increased health effects	**"Most Daylighting" Classrooms:** ❑ Progressed 20% faster on Math Test ❑ Progressed 26% faster on Reading Test	**Daylighting Schools:** ❑ Outperformed Non-Daylit schools by 5%-14%.

(Plympton et al., 2000)

Research Question

What effect does Daylighting have on Students' Learning and Classroom Electricity Consumption?

Research Materials: Human & Non-Human Data Collection

			
LI-200R Pyranometer Sensor	**LI-210R Photometric Sensor**	**EME Systems UCLC Amplifier**	**HOBO 4-Channel Data Logger**
• Measures solar radiation in watts/meter^2 • Detects radiation only in the visible spectrum. • Has an absolute error of 3%.	• Measures light intensity in kilolux. • Detects radiation only in the visible spectrum. • Has an absolute error of 3%.	• Enhances the signal from the sensor • Converts it to voltage output for the logger.	• Automatically monitors and collects measurement data from the sensors over time.

Research Materials: Human Data Collection

			
PMA2100 Dual Input Logging Radiometer	**"Wearable" LI-210R Photometric Sensor**	**Activities & Quizzes**	**Participant Questionnaire**
• Research grade logging radiometer • Can be used with over 85 different types of sensors. • Used to measure light in lux for our purposes	• Used to measure light intensity in lux close to eye level. • Resourcefully modified existing head gear product to allow sensor to be "wearable"	• 11th - 12th grade reading level passages • Related questions. • Designed for easy implementation.	Collected participants' opinions of: • Difficulty Level of activities • Lighting in each room • Temperature in each room • Preferred room

Research Methods: Non-Human Data Collection

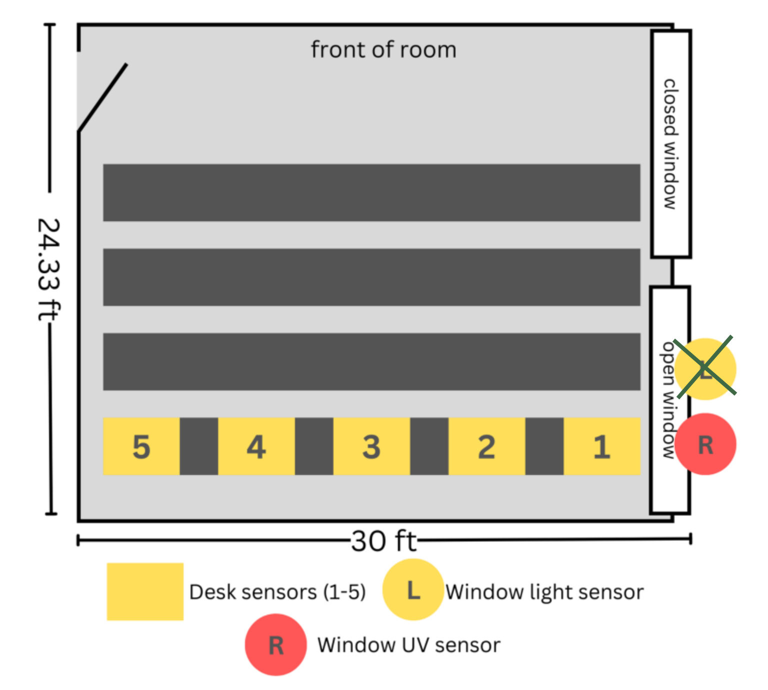
1. Window open, lights completely off
2. Set to run from Friday pm to Monday am
3. Recorded data every minute from each sensor
4. Sensors were placed as shown in Table 1, Fig. 1, and Fig. 2
5. Room was not disturbed during data collection
6. Collected in two similar sized rooms, with different window orientations

Sensor	Distance (feet) from Window
1	3
2	9
3	15
4	21
5	27

Table 1

Research Methods: Non-Human Data Collection

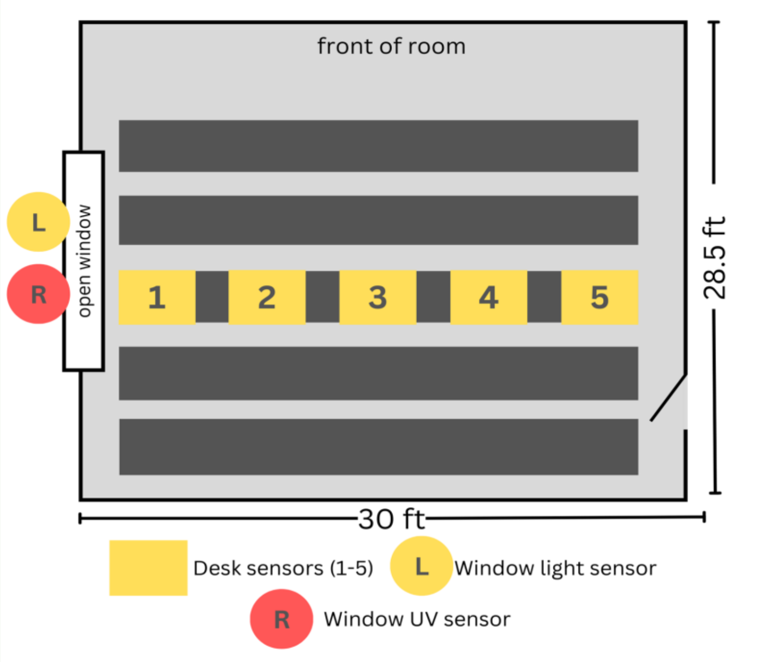
1. Window open, lights completely off
2. Set to run from Friday pm to Monday am
3. Recorded data every minute from each sensor
4. Sensors were placed as shown in Table 1, Fig. 1, and Fig. 2
5. Room was not disturbed during data collection
6. Collected in two similar sized rooms, with different window orientations



Fore Hall Room 106 – SOUTH
Figure 1

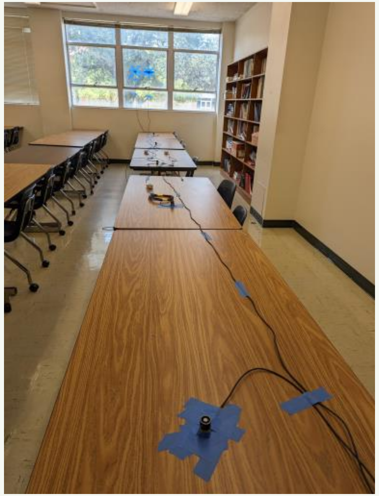
Research Methods: Non-Human Data Collection

1. Window open, lights completely off
2. Set to run from Friday pm to Monday am
3. Recorded data every minute from each sensor
4. Sensors were placed as shown in Table 1, Fig. 1, and Fig. 2
5. Room was not disturbed during data collection
6. Collected in two similar sized rooms, with different window orientations

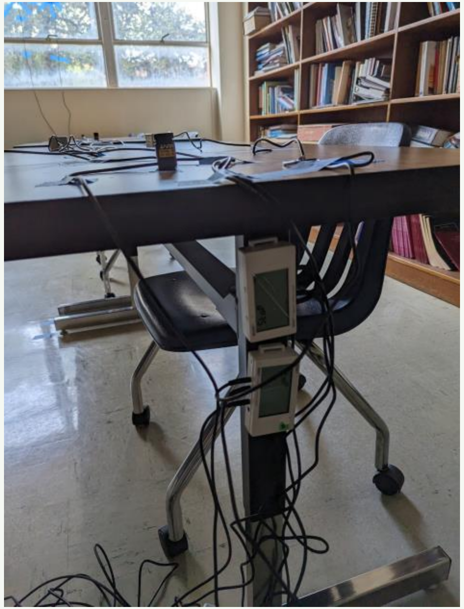


EC 113 – EAST
Figure 2

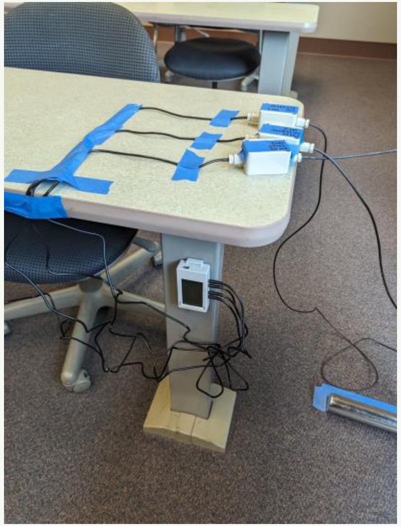
Research Methods: Non-Human Data Collection

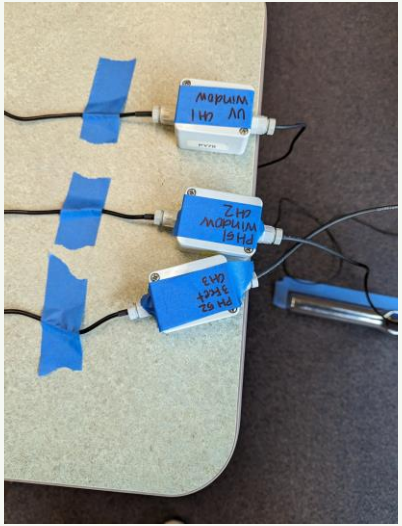


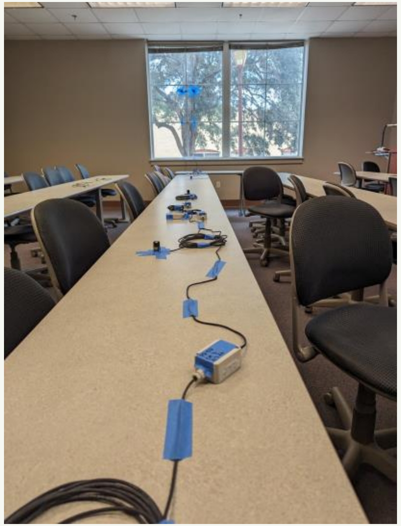
Research Methods: Non-Human Data Collection



Research Methods: Non-Human Data Collection

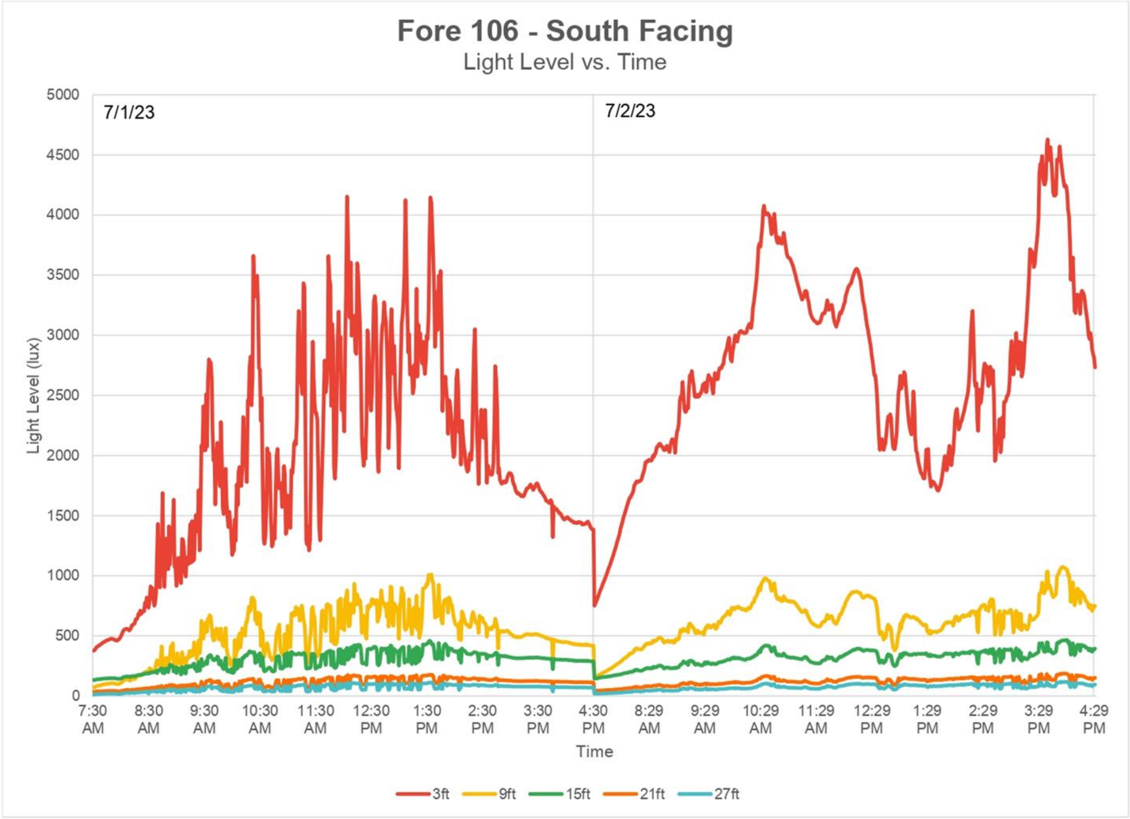






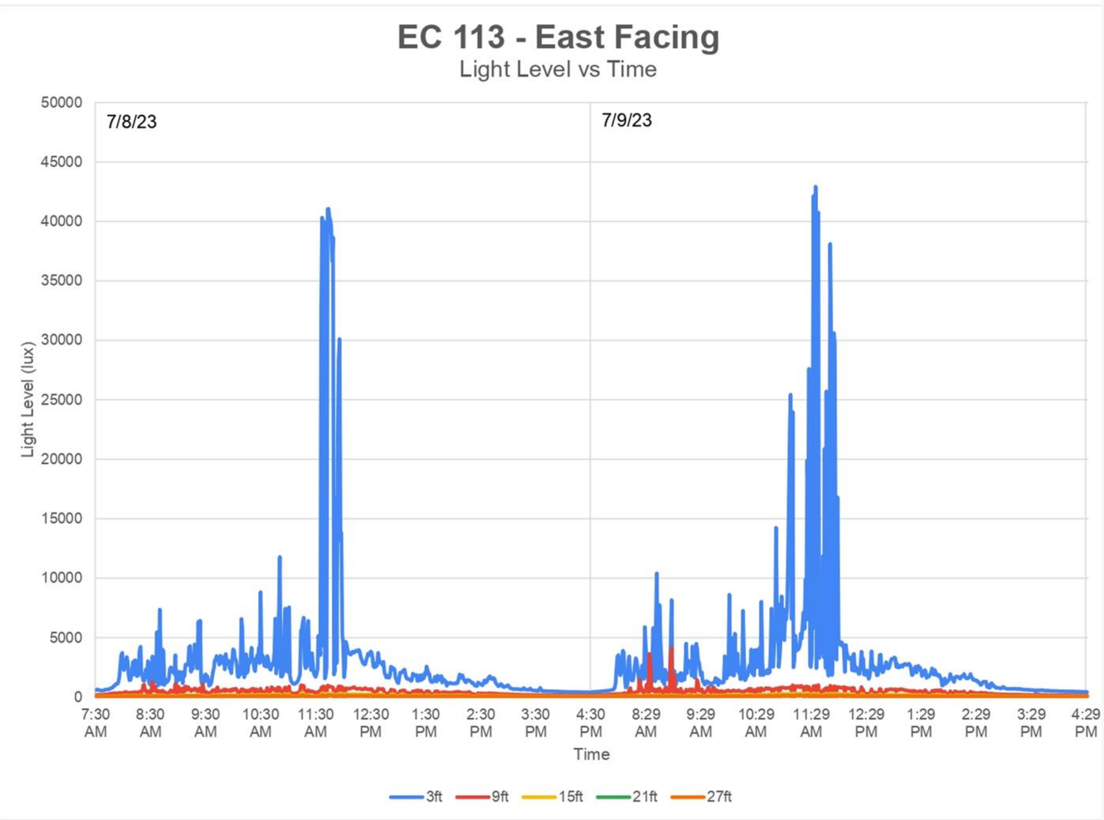
Research Methods: Non-Human Data Analysis

- Only data between a "typical" school day was used
  - 7:30a to 4:30p
- Calculated actual light level using multipliers for each sensor
- Converted to lux



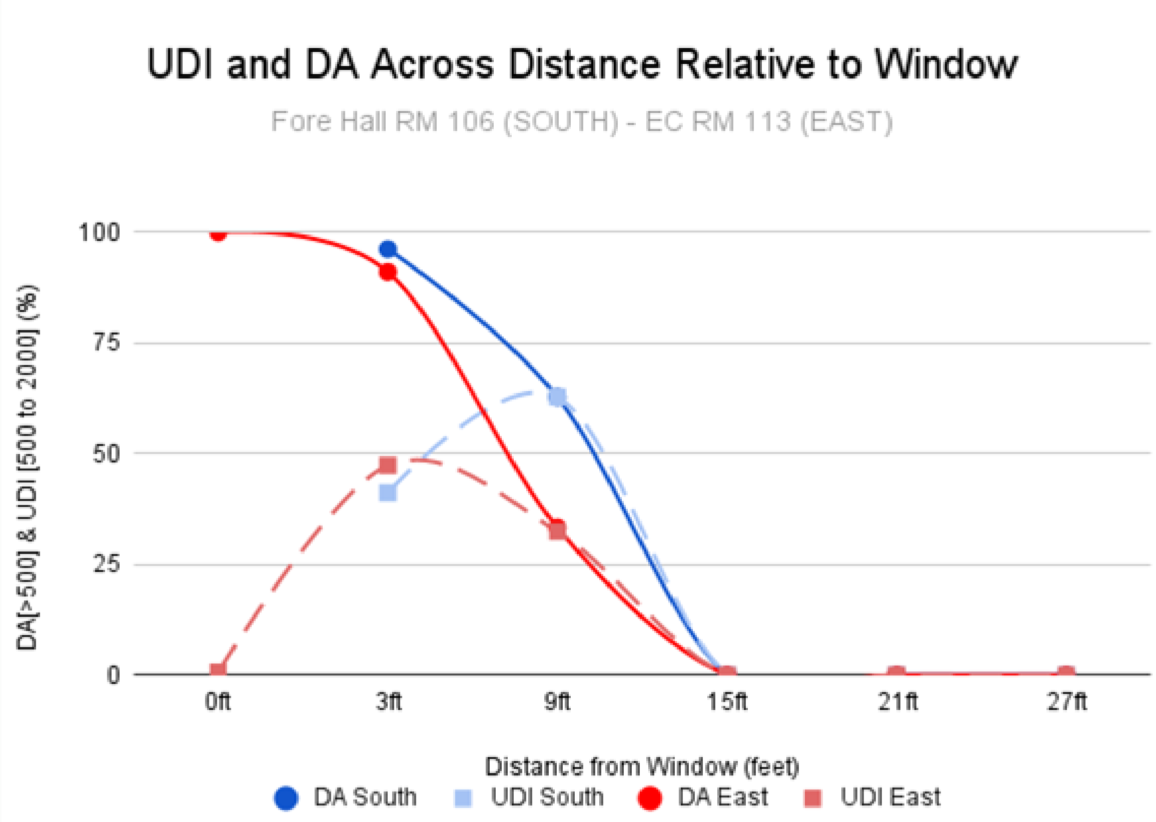
Research Methods: Non-Human Data Analysis

