Sustainable Fridge

ECE Team #11

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Problem Statement (Short Introduction)

The motivation behind the sustainable fridge project is for users to have an increase of fruits and vegetables in their diet. Current crisper drawer technology is unable to keep produce fresh for extended periods of time. To rectify this the team has devised a new crisper drawer design utilizing technology that is not currently implemented in crisper drawers. These new crispers will have an insulated environment such that the temperature and humidity of the drawer will be tailored towards the contents that are stored in the drawer. This environment will be monitored by a processing module with a temperature and humidity sensor. The environment will be adjusted by distributing the refrigerator unit's cooling power to an indicated crisper, this will be achieved by implementing a combination relays and solenoid valves. Feedback will be returned through a display, and the user will be able to control the temperature and humidity setting of each crisper. This will set the control for the processing module to compare with the current environment. If the sensor data does not match the preset data, an adjustment will be made, thus optimizing the environment for the contents inside. The user will also be able to turn on or off the drawers individually.

Requirements Specification

The user shall be able to store larger quantities of natural produce in this fridge and expect them to last longer as healthy and appealing as they were at the time of storage. The user shall also not worry about conflicting storage requirements for each type of produce stored as there shall be independent chambers with the required conditions preset for each type of produce.

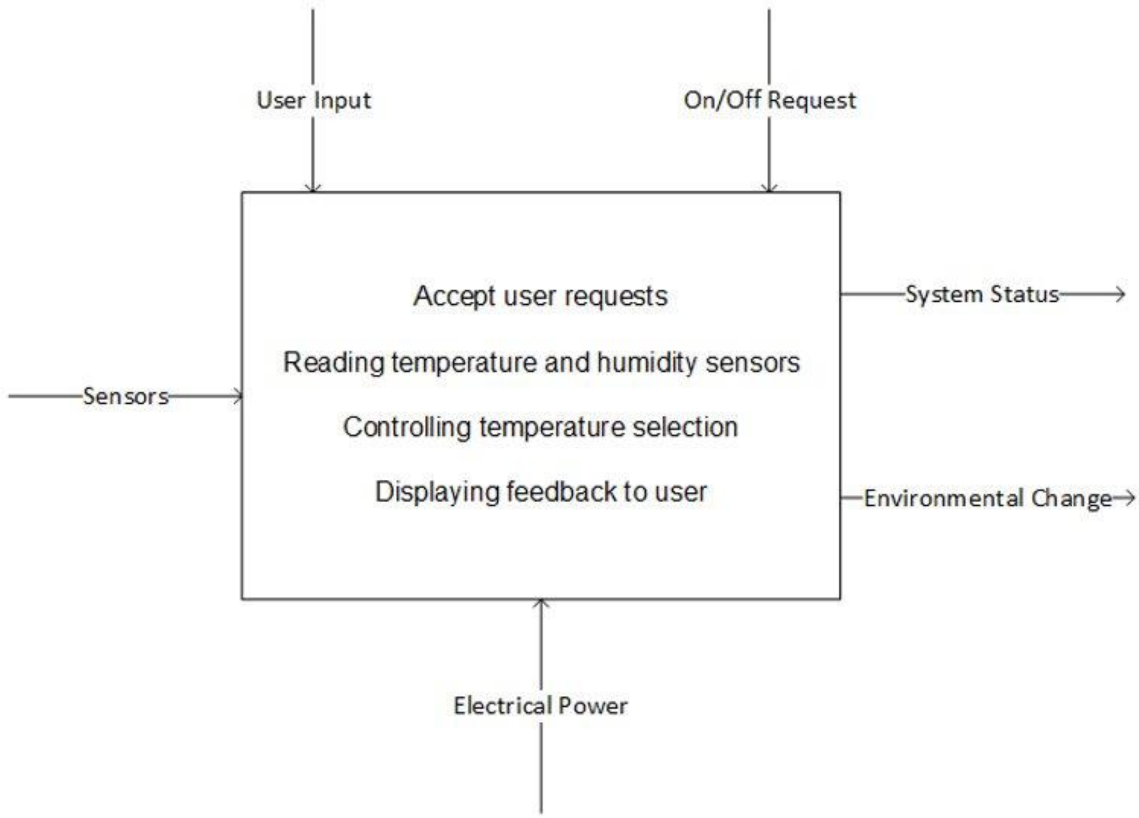
Therefore, the fridge shall have large chambers with isolated environments so that one would not interfere with another's. Moreover, there shall be presets of temperature and humidity loaded for each category of produce according to their specific requirements of ideal storage settings.

The Fridge shall also contain an LCD which will be the main output media to the user. There will be a main screen, displaying a representation of each chamber in list view, as well as a settings bar at the bottom of the list. The user will use buttons to navigate through this main screen, then for each chamber selected, the user will be presented with a list of presets to select according to the type of produce needed to be stored in the chamber in question. As an alternative to the presets, the user will also be presented with an option to disable a certain crisper and re-enable when they see fit to do so. The settings bar will provide the user options including changing Display Brightness and changing units between metric and imperial.

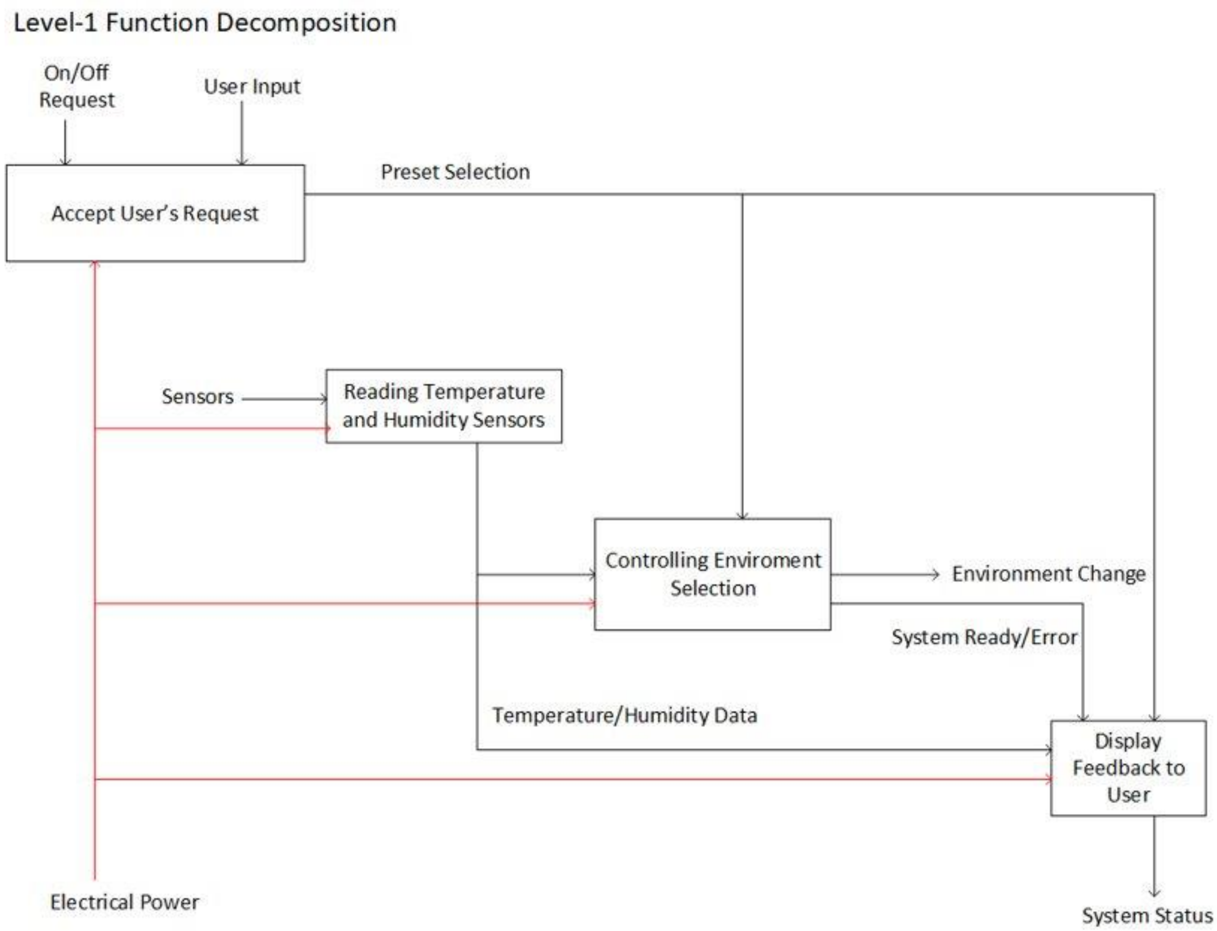
Buttons shall be the main input media from the user. There shall be four main buttons: up, down, back, and select. These buttons should be debounced through software handled by the slave raspberry pi, where an edge will be registered after a certain amount of time from the button press.

System design/architecture

Level-0 Functional Decomposition: The white box contains the top-level functions of the system, inputs, and outputs.

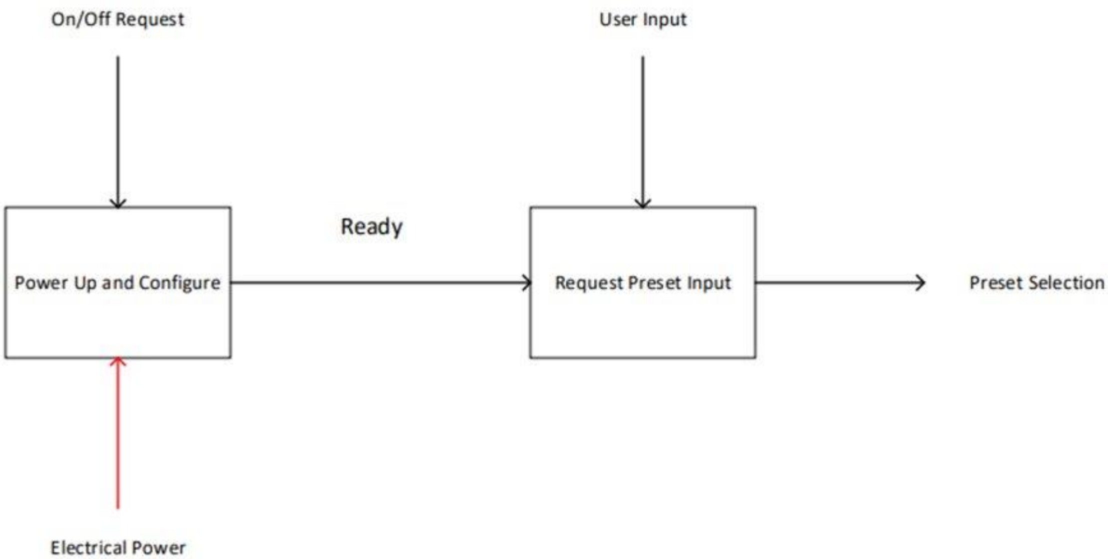


Level-1 Functional Decomposition: Demonstration of the relationship between the top-level functions specified in our Level 0 decomposition.

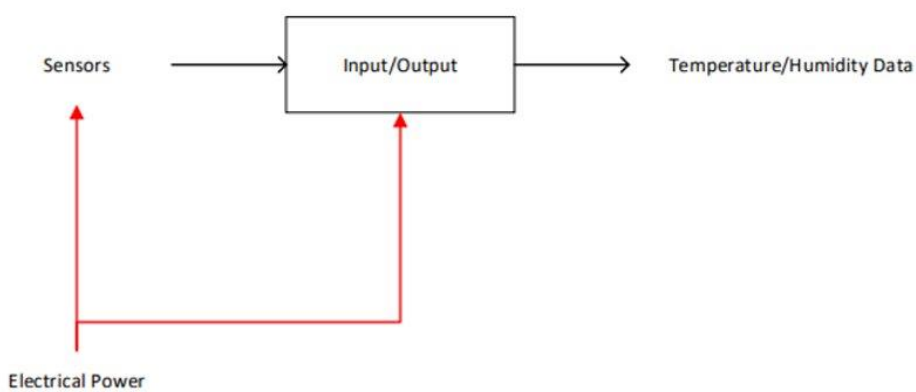


Level 2 Functional Decomposition: A closer look at each Level-1 function as it relates to inputs, outputs, and other functions. We have a Level-2 flow diagram for each of our four top-level functions specified above.

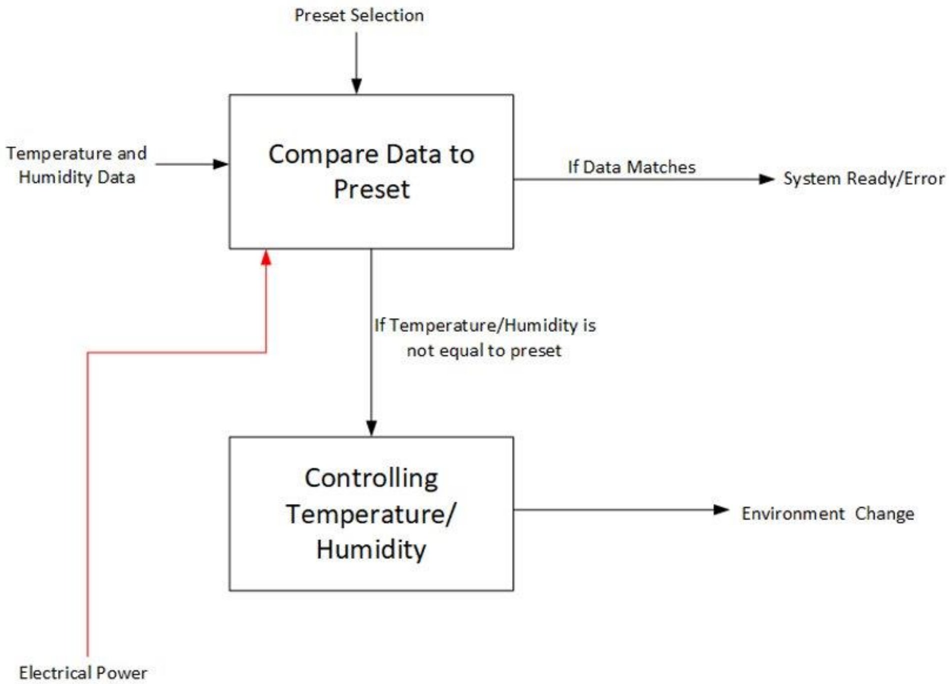
Function: Accept User Request



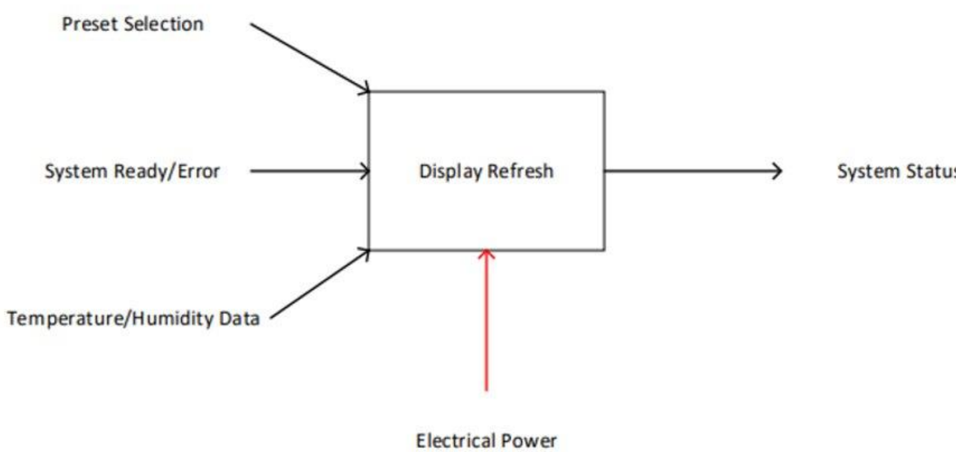
Function: Reading Temperature and Humidity Sensors



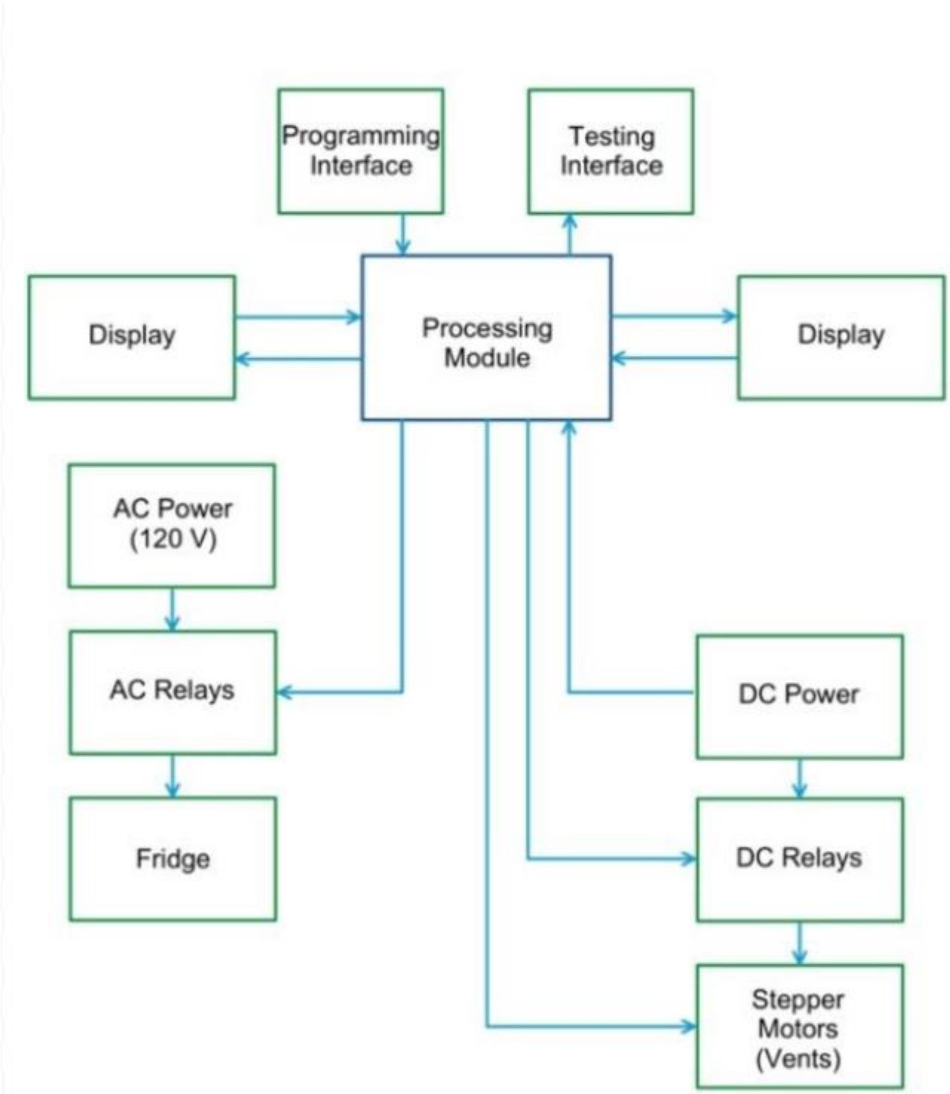
Function: Controlling Environment Selection



