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Modeling, IoT and Machine Learning for Smart Greenhouse

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Introduction

Greenhouse and Smart Greenhouse in Wind Tunnel

The objective is the development of smart greenhouses utilizing automated, remote monitoring sensors to maintain optimal living conditions for plant growth.
A smart system is introduced with continuous bioaerosol collection systems and ventilation-based air flow modeling to prevent the spread of pathogens.
Greenhouse conditions can be analyzed continuously along with aerosolized bacteria which may affect plant growth and eventually human health.

Coupled with internet-based technologies for remote monitoring and controlling of physical parameters, the spatial and temporal air sampling and ventilation-based air flow modeling enables the optimization of environmental parameters to maintain sanitation and increase the yield in greenhouses.
Crops are subject to many environmental factors that can affect the health of the plant. One of these factors is wind, possibly impacting bacteria on the plants.
In this study an actual greenhouse and a smart greenhouse in a wind tunnel setting, both equipped with sensors and bioaerosol collectors, have been tested for bacteria aerosols impacting on plants at 1 m/s ventilation airflow and in the smart greenhouse at 6 m/s, corresponding to the average wind speed in TX field

Greenhouse

Greenhouse Layout

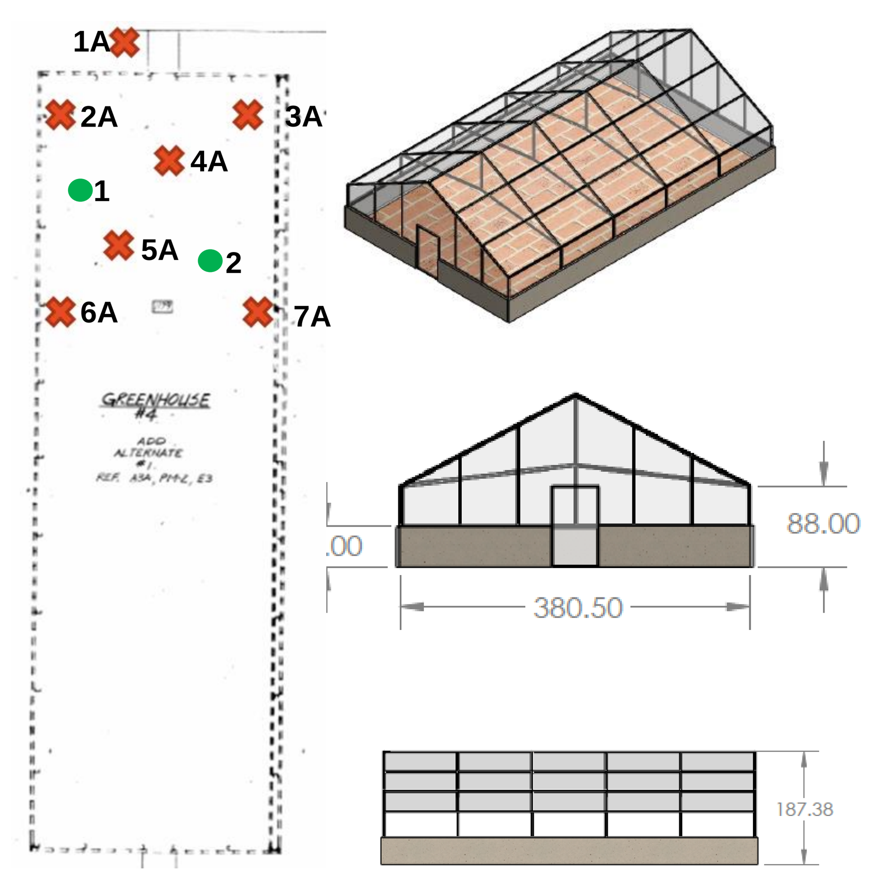


Figure 1: The locations of air sampling and leaf collections inside of the greenhouse labeled in red and green (left) and a greenhouse model with dimensions in inches (right)