- Only data between a "typical" school day was used
  - 7:30a to 4:30p
- Calculated actual light level using multipliers for each sensor
- Converted to lux



Research Methods: Non-Human Data Analysis

- Calculated the UDI and DA for both rooms
- Visually see how often lighting is both above 500 lux and within a “usable” range
- Glare > 3000 lux
    - Can be considered too bright to be useful



Research Methods: Non-Human Data Analysis

- Calculated the UDI and DA for both rooms
- Visually see how often lighting is both above 500 lux and within a "usable" range
- Glare > 3000 lux
  - Can be considered too bright to be useful

Results: Non-Human Data Analysis

$$E_L = P_L + A \quad \times$$

$$\Sigma(E_s + E_i) \quad E_s \quad n$$

Required Electric Lighting Power

- E_L: required electric lighting power
- P_L: lighting power density – 7.6 W/m^2 needed for 500 lux
- A: area of room in m^2
- E_S: illuminance set point – 500 lux
- E_i: illuminance from daylight
- n: number of calculation points on work plane – 5

Results: Non-Human Data Analysis

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

Required Electric Lighting Power

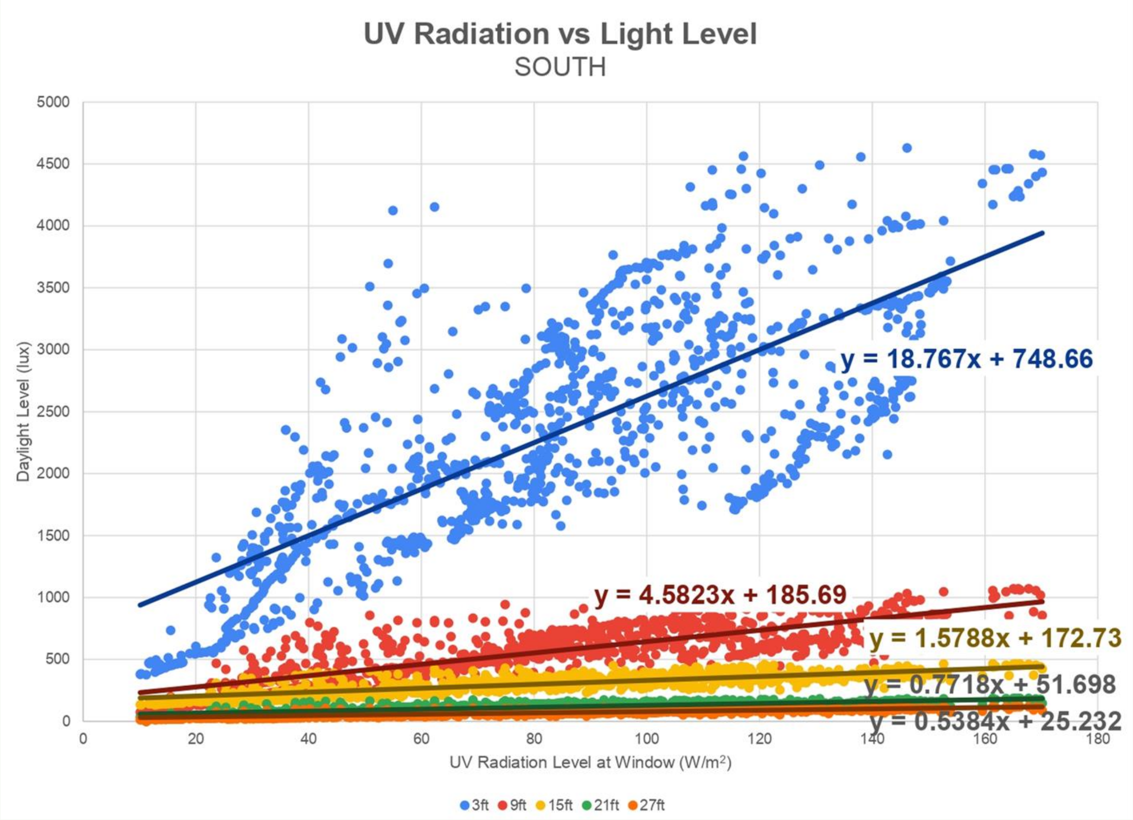
- Used to calculate the required electric lighting power needed to keep the work plane at a level of 500 lux
- Calculations completed for
  - 5 points on the work plane
  - For every 1-minute over two school day period
- Then compared to required electric lighting power used with no daylighting.

Results: Non-Human Data Analysis

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%

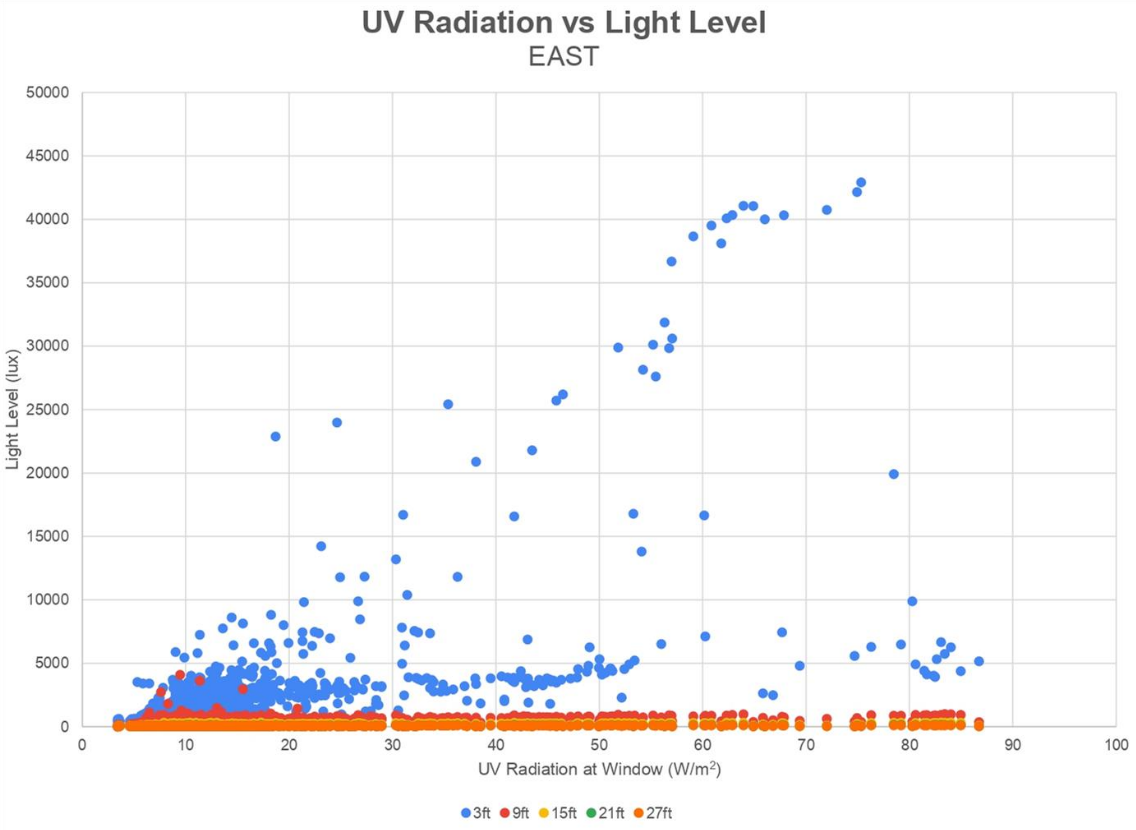
Results: Non-Human Data Analysis

- Plotted window UV/light levels versus light levels at each desk location
- Equation could be used to maintain 500 lux with daylighting & 1 sensor placed at the window
- Not yet done for East facing room



Results: Non-Human Data Analysis

- Plotted window UV/light levels versus light levels at each desk location
- Equation could be used to maintain 500 lux with daylighting & 1 sensor placed at the window
- Not yet done for East facing room



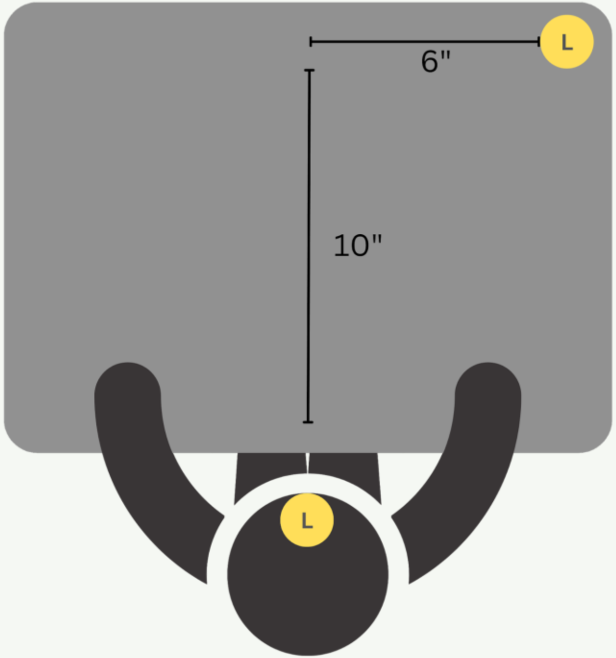
Research Methods: Human Data Collection

1. Place wearable and desk light sensor as shown in Fig. 1 and Fig. 2
2. Set data to be collected every 1-minute
3. Participants completed short reading activity (10 min) and quiz (10 min) in 3 classrooms with different lighting scenarios
4. Participants completed activity questionnaire

Wearable Sensor
Figure 1

Research Methods: Human Data Collection

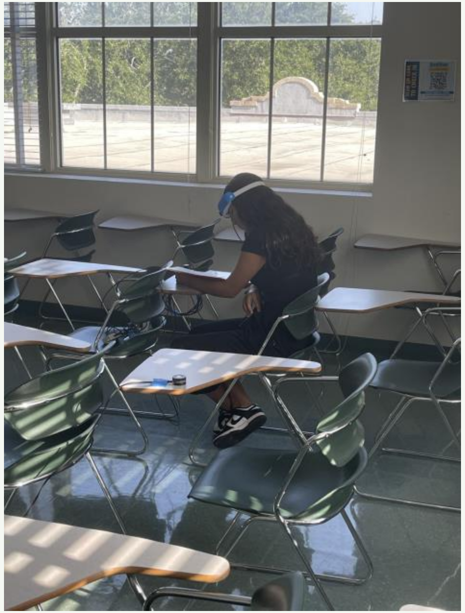
1. Place wearable and desk light sensor as shown in Fig. 1 and Fig. 2
2. Set data to be collected every 1-minute
3. Participants completed short reading activity (10 min) and quiz (10 min) in 3 classrooms with different lighting scenarios
4. Participants completed activity questionnaire

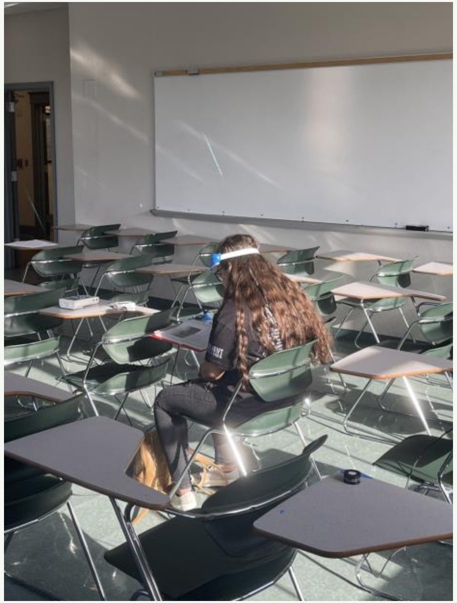


Sensor Placement
Figure 2

Research Methods: Human Data Collection

Research Methods: Human Data Collection





Research Methods: Human Data Analysis

- Our intent was to combine participants' accuracy on quiz and reading time/speed into one *efficiency score* to compare to lighting levels
- Due to the lack of data and time constraints, no definitive results were formed.
    - More participants/data collected
    - Longer data analysis period

Research Methods: Human Data Analysis

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

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

Curriculum Module

Analyzing the Effects of Different Lighting Levels on Plant Growth

In this math based lesson, students will statistically analyze the effects of different levels of lighting on plant growth using data collected over a period of time (SCI 5.2C). The simple analysis will be done with a focus on generating data tables and their matching scatterplots **(5.8C)**, as well as a basic statistical analysis **(5.9C)**.From there the students will draw conclusions based on the visual data and from their various measures of central tendency.

Curriculum Module

Analyzing the Effects of Different Lighting Levels on Plant Growth

Students will

- learn how to measure light levels using a simple light meter
- explore the relationship between light intensity and plant growth.
- collect data, create graphs, and analyze the results to draw conclusions about the impact of light on plant growth

This can be performed as an end of year project or an end of unit project in conjunction with a photosynthesis lesson in their science classes.

Curriculum Module

6th Grade Science

“Energy Resources, Cost and Conservation”

TEK 6.11A, B

Five day lesson in which students:

- RESEARCH and DESCRIBE why energy resource management is essential in order to reduce global energy
- How CONSERVATION can increase efficiency
- How we can use technology to MANAGE energy resources

Curriculum Module

Day 1

Vocabulary Pyramid

Electricity Scavenger Hunt

"Where Does Energy Come From" video & Card Sorting Activity

Day 2

Review

Activity " Watts Going On Here?" using kilowatt power meter

Day 3

Graphing Data from Day 2

Day 4

Energy Conservation Worksheet

Mix Pair Share:

Conserving or Wasting Energy

Day 5

Managing Energy Resources with Technology

Acknowledgements

This research was funded by the National Science Foundation (NSF, Award # 2206864). Any claims, findings, or recommendations expressed were created by authors and not reviewed nor necessarily reflect the views of NSF.

References

- https://ipvm.com/reports/how-lowering-light-levels-impact-quality
- Admin_stanpro. (2021, June 22). *Lighting educational institutions one room at a time*. Stanpro. https://www.standardpro.com/lighting-educational-institutions/
- Cornelius, S. (2015, March 9). *[10 classroom tips] improve test scores*. Edmentum Blog. https://blog.edmentum.com/10-classroom-tips-improve-test-scores-0
- Hinton, M. (2018, April 24). *Elementary School teachers can improve students' mental health, study finds*. Education Week. https://www.edweek.org/leadership/elementary-school-teachers-can-improve-students-mental-health-study-finds/2018/04
- *Hobo 4-channel analog data logger*. HOBO 4-Channel Analog Data Logger | Onset's HOBO and InTemp Data Loggers. (n.d.). https://www.onsetcomp.com/products/data-loggers/ux120-006m#specifications
- Journal of the American Institute of Architects. (2021, April 21). *Strategic Daylighting in schools: More is not always better*. Architect. https://www.architectmagazine.com/technology/lighting/strategic-daylighting-in-schools-more-is-not-always-better_o
- *Li-Cor Environmental*. Contact LI-COR Biosciences. (n.d.). https://www.licor.com/env/
- Nabil, A., & Mardaljevic, J. (2005). Useful daylight illuminance: A new paradigm for assessing daylight in buildings. *Lighting Research & Technology*, *37*(1), 41–57.
- Plympton, P., Conway, S., & Epstein, K. (2000a). American Solar Energy Society Conference. In *Daylighting in Schools Improving Student Performance and Health at a Price Schools Can Afford*. Madison, Wisconsin; Distributed by ERIC Clearinghouse..
- Reinhart, C. F., Mardaljevic, J., & Rogers, Z. (2006). Dynamic Daylight Performance Metrics for Sustainable Building Design. *LEUKOS*, *3*(1), 7–31. https://doi.org/10.1582/leukos.2006.03.01.001
- Silverman, S. (2020, October 2). *Why can't you just turn off the lights?* Your Teen Magazine. https://yourteenmag.com/family-life/communication/just-turn-off-the-lights
- Today, S. (2023, July 7). *Sunrise Time, Sunset Time July 7, 2023*. Sunrise, Sunset Times Today. https://www.suntoday.org/sunrise-sunset/2023/july/7.html
- Team, C. A. (2022, October 13). *Window to Wall Ratio Calculator*. Calculator Academy. https://calculator.academy/window-area-calculator/

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

Students: Andy Hernandez & Crystal Reyes

Faculty Advisors: Dr. Xiaoyu Liu & Dr. Marsha Sowell

Industrial Advisor: Enrique Molina

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

Objective:

The research objective of 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.