Function: Reading temperature and humidity



Design Architecture



Background knowledge

Key factors in produce degradation include Temperature, Humidity, and Ethylene gas sensitivity/production. Home refrigerators tend to be set at a temperature of approximately 4-5 °C. This temperature is a compromise to maintain food fresh for longer periods of time without the risk of freezing other items located in the shared refrigerated space [4]. As seen in TABLE 1 a more appropriate temperature for produce should be set to either a temperature below 4 degrees, as is the case for most leafy greens or above as recommended for okra, papaya, and passion fruit [3][4]. Certain plants known as "Climacteric" produce a colorless gas known as Ethylene during various stages of their lifecycle. For climacteric plants, the gas can cause them to ripen faster, making them sweeter and softer. In non-climacteric plants such as leafy greens this gas can cause produce to decay prematurely. This relationship must be considered when storing varied species of produce together [3][4][5][6]. Another factor to be taken into consideration is dehydration, since the produce is no longer attached to their corresponding plant it is left without a supply of water and minerals to continue its biological processes, meanwhile it will continue to consume what little resources it has until it has exhausted them. For this reason, to reduce water loss through transpiration, the produce will be stored in at a high humidity of 90% as indicated by the published data [3][4]. The reduction is water lost through the skin of the produce should allow the stored produce to continue its biological functions for a longer period before commencing the decay process [5][7]. The tables 1 & 2 provide some example data that will be used to demonstrate the teams process for deciding on the presets that will be implemented in the design. The data set utilized in this section has been supported by two scholarly sources [3][4]. The newly designed fridge will be able to support the final presets but will not be limited to the produce listed. The user will have to decide which category their new produce item falls into. The tables below indicate how the preset groupings are formed.

TABLE 1

Ideal Handling Conditions for Various Produce

Produce item	Storage Temperature (C)	Storage Temperature (F)	% Relative Humidity	Ethylene Production	Ethylene Sensitivity	Storage Life (days)
Acerola cherry	0	32	85 - 90	VL	L	42 - 56
Apple (malus pumila)	-1	30	90 - 95	VH	H	90 - 180
Apple (Yellow Newton)	4	40	90 - 95	VH	H	30 - 60
Apricot	-0.5	31	90 - 95	M	M	7 - 21
Artichoke	0	32	90 - 100	VL	L	7 - 21
Arugula	0	32	95 - 100	VL	H	7 - 10
Asparagus	2.5	36	95 - 100	VL	M	14 - 21
Avocado	3	37	85 - 90	H	H	14 - 28
Banana	13	56	90 - 95	M	H	7 - 28
Celery	0	32	98 - 100	VL	M	30 - 60
Chard	0	32	95 - 100	VL	H	10 - 14
Cilantro	0	32	95 - 100	VL	H	7 - 14
Collards	0	32	95 - 100	VL	H	10 - 14
Corn	0	32	95 - 98	VL	L	5 - 8
Cantaloupes	2	36	95 - 98	H	M	14 - 21
Mushrooms	0	32	90 - 95	VL	M	7 - 14
Okra	7	45	90 - 95	L	M	7 - 10
Onions	0	32	65 - 70	VL	L	30 - 240
Papaya	7	45	85 - 90	M	M	7 - 28
Parsinp	0	32	95 - 100	VL	H	120 - 180
Passion fruit	10	50	85 - 90	VH	M	21 - 28
Peach	0	32	90 - 95	M	M	14 - 28
Pear	0	32	90 - 95	H	H	60 - 210
Peas	0	32	90 - 98	VL	M	7 - 14
Pepper (Bell)	7	45	95 - 98	L	L	14 - 21
Pineapple	7	45	85 - 90	L	L	14 - 28
Pomegranate	7	45	90 - 95	VL	L	60 - 90
Rutabaga	0	32	98 - 100	VL	L	120 - 180
Spinach	0	32	95 - 100	VL	H	10 - 14
Summer squash	7	45	95 - 100	L	M	7 - 14
Sweet potato	13	55	85 - 95	VL	L	120 - 210
Tamarind	2	36	90 - 95	VL	L	21 - 28
Tomatillo	7	45	85 - 90	VL	M	21 - 28
Tomato	10	50	85 - 90	H	L	7 - 21
Watercress	0	32	95 - 100	VL	H	14 - 21
Watermelon	10	50	90 - 95	VL	H	14 - 21

** This table consists of a few examples taken from the appendix of the book *Postharvest Technology of Horticultural Crops* [3].
These examples will be used to demostrate the process of creating the system presets.
Groups may include all of the present produce, but are not be limited to the items in this table.

TABLE 2

Key

Ethylene Gas production rate		Ethylene Gas sensitivity
Very Low (VL)	<0.1 ul/kg-hr	Low (L)
Low (L)	0.1 ul/kg-hr	Moderate (M)
Moderate (M)	0.1 -> 10 ul/kg-hr	High (H)
High (H)	10 -> 100 ul/kg-hr	
Very High (VH)	<100 ul/kg-hr	

** This table is also refrenced from *Postharvest Technology of Horticultural Crops* [3].
Shown here are the five levels of Ethylene gas production along with their corresponding rates.
The three levels of Ethylene sensitivity are also included.

TABLE 3
Produce Sorted by Ethylene Susceptibility

Low susceptibility	Moderate susceptibility	High susceptibility
Acerola cherry	Apricot	Apple
Artichoke	Asparagus	Arugula
Corn	Celery	Avocado
Onions	Cantaloupes	Banana
Bell Pepper	Mushrooms	Chard
Pineapple	Okra	Cilantro
Rutabaga	Papaya	Collards
Sweet potato	Passion Fruit	Parsnip
Tamarind	Peach	Pear
Tomato	Peas	Spinach
Pomegranate	Summer squash	Watercress
	Tomatillo	Watermelon

**Produce from TABLE 1 is sorted based on Ethylene gas sensitivity.
The three groups map to the three sensitivity levels mentioned in TABLE 2.

TABLE 4
Low Susceptibility Group's Ethylene Production

VL	L	M	H	VH
Acerola cherry	Corn		Tomato	
Artichoke	Onions			
Rutabaga	Bell Pepper			
Sweet potato	Pine apple			
Tamarind				
Pomegranate				

**Low susceptibility group from TABLE 3 sorted by ethylene gas production rate

TABLE 4.1
Teperature Preferences of Produce with Low Susceptibility & (VL) Ethylene Production

30 - 35 (F)	35 - 40 (F)	40 - 45 (F)	> 45 (F)
Acerola cherry	Tamarind	Pomegranate	Sweet potato
Artichoke			
Rutabaga			

**TABLE 4 Very Low ethylene producers sorted by temperature preference

TABLE 4.2

Teperature Prefecences of Produce with Low Susceptibility & (L) Ethylene Production

30 - 35 (F)	35 - 40 (F)	40 - 45 (F)	> 45 (F)
Corn		Bell pepper	
Onions		Pineapple	

**TABLE 4 Low ethylene producers sorted by temperature preference

TABLE 4.3

Teperature Prefecences of Produce with Low Susceptibility & (H) Ethylene Production

30 - 35 (F)	35 - 40 (F)	40 - 45 (F)	> 45 (F)
			Tomato

**TABLE 4 High ethylene producers sorted by temperature preference

TABLE 5

Moderate Susceptibility Group's Ethylene Production

VL	L	M	H	VH
Asparagus	Okra	Apricot	Cantaloupes	PassionFruit
Celery	Summer squash	Papaya		
Mushrooms		Peach		
Peas				
Tomatillo				

**Moderate susceptibility group from TABLE 3 sorted by ethylene gas production rate

TABLE 5.1

Teperature Prefecences of Produce with Moderate Susceptibility & (VL) Ethylene Production

30 - 35 (F)	35 - 40 (F)	40 - 45 (F)	> 45 (F)
Celery	Asparagus	Tomatillo	
Mushrooms			
Peas			

**TABLE 5 Very Low ethylene producers sorted by temperature preference

TABLE 5.2

Teperature Prefecences of Produce with Moderate Susceptibility & (L) Ethylene Production

30 - 35 (F)	35 - 40 (F)	40 - 45 (F)	> 45 (F)
		Okra	
		Summer squash	

**TABLE 5 Low ethylene producers sorted by temperature preference

TABLE 5.3

Teperature Prefecences of Produce with Moderate Susceptibility & (M) Ethylene Production

30 - 35 (F)	35 - 40 (F)	40 - 45 (F)	> 45 (F)
Apricot		Papaya	
Peach			

**TABLE 5 Moderate ethylene producers sorted by temperature preference

TABLE 5.4

Teperature Prefecences of Produce with Moderate Susceptibility & (H) Ethylene Production

30 - 35 (F)	35 - 40 (F)	40 - 45 (F)	> 45 (F)
	Cantaloupes		

**TABLE 5 High ethylene producers sorted by temperature preference

TABLE 5.5

Teperature Prefecences of Produce with Moderate Susceptibility & (VH) Ethylene Production

30 - 35 (F)	35 - 40 (F)	40 - 45 (F)	> 45 (F)
			Passion fruit

**TABLE 5 Very High ethylene producers sorted by temperature preference

TABLE 6

High Susceptibility Group's Ethylene Production

VL	L	M	H	VH
Arugula		Banana	Avocado	Apple
Chard			Pear	
Cilantro				
Collards				
Parsnip				
Spinach				
Watercress				
Watermelon				

**High susceptibility group from TABLE 3 sorted by ethylene gas production rate

TABLE 6.1

Teperature Prefecences of Produce with High Susceptibility & (VL) Ethylene Production

30 - 35 (F)	35 - 40 (F)	40 - 45 (F)	> 45 (F)
Arugula			Watermelon
Chard			
Cilantro			
Collards			
Parsnip			
Spinach			
Watercress			

**TABLE 6 Very Low ethylene producers sorted by temperature preference

TABLE 6.2

Teperature Prefecences of Produce with High Susceptibility & (M) Ethylene Production

30 - 35 (F)	35 - 40 (F)	40 - 45 (F)	> 45 (F)
			Banana

**TABLE 6 Moderate ethylene producers sorted by temperature preference

TABLE 6.3

Teperature Prefecences of Produce with High Susceptibility & (H) Ethylene Production

30 - 35 (F)	35 - 40 (F)	40 - 45 (F)	> 45 (F)
Pear	Avocado		

**TABLE 6 High ethylene producers sorted by temperature preference

TABLE 7
Potential Groupings

Group 1 : 34 (F) : 90%	Group 2 : 32 (F) : 90%	Group 3 : 52 (F) : 90%	Group 4 : 50 (F) : 90%	Group 5 : 33 (F) : 90%	Group 6 : 44 (F) : 90%
Acerola cherry	Celery	Pomegranate	Tomato	Corn	Bell pepper
Artichoke	Mushrooms	Sweet potato	Passion fruit	Onions	Pineapple
Rutabaga	Peas	Watermelon		Apricot	Asparagus
Tamarind	Arugula	Banana		Peach	Tomatillo
Pear	Chard			Cantaloupes	Okra
Avocado	Cilantro				Summer squash
Apple	Collards				Papaya
	Parsnip				
	Spinach				
	Watercress				

**Compatible groupings formed by taking into account temperature preferences, ethylene sensitivity, and ethylene production rates.
The temperature for each group was determined by taking the average of all individual recommended temperatures.
Humidity was set at 90 % due to the similarity in humudity preferences across all groups. An exception being Onions which prefer low humidity.

Groups were formed by dividing the data up by low (L), moderate (M), and high (H) sensitivity to ethylene gas. Each of the three groups can then be divided by their own Ethylene gas production levels, very low (VL), low (L), moderate (M), high (H), and very high (VH) [3]. The subgroups can be further divided into their preferred storage temperature. Groups for presets can be formed by comparing temperature preference overlap. Additionally, it is important to note that ethylene gas compatibility must also be considered, high sensitivity items can be stored along with other sensitive items and low/very low ethylene gas producers.

TABLE 8
Recommended Groups

Group 1: 34 (F) : 90%	Group 2: 32 (F) : 90%	Group 3: 52 (F) : 90%	Group 4: 50 (F) : 90%
Acerola cherry	Celery	Bell pepper	Tomato
Artichoke	Mushrooms	Pineapple	Passion fruit
Rutabaga	Peas	Asparagus	
Tamarind	Arugula	Tomatillo	
Pear	Chard	Okra	
Avocado	Cilantro	Summer squash	
Apple	Collards	Papaya	
	Parsnip		
	Spinach		
	Watercress		

** Main presets to be implemented in sustainable fridge design.

The final 4 groups are characterized as follows:

Group 1:

This group pairs produce those outputs very low quantities of ethylene gas and is not sensitive to ethylene with produce that is sensitive to ethylene and produces substantial ethylene. The initial set of produce should not be affected by the high gas output of the second set, and the 2nd set will mainly interact with their own ethylene gas output. Lastly an additional constraint of temperature is to further extend the storage life of the produce.

Group 2:

This group combines produce that it both moderately and highly susceptible to ethylene, both groups produce very little ethylene making them a suitable match for joint storage.

Group 3:

Group 3 consists of produce with low ethylene sensitivity and low ethylene production combined with moderately ethylene sensitive produce which has very low, low, and moderate ethylene outputs. An additional trait this group shares is a preference for temperatures warmer than 0 °C.

Group 4:

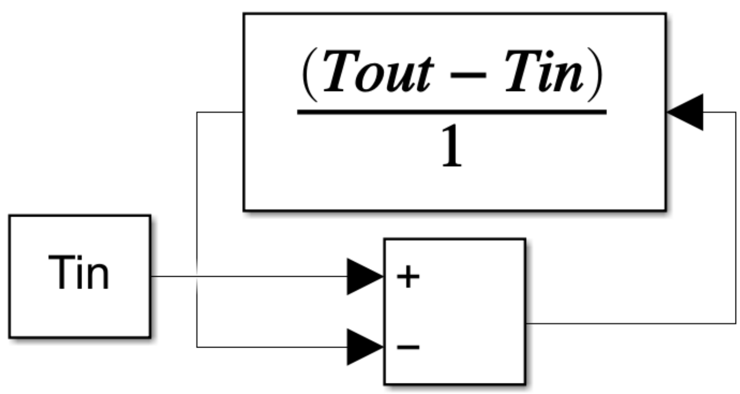
Group 4 will have low and moderate susceptibility produce with high and very high rates of ethylene gas production. Additionally, this group will also prefer warm temperature settings and will stay at a temperature of at least 7 °C.

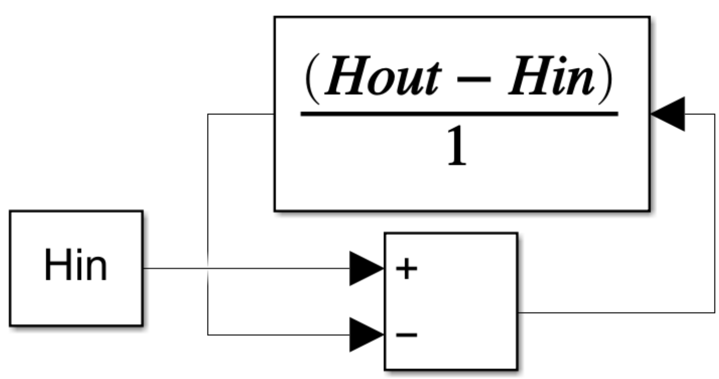
Lastly, if needed low ethylene susceptibility produce with a preference of warmer temperature may be stored in group 4 this would include produce such as: Pomegranate, Sweet potato, Bell peppers, and pineapple.

**Produce not listed in TABLE 1 will have to be put into one of these 4 groups depending on best fit between required produce parameters and device presets, this is recommended to achieve the longest storage life possible for the produce item.

