Solar Radiation Big Data Analysis for Strategic Positioning of Solar Panels

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Faculty Mentors: Dr. Mohammad M. Hossain and Dr. Marsha Sowell
Student Mentor: Lovekesh Singh
Industrial Advisor: Kevin Rees, P.E.

Abstract

The primary goal of this project is to learn the use of big data available on the National Renewable Energy Laboratory (NREL) solar position and intensity (SOLPOS) calculator, and use Microsoft Excel to analyze the data for strategic positioning of solar panels. The team collected data from SOLPOS to verify changes in solar irradiance (ETR) in latitude and longitudinal locations North, East and West of Corpus Christi, Texas. The irradiance was found to differ significantly between North and South locations, however little difference can be found between cities from West to East. In addition to measuring the solar radiation, the team gathered experimental data from Bishop, Texas and Corpus Christ, Texas to compare with the SOLPOS. The measured ETR was found to be consistently lower than the SOLPOS data. Temperature difference between the front and back of the solar panel showed dependence on the location and positioning of the panel.

Research Methodology

1. The NREL SOLPOS website was explored to obtain information on the ETR for several desired locations in the North America.
2. The SOLPOS website was used to obtain data for the desired locations which had similar Latitude and similar Longitude for comparison.
3. Extraterrestrial Tilted Irradiance (ETR) simulation data for 0°, 15°, 30°, and 45° tilted surface were gathered at 30 minutes intervals from January 1, 2023, through January 1, 2024.
4. Power of the solar panel was calculated (E = A*R*H*PR) at each time interval for every tilt orientation [E= Energy output from photovoltaic cell, A = Area of photovoltaic cell, R = Efficiency of photovoltaic cell, H = Solar Irradiance, PR = Performance rating with Industrial standard = 0.7]
5. For experimental data, the Fluke IRR1 meter and the Portable Segway Solar Panel were utilized; the portable solar panel was set up at 0°, 15°, 30°, and 45° tilt every hour and ETR measurements were taken. After 10 minutes delay, between angles, the temperature measurement was taken on front and back of the panel.
6. Data was then entered into Microsoft Excel and analyzed using a variety of methods.

Curriculum Module 1

Objective: Students will graph, interpret, and analyze data on solar panels to determine the *best graph for the data and decide the optimal angle placement of solar panels in Corpus Christi in addition to the students' city choice in Table 1.1.* TEKS – P1.A-G & P2.A-D

Day 1: Whole group instruction which reviews the process to graph Sin and Cos in Microsoft Excel and generate trigonometric graphs from the data using Worksheet "Graphing Lab A". Students may reference the video and instructional guide located in the Canvas module for additional instructions.

Students will prepare a ticket out the door to submit on Canvas during the last 5 minutes of class. The ticket out the door will be a short list of the steps necessary to enter data and create a sin or cos graph from that data using Microsoft Excel and/or Ti-NSpire.

Day 2: Students will be given "Graphing Lab B" to work on individually (with shoulder and or table partners if assistance is necessary). Students will use the SOLPOS website to obtain data on the city they have chosen. The students will utilize Microsoft Excel to analyze and graph the data. Once students have completed "Graphing Lab B" students will compare their solutions with the other students at their table.

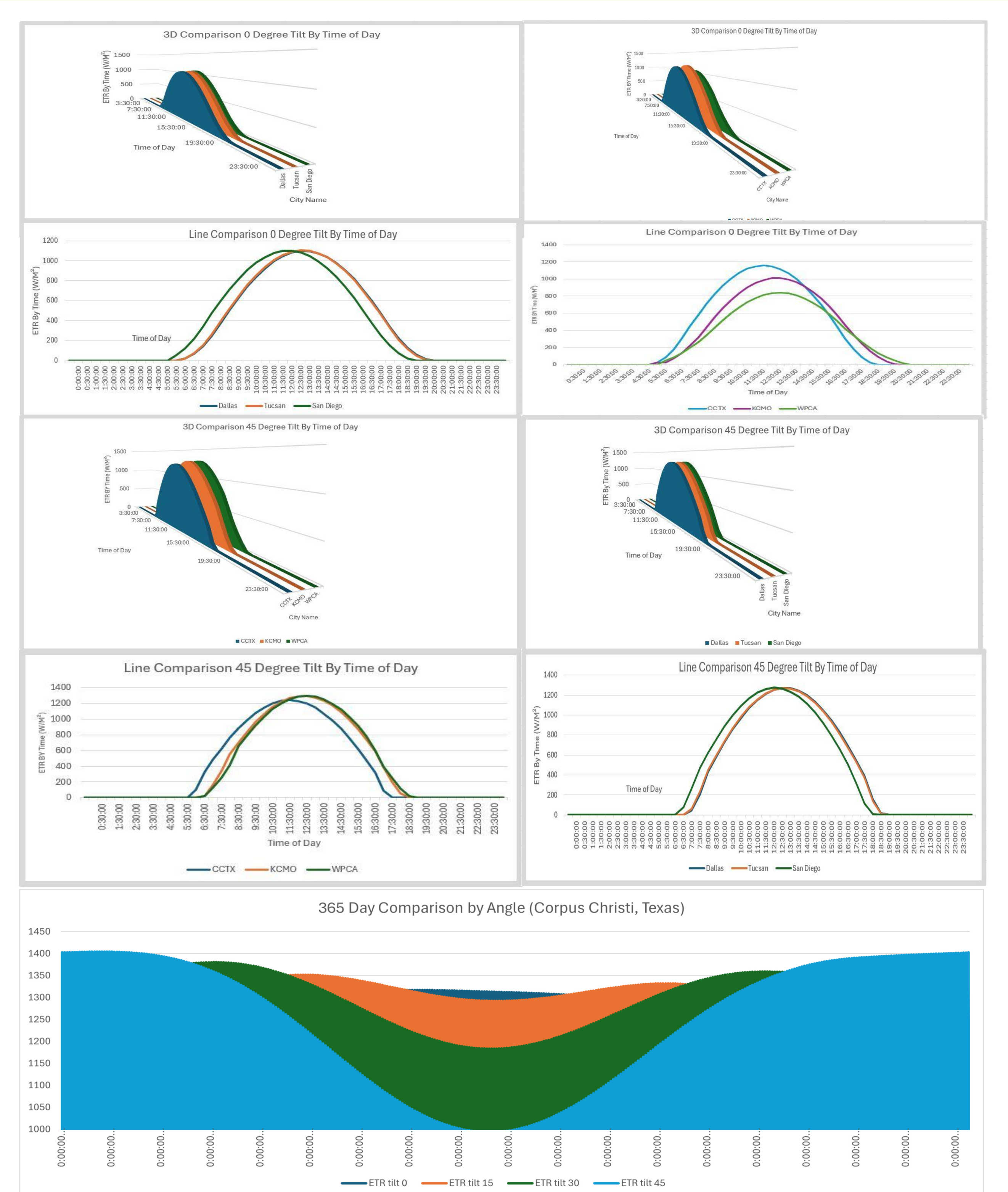
Students will compare their solutions with the posted solutions for "Graph Lab A" and "Graph Lab B" and compete a google questionnaire located on canvas about their results as a ticket out the door.

Day 3: Students will be instructed on the use of the IRR Data Meter and the Solar Panel operation and use. Students will collect and record experimental data for Table 2.2 throughout the day.

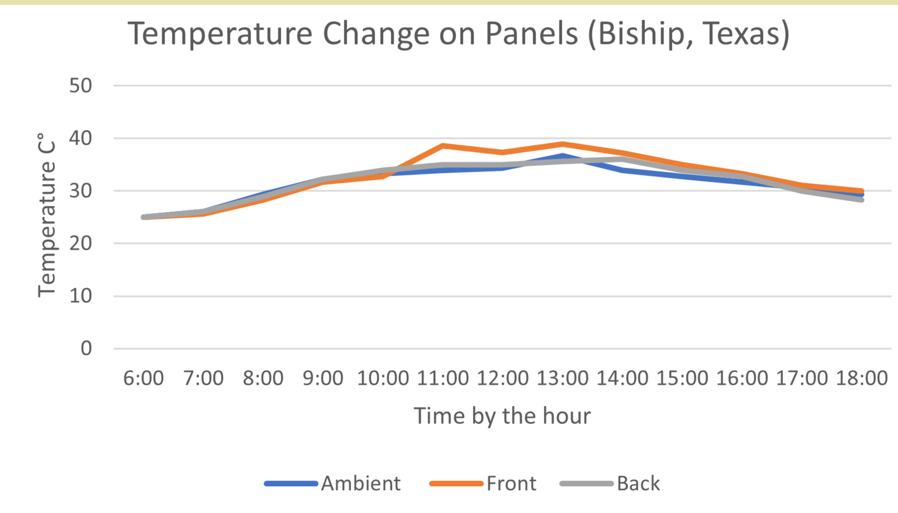
Day 4 & Day 5: Students will work in small groups and use as workdays to finalize their reports / PowerPoint presentations. Students will compile their data and create a Lab report using the "Analysis and Data Report" as a guide to thoroughly describe the solar data exploration activities, computations, and data findings. Student groups will present findings on Day 5.

