Closed System Evaluation of VerdeTerra's Indoor Air Purification System in Relation to CO2 Scrubbing

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1. Abstract

People are spending 80-95% of their lives indoors (Javier), where air quality is 2-5 times worse than outdoors (EPA). Indoor CO2 levels have been shown to reach unhealthy levels in occupied meeting rooms and classrooms (Myhrvold) (Erbiao), even with existing mitigation technologies (Wyon). The effects of increased CO2 include reduced cognitive performance of 10-15% (Cincinelli) and respiratory illnesses, such as asthma (EPA) (Mata). This is exacerbated by the climate crisis, as Heating Ventilation and Air Conditioning (HVAC) systems are becoming essential, and buildings are better sealed. HVAC systems account for 38% of a building's energy consumption and 12% of global consumption (González-Torres).

This study evaluates the efficacy of VerdeTerra's Prototype7, an innovative air purification system that utilizes cyanobacteria, specifically Spirulina, for biologically mediated CO2 reduction within indoor environments. We conducted a series of controlled experiments to compare the CO2 absorption efficiency of VerdeTerra's Prototype7 against traditional air purification technologies including standard HEPA/Charcoal filter-based purifiers and natural bioremediators like Spathiphyllum (Peace Lilly) plants. Our results demonstrate that Prototype7 is up to five times more effective than Two Spathiphyllum (Peace Lilly) Plants, and ten times more effective than a Market Home Air Purifyer with HEPA and activated charcoal filtration, offering a sustainable alternative to mechanical ventilation and chemical air scrubbing. These findings suggest that integrating cyanobacteria-based systems could revolutionize indoor air quality management, especially in tightly sealed environments where air exchange is limited. Further research is recommended to explore the long-term operational and environmental impacts of deploying such biotechnological solutions in diverse indoor settings.

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3. Introduction

3.1 Overview of Indoor Air Quality and Bioremediation

Indoor air quality (IAQ) is a critical public health concern that has significant implications for comfort, health, and productivity (González-Torres). Traditional methods for improving IAQ include mechanical ventilation and filtering out pollutants. However, bioremediation using microalgae presents a novel and sustainable alternative, particularly in reducing indoor carbon dioxide (CO2) levels, which are indicative of poor air quality when elevated (Vijayan).

3.2 Microalgae as a Solution for CO2 Reduction

Microalgae have been recognized for their efficient photosynthetic capabilities, which surpass those of terrestrial plants. These organisms can assimilate CO2 and convert it into biomass through photosynthesis, thereby reducing CO2 concentration in their environment. Studies demonstrated that certain species of microalgae, such as Chlorella and Spirulina, can thrive in indoor conditions, absorbing CO2, and potentially other volatile organic compounds (VOCs) and particulates (Anbarasan) (Peter).

3.3 Integration of Microalgae in Building Systems

Incorporating microalgae into building systems has been explored through the development of algal bioreactors and algae-integrated building facades. These systems use live algae cultures maintained in transparent panels or tubes that can be integrated into building exteriors or interiors. These systems not only reduce CO2 but also generate biomass that can be used for biofuels or other valuable biochemicals, presenting a dual benefit (Shaghayegh) (Peter).

3.4 Effectiveness and Efficiency of Microalgae Systems

Research found that algae-based air purification systems could significantly enhance IAQ by lowering CO2 levels effectively within controlled environments (Mata). Their experiments showed that a small-scale microalgal bioreactor could maintain lower CO2 levels over extended periods without the need for complex maintenance, making it a practical option for indoor spaces (Chun-Yen).

3.5 Health and Cognitive Benefits

Studies have shown that increased CO2 levels can affect decision-making performance (Myhrvold), with notable declines observed at concentrations as low as 1,000 Parts Per Million (PPM), far below levels considered harmful for physical health (Cincinell) (Erbiao) (Wyon). Further research demonstrated that cognitive function scores were 15% lower on average in environments with 945 ppm CO2 compared to 550 ppm

(Cincinell). These findings suggest that the standard acceptable CO2 concentration might need reevaluation concerning cognitive functions and overall indoor environmental quality. Lowering CO2 levels using microalgae also correlates with improved health and cognitive performance outcomes. Environments maintained with microalgal bioreactors showed not only reduced CO2 levels but also enhanced oxygen availability, which significantly improved cognitive function and productivity among the occupants (Mata).

3.6 Existing CO2 Removal Systems

Existing home air purification solutions use filters of activated charcoal. Charcoal is cheap, but limited in capacity and requires frequent replacement of filters. Active systems such as ionization, ultraviolet, and photocatalytic oxidation process work well to remove volatile organic compounds but increase CO2 levels in the process (Peadeep). They may also generate ozone. More exotic solutions include zeolite, that traps CO2 in the International Space Station, but requires the vacuum of space to then clean the filter. Chemical scrubbers, such as those used in submarines, require complex systems that produce a pungent odor, and require captured CO2 to be burned off (Mazurek).

3.7 Challenges and Future Prospects

While promising, the integration of microalgae in indoor environments faces challenges, including optimizing light and temperature conditions to maximize photosynthetic efficiency and managing the life cycles of the algae. Future research directed towards automated and self-sustaining systems that integrate sensor-based technologies for real-time monitoring and control of microalgal growth and health (Khan) (Mata).

3.8 Conclusions from Current Literature

The potential of microalgae to improve IAQ by reducing CO2 concentrations offers a sustainable alternative to traditional mechanical ventilation systems. The dual benefits of pollutant reduction and biomass production for sustainable applications mark microalgae as a promising solution in green building designs. Although there are some studies (Rodeheffer) that did not show impacts of CO2 on cognitive performance, the majority of experiments show performance impacts (Erbiao) (EPA) (Cincinelli) (Mata) (Myhrvold).

3.9 VerdeTerra Prototype7 System

VerdeTerra’s novel technical design utilizes photobioreactors as air scrubbers with cyanobacteria to capture CO2 for air purification indoors as seen in Figure 01 below. Utilizing nature’s most effective CO2 scrubber spirulina, which is 10-20x more effective at removing CO2 than any terrestrial plant. It will be the first CO2 air scrubber for HVAC systems. Offering full automation and only biomass collection service needed to keep cost and maintenance intervals in line with exiting HVAC services. The system will be the first control system directly interfacing photobioreactors with HVAC systems to reduce energy consumption by subverting the demand on the outside air requirements.

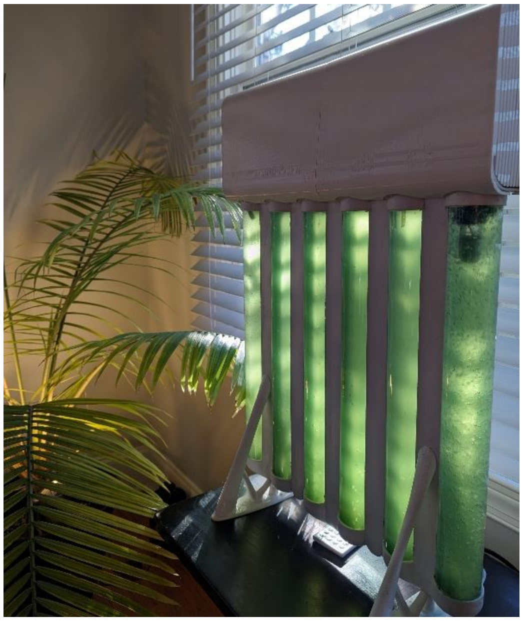

Figure 01: VerdeTerra Prototype7 in operation

3.10 Research Hypothesis

This research was conducted to test the hypothesis that VerdeTerra's Prototype7 air purification system, automated biofiltration system utilizing cyanobacteria, can reduce environmental CO2 concentrations, its effectiveness, and the performance versus air scrubbing plants and home air purifiers.

3.11 Research Objectives

The experiment will detail the following completed objectives:

1. Test the experimental system can create a closed system environment, by measuring CO2 loss over time.
2. Measure the efficacy, in terms of CO2 removed from a sealed environment by PPM reduction, of the VerdeTerra Prototype7.
3. Measure the efficacy, in terms of CO2 removed from a sealed environment by PPM reduction, for a market home air purifier.
4. Measure the efficacy, in terms of CO2 removed from a sealed environment by PPM reduction, for two Spathiphyllum (Peace Lilly) plants.
5. Compare the CO2 reduction capabilities of Prototype7 to those of standard home air purifiers and natural air scrubbing plants.