Greenhouse Light Images

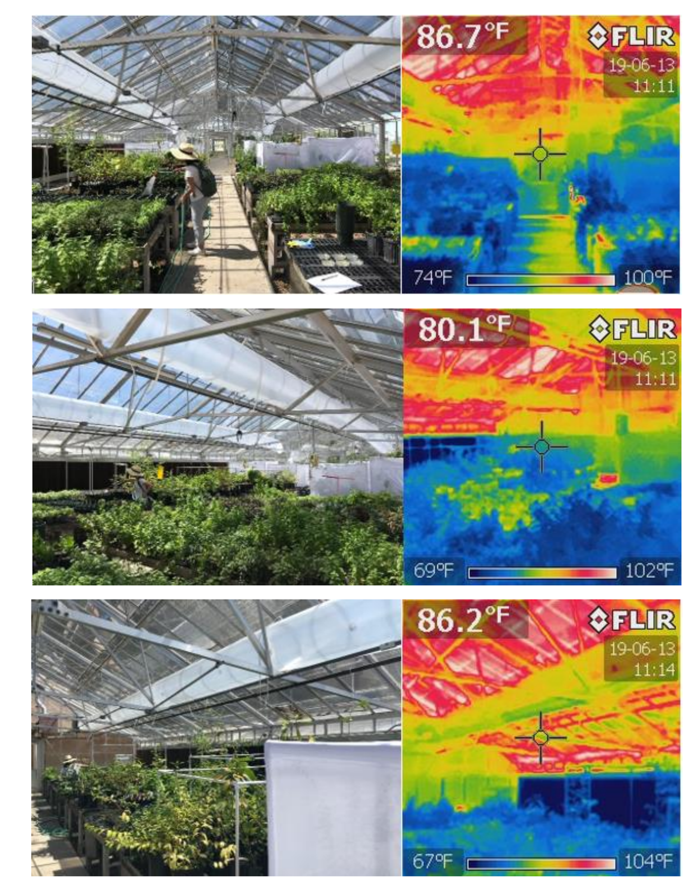


Figure 2: Visible light image (left) and Infrared image (right) displaying thermal differences from the greenhouse front view, left side view, and right-side view, respectively.

