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Designing a Humidity Control System for the OASYS Lunar Greenhouse: Optimizing Environmental Conditions for Sustainable Space Agriculture

Christianna M. Sequeira*

*Bachelor's of Applied Science Honours, Simon Fraser University, Canada, tsequeir@sfu.ca

Abstract

The OASYS Lunar Greenhouse, an initiative led by the Canadian Space Agency (CSA), aims to facilitate sustainable food production to support life in deep space. This project has the potential to transform the way astronauts access vital nutrients during long-term space missions. Still in its preliminary stages, the OASYS Lunar Greenhouse represents a significant contribution to the Gateway project - a lunar space station set to orbit the Moon as part of NASA's Artemis Mission, which lays the foundations for future human exploration of Mars. This paper, adapted from the thesis of the same name, focuses on addressing the challenge of maintaining optimal humidity levels within the OASYS Lunar Greenhouse to ensure successful plant growth under extreme lunar conditions. Specifically, the research involves designing an autonomous humidity control system capable of regulating humidity to meet the ideal conditions for plant cultivation. Using radishes as test species, the calculations and system designs presented in this paper are optimized for their growth but are adaptable for other plant species in the future. By filling a critical knowledge gap on humidity control in extraterrestrial greenhouse environments, this research provides a foundational framework for the development of sustainable life support systems. The proposed system contributes to the long-term viability of deep-space missions and supports ongoing efforts to establish human presence beyond Earth.

Keywords: Space; Environment; Humidity; Sustainability

Nomenclature

AVP	Actual Vapour Pressure
ET_o	Evapotranspiration Rate
h_a	Enthalpy of Air
h_v	Enthalpy of Vapour
h_{tot}	Total Enthalpy
RH	Relative Humidity
SVP	Saturated Vapour Pressure
T_c	Temperature (Celsius)
T_K	Temperature (Kelvin)
ω	Humidity Ratio

Acronyms/Abbreviations

CSA	Canadian Space Agency
I2C	Inter-Integrated Circuit
ISS	International Space Station
NASA	National Aeronautics and Space Administration
OASYS	Optimized Approach to Space Agriculture System
SPI	Serial Peripheral Interface
UART	Universal Asynchronous Receiver Transmitter

1. Introduction

As we head into a new age of space exploration with the upcoming Lunar Gateway and NASA's Artemis Mission in the 2030s, it is of the utmost importance that we are sufficiently prepared to equip humans with the knowledge and technology needed to survive in space. The key to their survival - food. In space, access to nutrients and food is limited, with minimal environmental conditions to assist like the processes we have on Earth. With the incoming Lunar Gateway Space Station set to orbit the moon next decade, one of the main research focuses is the Canadian Space Agency's (CSA) OASYS Lunar Greenhouse - a greenhouse intended to grow food on the moon in space conditions and provide astronauts with sufficient nutrients. Knowing this and understanding how greenhouses operate under extreme space conditions is vital to furthering technology that can be used to help humans survive in deep space, such as

Mars. Greenhouses have multiple different systems: Lighting, Humidity, Temperature, Nutrients among many others that all work in tandem to optimize the growth of the plants inside. This paper therefore focuses on the humidity control subsystem, and how to design it to optimize plant growth and withstand extreme lunar conditions.

1.1 Objectives

The Objectives of this research are as follows:

- **To develop a comprehensive Humidity Control System:** To simulate a humidity control system tailored for the OASYS Lunar Greenhouse. In order to do so, the integration of humidity sensors, control algorithms, and actuators to maintain optimal conditions for plant growth based on the requirements provided by the CSA is needed.
- **To optimize Environmental Conditions:** Research to identify and quantify the optimal humidity levels required for different stages of plant growth in a lunar environment is required in order to optimize the code to suite plant growth. To meet this objective, we would need to analyze the interaction between humidity, temperature, and other environmental factors within the greenhouse.
- **To Enhance Sustainability Efficiency:** After optimizing the control system, another objective would be to propose methods to minimize energy consumption and resource usage in the humidity control system. This would be used to evaluate the effectiveness of the system in maintaining stable humidity levels while ensuring the sustainability of agricultural practices.
- **To Test and Validate the System:** Validate the system's ability to adapt to varying conditions and maintain desired humidity levels. This would involve conducting simulations and, if feasible, experiments to test the performance and reliability of the humidity control system.