4. Methodology

4.1 Equipment

To conduct an objective evaluation of the CO2 scrubbing abilities a closed system is needed. To do this the team constructed a closed test-cell utilizing clear polycarbonate, aluminum for the outer structure, and silicone to create airtight seals between panels and joints.

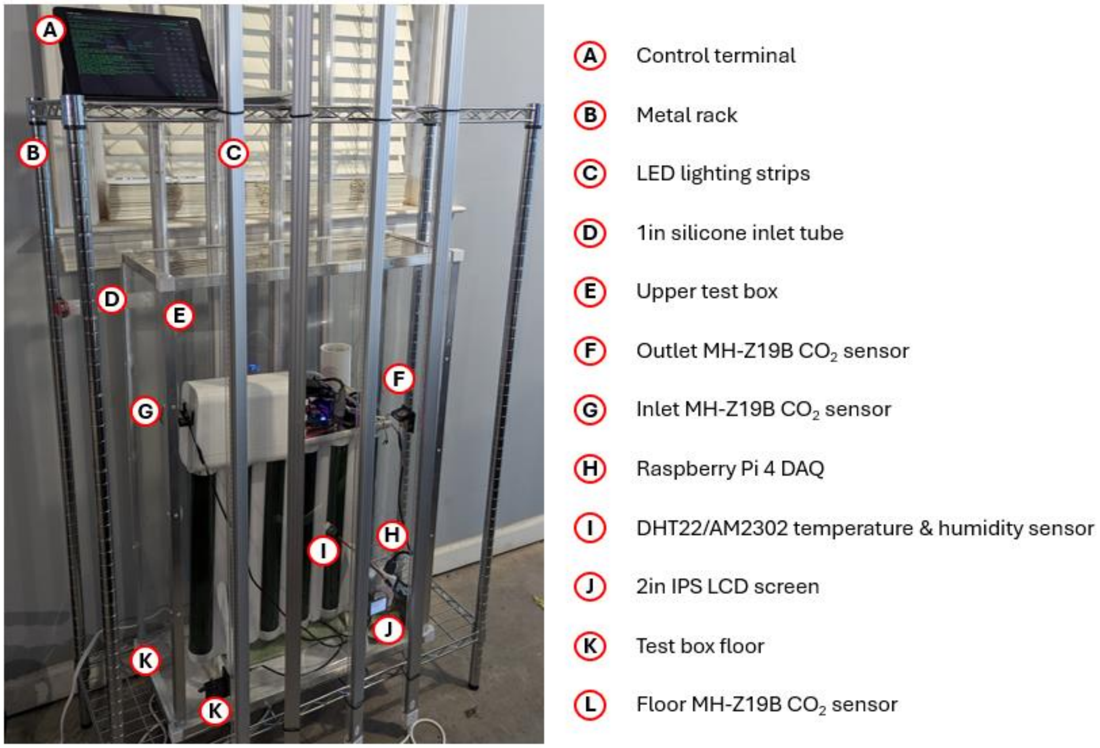

Figure 02: Major components for the Closed System Testing Chamber

The box, as shown above in Figure 02, was sized to fit the VerdeTerra Prototype7 air purification system, a market air purification system, and Spathiphyllum (Peace Lilly) plants. It has a dimension of 10in width x 24in length x 30in tall for a total volume of 7,200in^3. A removable floor was created to move test systems in and out of the sealed system. The floor was fitted with a silicone seal that when the upper box was placed on top created an air-tight seal. To input CO2 a 1in diameter silicone inlet tube 7in long was inserted into the upper side of the box. This tube was silicone sealed where it entered the box and had a plastic cap sealed with worm-type-clamp that would block off the opening when not in use. A 120v power strip was used to pass electricity into the system and the cable passthrough was sealed with silicone.

The closed system box was then placed on a metal rack affixed with the artificial lighting system. The artificial lighting system consisted of 8, 94in long, strip lights with 480 T8 LEDs per strip. The lights are rated to 72w, 9000lm, and 5000k each.

Data acquisition was managed by a Raspberry Pi 4. The sensor suite included: 3 independent MH-Z19B infrared CO2 sensors communicating via USB serial as seen in Figure 04 below, 3 1in x 1in fans to circulate air over the MH-Z19B sensor as seen in Figure 04 below, 1 DHT22/AM2302 temperature and humidity sensor communication via Raspberry Pi GPIO, 1 120v power plug extension cord to pass energy into the closed system, and a 2in IPS LCD screen to monitor the system. The sensor performance is listed below in Table 1.

Table 1: Sensor Performance

	Measures	Working Temperature (Fahrenheit)	Working humidity (%)	Measuring Range (PPM)	Accuracy
MH-Z19B	CO2 in PPM	32 to 122	0 ~ 90% RH	0 - 5000	± (50PPM +3% reading value)
DHT22/AM2302	Temperature and Humidity	-40 to 176	0 ~ 100% RH	N/A	humidity ±2% temperature ±0.2

Table 1: Performance specifications of data measurement sensors for closed system testing

4.2 Environment

External environmental conditions for the system were in two locations. The primary testing location for the rack, lighting, and closed system were kept in a dark garage with temperatures between 65-75 degrees Fahrenheit. To verify the sealing efficacy, the closed system was placed outdoors in a covered area in Atlanta, GA with temperatures between 55-75 degrees Fahrenheit and CO2 levels consistently below 400 PPM for the duration of seal validation testing as shown below in Figure 03.

