DESIGN DOCUMENT

MicroClimate

Maintaining Optimal Vapor Pressure Deficit in a Closed Area

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Abstract

MicroClimate is a simple and flexible system for controlling the vapor pressure deficit of closed environments to aid in indoor cultivation. This is designed for small scale indoor growing operations for the hobbyist and scientist alike. MicroClimate uses off-the-shelf heaters and humidifiers along with custom environmental sensing nodes to maintain target temperature and humidity parameters while logging data for failure detection and future analysis.

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Introduction

Background

Traditional agriculture is effective at producing incredible amounts of energy per unit of land, but the majority of field crops are not consumed by humans. Speciality crops such as fruits, vegetables, and herbs require intensive growing practices outdoors and are often the most sensitive to changes in environment which is becoming an ever-greater issue considering climate change. Many businesses across the United States and abroad are attempting to exploit specialty crop production by moving cultivation indoors and controlling environmental variables in order to maximize yield and quality.

An important variable in a plant's environment is vapor pressure deficit (VPD). To understand VPD, one must understand relative humidity. The air around us can hold different amounts of water particles depending on the temperature of the air: for example, a cubic meter of air can contain 28 grams of water at 86° F, but only 8 grams of water at 8° F.

VPD is the difference between the amount of moisture in the air and how much moisture the air can hold when fully saturated. This is important for plant development: at different stages of growth, plants seek to absorb more or less water from the air. Controlling the VPD allows for more optimal plant development. The equation for calculating VPD is as follows [1]:

$$VPD = vp_{\text{sat}} \times (1 - \text{relative humidity}/100)$$

Where:

vp_{sat} is the saturation vapor pressure in PSI, $vp_{\text{sat}} = e^{A/T+B+CT+DT^2+ET^3+F\ln T}$,

A = − 1.0440397 × 10^4 , B = − 11.29465, C = − 2.7022355 × 10^−2,

D = 1.289036 × 10^−5,E = − 2.4780681 × 10^−9 ,

F = 6.5459673, and T = T[° F] + 459.67.

Problem

Automated indoor cultivation solutions often cost thousands of dollars and are designed for large scale operations exclusively. There is a growing share of individuals attempting to join small-scale indoor cultivation predominately with the use of closed growing tents. Hobbyist indoor growers attempting to optimize their yield or research scientists looking to experiment with environmental variables cannot afford or often even make use of the industrial scale offered by current market solutions. This lack of access leads to high fluctuation and poor management of variables like VPD. Current small-scale solutions are limited to running off-the-shelf humidifiers and heaters and manually switching them on and off depending on inspected hygrometer readings.

Solution

MicroClimate seeks to act as a small-scale solution to VPD management of a closed growing environment that implements monitoring and data collection, appliance actuation, and environmental control in one system. Data acquisition nodes will collect temperature and humidity readings throughout the growing environment and will transmit this data to a web-accessible broker. The broker is programmed to reach and maintain a target VPD set by the user and will toggle the actuators, a space heater, humidifier, and dehumidifier, which act on the environment to maintain a steady VPD.

This product allows for flexible placement of daisy-chained humidity-resistant sensors within the closed environment for extensible data collection. Off-the-shelf appliances such as heaters and humidifiers which are likely already owned by serious hobbyist or research cultivators will be toggled via a custom power strip. These subsystems send and receive environmental and control data from a web-accessible server that runs a control system to maintain target environmental conditions, set by the user through a web interface.

Visual Aid

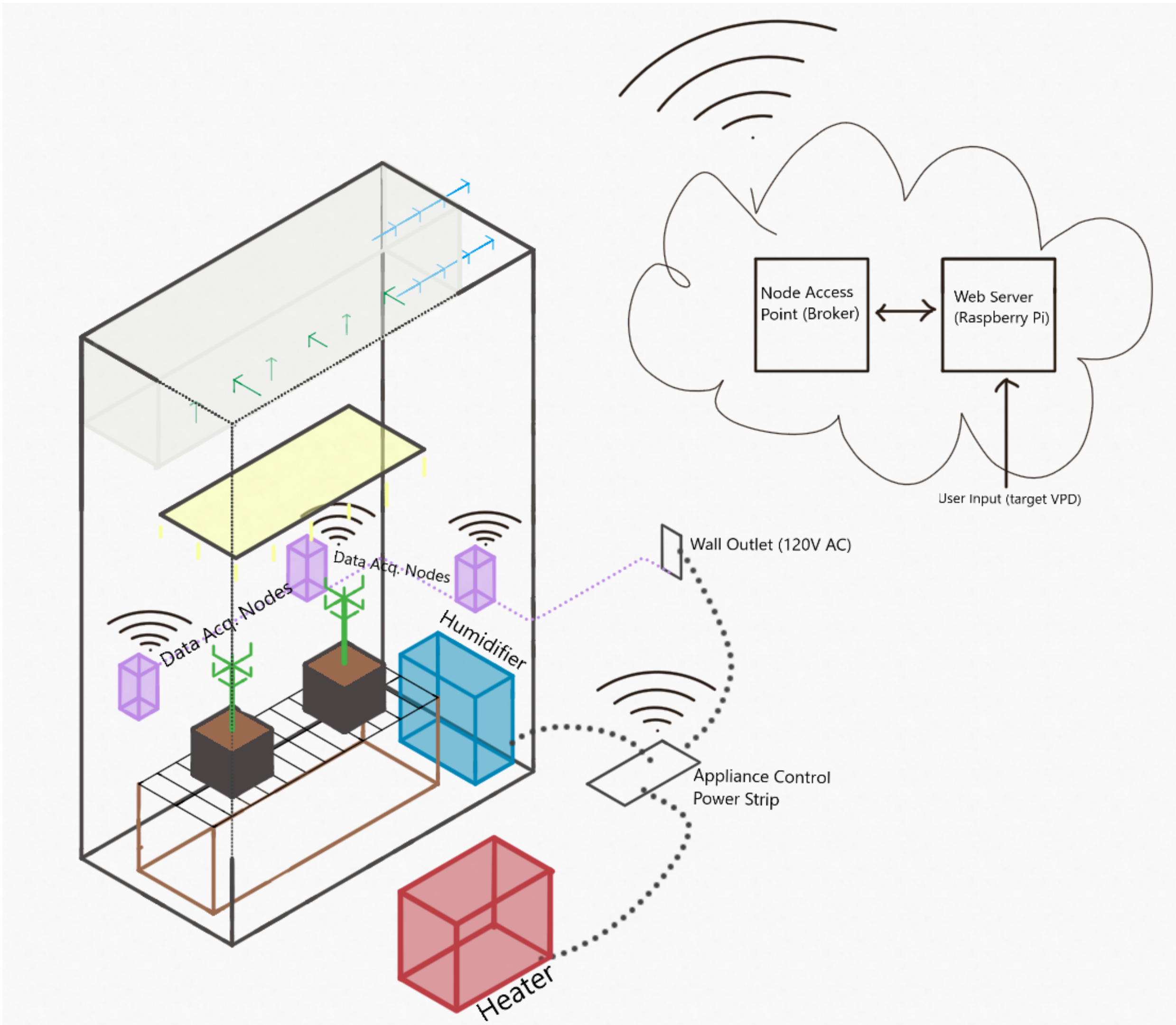

Figure 1: A Visual Aid of MicroClimate

High-level Requirements

- For 95% of operation under our closed growing environment, the VPD must stay within 10% of our target range.
- Target values/thresholds are able to be set manually through the interface the Raspberry Pi provides.
- The overseer receives >95% of data sent from data acquisition nodes and sent control information is acted upon 95% of the time.