Calculations to see if Temperature and Humidity in containers matches up with user selection

For the changing of the environment in the containers, the initial temperature and humidity will act as feedback to combine with the initial value





This leads with the transfer functions

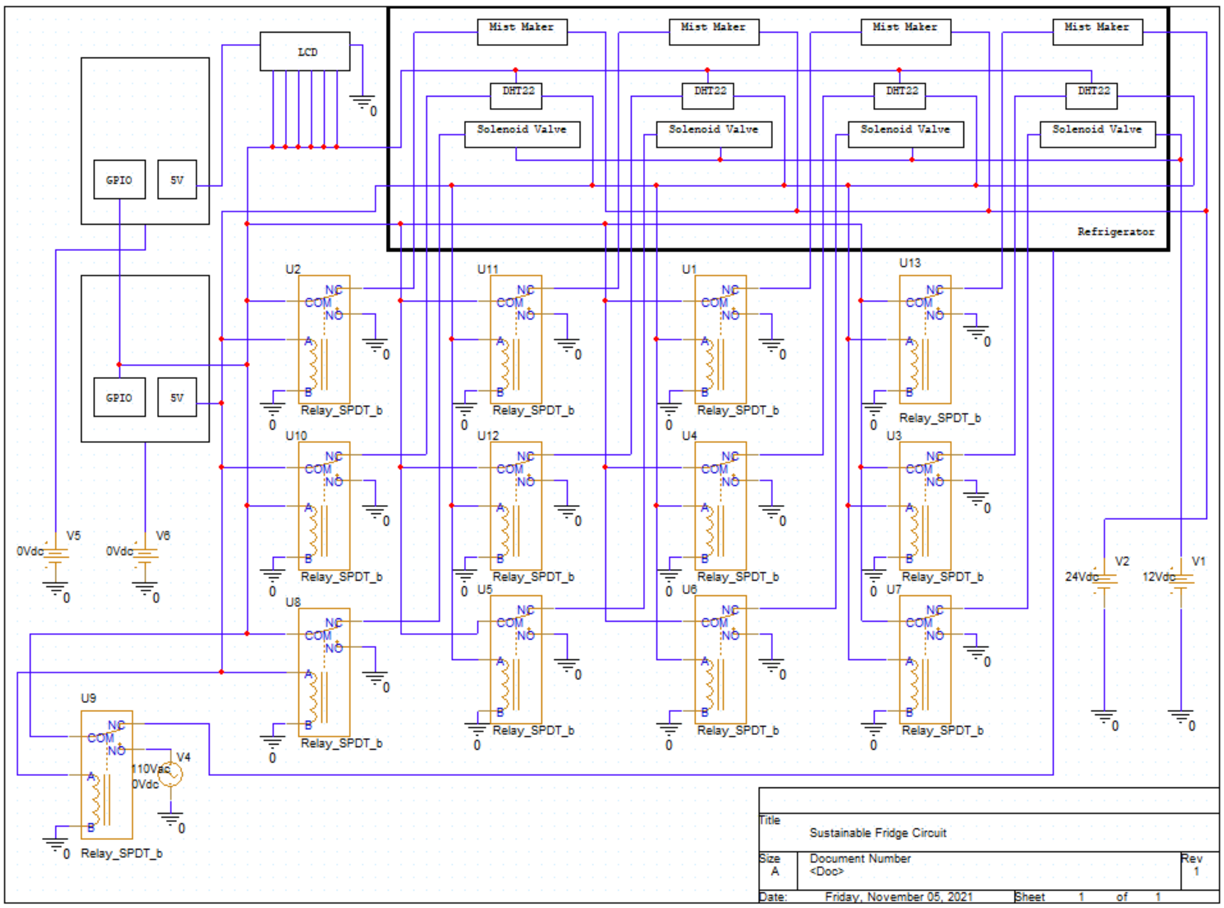
$$\frac{Tout}{Tin} = \frac{1}{1 + (Tout - Tin)} \qquad \frac{Hout}{Hin} = \frac{1}{1 + (Hout - Hin)}$$

Where: Tout – Final Temperature; Tin – Input Temperature; Hout – Humidity Output; Him – Humidity Input

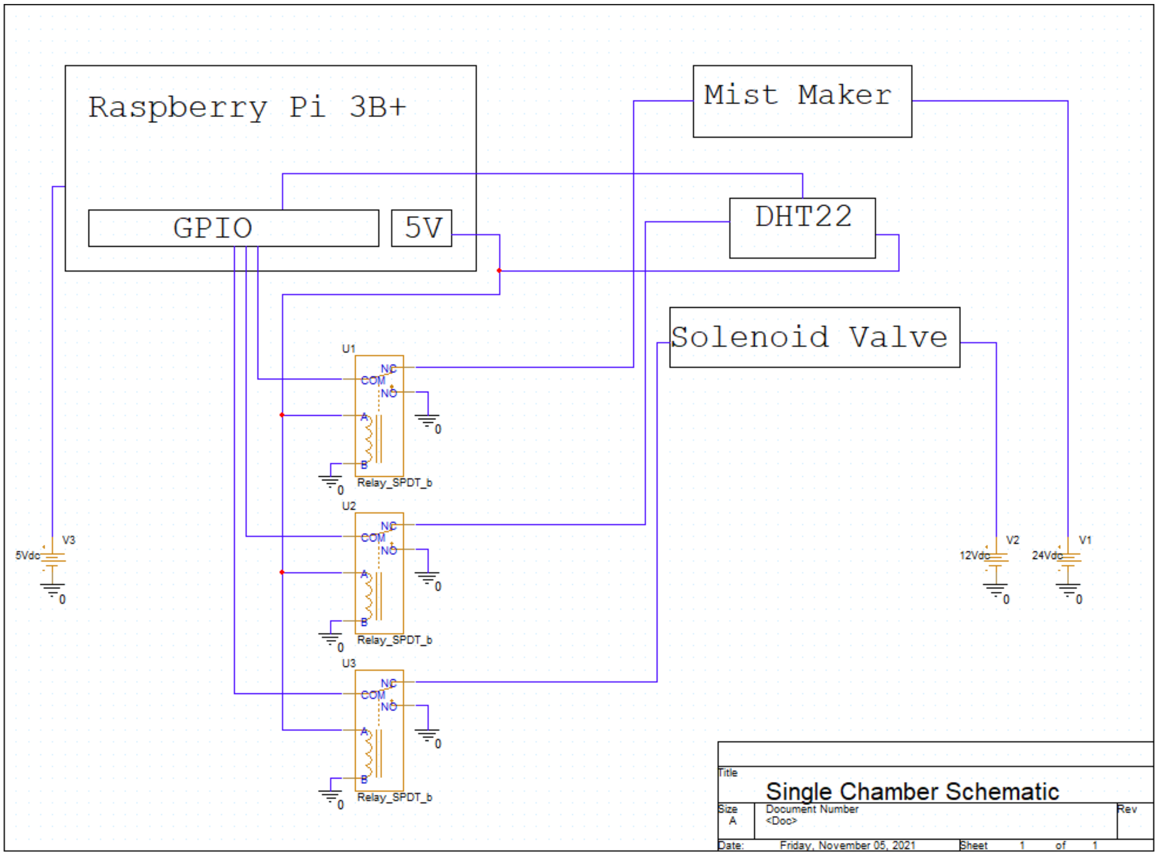
If Tout=Tin or Hout=Hin the function will equal to 1 signifying that the user's input and the final value match up

Detailed Design

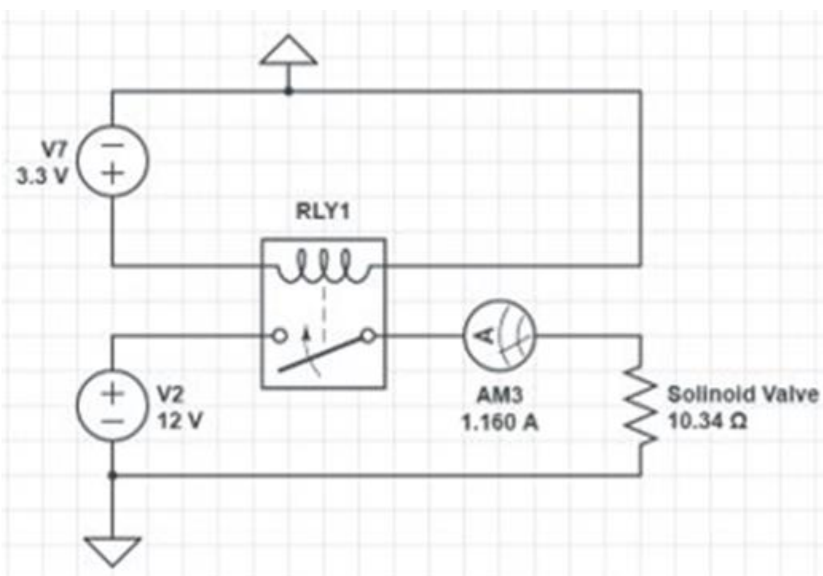
1) Circuit Schematics, State diagrams, algorithm flowcharts



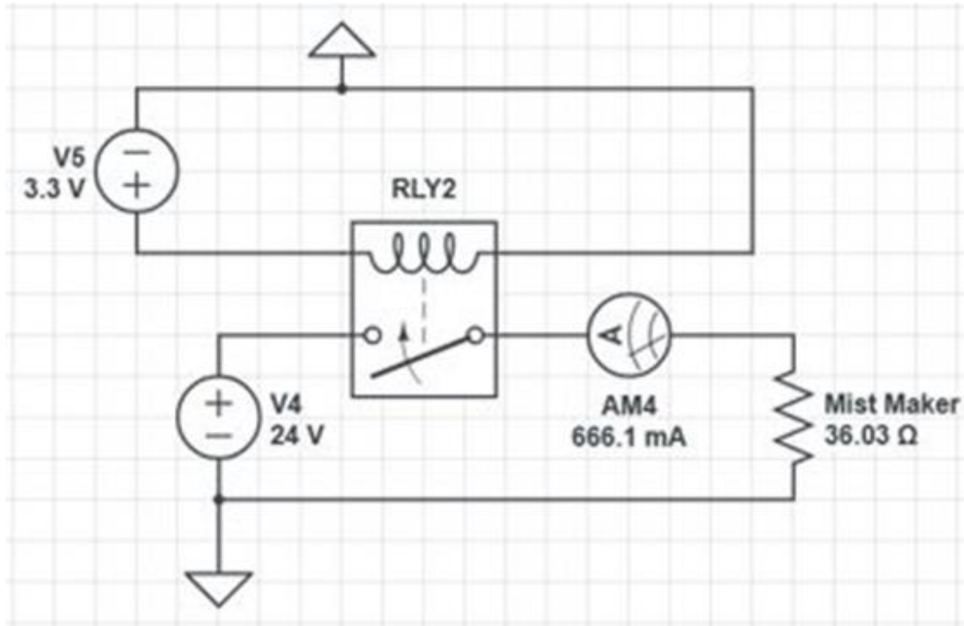
This initial circuit design will utilize at least 12 relays to control power delivery to all the individual system components. The refrigerator unit will be controlled by the Raspberry Pi through a smart power strip, represented here by the lower relay connected to 110 Vac. Two Raspberry Pi units will share the GPIO load through an I2C connection. Individual DC power supplies will also be controlled through the smart power strip.



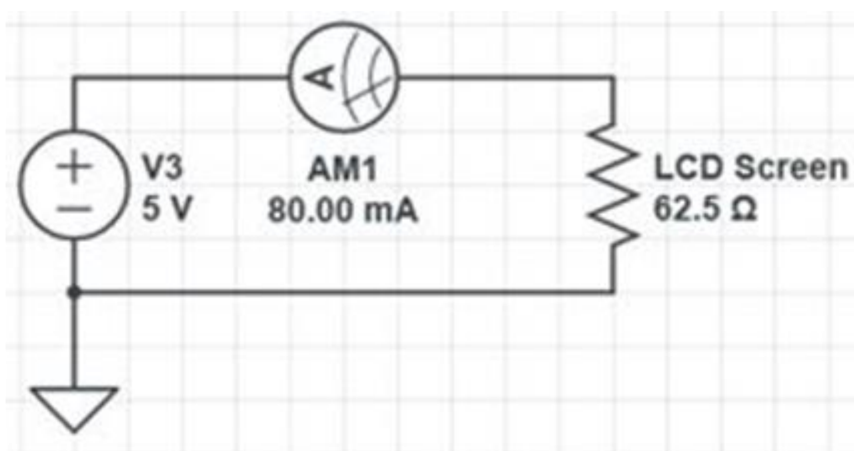
Each individual chamber will use 3 relays, a mist maker, a DHT22 sensor, and a solenoid valve.



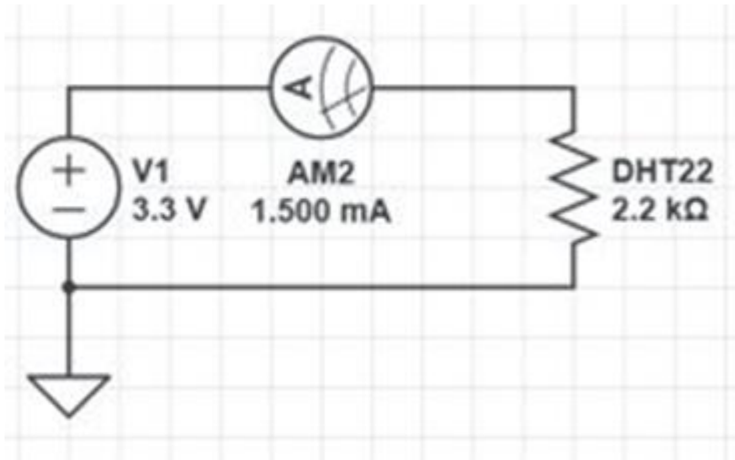
Schematic of the solenoid valve



Schematic of the mist maker



Schematic of the LCD Screen



Schematic of the DHT22

2) Component and Interface description

DHT22

The DHT22 is the component that is responsible for sensing and reporting back temperature and humidity data in the containers. How it works is that when given voltage, the sensor sends back a 40-bit array of data to give back to the processing module. There are 5 sets of 8 bits representing different values. From the most significant bit to least significant bit is the sets are humidity whole number, humidity decimal number, temperature whole number, temperature decimal number, and check number set [1]. The check number set is the sum of the values of the four previous sets [1]. If the check number set does not match the sum of the four sets, it will read as an error. If it matches, then the value is true.

Solenoid Valve

The Solenoid Valve is a component that is responsible for opening and closing the path for air to enter the container. How this is done is through a current running through the valve. When current runs through the valve, this will cause the pathway within the valve to open allowing air to pass through [2]. For it to close no current would have to run through.

16x4 LCD Screen

The LCD screen will be designed to display the current temperature/humidity in the fridge. How this works is when voltage is running through the device, it will be able to display text. The processing module will send out information to the LCD screen for the user to see the current values. It will show what options the user can do and display current values as well.

Buttons

The buttons will be used to select an action on the LCD screen. How this works is when the user pushes a button, the processing module will recognize this as an input and then run through the code to show a change in the display.

Drain System:

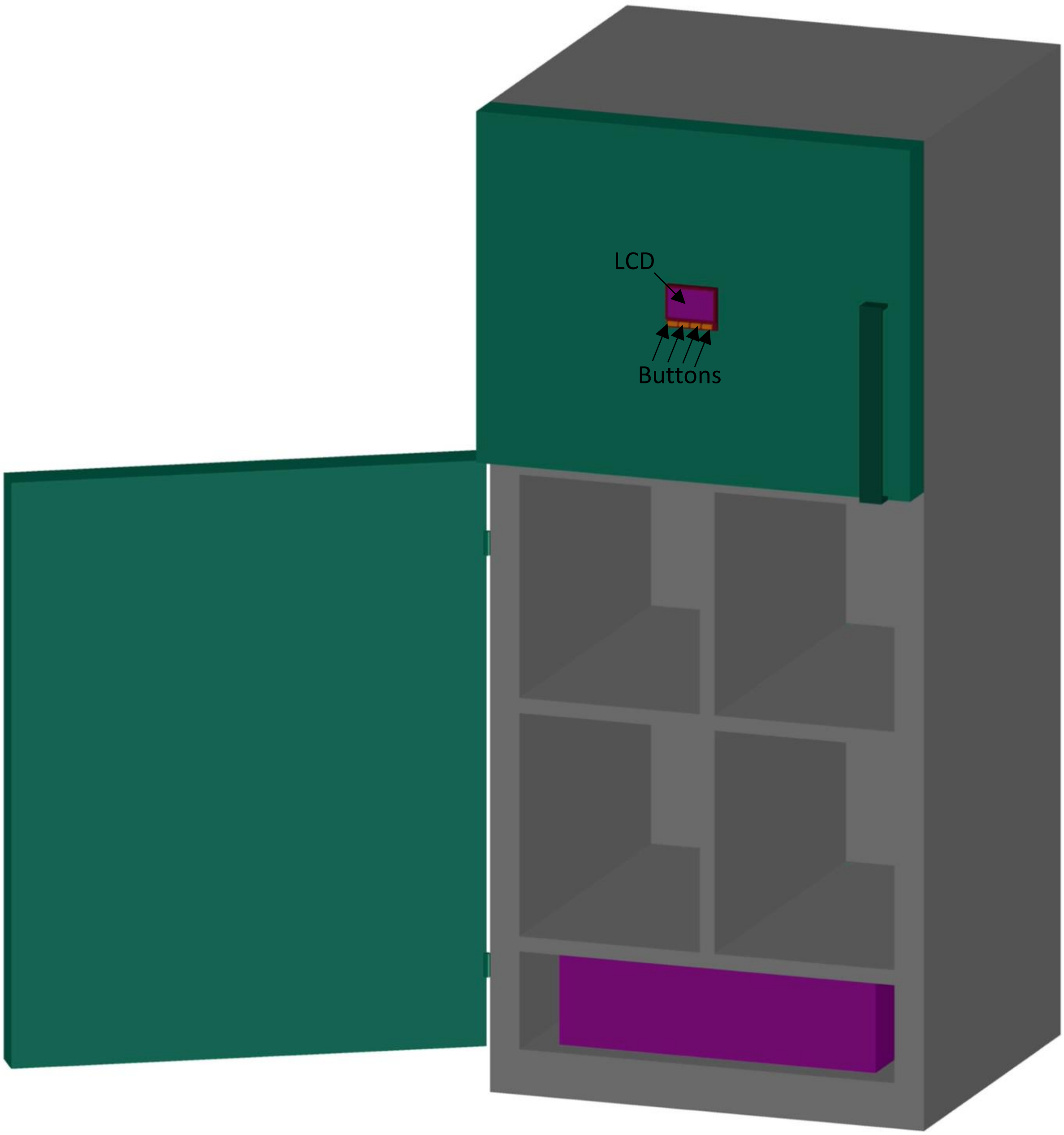
Each compartment will have a drain that will be connected to a drain tube which will deposit the extra water from the misters into the drain reservoir. To prevent unwanted temperature change in the chambers, we shall put a dip in the drain tubing. This idea is like the plumbing "traps" under sinks where the trapped water in the drain will prevent airflow. To prevent leakage, an overflow sensor will alert the user when the drain reservoir is full. The water level alarm will be a sensor that will notify the user that the drain reservoir needs to be emptied. This sensor will be attached near the top of the reservoir and will simply emit a repeated noise whenever it is submerged.

