

Spectral Radiation & Climate Control System

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Abstract

Design and build a low-cost growth chamber with automated spectral radiation and climate control that reduces energy use, space, and time for maximum crop yields. As a result of this project a new performance parameter was defined:

$$\text{E.A.T. Growth Effectiveness} = \frac{\text{Yield}(g)}{\text{Bed Area}(m^2) \times \text{Harvest Time}(d) \times \text{Energy Input}(kWhr)}$$

Controlled Variables

1. **Light:**
 - a. **Spectral Quality** - The light wavelength (λ , in nm) distribution, often presented in RGB ratios. Plants are better able to absorb different wavelength ranges, and some ranges correlate to different aspects of plant behavior (e.g. growth, flowering, coloring). Providing the plant with the ideal wavelengths will increase the growth rate.
 - b. **Photosynthetic Photon Flux Density (PPFD):** Number of photons per square meter, per second, at wavelengths that the plant can use for photosynthesis ($mol/m^2/s$). This is the primary unit to measure irradiation in biology, as the number of photons irradiating the leaf is more important than the total irradiated energy flux.
 - c. **Temporal Light Pattern:** The variation in light irradiance intensity over time. (See Figure 4)
 - d. **Daily Light Integral (DLI):** The daily light integral measures the quantity of energy the plant absorbs per day and is a function of the 3 light variables. Leaves can be damaged if irradiated with too much energy and providing not enough energy will limit growth of edible matter.
2. **CO₂ Concentration (ppm):** CO₂ is fundamental for photosynthesis and is measured in parts per million (ppm). Increasing CO₂ can increase photosynthetic rate but meets diminishing returns at high levels.
3. **Temperature (°C):** The temperature influences the leaves' ability to "inhale" CO₂ and "exhale" O₂ through its stomatal boundary. Changes in temperature alter the diffusion of CO₂ into the leaf and O₂ out of the leaf, impacting overall photosynthetic efficiency.
4. **Humidity (% RH):** Relative humidity, the percent of the maximum amount of moisture that can be stored in the air. Low relative humidity causes water stress in the plant.
5. **Airflow (m³/s):** Airflow facilitates gas exchange through plant leaves, providing a fresh supply of carbon dioxide for the plant to take in and allowing the plant to expel oxygen.



Figure 1 – Studies A (Top) and B (Bottom) in the Growth Chamber



Figure 2 –Specimens From Studies A (left) and B (right). Study A Produced More Edible Mass Per Plant Than Study B