Design

Overall System

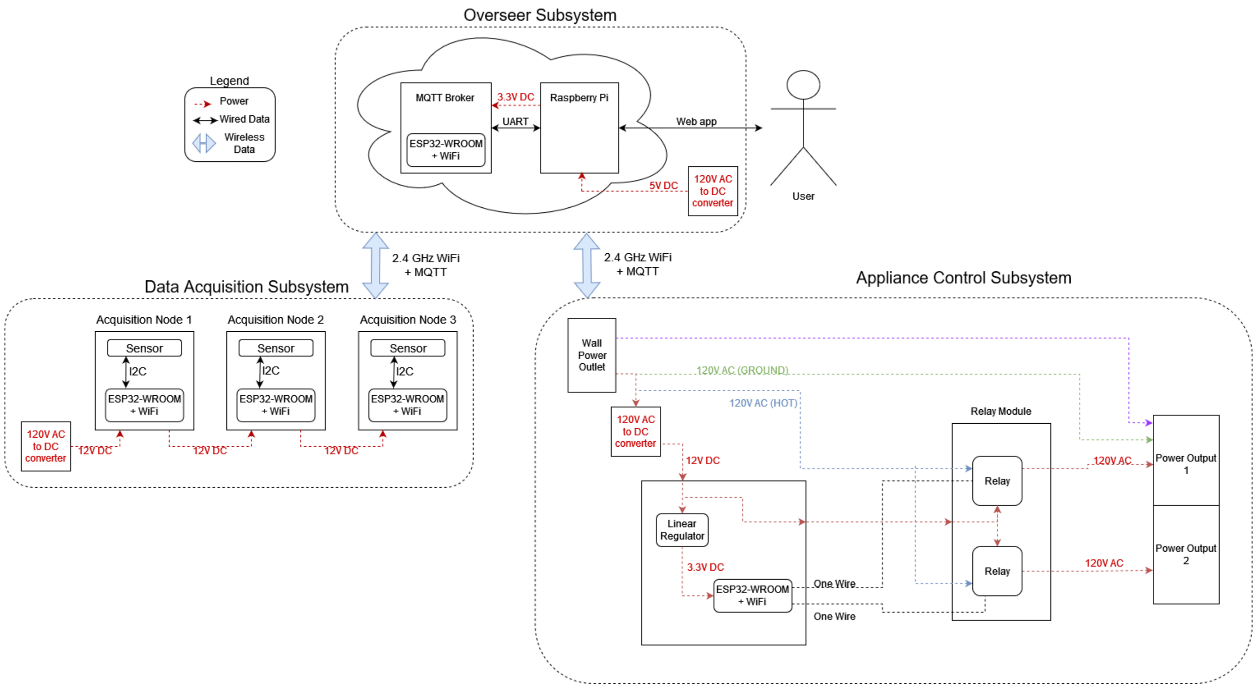

Figure 2: System Block Diagram

System Summary

Microclimate's 3 main systems are Data Acquisition, Appliance Control, and the Overseer. The temperature and humidity data from inside the growing environment is collected by the Data Acquisition nodes and sent to the Overseer wirelessly. Based on current environmental data and a user-set VPD target, the Overseer will send control signals to the Appliance Control Nodes wirelessly. The Appliance Control Nodes, listening to the Overseer, will enable or disable devices such as heaters and humidifiers via power toggling to alter the characteristics of the environment, namely the VPD. The Data Acquisition nodes will poll the environment, and this process will continue, effectively controlling the VPD of the closed area.

Physical Design

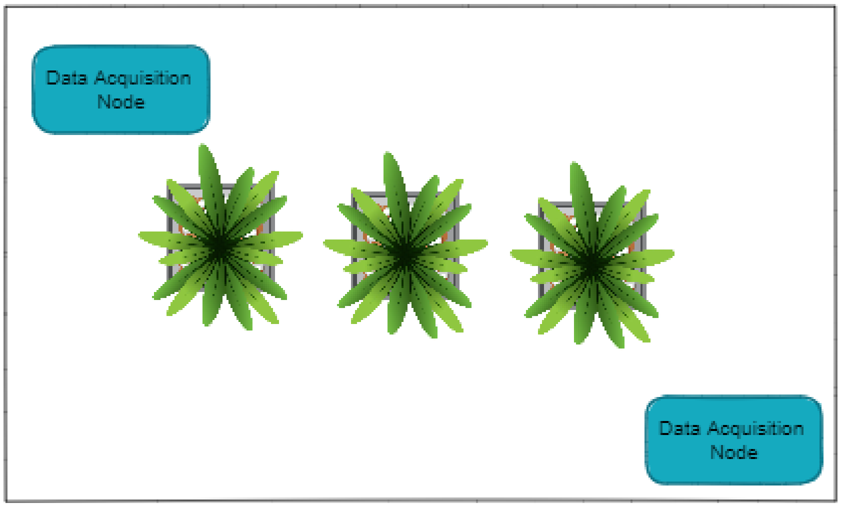

Figure 3: Top-Down View of Data Acquisition Nodes in Grow Tent. Adapted from [2]

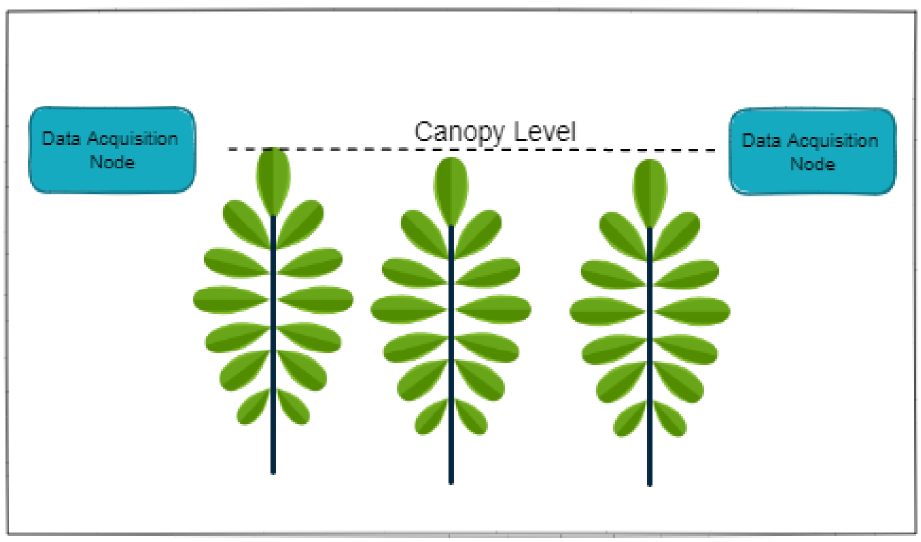

Figure 4: Side-View of Data Acquisition Nodes in Grow Tent. Adapted from [3].

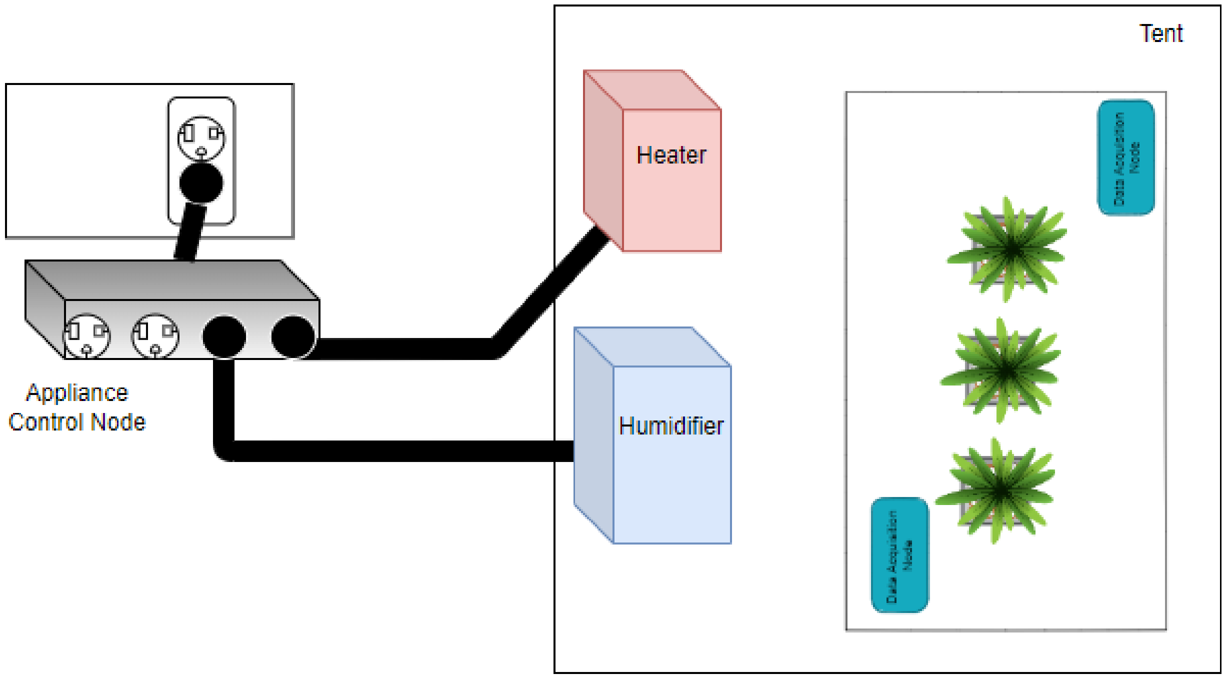

Figure 5: Placement of Actuators in Grow Tent. Adapted from [2]

Figures 3, 4, and 5 show the two aspects relating to the physical design of MicroClimate. The Data Acquisition nodes will be placed at canopy level in the grow tent, as seen in the top-down view in Figure 3 and the side-view in Figure 4. This placement is optimal for measuring the temperature and humidity as the canopy is where the measurements are most accurate in calculating the VPD. As seen in Figure 5, the Appliance Control Node will be placed outside the tent to prevent moisture from affecting the functionality of the device. Figure 5 also shows the placement of the two actuators: a heater and humidifier. These two will be placed to the left of the plants in the grow tent and be powered from the Appliance Control Node. By placing the two appliances on the same side, we reduce the wire length required, make maintenance easier, and allow control of environment variables to be more steady.