Research Question:

How much thermal energy can be generated by a compost tumbler?

Project Description:

• In the U.S. the estimated food waste at the household consumption level is 32% of purchased food.

•According to the 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.

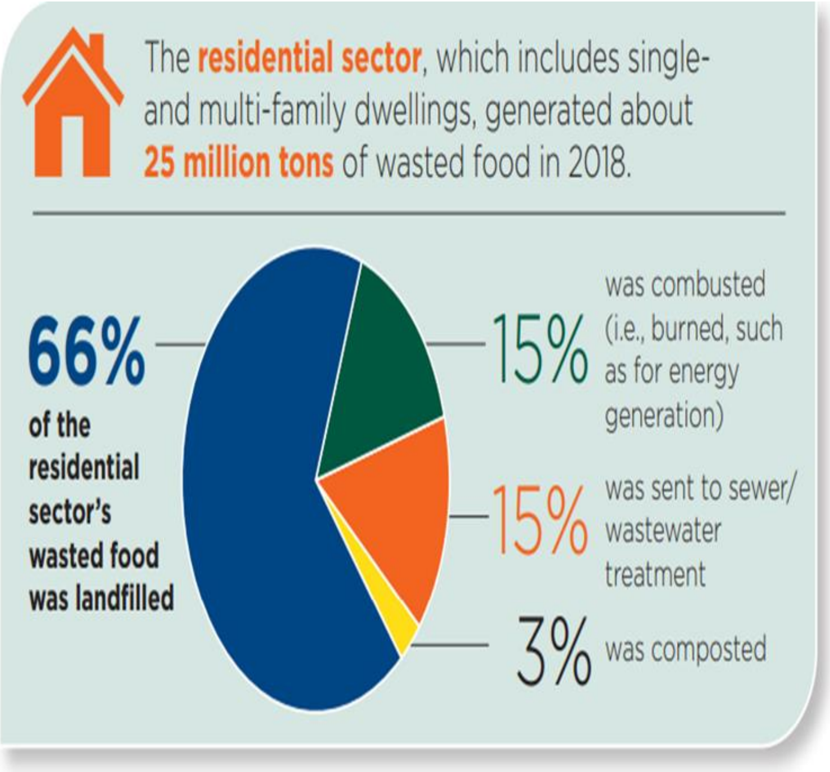


Fig 1.- USDA Food Waste [1]

Food waste converted into renewable energy

- **Composting in Backyard:**
  - Food and vegetable scraps
  - Most grass clippings and yard trim
  - Coffee grounds and paper filters
  - Dry leaves
  - Plant stalks and twigs
  - Shredded paper (non-glossy, not colored) and shredded brown bags
  - Shredded cardboard (no wax coating, tape, or glue)
  - Etc.

So Why Composting?

- Composting is the breakdown of organic material that leads to nutrient rich soil.
- Food waste in landfills cannot turn into compost because of the lack of aeration.
- Food waste in landfills produces leachate and harmful gases.
- One of the byproducts of composting is heat!
- Can it be harvested as renewable energy? Possibly!!!*
- There are many examples of citizens who have used heated water for greenhouses or homes using their own compost piles.

Food waste converted into renewable energy

- Biogas Burner/Digester in the Backyard

- Composter

Literature Review

- 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.

- 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.

- 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

Introduction

By setting up a simple compost bin, in 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. 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.

Procedure

- Set the bin, rinse if you have to.
- Stick the internal temperature probes in the chambers before you put food waste or dirt in the tumbler. Make sure they are secure with tape. Tape off any holes.
- Using a scale, weigh out the amount of food waste. We put our waste in a bucket and weighed it. We mixed a bunch of different types of waste: rice, watermelon, pineapple, oranges, onion, squash just to name a few.
- Place the food waste in chamber #1 of the tumbler. Since we have a dual chamber tumbler, one side will have food waste and topsoil, the other will have the grass, leaves and topsoil.

Procedure

- Measure out about 2.5 lbs of leaves, and 2.5 lbs of grass and mix into the tumbler. We noticed that with 5 lbs of grass and leaves took up more space than 15 lbs of food waste, the material is less dense.
- Measure out about 15 lbs of topsoil to go along with the food waste and another 15 lbs to go in with the grass and leaves mix.
- 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 of July 7th. We used HOBOLink.

Compost Bin #1

Brown Matter (Carbon):

- Dry Leaves and Small Twigs
- Top Soil Dirt

Greens Matter (Nitrogen):

- Grass Clippings

Compost Bin #2

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. 4 - Grass & Leaves
- Ambient Temp Sensor

Collection Parameter:

•5 minute intervals

•4 days

Results

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

Results/Observations

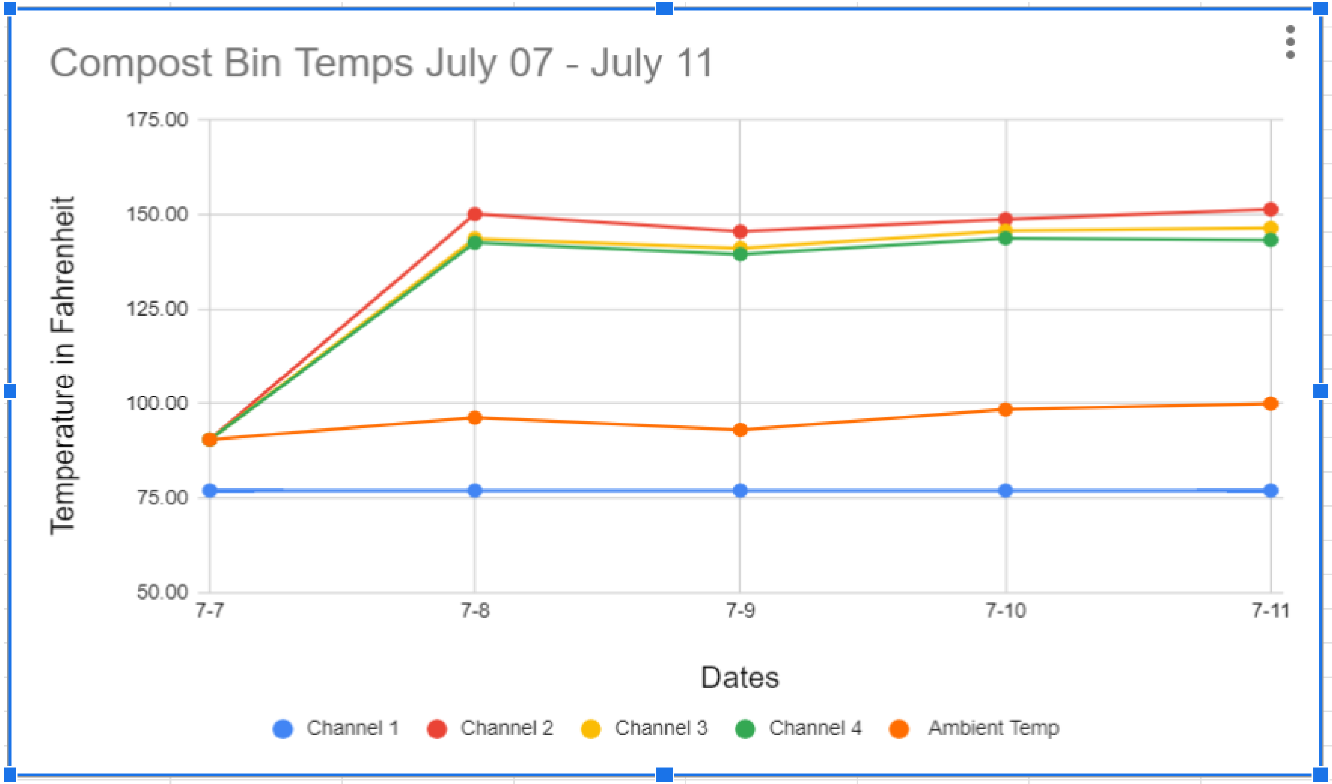
- Channel 1: Food Waste temperature sensor probe was faulty and recorded at 76.93.

- 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 on Sat., July 8th.

- 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:



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 and the data logger malfunctioned.
- 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.

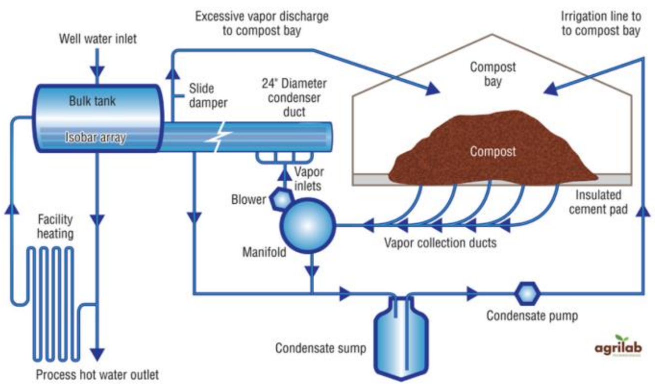
Conclusions: Why is this project difficult?

- Biomass as renewable energy is not as well established as wind power and solar power
- Many variables impacting composting:
  - Temperature
  - Oxygen
  - Moisture
  - C:N Ratio
  - Compost components
  - Complicated Biochemistry
- Sometimes energy output is not ideal

Implications for the Future

- Optimal combinations of materials
- Standardization of processes
- Development of heat capture devices or processes
- Sustainable model
- Development of Composting reactors
- Energy recovery and efficiency

Figure 1. Flow diagram of UNH heat recovery system



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

Students: Andy Hernandez & Crystal Reyes
Faculty Advisors: Dr. Xiaoyu Liu & Dr. Marsha Sowell
Industrial Advisor: Enrique Molina
Program Name: NSF RET I-READ Texas A&M University - Kingsville

ABSTRACT

- In the U.S. the estimated food waste at the household consumption level is 32% of purchased food.
- According to the 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.

Fig 1.- USDA Food Waste [1]

INTRODUCTION

OBJECTIVE: Study the potential of converting food waste into renewable energy in the backyard through experiments with different combinations of food waste types.

RESEARCH QUESTION: How much thermal energy can be generated by a compost tumbler?

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. 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.

METHODOLOGY

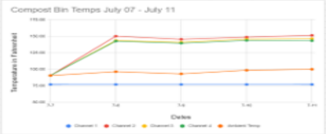
Compost Bin:
•Bin #1 - Dry leaves, grass clippings, and topsoil
•Bin #2 - Food waste and topsoil

Hobo Logger:
(TOP) Ch.1 - Food Waste
(BOTTOM) Ch.2 - Food Waste
(TOP) Ch. 3 - Grass & Leaves
(BOTTOM) Ch. 3 - Grass & Leaves

Collection Parameter:
- 5 minute intervals
- 7 days

RESULTS

- Data shows that on the line graph that temperatures peak range is between 12PM-5PM.
- Channel 2 temperature line is higher than channel 3 and 4 possibly due to higher water content from the food waste.
- The biggest temperature difference between channel 2 and the ambient temperature is 53.88°F at 3:58 PM.



Day	Time (PM)	Date	Channel 1	Channel 2	Channel 3	Channel 4	Ambient Temp. Sensor
			Probe/Sensor Input Temp. Fahrenheit				
0	3:00	7-7	76.55	90.42	90.42	90.42	90.42
1	3:58	7-8	76.55	150.12	143.66	142.58	96.24
2	12:05	7-9	76.55	145.51	141.10	139.51	93.09
3	4:00	7-10	76.55	149.74	145.70	143.74	98.43
4	5:07	7-11	76.55	151.35	146.43	143.30	99.58
	Average Temperature		------	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

Average temperature for Channel 2 is 137.23

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 and the data logger malfunctioned.
- 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 MODULE DEVELOPMENT

LEARNING MODULE: ***Compost: Generating Thermal Energy***

Lesson objective:
Students will learn that composting can generate thermal energy as a renewable resource.

OVERVIEW:

Brief overview of learning module:
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.

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.

OVERVIEW:

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 gather and graph the change in temperature of the compost and then 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.

ACKNOWLEDGEMENTS

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 author(s) & do not necessarily reflect the views of the National Science Foundation.

REFERENCES

[1] USDA Rural Development. "Don't Waste Uneaten Food!" *What is compost?* (n.d.). https://www.usda.gov/sites/default/files/documents/usda-food-waste-infographic.pdf
[2] B. Ellison & F. Linlin & N. Wilson. (2022). Journal of Cleaner Production. *What Food waste solutions do people support?, Vol. 330.* (129907). https://www.sciencedirect.com/science/article/pii/S0959652621040774#preview-section-abstract

Works Cited

[1] D. Alfonso-Solar & T. Gomez-Navarro & A. Herraiz-Canete & D. Perez & C. Vargas-Salgado. (2021). Renewable Energy-An International Journal. *Modelling biomass gasifiers in hybrid renewable energy microgrids; a complete procedure for enabling gasifiers simulation in HOMER, Vol. 174, (2021) 501-512.* *Modelling biomass gasifiers in hybrid renewable energy microgrids; a complete procedure for enabling gasifiers simulation in HOMER (notion.so)*

[2] K. Dobernig & B. Gozet & K. Schanes. (2018). Journal of Cleaner Production. *Food waste matters - A systematic review of household food waste practices and their policy implications, Vol. 182 (2018)* 978e991. *Food waste matters - A systematic review of household food waste practices and their policy implications (notion.so)*

[3] B. Ellison & F. Linlin & N. Wilson. (2022). Journal of Cleaner Production. *What Food waste solutions do people support?, Vol. 330.* (129907). https://www.sciencedirect.com/science/article/pii/S0959652621040774#preview-section-abstract

[4] E. Kiran & Y. Liu & W. Ng & A. Trzcinski. (2014). Fuel. *Bioconversion of food waste to energy: A review. Vol. 134, (2014) 389-399.* *Bioconversion of food waste to energy: A review (notion.so)*

[5] USDA Rural Development. "Don't Waste Uneaten Food!" *What is compost?* (n.d.). https://www.usda.gov/sites/default/files/documents/usda-food-waste-infographic.pdf

[6] How to build a compost tumbler: https://www.hgtv.com/outdoors/landscaping-and-hardscaping/how-to-build-a-diy-compost-tumbler

[7] How to extract heat from a compost pile: https://www.sciencebuddies.org/science-fair-projects/project-ideas/Energy_p035/energy-power/decomposing-energy-extracting-heat-energy-from-a-compost-pile#:~:text=It%20is%20produced%20as%20a,and%20nitrogen%20for%20protein%20production

Learning Module Development

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.

Learning Module:
Compost - Generating Thermal Energy

Overview of learning module:

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 (Paper, food waste, grass, leaves, topsoil, water).
4. Students will measure and graph the changes in temperature over a 1 week period, possibly longer.

Learning Module:
Compost - Generating Thermal Energy

- 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.

Learning Module:
Compost - Generating Thermal Energy

- 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.

Learning Module:
Compost - Generating Thermal Energy

- Variations of the project:
  - Size of the water reservoir
  - Improvements on design (vertical bin vs horizontal bin)
  - Power output calculations
  - C:N ratios comparisons (combination of material)
  - 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

[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.

Learning Module:
Compost: A Scientific Investigation

OVERVIEW - *In this four-part inquiry-based activity:*

- Students will practice using the scientific method while learning about decomposition, exploring how some types of garbage will decompose while others will not.
- Students can then go on to design their own experiment to test different variables affecting the rate of decomposition.

(leaves, paper, apple core, bread, plastic, foil)

Learning Module:
Compost: A Scientific Investigation

- 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 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.