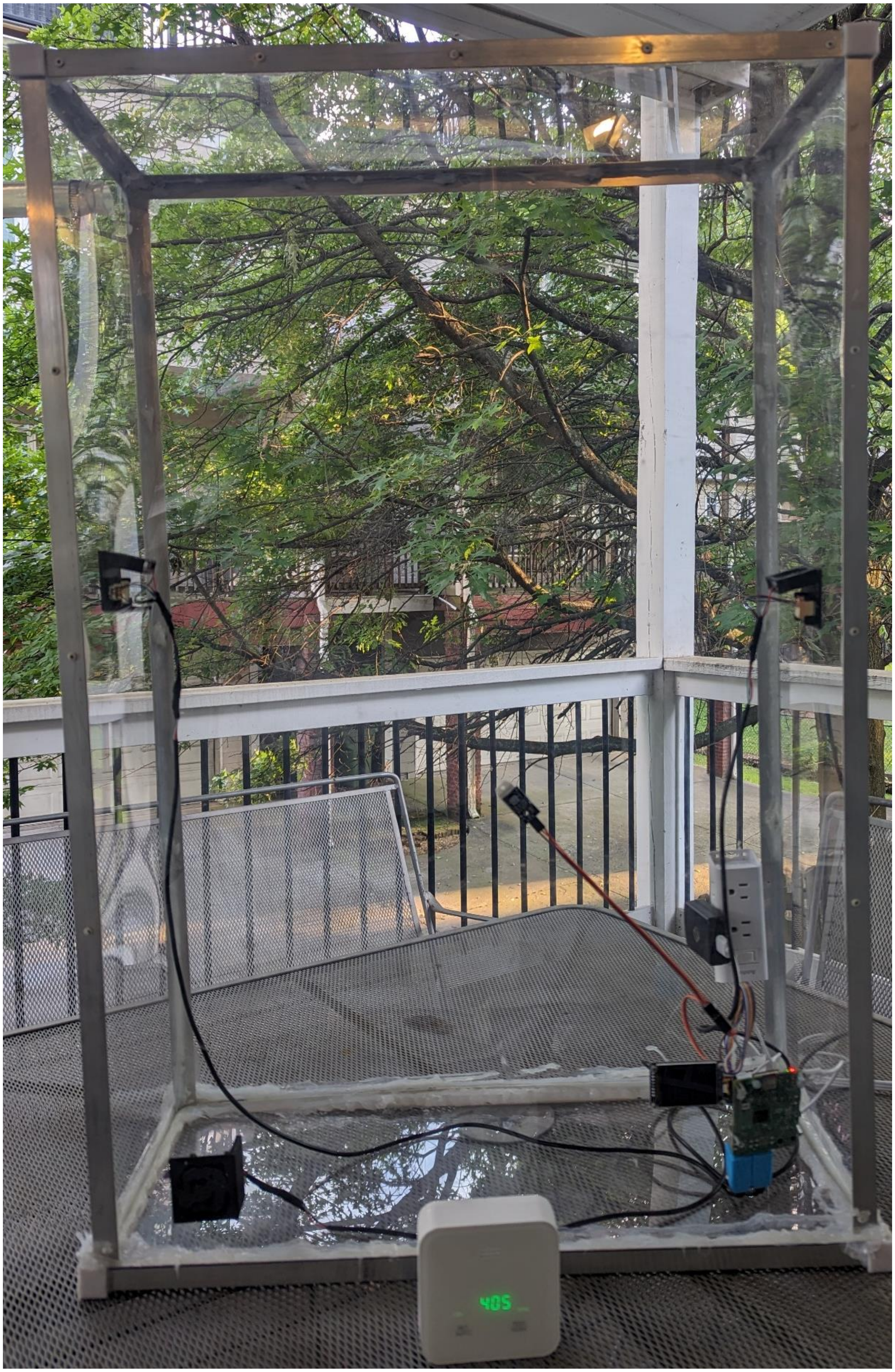

Figure 03: Seal Validation outdoor environment

4.3 Seal Validation Process

To verify the efficacy of the system to create a closed environment the system was placed outdoors in a covered area in Atlanta, GA with temperatures between 55-75 degrees Fahrenheit and CO2 levels consistently below 400 PPM. This was monitored through, U.S. National Weather Service data, and an external MH-Z19B infrared CO2 sensor to ensure the exterior environment stayed at or below 400 PPM. This exterior condition is needed to create a large differential in CO2 between the closed system and outside environment. If there were leaks in the system, the large differential would exacerbate the gas exchange to be seen in the data. Prior to starting, the closed system box was placed outdoors in a 400 PPM environment. The data acquisition system was activated by running the testing code on the Raspberry Pi 4. After 1 hour of stabilization the three independent MH-Z19B sensors were zeroed out by performing the free-air-calibration method. Setting a consistent 400 PPM baseline for measurement. The interior of the closed system had its CO2 raised by blowing human breath into the 1in silicone inlet tube. For each breath injection the air pressure was allowed to equalize after a few seconds of holding the pipe closed. This was done to allow the CO2 to mix after each injection and keep the system at atmospheric pressures. Once the three independent MH-Z19B sensors read a consistent value for CO2 near 5000 PPM the 1in injection pipe was closed with a plastic cap and secured with a metal worm-type-clamp to prevent leakage. The system was allowed to stabilize for 15 minutes, and the CO2 levels were monitored on the 3 MH-Z19B sensors to ensure the start condition was ready for the closed system. The system was then left to sit for 12 hours over the course of the day while the Raspberry Pi 4 logged three independent MH-Z19B infrared CO2 sensors, and 1 DHT22/AM2302 temperature and humidity sensor. At the end of the test, data was then collected and analyzed to determine the leakage rate of CO2.

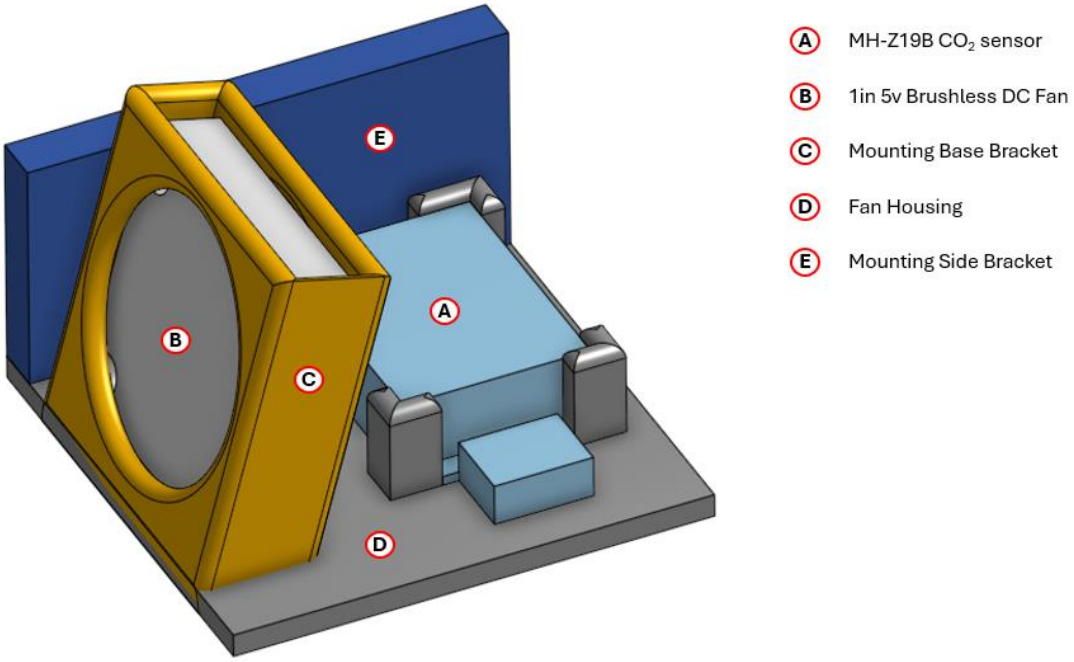

Figure 04: MH-Z19B infrared CO2 sensor bracket with fan

4.5 System Testing Process

Testing of the VerdeTerra Prototype7, Market Home Air Purifier, and Spathiphyllum (Peace Lilly) plants was conducted in an identical fashion. The test subject was placed onto the closed system floor, plugged into the 120v power strip (excluding plants), system started (excluding plants), and the closed system upper box placed over the test subject securing into the closed system floor.

Prior to starting, the closed system box was placed outdoors in a 400 PPM environment. The data acquisition system was activated by running the testing code on the Raspberry Pi 4. After 1 hour of stabilization the three independent MH-Z19B sensors were zeroed out by performing the free-air-calibration method. Setting a consistent 400 PPM baseline for measurement.

The whole closed system was then moved to the closed garage and placed onto the metal storage rack affixed with the artificial lighting system. The artificial lighting system consisted of 8, 94in long strip lights. The CO2 injection procedure then proceeded identically to the Seal Validation Process. The interior of the closed system had its CO2 raised by blowing human breath into the 1in silicone inlet tube. For each breath injection the air pressure was allowed to equalize after a few seconds of holding the pipe closed.

This was done to allow the CO2 to mix after each injection and keep the system at atmospheric pressures. Once the three independent MH-Z19B sensors read a consistent value for CO2 near 5000 PPM the 1in injection pipe was closed with a plastic cap and secured with a metal worm-type-clamp to prevent leakage. The system was allowed to stabilize for 15 minutes, and the CO2 levels were monitored on the 3 MH-Z19B sensors to ensure the start condition was ready for the closed system.

The system was then left to sit for 8 hours over the course of the day while the Raspberry Pi 4 logged three independent MH-Z19B infrared CO2 sensors, and 1 DHT22/AM2302 temperature and humidity sensor. At the end of the test, data was then collected and analyzed to determine the reduction rate of CO2 for each of the test subjects. Between each test the closed system was opened, wiped down with a clean cotton towel, and left to sit overnight to reach equilibrium with the environment.

4.6 Testing Samples

For the system performance testing three systems were compared. The first was the Market Air Purification System. It is a filter & fan box design with a fan pulling interior air through five stages of filters. Those filters, in order, are a dust washable filter, H13 HEPA filter, Blue Nanois Filter, HEPA filter, and an activated charcoal filter. The fan speed was set to its maximum speed for 1100 gallons per hour. The second system was a pair of Spathiphyllum (Peace Lilly) plants, these plants measured ten inches tall from dirt to tallest leaf with a five inch planter diameter. The Spathiphyllum was chosen for its efficacy of indoor air purification. These plants are the most efficient indoor air purifying plants (Wolverton), and two plants were chosen over one to provide the greatest chance of purification for the available test chamber space. The plants were procured from a local nursery the same day of testing and were visually inspected for health, noting no rotting, infections, or discoloration. Prior to testing, the plants were given one cup of water each, applied directly to the roots. The final testing sample was the VerdeTerra Prototype7. This device consisted of six 1.75in internal diameter by 18in tall clear tubes with monitoring and photobioreactor control mechanisms contained in the top box. The total liquid volume of the system is one gallon, and throughout the test the system maintained 85 degrees Fahrenheit 10 pH water. The initial algae culture and nutrient mix was a proprietary blend and testing was started after the algae culture reached full operational maturity density. The operational maturity density is controlled by Prototype7, and its exact targets are proprietary. During the test interior air bubbled up through the six tubes at 60 gallons per hour.