1.2 System Requirements

The requirements of the Humidity Control System used are derived from the Mission requirements developed by the CSA [1]. Below is a table that outlines the relevant mission requirements and the subsequent child humidity and temperature control system requirements.

Table 1. List of System Requirements [1]

Mission Requirements	**Humidity Control System Requirements**
RQMT-0004 The atmospheric pressure inside the lunar greenhouse shall be 0.5 atmosphere (50.663 kPa)	The Humidity Control System shall operate at 0.5 atmospheric pressure (50.663 kPa)
RQMT-0010 The internal average air temperature of the greenhouse shall be maintained between 5°C and 30°C	The humidity control system shall operate within 5°C and 30°C
RQMT-0011 The humidity in the greenhouse shall be maintained in the range of 45% to 70% and should be optimally be maintained in the range of TBD	The Humidity Control System shall be able to increase and decrease in the range of 45% to 70% and should optimize based on sensor readings for optimal plant growth
RQMT-0016 The greenhouse power system must be able to supply a peak power of TBC W to the TBC	The Humidity Control System should optimize its operations to meet power requirements

1.3 Literature Review

Radishes thrive best within a relative humidity range of 50%-60% for optimal growth [2]. Therefore, maintaining the appropriate humidity levels is crucial, as deviations from these values and the rate of change can significantly affect plant health and crop yield. When humidity is too low, it can increase stomatal resistance, hinder transpiration and reduce photosynthesis, which in turn slows plant growth [3]. When humidity is too high, it can promote fungal growth and suppress transpiration rates, negatively impacting plant health and productivity [2, 3]. Research indicates that the use of dynamic humidity control systems can improve plant yield compared to static systems, achieving up to an 85% improvement in growth under optimal conditions [3, 4]. In unpredictable environments like the Moon, where external conditions can vary drastically, it is essential to develop a humidity control system capable of dynamically adjusting greenhouse conditions to minimize adverse effects on plants.

According to a 2015 paper by Hurley et al., the lunar surface temperature can be most accurately modelled using an exponential decay function during the lunar night and a cosine function during the lunar day [5]. This is due to the lack of atmosphere on the moon, which leads to rapid radiative cooling when the surface is not exposed to solar radiation, which can be demonstrated by the exponential decay. Alternatively, during the day the cosine function can describe the increase and decrease in temperature as a function of solar zenith angle, which determined the intensity of the solar radiation from the Sun as a function of location and time.

As shown in Figure 1, these temperature variations are the most extreme at the moon's equator, where temperatures can reach 390 K during the day and 100 K at night [6]. Therefore, given these extreme variations in surface temperature, selecting the location of a greenhouse is important, as it directly influences the design, thermal management strategies and, consequently the humidity control requirements needed to maintain a stable internal greenhouse environment.

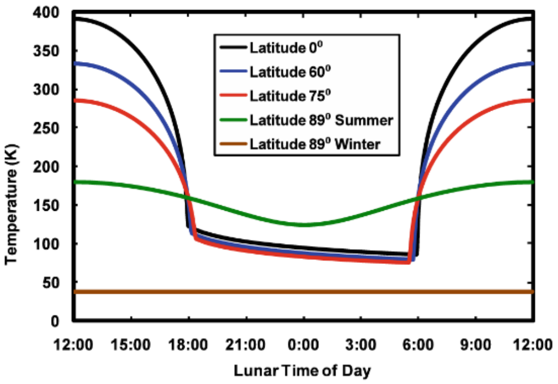


Figure 1. Lunar surface temperature variations as a function of local time and latitude [5]

2. Materials and Methods

2.1 System Design

Based on the literature review above, the humidity control system was designed to maintain ambient air conditions within specified mission requirements. The system consists of four core components: environmental sensors, a humidifier, a dehumidifier, and a microcontroller for decision-making and actuation.

- **Sensors:** These components monitor the surrounding air conditions—specifically, temperature, humidity, and pressure. Sensor data is continuously collected and used to determine whether environmental values remain within the bounds set by mission parameters.
- **Humidifier:** This component will increase the moisture by emitting water vapour into the air if it is determined to be to dry and out of the bounds of the mission requirements.
- **Dehumidifier:** This component will decrease the moisture by taking in water vapour from the air if determined to be too moist and out of the bounds of the mission requirements.
- **Microcontroller**: A microcontroller reads the sensor data and executes logic to determine whether to activate or deactivate the humidifier or dehumidifier accordingly.

