PhytoHome Design Document

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1 INTRODUCTION

1.1 PROBLEM AND SOLUTION OVERVIEW

By the year 2100, world population is projected to reach 10.9 billion [1]. Based on current world population statistics, this represents a 42% population increase in the next 80 years. In consideration of these statistics, a serious question to consider is whether traditional farming methods will suffice to provide the necessary produce for human flourishing. Many contemporary agriculturalists are beginning to view traditional farming methods incapable of efficiently producing the future world will require. Instead, they are increasingly looking to the concept of vertical farming which is the idea of using enclosed and controlled environment vertical infrastructure to accommodate layers of food production, thus reducing the amount of horizontal space needed.

To support the production of food in vertical structures it is expedient to integrate technologies that will facilitate and optimize the process. A method becoming popular in vertical farming is aeroponics, which uses a food/water system to feed and hydrate plant roots through injectors that disperse the nutrient-laden water as a spray. Using this method considerably reduces the amount of water needed to grow crops; to grow 1 kg of lettuce in traditional farming it would take 250L of water as opposed to 1L of water in aeroponics. The hopeful expectations of aeroponics in its ability to grow crops indoors has led to its commercialization, particularly for home production.

Many commercial aeroponic home systems do not include enclosed and controlled environments for the plant. This leaves the growth of the plant as a precarious exercise as the temperature and humidity preferences of home users vary and may not be optimal for plant growth. Moreover, as far as we have observed, all current commercial aeroponic systems use white-light LEDS which result in inefficiencies. This is because plants only absorb specific wavelengths from the EM spectrum, particularly from the blue and red channels. The rest is reflected or dissipated as heat energy.

These inefficiencies will be resolved by designing PhytoHome, a plant home that provides plants with an enclosed environment, temperature and humidity control, light from LEDs that emit only the specific wavelengths that are absorbed by plants. With these new features and technologies, an optimal environment for plant growth can be achieved and lighting power input per kg of food will decrease, improving the overall efficiency of home aeroponic systems. In additional, the greater reaching extent of PhytoHome to the larger problem of horizontal farming inefficiencies is that PhytoHome will be a scalable model with technological applications relevant to large-scale vertical farming.

1.2 VISUAL AID

FIGURE 1 puts into context the uniqueness of the PhytoHome solution. It is a combination of aeroponics with an enclosed, protected, controlled environment that uses sensors to increase system efficiency.

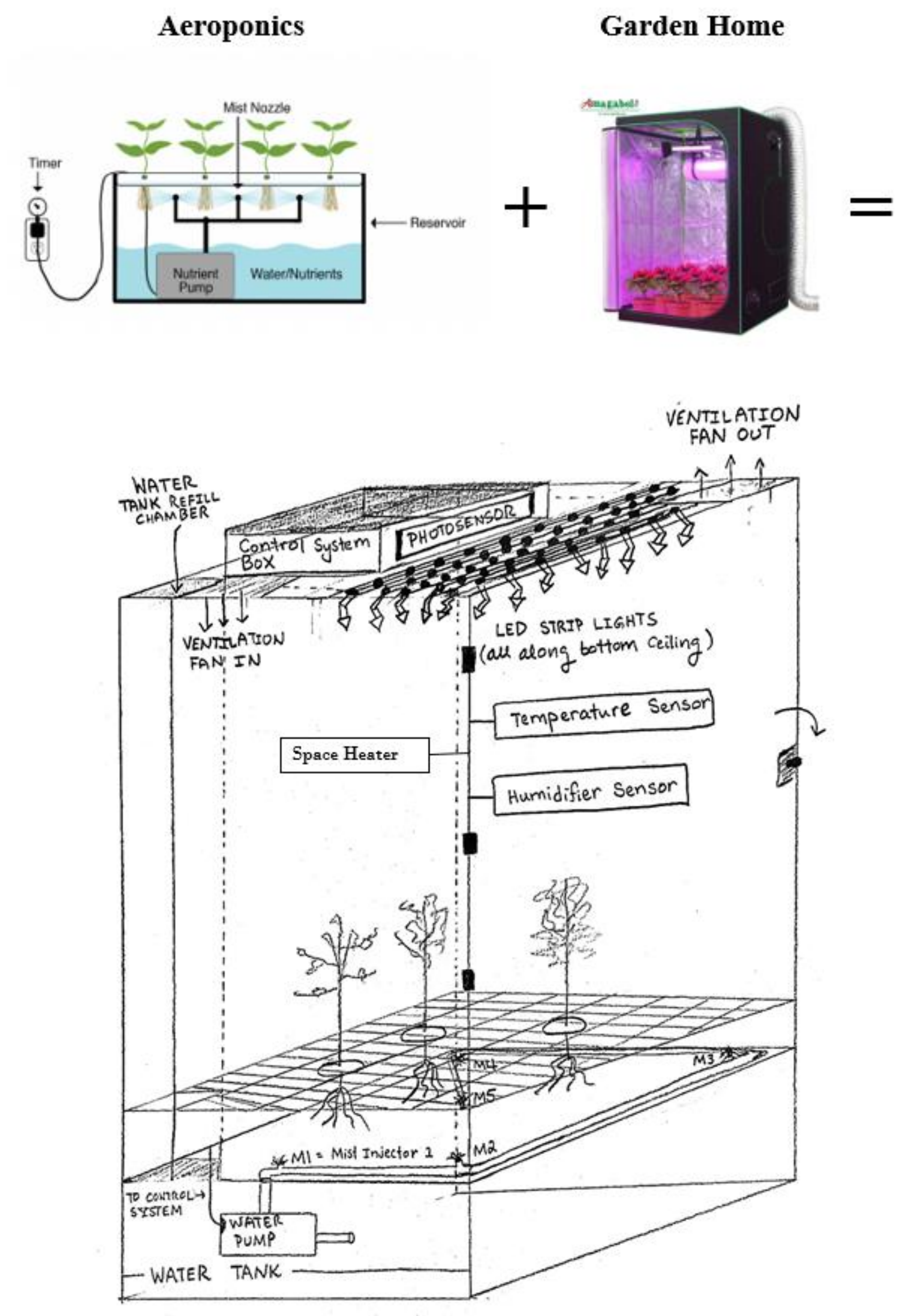

FIGURE 1. VISUAL AID

1.3 HIGH-LEVEL REQUIREMENTS LIST

- PhytoHome RAS (Regulated Aeroponic System) must be able to provide a temperature assisted environment that performs heating through either a small space heater or incandescent light and provide minor cooling through a fan ventilation system and water misting.
- PhytoHome must be able to provide approximately 25-30 Watts per square foot to the plants through the LED lighting, as well as monitor ambient sunlight to determine the amount of necessary operation time.
- PhytoHome must be able to provide intermittent or constant water misting directly to the roots of the plants to provide nutrients and sustain plant life.

2 DESIGN

2.1 BLOCK DIAGRAM

A modular representation of the key entities in the system are represented by the block diagram shown in **FIGURE 2**. The main control unit of the design is the microcontroller, which controls the habitat for the plants based off information it receives from three sensors. The photosensors indicate the brightness of the light in the lighting system, while the temperature and humidity sensors indicate the necessary heating and cooling for best ambience in the HVAC system. The water/feeding system is independent of sensors, and functions based on each plant's unique nutrition schedule. All these subsystems are essential to provide an optimal, controlled environmental conditions in PhytoHome.