Subsystem 1: Data Acquisition

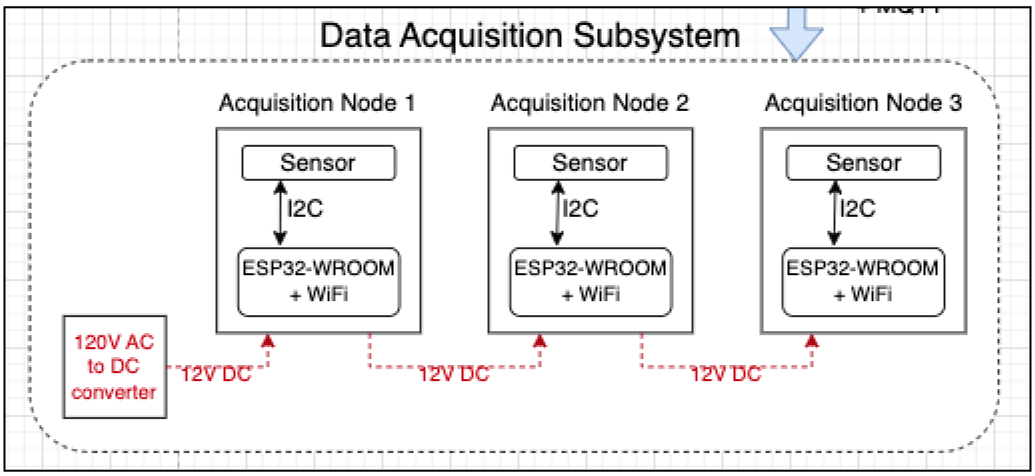

Figure 6: Data Acquisition Block Diagram

Data Acquisition Summary

The Data Acquisition nodes poll the environment for temperature and humidity data and output these values to the Overseer. They can be flexibly placed around the growing environment, but spreading the nodes with a focus on the canopy level is the suggested layout. The nodes should be small enough to not disrupt plant growth.

Microcontroller

We will be using an ESP32WROOM32E [4], a SoC MCU with built-in WiFi, I2C 2support, flash, and antenna. This chip speeds development by allowing us to avoid the pains of implementing a WiFi interface via UART. Power will be delivered at 3.3V from a linear regulator. The MCU will store a buffer of sensor readings locally and send these readings to the Overseer subsystem via WiFi and MQTT.

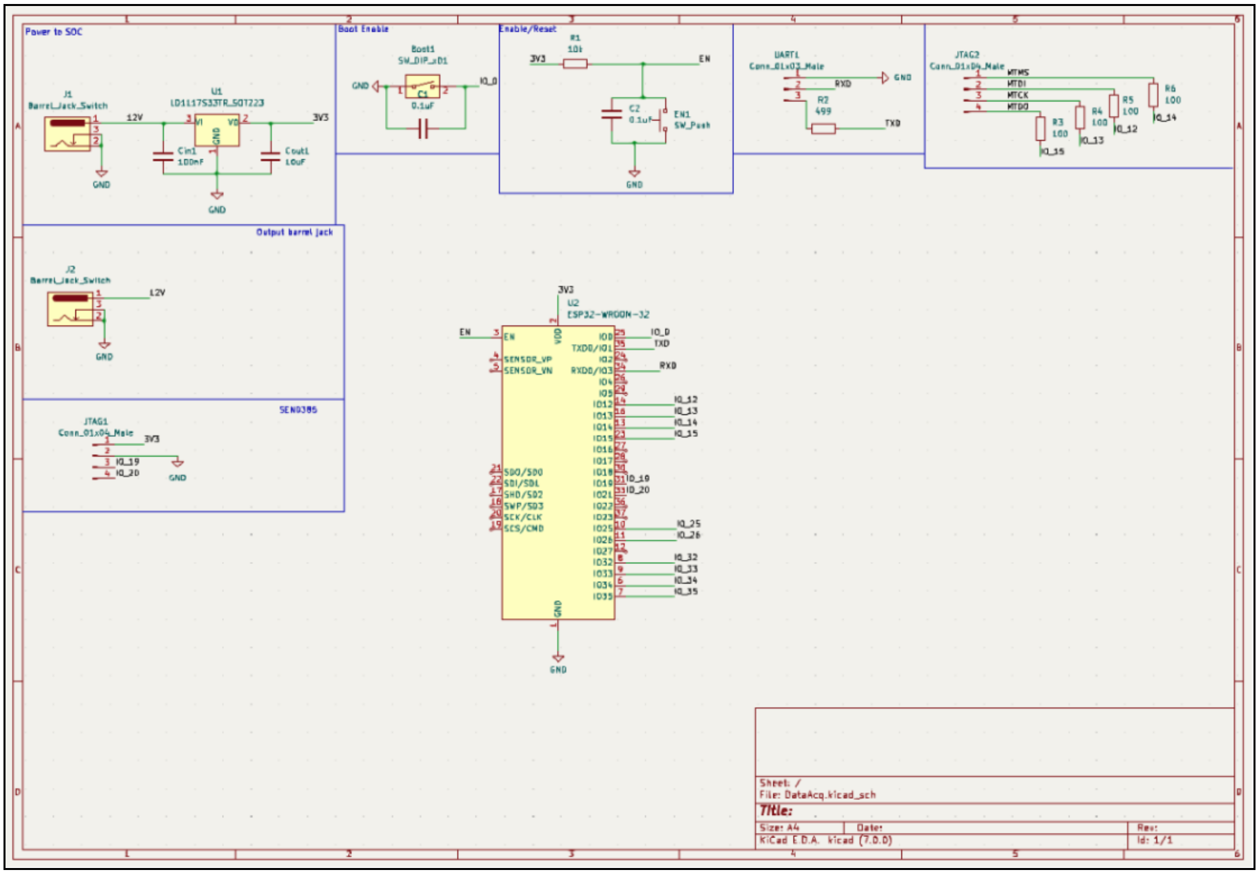

Figure 7: Data Acquisition Schematic

Temperature and Humidity Sensor

A combined temperature and humidity sensor probe will be used to poll the environment. The SEN0385 probe is based on the SHT3x-DIS humidity and temperature sensor IC which uses I2C for communication [5].

Enclosure

The Data Acquisition nodes will be inside our closed growing environment which can reach humidities of 85%. The enclosure will protect the electronics from excess water buildup. The 7301K113 from McMaster-Carr is a watertight enclosure that measures 2” x 2-⅝” X 1-¾” [6], which could be suitable for our nodes.

AC/DC Adapter, Jacks, and Cord

The Data Acquisition nodes will be supplied by power from an AC to DC wall wart that outputs in the range of 9V-15V DC. Power will be delivered from the wart to the first board via the included cable and a soldered power jack. To supply power to the other boards, a second output power jack will be soldered and connected to the input to allow for a passing through of the input power to the next board in the chain. Effectively, we are daisy chaining the power for the nodes. Something akin to the TMEZON 12 Volt 2A Power Adapter Supply will suit our needs, with an appropriately sized barrel jack.

As we are running power over an extended distance, the resistance of the power cord may lead to a non-negligible drop in voltage. We choose to run at a higher DC voltage than required by our system so we have additional room for losses. At each node, the voltage will be regulated to 3.3V.

Linear Regulator

A SMD linear regulator that accepts an input voltage of 5-12V and outputs 3.3V will be ideal. The LD1117S33CTR meets these requirements neatly [7].

Requirements and Verification

The requirements and verification techniques for those requirements for the Data Acquisition nodes can be found in Table 1.

Table 1: Requirements and Verification for Data Acquisition Nodes

Component	**Requirements**	**Verification**
Microcontroller	1: Must be able to transmit data over WiFi from within tent at over 1 Mbits/S 2: Must operate on and be able to set GPIO at 3.3V +/- 5% DC	1A: Place two nodes, one enclosed, and send fixed size files at max speed for 10 seconds. Measure total files transmitted and divide. 2A: Use multimeter to measure GPIO outputs with logic high (3.3V) and logic low (0V) set. 2B: Enable internal pull-up and pull down on GPIO pin, measure

		output voltage, and set the wire high or low with another 3.3V signal. Measure again.
Temperature and Humidity Sensor	1: Must poll environment with accuracy of +/- 5% 2: Must be able to take more than 10 readings per minute 3: Probes are resistant to high humidity (>85% RH) environment	1A: Take 10 measurements with sensor and compare to off-the-shelf hygrometer reading. 2A: Determine max sampling rate via I2C and validate parameters. 3A: Place probes in consistent, high humidity environment for 24 hours and take periodic readings.
Enclosure	1: Prevent enclosure interior humidity from exceeding 60% at and above 70° F	1A: Take internal humidity readings with a sensor when the enclosure is placed in a high-humidity environment.
AC/DC Adapter, Jacks, and Cord	1: Be able to provide a voltage >= 5V DC at a distance of 20 feet from 120V AC 2: Must not fail after repeated bends 3: Must handle maximum 1A across jacks and cord	1A: Use a voltmeter to check if output voltage exceeds 5V DC over 25 feet run of wire. 2A: Bend cord end 50 times and check continuity. 3A: Put a small resistive load (100mA) at the end of the circuit to test continuity and heat. Step up resistive load until target is met.
Linear Regulator	1: Provide 3.3V +/- 1% from a 5-12V source 2: Can operate within 0-300mA 3: Maintain stability below 250° F	1A: Measuring the output using an oscilloscope, ensuring it stays within 1% of 3.3V. 2A: Use a resistive load to deliver at most 300mA through the linear regulator, and measure the output current and voltage using a multimeter. 3A: During verification for requirement 1, use an IR thermometer to ensure IC stays below 250° F.