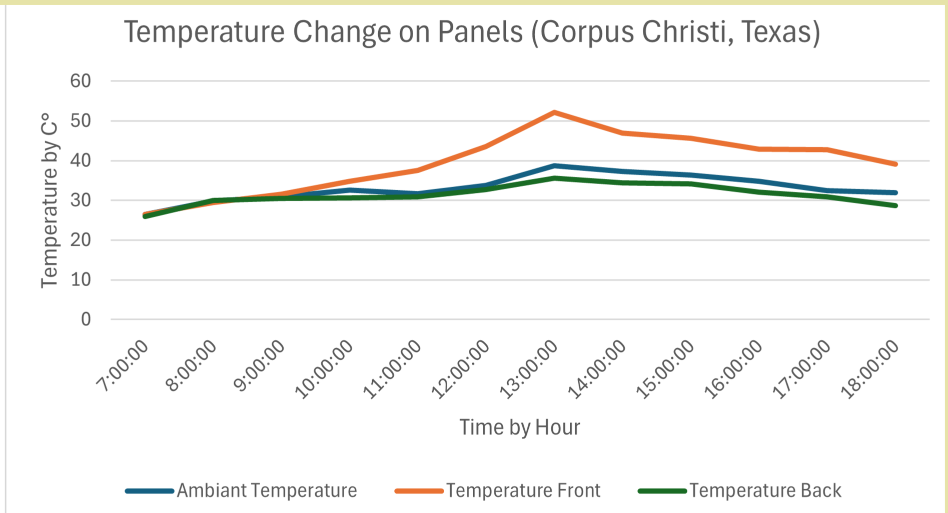
Results and Discussion

3D and 2D Comparisons (0° & 45°) between Cities with similar Longitude (Left) and Latitude (Right)

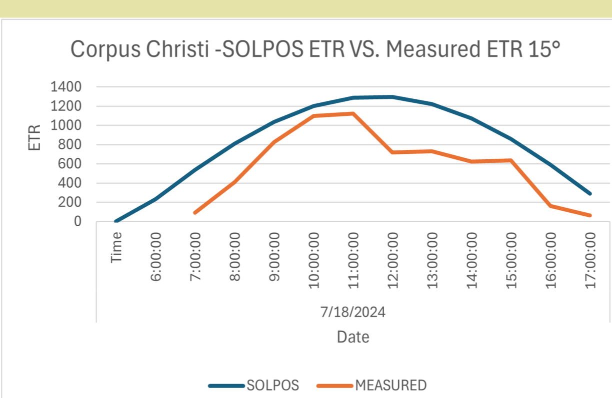


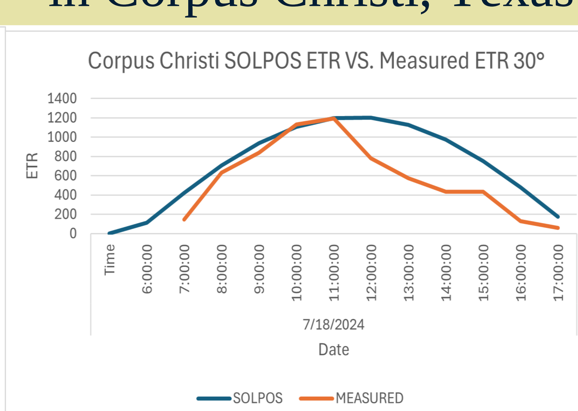
Comparing Front and Back Temperature of Solar Panels

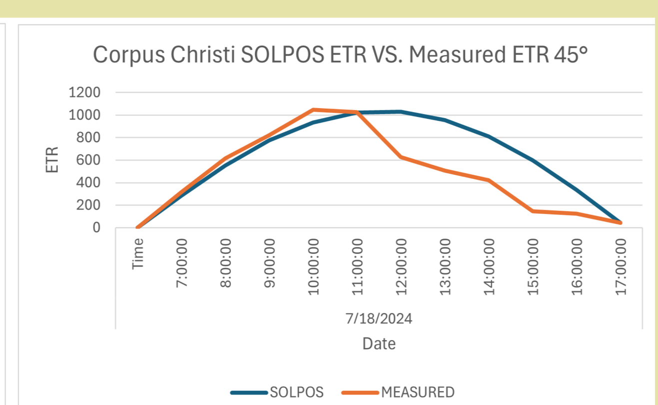


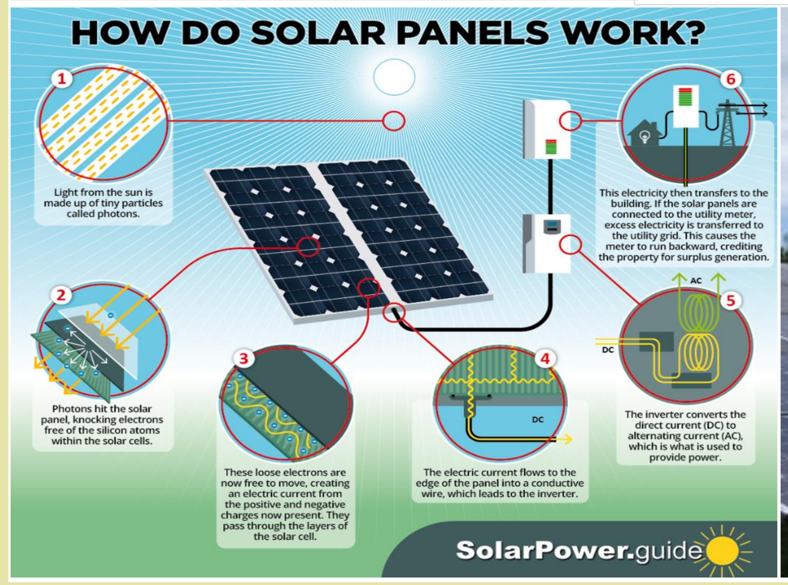


Comparing SOLPOS ETR with Measured ETR for 15°, 30°, & 45° tilt in Corpus Christi, Texas

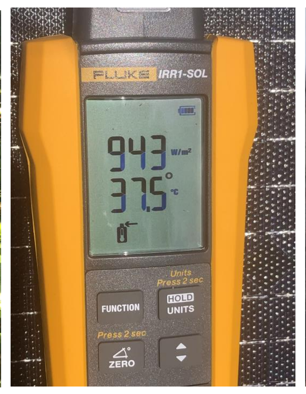


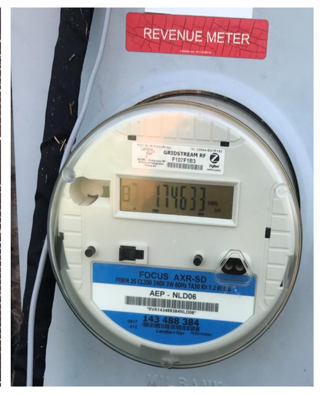






Sample Data Collection





Curriculum Module 2

Objective: Students will utilize different materials in front of the solar panel to study the effect on interference on ETR. TEKS – 5(A) & 8(D)

Day 1: Introduction: How would you design a table to collect the temperature outside, the temperature on the front and back of the panel, and the level of the panel for each 10 minutes. What is the reading for the solar panel: ETR Value: Each 10 minutes. Temperature: front and back for each 10 minutes. Using a level check to see if the panel is completely flat and if it is continuing to be flat throughout this experiment.

Day 2: Changing colors: - Leading questions:

What color will make the largest increase, if any, to your ETR value?
Why do you think this?
Yesterday, did the solar panel experience any changes to its surface? - Did it bend?
What effect, if any, do you think the colors will have on the changes to the surface?
Why do you think this?
What is the use of the colors on the panel? (interference - explain interference as something that will block or change the wave) (+ interference is the waves adding together called constructive interference) (- negative interference is the waves canceling out)
Do you want to change your answer to question 1? Why or why not?
How will you design a chart to collect: time, temperature front and back, change in level? Color you used.

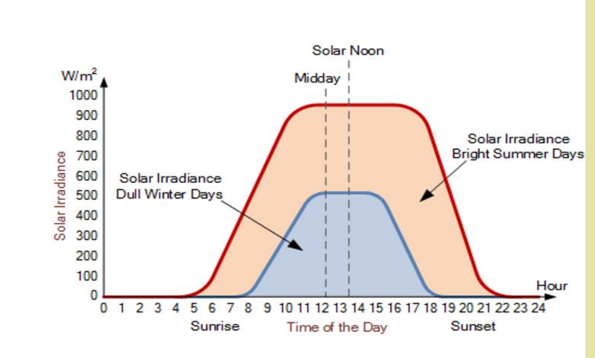
Day 3: Reflecting the sunlight back on the panel:

Can reflecting light back on the panel increase or decrease the amount of light captured?
Why do you think this?
How will you design a chart to collect: time, temperature front and back, change in level?
Select one person in the group to hold the mirror and practice reflecting the light back onto the panel.

References

1) https://midcdmz.nrel.gov/solpos/solpos.html
2) https://www.pveducation.org/pvcdrom/properties-of-sunlight/solar-radiation-on-a-tilted-surface
3) https://www.sciencedirect.com/topics/engineering/solar-constant
4) https://www.nrel.gov/grid/solar-resource/solpos.html
5) https://www.nrel.gov/docs/fy24osti/87524.pdf
6) https://www.cleanenergyreviews.info/blog/most-powerful-solar-panels
7) https://www.sunbasedata.com/blog/how-to-calculate-solar-panel-output
8) https://solarpower.guide/solar-energy-insights/how-do-solar-panels-work

Weather Related



Summary

Data suggests that peak solar irradiance (ETR) consistently occur between 12:00pm -12:30pm for all angles measured. The data demonstrated that maximum ETR was produced throughout the year at different time periods for different angles. The data clearly demonstrated the variation of ETR differed greatly between cities of similar latitude while cities of similar longitude differed slightly. Curriculum modules were developed based on the research experiences and findings. In the future, more data collection for different time periods are necessary in addition to additional measurements such as measured watts produced using a multimeter at the time of other data collection.

Acknowledgements

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Analysis of Wind Speed Pattern Changes Before and After Wind Farm Operations

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TEXAS A&M UNIVERSITY KINGSVILLE

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ABSTRACT

This study assesses how wind turbines in two distinct locations affect nearby wind fields. Using data from the National Solar Radiation Database and analyzing wind speed and direction in Excel, the research focuses on coastal and inland wind farms. Wind fields were studied at distances of 8 kilometers east, west, and downwind of the turbines, and 16 kilometers downwind. Significant differences on the wind speeds were found among downwind locations for both inland and coastal wind farms.