Thank You

Optimization of Wind Farm Layouts Through Wind Turbine Coordination

Teachers

Mr. William Johnson - Flour Bluff High School (FBISD)
Mr. Kurt Mann - Falfurrias Jr. High School (BCISD)

Faculty Advisors

Dr. Kai Jin - Research Project Mentor (TAMUK)
Dr. Marsha Sowell – Curriculum Development Mentor (TAMUK)

Student Mentor

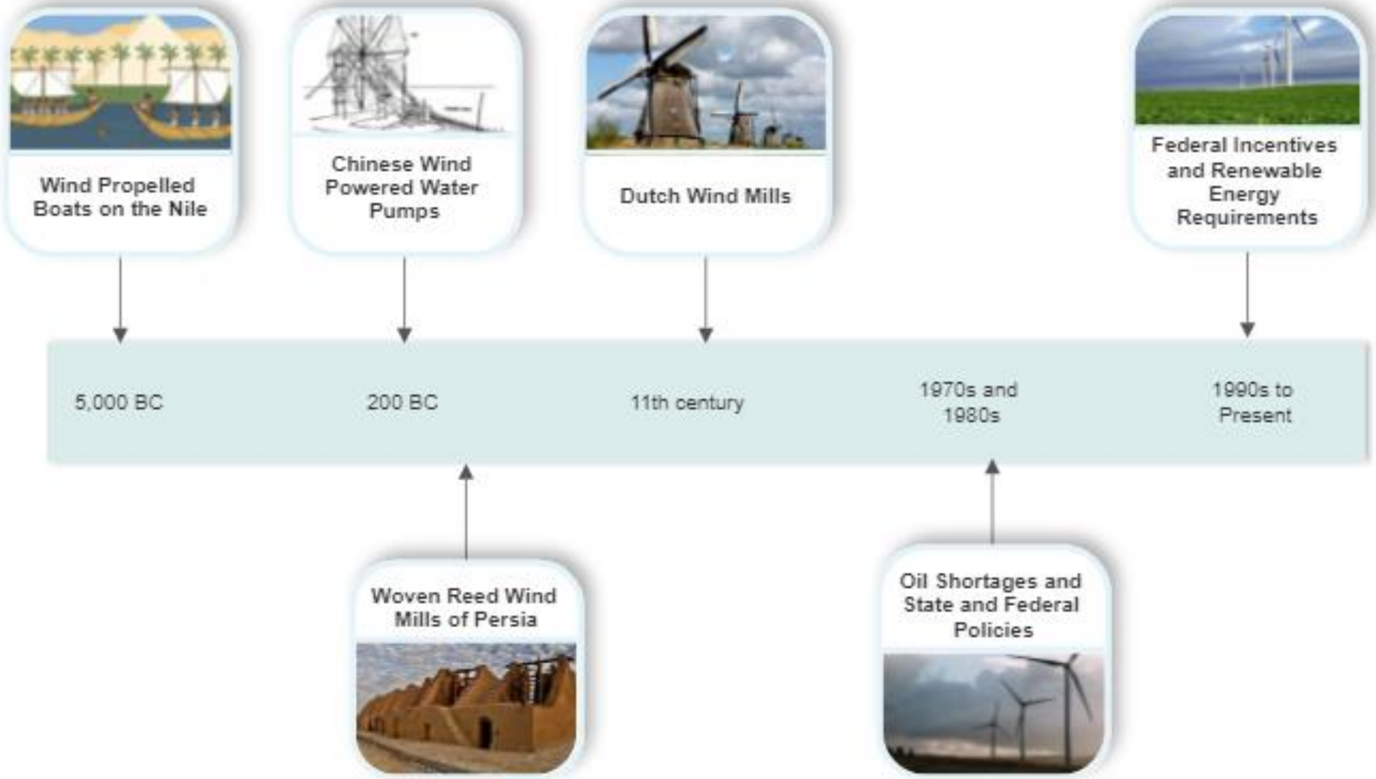
Rikki Ramos (TAMUK)

Industrial Advisor

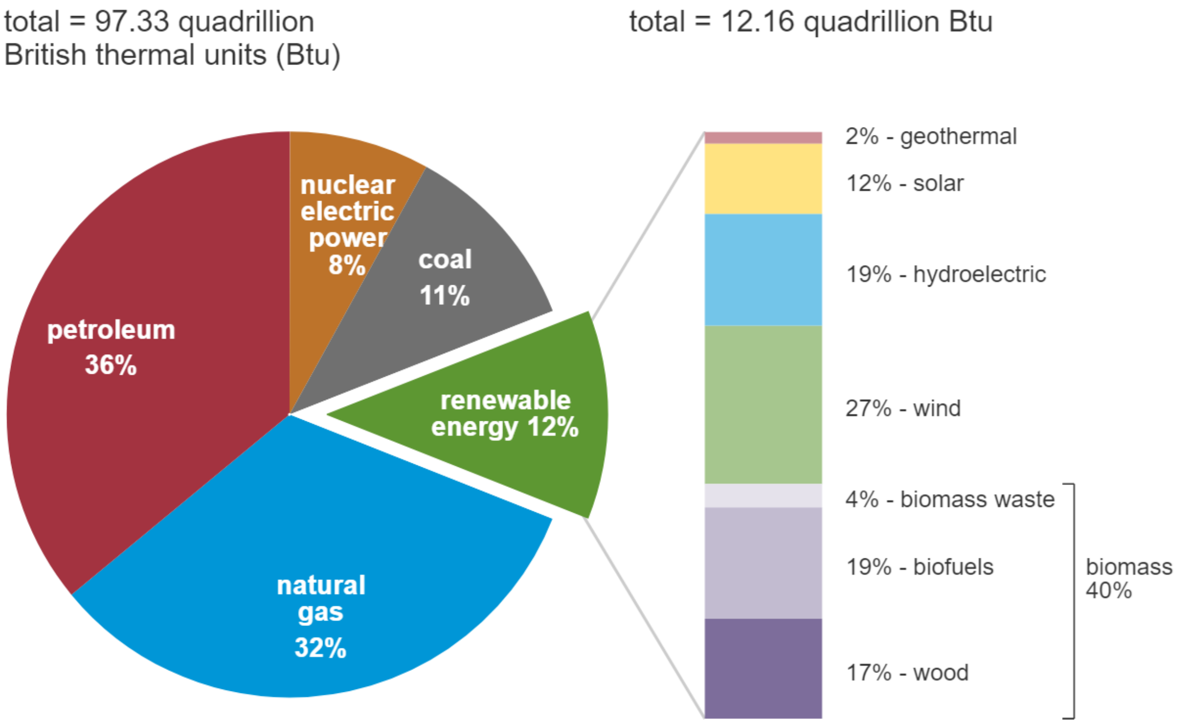
Rene Ramirez, Jr, P.E., PMP

RET Site: Integrating Data-driven research in Renewable Energy Across Disciplines (I-READ)

A Look At Wind Energy Through Time

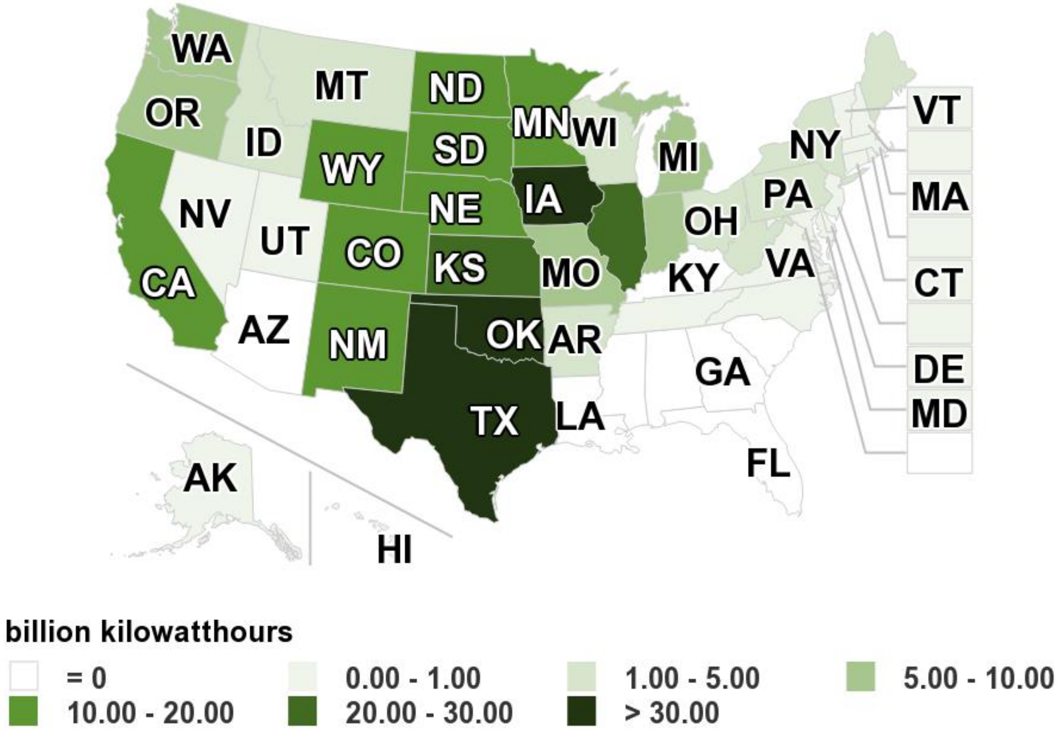


U.S. primary energy consumption by energy source, 2021



Data source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2022, preliminary data
Note: Sum of components may not equal 100% because of independent rounding.

U.S. utility-scale wind electricity generation by state, 2022

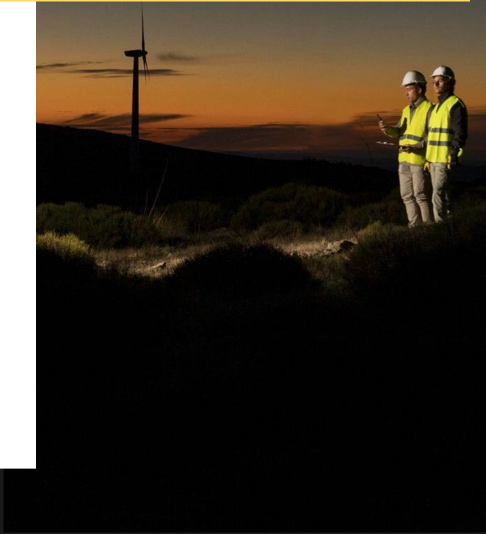


eia Data source: U.S. Energy Information Administration, *Electric Power Monthly*, Table 1.14.B, February 2023, preliminary data

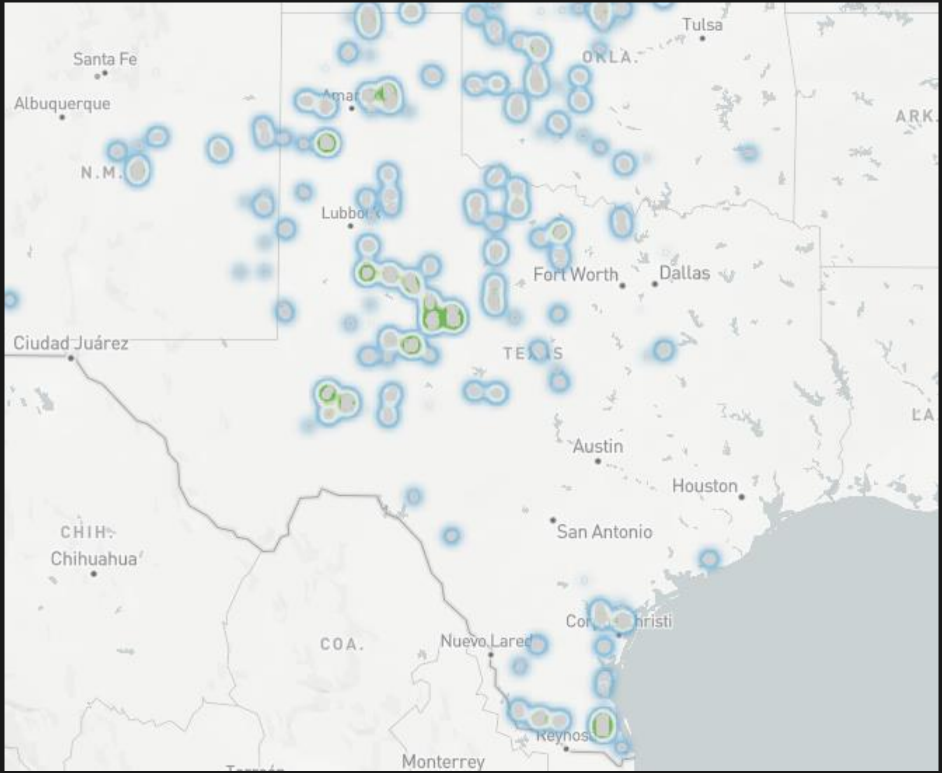
Texas
113.88 BkWh

Iowa
44.664 BkWh

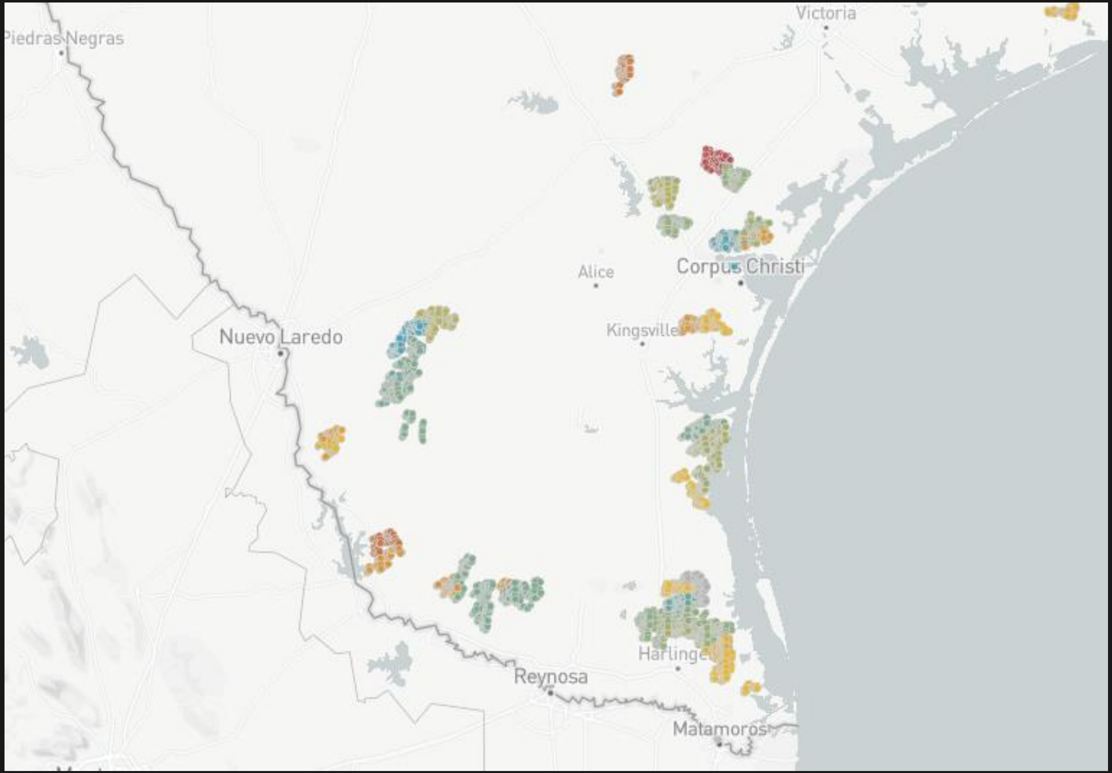
Oklahoma
37.418 BkWh



Texas is situated in a natural wind belt that generates a high volume of wind.



Texas is situated in a natural wind belt that generates a high volume of wind.



Texas is situated in a natural wind belt that generates a high volume of wind.

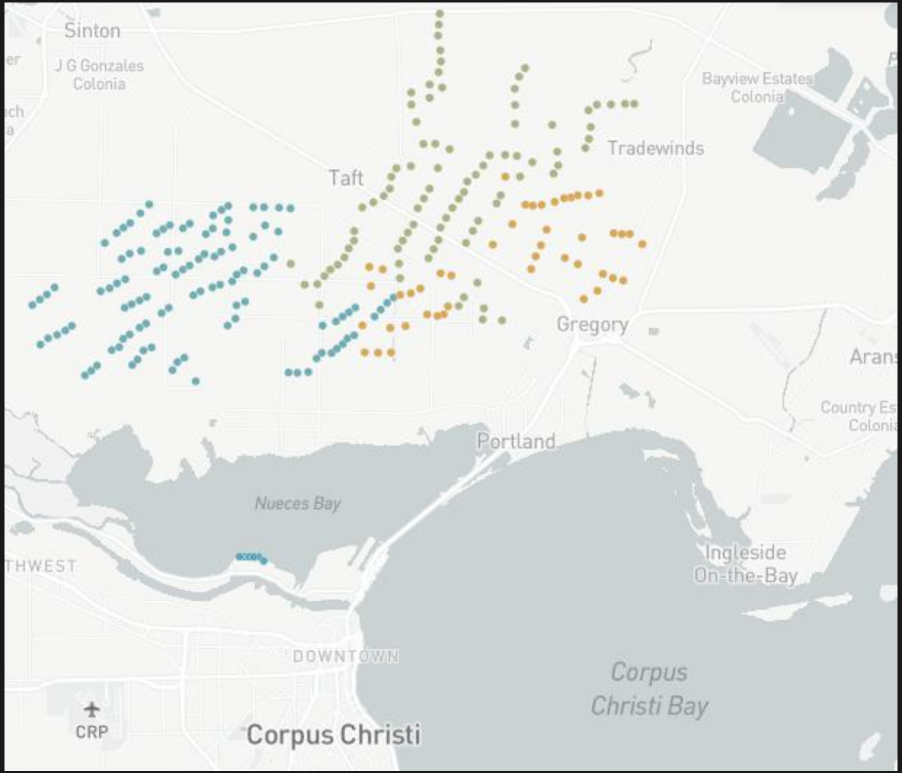
Questions for consideration:

1. Organize

1. Reduce Fatigue over time

1. Optimal Power Production

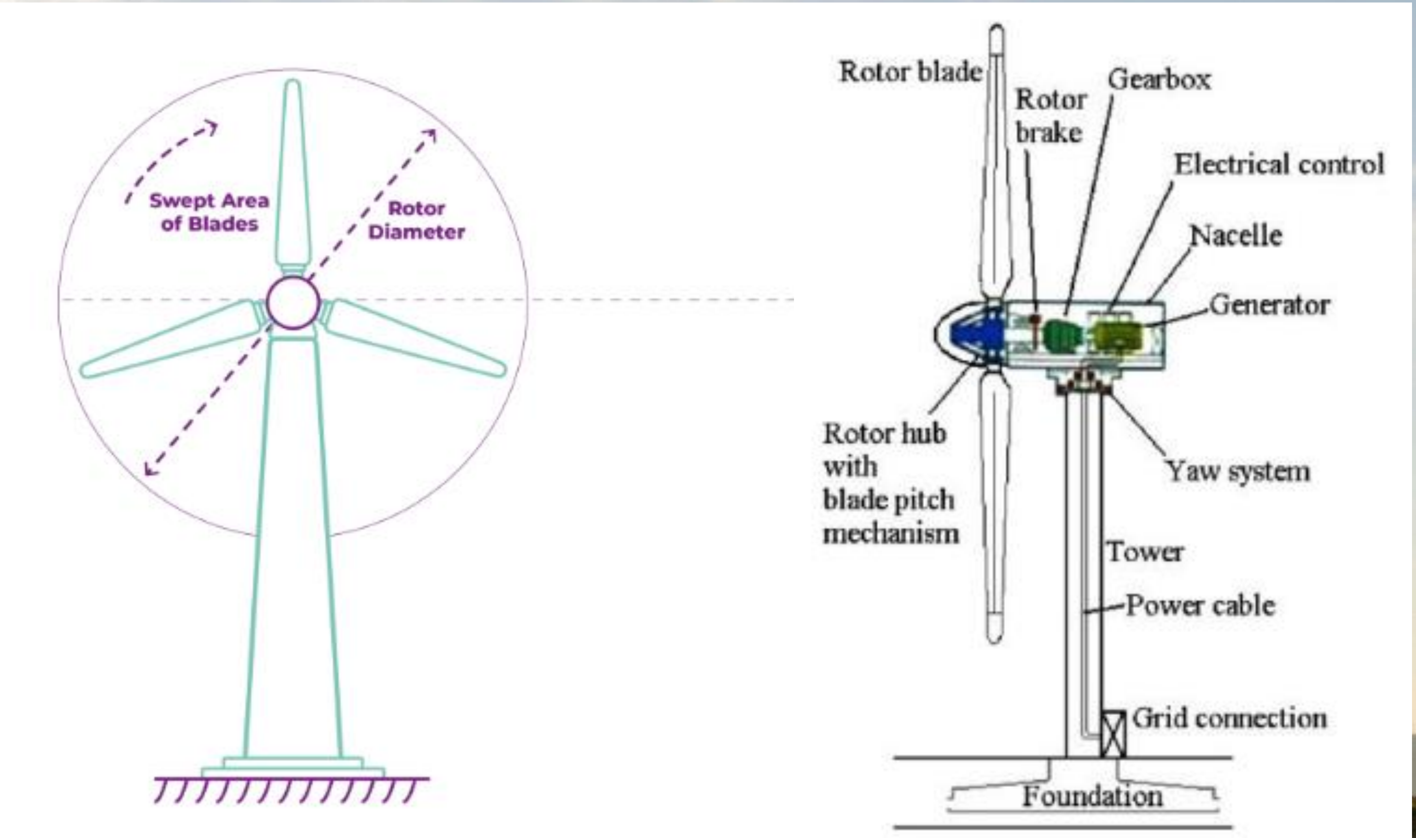
1. Reduce Environmental Impact



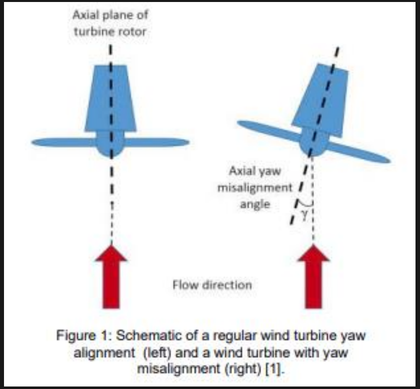
Research Objectives

- Investigate the effectiveness of turbine coordination techniques to optimize power production.
- Investigate how the use of turbine coordination techniques may enhance overall performance.
- Investigate the impact of turbine coordination techniques in reducing fatigue loads.
- Investigate the scalability and applicability of turbine coordination techniques.

Wind Turbine Components

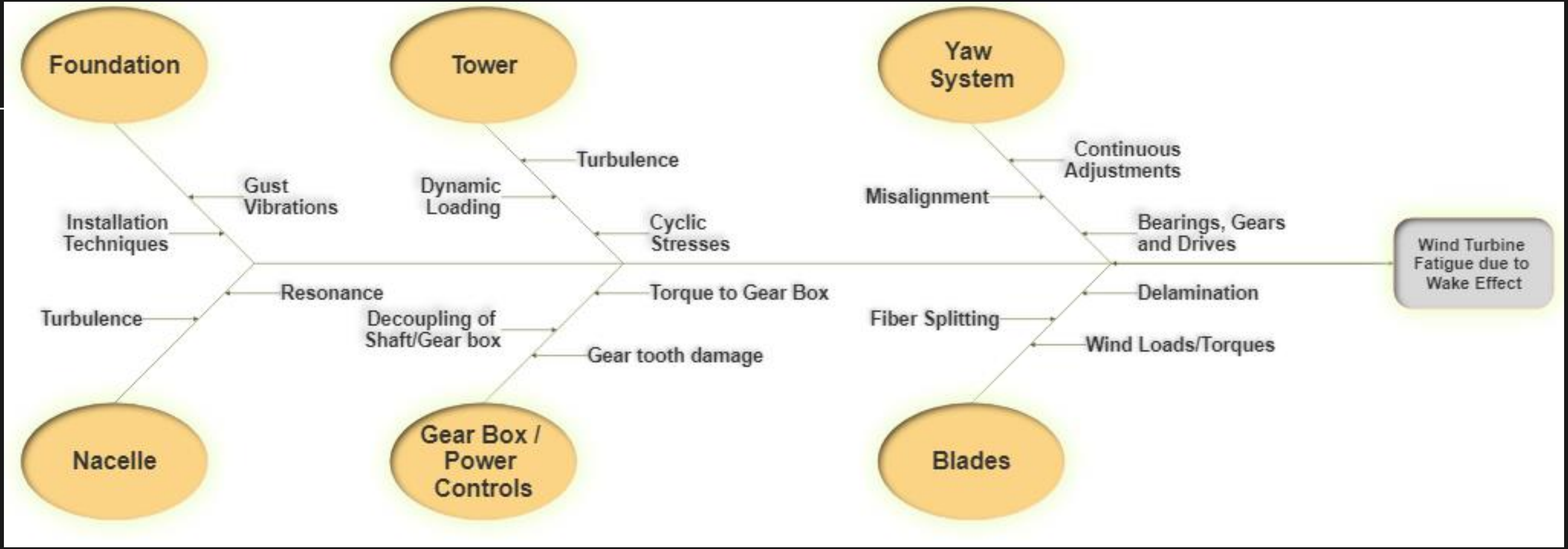


Wind Turbine Fatigue

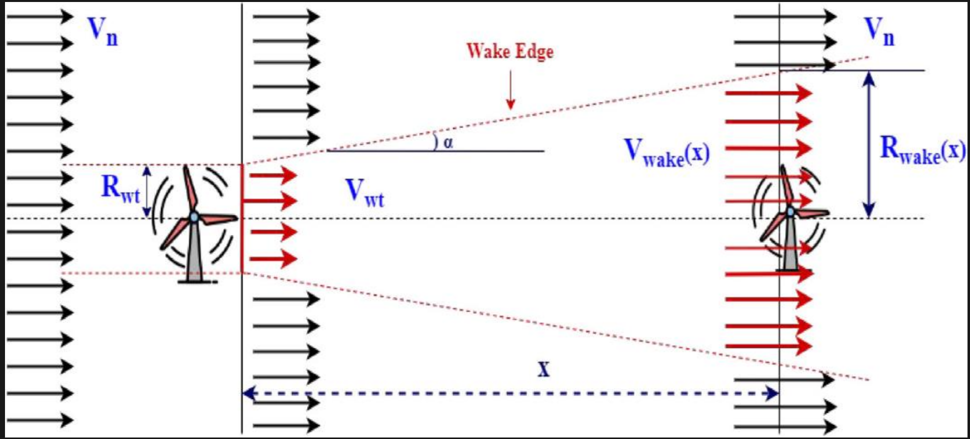


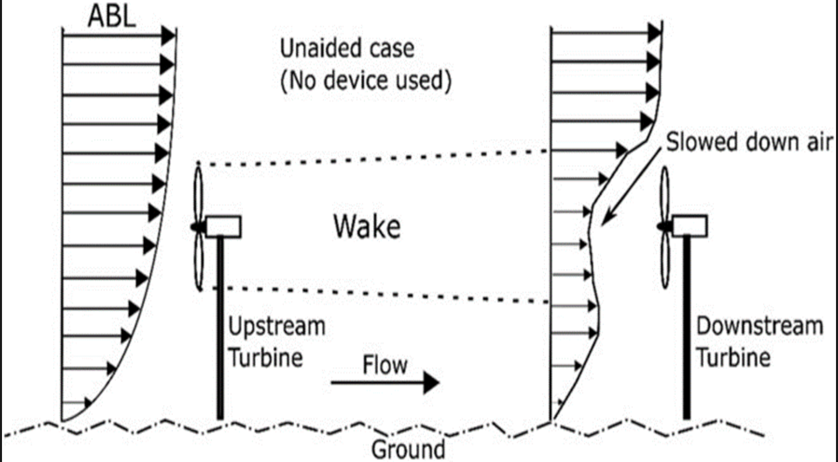
Improper Installation
Corrosion
Delamination
Forces of Nature
Wake Effect

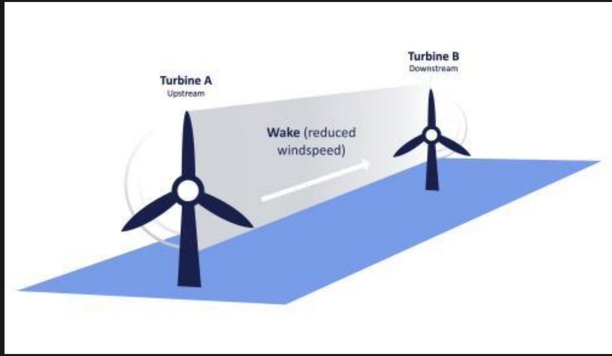
Fatigue due to Wake Effect



Wake Effect


V_n
Wake Edge
α
$V_{wake}(x)$
$R_{wake}(x)$
R_{wt}
V_{wt}
V_n
x


ABL
Unaided case
(No device used)
Slowed down air
Wake
Upstream
Turbine
Flow
Downstream
Turbine
Ground


Turbine A
Upstream
Turbine B
Downstream
Wake (reduced
windspeed)

Jensen Model and Formula Based Data

Equation #1

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

downstream wind speed

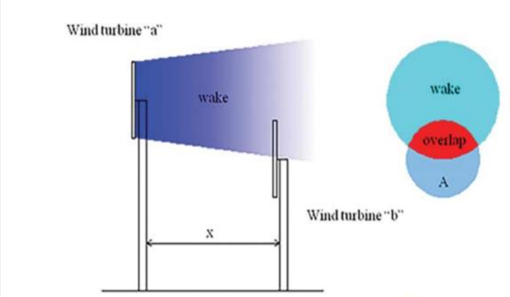


Figure 1. Scheme of a wake model with different height wind turbines (Chen et al. 2013).

Equation #2

$$U_{\text{def}} = \frac{2a}{(1 + \alpha(x/r_r))^2}$$

"Slow down zone"
axial induction factor
(Capture, Thrust)

Equation #3

$$\alpha = \frac{0.5}{\ln(z/z_0)}$$

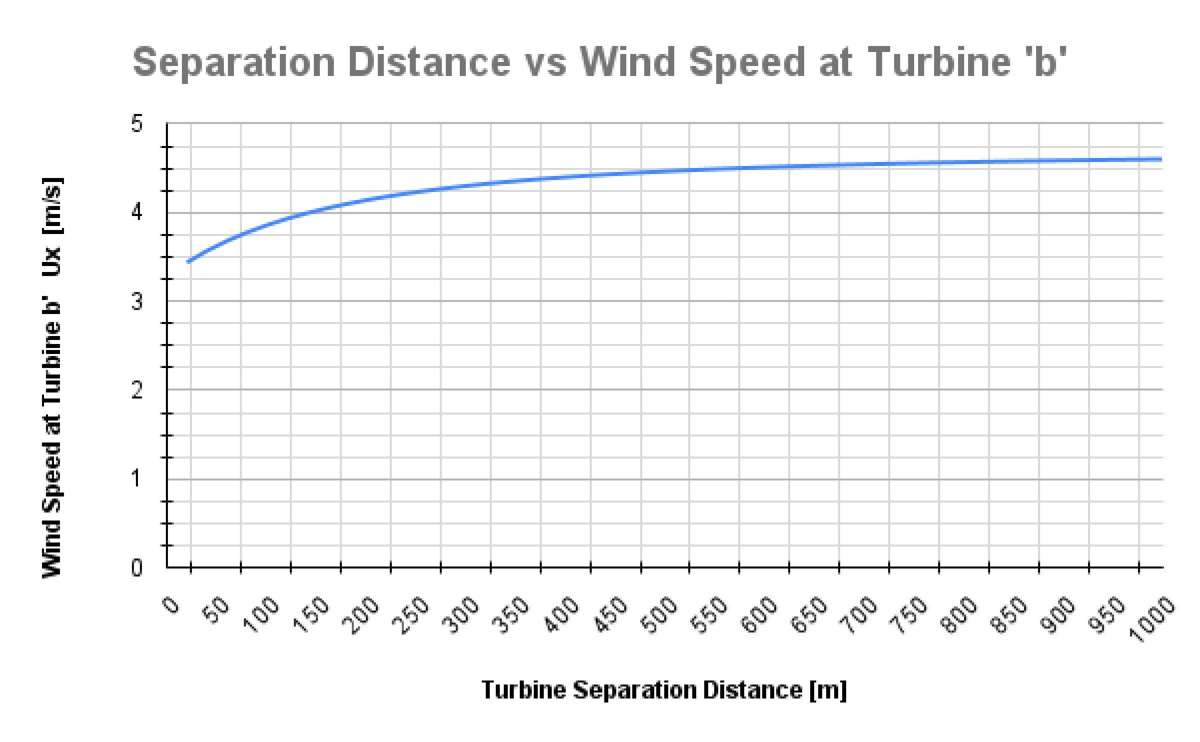
entrainment constant (wake size)