Subsystem 2: Appliance Control

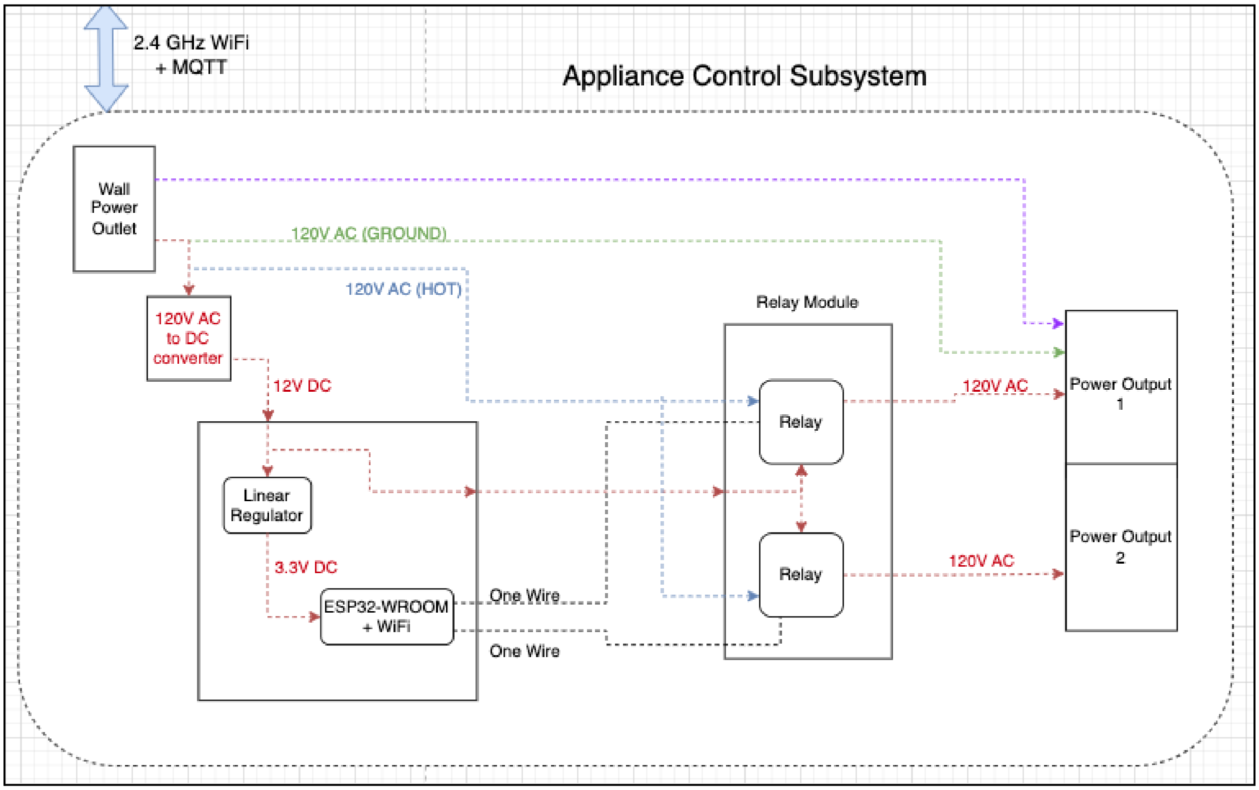

Figure 8: Appliance Control Block Diagram

Appliance Control Summary

The Appliance Control Node serves to provide controllable power to each individual appliance. This node will use a microcontroller to send control signals to relays, allowing power from the wall to flow through or not flow through to the output outlet. The purpose of the node is to individually control each appliance that is plugged into the node, allowing for better control of environment variables.

The Appliance Control Node will interact with the Overseer by continuously polling the Broker to retrieve control data. This allows the subsystem to retrieve and subsequently send control signals to the relays, allowing for the control information to be acted upon at a high rate (>95%) and the VPD to be maintained within the acceptable 10% of the target range.

Microcontroller Unit

The microcontroller unit is the controller of the Appliance Control Nodes. This unit consists of a microcontroller, power in, linear regulator, and headers for data and power out. The microcontroller we will be using is a ESP32WROOM32E [4]. This will continuously pull control data from the Broker using the MQTT protocol [8]. That data will be used to then turn on or off the signal wires that go to the relays. More specifically, the data wires will be connected to a set of headers that will then be wired to the relay units. The unit takes in a 12VDC power through a barrel jack. This power goes to a set of headers that will send the 12VDC to the relay modules in order to power them. This power will also go through a linear regulator to take the 12VDC to 3.3VDC and deliver that to the ESP32WROOM32E. The linear regulator that will be used is the LD1117S33CTR which can convert the 12VDC to 3.3VDC [5]. A detailed schematic of the Microcontroller Unit can be found in Figure 9.

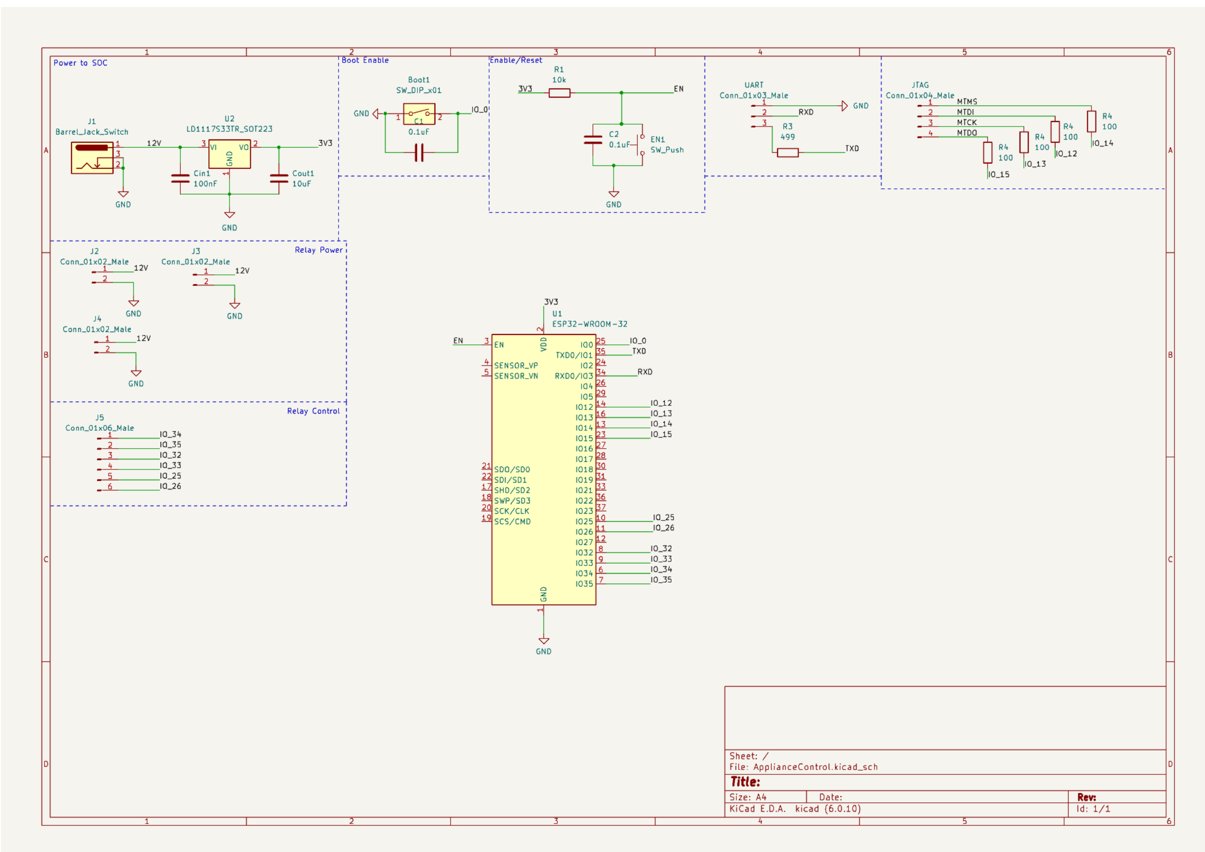

Figure 9: Microcontroller Unit Schematic

Relay Module

The relay of choice is the Omron G5LE. This relay has an operating voltage of 12VDC and provides a maximum switching voltage of 250VAC [9], which is more than enough for this project. The relay also has a long operation lifetime of a minimum of 100,000 switches. The Hot wire from the wall will connect to the NO (Normally Open) connection on the relay, and the output of the relay (COMM) will go straight to the output outlet. This will ensure the power will only flow to the output when the microcontroller sets the control signal to high. The relays will be paired up and placed on modules, more specifically the Pololu Basic 2-Channel SPDT Relay Carrier [10]. This allows for fewer wires as the module takes on power input and gives it to both relays and for better organization of the overall Appliance Control unit.