BACKGROUND

- Wind resources are decided by different factors.
- The energy production and efficiency of wind farms are significantly impacted by the wind speed.
- The impact of the operation of a wind farm on the available wind resources in its downwind direction is unknown.
- It is important to find out the impact on future wind farm planning and development.

RESEARCH QUESTION

Does a wind farm influence the wind speed of surrounding areas?

RATIONALE

The operation of a wind farm may diminish the potential energy production of nearby sites.

METHODOLOGY

PHASE 01: Determine a location of a wind turbine using the US Wind Turbine Database

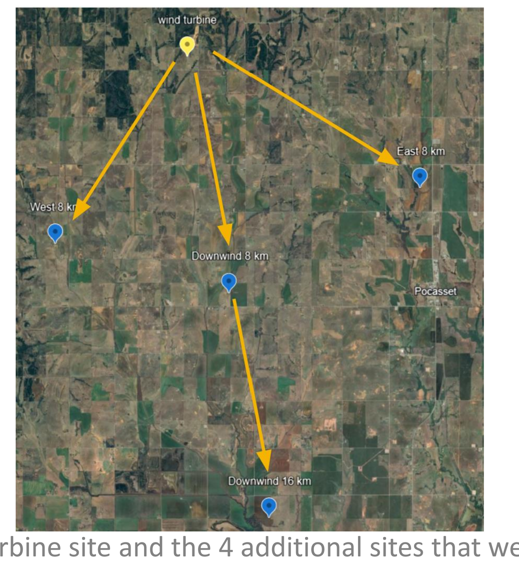
PHASE 02: Download data pre- and post- operation of wind turbines using National Solar Radiation Database

PHASE 03: Locate 4 sites to analyze: three 8 km to the east, west, and downwind and one 16 km downwind using RouteCompass & Google Earth

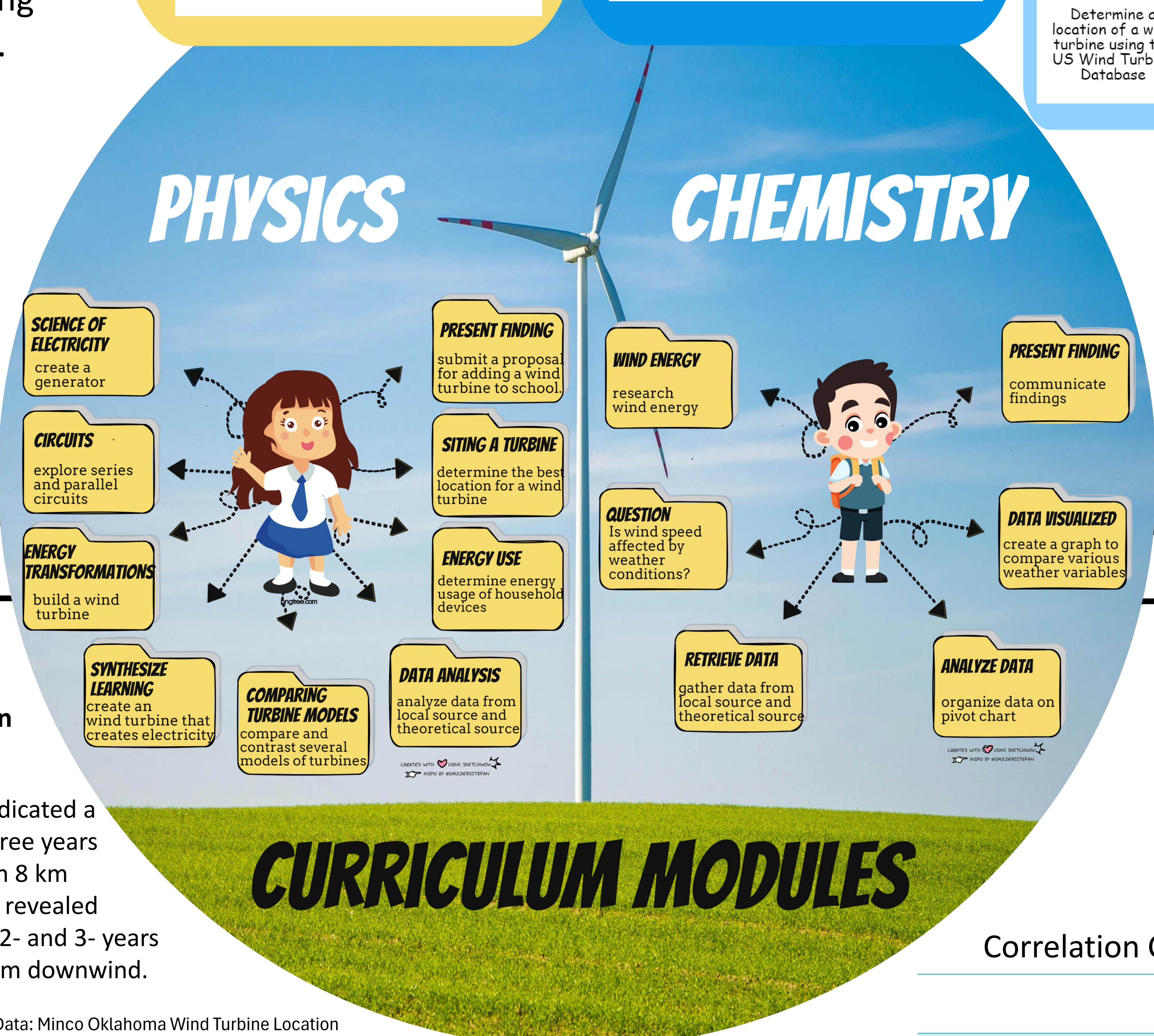
PHASE 04: Analyze data pre- and post- operation to calculate average wind speeds across 4 downwind sites.

PHASE 05: Perform T-test & correlation analysis for the monthly and daily data sets

Wind Turbine and 4 additional sites at 4km, 8km, 16km analyzed in the comparison. Penescal Wind Turbine, South of Baffin Bay



Wind Turbine site and the 4 additional sites that were analyzed Minco Wind Turbine, Minco Oklahoma

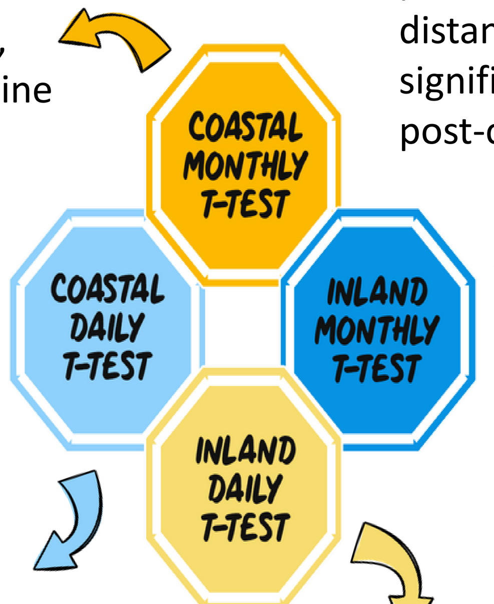


RESULTS

Null Hypothesis: There is no significant difference in average wind speed between pre- and post-operation of wind farms in their surrounding areas. (α = 0.05)

Coastal T-test results monthly indicated a significant decrease the first three years consistently at all locations East, West and Downwind of the wind turbine at 8km and 16km.

Inland T-test results indicated a significant decrease three years post-construction at an 8 km distance. Further tests revealed significant differences 2- and 3- years post-construction 16 km downwind.



Coastal Monthly Data: Baffin Bay Wind Turbine Location

	West 8 km	East 8 km	Downwind 8 km	Downwind 16 km
1 year	0.028	0.029	0.029	0.029
2 years	0.044	0.046	0.046	0.046
3 years	0.016	0.016	0.016	0.017
5 years	0.107	0.107	0.107	0.108
10 years	0.93	0.929	0.932	0.952

Inland Monthly Data: Minco Oklahoma Wind Turbine Location

	West 8 km	East 8 km	Downwind 8 km	Downwind 16 km
1 year	0.103	0.104	0.119	0.078
2 years	0.033	0.034	0.046	0.037
3 years	0.073	0.114	0.106	0.008
5 years	0.117	0.125	0.175	0.061
10 years	0.580	0.600	0.772	0.495

Coastal T-test results indicated a significant difference consistently daily in the month of April, and differences in year 1 post operational in May and November. These results are observed in distances of 8km and 16km.

Inland T-test results indicated a significant difference three years later in January, at distances of 8 and 16 km. It also showed a difference in the two years following in October, at distances of 8 and 16 km.

CONCLUSIONS

- The data shows that there is a significant difference of average wind speed between pre- and post- operation for both the inland and coastal wind farms and the surrounding areas.
- The number of significant differences between inland and coastal wind farms is different.

Correlation Coefficients for various weather variables at 8 km downwind

	Coastal	Inland
Wind speed & Temperature	-0.045	0.090
Wind Speed & Pressure	-0.040	-0.241

FUTURE RESEARCH

- Further research is needed to investigate other factors that could influence wind speed. Initial analysis does not show a correlation between wind speed, temperature, and pressure.
- Examination of the terrain for possible impediments, both natural and manmade.
- Additionally, research should explore how location differences between inland and coastal wind farms affect wind speed.

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.