Figure 2 illustrates the system architecture. Control logic is embedded in the microcontroller, which continuously receives real-time data from the sensors. When relative humidity measurements fall outside the designated range, the microcontroller triggers the appropriate component to correct the imbalance.

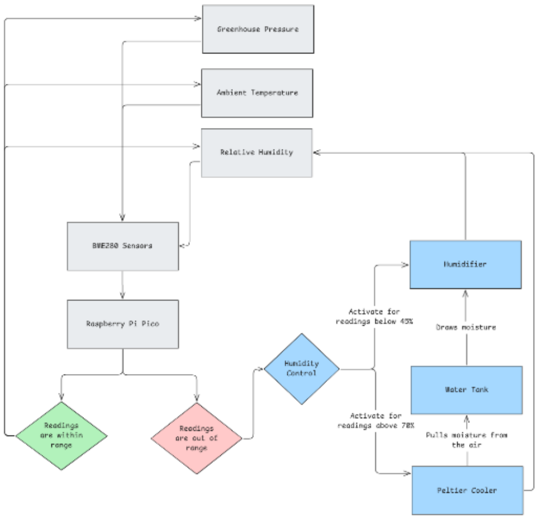


Figure 2. Humidity Control System Overview Design Schematic

2.2 Methods

The methods used in this research followed a structured design approach, including high-level system design, component selection, integration, and testing. Due to the inability to recreate the lunar thermal environment in a lab setting, simulations were conducted using Python and MATLAB to evaluate the viability of the system under expected extraterrestrial conditions. These simulations modelled sensor responsiveness, control loop dynamics, and response time to environmental perturbations.

2.3 Component Selection

The chosen components for the prototype were selected based on cost, size, ease of integration, and performance:

- **Raspberry Pi Pico**: Selected for its low cost, compact form factor, and compatibility with CircuitPython. Python was chosen as the programming language due to its simplicity, widespread use in rapid prototyping, and the availability of libraries for sensor data handling and control algorithms. The Pico's support for various communication protocols (I2C, SPI, UART) makes it well-suited for sensor integration.
- **BME280 Sensor**: This sensor was chosen due to its ability to measure temperature, humidity, and pressure in a single compact package. It offers high accuracy, low power consumption, and digital output, making it ideal for environmental monitoring in constrained systems like space-based greenhouses.
- **Ultrasonic Humidifier**: An ultrasonic humidifier was selected for its ability to increase moisture without altering air temperature, using

high-frequency piezoelectric vibrations to atomize water. This method introduces minimal thermal disturbance to the environment—an important consideration for controlled habitats. Moreover, existing literature suggests that the ultrasonic frequencies used may also promote plant growth, adding a potential ancillary benefit to the greenhouse environment [7].

- **Peltier-Based Dehumidifier**: A Peltier thermoelectric cooler was employed as a dehumidification mechanism. While its efficiency is lower compared to other cooling technologies, it offers significant advantages in terms of compactness, low maintenance, and ease of integration into an enclosed system—making it a practical choice for prototyping purposes.

It is important to note that thermal management and heat dissipation strategies are outside the scope of this project. However, their impact is acknowledged and discussed as an area for future work.

3. Theory and Calculations

The design of the humidity control system is driven by the calculations presented in this section. In order to appropriately select and size components such as sensors, humidifiers, and dehumidifiers, a fundamental understanding of the environmental dynamics and constraints of the system is essential. These calculations help define the operating conditions and resource requirements (e.g., water and power), which ultimately inform component selection and design.

Using the mission requirement values in Table 1, the following calculations used the maximum and minimum requirements to determine the behaviour and the extreme bounds of the system.

3.1 Evapotranspiration

To accurately assess the dynamic impact of plant growth on the internal climate of the system, it is important to understand evapotranspiration—the process through which plants release moisture into the air [8]. This factor is especially important in closed-loop systems where water input is limited and must be carefully managed.

Evapotranspiration is typically measured in millimeters per day (mm/day), and while experimental measurement offers high accuracy, theoretical estimation can be performed using the Penman-Monteith equation, a widely accepted standard in agricultural and environmental studies [8]:

$$\lambda ET_o = \frac{\Delta(R_n - G) + \left[86{,}400 \frac{\rho_a c_p (e_s^o - e_a)}{r_a}\right]}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \tag{1}$$

Using the additional variables, and equations provided in Appendix A, the resulting estimated evapotranspiration rate is 0.337 mm/day, and converting that to grams we get 30.33 grams/day. Due to the preliminary nature of the mission, many required parameters—such as plant size, leaf area index, and grow light intensity—are currently unknown. Consequently, assumptions were made, particularly for radish crops, and can be refined as the project matures.