Power: AC/DC Converter and Linear Regulator

The power from this unit will come from a wire plugged into the wall which will then “split” into two parts: a AC/DC converter to power the relays and microcontroller and the wires that will go through the relays and to the output outlet. In order to power the relays, we need 12VDC. This can be accomplished by using a TMEZON 12 Volt 2A Power Adapter Supply. The output of this converter will go to a barrel jack connector on the microcontroller unit. This 12VDC will then be routed to the relays through header pins on the microcontroller unit. As mentioned earlier, since ESP32WROOM32E requires 3.3VDC for power, the LD1117S33CTR linear regulator will take the 12VDC down to a suitable level for the microcontroller. In addition, this linear regulator provides the required amperage for the microcontroller. For the output wires, the three wires that compose the 120VAC line will be separated. The ground and neutral wires will be wired up to all of our output outlets. The hot wire on the other hand will go through the relays and then arrive at the outlet depending on the control signals.

Requirements and Verification

Table 2: Requirements and Verification for Appliance Control node

Component	**Requirements**	**Verification**
Appliance Control Node	1: Must be able to set output voltages of multiple outlets in order to control appliances 2: Must provide enough power to allow appliances to work at full capacity 3: Relays must accurately allow a 120VAC voltage through given a high coil voltage 4: Must use control signals from Broker using WiFi and MQTT protocol to set output voltages	1A: Plug an appliance into the circuit and ensure that the appliance turns on per a 'ON' control signal or off on a 'OFF' signal 2A: Measure or research appliance power intake and measure power output at each output outlet. 3A: Test output voltage from the relay when the coil voltage is high against when it is low 4A: See Microcontroller Verification
Microcontroller Unit	1. Must be able to communicate and receive data over WiFi using the MQTT protocol from Broker at speeds greater than 5 Mbits/s 2. Must convert 5VDC to 3.3 VDC for powering the microcontroller 3. Must output 5VDC at power out headers 4. Must set correct 3.3VDC output signals based on data from the Broker 5. Must output appropriate 3.3VDC signal at control headers	1A: Connect the microcontroller to the Broker and send an acknowledge from the broker to the microcontroller 2A: Measure the voltage before and after the linear regulator 2B: Must be within 5% of 3.3VDC to be successful 3A: Measure voltage at all power out headers and ensure it is within 5% of 5VDC 4A: Set a sample variable to 'ON" or 'OFF' on the broker and measure the output at the associated GPIO pin on the

		microcontroller 5A: In conjunction with 4, test that the output voltage at the related control header is also 3.3VDC +/- 5% VDC.

Subsystem 3: Overseer

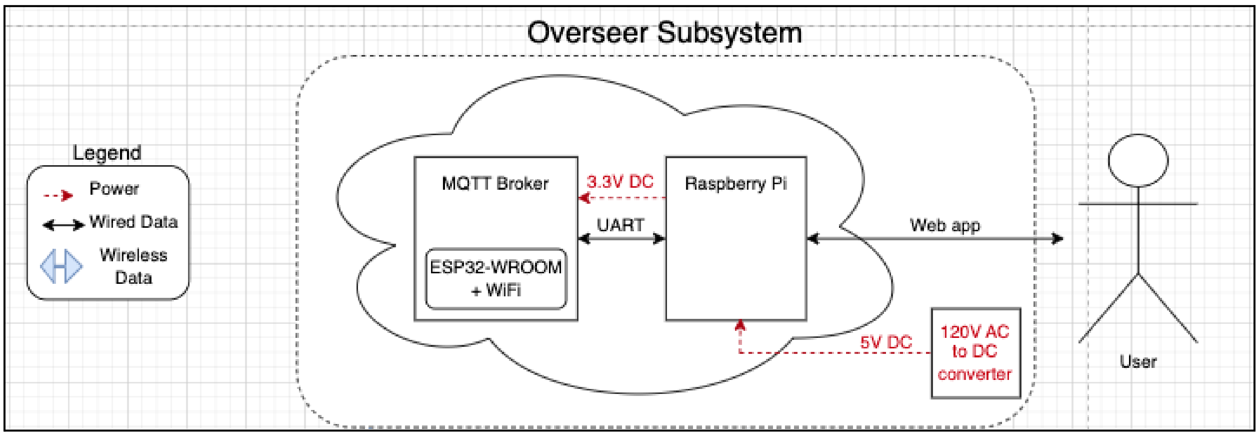

Figure 10: Overseer Block Diagram

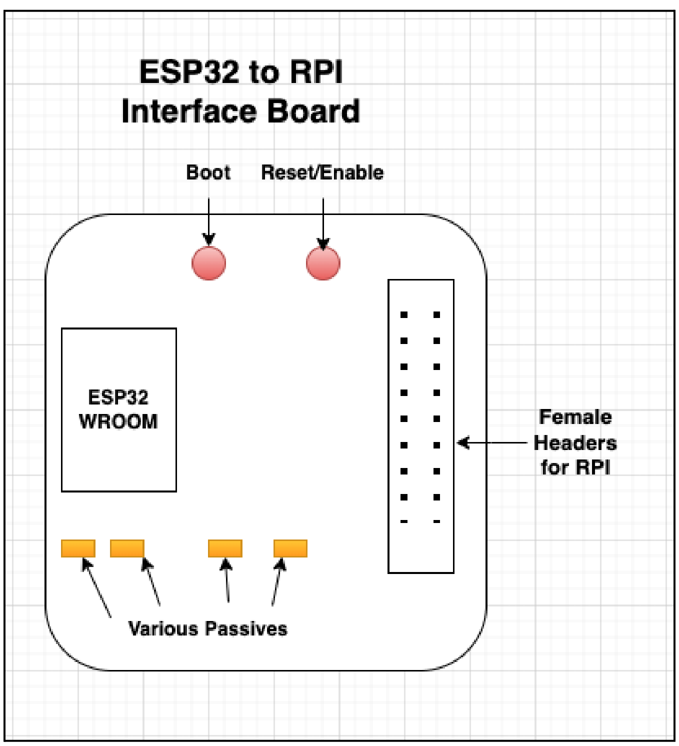

Figure 11: ESP32 to RPI Interface Board

Overseer Summary

The overseer subsystem is responsible for reading sensor data, determining what actuators must be turned on/off (based on a control systems algorithm), and sending the appropriate instruction signals to the appliance control subsystem. Further, it sends sensor data to be displayed to the Raspberry Pi and also receives new thresholds (from RPI user interface) to adjust its control system logic. Besides the two-way communication between the Raspberry Pi and broker MCU, all of these communications are done via MQTT.

Microcontroller/Broker

We will be using an ESP32WROOM32E [4], a SoC MCU with built-in WiFi, I2C support, flash, and antenna. This broker will be placed closely outside the growing environment because its communication to other subsystems is wireless. The broker will determine what actuators to turn on/off based on the sensor data it receives from our data acquisition subsystem, as well as thresholds determined by the user via the Raspberry Pi interface. Through the same interface, the broker will send sensor data to be displayed to the Raspberry Pi. This microcontroller will be instantiated as a WiFi Access Point(AP) and communicate with the sensor nodes and appliance control subsystem via MQTT network protocol. Communication between the broker and Raspberry Pi will be done via a PCB interposer or interface board.(Figure 11)We will design this interface based on the ESP32 and Raspberry Pi specifications and UART communication protocol.

User Interface

We will be using a Raspberry Pi 3 Model B V1.2. The Raspberry Pi will host a website that will display an interface for users to toggle humidity and temperature thresholds that he or she deems fit for the optimal growth of their plants. If these thresholds are changed, that data will be sent via UART through the Raspberry Pi to ESP32WROOM32E interface board and implemented in the MCU’s control system logic.