Effect of Daylighting on Students' Learning and Classroom Electricity Consumption

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Faculty Mentors: Dr. Hui Shen, Dr. Marsha Sowell
Curtis Davenport (Student Mentor), Ralph Pitzer, P.E. (Industrial Advisor)
Texas A&M University – Kingsville

Abstract

This study examines the impact of daylighting on student learning and classroom electricity consumption. Daylighting, the use of natural light to illuminate indoor spaces, offers benefits such as improved student performance and reduced energy use. The research included both non-human and human data collection.

Non-human data was gathered using photometric sensors placed at 0, 10.5, and 21 feet from South and North-facing windows in two rooms with different orientations. Data was collected in increments of 5 minutes over a 72-hour period. Useful Daylight Illuminance (UDI), Daylight Autonomy (DA), and Energy Savings percentages were calculated for typical working/school hours (8AM to 5PM).

Human data collection involved participants in three rooms with different lighting conditions: natural light only, electric light only, and a combination of both. Participants completed reading activities and multiple-choice questions while wearing photometric sensors and provided feedback on lighting comfort.

The findings highlight the potential of daylight to enhance learning environments and reduce electricity consumption. Further research with larger samples is needed to confirm the correlation between daylighting and academic performance.

Key Definitions & Concepts

- **Daylighting**-the practice of using natural light from the sun to illuminate the interior spaces of buildings
- **Pyranometer**-device that measures global solar radiation
- **Photometric Sensor**-device that measures light as seen by the human eye in lux or lumens
- **Lux**-the SI unit of illuminance, equal to one lumen per square meter. (500 lux is the ideal level for workspaces)
- **Daylight Autonomy (DA)**- represents the percentage of the occupied time during which a space receives enough daylight to meet the required lighting level (500 lux), without the need for artificial lighting. [1]
- **Useful daylight illuminance (UDI)**-a metric used to assess the quality of natural light in a building. The UDI range is usually defined between 100 and 2,000 lux. [2]

Methodology

Instrumentation

- LI-210R Photometric Sensors
- LI-200R Pyranometer
- HOBO 4-Channel Analog Data Logger
- Solar Light PMA2100 Radiometer

Manning Hall Room 220
South and West Facing Windows

Manning Hall Room 224
North and West Facing Windows

Non-Human Data Collection

- Sensors were placed 0 ft, 10.5 ft, and 21ft from South and North windows in each room.
- HOBO data loggers were programmed to measure and record every five-minutes for 72 hours
- Electric Lights turned off, room locked and undisturbed
- Manning Hall room 220 21x30.5 ft
- Manning Hall room 224 21x30.5 ft

Human Data Collection

- Participants wore sensor on head and placed another on desk to measure lux
- completed reading activity then answered 5 multiple choice questions
- Rated the comfortability of the light in the room
- Recorded lux and student score on assessment
- Repeated in three different lighting scenarios

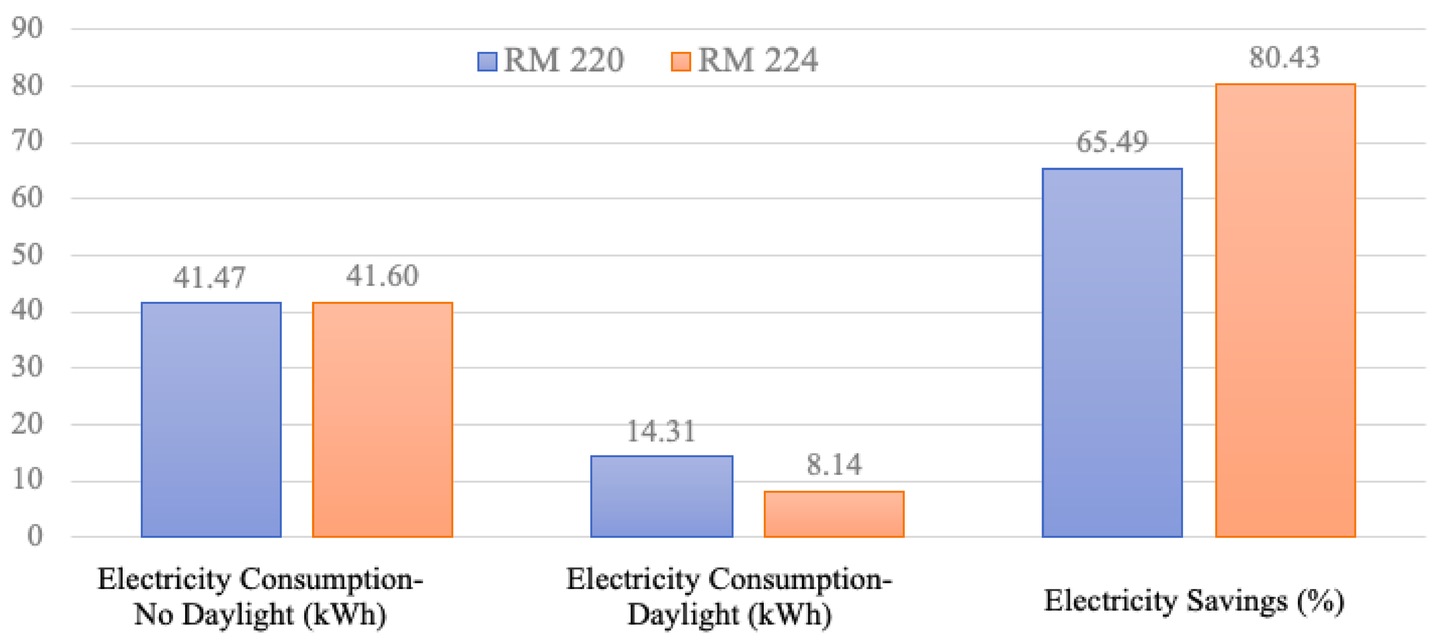
Results

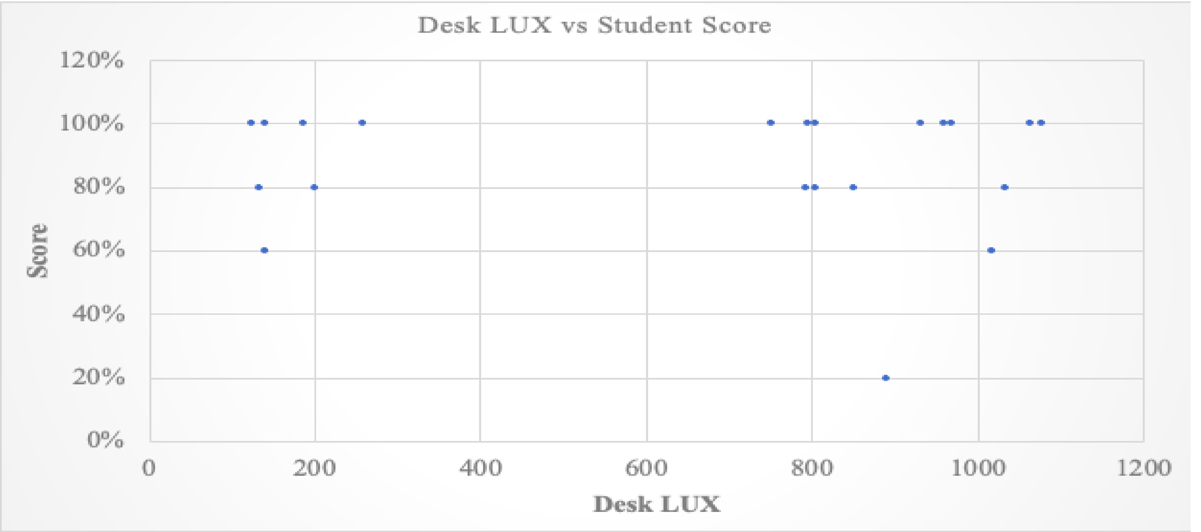
Manning RM 220 South and West Windows 8am-5pm

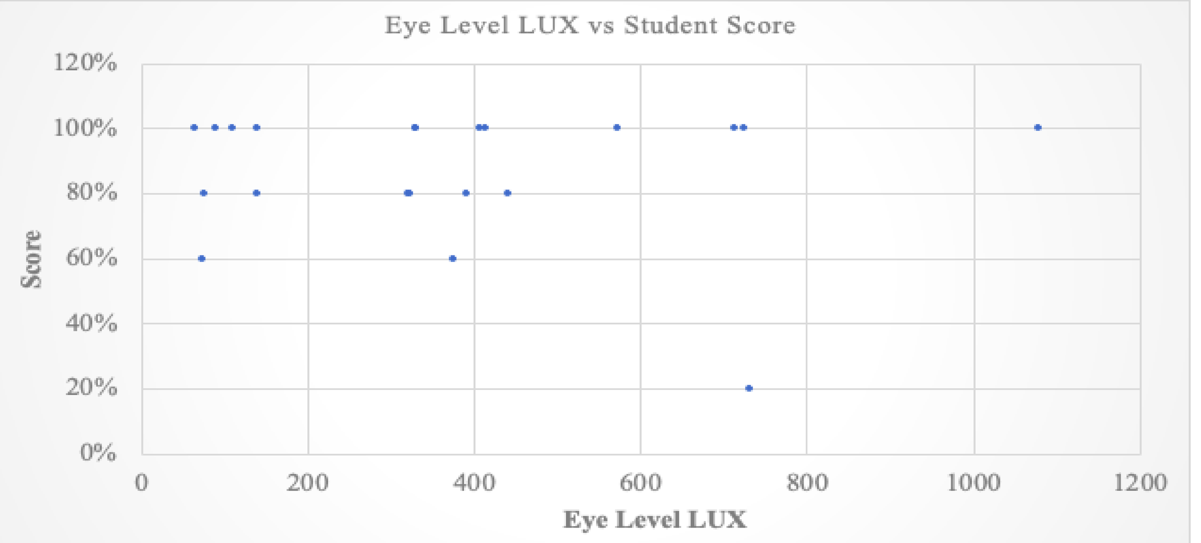
LUX	Windowsill	10.5 ft from Window	21ft from Window
DA >500	98.77%	39.51%	0.00%
UDI (>=100,<500)	1.23%	60.49%	2.16%
UDI (>=500,<1000)	15.74%	39.51%	0.00%
UDI (>=1000,<2000)	39.51%	0.00%	0.00%
UDI (>3000)	15.74%	0.00%	0.00%

Manning RM 224 North and West Windows 8am-5pm

LUX	Windowsill	10.5 ft from Window	21ft from Window
DA >500	100.00%	39.69%	7.69%
UDI (>=100,<500)	0.00%	60.31%	89.54%
UDI (>=500,<1000)	6.77%	39.69%	7.69%
UDI (>=1000,<2000)	61.54%	0.00%	0.00%
UDI (>3000)	5.85%	0.00%	0.00%







Participant Light Comfortability Rating

Participant	Mixed Light RM 220	Electric Light RM 222	Natural Light RM 224
1	2	4	5
2	2	4	5
3	2	2	5
4	3	5	1
5	3	5	4
6	3	4	5
7	4	3	5
Average Rating:	**2.71**	**3.86**	**4.29**

KEY

1	2	3	4	5
Not Comfortable	Semi-Comfortable	Neutral	Comfortable	Very Comfortable

Curriculum Modules

Analyzing the Effects of Daylight on Student Performance

Students will investigate the relationship between daylighting and student performance.