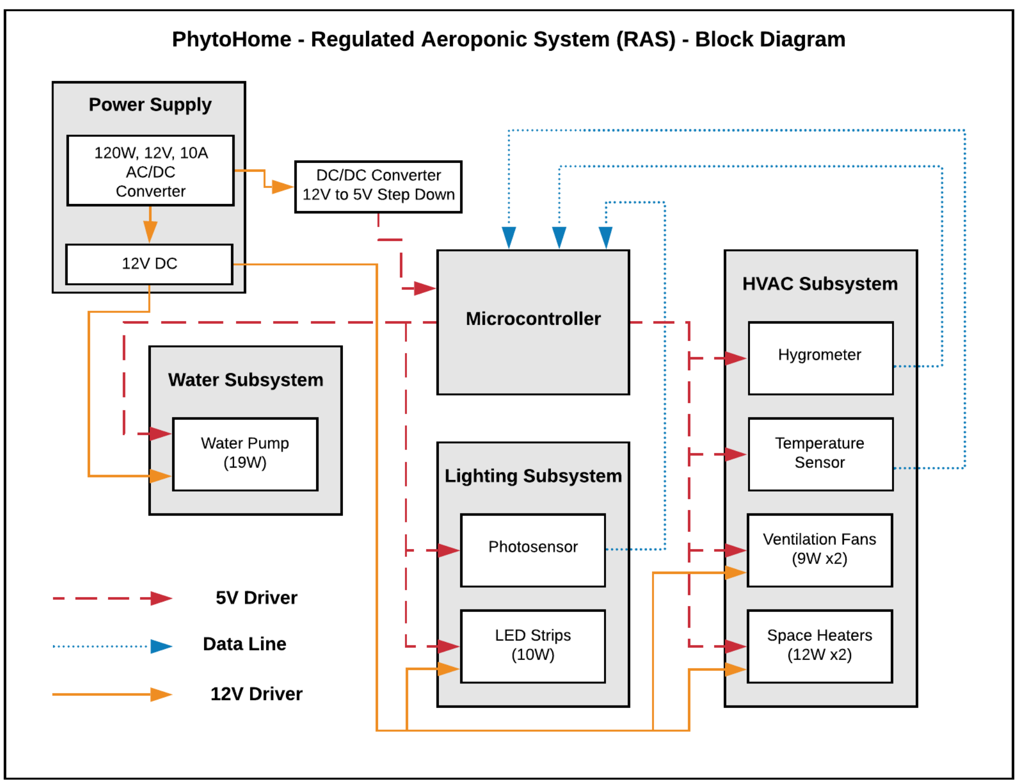

FIGURE 2: BLOCK DIAGRAM

2.2 PHYSICAL DESIGN

FIGURE 3 shows the projected physical design of PhytoHome, along with rough location estimates of were all components will be located. As shown, two circulation fans will be mounted on the top positioned beside the control system and the photosensor. Beneath the ceiling of PhytoHome will be 5 LED light strips. Tentatively, inside PhytoHome mounted on the aluminum side legs and opposite the fans will be the temperature sensor, hygrometer, and space heaters. The water tank, water pump, and mist injectors will be below the mesh netting where the plants will rest. The plant roots will grow below the middle mesh netting panel.

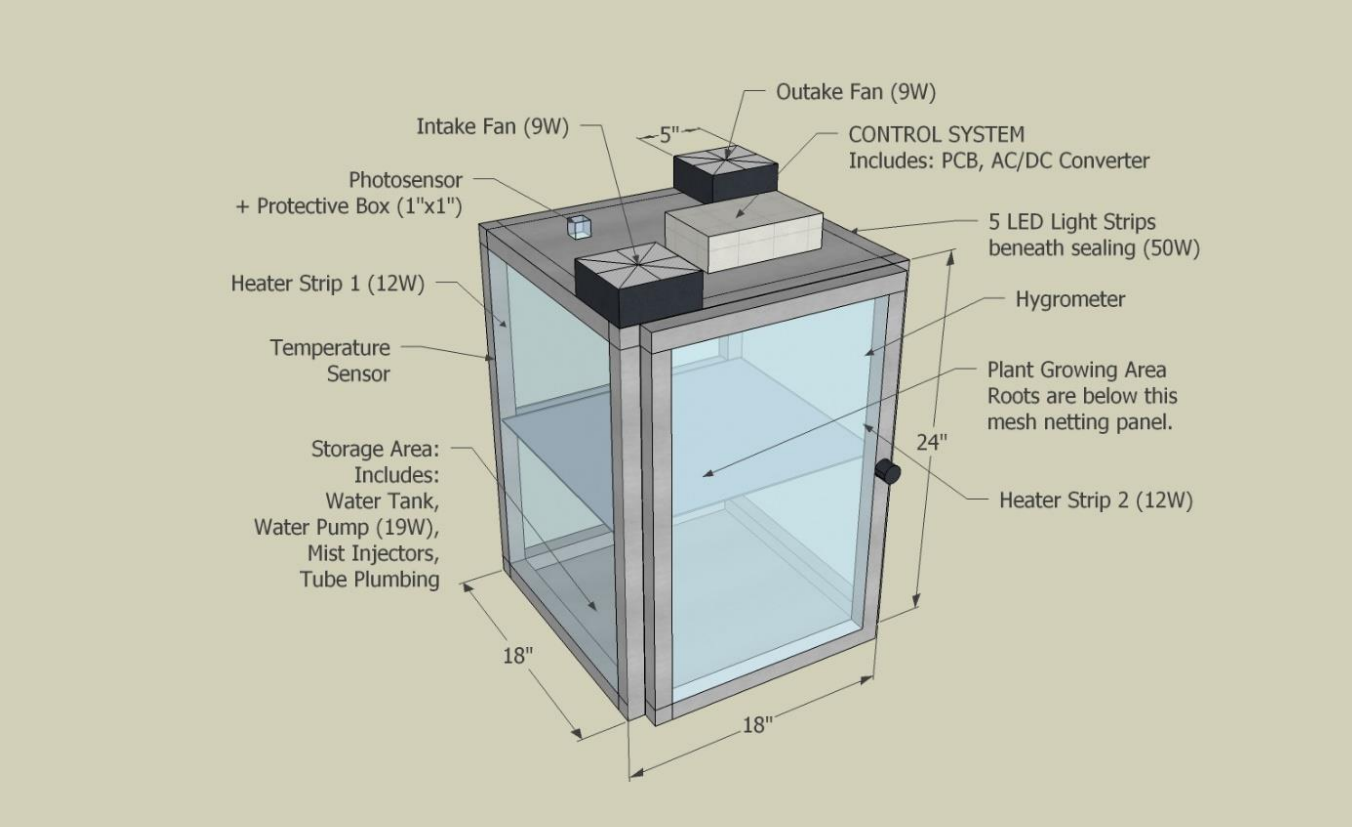

FIGURE 3. PHYSICAL DESIGN

3 FUNCTIONAL OVERVIEW

3.1.1 POWER SUPPLY

The power supply has two primary tasks: the first is to supply the power to maintain constant data transfer from the temperature, humidity, and photosensor sensors to the microcontroller; the second is to provide power whenever necessary to operate the intermittent, larger loads of each subsystem, namely the ventilation fans and space heater/s for the HVAC system, the LEDs for the lighting system, and water pump/s for the water/feeding system. For the water/feeding system, power will be supplied to a motor water pump/s to pressurize the water tubes that connect with the injectors.

3.1.2 MICROCONTROLLER

The microcontroller, ATMega328P, is the brains and will receive data from the sensors and compute this data to determine how to manage all the other subsystems. All sensors belonging to the Lighting and HVAC subsystems will b e connected as inputs to the microcontroller while its outputs will be used to power and control the remaining entities, namely the water system pump, lighting system LEDs, and HVAC space heater, humidifier, and ventilation fans.