Control System Circuit

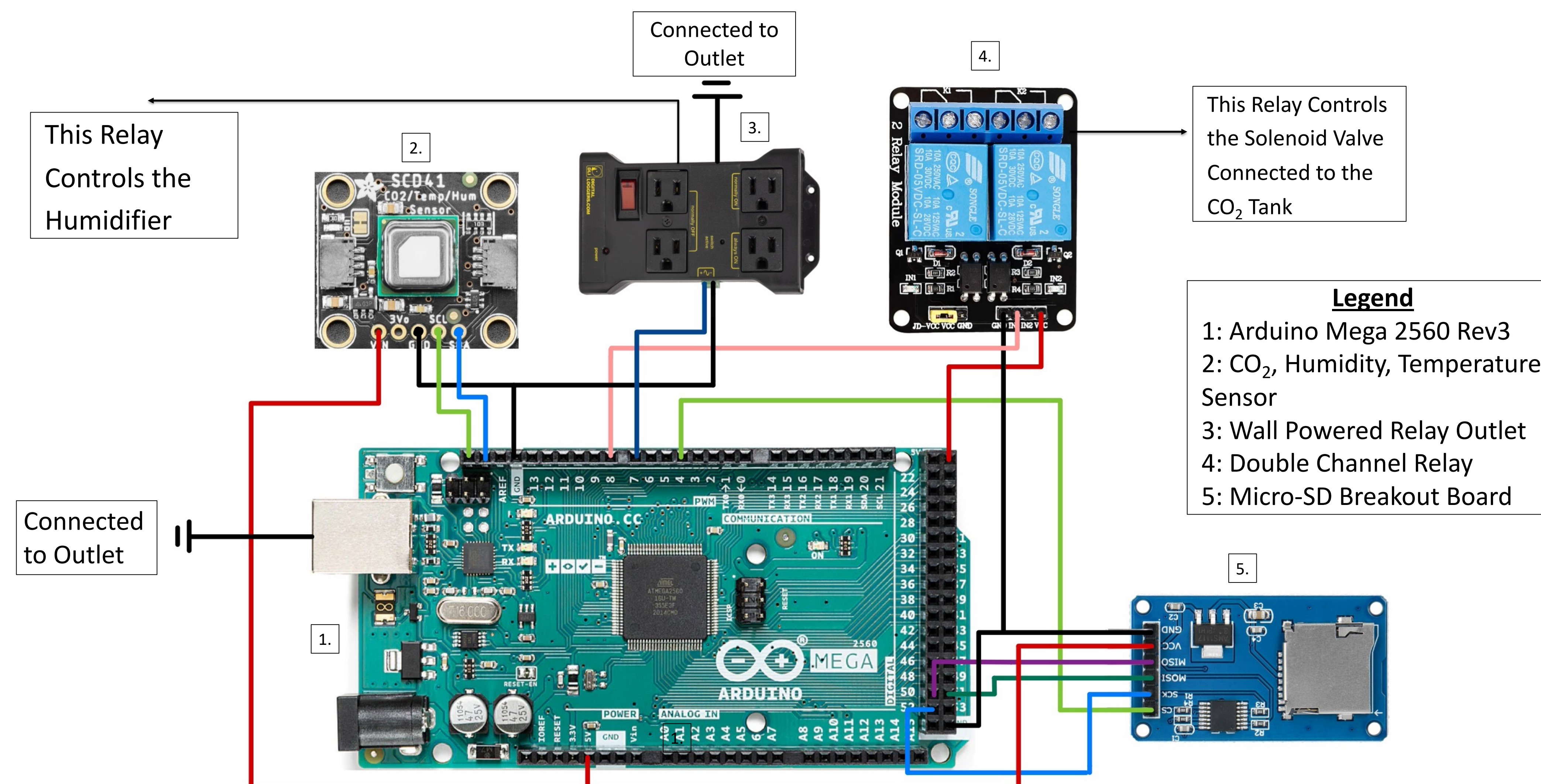


Figure 3 – Control System Circuit Used to Regulate CO₂ Concentration and Humidity Within the Growth Chamber While Logging Environmental Data to a Micro-SD Card.