4.7 Data Collection and Analysis

For the Seal Validation and System Testing Processes the data collection and analysis was the same. The Raspberry Pi 4 data collection stored the data in CSV format on its local flash storage. This data was then collected via a terminal connection. The raw data was cleaned to remove data outside of the experimentation (such as adding in CO2 or removing the Closed System Box at end). This data was then plotted on a time (in minutes) vs CO2 (in PPM) graph with a linear trendline fitted for the Seal Validation testing and System Testing (in respect to the Market Home Air Purifier, and Spathiphyllum (Peace Lilly) plants). The VerdeTerra Prototype7 trendline best fit was an exponential trendline. The Seal Validation linear trendline slope was then evaluated to determine a leakage rate of CO2 over time as represented by the trendlines slope.

For System Testing Process experiments, each experiment (Prototype7, Market Home Air Purifier, and Spathiphyllum (Peace Lilly) plants) was conducted two times. All tests of similar type were then evaluated for deltas to develop a range, then averaged to create a representative performance. For the System Testing Processes, the average performance for each type (VerdeTerra Prototype7, Market Home Air Purifier, and Spathiphyllum (Peace Lilly) plants) was plotted on a single graph to compare the deltas in performance as described by their slopes.

5. Results

5.1 Comparison of the CO2 Reduction Capabilities of Prototype 7 to Market Home Air Purifiers and Two Spathiphyllum (Peace Lilly) Plants

The VerdeTerra Prototype7 system shows that at higher CO2 concentrations it is up to five times more effective than Two Spathiphyllum (Peace Lilly) Plants, and ten times more effective than a Market Home Air Purifyer with HEPA and activated charcoal filtration as shown in Figures 05 and 06 below. One note was that both the Two Spathiphyllum (Peace Lilly) Plants and the Market Home Air Purifier had linear CO2 scrubbing rates, while the Prototype7 had an exponential equation governing performance of CO2 scrubbing. The Prototype7 was much more efficient at scrubbing CO2 at higher concentrations, exponentially tapering off as CO2 concentrations reached the 400 PPM measurement floor. For all experiments the temperature stayed between 72-80 degrees Fahrenheit as seen in Figure 08, while the relative humidity was between 65-85% as seen in Figure 07.

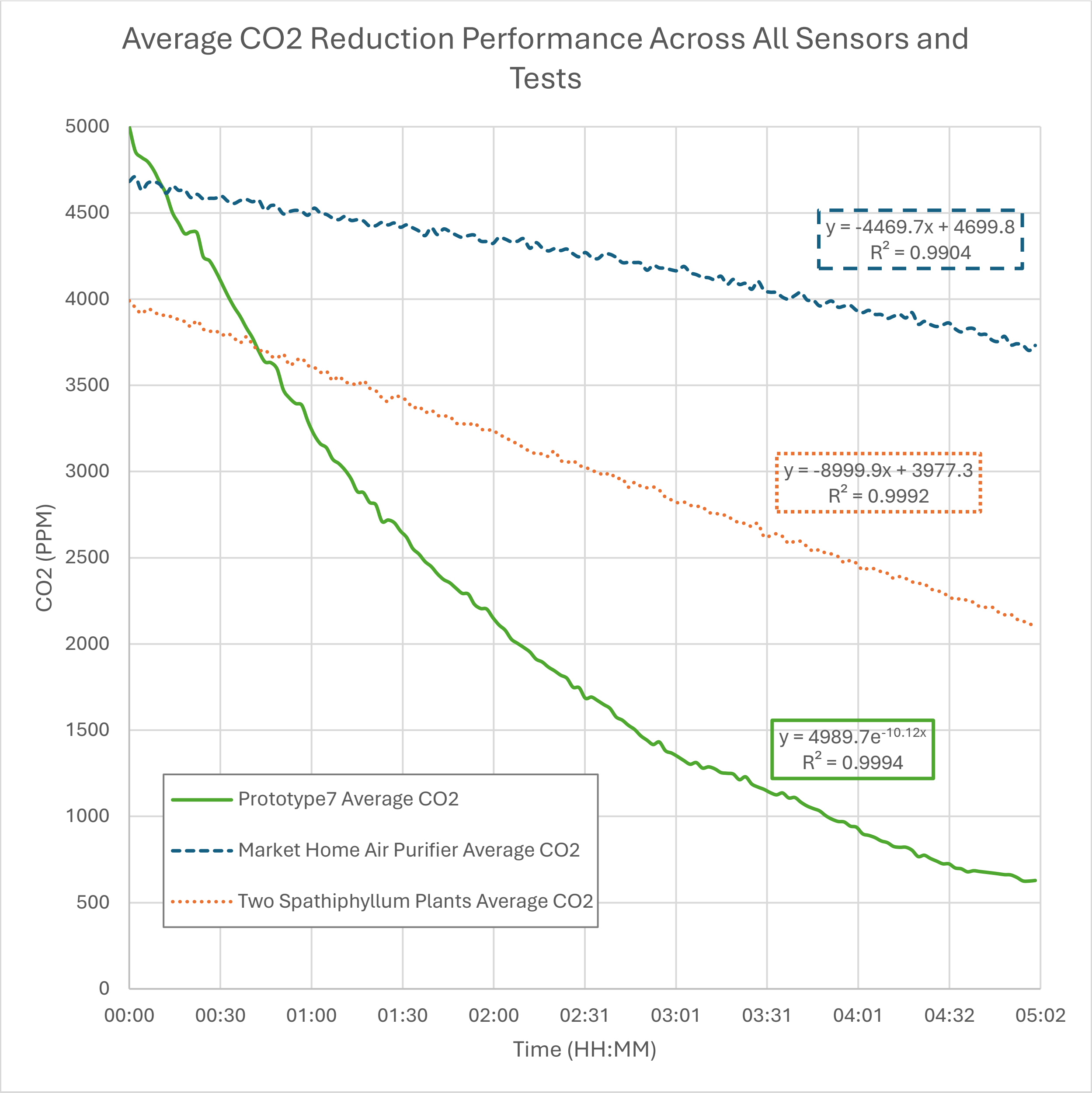

Figure 05: CO2 Reduction Performance of test subjects averaged from 3 CO2 sensors for each experiment then averaged across two experiments for each test subject. Line equation and R-squared fitment shown for each subject.