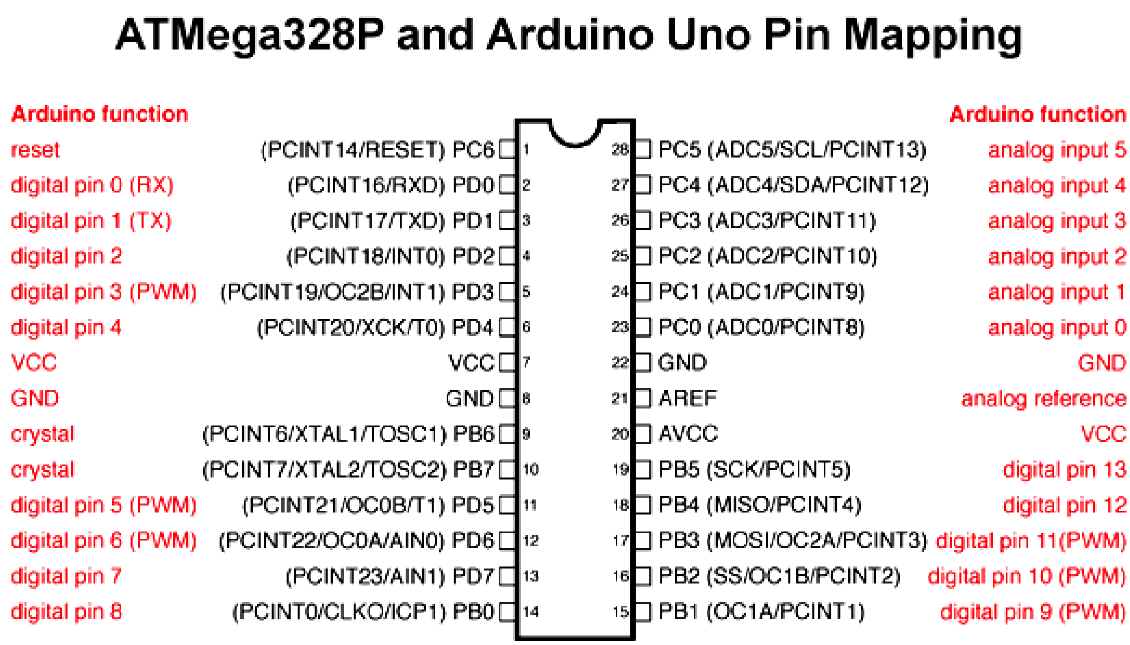

FIGURE 4. ATMEGA328P PIN LAYOUT [5]

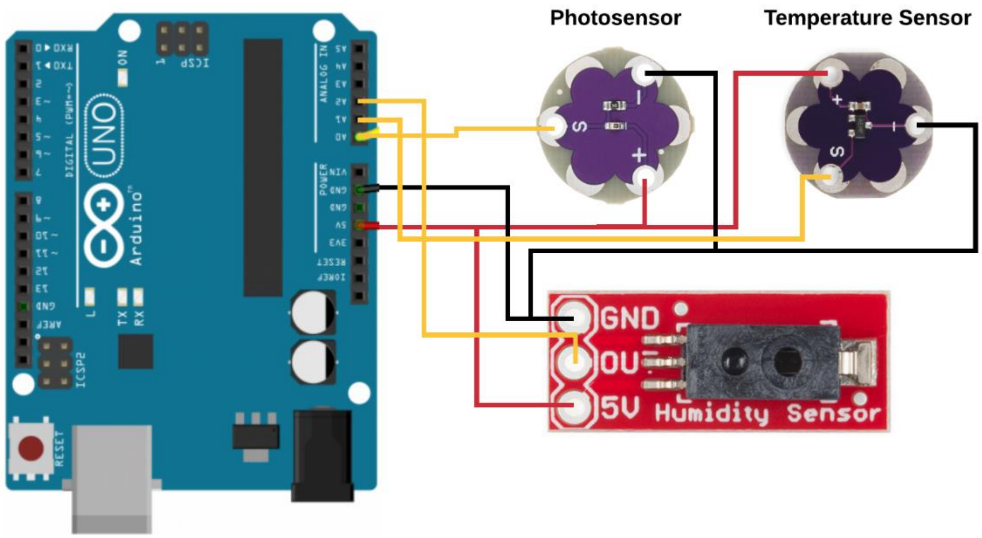

FIGURE 5. SENSOR/COMMUNICATION PHYSICAL LAYOUT

3.1.3 WATER SUBSYSTEM

The water subsystem consists of the water tank, pump/s, and injectors positioned on the bottom of the PhytoHome system. It delivers nutrient-laden water to the roots of the plants in the feeding chamber by pressurizing service tubes with a water pump. This ensures that the amount of water and nutrients necessary for optimal plant growth is controlled efficiently. It is beneficial that this subsystem be physically attached to the overall design because it allows for ease of water transfer via the injectors, which distribute the water resourcefully.

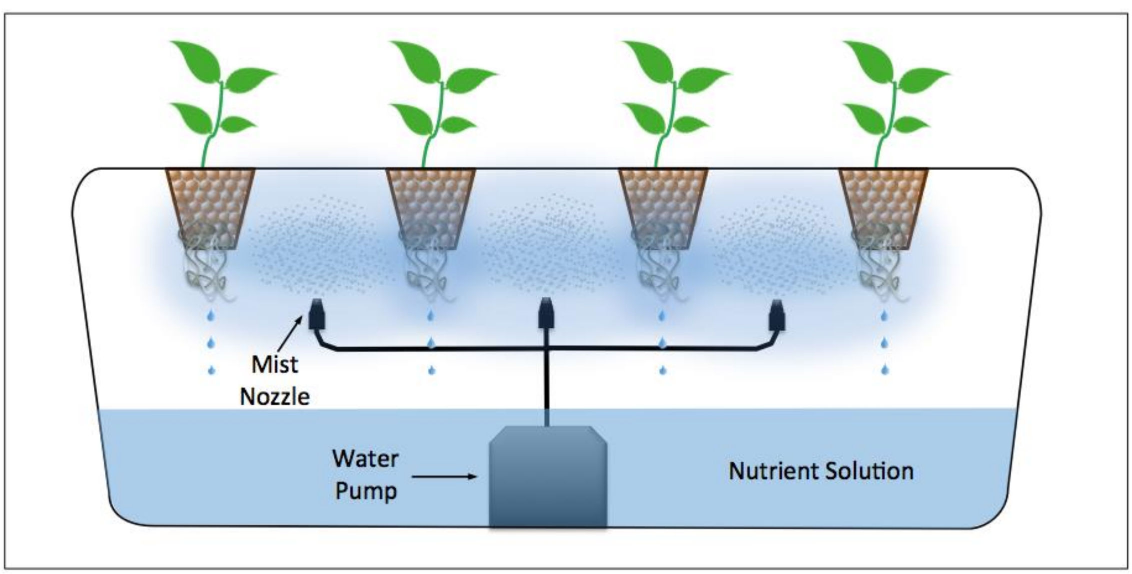

FIGURE 6. WATER PUMP & MISTING SYSTEM

3.1.4 HVAC Subsystem

The HVAC subsystem is responsible for monitoring and controlling the temperature and humidity of the plant’s environment. This is achieved through sensors, ventilation fans, and a space heater. It is crucial that all these sensors and devices must function accordingly so that they may send the correct signals to the microcontroller to properly adjust any environmental factors. In order to do this, it is imperative to understand how each sensor and mechanism operates, and what parameters are needed for desired performance.

One main sensor in the HVAC subsystem is the hygrometer. This is a sensor that is used to continuously record humidity data of the environment and provide it to the microcontroller to maintain optimal humidity levels for plant growth. It is known that most vegetative plants thrive between 50% - 70% humidity levels, while most flowering plants thrive between 50% - 60% [6]. To monitor that the humidity levels in the PhytoHome remain within this threshold, Honeywell’s HIH-4030 humidity sensor breakout board is used.