3.2 Water Requirements

Water is a critical and limited resource in remote environments such as the Moon. For sustainable operation, it is necessary to quantify the amount of water vapor required to maintain target humidity levels within the system. To do this, we consider the relationship between relative humidity, temperature, and absolute moisture content using the ideal gas law and saturation vapor pressure:

$$SVP = 0.61078 * exp\left(\frac{17.27 * T_c}{T_c + 237.3}\right) \tag{2}$$

$$AVP = RH * SVP \tag{3}$$

$$n = \frac{(AVP * 1000)}{(R * T_K)} \tag{4}$$

Using this method and calculating the water required at the extreme conditions, the mass of water vapor required to move between the lower and upper bounds of the desired humidity range results in approximately 4.4 grams of water at the maximum. Assuming a closed-loop system, and incorporating the estimated daily contribution of 30 grams from evapotranspiration, the total mass of water in circulation is approximately 35 grams. This estimation provides a basis for determining the capacity and cycling frequency of both the humidification and dehumidification components.

3.3 Power Requirements

Like water, power is a limited and valuable resource in space environments. Determining the power consumption of the humidity control system is therefore vital to ensure energy efficiency and compatibility with overall habitat energy budgets. To calculate power requirements, psychrometric equations were used to determine the energy required to shift the system's air from one humidity level to another [9].

$$\omega = 0.622\left(\frac{p_v}{p_{tot} - p_v}\right) \tag{5}$$

$$h_a = 1.005 * T_c \tag{6}$$

$$h_v = 2500.9 + (1.8 * T_c) \tag{7}$$

$$h_{tot} = h_a + (\omega * h_v) \tag{8}$$

$$\Delta h_f = h_{hot} - h_{cold} \tag{9}$$

$$Power_{req} = \frac{\Delta h_f}{t_{rate} * 3600} \tag{10}$$

By calculating the change in enthalpy between two extreme states (minimum temperature and humidity, maximum temperature and humidity), the energy required to condition the air can be estimated. The final result of these calculations indicates that approximately 10.5W of power is required to adjust the humidity within the full operating range of the system. This value represents the required capacity for the humidifier and dehumidifier units and acts as a lower bound for component specification.

4. Testing and Analysis

Following the individual verification of each component, the humidifier and Peltier cooler were tested with the software to confirm proper actuation. These tests were first conducted independently to validate basic control logic, and then together to assess system integration and full operation within the greenhouse enclosure.

4.1 Constant Humidification Testing

Initial tests were conducted to observe the system's response during constant humidification scenarios. The results indicated that in a fully sealed greenhouse environment, the relative humidity increased rapidly from 64% to 80% within approximately 2 minutes. When ventilation was introduced, however, the rate of humidity increase was significantly reduced, with relative humidity reaching 73% over a longer duration of 5.5 minutes. This demonstrates the dampening effect of ventilation and suggests that in a real-world setup—where airflow from components such as circulating fans or Peltier coolers is present—the humidity increase would follow a slower profile.