Equation #4

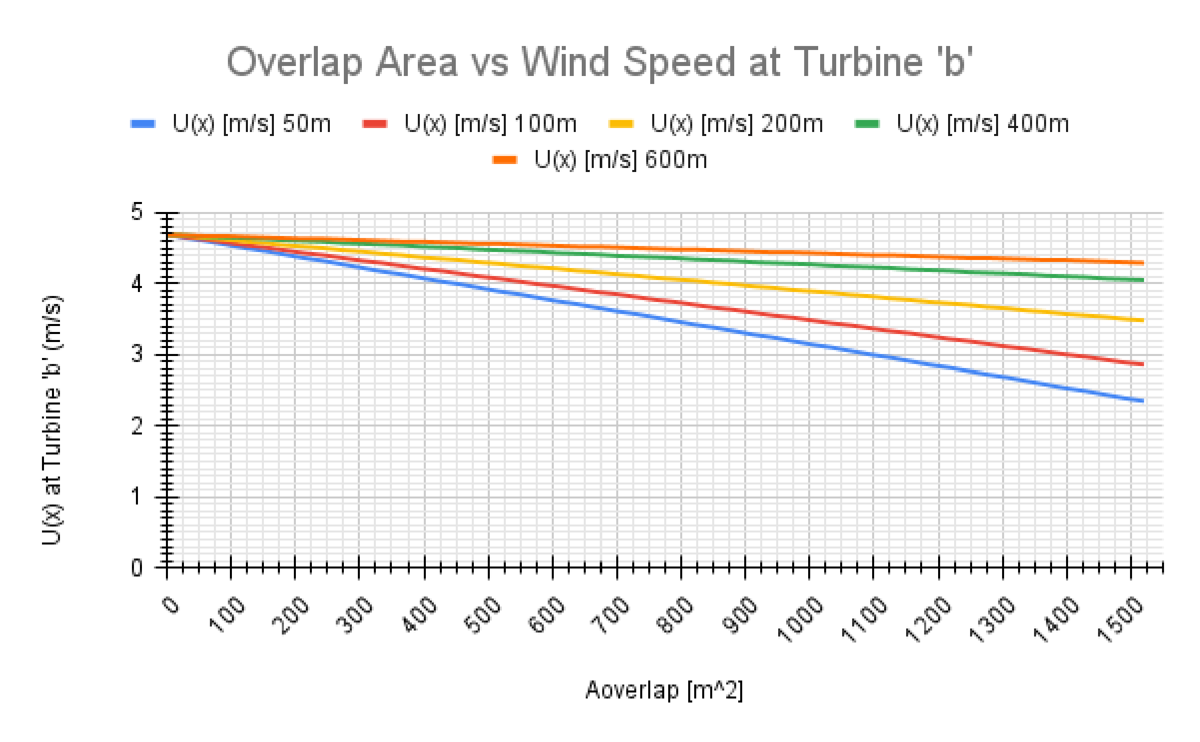
$$r_1 = \alpha x + r_r$$

wake radius

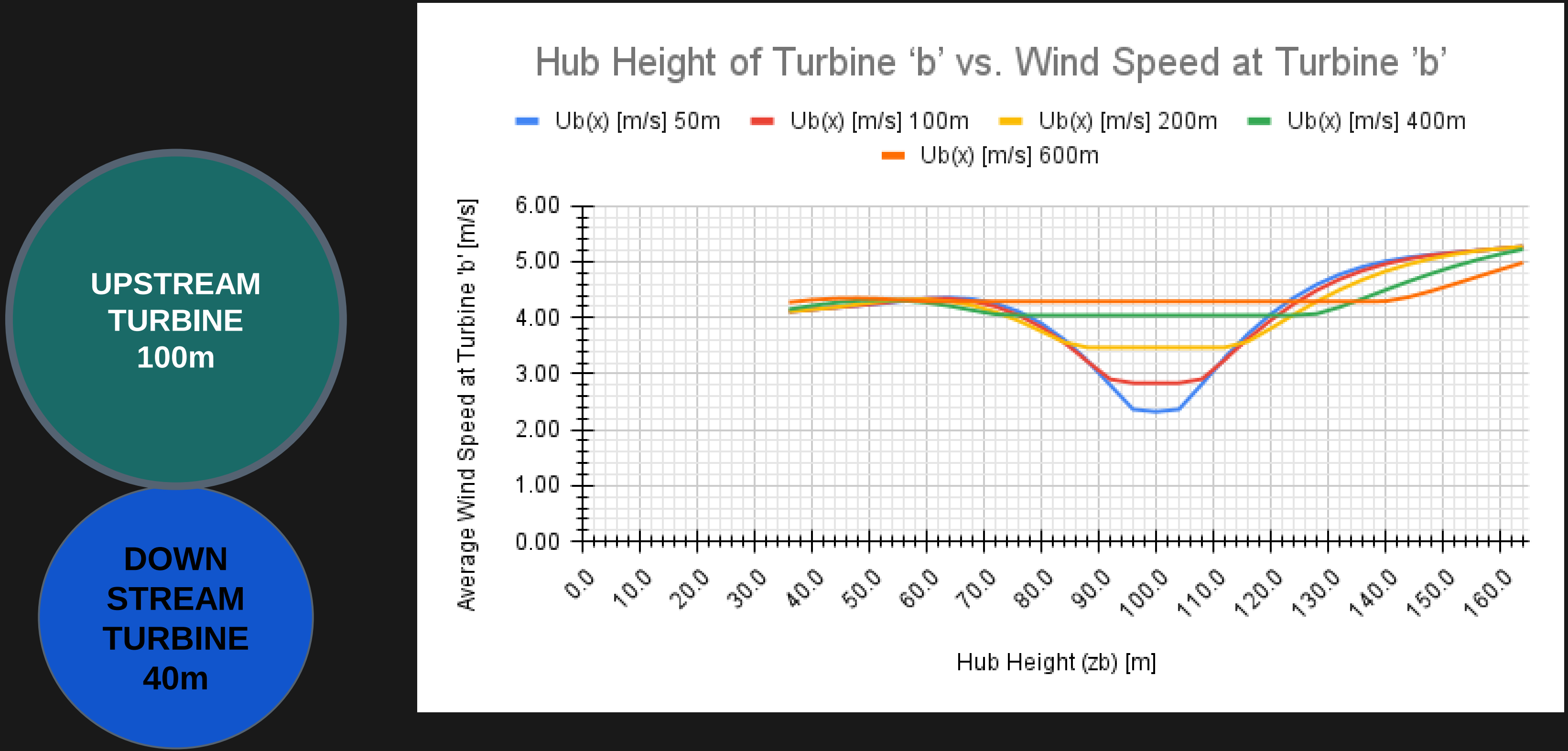
Separation Distance vs. Turbine 'b'



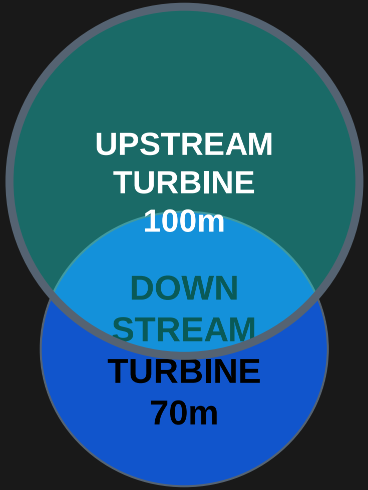
Overlap Area vs. Wind Speed at Turbine ’b’

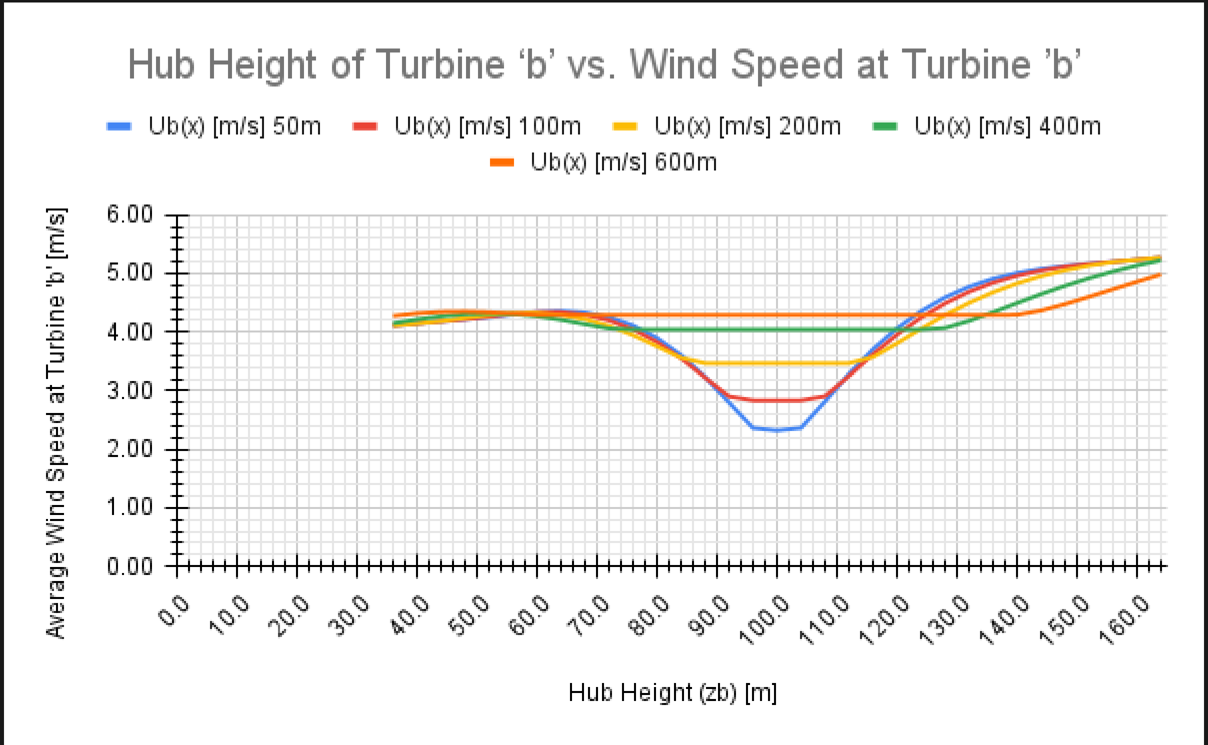


Hub Height at ‘b’ vs. Wind Speed at ’b’

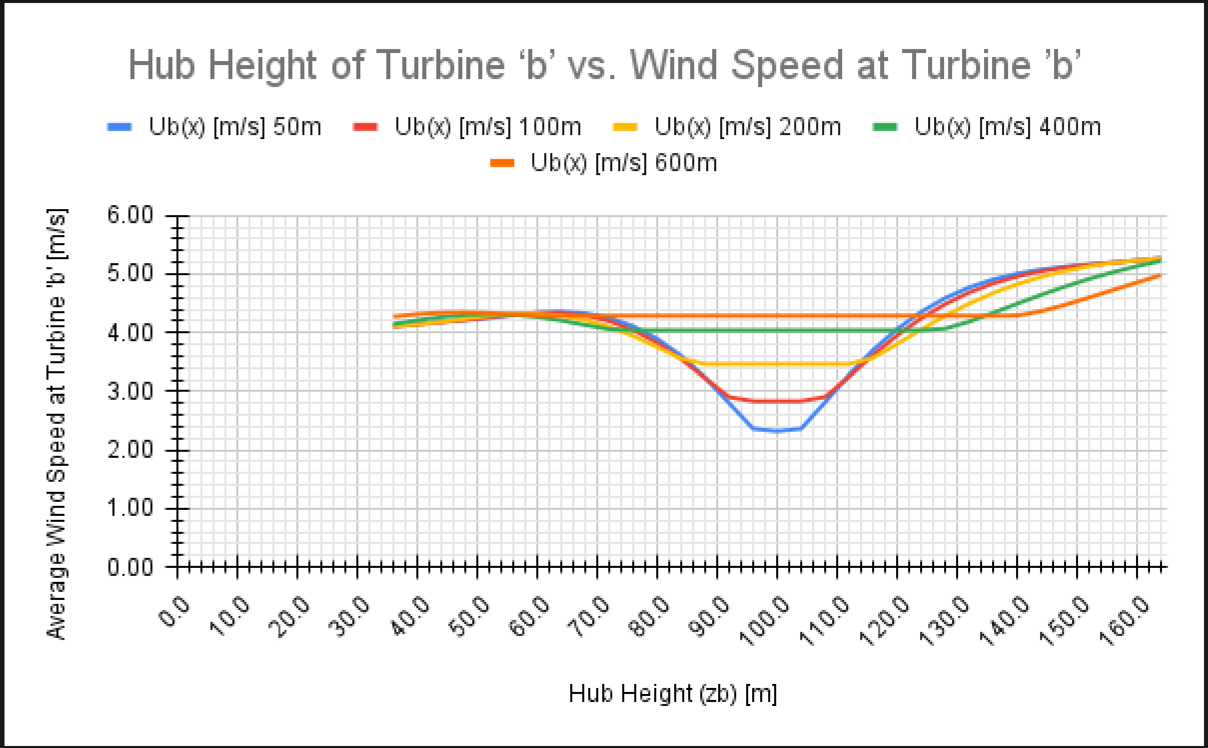


Hub Height at ‘b’ vs. Wind Speed at ’b’

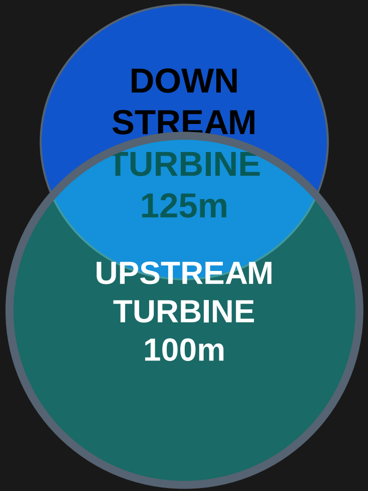


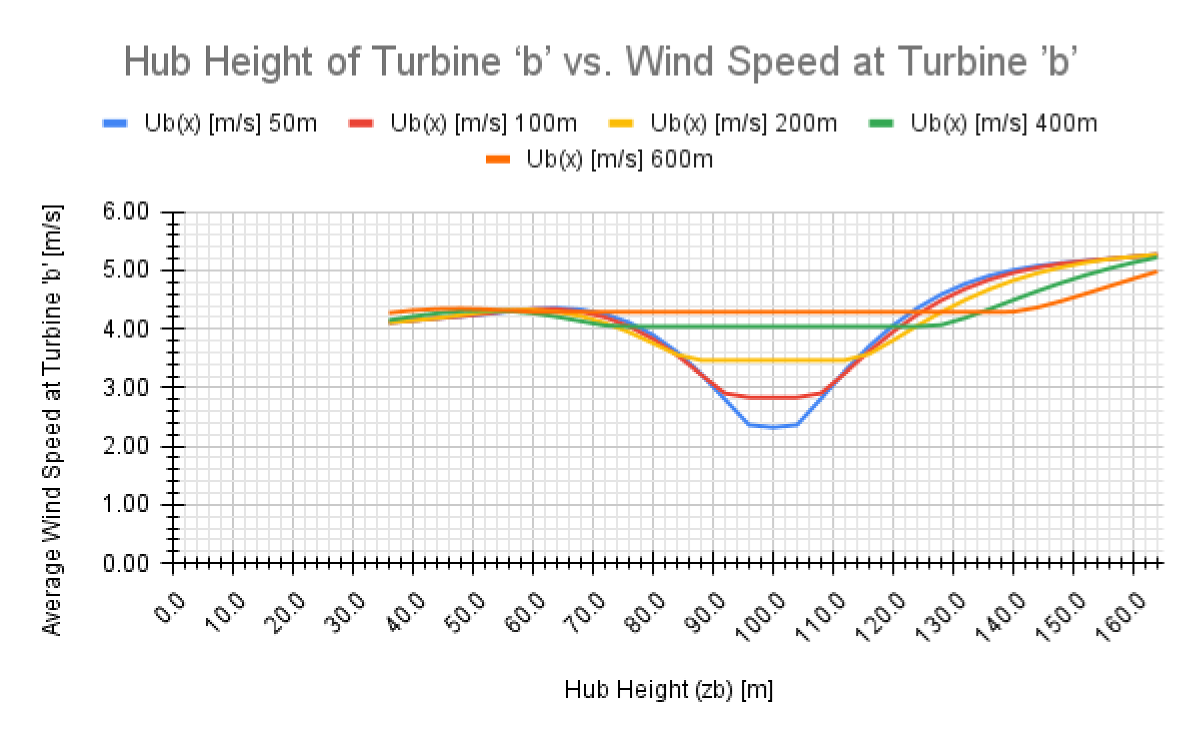


Hub Height at ‘b’ vs. Wind Speed at ’b’

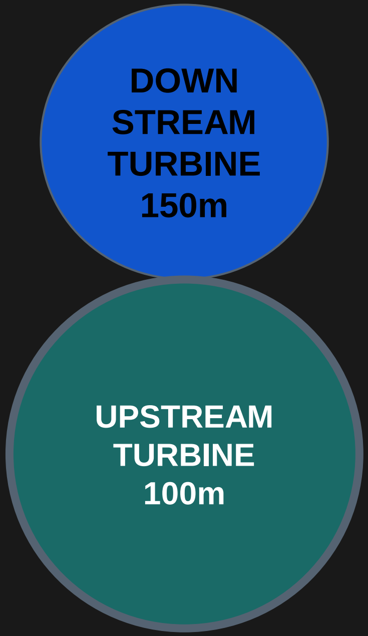


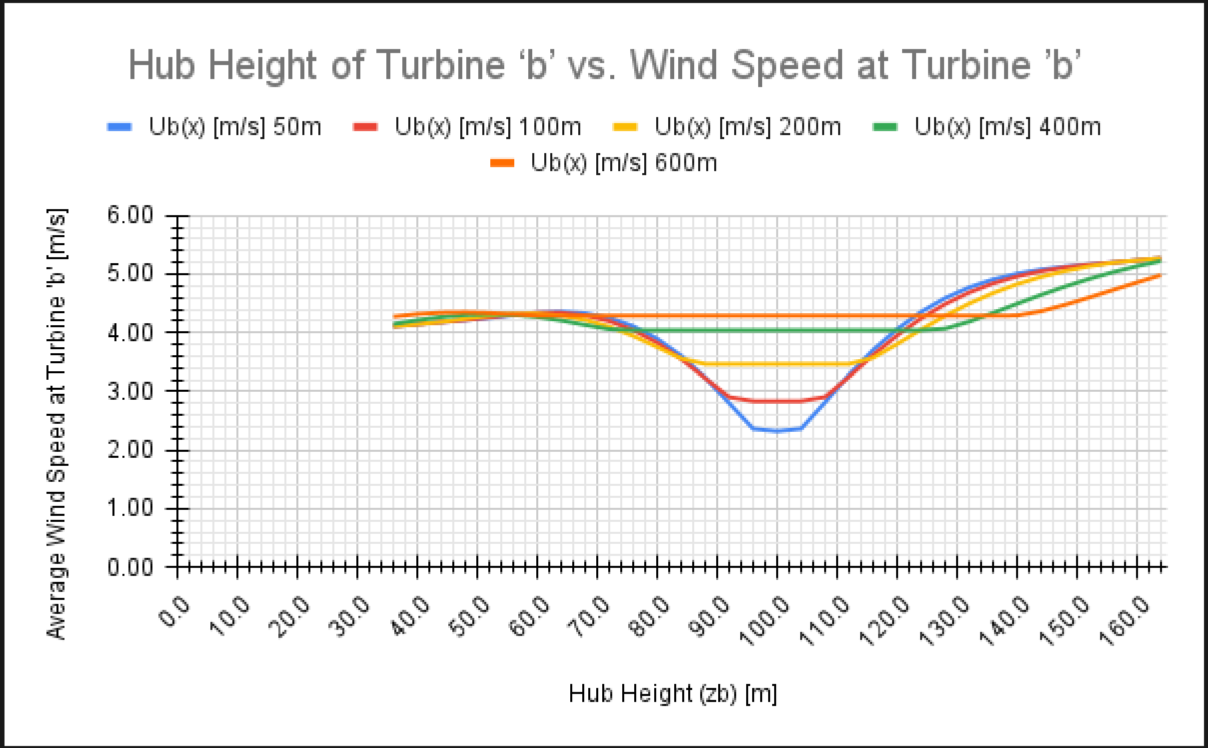
Hub Height at ‘b’ vs. Wind Speed at ’b’





Hub Height at ‘b’ vs. Wind Speed at ’b’