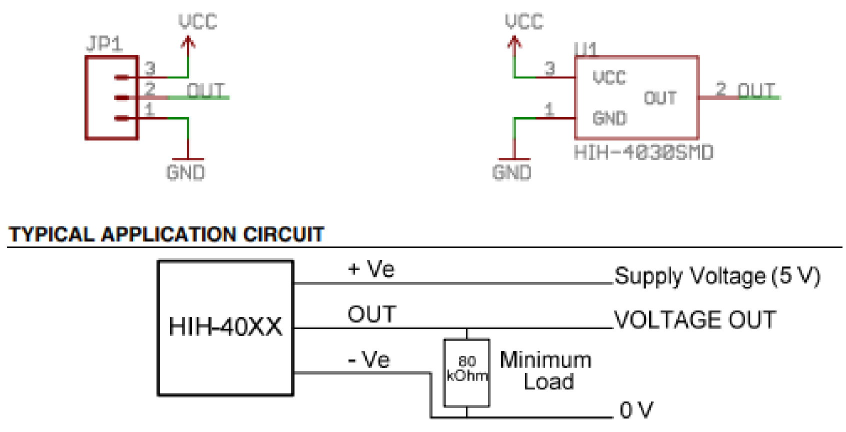

Figure 7. HIH-4030 Schematic

According to the datasheet, this sensor measures *relative humidity (%RH)* and delivers it as an output voltage signal through an ADC on a microcontroller [7]. The technical specifications will be further outlined in **TABLE 1**, but one thing to note is that this sensor *must* work in conjunction with a temperature sensor. The reason for this being is that in order to get the *true relative humidity*, not just the *relative humidity*, the following formulas are used:

$$V_{out} = \left(V_{supply}\right)(0.0062(sensorRH) + 0.16)\ ; typical\ at\ approx.\ 25℃ \qquad (3.1.4.1)$$

$$sensorRH = \frac{\frac{V_{out}}{V_{supply}} - 0.16}{0.0062} \qquad (3.1.4.2)$$

$$trueRH = \frac{sensorRH}{1.0546 - 0.00216T}\ ; T\ in\ ℃ \qquad (3.1.4.3)$$

To verify that the value obtained for the *true relative humidity* is indeed correct, the supplemental graphs given in the datasheet can be used [7], and the formulas outlined in (3.4.1.1-3) are used to affirm the *true relative humidity*. **FIGURE 9** shows the relationship between the operating ambient temperature and the *(true) relative humidity* present. **FIGURE 10** shows the expected *(true) relative humidity* based on the output voltage.

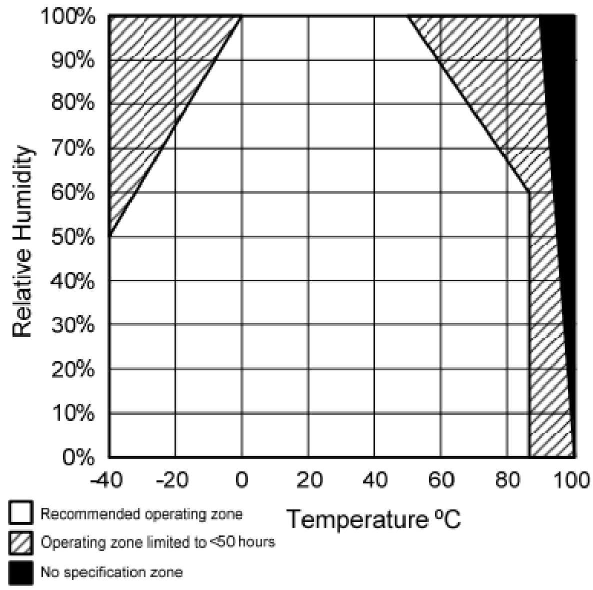

FIGURE 8. OPERATING ENVIRONMENT TEMPERATURE VS. HUMIDITY

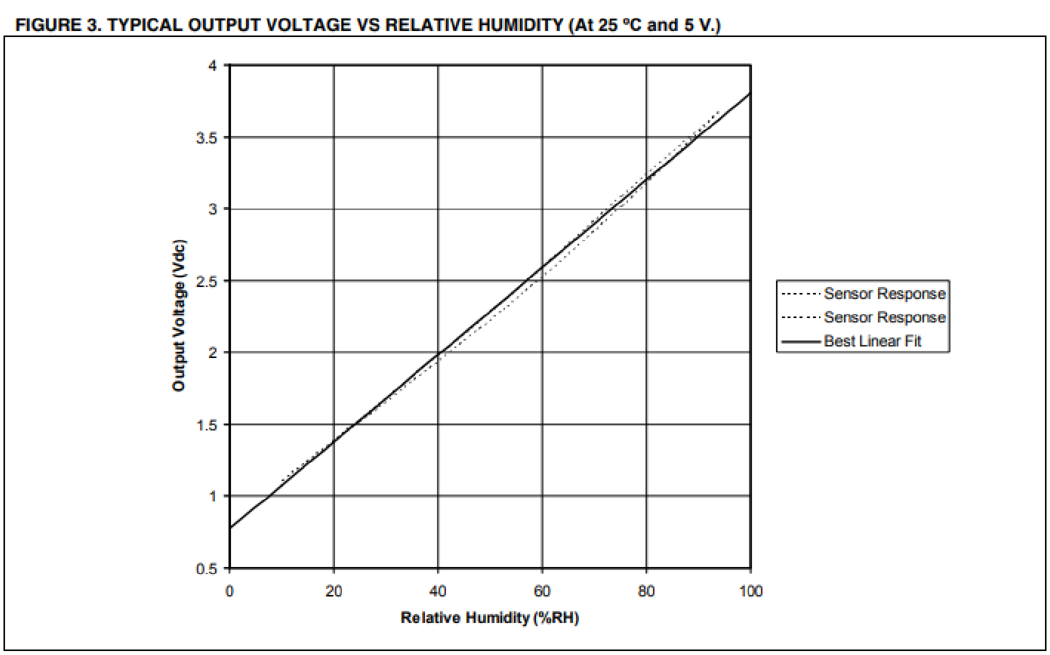

FIGURE 9. OPERATING ENVIRONMENT

The temperature sensor is the second sensor used in the HVAC system that not only assists with determining the *(true) relative humidity*, but also ensures that the plants are growing in an environment where the temperature maximizes their growth. Research suggests that cool season crops, such has many herbs and salad greens, thrive in temperatures between $16℃ - 22℃$, whereas warm season crops, such as tomatoes and cucumbers, thrive in temperatures between $18℃ - 28℃$ [6].

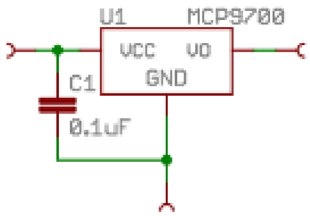

FIGURE 10. TEMPERATURE SENSOR SCHEMATIC

Therefore, the LilyPad Temperature Sensor MCP9700 is to be utilized. Using an ADC signal line on the microcontroller, this sensor will output $10mV/℃$, with 0.5 V at $0℃$. The following formulas will be used to take the analog data from the sensor and use it to interpret and gauge the ambient temperature:

$$V_{out} = rawTemp * \left(\frac{3.3}{1023.0}\right) \qquad (3.1.4.4)$$

$$℃ = (V_{out} - 0.5) * 100 \qquad (3.1.4.5)$$

$$℉ = \left(℃ * \frac{9}{5}\right) + 32 \qquad (3.1.4.6)$$

The value that is denoted as *rawTemp* is actually the current that is flowing through the signal tab. This is read by the analog input on the microcontroller, and therefore needs to be converted to obtain to correct Celsius or Fahrenheit readings, hence the given formulas. Using chart for the output voltage versus the ambient temperature given in **FIGURE 12**, it can be seen both that both have a linearly proportionally relationship. This information can be used to debug the sensor, should problems arise.

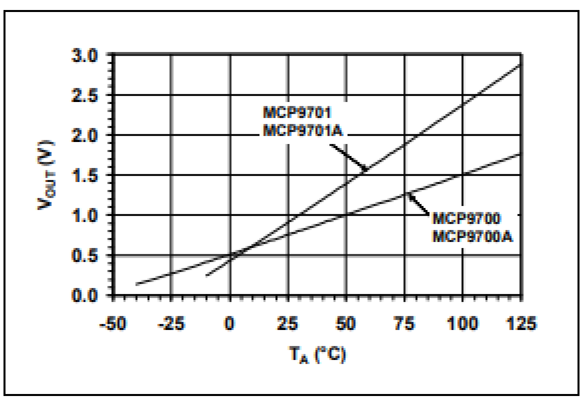

FIGURE 11. TEMPERATURE SENSOR SCHEMATIC

The ventilation fans and space heaters are also entities of the HVAC system, and they are crucial to bringing the humidity and temperature to desired levels once they fall out of range. For example, if the aeroponics chamber is too cold, the space heater will turn on to achieve optimal plant growth temperatures. If the humidity levels are too high, then the ventilation fans will turn on to reduce the water moisture in the air. Both therefore are incumbent to monitor and maintain accurate environmental conditions for maximal plant growth.