- calculate, using technology, the correlation coefficient between two quantitative variables and interpret this quantity as a measure of the strength of the linear association **A.4(A)**
- compare and contrast association and causation in real-world problems **A.4(B)**
- write, with and without technology, linear functions that provide a reasonable fit to data to estimate solutions and make predictions for real-world problems **A.4(C)**

Types of Lighting Influence The Growth of Plants

Students will:

- investigate the influence of lighting types on the growth of plants
- identify the factors that affect the growth and energy conservation in plants (**B.11A)**
- analyze the amount of growth dependent on the lighting source

Conclusion

- The ideal UDI range 500-1000 lux was reached about 40% of the time in the center of each classroom
- Room 220 observed 65.49% energy savings when utilizing daylighting
- Room 224 observed 80.43% energy savings when utilizing daylighting
- Participants favored room 224 with natural lighting only
- No significant findings between lux and student score

Future Approaches

- Include more classrooms and students to obtain a more robust data set and achieve statistically significant results.
- Conduct the study over a longer period to account for variations in student performance and lighting conditions
- Use additional sensors and loggers for more extensive data collection.
- Include students from a wider age range to determine if the impact of daylighting varies across different educational levels.

References

[1] Reinhart, C. F., Mardaljevic, J., & Rogers, Z. (2006). Dynamic Daylight Performance Metrics for Sustainable Building Design. *LEUKOS*, *3*(1), https://doi.org/10.1582/leukos.2006.03.01.001

[2] Nabil, A., & Mardaljevic, J. (2005). Useful daylight illuminance: A new paradigm for assessing daylight in buildings. *Lighting Research & Technology*, *37*(1).

Acknowledgements

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Assessing Heat Generation in Anaerobic Composting of Yard and Food Waste for Backyard Renewable Energy Potential

TEXAS A&M UNIVERSITY KINGSVILLE

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

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Student Mentor: Ravi Chandra Madasani (TAMUK)

Faculty Advisors: Dr. Xiaoyu Liu - Research Project Faculty Mentor (TAMUK)

Dr. Marsha Sowell – Curriculum Development Faculty Mentor (TAMUK)

Industrial Advisor: Enrique Molina

ABSTRACT

This research investigates the potential of anaerobic composting of yard and food waste for renewable energy generation in a backyard setting, focusing on heat production. The study employed various bin models and temperature sensors to measure the heat generated during the anaerobic composting process. A comparative analysis was conducted between composting yard waste alone and a combination of yard waste and food waste. The findings provide insights into the amount of heat generated in small-scale composting scenarios. Additionally, the project developed curriculum modules to teach students the primary concepts investigated. These educational modules aim to help students understand composting and energy production through temperature differentials, thereby linking practical composting techniques with renewable energy concepts.

METHODOLOGY

Data Logger: HOBO data loggers used to measure temperature in degrees Fahrenheit.

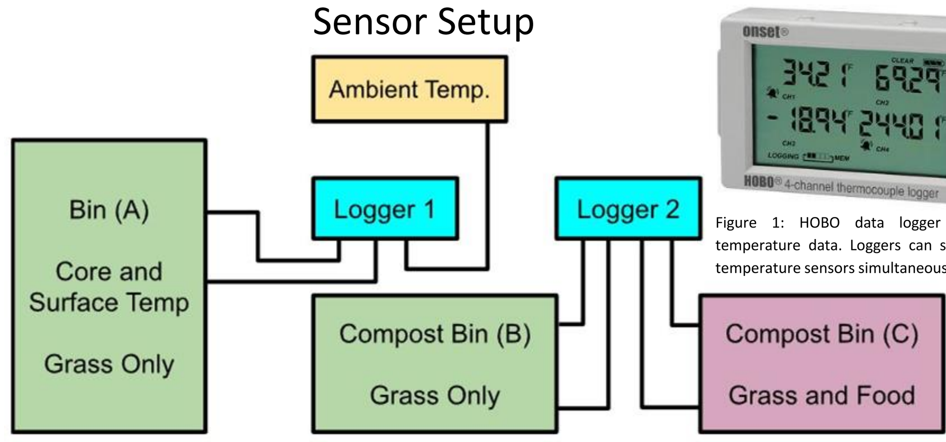

Figure 2: Sensor placement in bins for the anaerobic composting experiment.
An ambient temperature sensor was suspended in the air to measure surrounding conditions.
Bin A: Core temperature sensor at 54 cm depth, surface temperature sensor at 13 cm depth.
Bins B and C: Rotating compost tumblers with two sensors on the left and right sides at the same depth.

Figure 1: HOBO data logger used to collect temperature data. Loggers can support up to four temperature sensors simultaneously.

Trash Can (A) (mass in lbs)		
Load 1	Grass	14
Load 2	Grass	21.4
Load 3	Grass	25
Load 4	Grass	24.2
Load 5	Grass	26.2
Total		110.8

Table 1: Mass of biomass loaded into Bin A for the anaerobic composting experiment. Bin A contained 110.8 pounds of grass.

Compost Bin B (mass in lbs)		
Load 1	Grass	25.2
Load 2	Grass	17
Total		42.2

Table 2: Mass of biomass loaded into Bin B for the anaerobic composting experiment. Bin B contained 42.2 pounds of grass.

Compost Bin C (mass in lbs)		
Load 1	Grass	4.2
Load 2	Food	13.8
Load 3	Grass	5
Load 4	Food	12.6
Load 5	Grass	6.8
Total		42.4

Table 3: Mass of biomass loaded into Bin C for the anaerobic composting experiment. Bin C contained 26.4 pounds of food and 16 pounds of grass, totaling 42.4 pounds.

Data Collection:

- Duration: July 14, 2024, 8 PM to July 21, 2024, 8 PM

Figure 3: Trash Bin A used for the anaerobic composting experiment, with an approximate volume of 115 gallons.

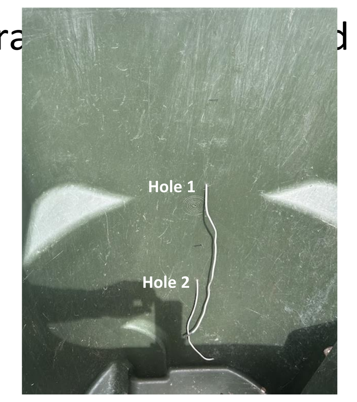

Figure 4: Holes drilled into Bin A for sensor insertion. Hole 2, as seen above, is for the core temperature sensor, and Hole 1 for the surface-level temperature sensor. Both holes were drilled slightly lower than the desired height of the sensors to accommodate downward movement of the material during composting.

Figure 5: Assembled 43-gallon compost tumbler used for Bins B and C in the anaerobic composting experiment.

Figure 9: The figure depicts the orientation of all bins, sensor wires, and loggers in the garage environment, with the garage remaining closed throughout the duration of the experiment.

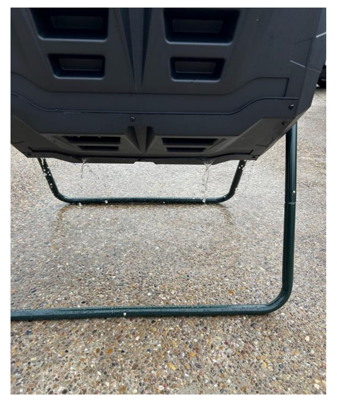

Figure 6: Water leakage from the compost tumbler prior to the attempted waterproofing. The image illustrates the extent of leakage observed before any waterproofing measures were applied.

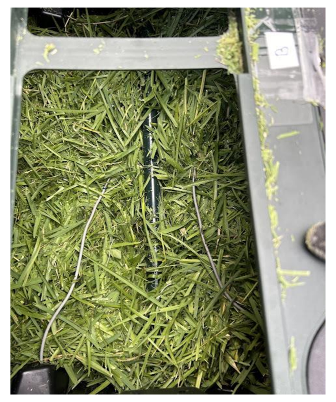

Figure 7: Temperature sensor placement in Bin B with grass at the midpoint of the biomass material. The figure shows the locations of temperature sensors inserted on the left and right sides of the compost tumbler.

Figure 8: Temperature sensor placement in Bin C with grass and food at the midpoint of the biomass material. The figure shows the locations of temperature sensors inserted on the left and right sides of the compost tumbler.