Interface

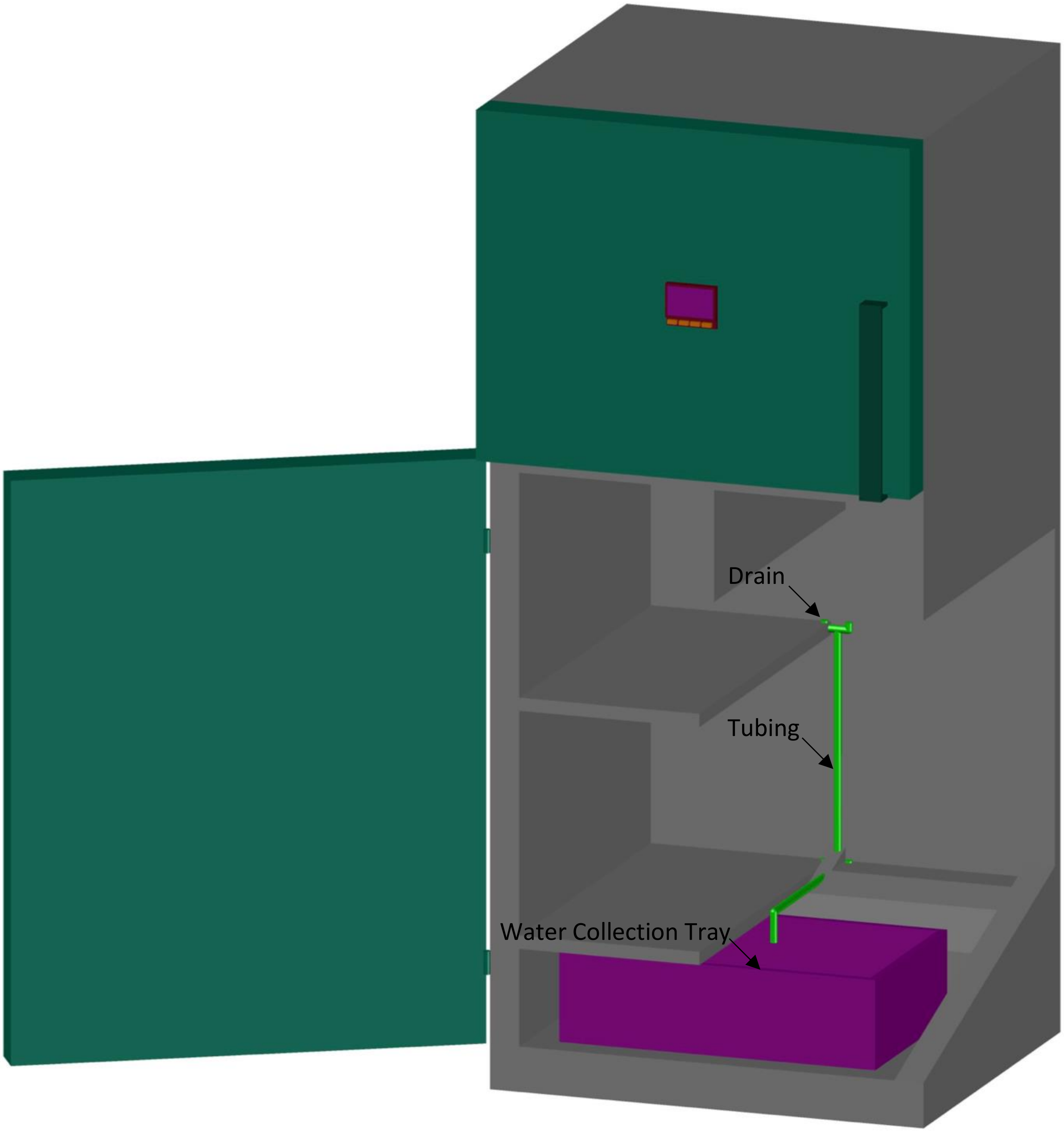
The interface will be the Raspberry Pi where all the components will meet and connect and communicate with one another. How this will work is that the results of one of the components will result in a change in another part of another component(s).

Mechanical Design

The following diagrams show the refrigerator body reflecting modifications to be done:

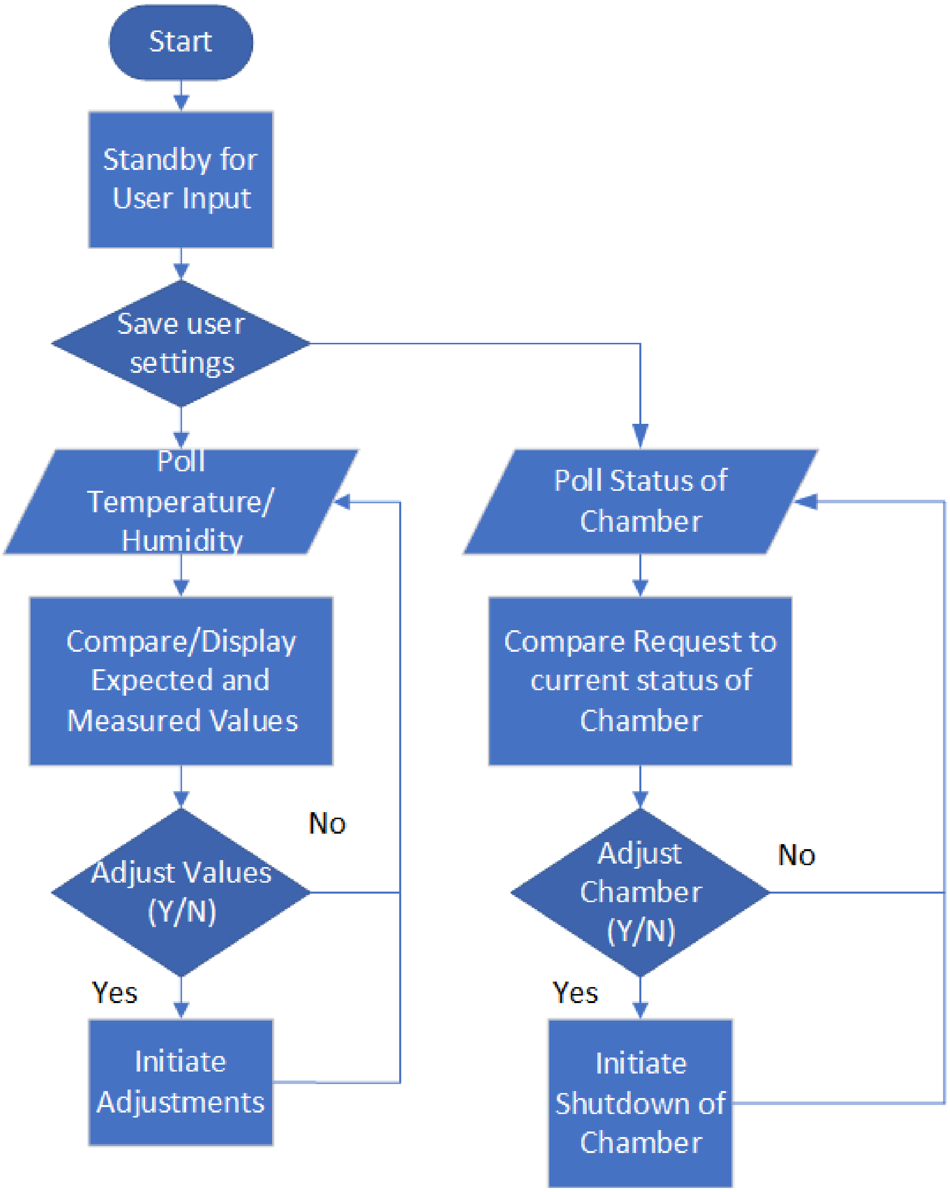


External View



Internal View

3) Flow diagrams + main parameters for simulation projects



How the Flow diagram works is that it will wait for user input. Once Given user input, it will save the user setting adjustments for later. Then it will go down two paths. Path one will get current readings of the temperature/humidity in the container. Next it will decide between two routes based on if the values match or not. If they do not match then it will initiate adjustments. Once it is done initiating adjustments it will go back in a loop to show the temperature/ humidity values. If it does match though it go to the temperature/ humidity value section.
Path two will check the current status of the container. Next it will compare that status with the requested command. Next it will decide between two routes based on that comparison. If they do not match then it will initiate a shutdown of the chamber and loop back to checking the status. If they do match then it just go back to the status section.

4) Detailed description of software structure

The software implemented will span through at least two raspberry pi's. First, the "slave" raspberry pi will handle the I/O interfacing with the user, which mainly consists of choosing a preset for each chamber as input which propagates into the "master", and sensor monitoring as output to the LCD. The "master" raspberry pi will poll through the chambers, comparing the temperature and humidity recorded by the sensors with the preset of the chamber in question. The readings will be sent to the "slave" which will display to the LCD, and the "master" will actuate the needed components that will moderate the temperature and/or humidity as needed.

The LCD will be the main output media to the user. There will be a main screen, displaying a representation of each chamber in list view, as well as a settings bar at the bottom of the list. The user will use buttons to navigate through this main screen, then for each chamber selected, the user will be presented with a list of presets to select according to the type of produce needed to be stored in the chamber in question. As an alternative to the presets, the user will also be presented with an option to disable a certain crisper and re-enable when they see fit to do so. The settings bar will provide the user options including changing Display Brightness and changing units between metric and imperial.

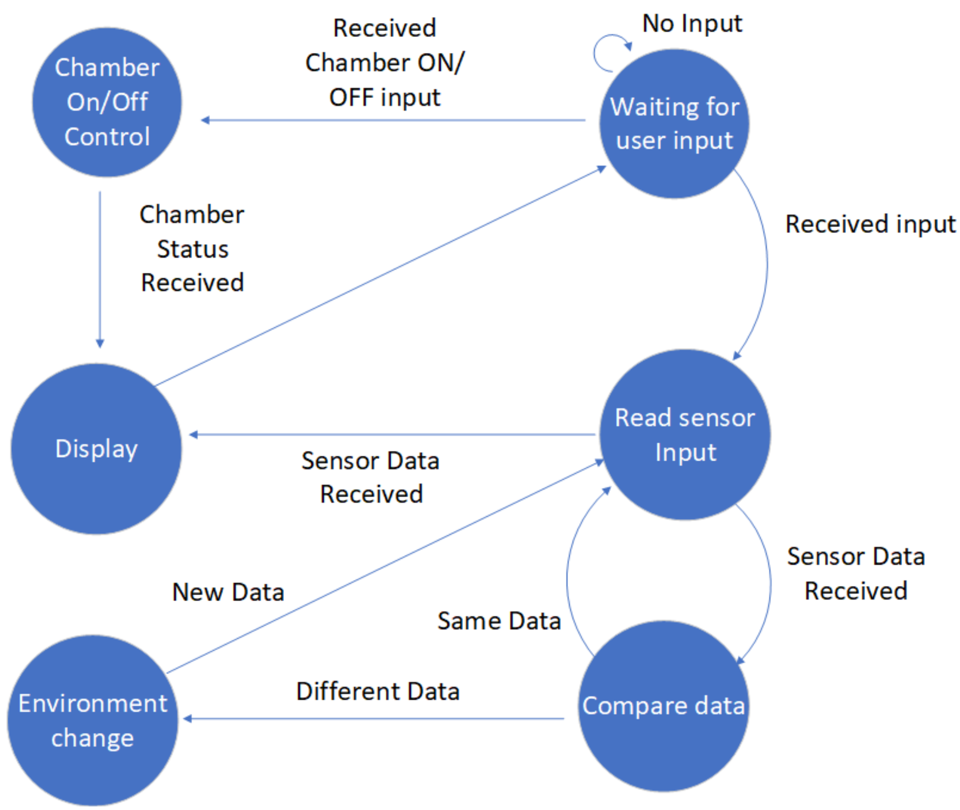
Buttons shall be the main input media from the user. There shall be four main buttons: up, down, back, and select. These buttons should be debounced through software handled by the slave raspberry pi, where an edge will be registered after a certain amount of time from the button press.

Temperature/Humidity sensor: In five-minute intervals, the master raspberry pi will accept data input from the sensors through GPIO ports, after calling the relay function that will activate the sensors. The data will only be recorded and handled in one chamber at a time. The raw data will be converted to Metric/Imperial units (according to a setting set by the user) and will be compared with the presets as given from the slave raspberry pi. From our initial testing, we noticed that DHT22 sensors can and will record “noise values”, which are spikes of high magnitude above or below the previous values. Therefore, the final code shall detect such values and retry the recording.

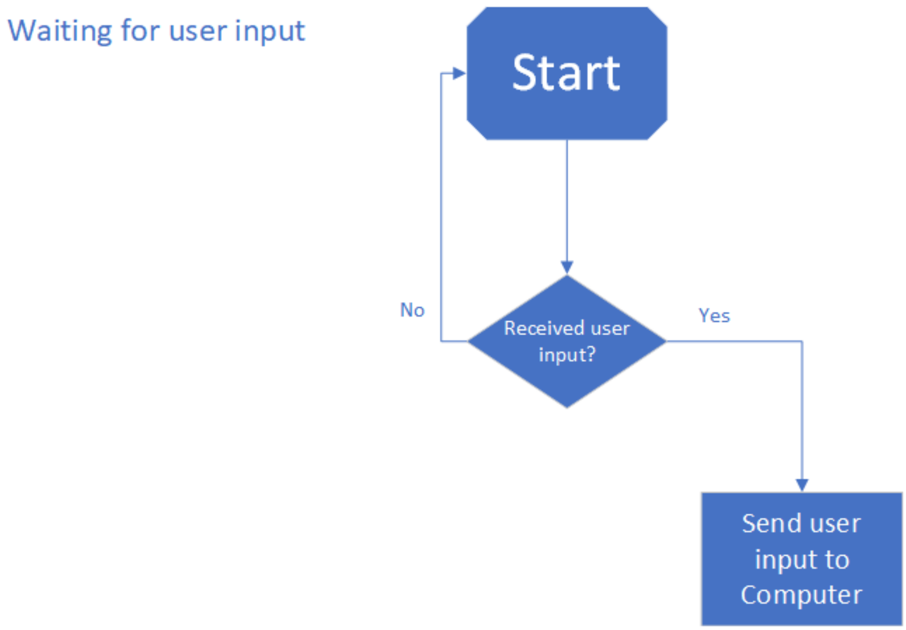
Solenoid Valves: After comparing the measured temperature with the preset of the chamber in question, certain logic will be operated: If the recorded temperature is less than the preset, the master will contact the slave to display an error message (this is a point where the system would require human interference). If the recorded temperature is within the preset boundaries, the temperature data will be sent to the slave which will display it. If the recorded temperature is higher than the preset, the master will actuate the relays needed to allow cold air to enter the chamber and send the temperature data to the slave.

Misters: After comparing the measured humidity with the preset of the chamber in question, certain logic will be operated: If the recorded humidity is greater than the preset, the master will contact the slave to display an error message (this is a point where the system would require human interference). If the recorded humidity is within the preset boundaries, the humidity data will be sent to the slave which will display it. If the recorded humidity is lower the preset, the master will actuate the relays needed to activate the misters and send the humidity data to the slave.

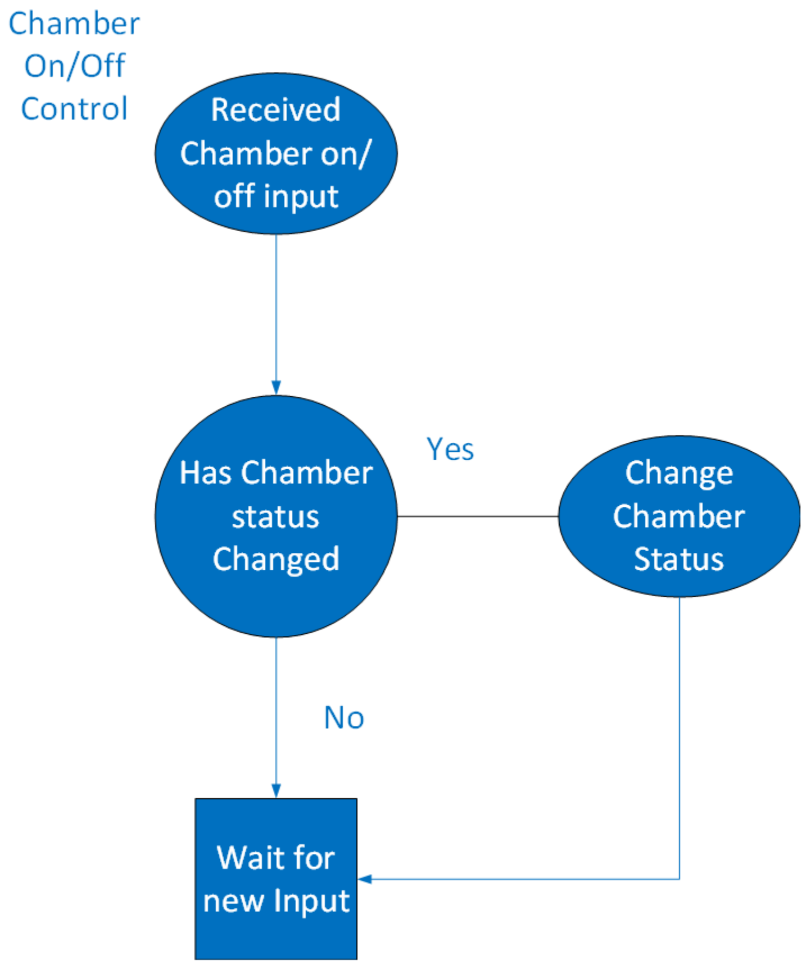
C) Include flow diagrams with identifications of subroutines and main parameters for simulation projects.