3.1.5 LIGHTING SUBSYSTEM

The lighting subsystem is purposed to provide the necessary radiation for the plants to undergo photosynthesis. Tentatively, the LEDs will be used to deliver only the proper blue and red wavelengths that are best absorbed by plants. Unnecessary wavelengths would thus be omitted. To determine how much LED light is needed from the system, photosensors will be used to detect natural light entering the PhytoHome.

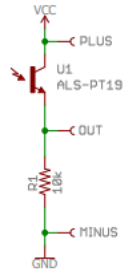

FIGURE 12. LIGHT SENSOR SCHEMATIC

This light sensor can detect up to 10,000 lux, which is the minimum recommended lux necessary for photosynthesis to occur. Based off the feedback from these sensors, the LEDs will adjust accordingly to just how bright they need to be. Ideally, the LEDs will turn off and on to match the cycle of an ordinary day.

Illuminance	Example
0.002 lux	Moonless clear night sky
0.2 lux	Design minimum for emergency lighting (AS2293).
0.27 - 1 lux	Full moon on a clear night
3.4 lux	Dark limit of civil twilight under a clear sky
50 lux	Family living room
80 lux	Hallway/toilet
100 lux	Very dark overcast day
300 - 500 lux	Sunrise or sunset on a clear day. Well-lit office area.
1,000 lux	Overcast day; typical TV studio lighting
10,000 - 25,000 lux	Full daylight (not direct sun)
32,000 - 130,000 lux	Direct sunlight

FIGURE 13. RELATIVE ILLUMINANCE CHART

FIGURE 14 indicates the relative illuminances associated with different variations of light. It can be seen that direct sunlight yields between 32,000 – 130,000 lux. However, plants on earth usually don't get direct sunlight, as they are not in close proximity from the sun. Due to this, it can be reasoned that full daylight, which is between 10,000 and 25,000 lux, is necessary for proper photosynthesis in plants. This range would not only suffice in maintaining plant growth, but also will aid in promoting it as well.

To measure and make sure that enough lux is delivered to the plants, the LilyPad Light Sensor will be used to monitor lux levels. It will output voltages between 0 V and 3.3 V depending on the amount of ambient light shining on it. The following charts aid in assessing whether or not the output voltages are in accordance to this sensor's luminescence calibrations.

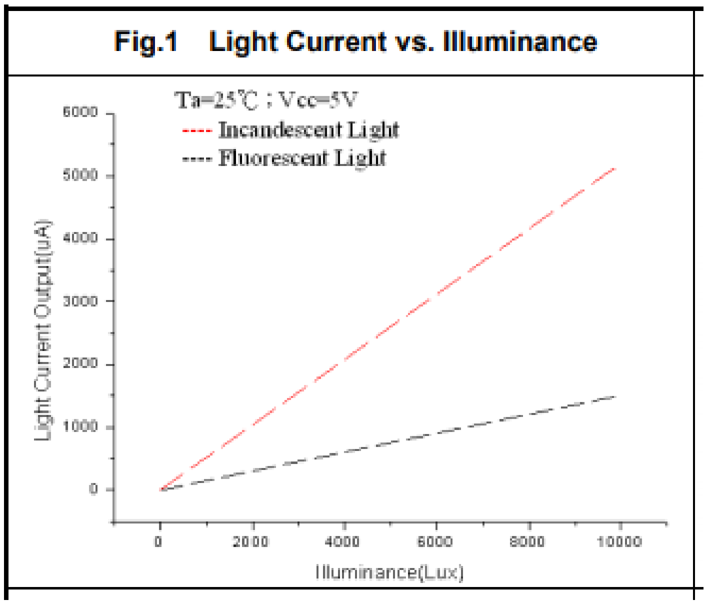

FIGURE 14. LIGHT SENSOR'S CURRENT VS. ILLUMINANCE

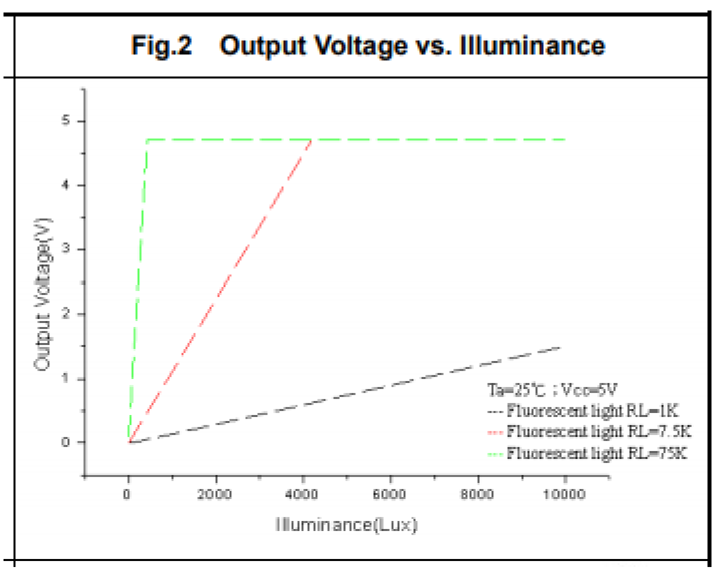

FIGURE 15. LIGHT SENSOR'S OUTPUT VOLTAGE VS ILLUMINANCE

3.2 REQUIREMENTS & VERIFICATION TABLE

TABLE 1: REQUIREMENTS AND VERIFICATION TABLE

Requirements	Verification	Verification Status (Y/N)
Power System		
1. Outputs 12V ± 5%, 6.92A ± 5% supplied to entire PhytoHome Subsystems (79 W): 42 W for HVAC system, 15 W for lighting system, 19 W for water pump, 4 W for all sensors, 3 W for microcontroller.	1. For a start, the AC/DC converter rated voltage and current are 12V and 10A, respectively. This means that we are within the limits of the AC/DC converter expected performance. The surest way to quantitatively ensure that the converter is supplying the necessary power is to measure the voltage and current across its lines. This will also be verified by evaluating the performance of the individual subsystems as described in the other requirements.	
2. Outputs 5V ± 5%, 1A ± 5% to the microcontroller for the photosensor, temperature sensor, and humidity sensor.	2. Connect the DC to DC converter's Vin to 12V coming from AC to DC adapter. Also connect to GND Connect the DC to DC's Vout to the 5V power line on the microcontroller PIN 7 (PD7) (optional: connect a 10 microF capacitor between Vout of the DC to DC converter and GND & between Vin of the DC to DC converter and GND)	

3. In case of a short or unusually large surgency of voltage being drawn through the AC to DC adapter from the wall outlet, the device will automatically shut down and halt all power/voltage signals to rest of the system	Use a voltmeter to ensure that 5 V are in fact being maintained to the microcontroller PIN 7 (PD7) 3. The AC to DC converter has a built-in fuse that detects for any abnormally high levels of voltage	
<u>Microcontroller</u> 1. The microcontroller serves 5V ± 5%, 1A ± 5% to photo/temperature/humidity sensors and also biases BJT-based driver circuits to serve as switching circuits.	1. Connect microcontroller PIN 20 (AVCC) to the 5V power lines for the photo/temperature/humidity Sensors. Use a voltmeter to ensure that 5 V are in fact being sourced from the microcontroller PIN 20 (AVCC) If voltage being delivered from PIN 20 (AVCC) is above the maximum voltage rating, insert a resistor to step voltage down to desired value Connect microcontroller PIN 22 (GND) to ground, and connect the grounds of photo/temperature/humidity sensors to this pin too Use a voltmeter to ensure that 0 V is in fact the voltage reading at	