Smart GH in Wind Tunnel

Smart Greenhouse in Wind Tunnel Layout

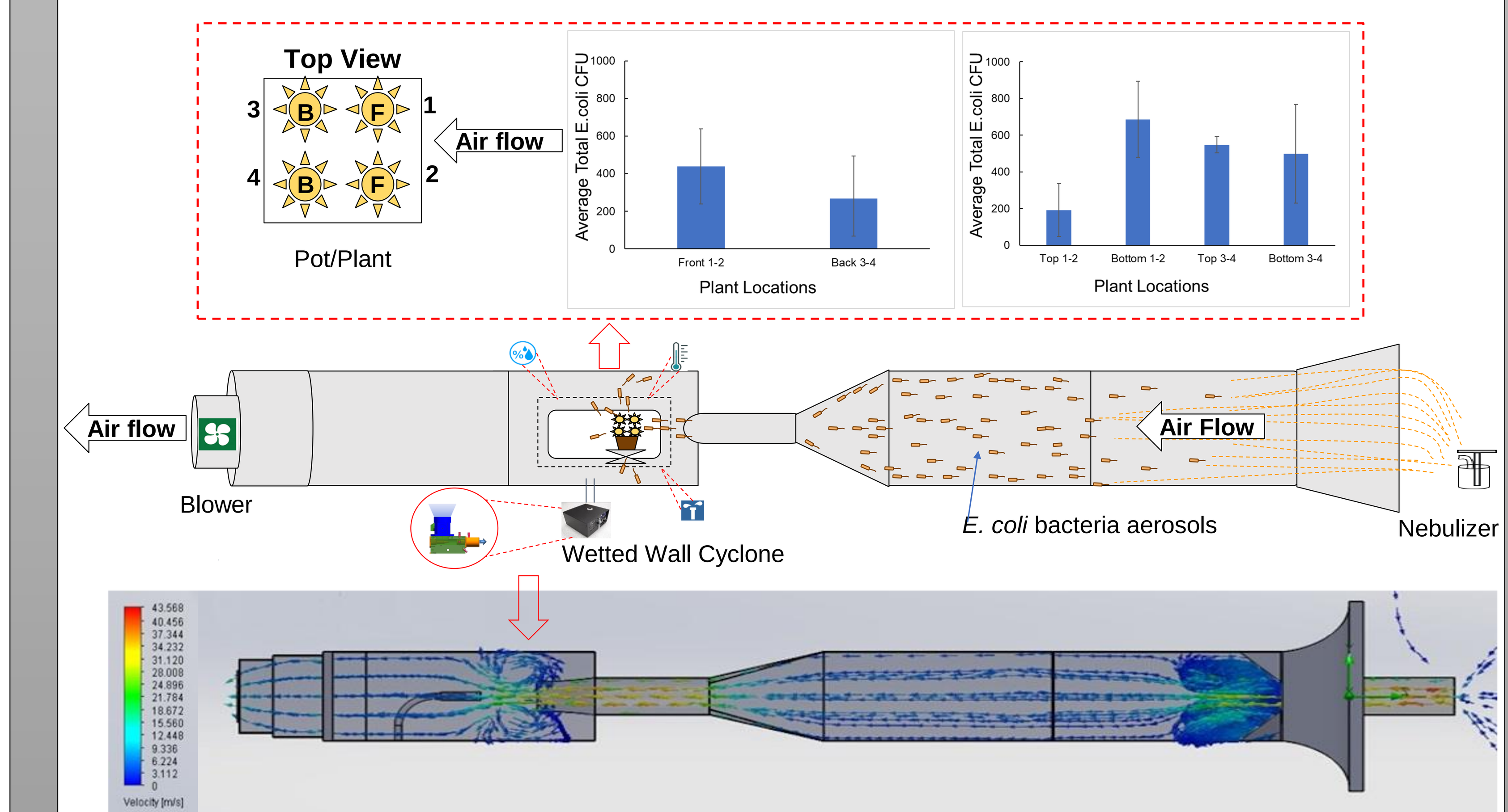
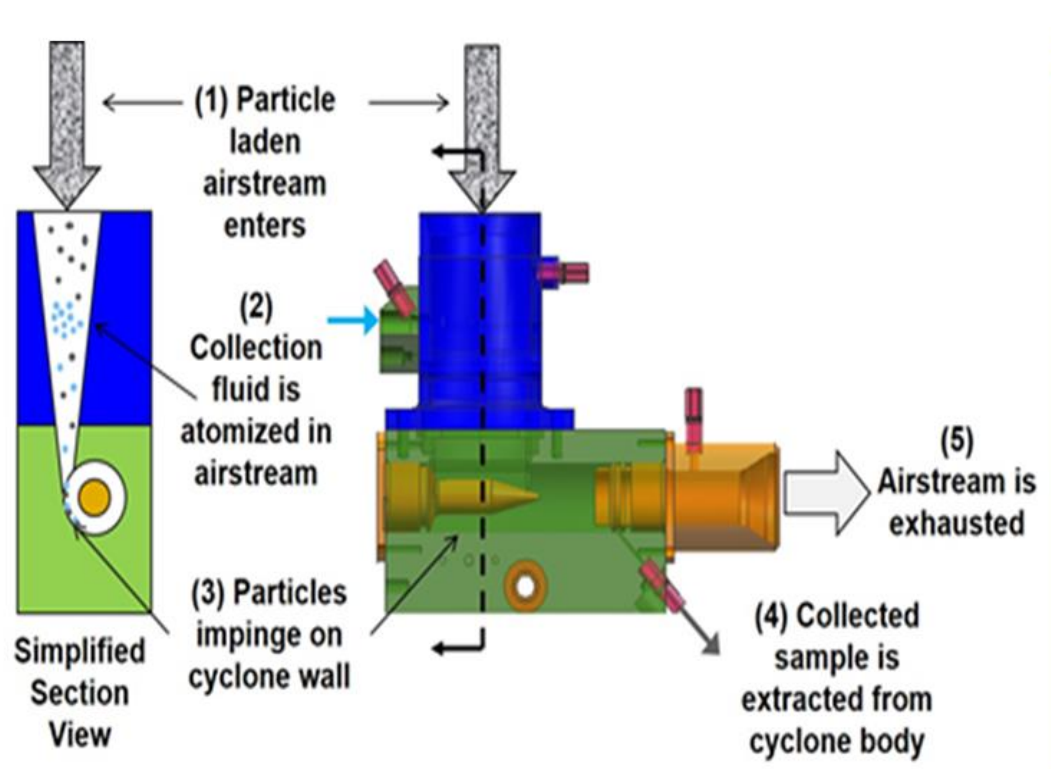