This state diagram shows the 6 subroutines which are broken down into the following flowcharts.

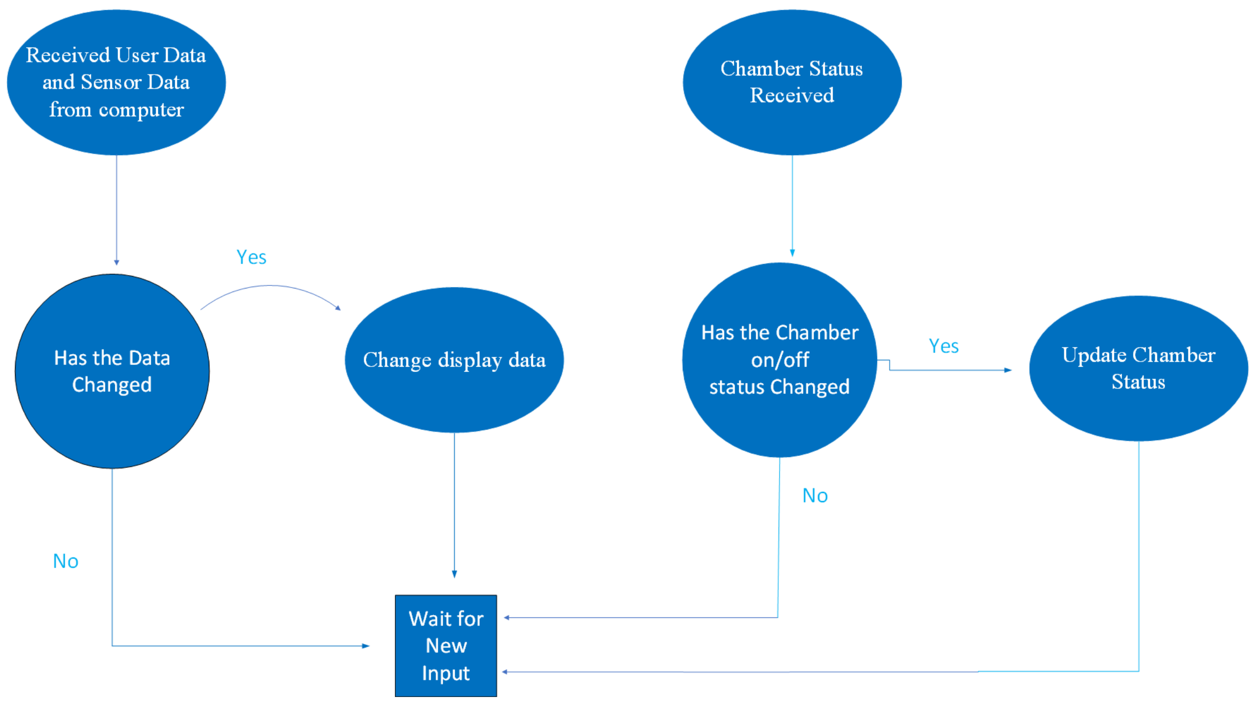


Once it starts, the waiting for user input subroutine toggles the received user input parameter. If no input is detected then the subroutine just cycles back to start which then goes back to received user input in an eternal loop until an input is detected. After a user input is received, that signal is sent to the processing module computer.



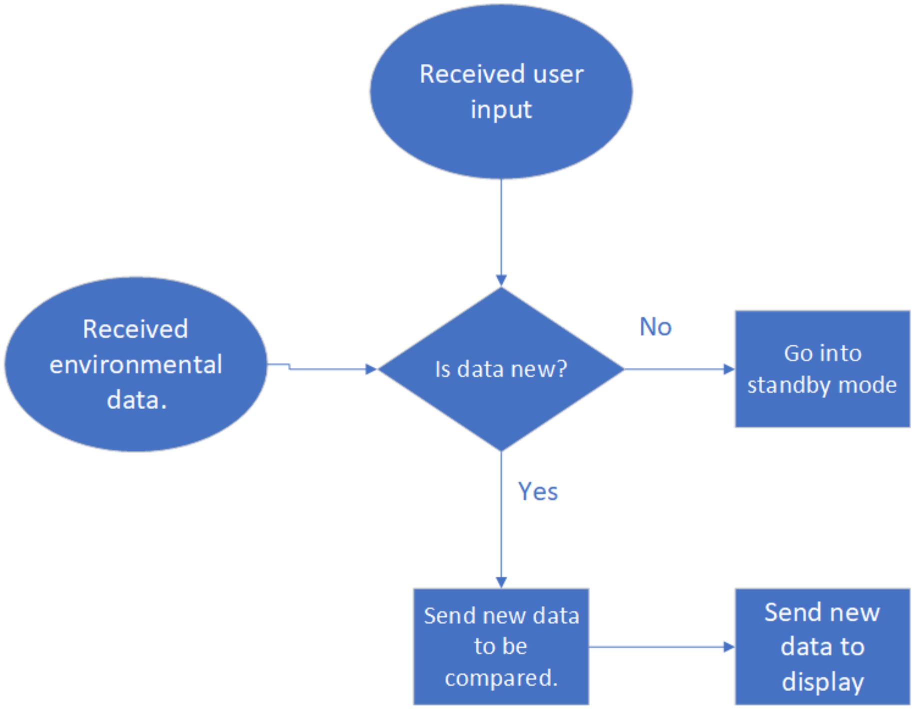
After receiving a chamber on/off input request, the Chamber On/Off Control subroutine will determine if the chamber status needs to change. If a change is required, the chamber control will turn off or on the chamber that was requested to change before it waits for new input mode. On the other hand, if the chamber status does not need to change it just waits for new input mode.

Display



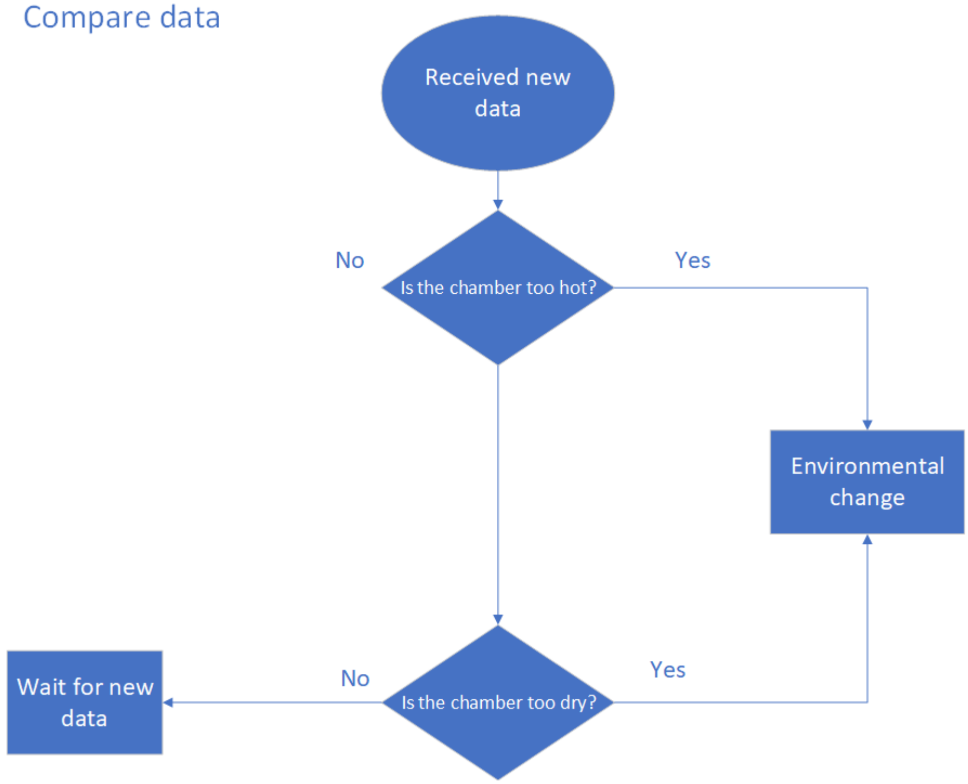
The Display subroutine after receiving the sensor data from the processing module computer determines if the data has changed. If it has then it changes the display data and then goes to waiting mode till data is received again, but if the data has not changed then it just goes to waiting mode till data is received again. The subroutine also receives a chamber status signal from the chamber of/off control. If the status has changed then the display will update the chamber status and then go to wait for new input mode. If the status has not changed then it just goes to wait for new input mode.

Read sensor input

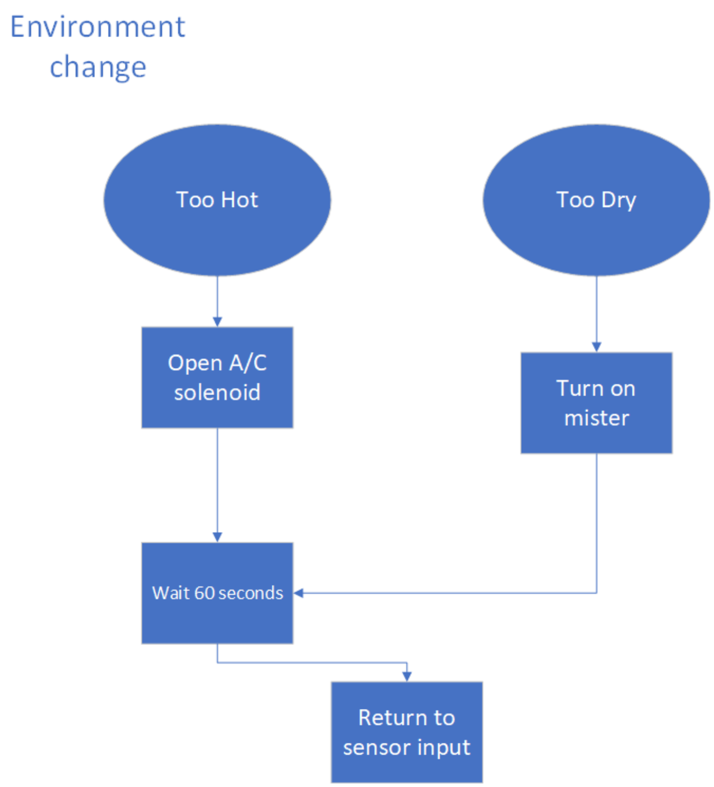


The Read sensor input subroutine receives user input and then checks to see if the data is new. If the data is new then the environmental data is then sent to the compare data subroutine and to the display subroutine. If data has not changed, then subroutine goes into standby mode.

Compare data



The compare data subroutine receives the new data from the read sensor input subroutine and determines if the chamber is to hot or dry. If it is, the data is sent to the environmental change subroutine. If the data is not too hot or dry, then the subroutine goes into waiting mode till new data is sent.



In the Environment change subroutine, a too hot or too dry signal will appropriately open the Solenoid and/or turn on the mister. It will then wait for 60 seconds then close the solenoid and turn off the mister. After the subroutine returns to the read sensor input subroutine.

Prototype Progress report

Acquired components:

Refrigerator

Raspberry Pi 3B+

DHT22 and DHT11 temp sensors

Character LCD screen

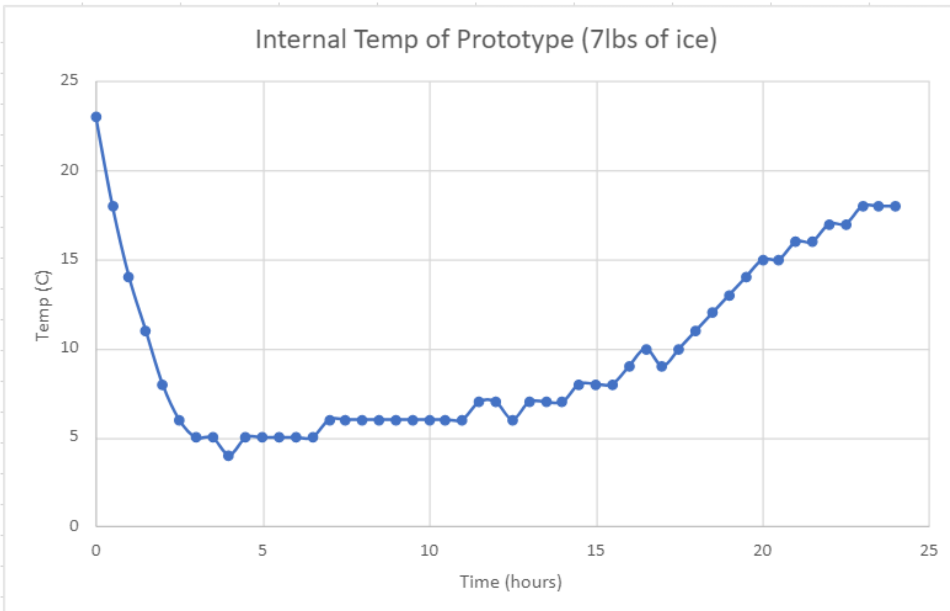
Note: We are currently working with the Patriot Green Fund to apply for funding for our project. When the application process is complete, we will be able to purchase more components.

Experimental progress:

Experiment 1:

We carried out our second test by using a polystyrene cooler as a model of a chamber and filled it with a 7lb bag of ice in a room temperature environment (23 C). Our goal was to test the viability of similar materials in our chambers and to get an idea of how rapidly temperatures in the chamber would rise.

Results of Experiment 1:



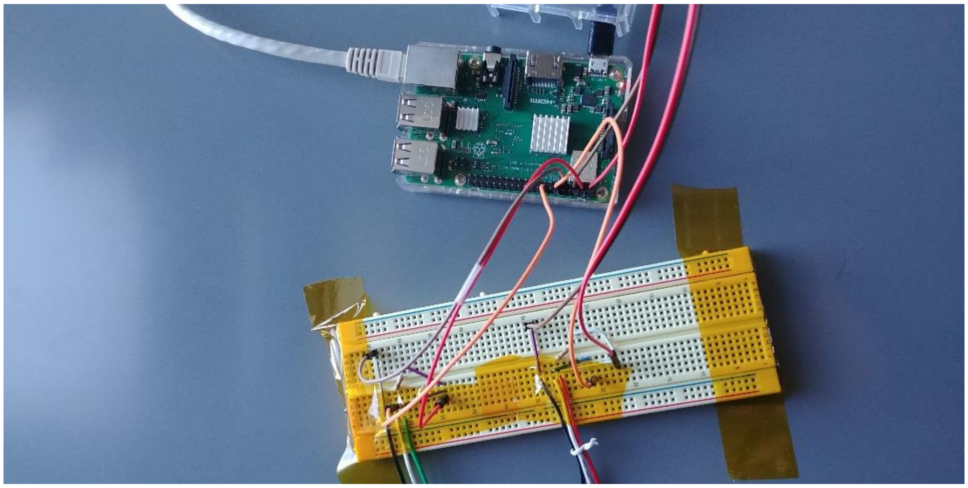
The initial internal temperature of the cooler was 23 degrees Celsius. In the first few hours, it cooled to 5 degrees Celsius. After 24 hours, the internal temperature of the cooler was still below the starting temperature. Overall, this experiment was a success. However, the DHT11 sensor data needs to be validated with a thermometer.

Experiment 2:

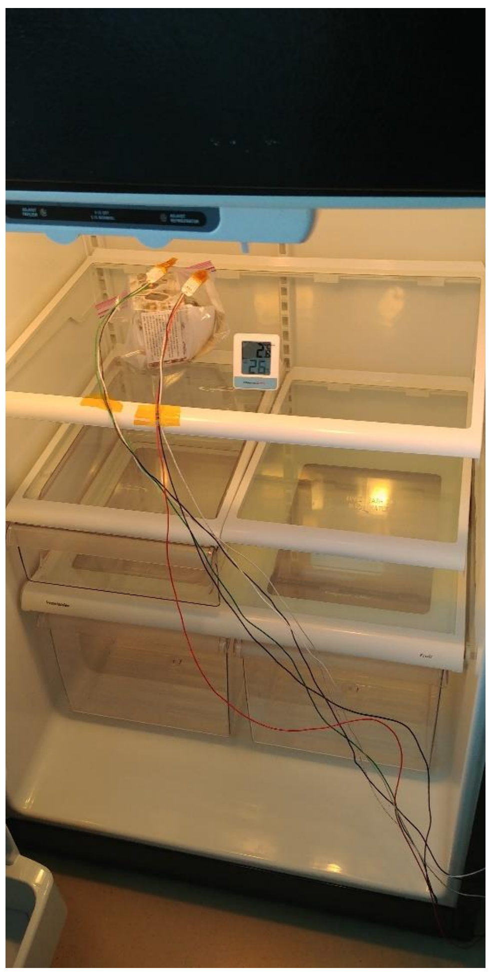
Results of Experiment 2.a:

The purpose of experiment 2.a is to test the functionality of new DHT22 code while also testing the performance of the DHT22 sensor at different VDD voltages. The test was run as follows.