2. The microcontroller collects data from the photosensor, the temperature sensor, and the humidity sensor as an analog read, and then biases the BJT-based driver circuits accordingly.	microcontroller PIN 22 (GND) 2. Connect microcontroller PIN 23 (PC0/ADC0) to the output signal "S" line of the photosensor (light sensor) Connect microcontroller PIN 24 (PC1/ADC1) to the output signal "S" line of the temperature sensor Connect microcontroller PIN 25 (PC2/ADC2) to the output signal "OUT" line of the humidity sensor Connect microcontroller PIN 4 (PD2) to the BJT of water pump, with a 1k ohm series resistor Connect microcontroller PIN 6 (PD4) to the BJT of the space heater, with a 1k ohm series resistor Connect microcontroller PIN 11 (PD5) to the BJT of the LED strips, with a 1k ohm series resistor Connect microcontroller PIN 13 (PD7) to the BJT of the ventilation fan, with a 1k ohm series resistor	
<u>Water Subsystem</u> 1. When decided upon by the core algorithm of the control unit, the switch	1. Make sure that the microcontroller PIN 4 (PD2) is to be connected to	

circuit of the water pump should be biased and switched on to supply 12V to the water pump, ensuring that the proper PSI is provided to the water service tubes to obtain a mist injection to the root feed chamber.	the base of a BJT, with a base resistance of 1k ohm Double check that the collector of this BJT will be connected to the negative terminal of the water pumps. Qualitatively this can be checked by visually observing the spraying of the injectors for uniformity in the spraying cone pattern Measure the collector current and ensure that it's in saturation with the provide voltage of the microcontroller at the base of the BJT.	
<u>HVAC Subsystem</u> 1. Humidity sensor needs a minimum input voltage of 4.0 V DC and a maximum input voltage of 5.8 V DC, with the recommended operating voltage as 5.0 V 2. Humidity sensor readings must remain between 50% - 70% for optimal vegetative plant growth, and between 50% - 60% for optimal flowering plant growth	1. Use a voltmeter to check that the voltage being maintained in the + terminal of the humidity sensor from PIN 20 (AVCC) of microcontroller is approximately 5V DC. Visually ensure that this voltage reading is not below 4.0 V DC, nor above 5.8 V DC 2. During testing, use **FIGURE 10** to ensure that the output voltage readings displayed on a serial monitor (when first uploading Arduino code) are in accordance with the	

	relative humidity readings in the figure If growing vegetative plants, the output voltage readings should yield values between 2.2 V and 2.9 V for a 50% - 70% *relative humidity* If growing flowering plants, the output voltage readings should yield values between 2.2 V and 2.6 V for a 50% - 60% *relative humidity* If humidity does not fall in these ranges and is too <u>*high*</u> for either vegetative or flowering plants, send signal from microcontroller PIN 13 (PD7) to turn on ventilation fans by allowing current (5 mA) to flow through this BJT. The current should continue flowing (i.e. ventilation fans should remain ON) until humidity sensor detects humidity has decreased down to the desired range If humidity does not fall in these ranges and is too <u>*low*</u> for either vegetative or flowering plants, send signal from microcontroller PIN 4 (PD2) to turn on misters by allowing current (5 mA) to flow through this BJT. The current should	

3. The temperature sensor needs a minimum input voltage of 2.3 V DC and a maximum input voltage of 5.5 V DC, with the recommended operating voltage as 5.0 V 4. The temperature needed to grow the herbs is required to be within 16℃ to 22℃ degrees Fahrenheit. The efficiency of this depends on proper insulation. Based on further research, this temperature range may change. Furthermore, the space heater should be able to raise the temperature within at least ten minutes.	continue flowing (i.e. water should continuously be sprayed to roots) until humidity sensor detects humidity has increased up to the desired range 3. Use a voltmeter to check that the voltage maintained in the + terminal of the temperature sensor from PIN 20 (AVCC) of microcontroller is approximately 5V DC. Visually ensure that this voltage reading is not below 2.3 V DC, nor above 5.5 V DC 4. During testing, use **FIGURE 11 MCP9700** data line to ensure that the output voltage readings displayed on a serial monitor (when first uploading Arduino code) are in accordance with the *ambient temperature* readings in the figure If growing cool season plants, the output voltage readings should yield values between 0.6 V and 0.7 V for 16℃ to 22℃ *ambient temperature* If growing warm season plants, the output voltage readings should yield values between 0.7 V and 0.8 V for 18℃ to 28℃ *ambient temperature*	

	If temperature does not fall in these ranges and is too <u>*low*</u> for either cool or warm season plants, send signal from microcontroller PIN 6 (PD4) to turn on space heaters by allowing current (5 mA) to flow through this BJT. The current should continue flowing (i.e. space heater should remain ON) until sensor detects temperature has increased up to the desired range If temperature does not fall in these ranges and is too <u>*high*</u> for either cool or warm season plants, send signal from microcontroller PIN 13 (PD7) to turn on ventilation fans by allowing current (5 mA) to flow through this BJT. The current should continue flowing (i.e. ventilation fans should remain ON) until sensor detects temperature has decreased down to the desired range	
<u>Lighting Subsystem</u> 1. Light sensor (photosensor) needs a minimum input voltage of 0.5 V DC and a maximum input voltage of 6.0 V DC, with the recommended operating voltage as 5.0 V	1. Use a voltmeter to check that the voltage maintained to the + terminal of the light sensor from PIN 20 (AVCC) of microcontroller is approximately 5V DC. Visually ensure that this voltage reading is not	

2. Based on the photosensor lux detection of up to 10k lux, the LEDs will vary their output lux to work in conjunction with ambient light to ensure the plants are always receiving at least 25-30W/square foot.	below 0.5 V DC, nor above 6.0 V DC 2. During testing, use **FIGURE 15** to ensure that the output voltage readings displayed on a serial monitor (when first uploading Arduino code) are in accordance with the *luminescence* readings in the figure, approximately 1.5 V If the photosensor detects that lux levels fall below 10,000 lux, send signal from microcontroller PIN 11 (PD5) to turn on LEDs to supply the deficit of the light to maintain lux levels at at least10,000 lux	

3.3 PHYTOHOME CIRCUIT SCHEMATIC

The PhytoHome PCB will consist mainly of the microcontroller, resistors, diodes, transistors, and the DC-DC converter. The LEDs, Water Pump, Fans, and sensors will all be separate from the PCB. The sensors are not mounted on the PCB due to optimal design location requirements.