Figure 3: The top view shows the 4 plants labeled for leaf samples in relation to air flow. A leaf was taken from the top and bottom of each plant in the pot and stored in liquid. Samples were labeled based on the pot location in the row (front (1-2) or bottom (3-4)) and the leaf location, top or bottom (T/B 1-4). The graphs show higher average total *E. coli* colony forming units (CFU) counts for plants in the front row (left graph) and the front bottom top (right graph) locations on the plant. There was no significant difference between the top and bottom contaminations for plants in the back row. The middle diagram shows the experimental layout. throughout the wind tunnel. The bottom image is the computational model of the airflow pattern in the wind tunnel.

Bioaerosol Sampler

The Viable Bioaerosol Sampler (VBAC), also known as the Wetted Wall Cyclone (WWC), was used to collect air samples at 100 liters/minute within the greenhouse and wind tunnel setting. The WWC is capable of collecting aerosolized bacteria in large air spaces and concentrate them over a million times from liters of air into microliters of liquid to be analyzed and quantified.

- High air volume ultra efficient air sampler with disposable interface.
- Parts are all commercial off-the-shelf (COTs) or Modified COTs which lower end user costs.
- Air samples collected via cyclone and stored in liquid for future use.
- Liquid samples usable by wide variety of standard analysis methods.

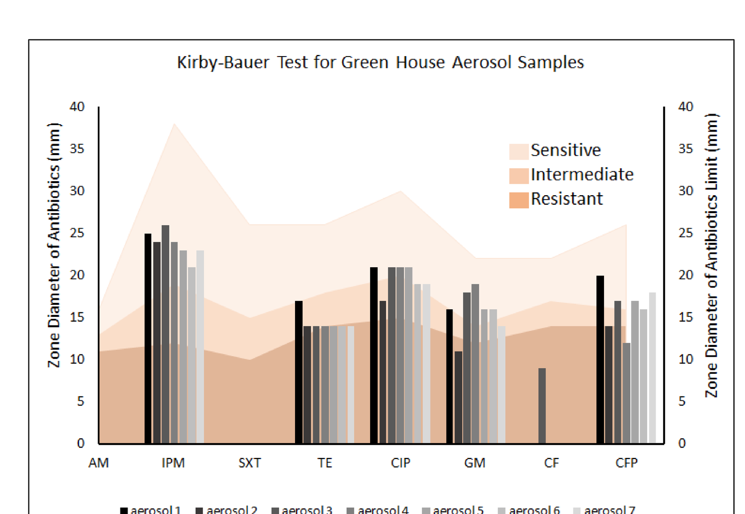


Results

Kirby-Bauer Test

Sample #	AM	IPM	SXT	TE	CIP	GM	CF	CFP
Aerosol 1	0	25	0	17	21	16	0	20
Aerosol 2	0	24	0	14	17	11	0	14
Aerosol 3	0	26	0	14	21	18	9	17
Aerosol 4	0	24	0	14	21	19	0	12
Aerosol 5	0	23	0	14	21	16	0	17
Aerosol 6	0	21	0	14	19	16	0	16
Aerosol 7	0	23	0	14	19	14	0	18
Leaf 1	0	24	0	18	21	17	18	16
Leaf 2	13	27	16	23	24	54	0	14

Table 1:Resistance (red), intermediate sensitivity (yellow) and sensitivity (green) of the collected aerosol (1A-7A) and leaf (1-2) samples to each antibiotic tested (AM, IPM, SXT, TE, CIP, GM, CF, CFP)