Figure 10: The figure shows the buckets setup for capturing the liquids dripping from the compost tumbler containers, which began on Wednesday, July 17, 2024.

Analysis:

- Comparative analysis of heat generation in bins with different compost materials

ACKNOWLEDGEMENT

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RESEARCH OBJECTIVES

- **Investigate heat generation from anaerobic composting of yard and food waste.**
- **Compare core temperatures of grass to surface level temperatures.**
- **Compare core temperatures between large and small bins.**
- **Compare core temperatures of small bins with grass-only versus grass/food.**

INTRODUCTION

Food waste is organic waste discharged from various sources, including food processing plants, domestic and commercial kitchens, cafeterias, and restaurants. Traditionally, food waste is incinerated; however, incineration can cause air pollution and result in the loss of the chemical values of food waste.[2]

In the US, each person wastes 422 grams of food daily (2018). This amounts to 51,608,760,000 metric tons annually, underscoring the need for improved food waste management and more efficient resource use.[1]

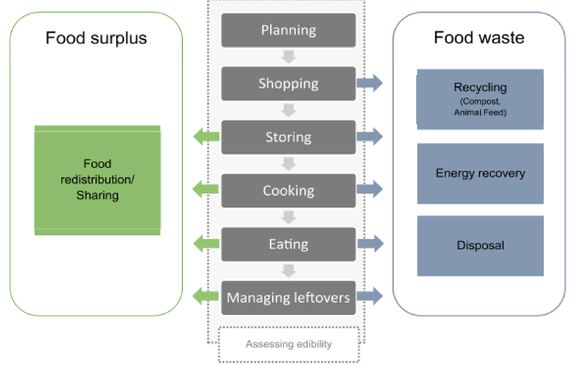


Figure 11: Household routines, including planning, shopping, storing, cooking, eating, and managing leftovers, play a decisive role in both food provisioning and food waste generation.[3]

Heat production during composting may provide a way utilize otherwise lost energy. As decomposition liberates heat, the surrounding compost substrate and its air and water increase in temperature.[4] This research investigates the potential of anaerobic composting of yard and food waste for renewable energy generation in a backyard setting, focusing on heat production.

RESULTS

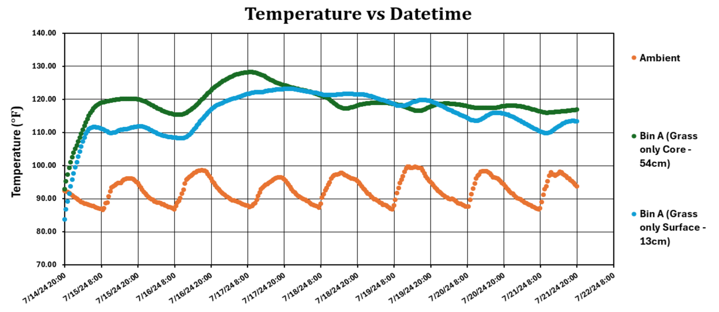


Figure 12: Comparison of ambient temperature and bin A core and surface temperatures. This graph allows for observations of the relationship between core heat temperature and surface temperature.

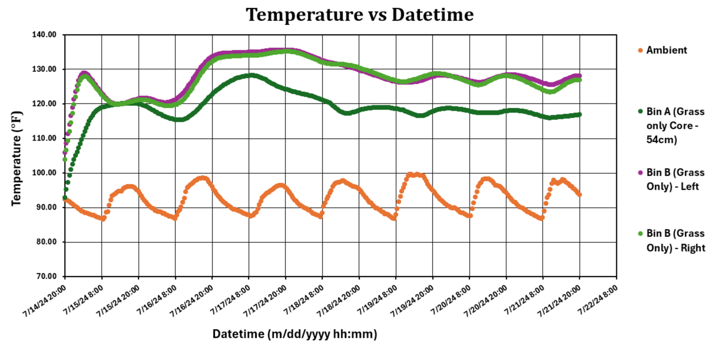


Figure 13: Comparison of ambient temperature and bin A core with Bin B core temperatures. This graph allows for observations of the relationship between core heat temperature of different biomass amounts.

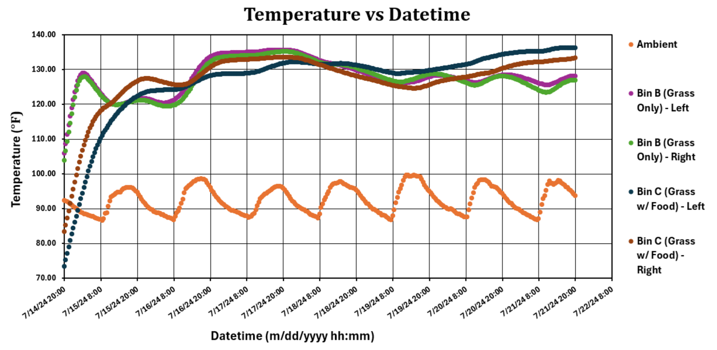


Figure 14: Comparison of ambient temperature and Bin B core with Bin C core temperatures. This graph allows for observations of the relationship between core heat temperature of different biomass material.

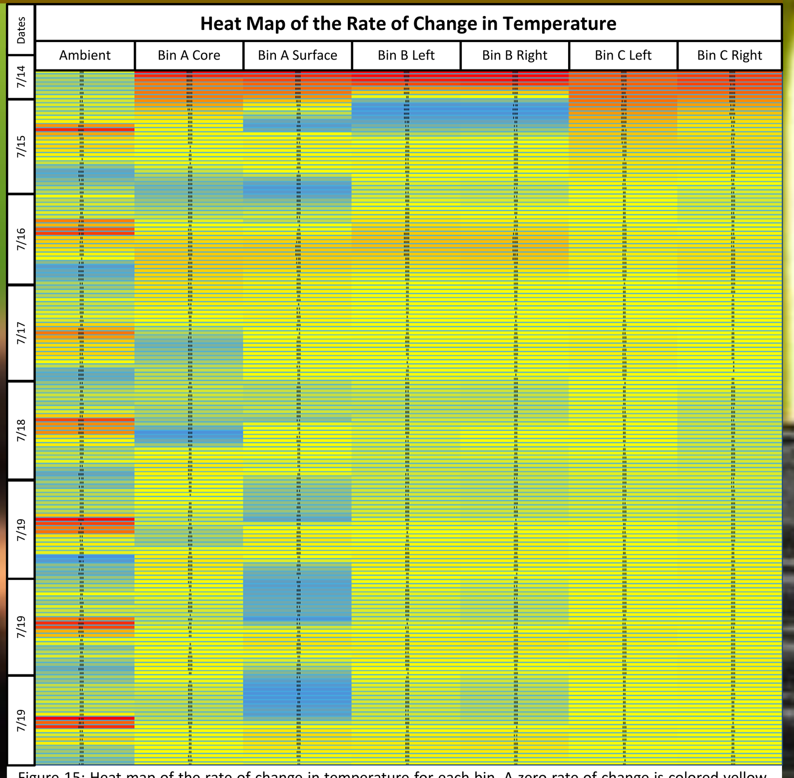


Figure 15: Heat map of the rate of change in temperature for each bin. A zero rate of change is colored yellow, positive rates of change are colored red, and negative rates of change are colored blue. Darker colors indicate higher magnitudes of the rate of change. Each column uses its own values as its baseline.

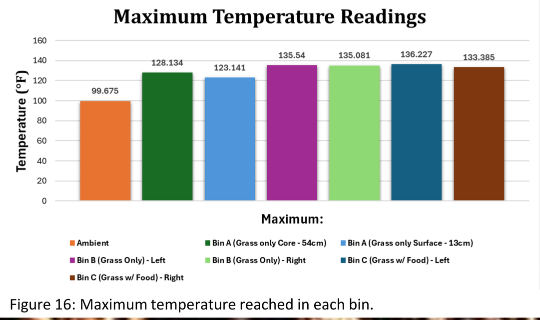


Figure 16: Maximum temperature reached in each bin.

CONCLUSIONS

Research showed heat can be produced through the anaerobic composting of yard and food waste. Maximum temperatures in each bin exceeded the ambient temperature by 23°F to 36°F (Fig. 16).

Comparison of Core Temperatures of Grass to Surface Level Temperatures in Bin A: Bin A core and surface temperatures initially increased at similar rates. Core temperatures rose to a higher max temperature before plateauing (July 17th) and then decreasing over the next few days (Fig. 12).

Comparison of Core Temperatures Between Large and Small Bins Containing Grass Only: Both the large (115 gallons) and small (43 gallons) bins showed early temperature increases. The small bin had a slightly higher positive rate of temperature increase, leading to a much higher initial temperature (Fig. 13). Bin B temperature then decreased to match the temperature of Bin A. However, temperatures in Bin B increased over the next few days, yielding the highest midweek temperatures of all bins before reducing temperature towards the week's end.

Comparison of Core Temperatures of Small Bins with Grass-Only Versus Grass/Food: Bins containing additional food waste had the longest sustained initial rate of increase (Fig. 14). These bins also exhibited the longest continuous rate of increase without a measurable high negative rate of temperature change at the week's end (Fig 15). While temperatures in Bin B declined towards the week's end, both sensors in Bin C increased in temperature.

Key Observation: Around July 17th (16:00 to 21:00), fluid began leaking from all three bins. Buckets were put in place to catch draining liquids where possible (Fig. 10). This release of fluid corresponded with temperature drops observed at midweek. Additional research is needed to examine how fluid loss may affect heat production within the bins. Further research can also explore the effects of adding more carbon-based materials to the compost, such as dry leaves, shredded paper or cardboard. These findings provide valuable insights into the production of heat through anaerobic composting of yard waste and can serve as a foundation for future research on heat capture and utilization.