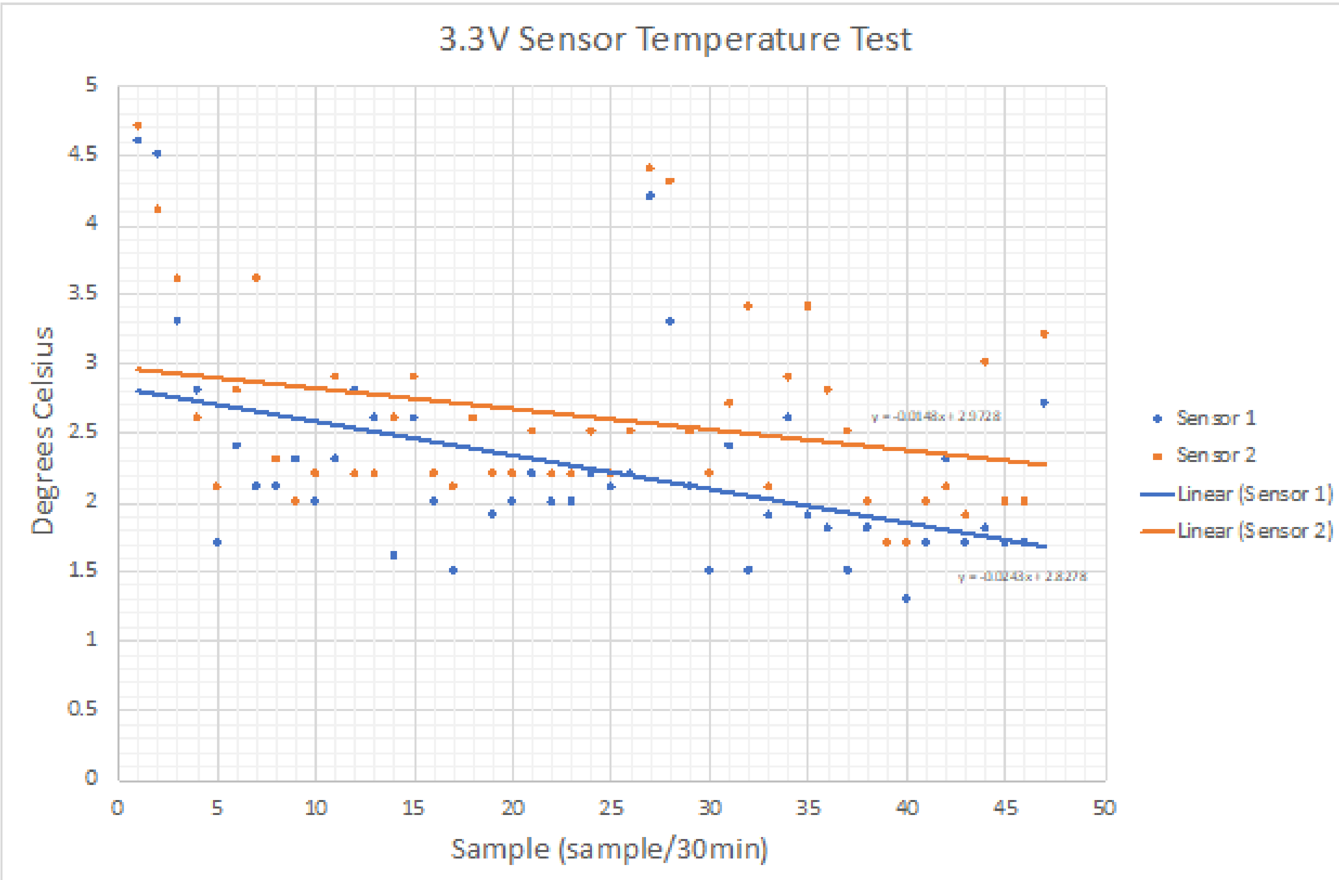
1. A breadboard with 2 DHT22 circuits was set up, and VDD was set to 3.3V.



2. Two DHT22 sensors were placed below the refrigerator cold air blower in such a way that they were suspended and not physically in contact with any surface. A Thermapro temperature and humidity sensor was also placed nearby to provide data for future percent error calculations (see Tables 9.1 & 9.2).



3. The new DHT22 python code was initiated and left to collect data for 24 hours. Data was sampled at a rate of one sample every 30min resulting in 48 temperature data points and 48 humidity data points. The results of the test are shown below.



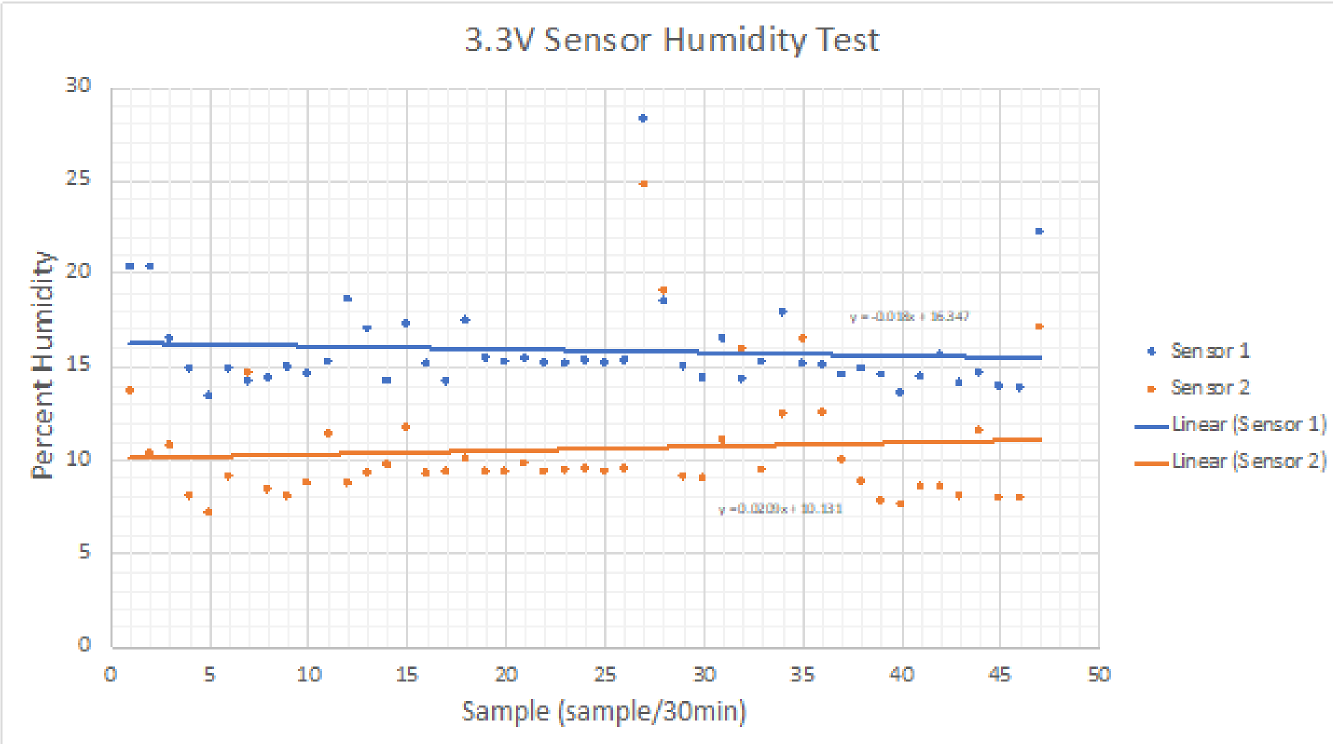
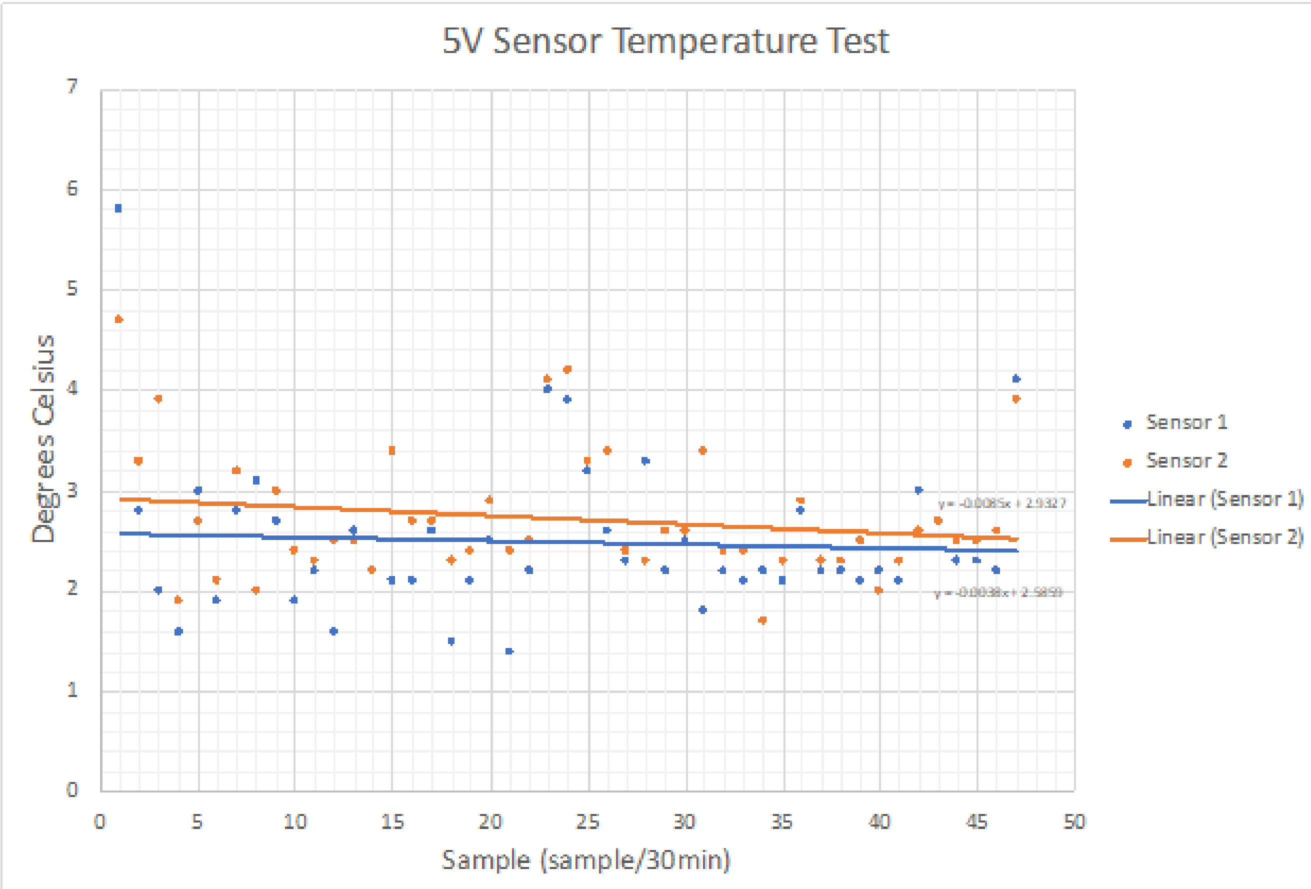


Table 9.1
3.3V Test Percent Error Calculations

Sample	Temp % Error 1	Humidity % Error 1	Temp % Error 2	Humidity % Error 2
1	28.125	36.25	26.5625	57.1875
46	30.76923077	44.4	53.84615385	68
47	58.82352941	28.38709677	88.23529412	44.83870968

** Samples for percent error calculations taken at the beginning and end of the test

4. The results 2a yielded unsatisfactory percent error values. It was hypothesized that the error was due to the volatile environment present within the refrigerator as its environment is modified every time the door is opened. The VDD was changed to 5V and the script was run again.


5V Sensor Temperature Test
Degrees Celsius
Sample (sample/30min)
Sensor 1
Sensor 2
Linear (Sensor 1)
Linear (Sensor 2)
y = -0.0085x + 2.9327
y = -0.0038x + 2.5859

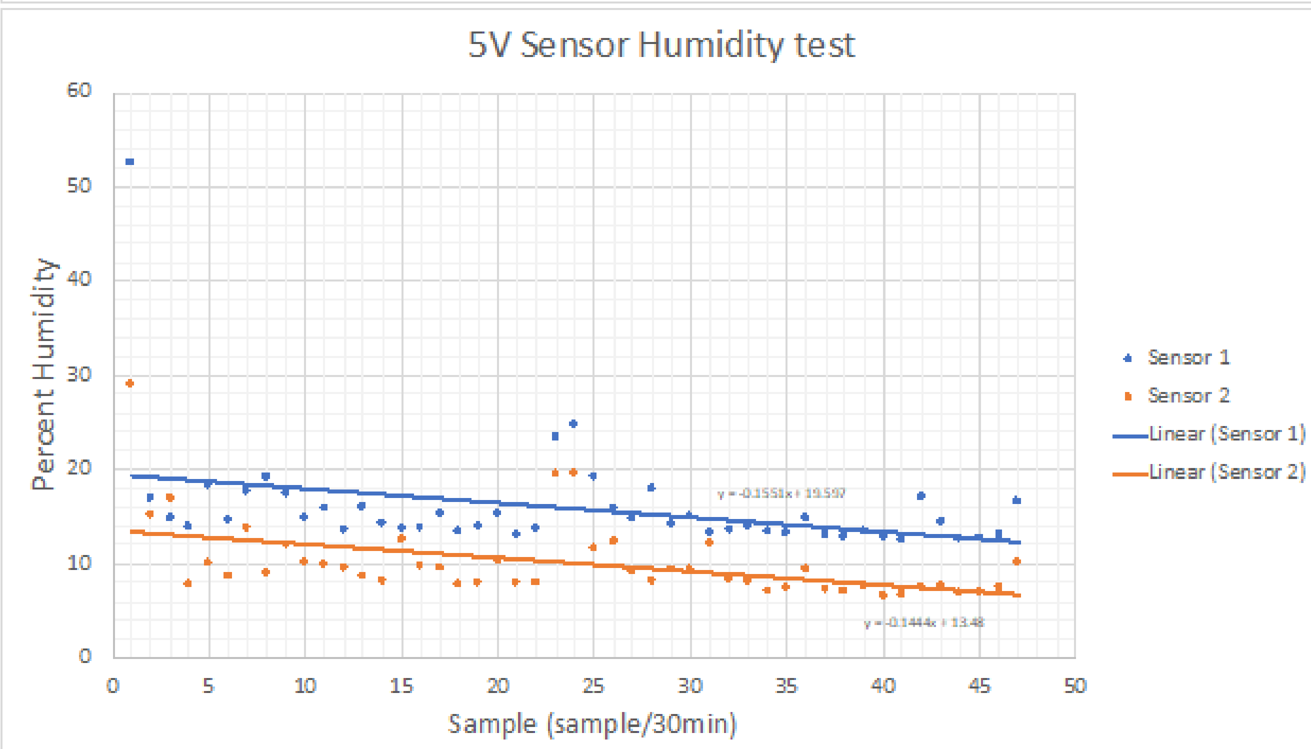

5V Sensor Humidity test
Percent Humidity
Sample (sample/30min)
Sensor 1
Sensor 2
Linear (Sensor 1)
Linear (Sensor 2)
y = -0.1551x + 19.597
y = -0.1444x + 13.48

Table 9.2
5V Test Percent Error Calculations

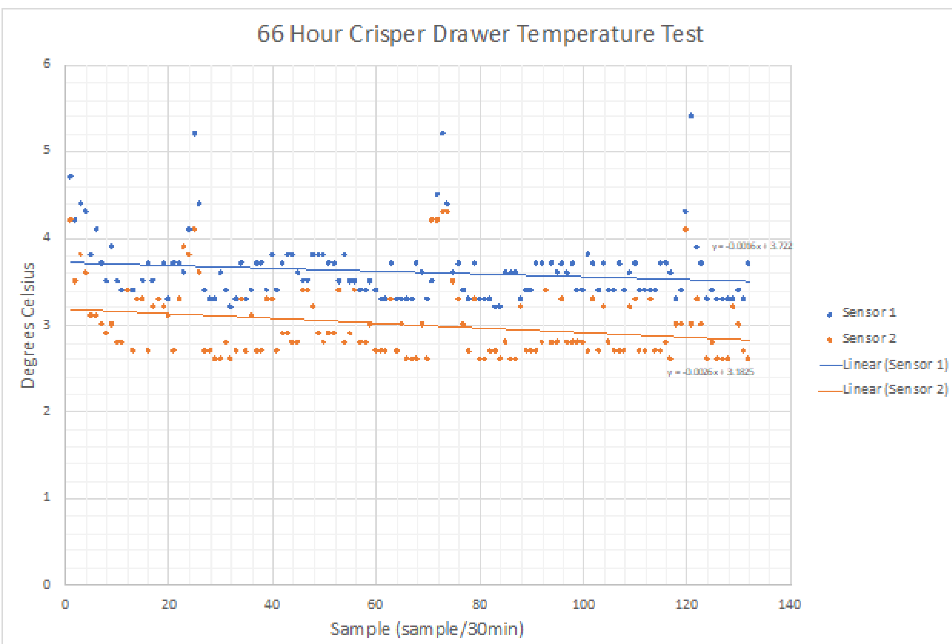
Sample	Temp % Error 1	Humidity % Error 1	Temp % Error 2	Humidity % Error 2
1	87.09677419	13.91304348	51.61290323	37.17391304
42	42.85714286	32	23.80952381	70.4
46	57.14285714	48	85.71428571	70.8
47	28.125	25.45454545	21.875	54.54545455

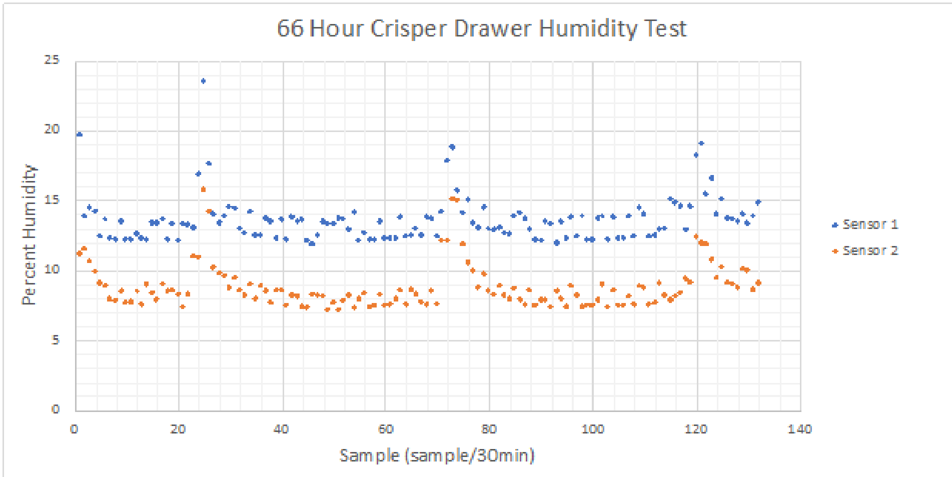
** Samples for percent error calculations taken at the beginning and end of the test

5. The results of the second run were equally unsatisfactory, and there was no noticeable improvement from the increase in VDD.