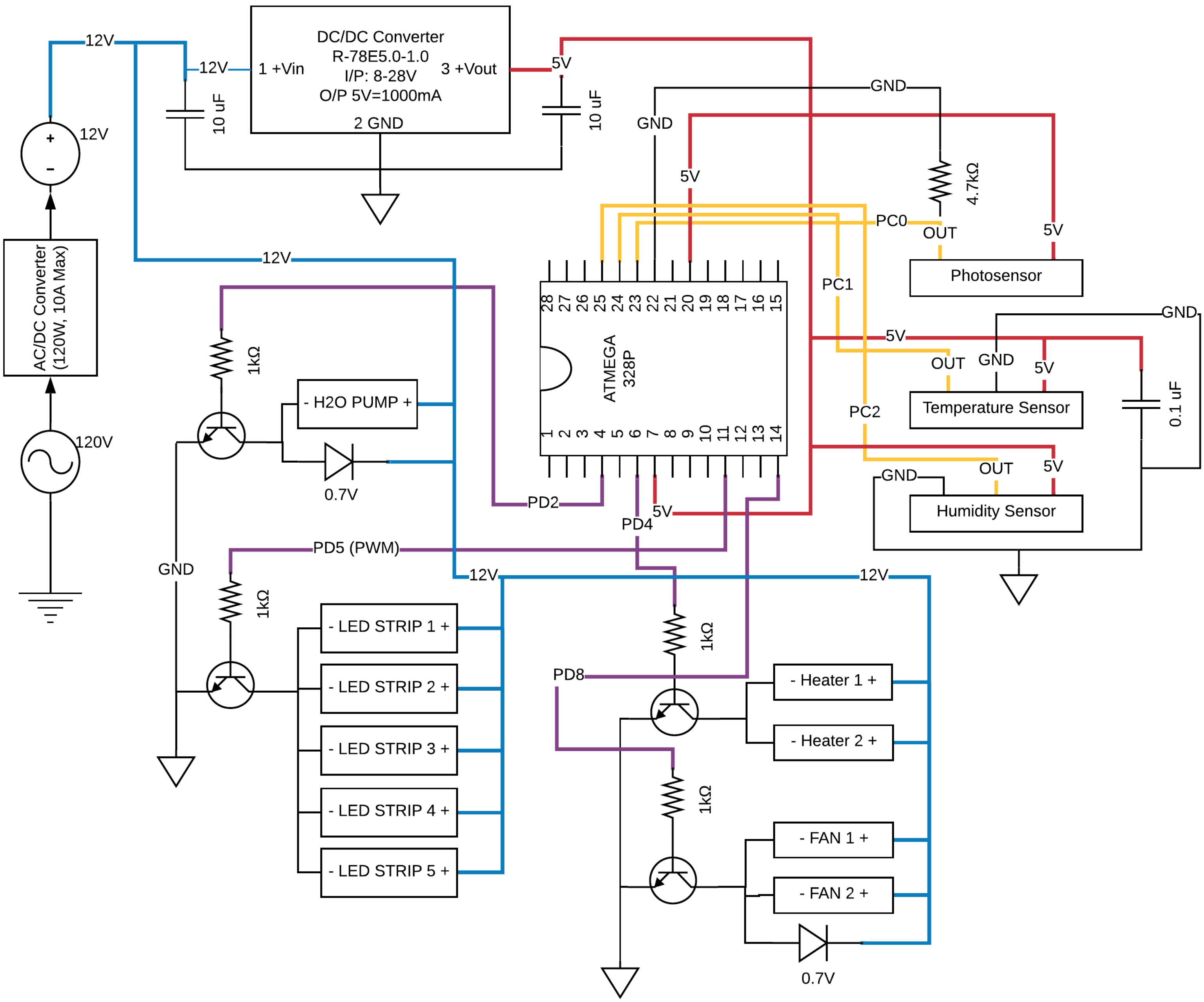

FIGURE 10: PHYTOHOME CIRCUIT SCHEMATIC

3.4 PhytoHome Microcontroller Software Flow Chart

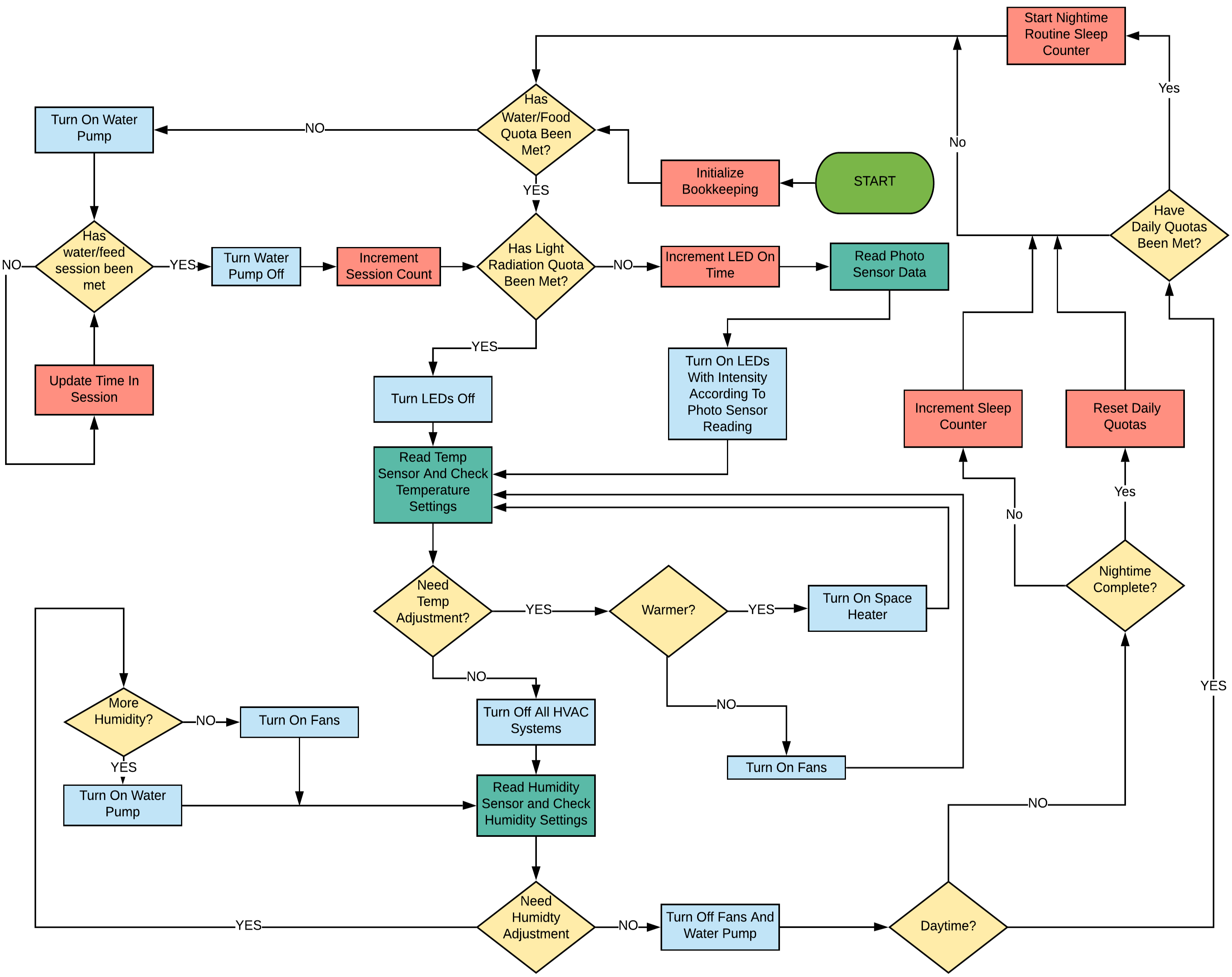

Figure 7: PhytoHome Microcontroller Software Flow Chart

3.5 TOLERANCE ANALYSIS

From the subsystems that are necessary to maintain the habitat necessary for plant growth, the most precarious is the HVAC system in the sense that its operation depends on the variability of PhytoHome's environment, which is dependent on user preference (i.e. how cool or warm a person likes their house and how often they change the temperature). The main concern is whether the heating system will be able to raise the PhytoHome's ambient temperature, because temperatures above the ideal 75 degrees for plant growth are far less detrimental to the plant's health than those below it. Presumably, this has been observed by many people when eighty or ninety degree weather does not have the same negative effect that a cold front of 40 or 50 degrees has. In the presence of abundant water, plants can withstand higher temperatures as it prevents dehydration and withering. However, no amount of water or reasonable amount of light can prevent the damage that is caused by cold temperature relative to the plant ideal.

To gain insight on what sort of environmental conditions PhytoHome will have to operate in, it can be expedient to break down the problem into cases. Starting with the simpler one brings us to a home that is consistently year-round at room temperature. In this environment, the responsibility of the HVAC system is at a minimum. The heating system would have to raise the temperature in the ballpark of 7 degrees. For this the heating system would have to provide approximately 3mW of heat energy to the environment as calculated using the standard constant-volume calorimetry equation (an example of the calculations and equations will be given for the last case). This can be provided by the space heaters being used.

The second case is a home without central cooling during the summer but heating during the winter. In the winter the home will most likely be around room temperature or warmer. This requires minimal work from the space heater. To handle temperatures above the ideal to about ten degrees, more water will simply be provided. The summer will be result in a similar situation. In the event of extreme heat (i.e. anything above 85 degrees) the fans will be turned on to provide ventilation that can reduce humidity, since high humidity will slow down the water cycle through the plant, causing withering.