Spectral and Climate Data

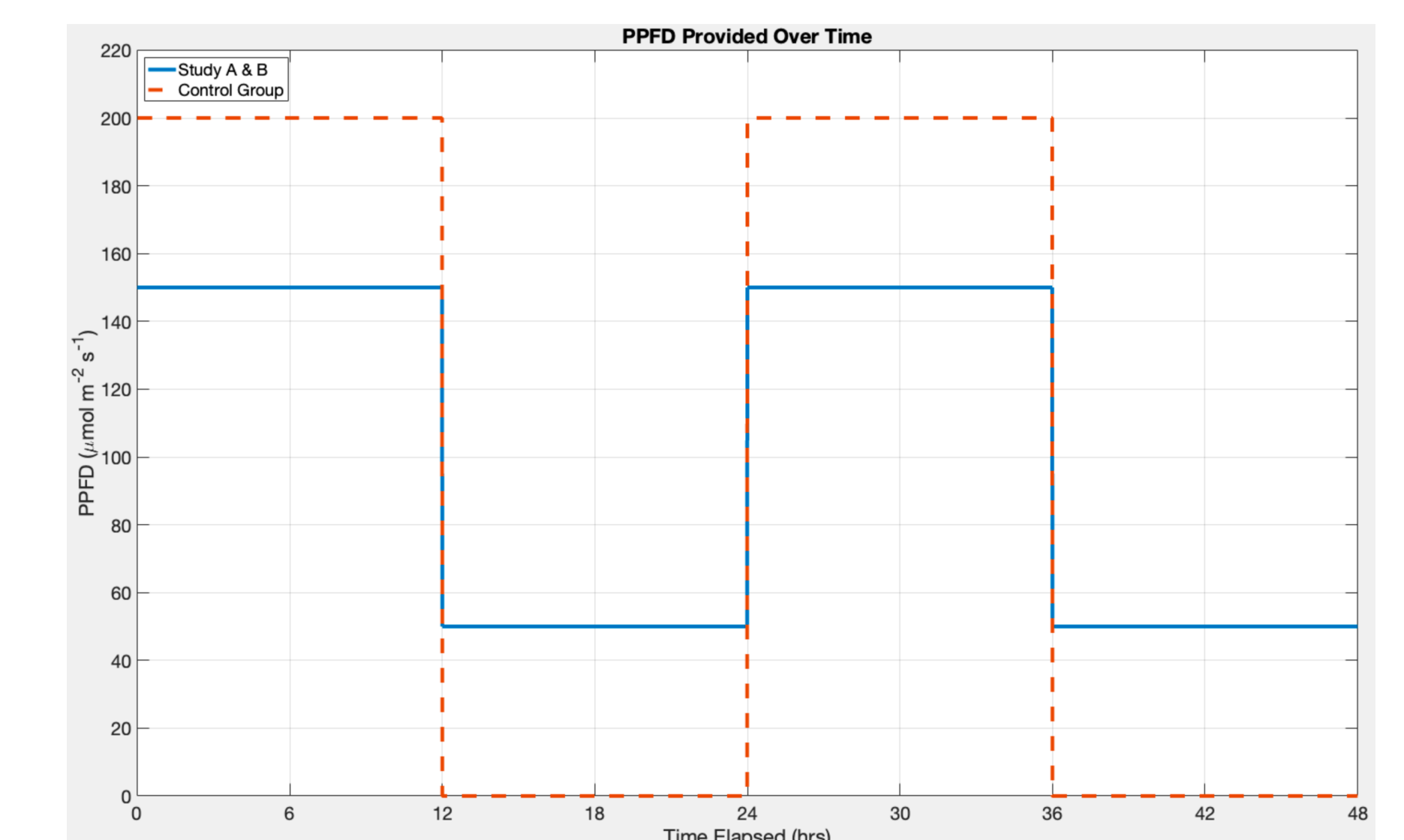


Figure 4 – Graph of PPFD for Study A, Study B, and Control Group

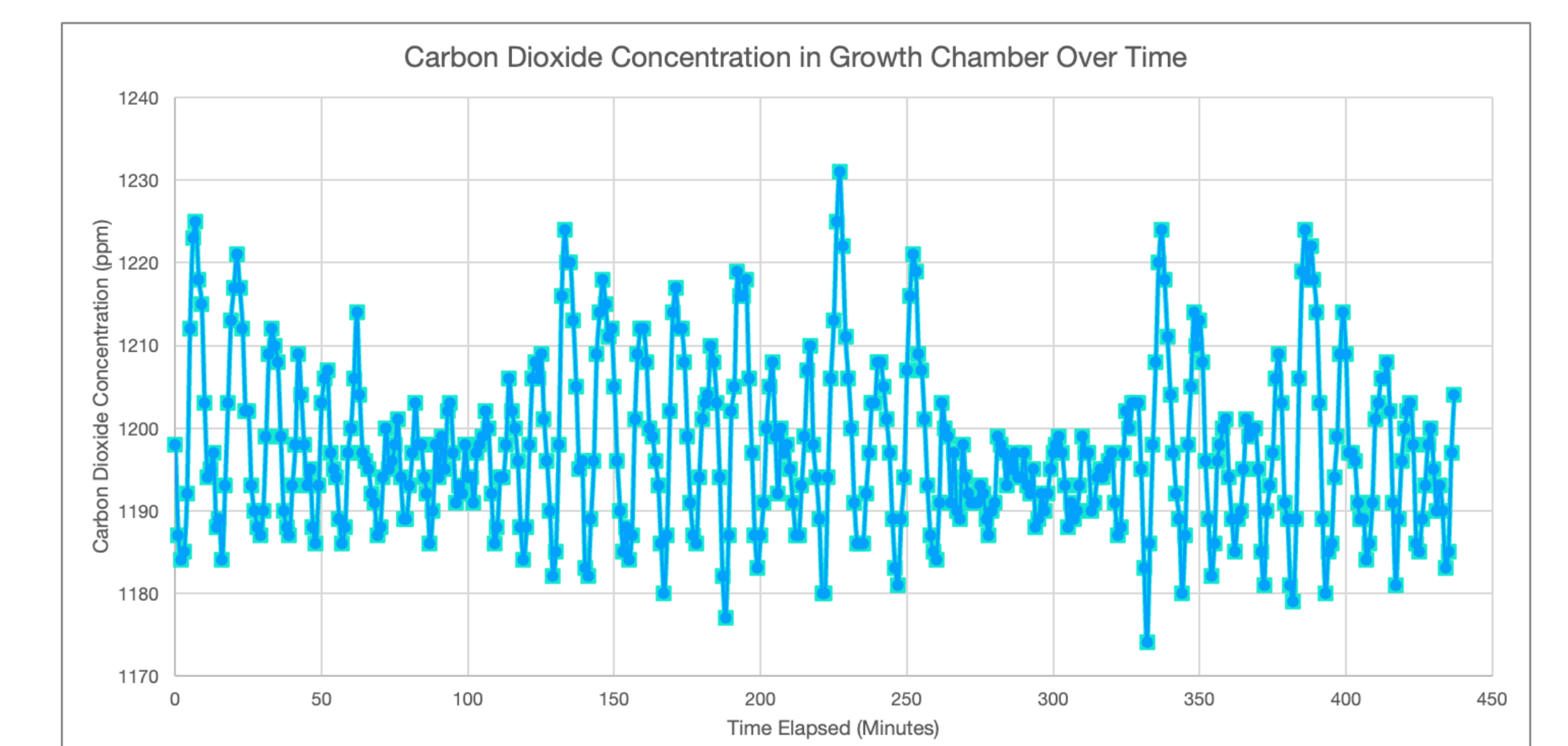


Figure 5 – CO₂ Levels Over Time. Average CO₂ Concentration was 1197ppm, With a Maximum Overshoot of 1231ppm and a Minimum Undershoot of 1174ppm