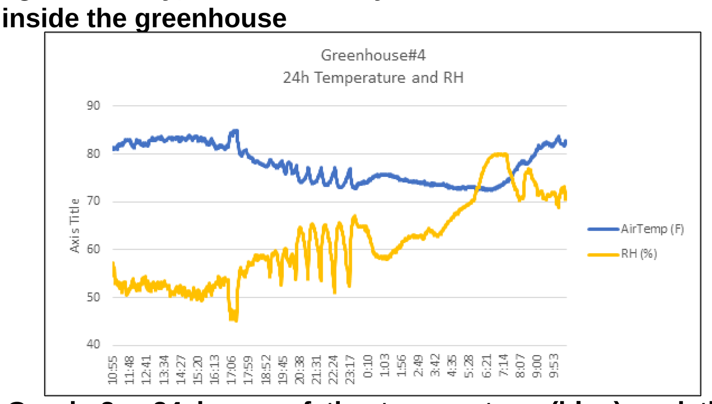


Graph 1: Zone diameters of aerosol samples 1A-7A in comparison to the resistance and sensitivity levels (orange) for each antibiotic.

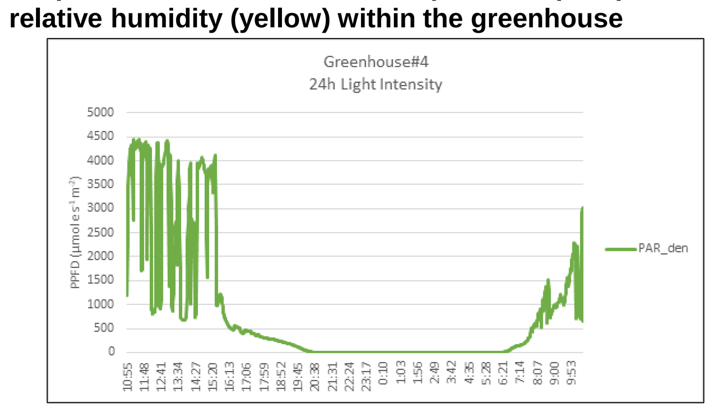
Sensor Data

	Temperature (°F)	RH (%)	Light density (µmole s^{-1} m^{-2})	Air velocity (m/s)
Minimum	72.6	45.1	0.0	0.01
Mean	**77.7**	**61.5**	**1397.7**	**0.36**
Maximum	85.0	80.1	4450.0	0.97

Table 2: Overview of the temperature, relative humidity, light intensity, and air velocity collected with the sensors inside the greenhouse



Graph 2: 24 hours of the temperature (blue) and the relative humidity (yellow) within the greenhouse



Graph 3: 24 hours of the light intensity within the greenhouse

Conclusion

Greenhouse

- Greenhouse was equipped with sensors to monitor temperature, relative humidity, light intensity and air velocity
- The highest temperature at the greenhouse sampling location was 80°F and the lowest relative humidity was 45%
- *Bacillus cereus* bacterium contamination in the air conditioner condensate becomes aerosolized and spreads with the ventilation airflow all over the greenhouse
- About 53% of aerosol samples collected in the greenhouse showed antibiotic resistance
- The collected bacteria exhibited highest resistance to antibiotics Ampicillin (AM), Sulfamethoxazole-trimethoprim (SXT), Tetracycline (TE), and Cephalothin (CF)

Smart Greenhouse in Wind Tunnel

- Leafy plants exposed to bacteria at average wind speed in Texas fields (6 m/s) at 76ºF and 50-52% relative humidity
- The number of *E. coli* cells depositing on leaves in repeated testing differs consistently depending on the position of the leaf on the plant (front or back row, top or bottom leaf)
- *E. coli* culturable counts were similar to other leaves from the same pot
- One leaf from each pot had significantly higher number of colonies
- The bottom leaves of the front plants are more likely to be impacted with *E. coli*
- Computational airflow model shows turbulent vortex development in front of the plants shown in the computational model results in increased bioaerosol impaction

Current and future work will focus on particle tracking velocimetry testing to determine the size distribution and pathway of aerosolized bacteria at different environmental conditions including temperature, humidity and wind speed, and the completion of remote sensor system for the smart greenhouse setup. Environmental factors that may trigger antibiotic resistance will be identified and greenhouse conditions will be optimized to prevent its development in bacteria that impact on the leaves of vegetables during cultivation and may be ingested with food.

Acknowledgement

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