Power

To provide power to the overseer subsystem we will utilize a 5V power adapter and a microUSB cable. We will use a power adapter to supply power from an output in the range of 5.1V DC directly to the Raspberry Pi Model B via microUSB. Conveniently, the Raspberry Pi Model B outputs a 3.3V DC signal through multiple GPIO pins,[11] which is exactly what we need to power the ESP32WROOM32E broker.

Requirements and Verification

The Requirements and Verification for the Overseer node can be found in Table 3.

Table 3: Requirements and Verification for Overseer node

Component	**Requirements**	**Verification**
ESP32WROOM	1: Broker MCU be able to transmit data to Raspberry Pi outside of the tent at over 5 Mbits/S. And vice-versa. 2: Broker MCU must operate on and 3.3V and Raspberry Pi must operate on 5.1 V, 2.1A . Also, Broker be able to set GPIO at 3.3V +/- 5% DC	1A: Place these two nodes apart and send fixed size files at max speed for 10 seconds. Measure total files transmitted and divide. 2A: Use a multimeter to measure GPIO outputs with logic high (3.3V) and logic low (0V) set. 2B: Enable internal pull-up and pull-down on the GPIO pin, measure output voltage, and set the wire high or low with another 3.3V signal. Measure again.

Tolerance Analysis

The Overseer Subsystem is critical to MicroClimate and is the brain of the entire system. In specific, the Broker MCU(ESP32-WROOM-32) is responsible for reading data from the Data Acquisition subsystem, pulling user-inputted thresholds from the Raspberry Pi, computing a control systems algorithm that makes decisions about actuator toggling, and sending the appropriate data to the appliance control subsystem. So when it comes to the overseer, timing is very important because the system needs to respond *accurately* to the real-time needs of the plant. Along with timing, understanding the environmental-altering ability of our actuators, heaters and humidifiers, is crucial to the success of our project. The accuracy of our sensors is paramount to understanding our environment, which is the foundation of all other subsystems.

VPD and Actuators

Along with the timing of the messages, the ability of the heater and humidifier to heat up and increase the humidity of the environment are crucial to MicroClimate's function. If either is placed incorrectly relative to the growing environment or simply lacks the power to impact the environment sufficiently, new temperature and humidity targets must be made. As VPD relates to both temperature and humidity non-linearly, there are many potential configurations of these variables to achieve the goal VPD. Figure 12 shows the sliding nature of the target VPD for an example crop.

ROOM VPD: VAPOR PRESSURE DEFICIT RECOMMENDATIONS (kPa)

TEMPERATURE		RELATIVE HUMIDITY											
°C	°F	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%
15	59	1.11	1.02	0.97	0.85	0.77	0.68	0.60	0.51	0.43	0.34	0.26	0.17
16	61	1.18	1.09	1.00	0.91	0.82	0.73	0.64	0.55	0.45	0.36	0.27	0.18
17	63	1.26	1.16	1.06	0.97	0.87	0.77	0.68	0.58	0.48	0.39	0.29	0.19
18	64	1.34	1.24	1.13	1.03	0.93	0.83	0.72	0.62	0.52	0.41	0.31	0.21
19	66	1.43	1.32	1.21	1.10	0.99	0.88	0.77	0.66	0.55	0.44	0.33	0.22
20	68	1.52	1.40	1.29	1.17	1.06	0.93	0.82	0.70	0.58	0.48	0.35	0.23
21	70	1.62	1.49	1.37	1.24	1.12	0.99	0.87	0.75	0.62	0.50	0.37	0.25
22	72	1.72	1.59	1.45	1.32	1.19	1.06	0.92	0.79	0.66	0.53	0.40	0.26
23	73	1.82	1.68	1.54	1.40	1.26	1.12	0.98	0.84	0.70	0.56	0.42	0.28
24	75	1.94	1.79	1.64	1.49	1.34	1.19	1.04	0.89	0.75	0.60	0.45	0.30
25	77	2.06	1.90	1.74	1.58	1.42	1.27	1.11	0.95	0.79	0.63	0.47	0.32
26	79	2.18	2.02	1.85	1.68	1.51	1.34	1.18	1.01	0.84	0.67	0.50	0.34
27	81	2.32	2.14	1.96	1.78	1.60	1.43	1.25	1.07	0.89	0.71	0.53	0.36
28	82	2.46	2.27	2.08	1.89	1.70	1.51	1.32	1.13	0.94	0.76	0.57	0.38
29	84	2.60	2.40	2.20	2.00	1.80	1.60	1.40	1.20	1.00	0.80	0.60	0.40
30	86	2.76	2.54	2.33	2.12	1.91	1.70	1.48	1.27	1.06	0.85	0.64	0.42
31	88	2.92	2.69	2.47	2.24	2.02	1.80	1.57	1.35	1.12	0.90	0.67	0.45
32	90	3.09	2.85	2.61	2.38	2.14	1.90	1.66	1.43	1.19	0.95	0.71	0.48
33	91	3.27	3.02	2.76	2.51	2.26	2.01	1.76	1.51	1.26	1.01	0.75	0.50
34	93	3.46	3.19	2.92	2.66	2.39	2.13	1.86	1.59	1.33	1.06	0.80	0.53
35	95	3.65	3.37	3.09	2.81	2.53	2.25	1.97	1.69	1.40	1.12	0.84	0.56

Mid / Late Flower   Early Flower / Late Veg   Propogation / Early Veg

Figure 12: Common VPD targets and their relationship with temperature, humidity, and growth stage [12].

Based on previous experiences with off-the-shelf heating elements and the insulating properties of a grow tent, I expect temperatures in the range of 60-75° F to be attainable for extended durations of time, while humidity has a much wider range from 35-75%. With this in mind, our control system will aim to select temperature and humidity values within this range to meet the VPD target. Using the VPD equations found in [1], the range of VPD that can be achieved from these parameters is graphed in figure 13. The overseer control system will aim to achieve temperature and humidity values within these ranges.

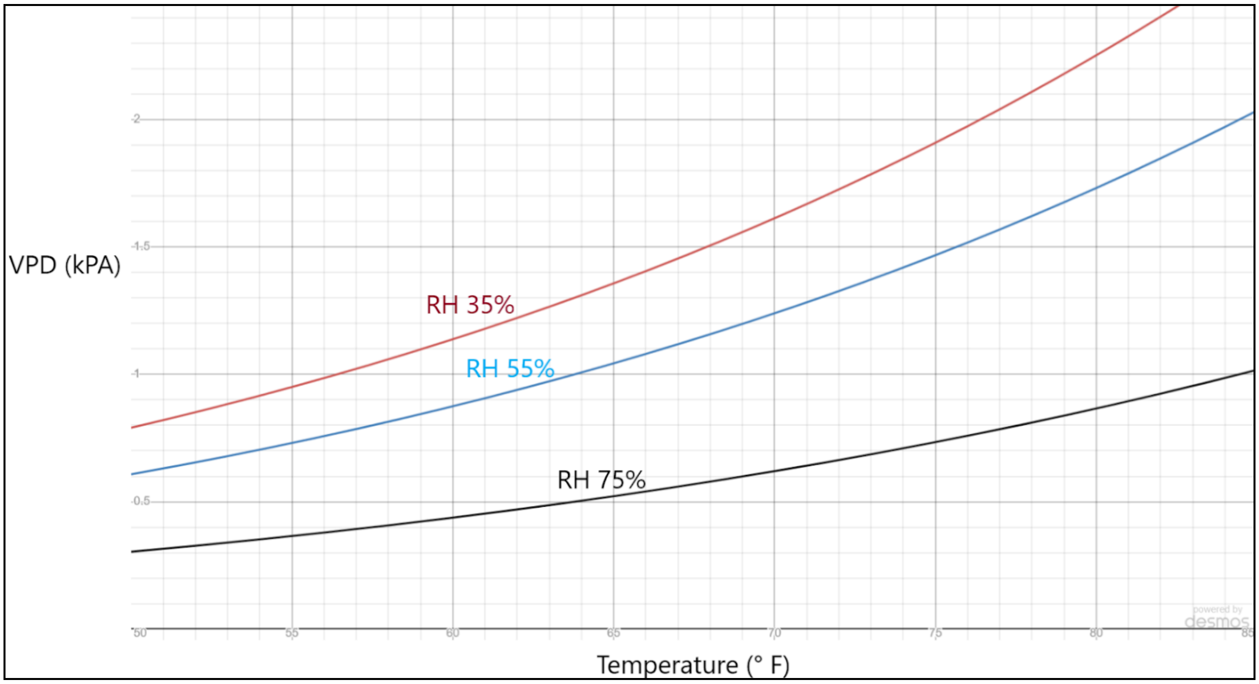

Figure 13: The available range VPD given constrained temperature, graphed at varying humidity levels.