Results of Experiment 2.b:

The purpose of experiment 2.b was to record the environment within the stock refrigerator crisper drawers. The temperature and humidity data were logged and displayed below. As expected, the temperature and humidity data demonstrated parabolic behavior as the refrigerator allows the temperature to increase to a maximum threshold temperature before resuming the cooling cycle. The increase in temperature allows for the humidity to increase within the drawers thus exhibiting the parabolic trend seen below.





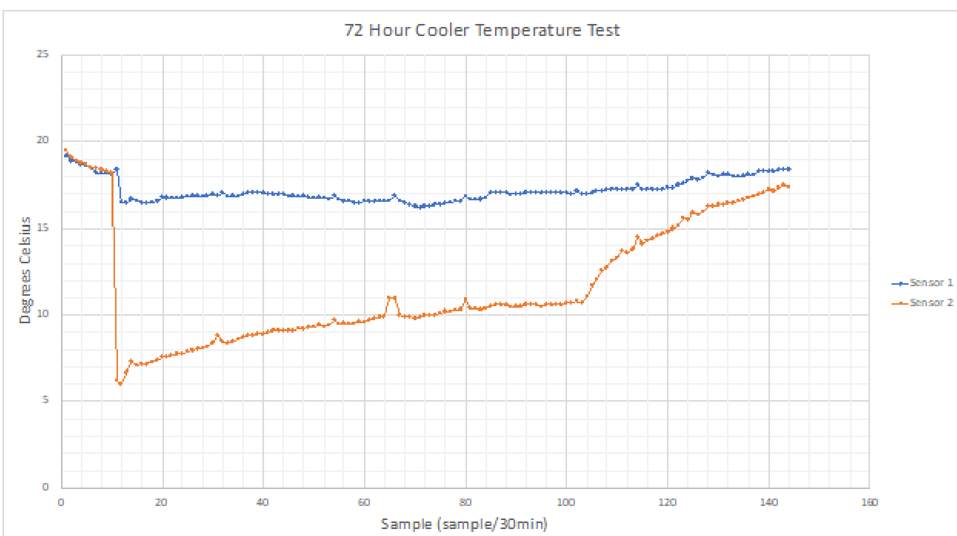
Results of Experiment 2.c:

The purpose of experiment 2.c was to replicate the results of experiment 1 with the new Python3 code and DHT22 sensor. Additionally, the experiment was intended to demonstrate the robustness of the new program and performance of the DHT22 in a stable environment for a prolonged period. Multiple hand measurements were taken to test the sensors' accuracy as well. The experiment was run as follows.

1. The original circuit and DHT22 setup from 2.a were implemented once again at 5v.
2. Two 1”, 11 Liter coolers were setup side-by-side to have a 2” insulating barrier between the two chambers. The experiment will also illustrate if more insulation will be required in future prototypes.

3. The program was initiated, and cooler 2 was filled with 5 liters of ice after the 10th data point was collected. The setup was left running in a stable environment with an exterior temperature of 18.3 degrees Celsius.

4. During the 72hr run manual data recordings were taken at random intervals. The results and percent error calculations can be seen below.



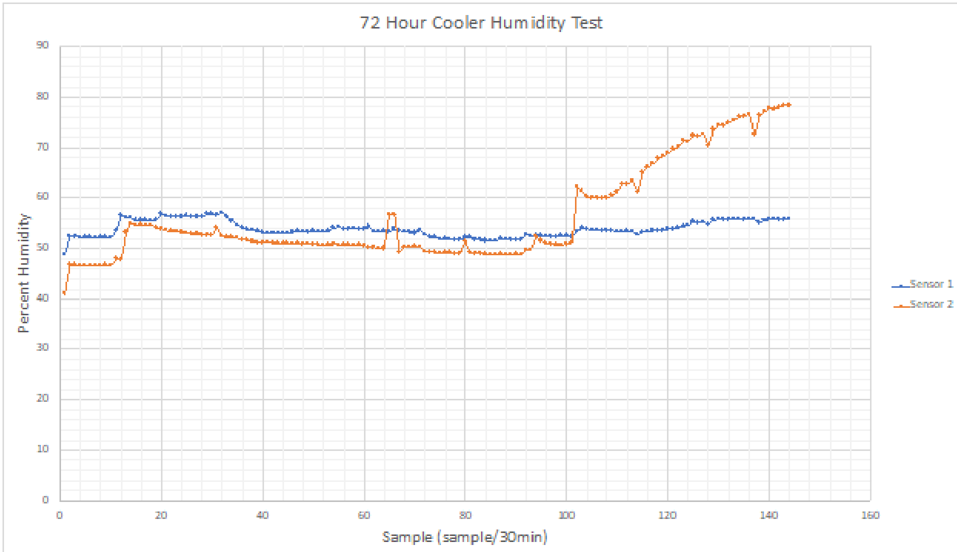


Table 9.3
Cooler Test Percent Error Calculations

Sample	Temp % Error 1	Humidity % Error 1	Temp % Error 2	Humidity % Error 2
9	0.55	11.06	1.08	4.00
18	3.51	6.73	9.88	4.21
30	2.30	5.37	4.55	6.07
52	1.75	4.90	1.06	7.82
64	1.78	4.71	0.00	9.09
78	1.78	3.60	0.00	9.07
90	1.73	3.60	0.00	9.44
100	1.16	3.14	0.94	8.93
112	0.57	4.90	2.16	7.79
126	1.66	8.04	2.47	7.31
136	0.55	7.31	1.18	6.46
144	0.00	7.31	2.25	8.95

** Manual samples for percent error calculations taken at random intervals during the testing period

The 2” insulation thickness proved to be sufficient with only minimal change in temperature and humidity seen within the empty chamber 1, additional air gaps between the chambers can further improve performance.

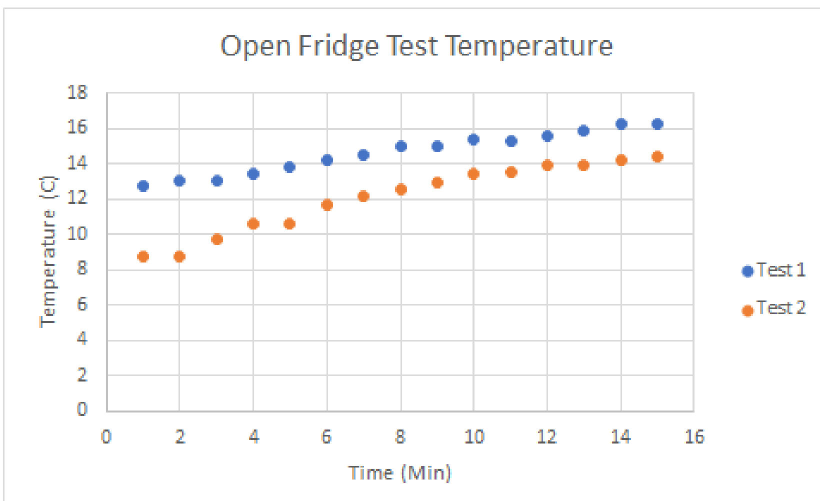
In a stable environment the DHT22 demonstrated an increase in accuracy and yielded much improved percent error numbers. This can be improved upon through increasing sampling rate, detecting and replacing noise values with more accurate values.

Experiment 3: Rate of change in environment with fridge door open with crisper drawer open

With this experiment, we were to find the difference in temperature over time with both the fridge open and drawer open to see the effect it had on both the DHT22 and the digital reader thermometer/humidity reader. The placement of the sensor the digital reader would be where the environment of the fridge and the room would then affect the readings. This test would last about 15 minutes.

The pictures below are how the experiment was done for test 1. These pictures (left to right) were taken at 1 minute, 10 minutes, and 15 minutes. The digital reader at 1 minute was off due to being in the fridge prior to the start and then over time, converted to the values in the DHT22 had.

Results of Experiment 3:



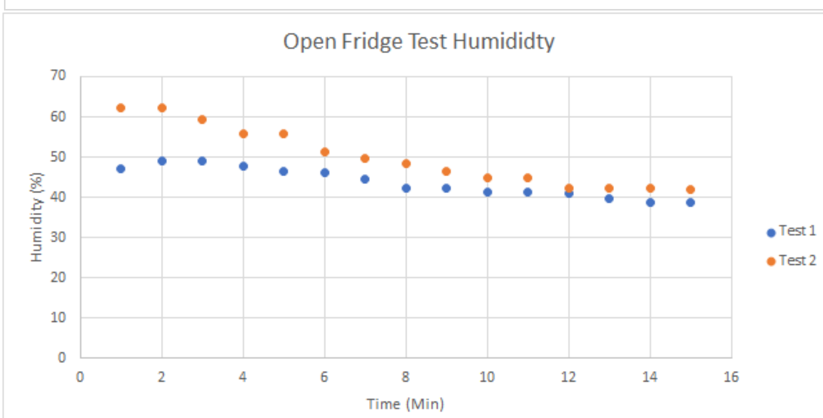


Table 10.1
Experimental vs Theoretical Temperature Test 1

Minute	DHT22 Temp (C)	DR Temp (C)	Aproximation Error (%)
1	12.7	8.3	53.01
10	15.4	15.3	0.65
15	16.2	16.6	2.41

Table 10.2
Experimental vs Theoretical Humidity Test 1

Minute	DHT22 Humidity (%)	DR Humidity (%)	Aproximation Error (%)
1	47.2	46	2.61
10	41.4	39	6.15
15	38.6	36	7.22

Table 10.3
Experimental vs Theoretical Temperature Test 2

Minute	DHT22 Temp (C)	DR Temp (C)	Aproximation Error (%)
1	8.7	7.4	17.57
7	12.2	12.8	4.69
15	14.4	15.5	7.10

Table 10.4
Experimental vs Theoretical Humidity Test 2

Minute	DHT22 Humidity (%)	DR Humidity (%)	Aproximation Error (%)
1	62.1	40	55.25
7	49.6	41	20.98
15	42	36	16.67

Results show that the sensor being nearby two separate environments caused a change in the reading compared to the previous tests where the environment was more closed in. The DHT22 sensor was able to get good temperature measurements when compared with the digital reader. The humidity results of this experiment tell us for this project, placement of the sensors is important to avoid any errors in the readings. With the points for Test 2 at the 5th data plot, that ended up being an error in the results with its value being in the negative temperature and giving a humidity over 100%. For the plot, it is the same as the 4th data plot. To avoid this issue next time, will use the method explained in the component section. This experiment showed the best option would be to place it near the solenoid valve and humidifier to have better readings at the of our containers for the fruits and vegetables.

Experiment 4: Two separate container environments

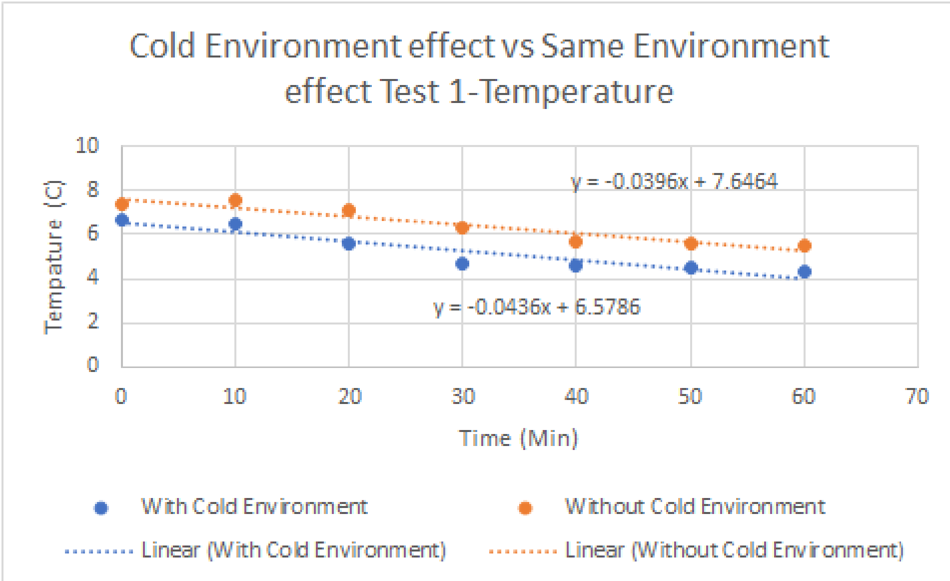
For this experiment, it was to see the effects of a crisper drawer containing a tray filled with ice on an empty, adjacent crisper drawer containing the sensor and a digital reader. To see if a change in temperature made an effect on the sensor drawer, we will compare the container with no ice and the container with ice to see an actual effect. The digital readers and sensors were exposed to the room environment long enough to notice a change in temperature and humidity when put into the fridge. Then for an hour, it measures the change in temperature and humidity. The point of this experiment is to see if an environment influences another environment.

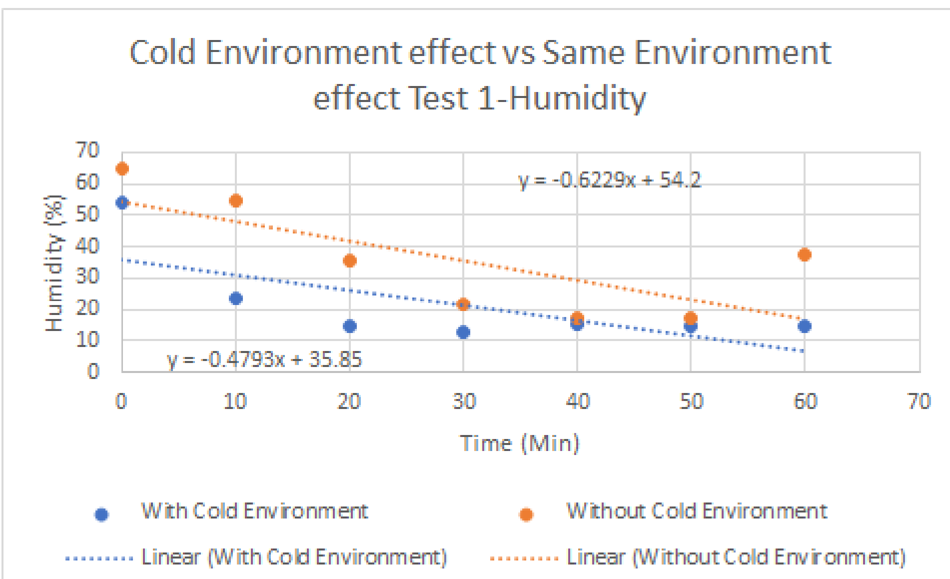
The pictures shown below is how the experiment was done for experiment 2 with ice. On the left shows the temperature when it started at 0 minutes and the right pictures shows after an hour. The sensor is reading temperatures in the left crisper drawer.

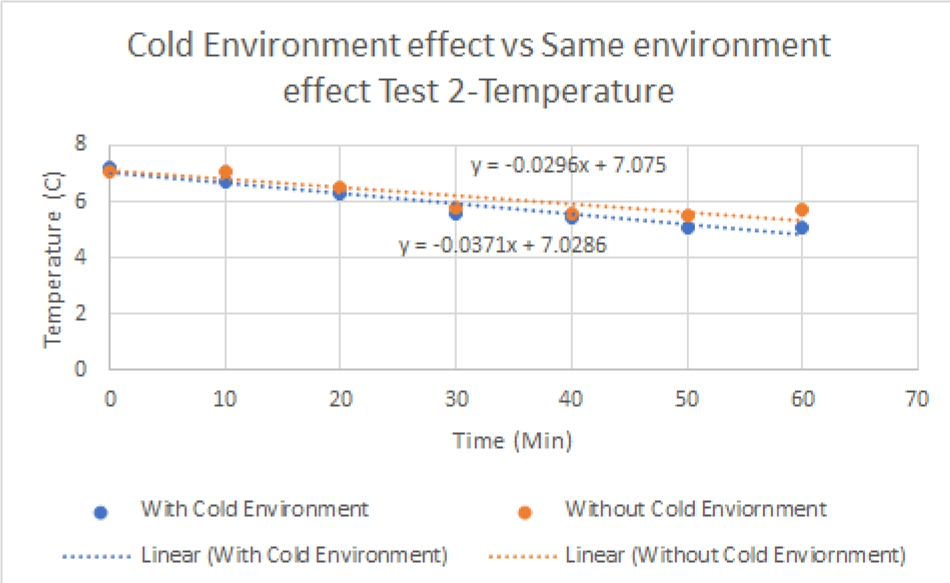

The pictures shown below are for experiment 2 with no ice. The left picture shows at 0 minutes and the right picture shows at 40 minutes. The left side is with the sensors the right side is with no ice


Results of Experiment 4:

The figures below show the results of the tests of the experiment. Note for the intercept, the equation is for the “Without Cold Environment” and Bottom is for “With Cold Environment”.