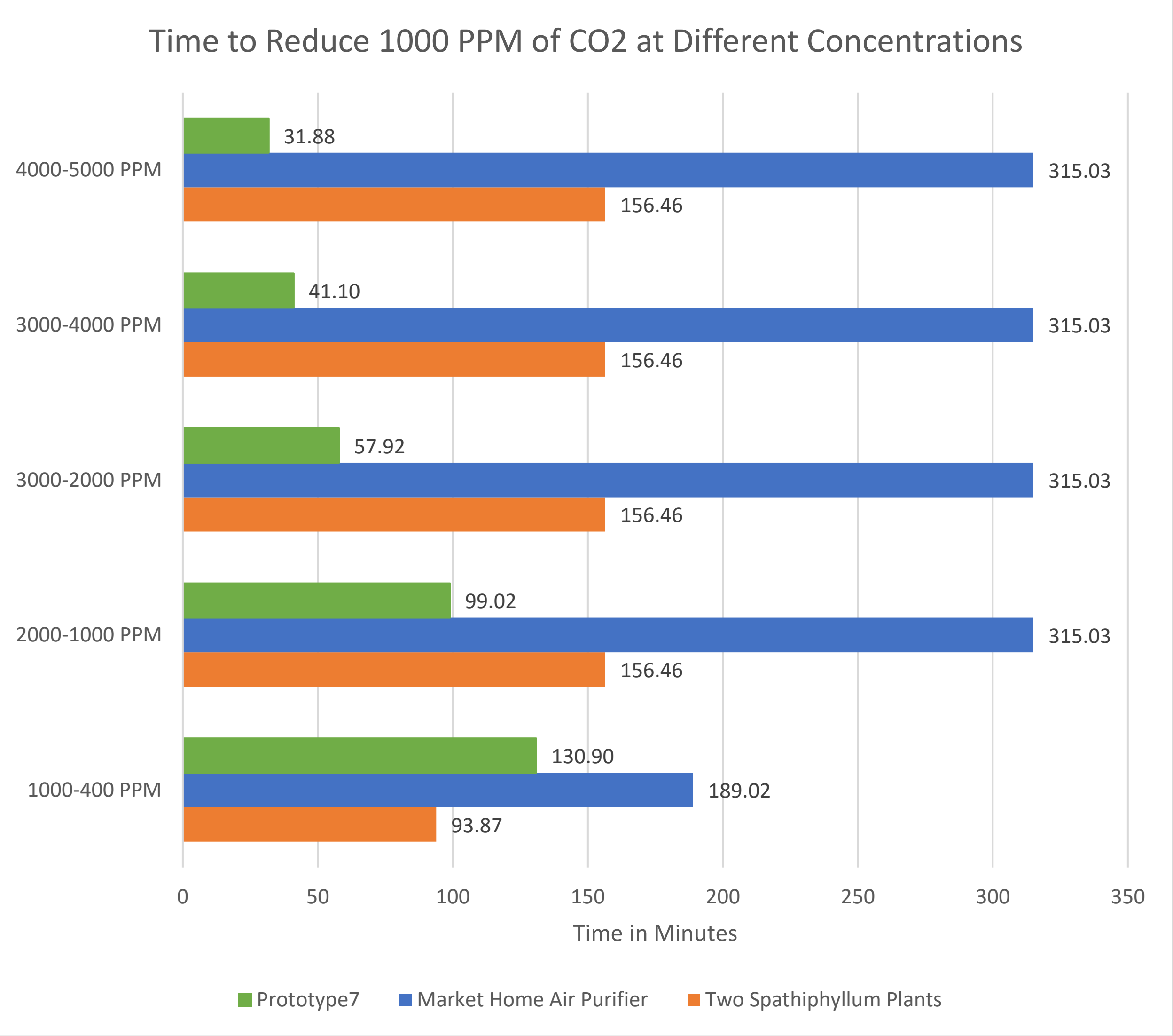

Figure 06: Time (in minutes) for each test subject to reduce 1000 PPM of CO2 for different CO2 concentration ranges.

Figure 07 and Figure 08 below shows the test humidity and temperature respectively for each subject averaged across both tests. A moving average trendline was then calculated, shown dotted, to assist in viewing the temperature trends. This was necessary due to the temperature and humidity data loss during the test. The chosen sensor would lose information packets and only report intermittently. Thankfully the received packets were well distributed throughout the test, and it is possible to see the overall temperature and humidity trends.

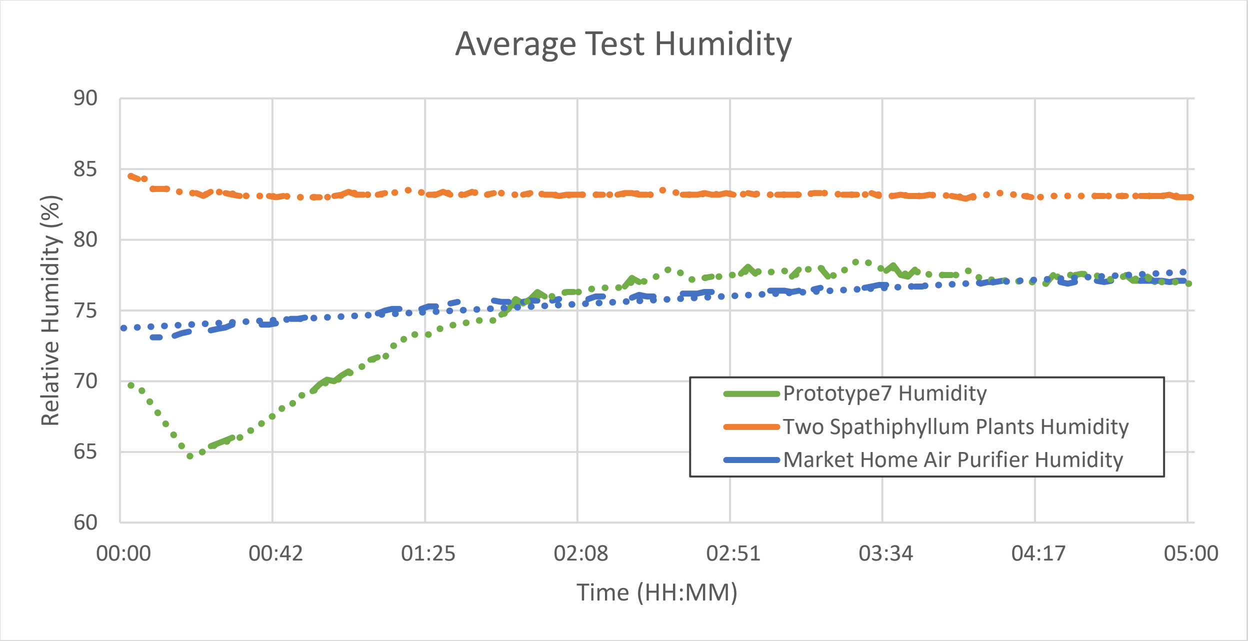

Figure 07: Test humidity (%) for each test subject averaged across two tests with a calculated moving average trendline shown dotted.

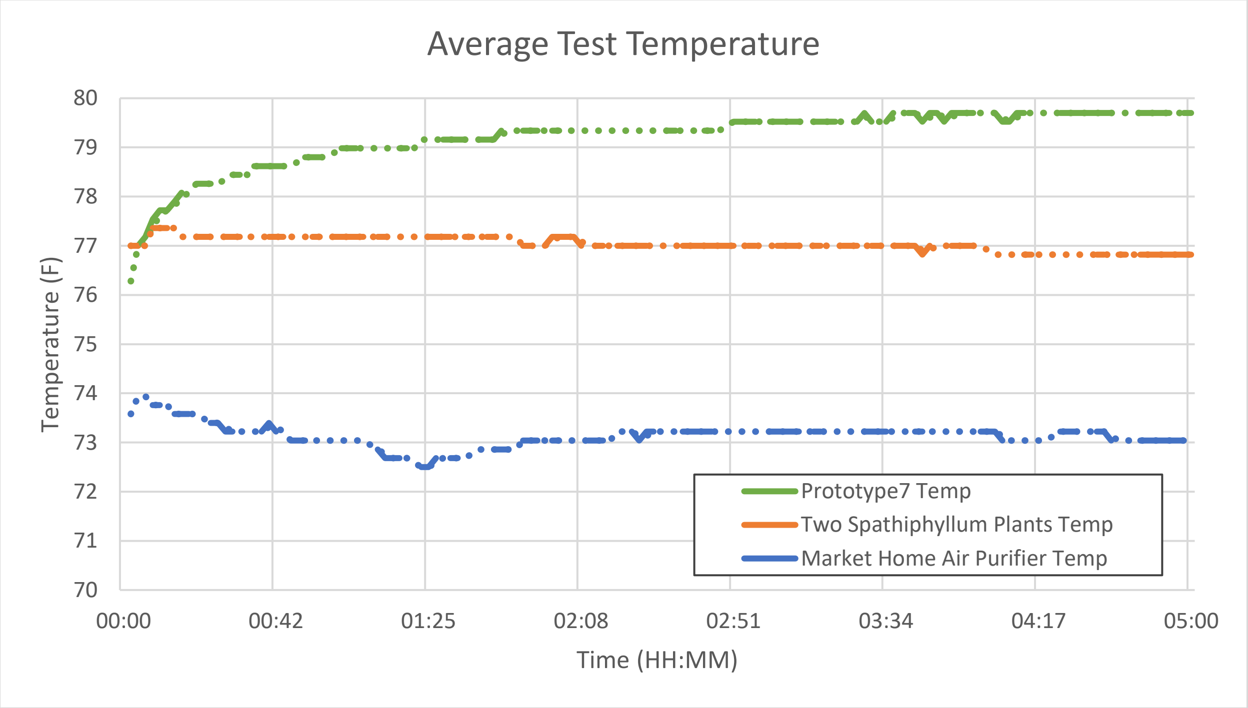

Figure 08: Test temperature (F) for each test subject averaged across two tests with a calculated moving average trendline shown dotted.