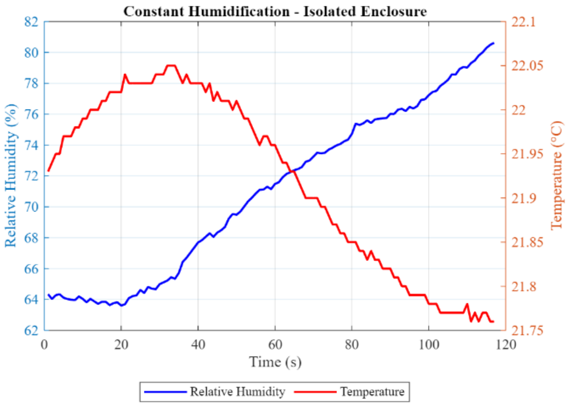


Figure 3. Isolated Humidification Test

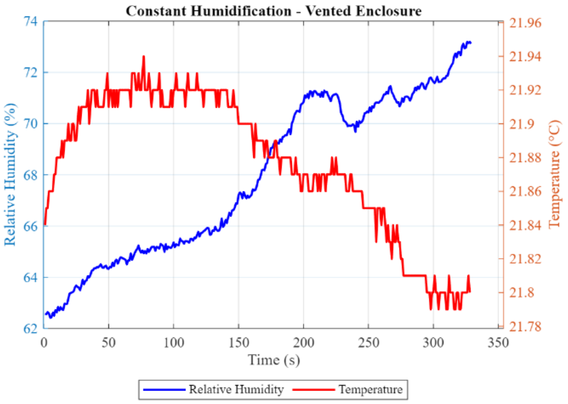


Figure 4. Vented Humidification Test

In both sealed and ventilated scenarios, no condensation was observed, which is ideal for greenhouse operations. A consistent trend was also noted: as relative humidity increased, ambient temperature decreased steadily. This is attributed to evaporative cooling—the process of water vapor absorbing heat from the air during phase change—emphasizing the strong coupling between humidity and thermal regulation.

This connection between temperature and humidity highlights the importance of integrated environmental control. A rapid humidity rise without adequate cooling can cause condensation and instability, whereas a temperature drop below optimal levels may inhibit plant growth. Moreover, a gradual increase in humidity, as seen in the ventilated case, may provide a more favorable environment for plants to adapt. Figure 5 illustrates the comparison between sealed and ventilated humidity rise rates.

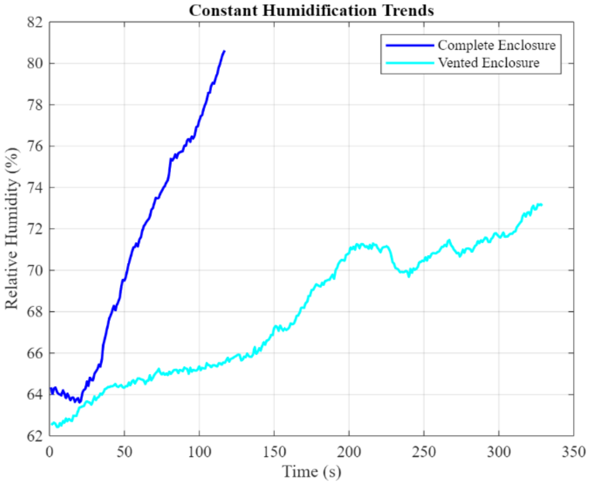


Figure 5. Comparison of Humidification Rates

Based on these graphs, the rate of change in humidity for each test was calculated as follows:

- Humidification rate in the fully sealed enclosure: 0.1719 RH%/s
- Humidification rate in the ventilated enclosure: 0.0323 RH%/s

4.2 Constant Dehumidification Testing

Tests were also performed to evaluate the system's ability to decrease humidity levels. In a sealed environment, relative humidity dropped steadily from 51% to 48.5% over approximately 4 minutes. In contrast, when ventilation was introduced, the change was smaller and more sporadic, decreasing only from 48.4% to 47.6% over a 3-minute period. This again confirms that ventilation, including the airflow from the Peltier cooler's fan, slows the rate of humidity change.

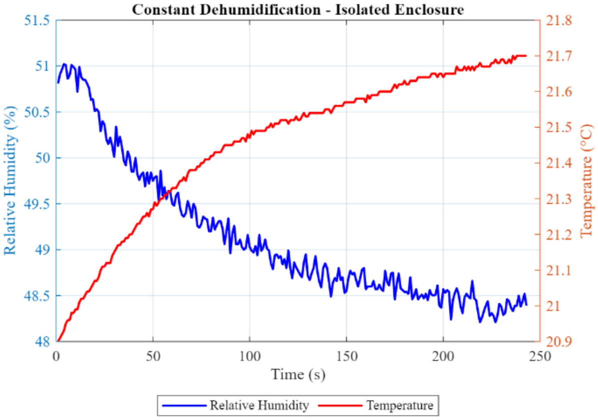


Figure 6. Isolated Dehumidification Test

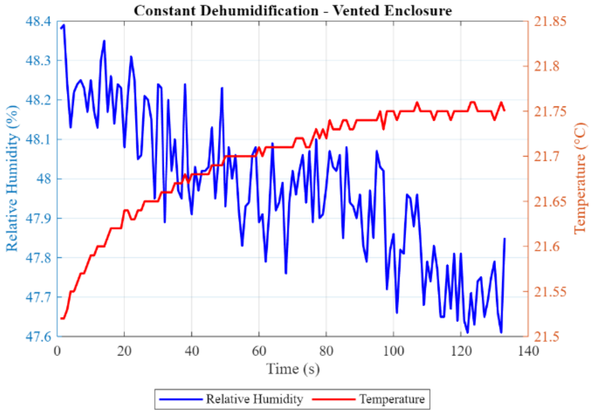


Figure 7. Vented Dehumidification Test

No condensation was observed during either test. This was expected given the short duration and low voltage operation of the Peltier module, which limited cooling power. However, under extended durations and higher power conditions, condensation is anticipated—supporting future validation of evapotranspiration calculations.