The last case is when a home has a central cooling system. This case provides the most concern since it is a common trend for users to set the home temperature to a range of temperatures from 60 to 68 degrees. In the worst-case scenario, a change of fifteen degrees would have to be provided. To calculate the heat energy necessary, we use constant-volume calorimetry methods as promised. The equation used is Equation 1, and it is provided below:

$$Q = \rho * V * c * T \qquad \text{(Eqn. 1)}$$

In this equation, **Q** represents the heat energy required to enter the system to obtain a change in temperature **T** in kelvins. The air density **ρ** and volume of the space **V** are used to calculate the mass of the air in PhytoHome. Finally, the specific heat **c** tells how much heat energy is required to change a unit of mass for a specific substance by one-degree kelvin. According to the worst-case scenario specified, namely having to raise the temperature of PhytoHome from 60 degrees to around 75 degrees, the change in Fahrenheit temperature must be converted to a change in kelvin using Equation 2 shown below:

$$\Delta T = (5/9) * \Delta F \qquad \text{(Eqn. 2)}$$

Here **ΔF** is the change in temperature in Fahrenheit and **ΔT** in Kelvin. For a change in 15 degrees Fahrenheit we then have a change of 8.33 degrees Kelvin. Therefore, **T** in equation 1 will have a value of 8.33. The air density is 1.225 kg/m^3, the volume .04 m^3, and the specific heat for air in the range of temperatures to be operated in is .718. Evaluating Equation 1 with these values gives:

$$\mathbf{Q = 1.225\ (kg/m^3)*(.04m^3)*(.718)*(8.33) = .293\ J.}$$

If we want to provide this heat energy over the course of a minute, then dividing both sides by 60 seconds, and letting **P** be the results yields:

$$\mathbf{P = .00488\ J/S = 4.88mW.}$$

In other words, the space heater has to provide 4.88 mJ per second. The space heaters being used can provide up to 12 W of heat energy. Therefore, PhytoHome is well equipped to handle cold temperatures, provided with proper insulation. This last remark is actually vital to ensure efficiency as well as functionality.

4 COST AND SCHEDULE

4.1 COST ANALYSIS

Below is the cost projection for the implementation of PhytoHome. Table 1 represents the material costs for one PhytoHome unit. Note that Table 1 does not include design or R&D costs. It is only a raw material estimate. The additional design labor and R&D costs are estimated as follows.

If all three team members works 10 hours per week for the next eight weeks, and our time is worth $35/hour the total cost of labor design is

$$\text{Total Labor Cost} = 3 * \frac{\$35}{hr} * \frac{10hr}{week} * 16\ week = \$16{,}800$$

Finally, additional R&D costs are estimated to be 1x the PhytoHome Cost Per Unit due to testing various parts to see which ones perform best and due to potential mishaps during the design process.

Thus, the total cost of PhytoHome is estimated to be as follows:

$$\textbf{PhytoHome Total Cost} = \mathbf{2} * \frac{\mathbf{\$318.07}}{\boldsymbol{unit}} + \mathbf{\$16{,}800} = \mathbf{\$17{,}436.14}$$

TABLE 1: PHYTOHOME COST PER UNIT (ESTIMATE)

PART	COST
ATMega328P	$4.30
LilyPad Light Sensor	$3.50
LilyPad Temperature Sensor	$4.50
SparkFun Humidity Sensor Breakout	$18.95
Polycarbonate Plastic Sheet	$8.99 (x2)
Plant Mesh Netting	$2.00 (estimate)
Water Tank	$7.00
Submersible Water Pump	$22.99
Misting Service System	$19.99

LED Grow Lights	$8.95 (x5)
Ventilation Fans	$17.95 (x2)
Polymide Heater Plates	$3.25 (x2)
AC to DC Converter	$21.99
Protective Fan Covers	$3.50 (x2)
Acrylic Plexiglass Sheets	$9.25 (x4)
Plexiglass Laser Cut Sheets	$0.31 (x6) (estimate)
Plastic Waterproof Junction Box	$10.99
NPN Transistors	$0.95 (x4)
DC/DC Converter	$4.95
Water Pump to Service Tube Brass Adapters	$7.12 (estimate)
Miscellaneous (Resistors, Diode, Capacitors, Sealant/Mounting Tape, Jumper Wires, etc.)	$15.00 (estimate)
Machine Shop Aluminum Enclosing/Support Beams, Support Brackets, etc.	$10.00 (estimate)
PCB Creation	$10.00 (estimate)
TOTAL COST (Estimate)	**$318.07**

4.2 SCHEDULE

TABLE 2: DESIGN IMPLEMENTATION SCHEDULE

Week	Goal	Pablo Catalan	Joseph Rapp	Umme Kulsoom
10/07 - 10/13	Implement Lighting, HVAC, and Water Subsystems	Write microcontroller code based on software flow chart in figure 7 and build and build full breadboard circuit based on figure 6	Write microcontroller code based on software flow chart in figure 7 and build and build full breadboard circuit based on figure 6	Write microcontroller code based on software flow chart in figure 7 and build and build full breadboard test circuit based on figure 6
10/14 - 10/20				
10/21 - 10/27	Test Design, PCB Design, Complete Machine Shop Deliverables	Test code and circuit and design PCB	Test code and circuit and work on physical design drawing for Machine Shop	Test code and circuit and design PCB

10/28 - 11/03	Machine Shop Meeting + Drawing Deliverables Deadline + Test Design	Test code and circuit and design PCB	Test code and circuit and design PCB	Test code and circuit and design PCB
11/04 - 11/10	Test Design and Prepare for Incorporating Design into Physical PhytoHome	Test and Prep for Incorporating Design	Test and Prep for Incorporating Design	Test and Prep for Incorporating Design
11/11 - 11/17	Incorporate Physical Design into PhytoHome and Test	Incorporate Design and Test – Prepare for Demo	Incorporate Design and Test – Prepare for Demo	Incorporate Design and Test – Prepare for Demo
11/18 - 12/01	**11/18 - 12/01**	Write Final Report	Write Final Report	Write Final Report

5 DISCUSSION OF ETHICS AND SAFETY

In IEEE Code of Ethics statement #7 mentions undertaking "technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations" [2]. A legitimate safety issue is that the task of creating PhytoHome is being undertaken by engineering students with limited professional experience. Thus, here it is ethically necessary to fully disclose our pertinent limitations, namely lack of experience that increases the risk of accident and warrants additional measures of technical review and criticism.

There are two safety issues relevant to our project. The first is that of potentially misdesigning our circuit to cause electrical failure in such a way that increases the risk of electrical shock, burns, and fire hazard. The second is the danger of having electronics operating in and/or near water sources. While considering these two safety issues that may arise during the development of our project, it is important to consider the ethical obligation to avoid harm that is set forth in section 1.2 of the ACM Code of Ethics and Professional Conduct, part of which says, "Well-intended actions, including those that accomplish assigned duties, may lead to harm" [3]. Thus, even though our team has set forth to embark on a process of well-intended actions in order to solve a problem we consider serious to the bettering of our world, these actions may unintentionally lead to harm, and we are, as the ACM code goes on, "obliged to undo or mitigate the harm as much as possible" [3].

Intentional or accidental misuse of our product is foreseen if the mechanical design is altered in such a way the safety precautions which involve separation of circuitry from water and tampering with the location of the heat source to place it in an area of PhytoHome that increases user risk of burns. Additional misuse that our current design would not have control over could come from use of PhytoHome for a process that facilitates the growth of plants used in the production of illegal drugs.

We will thus seek to avoid ethical these and other potential ethical breaches and safety issues by disclosing any obligated ethical information, consulting superior technical support when deemed necessary, and through careful design to limit device alterability and testing of PhytoHome in order to ensure sufficient safety measures. In addition, since, as the Illinois General Assembly Professional Engineering Practice Act of 1989 states, "The practice of professional engineering in the State of Illinois is hereby declared to affect the public health, safety, and welfare and to be subject to regulation and control in the public interest" [4], we will take our project seriously and work towards a deliverable that is safe and benefits the public welfare.

6 REFERENCES

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