5.2 Experimental System Closed Environment Testing

It is necessary to verify the closed system to prove that measured system testing data was from system CO2 scrubbing and not leaking from the system enclosure. To verify the closed system was able to hold CO2 concentrations without leaking the system was set up in the same manner as during system testing. The closed system was left outdoors for 13 hours, more than two times the total system testing length. This exterior condition is needed to create a large differential in CO2 between the closed system and outside environment of 400 PPM. If there were leaks in the system, the large differential would exacerbate the gas exchange to be seen in the data. Over this time all three CO2 sensors showed strong correlation as seen in Figure 09. The CO2 readings were overall linear with noise within the sensor measurement variation of ±50 PPM as seen in Figure 09. The slope of the CO2 sensors averaged for all three sensors shows an average leakage rate of 28 PPM per hour, or a total of 369 PPM leakage over 13 hours. For our system testing we focused on a 5-hour window, the leakage over this period is 142 PPM with a ±50 PPM error range from the sensors.

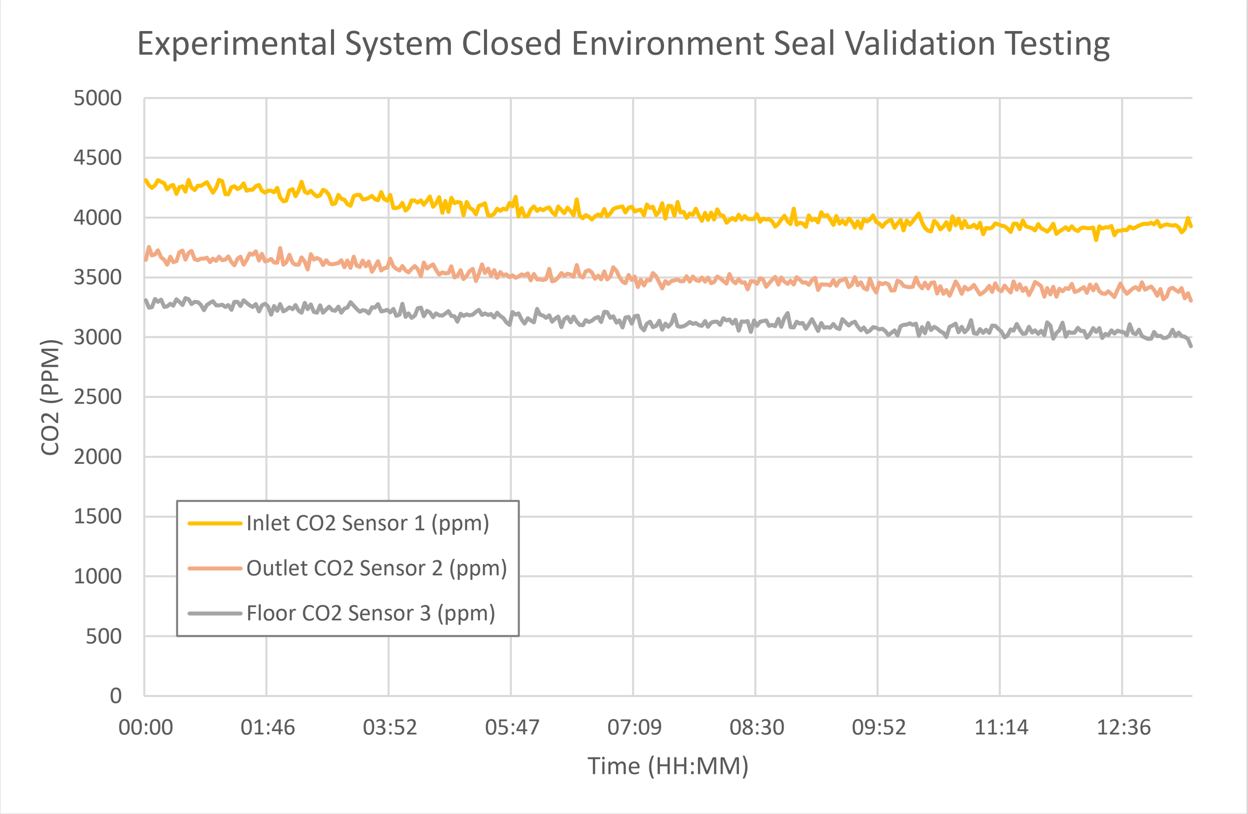

Figure 09: Experimental System Seal Validation testing results across three independent MH-Z19B CO2 sensors over the course of 13 hours.

5.3 Efficacy of the VerdeTerra Prototype7

The correlation between the three CO2 sensors throughout Protoytype7 experiment B had a range of 54 PPM, or within the ±50 PPM sensor error range. Experiment A range was larger, at 300 PPM in the 5000-2000 PPM concentrations, but settled to 52 PPM under 2000 PPM as seen in Figure 11. The Inlet CO2 sensor specifically showed variation in experiment A, excluding this sensor the Outlet and Floor CO2 Sensors stayed around the ±50 PPM sensor error fluctuation throughout the experiment.

Two experiments for the Prototype7 were conducted, with experiment B outperforming experiment A in terms of CO2 scrubbing ability. Experiment A brought CO2 concentrations from an average starting point across all three sensors of 4700 PPM to an average of 816 PPM in 5 hours as seen in Figure 11. Experiment B was able to reduce CO2 concentrations from a higher starting average of 5000 PPM to 400 PPM (measurement floor) in 4.5 hours as seen in Figure 11. With an average per-hour CO2 removal across both tests for the duration of the test of 900 PPM per hour.

Figure 10: Closed system test for VerdeTerra Prototype7

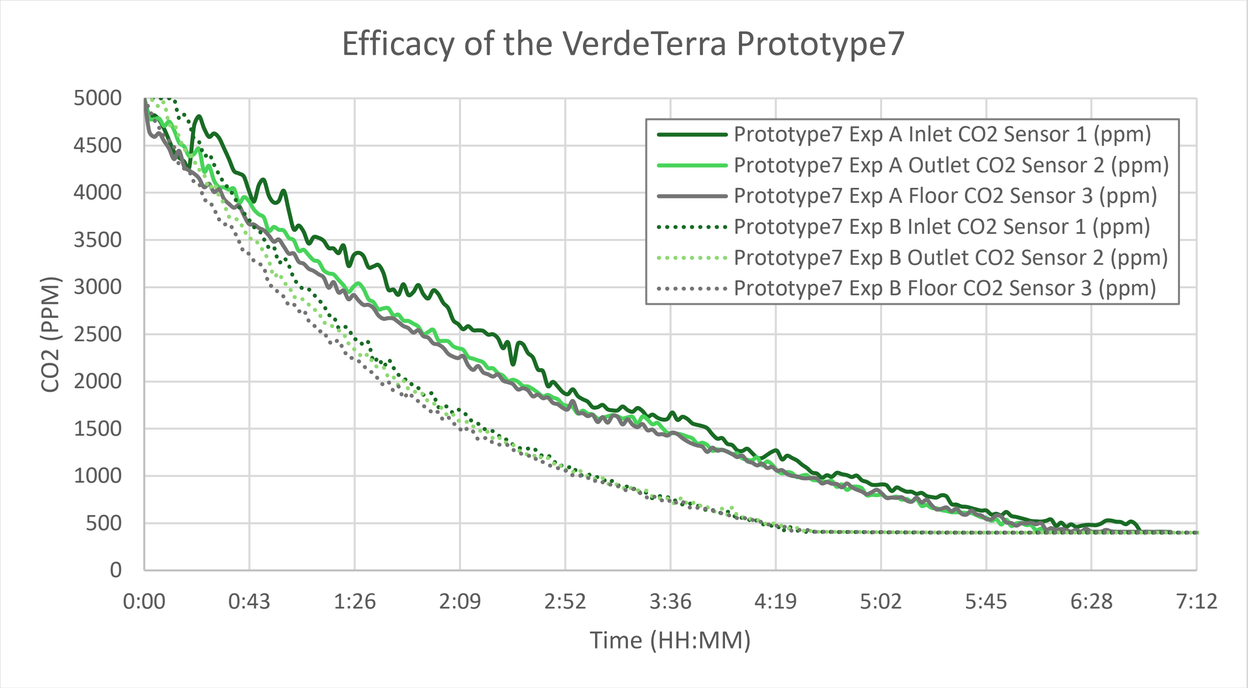

Figure 11: Efficacy of the VerdeTerra Prototype7 testing results across three independent MH-Z19B CO2 sensors over the course of 7 hours.