Equipment and Experimentation

Part 1

Create grid array

Gather baseline wind data using the anemometer

Part 2

Use baseline data from upstream turbine to get wake effect wind data

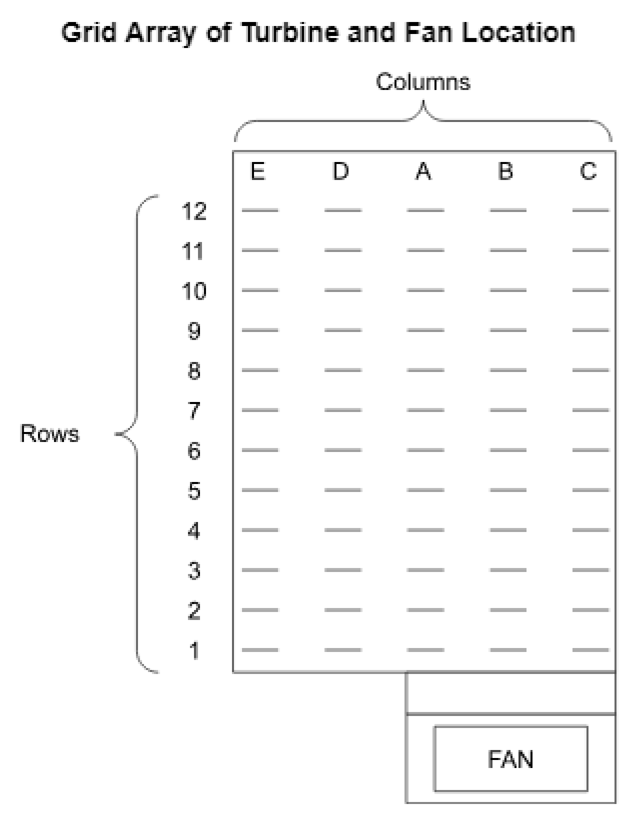
Compare baseline wind speeds to wake effect wind speeds

Part 3

Gather voltage data for upstream and downstream turbine

Analyze data to look for locations depicting greater power output within the wake

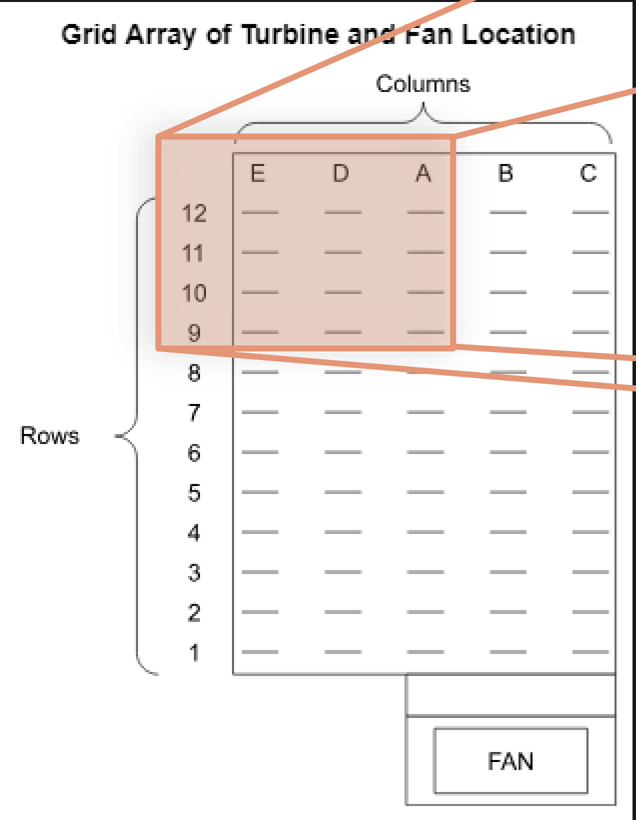
Setup

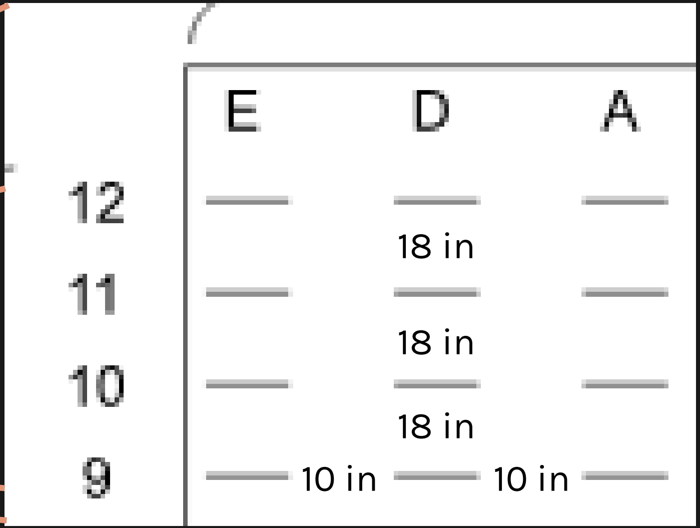


Grid Array of Turbine and Fan Location
Columns
E D A B C
Rows
12
11
10
9
8
7
6
5
4
3
2
1
FAN

Wind Power

Setup



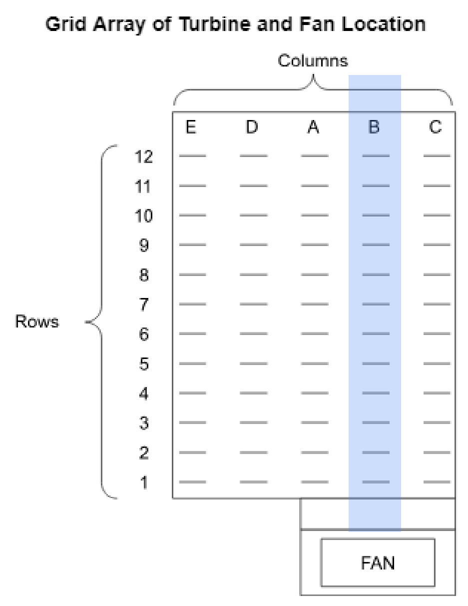


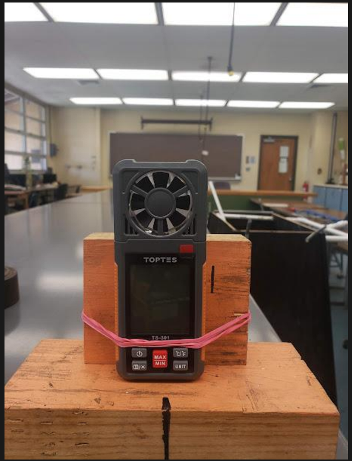
Displacements and Angles from Center of Fan										
Row Position	Column Position									
	A		B		D		E		C	
	Displacement (m)	Angle (°)	Displacement (m)	Angle (°)	Displacement (m)	Angle (°)	Displacement (m)	Angle (°)	Displacement (m)	Angle (°)
1	0.83	107.88	0.79	90.00	0.94	122.83	1.10	134.06	0.83	72.12
2	1.27	101.53	1.24	90.00	1.34	112.20	1.46	121.48	1.27	78.47
3	1.72	98.49	1.70	90.00	1.78	106.62	1.86	114.12	1.72	81.51
4	2.17	96.71	2.16	90.00	2.22	103.24	2.29	109.44	2.17	83.29
5	2.63	95.55	2.62	90.00	2.67	100.99	2.72	106.24	2.63	84.45
6	3.08	94.72	3.07	90.00	3.12	99.39	3.17	103.92	3.08	85.28
7	3.54	94.11	3.53	90.00	3.57	98.19	3.61	102.18	3.54	85.89
8	4.00	93.64	3.99	90.00	4.02	97.26	4.06	100.82	4.00	86.36
9	4.45	93.27	4.45	90.00	4.47	96.52	4.51	99.73	4.45	86.73
10	4.91	92.97	4.90	90.00	4.93	95.92	4.96	98.84	4.91	87.03
11	5.37	92.71	5.36	90.00	5.38	95.41	5.41	98.09	5.37	87.29
12	5.82	92.50	5.82	90.00	5.84	94.99	5.87	97.46	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)