As with humidification, these tests revealed an inverse relationship between temperature and humidity. During dehumidification, humidity levels decreased while temperature rose. This mirrors the trend observed during humidification, further validating the correlation between thermal and moisture dynamics. Figure 8. provides a comparison of dehumidification rates under sealed and ventilated conditions.

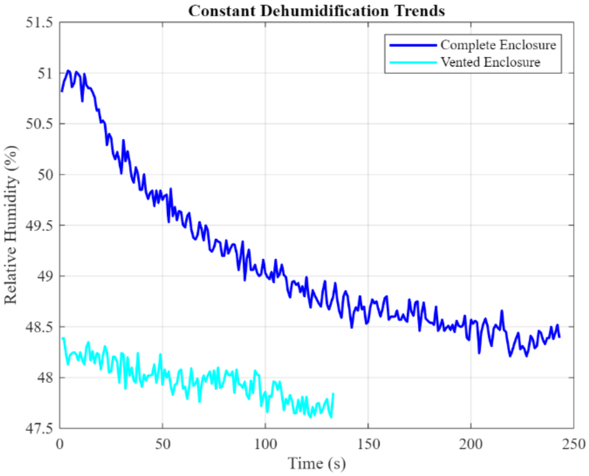


Figure 8. Comparison of Dehumidification Rates

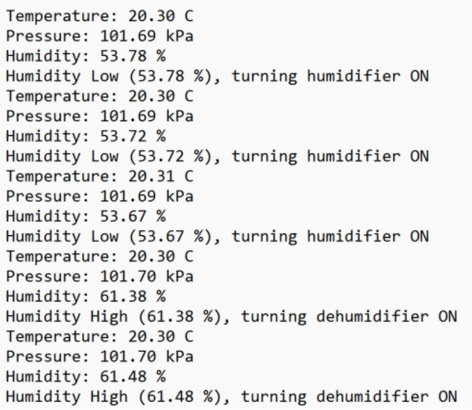
Based on these graphs, the rate of dehumidification for each test was calculated as follows:

- Dehumidification rate in the fully sealed enclosure: -0.0098 RH%/s
- Dehumidification rate in the ventilated enclosure: -0.0042 RH%/s

4.3 Complete System Integration Testing

Upon verifying individual component performance, full system integration testing was carried out to assess real-time humidity control within the greenhouse. The system was tested with the actuators (humidifier and Peltier cooler) controlled via software, responding to sensor data.

For the first test, a relative humidity setpoint of 54% was established. The system was programmed to activate the humidifier if the reading dropped below 54%, and to activate the dehumidifier if it exceeded 54%. User input, such as manually increasing humidity by blowing on the sensor, was used to validate the system's response. Figure 9 shows the successful operation of the system, with both actuators responding appropriately.



```
Temperature: 20.30 C
Pressure: 101.69 kPa
Humidity: 53.78 %
Humidity Low (53.78 %), turning humidifier ON
Temperature: 20.30 C
Pressure: 101.69 kPa
Humidity: 53.72 %
Humidity Low (53.72 %), turning humidifier ON
Temperature: 20.31 C
Pressure: 101.69 kPa
Humidity: 53.67 %
Humidity Low (53.67 %), turning humidifier ON
Temperature: 20.30 C
Pressure: 101.70 kPa
Humidity: 61.38 %
Humidity High (61.38 %), turning dehumidifier ON
Temperature: 20.30 C
Pressure: 101.70 kPa
Humidity: 61.48 %
Humidity High (61.48 %), turning dehumidifier ON
```

Figure 9. Image of Serial Monitor Output

A second test was conducted under the same setpoint but without user input, to assess autonomous control. As shown in Figure 10 humidity initially rose due to the humidifier's operation until the 54% threshold was reached around the 2-minute mark. The data then showed a small peak followed by a gradual decline, confirming the activation of the Peltier cooler and the system's ability to self-regulate.