5.4 Efficacy of the Market Home Air Purifier

The correlation between the three CO2 sensors throughout Market Home Air Purifier test had a range of 1500 PPM as seen in Figure 13. The individual sensor performance was within the ±50 PPM sensor error range throughout the test. The starting point for experiment A and B Inlet CO2 sensor was greater than the 5000 PPM measurement range as seen in Figure 13. However, the strong linear data from other sensors and the in-range Inlet data show that a backwards calculation for starting CO2 is feasible. The backward calculation shows that the Inlet CO2 sensor starting condition was 5,720 PPM. This was done by taking the delta in y-intercept between Outlet and Floor CO2 sensors and adding the 800 PPM delta to the Outlets 4920 PPM y-intercept. The variance between experiment A and B for each of the three sensors was within ±50 PPM sensor error range throughout the experiment. With a similar linear slope from all sensors across both tests.

The efficacy of Market Home Air Purifier at removing CO2 was an average of 1103 PPM over the course of the 5-hour test window for experiment A and 1068 for experiment B. This was calculated by averaging the performance of each of the three sensors for each experiment over the 5-hour window. With an average per-hour CO2 removal across both tests of 217 PPM per hour.

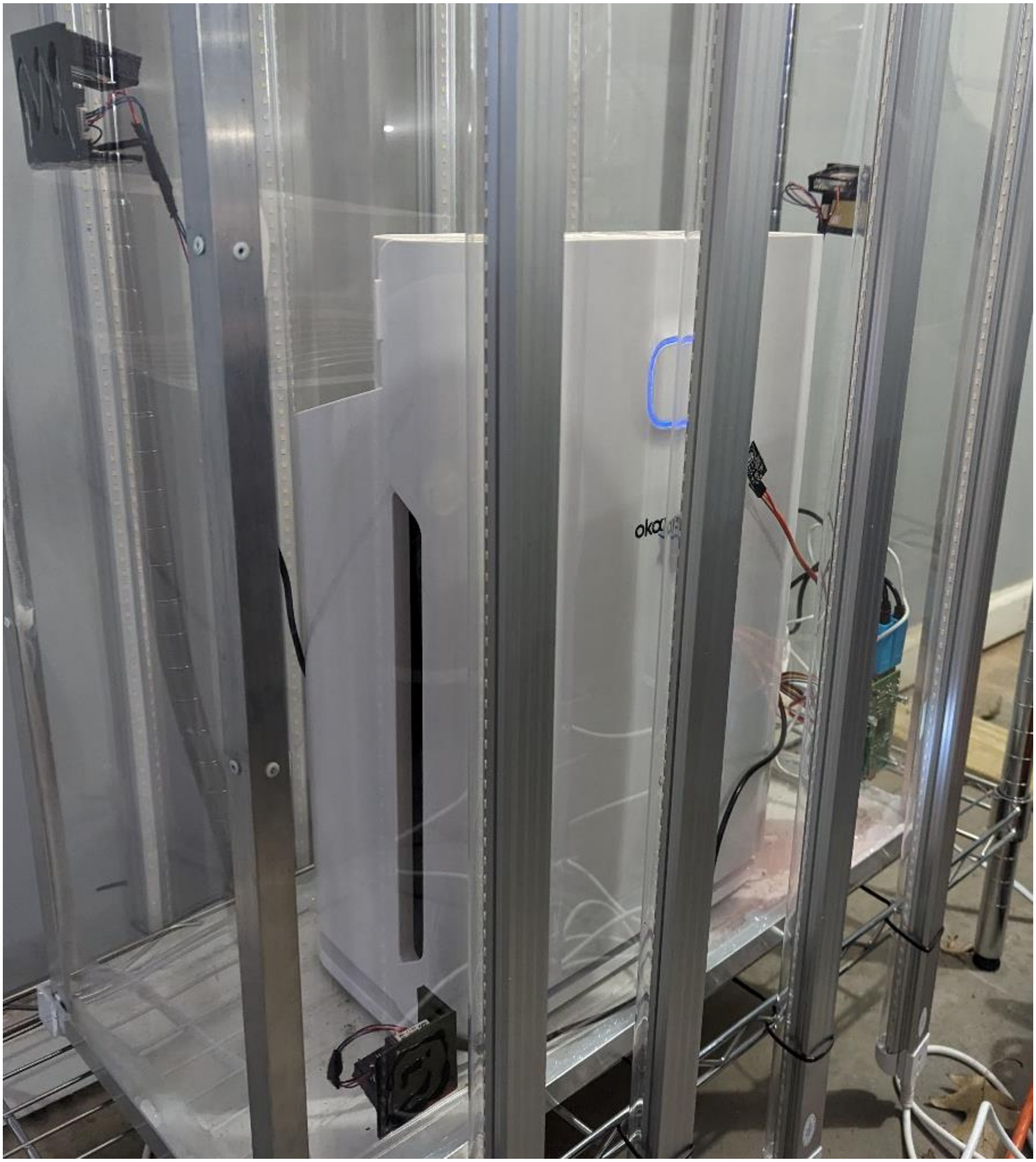

Figure 12: Closed system test for Market Home Air Purifier

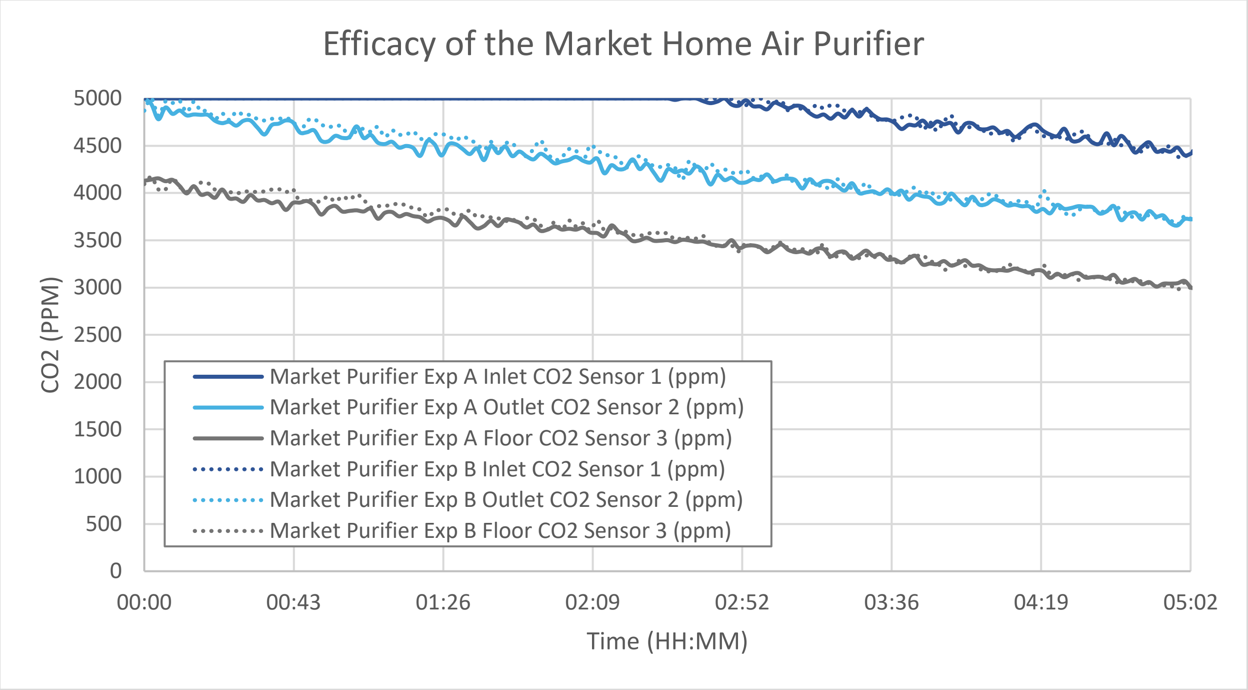

Figure 13: Efficacy of the Market Home Air Purifier testing results across three independent MH-Z19B CO2 sensors over the course of 5 hours.