The Overseer will have to run a small control system to maintain VPD for our environment. To achieve this, target temperature and humidity values will be derived within the Raspberry Pi unit and sent to the broker MCU, where the control takes place. The exact time-to-rise and time-to-settle of VPD varies drastically depending on multiple factors: the difference between the current VPD and target VPD, heater and humidifier output capacity, and the quality of the seal of the environment. Plant growth is a relatively slow process on the human timescale and incredibly slow on the microelectronics timescale, so room for variance is afforded.

Given the assumption of a 2' x 4' x 6' tent at room conditions, there is approximately 1.757 kg of air with a total heat capacity of 1779.1 joules/° K [13]. A 1500 W space heater can produce > 5000 BTUs, which translates to over 500,000 joules [14]. A 10° K difference in temperature will result in a total need of 17780.84 J, which is well in the capacity of a space heater. The heater can take a significant amount of time for this temperature to settle: if the temperature cannot be achieved within 1 hour, a lower temperature target and corresponding humidity target will be chosen to reach the same VPD.

Timing

Based on previous IoT projects, wireless latency between ESP32 devices is usually in the 10-30ms. Let's say that sensor A sends a signal to the broker to turn off the humidifier at t=0 sec, and because of additional CPU requirements at the time of the ESP32 it takes a total of 30*3=90 ms(including 30ms computation time) to reach the MCU board in the appliance control module. At t=10ms, sensor B sends a signal to the broker to turn on the humidifier, however it only takes 50 ms in total to reach the appliance control subsystem. We want to have the latest data, however if this happens the worst possible loss of data would be a difference of 40ms. This is miniscule in terms of the success of the control systems algorithm, and certainly won't affect the plants' overall health.

Sensors

The sensor probes we are using to monitor the environment are the DFRobot SEN0385 with temperature and humidity ranges well within our environment limits (-40 - 125° C, 0-100% RH) and accuracies of ±0.2° C and ±2% RH [15]. With these ranges and the rapid polling capability in mind, a consistent and quality understanding of the environment is expected. Our sensors will be strategically placed at plant canopy level, where the majority of the leaves are, in order to get the most useful readings of the VPD the plant experiences.

Cost and Schedule

Cost Analysis

Labor Costs:

($/hour) x 2.5 x hours to complete = TOTAL
90k/year -> $43.27/hr

Aadarsh Mahra: $43.27/hr x 2.5 x 45 hours = $4867.88
Jeffrey Taylor: $43.27/hr x 2.5 x 45 hours = $4867.88
Smit Purohit: $43.27/hr x 2.5 x 45 hours = $4867.88

TOTAL COST OF LABOR = $14,603.63

Component Costs:

Table 4: Component Description and Cost

Item	Manufacturer	Quantity	Cost
ESP32-S3-WROOM-1-N4R8	Espressif	6	$3.69
SEN0385	DFRobot	2	$19.90
2-Channel Relay Carrier with 12VDC Relays	Pololu	2	$9.49
Raspberry Pi 3	Raspberry Pi	1	$35.00
LD1117S33CTR Voltage Regulator	STM	6	$0.66
VEL12US120-US-JA DC power supply	XP Power	2	$12.71
54-00166 2.1mm barrel jack	Tensility International Corporation	6	$0.74
10-03921 Plug to Plug cable	Tensility International Corporation	2	$6.79
Commercial Grade Tamper-Resistant Single Outlet	Pass & Seymour	4	$3.48
20-Amp Self-Test GFCI Outlet Ivory	Smart Electrician	1	$14.99
7301K113 Electronics Washdown Enclosure	McMaster-Carr	2	$9.90
PCB Components (Capacitors, resistors, headers, cables/wires)	n/a	n/a	$25.00

Total Cost of Components = $237.03

Total Costs:

Grand Total = Cost of Labor + Cost of Components = $14,603.63 + 237.03

= **$14840.66**

Schedule

Week	Deliverables	Division
2/20	Purchase prototyping parts. Draft PCB. Complete high-voltage training.	All
	Establish AP creation and access on dev board.	Aadarsh
	Prototype I2C communications on dev board.	Jeff
	Establish WiFi connection on dev board.	Smit
2/27	Have PCB ready for board review. Create BOM and order parts.	All
	Establish MQTT broker over WiFi.	Aadarsh
	Interface with sensor and AC adapter, validate requirements.	Jeff
	Interface with relay board and voltage regulator, validate requirements.	Smit
3/6	Finalize PCB and place orders.	All
	Draft temperature and humidity software control system.	Aadarsh
	Validate MCU requirements.	Jeff
	Draft physical layout of appliance control. Practice 120V wiring.	Smit
3/13	Spring Break! Rest and Relax	All
3/20	Assemble PCBs. Validate PCB functionality. Re-draft if needed.	All
3/27	Place **FINAL** PCB orders.	All
	Finalize temperature and humidity software control system.	Aadarsh
	Validate enclosure requirements. Begin integrating data acq. and overseer.	Jeff
	Wire 120V outlets with relay boards.	Smit
4/3	Assemble PCBs. Begin system integration.	Aadarsh
	Assemble PCBs. Continue system integration.	Jeff
	Fully assemble appliance control node.	Smit
4/10	Touch up any rough edges and iron out bugs. Perform integration tests.	All
4/17	Perform Mock demo. Prepare Full Demo.	All
4/24	Demo Final Product. Prepare Final Presentation.	All

Ethics and Safety

Ethics

MicroClimate will adhere to the fullest extent of the IEEE [16] and ACM [17] ethical codes. In our design, we will put ethical, sustainable, and safe practices at the forefront. We will also make sure that each of us uphold and practice these ethics guidelines.

We will ensure that we are lawful in our design and will not use anyone else's work without proper permissions and crediting those works. In our design process, we will make sure that any decisions we make are fully and unambiguously lawful and safe. When we are doing research on our design and ways to implement it, if we are to use any previously implemented or researched ideas we will be sure to properly cite the work. In case of technical issues, we will ask and graciously accept advice. Within our group, we have a Discord server where we share ideas, ask questions, and make decisions. This is also where we give feedback on each other's ideas and designs, creating a singular area where all design decisions are born and finalized. When we run into technical issues that we cannot solve, we will reach out to the appropriate channels for help, such as Office Hours.

We will also treat all peers, course staff, and members of our team with the utmost respect. As mentioned before, to foster an environment of teamwork within our group, we have a Discord server that serves as an open forum. Other technologies we will be using to continue having a smooth team experience are Google Drive for sharing files and a GitHub for version control of code and schematics. We will be having meetings at least once a week to check on progress by ensuring everyone is fulfilling their responsibilities and adhering to expectations.

Our design will avoid harm not only to ourselves, but any who use it. As explained in the following section, our design will take the utmost care to ensure that we are not harmed during any part of the building phase of the project. In addition, our project will have multiple safeguards to ensure that users will be safe from physical harm from our project. Ensuring our design does not do harm includes ensuring the system is secure and will not violate our user's privacy. As outlined further in the Safety section, any data that is generated will remain within the system and used only for the purposes outlined in this document.

Safety

There are a multitude of safety concerns involved with this project. In terms of electrical safety, a particular concern is related to the Appliance Control nodes. These nodes will be dealing with 120VAC from a wall outlet. In order to ensure we are safely working with this high voltage, a variety of precautions will be in place. First and foremost, we will all follow every ECE 445's guideline with working with high voltage, including any training that is needed. When working with anything that will touch the 120VAC, the plug must be out of the wall for at least 5 minutes beforehand and it must be checked for any current before any work can be done. While working on the wiring, appropriate tools will be used and PPE must be worn [18]. Finally, we will be sure to work in a safe environment, that is an environment that is free of obstacles and hazards, including moisture.

Our Appliance Control node design will include a Ground Fault Circuit Interrupter (GFCI), ensuring we and the users are safe from electric shocks in this subsystem. We will also be sure to double and triple check any appliances used to make sure that they will not require too much power draw, therefore reducing the risk of an electrical fire. To protect users of MicroClimate, there must be no exposed wiring and all wiring must be properly insulated and secured. In addition, a manual, physical switch will be added to allow the user to stop the flow of electricity. All wiring and the PCB's will also be enclosed.

For our Data Acquisition nodes, we will have an enclosure that is watertight to not only protect the electronics inside, but also to provide a safe operating environment for the user and their plants.

Safety also involves data safety and privacy. Any data sent from the Data Acquisition nodes or Overseer nodes will be over a private, secure network. There will be no ability to access data from outside the system except where we allow it to be seen from a website. All data will only be used for the purposes outlined in this proposal and will only be stored locally within the system for logging and monitoring purposes.

More information on safety as it relates to this project can be found in Appendix I, which includes an (unsigned) Standard Operating Procedure.