MODULES

Environmental Systems (Science) Module

Composting in the Classroom

Background Information and Vocabulary Exploration

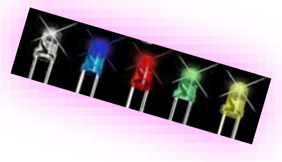
- Students will be given the opportunity to research and explore the science behind composting.

Composting Project (Weeks 1 through 6)

- Activities over several weeks will include:
  - Setting Up Composting Bins
  - Daily Monitoring and Rotation
  - Data Collection
  - Week-by-Week assessment the decomposition progress of each bin
  - Final Report and Presentation

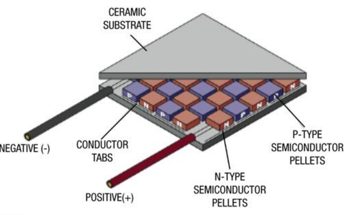
Physics Modules

Thermoelectric Generator Investigation Activity



Four Day Activity

- ❖ **Day 1: In-depth Background**
  - ➢ Students will gain a comprehensive understanding of thermoelectric generators, the Seebeck effect, and related principles.
- ❖ **Day 2: LED Module**
  - ➢ Students will use a thermoelectric generator to power an LED and understand the conversion of heat energy to electrical energy.



- ❖ **Day 3: EMF Module**
  - ➢ Students will measure the EMF produced by the TEG and calculate the current using a known resistance.

- ❖ **Day 4: Heat vs EMF Module**
- ❖ Students will measure and graph the voltage output of the TEG as the heat input is varied.

Modeling Impact Of Wake Steering On Wind Farm Development

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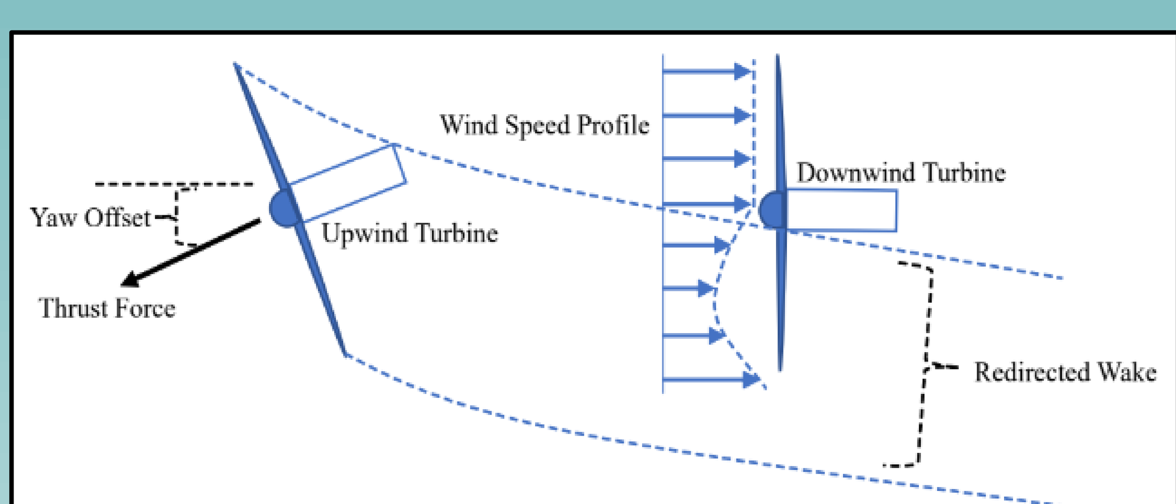
INTRODUCTION

Electricity from wind turbines is a significant carbon-free energy source, now surpassing coal as the second largest contributor to energy generation. Wind farms, particularly in Texas, have seen substantial growth in capacity, highlighting the need for enhanced turbine efficiency to improve cost-effectiveness. As turbines increase in size, reaching projected heights of 500 feet by 2035, maximizing energy production becomes crucial despite challenges such as wake effects between turbines. This study investigates wake steering techniques, which have shown promise in increasing energy output by up to 13%, aiming to build on previous research and optimize turbine performance.

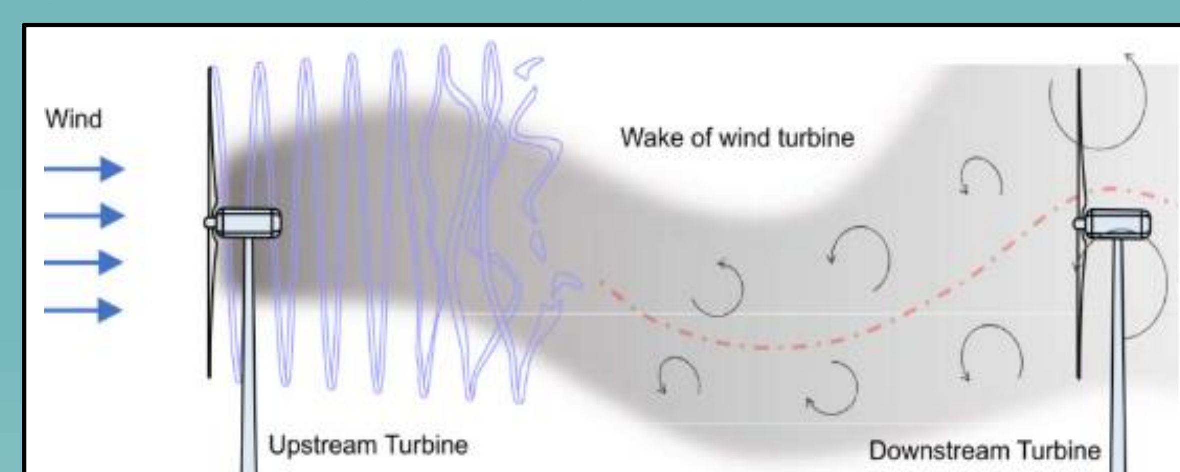
WAKE STEERING

This project focuses on utilizing wake steering to optimize wind farm layout and increase power production. Wake steering is a wind farm control strategy that redirects the wakes of upstream turbines away from downstream turbines by adjusting the yaw angle of the turbines. This allows downstream turbines to experience higher wind speeds and produce more power, although there is a slight reduction in power production at the upstream turbines. By mitigating wake losses through strategic orientation adjustments, wake steering enables downstream turbines to operate more efficiently and extract more energy from the wind. This approach not only increases the overall power production of the wind farm but also enhances its economic potential, particularly in locations with land constraints or larger capacities. Field trials and simulation studies have demonstrated the success of wake steering in increasing energy production, providing design flexibility, and optimizing wind farm layouts.



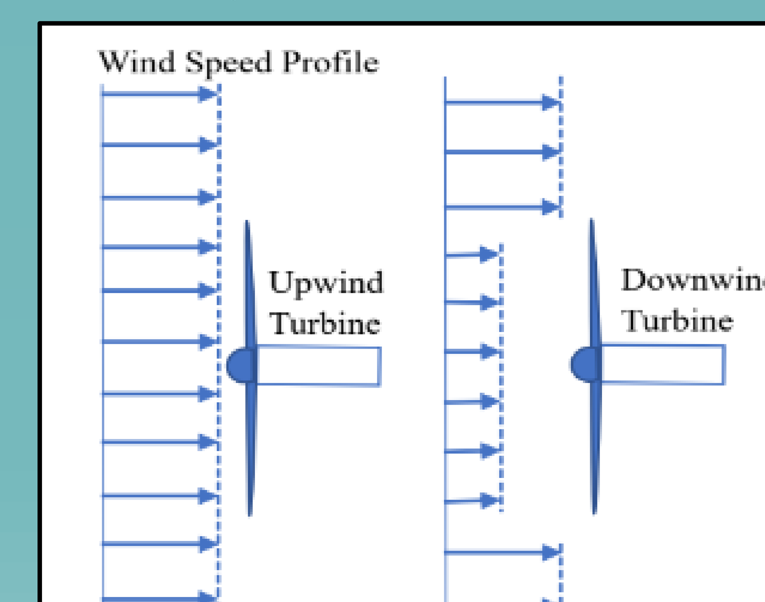
WAKE EFFECT

Wake effect is a consistently studied phenomenon in wind turbine operation and wind farm layout optimization, where the interaction between the turbine blades and the wind creates a downstream area with reduced wind speed and increased turbulence. The wind turbine wake effect refers to the disturbance in the airflow caused by a wind turbine. When wind passes through a turbine, it generates power but also creates a wake. This wake is a region of slower, turbulent air that is formed behind the turbine. This wake can impact the performance of downstream turbines by reducing their efficiency and power output. This effect is similar to how a boat leaves a wake in the water behind it. To minimize this effect, turbines are strategically placed to ensure optimal distance and alignment with prevailing winds. Effective wind farm design strategies can mitigate wake interference and enhance overall wind farm performance. Understanding and addressing the wake effect is fundamental to maximizing energy yield, reducing costs, and advancing sustainable wind energy solutions. Ongoing research aims to further optimize these strategies for even greater efficiency.