5.5 Efficacy of the Two Spathiphyllum (Peace Lilly) Plants

The correlation between the three CO2 sensors throughout Two Spathiphyllum (Peace Lilly) Plants test had a range of 1729 PPM as seen in Figure 15. The individual sensor performance was within the ±50 PPM sensor error range throughout the test. The variance between experiment A and B for each of the three sensors was within 450 PPM throughout the experiment, which directly correlates to the 500 PPM lower starting condition. With a similar linear slope from all sensors across both tests as seen in Figure 15.

The efficacy of the Two Spathiphyllum (Peace Lilly) Plants at removing CO2 was an average of 2176 PPM over the course of the first 5-hours for experiment A and 2068 for experiment B as seen in Figure 15. This was calculated by averaging the performance of each of the three sensors for each experiment over the first 5-hours of the experiment. With an average per-hour CO2 removal across both tests of 424 PPM per hour.

Figure 14: Closed system test for two Spathiphyllum (Peace Lilly) plants

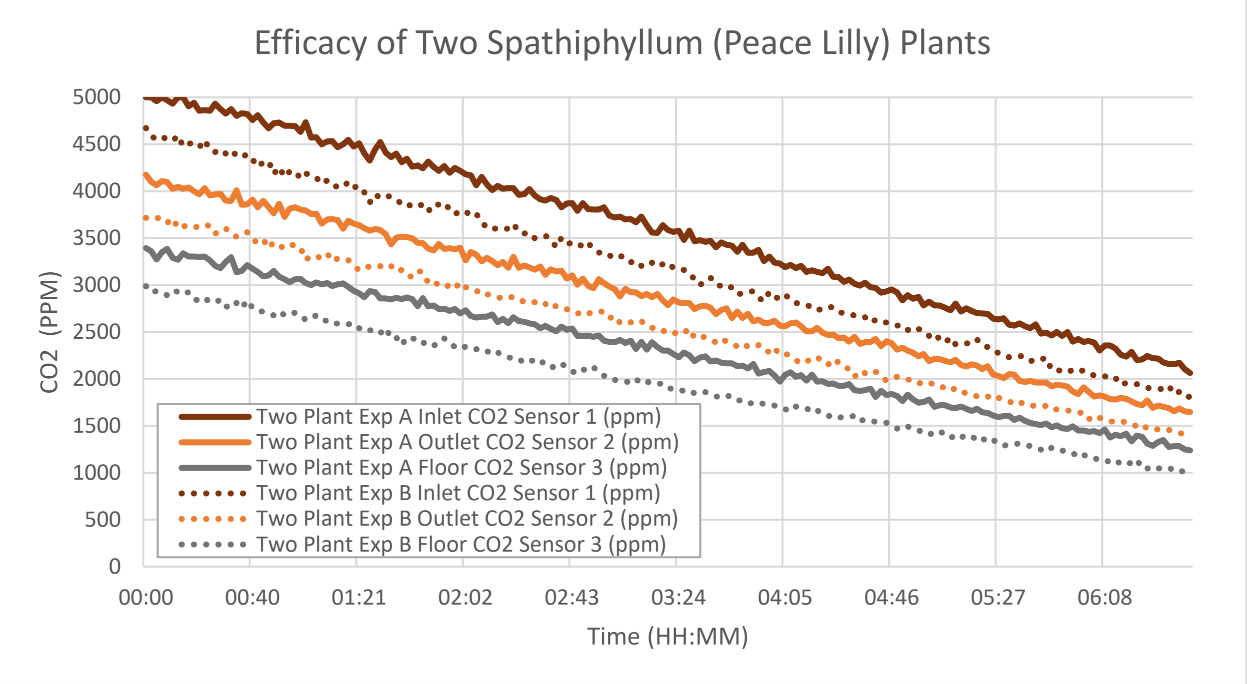

Figure 15: Efficacy of the two Spathiphyllum (Peace Lilly) Plants testing results across three independent MH-Z19B CO2 sensors over the course of 6.5 hours.

6. Discussion

The results from the evaluation of VerdeTerra's Prototype7 present compelling evidence on the effectiveness of integrating cyanobacteria-based systems, particularly those utilizing Spirulina, into indoor air quality management practices. This discussion delves into the implications of these results, comparing them with existing literature, and explores the potential commercial viability and broader impacts of deploying such technology.

6.1 Efficacy of Prototype7 in CO2 Reduction

Prototype7 demonstrated a significantly higher efficiency in CO2 reduction compared to both the traditional HEPA/Charcoal filter air purifiers and Spathiphyllum plants used in the study. This aligns with the findings which highlighted the superior photosynthetic efficiency of microalgae compared to terrestrial plants in sequestering carbon dioxide in controlled environments (Pradeep) (Mata). The exponential decrease in CO2 levels observed with Prototype7 stems from the high surface area to volume ratio provided by the micro-tubular design of the photobioreactors, which maximizes light exposure and gas exchange rates—key factors in optimizing photosynthesis in algae. The bottoming out of CO2 scrubbing at lower concentration levels could be influenced by the algae having been saturated with the previously higher CO2 concentrations, algae growth rate limiting light penetration through the tube after higher activity in the higher concentrations, or through the lower concentrations creating lower photosynthesis activity. Further studies would be needed to isolate these variables.

6.2 Comparison with Traditional Air Purification Methods

Traditional air purification methods, such as HEPA filters, effectively trap particulates but do not reduce CO2 levels. This limitation is significant in tightly sealed environments where air exchanges are minimal. Activated charcoal filters have the potential to secure CO2 but are not a viable solution for large spaces. The ability of Prototype7 to actively reduce CO2 can complement these systems by addressing a broader range of indoor air quality issues, including the buildup of airborne pathogens and VOCs, which are often correlated with higher CO2 levels. The Prototype7 solution also provides the ability to humidify the interior air in over-conditioned or dry environments as shown above in Figure 07.

6.3 Challenges and Future Prospects

Despite the promising results, additional challenges need addressing before wide-scale implementation is feasible. The maintenance of algal cultures, including nutrient balancing, harvesting, and system cleaning, requires automated solutions to ensure reliability and cost-effectiveness. Furthermore, the long-term stability of these systems under different environmental conditions—such as variations in light, temperature, and air quality—needs thorough investigation (Khan).

The development of sensor-based technologies for real-time monitoring facilitates the integration of these bioreactors into smart building designs. These technologies would not only optimize the operational parameters but also predict maintenance needs, thereby enhancing system reliability (Peter) (Shaghayegh).

6.4 Limitations of the Study

The controlled laboratory setting, while ideal for isolating variables and testing specific hypotheses, may not perfectly simulate the complex dynamics of indoor environments in residential or commercial buildings. Additionally, the scalability of the Prototype7 system will need evaluation with larger systems. The long-term durability and maintenance needs of the system in a real-world setting remain to be evaluated.

6.6 Conflicts of Interest

The research was conducted by employees of VerdeTerra, the company that developed Prototype7, which could lead to potential conflicts of interest. The funding for the research also came from VerdeTerra, which may have an inherent interest in positive outcomes that could benefit the company commercially. It is crucial for further independent studies to be conducted to verify the results and mitigate any bias introduced by the initial experimental setup.

7. Conclusions and Recommendations

VerdeTerra’s Prototype7 represents a significant advancement in indoor air quality technology, with the potential to transform building environmental management practices. Its ability to efficiently reduce CO2 levels, coupled with potential energy savings and health benefits, underlines the importance of further developing and refining this technology for commercial use.

Future research should focus on optimizing the design and scalability of these systems for different building types and climatic conditions. Longitudinal studies on the impact of such systems on overall building health metrics would also be valuable. Additionally, exploring synergistic effects with other biotechnological innovations could lead to the development of integrated solutions that address a wider range of indoor environmental quality parameters.

8. References

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