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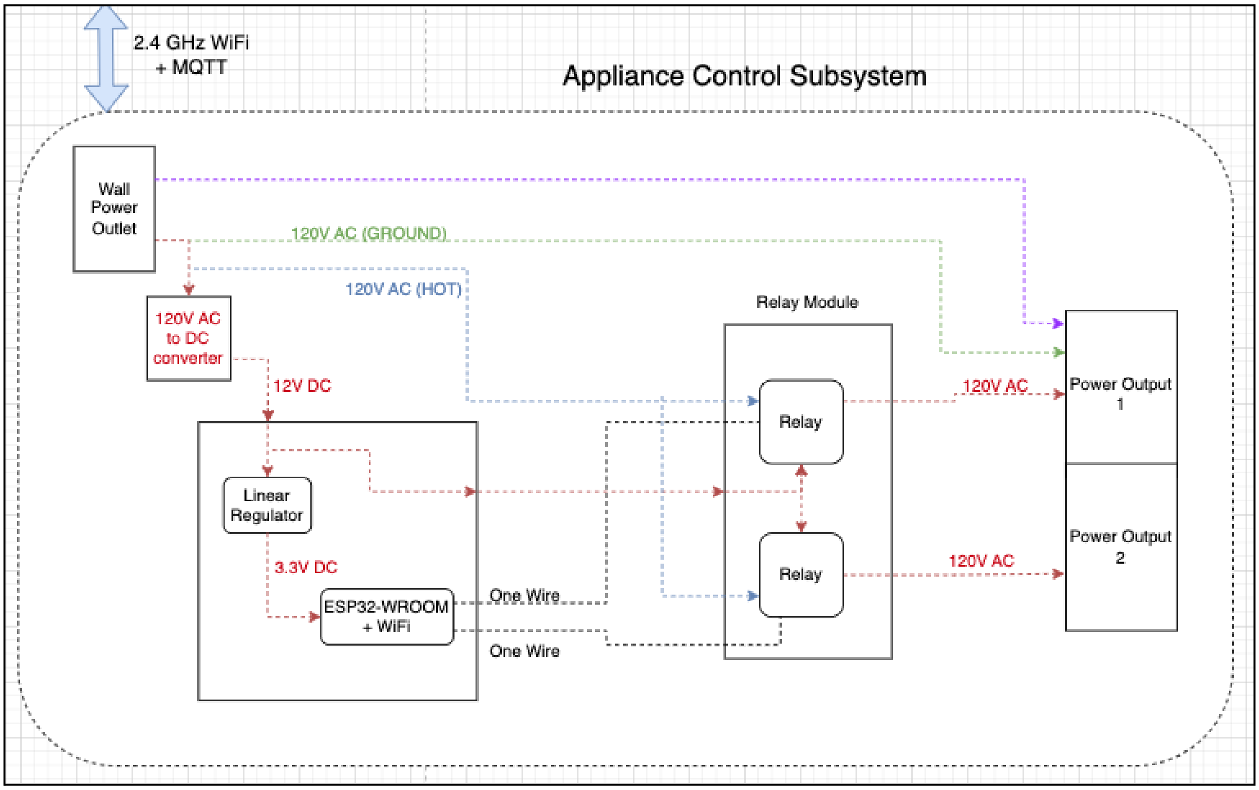
Appendix I

Standard Operating Procedure for Hazardous Electrical Procedures and/or Equipment

I. Briefly describe the project, equipment involved, and expected results of normal operation.

MicroClimate is a Vapor Pressure Deficit (VPD) management system that monitors and controls environmental variables such as temperature and humidity to maintain a certain VPD range. The Appliance Control Subsystem is of particular interest, as it interacts with 120VAC from the wall. The Appliance Control Node serves to provide controllable power to each individual appliance used to control the VPD. This node will use a microcontroller to send control signals to relays, allowing power from the wall to flow through or not flow through to the output outlet. The equipment involved are relays and the appliances we are using. In normal operation, the subsystem should send control signals to the relays and they should allow/disallow current to flow through, powering the appliances.

II. Sketch a single-line diagram of the experiment or equipment which illustrates the primary function(s) and component(s) of the system. Include text where helpful.



III. Electrical Hazard Recognition:

Provide the operating parameters of your equipment or those used during the procedure described above (under normal operation conditions).

Electrical Parameters (General):

Parameter	LOWEST	HIGHEST
VOLTAGE [V]	0	120V
CURRENT [A]	0	15A
POWER [W]	0	1500W
FREQUENCY [Hz]	0	60 Hz

Does this experiment use any custom or home-built equipment?

YES NO

Is testing (e.g., with a multimeter) performed above 50 V or 5 mA?

YES NO

Is Lockout/Tagout required for this experiment or equipment?

YES NO

UIUC Electrical Hazard Classification: Medium Risk

IV. Electrical Hazard Mitigation:

For each hazard identified on the previous page, provide steps for how the risk will be reduced. If not possible to reduce risk, explain how the risk will be managed.

HAZARD	RISK MITIGATION
120 VAC - Shock Hazard	The risk will be reduced by ensuring that when working with the components that relate to the 120 VAC, we ensure that we have tested the circuit first with lower and safer voltages. In addition, we will ensure that the component has been discharged and not plugged in for at least 5 minutes. There must be no current flowing through the system. Finally, in our design, we have incorporated safety components such as a GFCI. Since a critical part of our project relies on the 120VAC, we will be unable to fully reduce the risk but through these measures, it will be managed.

V. Additional Hazard Recognition and Mitigation:

Include pertinent information regarding additional (non-electrical) hazards associated with this procedure. Refer to the American Chemical Society's tools for hazard assessment as needed.

Chemical:

REAGENT	CONCENTRATION	QUANTITY	GHS HAZARDS

Physical / Mechanical:

HAZARD	LOCATION	MITIGATION	NECESSARY PPE

ADDITIONAL RISK MITIGATION:

For each hazard identified above, provide a narrative of how the risk will be minimized. If not possible to reduce risk, explain how the risk will be managed.

HAZARD	RISK MITIGATION

VI. Electrical Personal Protective Equipment

Is PPE required? YES NO

Required PPE**; circle all that apply:**

Eye protection

Gloves, disposable

Gloves, leather

Lab coat

Flame-resistant (blue) lab coat

Face shield

Hearing protection

Hard hat

Grounding stick/wand (negligible resistance; "soft" grounding)

Discharge stick/wand (some resistance; "hard" grounding)

VII. Other

PROCEDURAL DETAILS: Provide a specific and detailed process description. If appropriate, refer to instrument operating instructions.

Safe assembly and operation of the Appliance Control Subsystem starts with wires connecting the wall power to each relay. These wires will have the appropriate AWG per the voltage, current, and length specifications. In attaching the wires to the relays, we will ensure all power is off and there is no current flowing through the circuit. Once the relays are connected, we will test the circuit for any problems with a lower and safer voltage. After this has been checked and approved, we will only then test with the high voltage. In safe operation, the system will provide current to the relays at all times but the relays will only pass that current to the appliances when the control signal is sent. In addition, there must be no risk of fire through our design.

OUT-OF-NORMAL EVENTS: Provide a list of several points or types of failures associated with this procedure or equipment. Also include any emergency shutdown procedures.

There are several points of failure in this system. One main point of failure is the relays. If the relays stop operating at a safe level, we may get fluctuations in the switch, causing voltage swings and a possible fire and shock hazard. Another point of failure is the wiring. While all steps will be taken to ensure safe and proper wiring, the wires may come loose or become frayed. In this case, not only will the subsystem be in danger of not working, but there is a danger of shock and fire. A final point of failure is a surge from the wall outlet. This can be fixed with an emergency shutdown procedure, such as implementing a circuit breaker and a GFCI outlet.

TRAINING: Enumerate and explain the training requirements for a researcher to undertake this procedure.

1. The only training required for this procedure is the following courses on https://ovcrportal.research.illinois.edu/Training/: Laboratory Safety Training, Electrical Safety: Risk Assessment, Electrical Safety: Recommended Practices, and Electrical Safety: Fundamentals.
2. There should be no training required to operate the device

REVIEW AND APPROVAL: Each scientist in the chain of responsibility must review and sign. This document must be reviewed on an annual basis.

Principal Investigator:

____

PI Signature:

____

____

Date of last review of assessment: ___________________________

Trained Personnel:

PRINT NAME	SIGNATURE	DATE

Appendix II

Abbreviations

ACM - Association for Computing Machinery

AP - Access Point

COMM - Common, in the context of a relay

I2C - Inter-Integrated Circuit; Communication Protocol

IC - Integrated Circuit

IEEE - Institute of Electrical and Electronics Engineers

MCU - Microcontroller Unit

MQTT - Message Queuing Telemetry Transport

NO - Normally Open, in the context of a relay

RH - Relative Humidity

RPI - Raspberry Pi

SOC - System on Chip

SPDT - Single Pole Double Throw

UART - Universal Asynchronous Receiver-Transmitter

VPD - Vapor Pressure Deficit

MCU - MicroController Unit