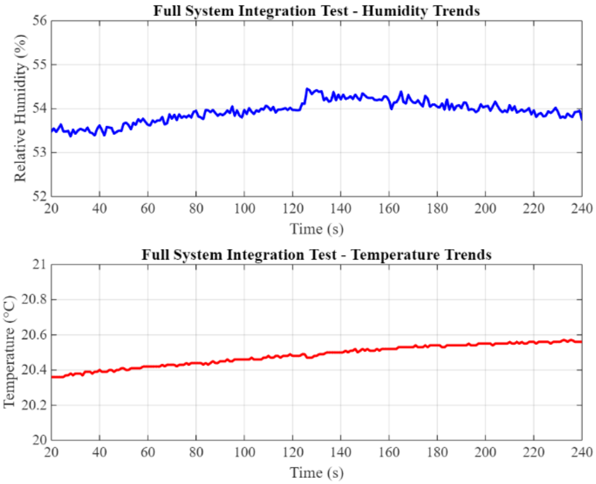


Figure 10. Total Integration Test Results

While these tests confirm the software and hardware functionality under stable conditions, further testing is required to evaluate performance under extreme environmental changes. Additionally, temperature trends revealed a gradual increase during the test, which—although minor—could become significant without proper heat dissipation from the Peltier cooler's hot side. This underlines the need for better thermal management in future iterations of the system.

5. Results

After testing each component and integration, resulted in a complete working model as shown in Figure 11. In this prototype, a program is run from a microcontroller that reads temperature, humidity, and pressure data from within the greenhouse. If the relative humidity values within the greenhouse are not at the setpoint (ideal humidity for plant growth) it turns on and off the respective components- humidifier and peltier cooler to maintain humidity with the given bounds. If the humidity goes beyond the bounds specified, it prints an alert notifying users/astronauts to troubleshoot (as stated in the mission requirements [1]).

Figure 11. Image of Tested Working Model

6. Future Work

As shown in Figure 10, the slight increase in temperature demonstrates that while the system operates effectively under Earth conditions, a consistent rise in temperature in the isolated environment of space could pose a significant concern without proper thermal management. One of the primary objectives for future development is the integration of a robust thermal control system. The current software architecture and electrical design have been developed with modularity in mind, allowing for the straightforward incorporation of temperature regulation components. However, the selection of appropriate actuators and thermal management strategies requires extensive research. Managing heat on the lunar surface presents unique challenges due to the extreme temperature fluctuations between lunar day and night, the absence of an atmosphere to support convective heat transfer, and the need for both passive and active thermal control systems. As part of the next design phase, the integration of a Peltier cooler will be explored for active heat removal. This component could help stabilize internal temperatures by transferring excess heat away from sensitive components, ensuring reliable operation in the harsh lunar environment.

In addition to the incorporation of thermal management strategies, some steps may include:

- **Improving Evapotranspiration Rate Accuracy:** The current calculations are based on theoretical models and approximations. Further testing with real plant data is required to refine these estimates. This includes controlled experiments under varying humidity and temperature conditions to develop a more precise model of water loss and absorption within the system.

- **Expanded Environmental Testing:** While initial prototype tests have been con ducted under controlled and stable conditions, further validation is necessary under more extreme environments. Future experiments should expose the system to variable external conditions, such as testing in cold outdoor environments to simulate lunar 45-night conditions or using external heat sources to mimic prolonged solar exposure. This will help assess the robustness of the control algorithms and the durability of the components.
- **Adapting to Evolving Mission Requirements**: Some mission parameters, such as the final greenhouse size, power availability, and overall environmental constraints, are still subject to change. As these specifications become clearer, the system design and operational parameters will need to be updated accordingly to ensure compatibility with the final mission objectives.
- **Assessing the Impact of Solar Radiation on Electrical Components:** Expo sure to high-intensity solar radiation and cosmic rays can degrade electronic components over time. Additional research is needed to determine shielding requirements, material selection, and redundancy strategies to protect the system from long-term radiation damage.
- **Additional Analysis on Power Management Modes:** To optimize energy efficiency, further investigation is needed into the high-power and low-power operational modes of both the humidification system and the Peltier cooler. Specifically, an analysis comparing continuous operation at variable speeds versus an on-off cycling approach could provide insights into the most efficient strategy for maintaining stable humidity levels while minimizing power consumption. Additionally, while fans play a crucial role in air circulation, they may not require frequent switching on and off; instead, operating them at a constant lower speed could help maintain uniform conditions within the greenhouse while reducing overall power draw.