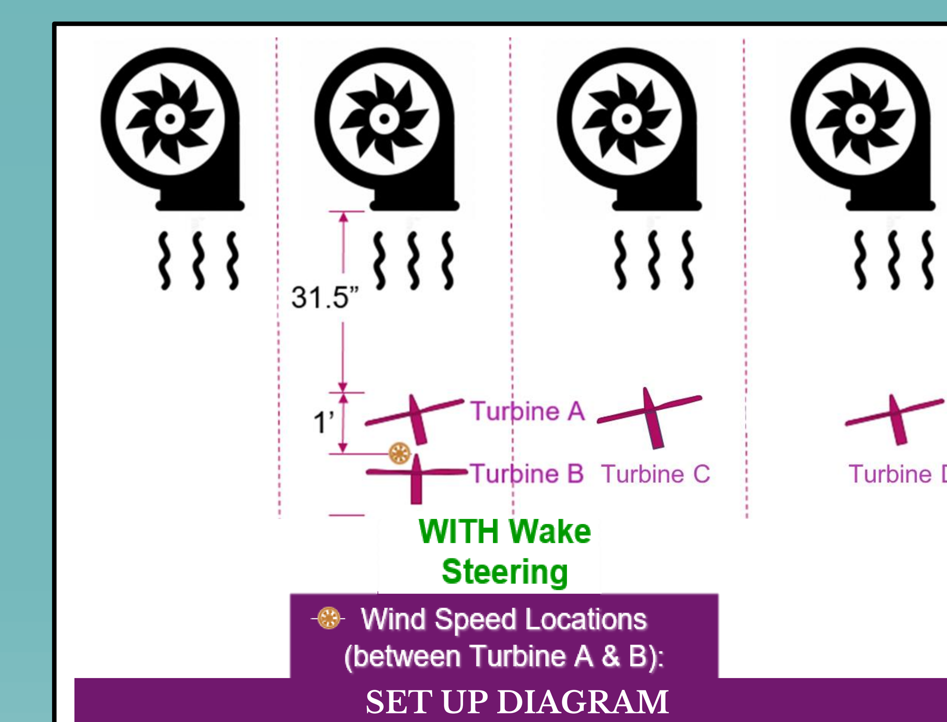
WAKE LOSS

Wind turbine wake losses refer to the reduction in energy production caused by the wake effect. When a wind turbine operates, it creates a wake of slower, turbulent air behind it. This wake can affect other turbines by causing them to operate in less optimal conditions which diminishes their efficiency and overall energy output. As a result, these downstream turbines generate less power than they would in undisturbed wind which leads to a significant reduction in the overall energy output of the wind farm. Wake losses are a critical consideration in wind farm layout design. By strategically spacing turbines and optimizing their alignment with prevailing winds, it is possible to minimize these losses and improve the efficiency of the entire wind farm. Proper turbine placement ensures that each turbine can operate in the best possible wind conditions, and therefore maximizing power production and the economic viability of the wind farm.



METHODS

- **Baseline Measurements:**
  Set up four industrial blowers. (See Diagram Below)
  Measure initial wind speeds at various distances using an anemometer.
- **Single Turbine Measurements:**
  Place the first turbine 31.5 inches from a blower.
  Position a second turbine at incremental distances (1-foot steps) behind the first, up to 10 feet.
  Measure and record wind speed and voltage at each position.
- **Wake Steering Tests:**
  Switch the first turbine to wake steering.
  Repeat measurements for the second turbine.



CURRICULUM MODULES

- **PB1: Physics in Wind Turbine Analysis**
  Observe wake steering effects on turbine models and analyze physics properties to optimize wind farm layouts, explaining how wind speed and generated energy vary by turbine location.
- **B4B: AP Biology - Engineering Practices**
  Identify biological problems and apply solutions using proper tools and models.
- **G10A: Geometry - Trigonometric Ratios in Right Triangles**
  Use **trigonometric ratios to calculate angles at which wind strikes turbines and analyze resulting wake effects.**
- **A2B: Statistics - Analyzing Functions in Wind Turbine Data**
  Identify and interpret quadratic relationships in wind speed and turbine output data, analyzing data to identify these relationships.

CONCLUSIONS

The purpose of this research project was to show the effects that wake steering has on increasing energy production through optimizing wind farm layouts. This project showed that wind speed and voltage were increased when the yaw angles of upstream turbines were adjusted to deflect the wakes and mitigate wake losses. The upstream turbine did show a slight reduction in power production, but the succeeding turbines increased to the point that this initial loss was offset. The data of this study supports the use of wind steering and stresses the importance of optimizing wind farm layouts. The model turbines effectively replicated a scaled-down, controlled simulation of a wind farm layout. Adjustments of turbine angles can lead to significant efficiency gains. The findings suggest that further research and application of wake steering can enhance the overall performance of wind farms.

FUTURE STUDIES

- Determining the effects of wake steering on column C and column D.
- Graphing the effects of wind steering on plant growth.
- Investigating the long-term impacts of wake steering on turbine longevity and maintenance.
- Exploring the economic implications of large-scale implementation of wake steering in wind farms.

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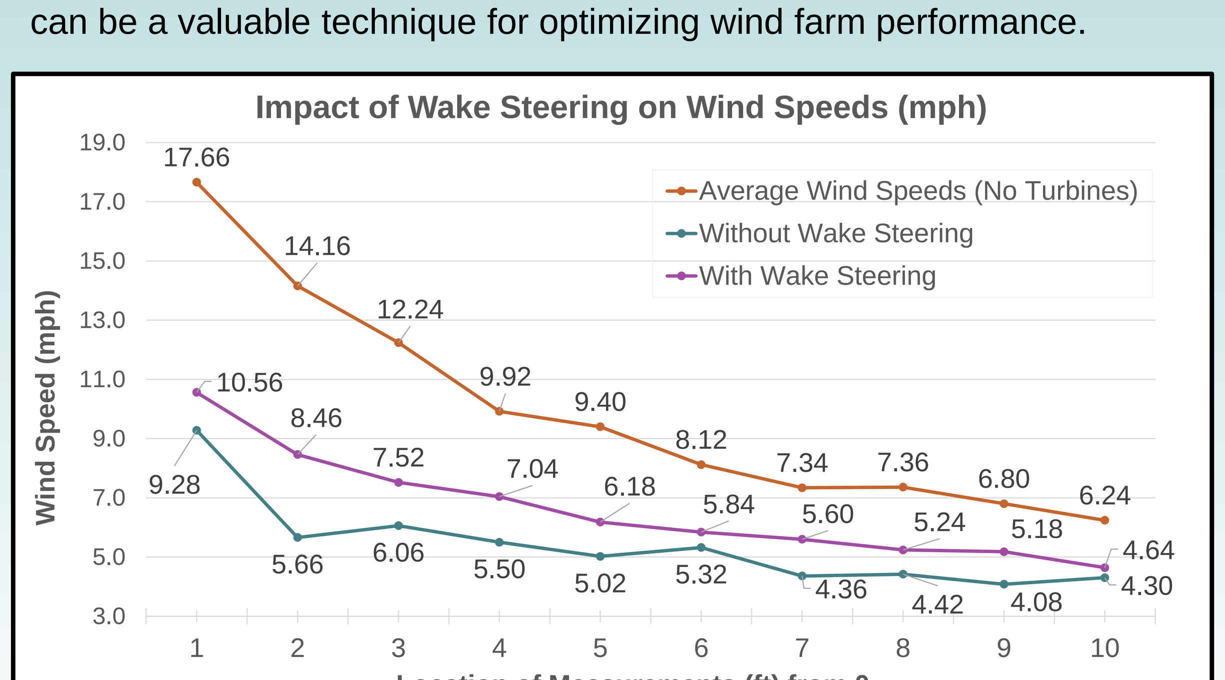
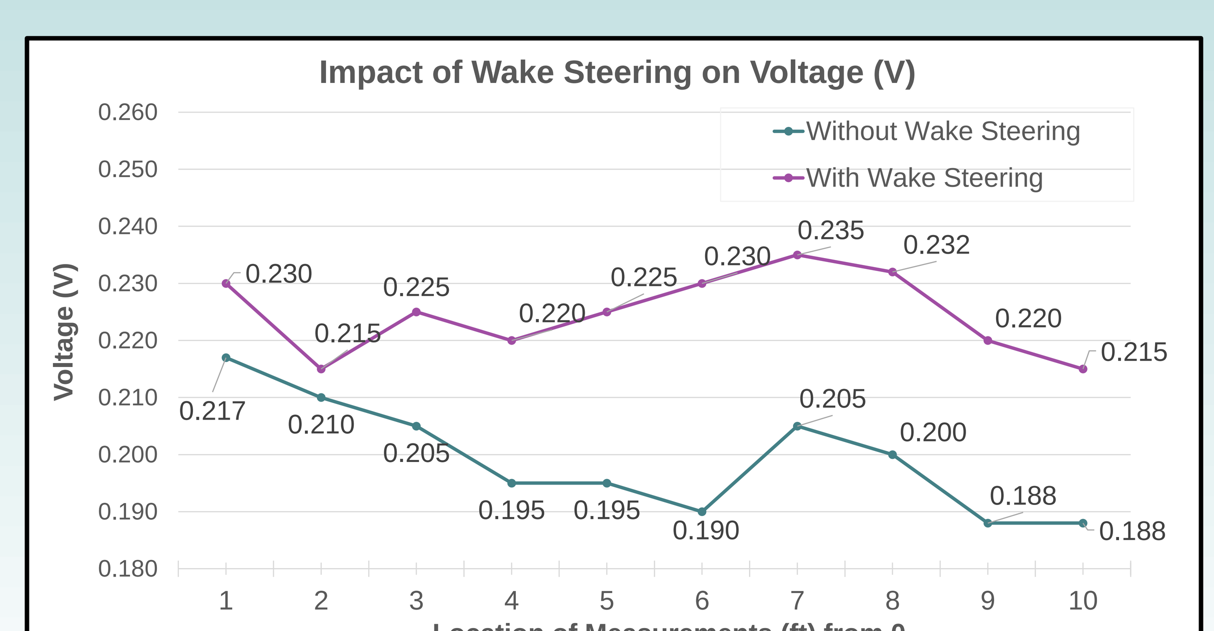
DATA ANALYSIS

The results indicate that wake steering can lead to significant improvements in wind farm efficiency. Data collected from various turbine configurations showed an increase in energy production when turbines were angled away from direct wind. These results support the hypothesis that wake steering can be a valuable technique for optimizing wind farm performance.





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