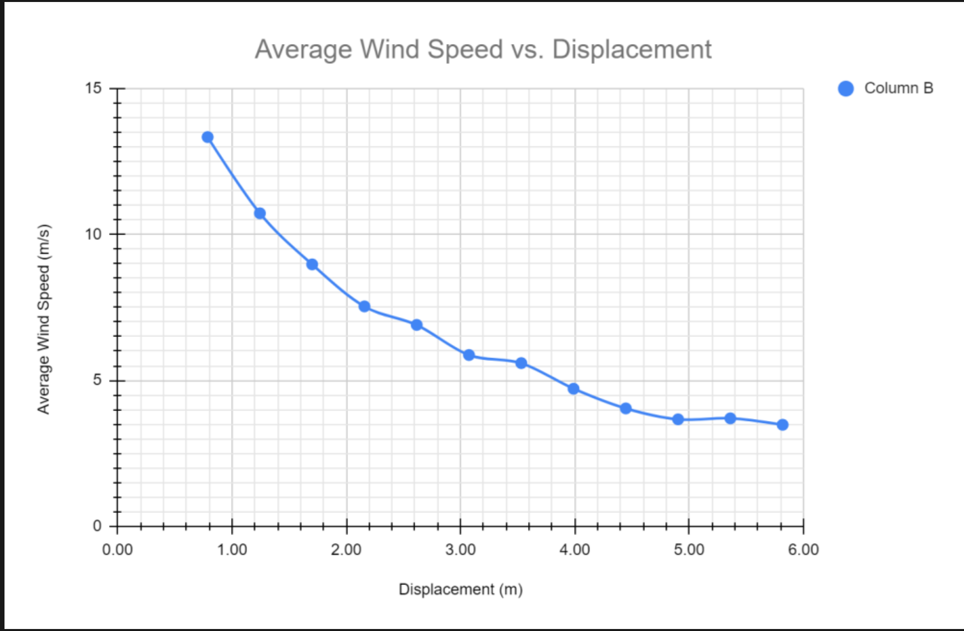
Part 1 - Baseline Average Wind Speed

Grid Array



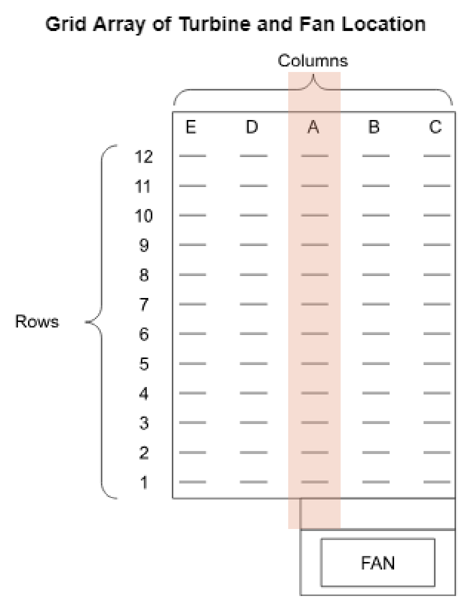


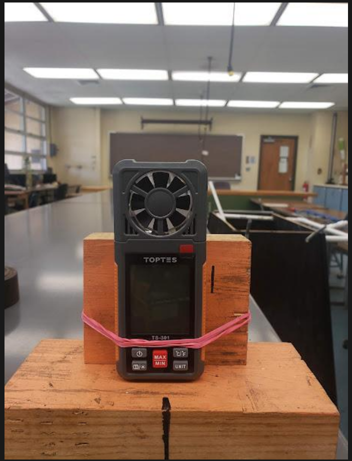
Average Wind Speed



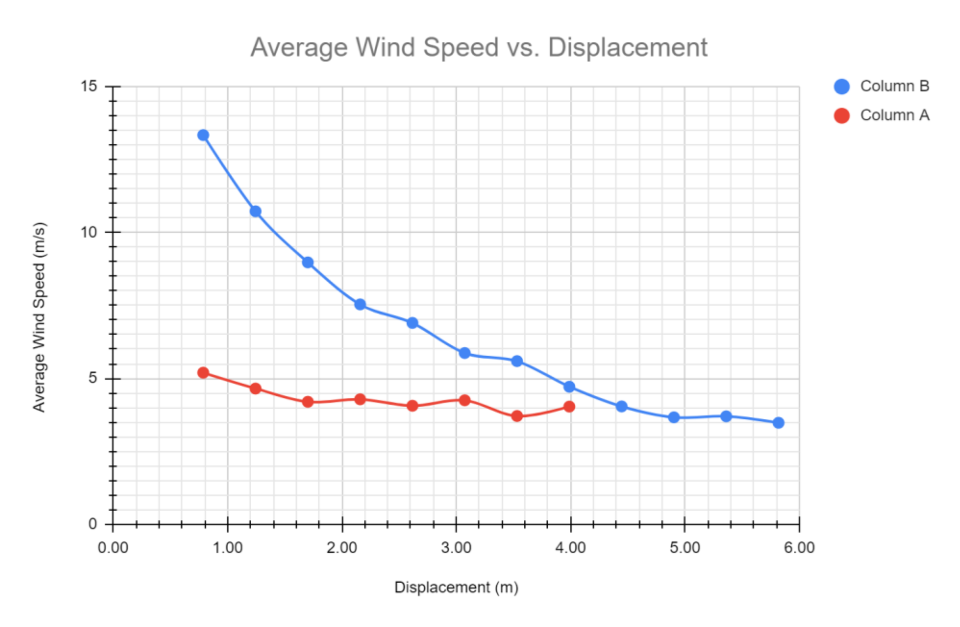
Part 1 - Baseline Average Wind Speed

Grid Array



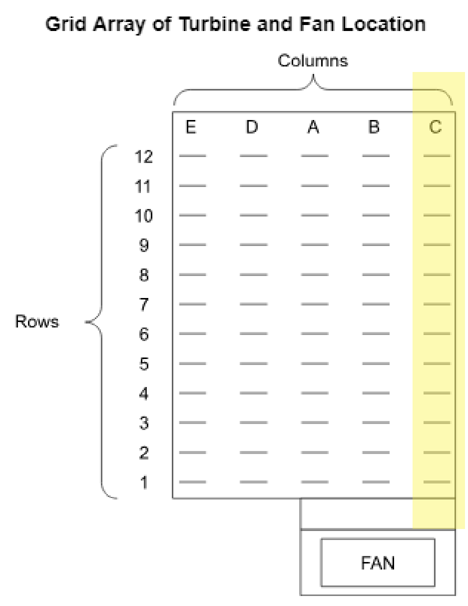


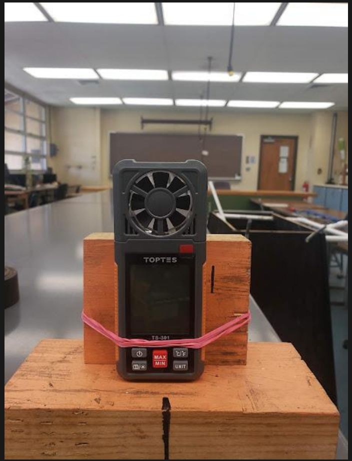
Average Wind Speed



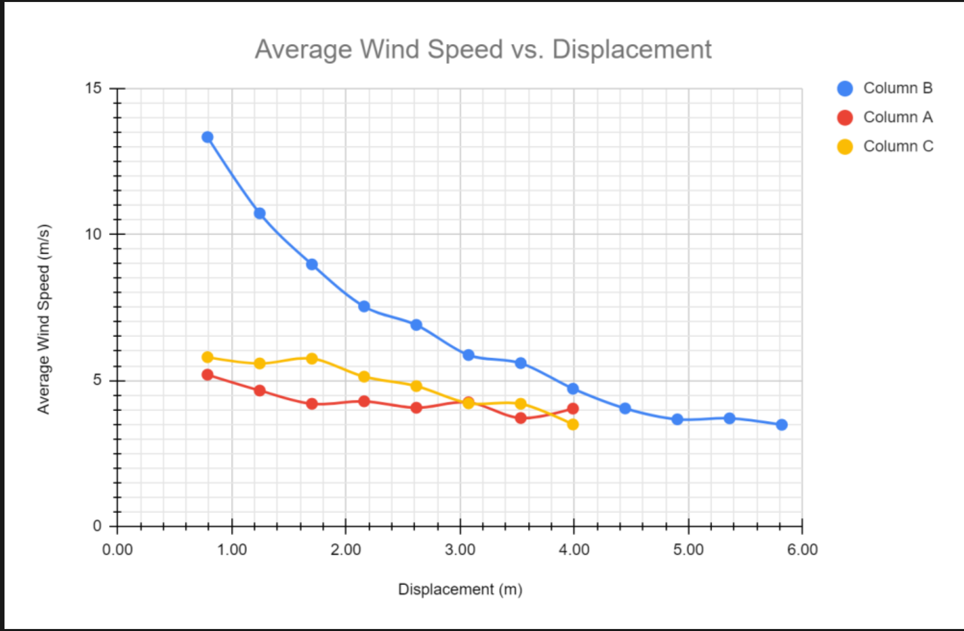
Part 1 - Baseline Average Wind Speed

Grid Array



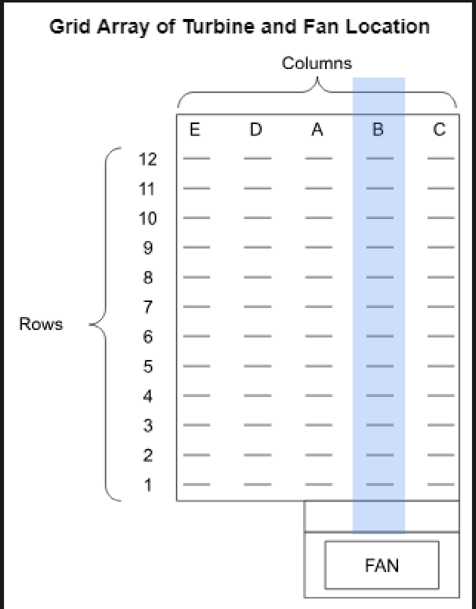


Average Wind Speed

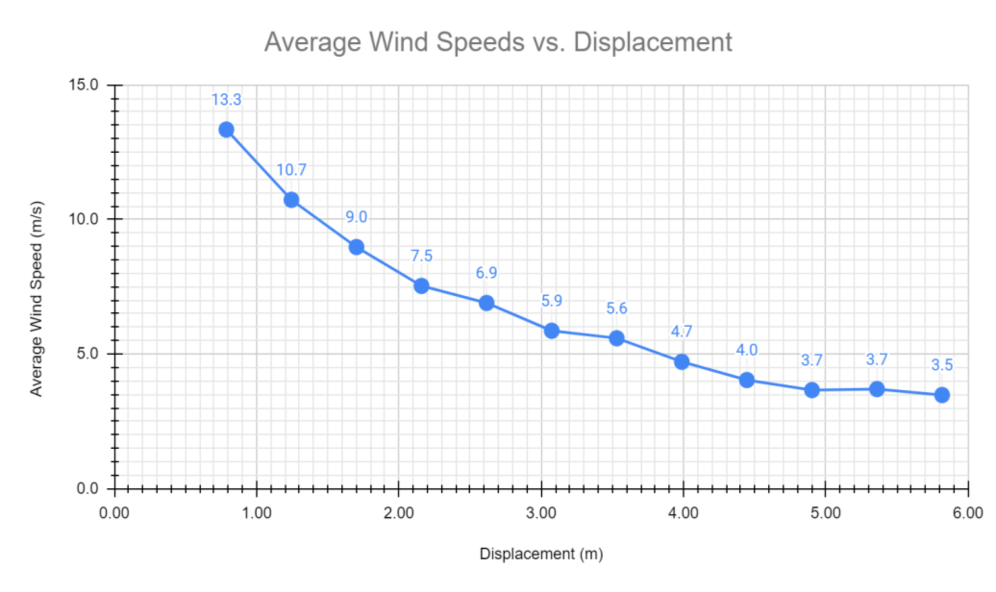


Part 2 - Compare Baseline Averages to Wake Effect Wind Speed Averages

Grid Array

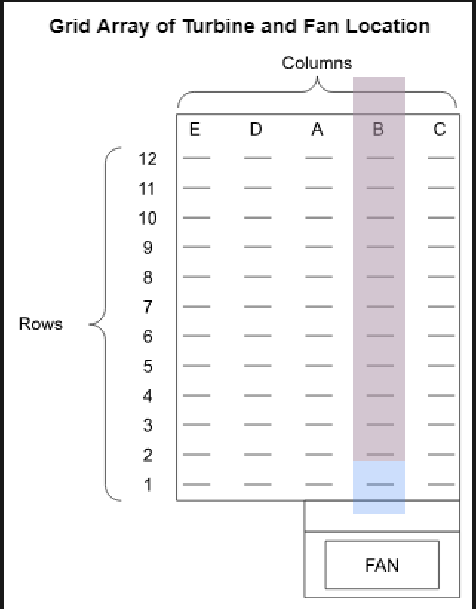


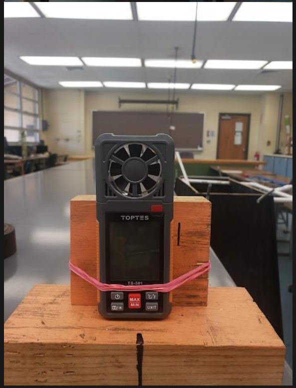
Comparison of Averages



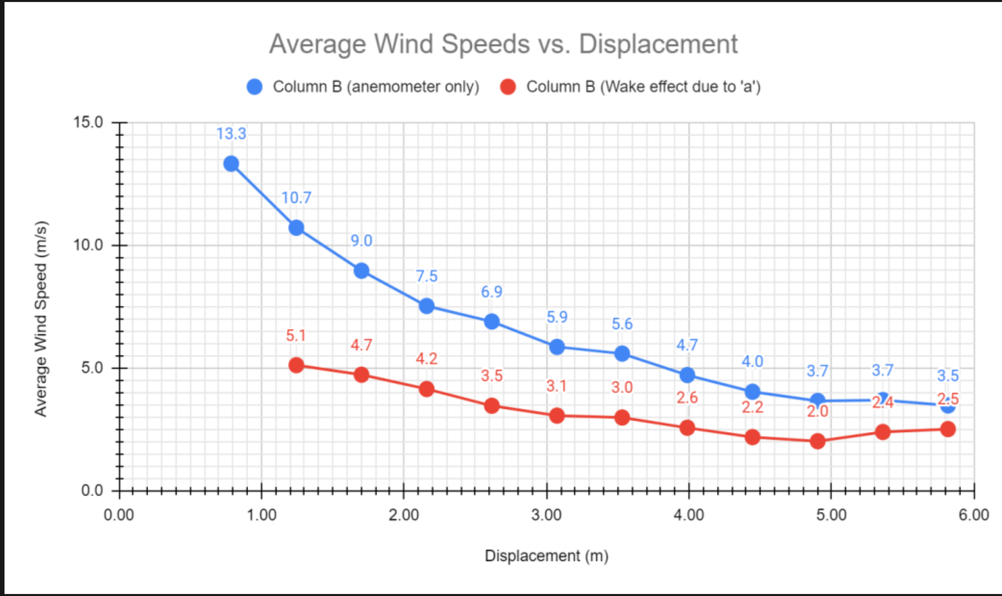
Part 2 - Compare Baseline Averages to Wake Effect Wind Speed Averages

Grid Array



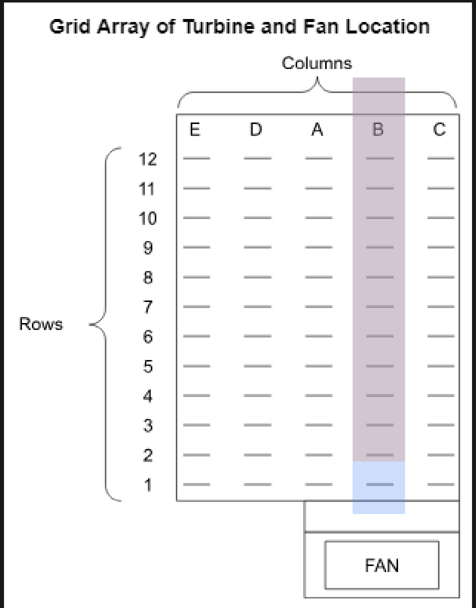


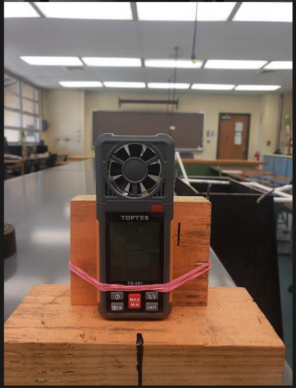
Comparison of Averages



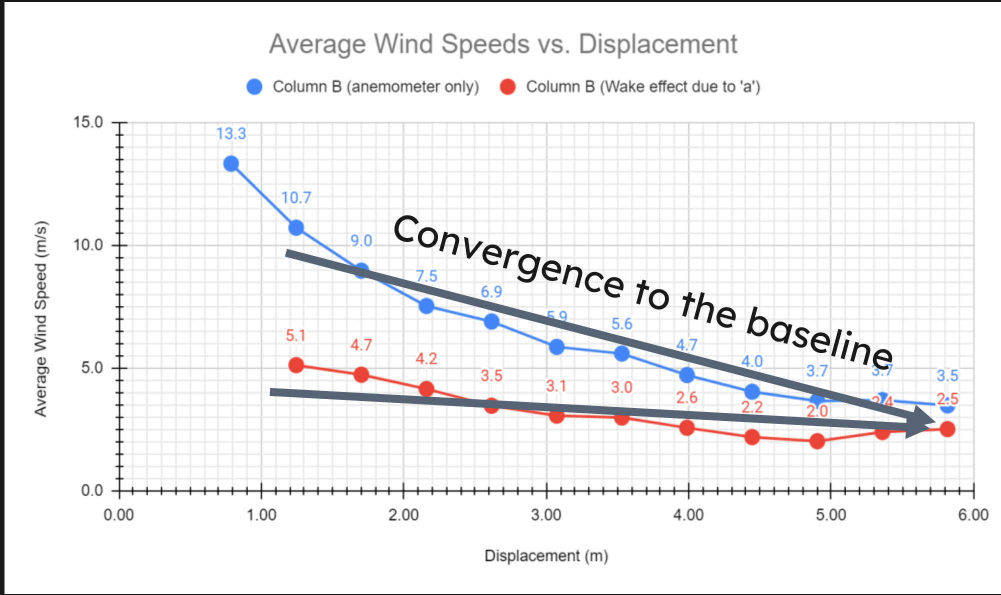
Part 2 - Compare Baseline Averages to Wake Effect Wind Speed Averages

Grid Array



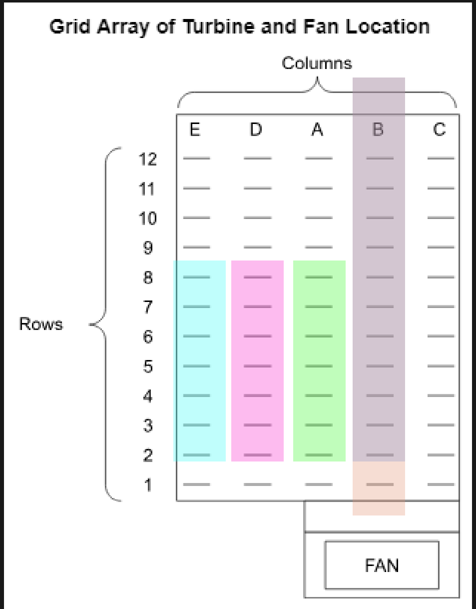


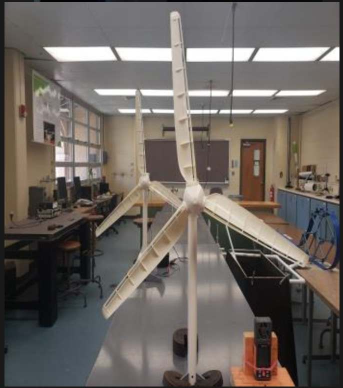
Comparison of Averages



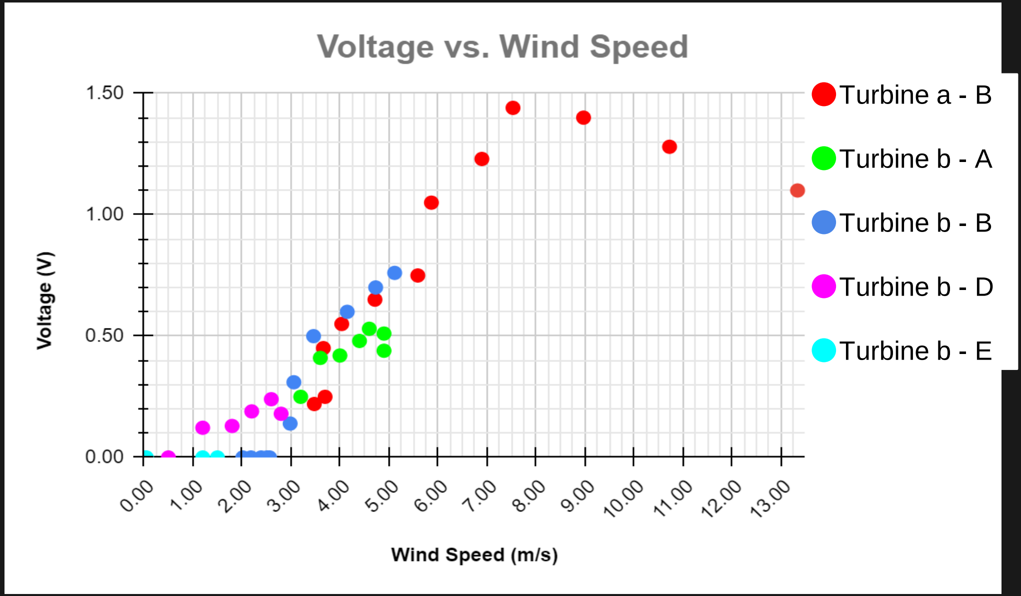
Part 3 - Analyze Voltage Data

Grid Array





Voltage Change with Speed



Part 3 - Analyze Voltage Data

Heat Map of the % of Max Voltage

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

Part 3 - Analyze Voltage Data

Heat Map of the % of Max Voltage

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

Conclusion

Staggered Placement

1. Reduce variations in speed (fatigue)

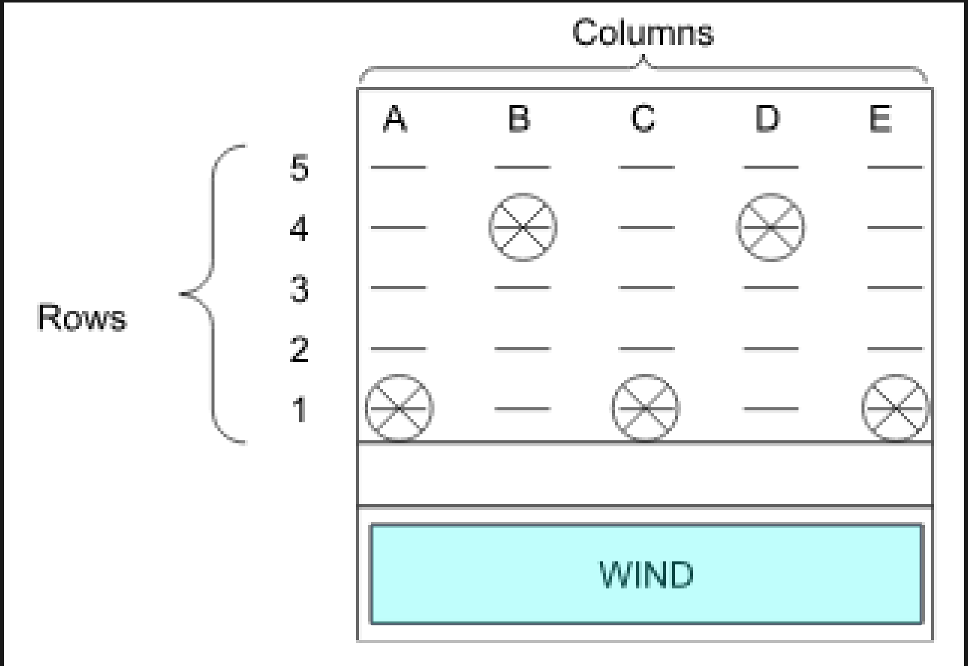
1. Optimal locations for power generation

Future Research

1. Investigate hub height on wind farm coordination

1. Investigate the forces on wind turbines

Optimal Turbine Locations

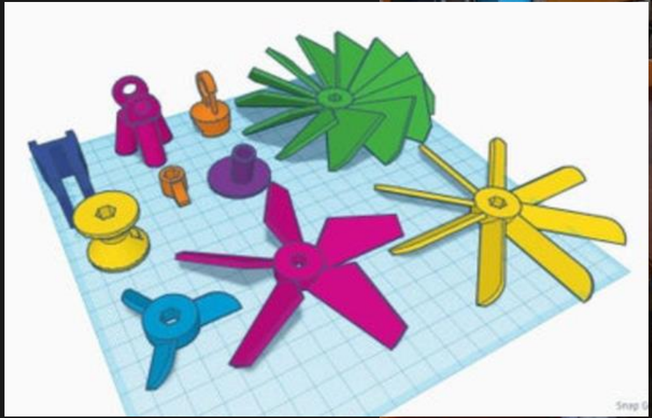


Middle School Modules

- Modules will aid students in understanding the following principles and concepts of wind turbines:
  - Renewable Energy
  - Kinematics (Speed, Velocity, and Vector Displacement)
  - Work, Energy, and Power
  - Rotational Motion (Angular Velocity and Acceleration, Torque, and Angular Momentum)
  - Engineering Design Process

- Objectives
  - Understand the basic principles of wind turbines and their role in converting wind energy to electrical energy.
  - Explore the concept of rotational motion and its application in wind turbine operation.
  - Investigate the relationship between blade movement, wind speed, and energy production.
  - Apply simple mathematical concepts to analyze and compare wind turbine designs.

- Assessments
  - Lab Based (Reports, Journals)
  - Project Based (Create Physical Turbine)



High School Modules

Students need to:

Wind Turbine Investigations: Exploring Physics Principles

Wind Turbine Investigation #1

Students will measure wind speeds and analyze the implications of wake losses.

Wind Turbine Investigation #2

Students will convert wind energy into kinetic energy and analyze rotor energy capture.

Wind Turbine Investigation #3

Students will measure and calculate the angular velocity, acceleration, and torque.

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 author(s) and do not necessarily reflect the views of the National Science Foundation.

Resources

Timeline Nile River (Slide 2) https://images.squarespace-cdn.com/content/v1/534bc290e4b0c263af942021/5ef8f8c9-a26f-4b9d-afbe-a1669507fe98/Ancient+Sailing+Craft+800w.jpg?format=1500w

Pie Chart (Slide 3)
https://www.eia.gov/energyexplained/wind/history-of-wind-power.php#:~:text=People%20have%20been%20using%20wind,Persia%20and%20the%20Middle%20East.

USA Graphic (Slide 4)
https://www.eia.gov/energyexplained/wind/where-wind-power-is-harnessed.php

Wake Effect Model (Slide 12)
https://journals.sagepub.com/cms/10.1177/0309524X221122501/asset/images/large/10.1177_0309524x221122501-fig2.jpeg

Yaw Misalignment (Slide 10)
https://uol.de/f/5/inst/physik/ag/wesys/download/JSK_MasterThesisDescription.pdf

Wake Effect (Slide 12)
https://www.sciencedirect.com/science/article/abs/pii/S0960148117308790

Thanks!

Do you have any questions?