7. Conclusion

In conclusion, this project aims to make a significant contribution to space exploration by enhancing the understanding of the factors in humidity control systems. Given the critical role that food production plays in manned space missions, the design of the CSA's OASYS Lunar Greenhouse will be crucial in supporting future lunar and deep-space exploration missions. This research plans to highlight the interconnection between thermodynamics, humidity regulation, and control systems, demonstrating how these components will work together to create a self-sustaining greenhouse capable of functioning under harsh lunar conditions. By understanding how to develop a dynamic humidity control system, this work will not only support the OASYS project but also assist in the design of future plant growth systems.

Appendix A Evapotranspiration Values & Assumptions

Table 1. Main Calculated Values

Variable	Definition	Value	Reference
λ	Latent heat of evaporation of water (MJ/kg)	2.4606	[10]
R_n	Net radiation at the crop surface (MJ/m²/day)	3.2647	[11]
G	Soil heat flux density (MJ/m²/day)	1.1816	[12]
e_s	Saturation vapor pressure (kPa)	2.5577	[13]
e_a	Actual vapor pressure (kPa)	1.260	[13]
ρ_a	Mean air density (kg/m³)	1.2165	[14]
c_p	Specific heat of air (MJ/kg/°C)	1.005	[15]
Δ	Slope of saturation vapor pressure-temperature curve (kPa/°C)	0.0969	[13]
γ	Psychrometric constant (kPa/°C)	33.2676	[16]
r_s	Bulk surface resistance (s/m)	500	[17]
r_a	Bulk aerodynamic resistance (s/m)	3955.4472	[17]

**R_n is the total of incoming and outgoing radiation that the crop experiences. Since the greenhouse structure is under development, crop radiation from space is unknown. For now, radiation is based on grow light data [11. Future versions can integrate lunar radiation data [22].*

Table 2. Additional Calculated Values

Variable	Definition	Value	Reference
eT(min)	Vapor pressure at minimum temperature (kPa)	0.8723	[13]
eT(max)	Vapor pressure at maximum temperature (kPa)	4.2431	[13]
E	Energy per mole of photons	3.6142E-19	See Below
LA	Total Leaf Area (m²)	0.036	See Below
d	Zero plane displacement height (m)	0.02	[17]
z_{om}	Roughness length for momentum transfer (m)	0.00369	[17]
z_{oh}	Roughness length for heat/mass transfer (m)	0.000369	[17]
u_z	Wind speed at height z_m (m/s)	0.0314	See Below
LAI_active	Active sunlit leaf area index	0.02	[17]

Manual Calculations:

- Energy per mole (E): $E = \frac{h*c}{\lambda*10^{-9}}$
- Total Leaf Area (LA): $Average\ Size\ of\ Radish\ Leaf * Leaves\ per\ plant * Number\ of\ Plants$
- Wind Speed (u_x): $u_z = \frac{rpm\left(\frac{r}{1000}\right)*2\pi}{60}$

Table 3. Additional Values Used

Variable	Definition	Value	Reference
–	Number of Plants	9	[1]
GA	Area of Growing Medium (m²)	0.09	[1]
–	Days in a cycle	42	[1]
M	Ratio of molecular weight (water vapor to dry air)	0.622	[18]
DLI	Daily Light Integral (mol/m²/day)	15	[19]
λ	Wavelength (nm)	550	[20]
c	Speed of light (m/s)	3E8	N/A
h	Planck's Constant (Js)	6.626E-34	N/A
e	Avogadro's Number (photons/mol)	6.022E+23	N/A
k	Von Karman constant	0.41	[17]
r_l	Stomatal resistance of illuminated leaf (s/m)	100	[17]

Table 4. Assumed Values

Variable	Definition	Value
z_m	Wind measurement height (m)	0.15
z_h	Humidity measurement height (m)	0.15
–	Leaves per plant	10 ([21])
–	Average Size of Radish Leaf (m²)	0.0004
h	Crop height (m)	0.03
r	Radius of fan (mm)	60
rpm	Speed of fan (rpm)	2000

These values are used in the Penman-Monteith equation. Since the OASYS system is in early development, the values are estimates based on average radish properties.

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