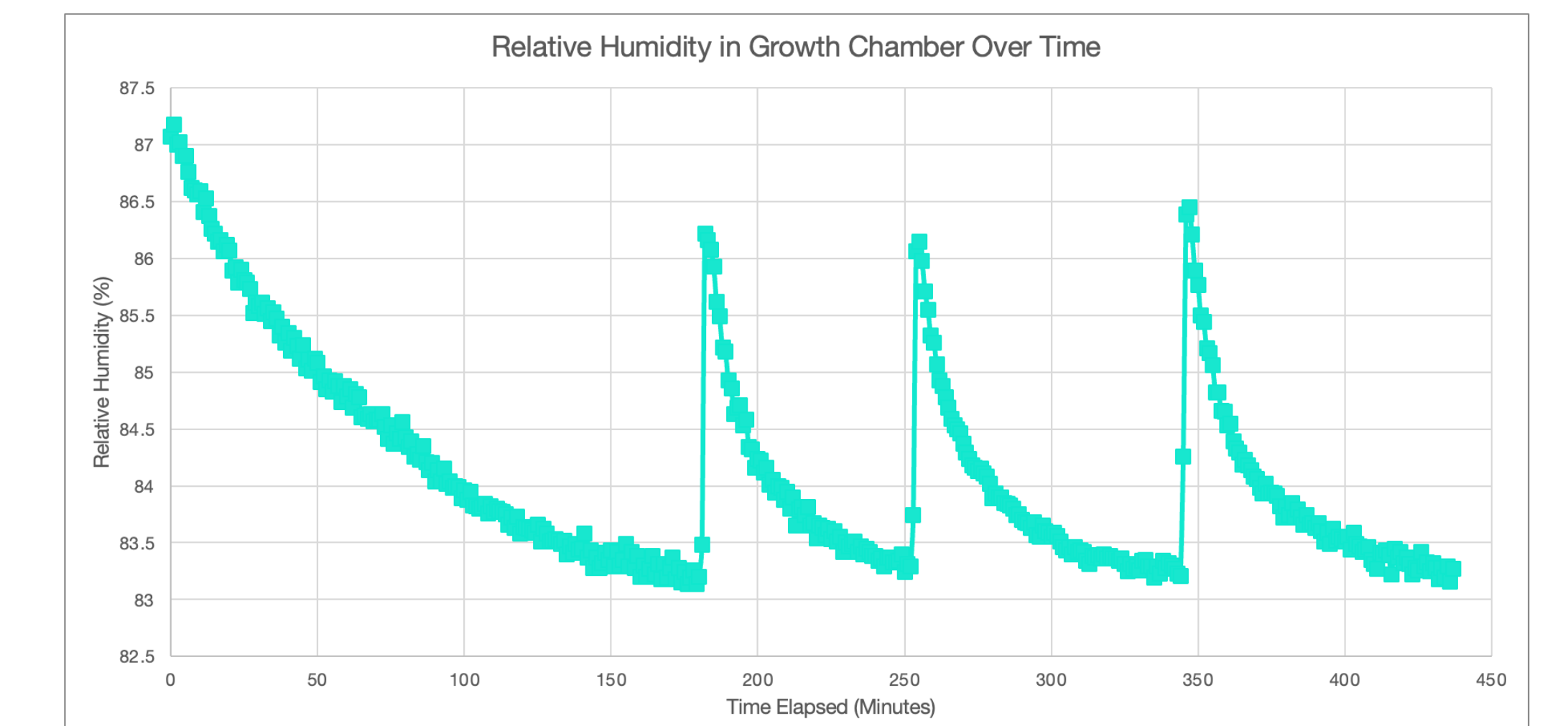


Figure 6 – Humidity Levels Over Time. Average Humidity Levels Were 84.12%

Environmental and Spectral Conditions Provided in Each Study for Lettuce (*Lactuca Sativa*)

Three Groups Were Grown With a DLI = 8.64 mol/m²/day for 40 Days to Compare E.A.T. Effectiveness From Varied Spectral and Environmental Conditions

Study A: Optimal Environment. (Inside Growth Chamber). Spectral Quality: 3R:1B, LED Bulbs

Study B: Optimal Environment. Suboptimal Lighting (Fluorescent)

Control: Suboptimal Environment (Outside Growth Chamber). Suboptimal Lighting (Fluorescent)

	Spectral Quality	Spectral Intensity (PPFD)		Temporal Light Pattern (hr)	CO ₂ Concentration (ppm)	Temperature (°C)	Humidity (%RH)	Airflow (m ³ /s)
		High	Low					
Study A	3R:1B	150	50	12	1200	24	85	0.5
Study B	4100 K	150	50	12	1200	24	85	0.5
Control	6000 K	200	0	12	Ambient (~400)	Ambient (~27)	Ambient (~40)	0

Results

	Number of Mature Plants	Adjusted Lighting Energy (kWhr)	Adjusted Environmental Control Energy (kWhr)	Adjusted Net Usage (kWhr)	Fresh Weight (g)	Fresh E.A.T. (g/m ² /kWhr/Day)	Dry Weight	Dry E.A.T. (g/m ² /kWhr/Day)
Study A	43	5.38	54.3	59.7	132.5	0.3478	11.01	0.02892
Study B	73	17.7	54.3	72.0	153.8	0.1910	13.02	0.01617
Control	17	26.5	0	26.5	7.134	0.02400	0.4072	0.001369

Environmental Power For Studies A And B Adjusted By: $P_{\text{environment, adjusted}} = P_{\text{environment}} * V_{\text{used for growth}} / V_{\text{chamber total}}$

Spectral Power For Study B Adjusted By: $P_{\text{spectral, adjusted}} = P_{\text{spectral used}} * A_{\text{plant bed}} / A_{\text{growth chamber rack area}}$

Conclusions

- Spectral Quality 3R:1B with LED Bulbs improved E.A.T. Growth Effectiveness by 80% over Study B.
- Optimal Environment with Spectral Quality 3R:1B, LED Bulbs improved E.A.T. by 1,340% over Control Study.

Acknowledgements

Dr. John Mertens
Andrew Musulin
Dr. David Branning
Dr. Nikisha Patel
Evan Hunter

Thank you to Travelers Insurance for funding our project!

References

Please scan this QR code to see our references!