Cold Environment effect vs Same Environment effect Test 1-Temperature
Tempature (C)
Time (Min)
y = -0.0396x + 7.6464
y = -0.0436x + 6.5786
10
8
6
4
2
0
0
10
20
30
40
50
60
70
With Cold Environment
Without Cold Environment
Linear (With Cold Environment)
Linear (Without Cold Environment)


Cold Environment effect vs Same Environment effect Test 1-Humidity
Humidity (%)
Time (Min)
y = -0.6229x + 54.2
y = -0.4793x + 35.85
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
With Cold Environment
Without Cold Environment
Linear (With Cold Environment)
Linear (Without Cold Environment)



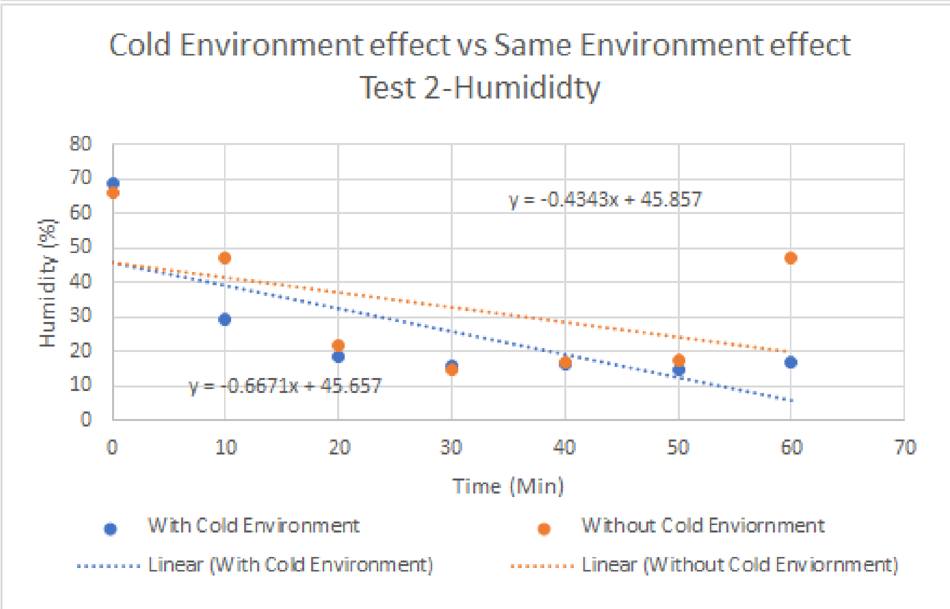


Table 11.1

Experimental vs Theoretical Temperature, With Ice Test 2

Minute	DHT22 Temp (C)	DR Temp (C)	Aproximation Error (%)
0	7.2	8.8	18.18
60	5.1	4.5	13.33

Table 11.2

Experimental vs Theoretical Humidity, With Ice Test 2

Minute	DHT22 Humidity (%)	DR Humidity (%)	Aproximation Error (%)
0	68.6	47	45.96
60	16.1	22	26.82

Table 11.3
Experimental vs Theoretical Temperature, Without Ice Test 2

Minute	DHT22 Temp (C)	DR Temp (C)	Aproximation Error (%)
0	7.1	7.5	5.33
40	5.6	4.8	16.67

Table 11.4
Experimental vs Theoretical Humidity, With Ice Test 2

Minute	DHT22 Humidity (%)	DR Humidity (%)	Aproximation Error (%)
0	65.80	45.00	46.22
40	16.70	22.00	24.09

The results of the experiment show that temperature and humidity sensor is not affected by the change in environment from an adjacent compartment. The rate of change for temperature is close and shows that there is little to no change with the different environment and with a same environment. At points, the humidity with no ice and with ice almost match to be the same except for a few times. For unknown reasons it makes spikes in its values and has greater approximation errors as a result. This will be addressed by making code to only allow act on values that are not obviously inaccurate.

Testing Plan

Testing will be done in Four main experiments, but equipment and software testing will happen throughout the building phase to make sure both software and equipment works as intended without being connected to other devices first. Testing individual functions is necessary to ensure components turn on, off, open, or close depending on the software and device being tested.

Experiment #1 (Mission Requirement Evaluation)

Goal: Measurement of Decay in contents of Crisper.

System Components: Completed Fridge, Measuring Devices, DC

Testing Process:

- After turning on and selecting crisper number and contents from list, measuring devices will measure how much vitamin A and other decaying elements decrease over the testing period.
- Data collection from devices will be done every 24 hours for each food item in crisper being tested for 1-2 weeks.
- Data collection will be done twice for 2-4 fruit types and 2-3 vegetable types.

Data Processing and Visualization: The data will be plotted onto a graph with datapoints for each food.

Evaluation: Data will be compared to average decaying times of food items. Will see if our fridge increases amount of days food stays fresh and how much longer they stay fresh.

Note: A test could be done with an Assortment of Fruits and Vegetables in each crisper. We can experiment with a crisper having a mix of fruits or vegetables if there is time.

Experiment #2 (Operational Requirement Evaluation)

Goal: To test that all devices work as supposed to once fridge is put together fully.

System Components: Completed Fridge, Measuring Devices

Testing Process:

- After turning on, we will measure current, voltage, and power into all devices.
- Will test the display and interface by going back and forth through compartment numbers and food lists using interface buttons and seeing feedback on display.
- Will test each compartment's ability to maintain a steady environment by choosing a food setting then analyzing the data from that compartment.
- Data collection will be from the sensor.
- Data collection will be done for 1-2 hours for each compartment taking temperate and humidity data every 10 mins.
- Data collection will be done 5 times for each compartment. Changing the user input in such a way that only one variable changes for 4 of the trials. For example, for trial 1 only temperature increases, but for trial 2 only humidity increases, and so on. The fifth trial though will be changing selected food items every 20 mins, thus changing the environment each time.

Data Collection: Measurment's will be recorded

Evaluation:

- Verification that measurements match the desired values.
- Verification that displays and interface works, by showing feedback of interface chooses and sensor data.
- Verification that environment becomes steady after obtaining the desired environment.

Experiment #3 (Functional Requirement Evaluation)

Goal: To make sure that DHT sensor data is correct.

System Components: Fridge, Battery powered temperature and humidity sensor

Testing Process:

- A comparison will be made between the DHT sensor data and a battery temperature and humidity sensor that will be placed in each compartment.

- Data collection will be for 8 hours, with new user input every 2 hours. We will change either the temperature or humidity user inputs, but not both at the same time.
- Sensor data will be sampled every 10 mins.
- Data collection will be done twice for each crisper.

Data Processing and Visualization: Data collected from both sensors will be put in a graph to compare.

Evaluation: By focusing on data comparing DHT sensors to the battery powered sensor's temperature and humidity values, we can determine that the DHT sensors are working correctly.

Note: Testing time could be extended to be for 12 hours with changing times being every 3 hours if not enough data is being generated. May also need to change sensor data sampling times every 5mins instead of 10mins.

Experiment #4 (Function Error Requirement Evaluation)

Goal: To have processing module detect errors and either fix them by restarting device or shutting them down and telling user about error.

System Components: Fridge, Battery powered temperature and humidity sensor, PC, Timer

Testing Process:

- After turning on will induce error in the form of removing a DHT sensor to see how processing module handles not having a sensor.
- Data collection will be in the form of timing how long it takes an error message to show up on the Display.
- Will be done 3 times.
- Another error test will be keeping crisper door open for 2 hours.
- Data collection here will be by both sensors with sensor data being taken every 10 mins.
- At the same time will time how long error message takes to show on display.
- Data collection will be done 3 times.

Data Processing and Visualization: Raw data in the form of the display times will be record for removing sensor error. Raw data in the form of sensor data will be recorded alongside display times then plotted using a PC to see if error message sending times need to be adjusted in code for crisper door error.

Evaluation:

- Will focus on Detecting times for errors.
- Verify display error messages happen.

Tasks

Hardware Implementation:

The hardware team consists of Nestor, Matthew, and Michael, who will oversee the following tasks:

- Mounting the Components:
    1. Fixing the components to their final position
       The components and their positions will first be measured to make sure they can be mounted safely. After they will be placed in their positions to see if any adjustments need to be made before mounting and installing begins.
        - Responsible: Nestor
    2. Soldering components to the data and/or power cables
       All soldering of components will happen before installation of those components into their compartments.
        - Responsible: Nestor

- Mechanical modifications:
    1. Drilling into the fridge
       Drilling holes into a fridge requires careful consideration. To avoid cutting into components, drilling a hole into the side of the fridge is the best option. The drill will be set to the slowest setting and after cutting each layer we will do a visual check for damageable components.
        - Responsible: Matthew
    2. Making A/C tube connections
       The tubing shall be run out of the box that is collecting the cool air and into each compartment. To make the build process easier, the tubing will be attached to the compartments before placing the compartments in the fridge.
        - Responsible: Matthew
    3. Installing drain system.
       Installing the drain system will be done in a comparable way as the A/C tube connections but with smaller tubes. The drain tubes will be prefabricated to the compartments before placement.
        - Responsible: Matthew
- Wiring:
    1. Cable management
       The cables shall be enclosed within a liquid tight conduit tubing to keep it both protected and organized. They will have no sharp bends in the tubing for both safety and so that the wires will not be at risk of being pinched.
        - Responsible: Michael

Early in the semester, the hardware team will attempt to locate a refrigerator from the transfer station to practice drilling, wiring, and mounting. This is to help ensure that no mistakes will occur when working on our final system.

Software Implementation:

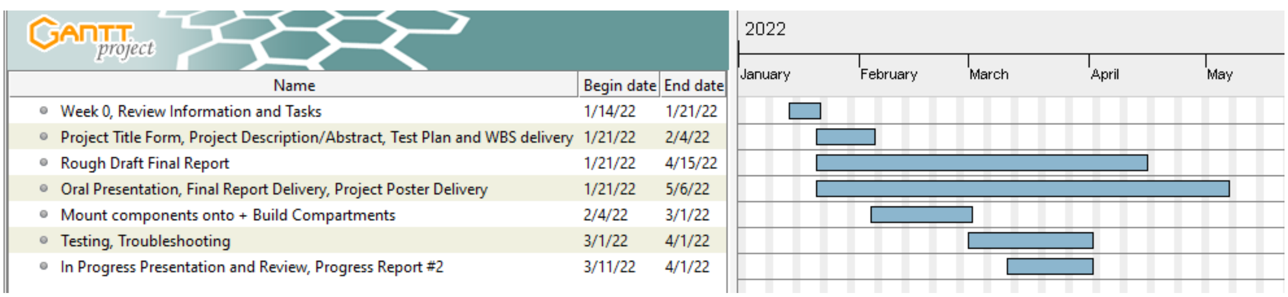
- Code at the external I/O level:
    1. LCD will be the main output media to the user. There will be a main screen, displaying a representation of each chamber in list view, as well as a settings bar at the bottom of the list. The user will use buttons to navigate through this main screen, then for each chamber selected, the user will be presented with a list of presets to select according to the type of produce needed to be stored in the chamber in question. The user will also be presented with an option to disable a certain crisper or re-enable it when they see fit to do so. Otherwise, if no produce is in a crisper or on/off option selected than the crisper will automatically be set to a predetermine basic environment. The settings bar will provide the user options including changing Display Brightness and changing units between metric and imperial.
        - Responsible: Cameron, Zach, Ahmed
    2. Buttons shall be the main input media from the user. There shall be four main buttons: up, down, back, and select. These buttons should be debounced through software handled by the slave raspberry pi, where an edge will be registered after a certain amount of time from the button press.
        - Responsible: Ahmed
- Code at the relays level:
    1. Temperature/Humidity sensor: In five-minute intervals, the master raspberry pi will accept data input from the sensors through GPIO ports, after calling the relay function that will activate the sensors. The data will only be recorded and handled in one chamber at a time. From our initial testing, we noticed that DHT22 sensors can and will record “noise values”, which are spikes of high magnitude above or below the previous values. Therefore, the final code shall detect such values and retry the recording. The raw data will be converted to Metric/Imperial units (according to a setting set by the user) and will be compared with the presets as given from the slave raspberry pi.
        - Responsible: Ahmed
    2. Solenoid Valves: After comparing the measured temperature with the preset of the chamber in question, certain logic will be operated: If the recorded temperature is less than the preset, the master will contact the slave to display an error message (this is a point where the system would require human interference). If the recorded temperature is within the preset boundaries, the temperature data will be sent to the slave which will display it. If the recorded temperature is higher the preset, the master will actuate the relays needed to allow cold air to enter the chamber and send the temperature data to the slave.
        - Responsible: Cameron

3. Misters: After comparing the measured humidity with the preset of the chamber in question, certain logic will be operated: If the recorded humidity is greater than the preset, the master will contact the slave to display an error message (this is a point where the system would require human interference). If the recorded humidity is within the preset boundaries, the humidity data will be sent to the slave which will display it. If the recorded humidity is lower the preset, the master will actuate the relays needed to activate the misters and send the humidity data to the slave.
    - Responsible: Zach

Milestones

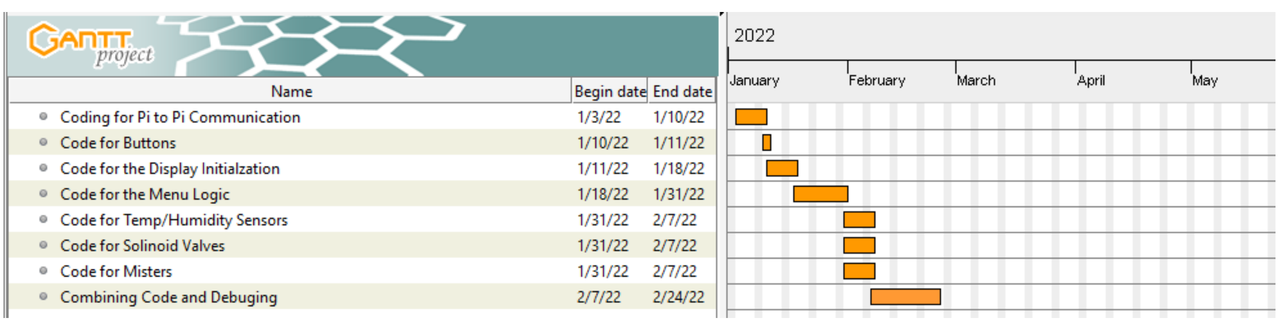
- Obtained Fridge
- Created 2 models of prototypes
- Did multiple experiments

General Schedule



Name	Begin date	End date
Week 0, Review Information and Tasks	1/14/22	1/21/22
Project Title Form, Project Description/Abstract, Test Plan and WBS delivery	1/21/22	2/4/22
Rough Draft Final Report	1/21/22	4/15/22
Oral Presentation, Final Report Delivery, Project Poster Delivery	1/21/22	5/6/22
Mount components onto + Build Compartments	2/4/22	3/1/22
Testing, Troubleshooting	3/1/22	4/1/22
In Progress Presentation and Review, Progress Report #2	3/11/22	4/1/22

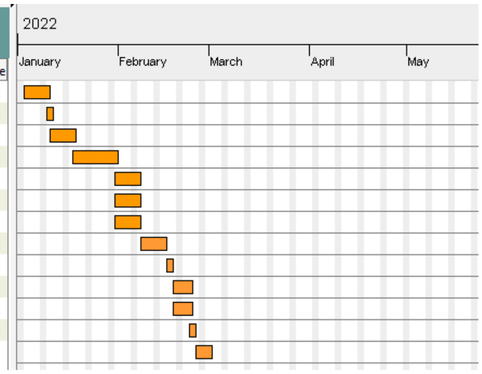
Schedule for Code Team



Name	Begin date	End date
Coding for Pi to Pi Communication	1/3/22	1/10/22
Code for Buttons	1/10/22	1/11/22
Code for the Display Initialzation	1/11/22	1/18/22
Code for the Menu Logic	1/18/22	1/31/22
Code for Temp/Humidity Sensors	1/31/22	2/7/22
Code for Solinoid Valves	1/31/22	2/7/22
Code for Misters	1/31/22	2/7/22
Combining Code and Debuging	2/7/22	2/24/22

Schedule for Build Team

Name	Begin date	End date
Find Access points and drill holes to run control wires into fridge	1/3/22	1/10/22
Mount Enclosure box on A/C vent. Mount Outside control box to Hold pi, relayes, etc	1/10/22	1/11/22
Mount display on fridge door.	1/11/22	1/18/22
Run control wires for tube control from control box to the A/C vent box that is inside the Fridge.	1/18/22	1/31/22
Run and connect wires from the control box to the display for the power and control to LCD screen, and buttons.	1/31/22	2/7/22
Build compartment to be placed into fridge	1/31/22	2/7/22
Cut holes into compartments for A/C tubeing and control wires	1/31/22	2/7/22
Cut holes into Compartments for water draining	2/8/22	2/15/22
Build water catcher	2/16/22	2/17/22
Attach Compartments into the inside of fridge leaving a gap behind for the wire tubeing	2/18/22	2/23/22
Attach Compartments into the inside of fridge leaving a gap underneath for the water collector	2/18/22	2/23/22
Connect Water tubeing from Compartments to water Catcher	2/23/22	2/24/22
Finish connecting rest of tubeing and control wires.	2/25/22	3/1/22



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