University of Ottawa
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GNG 5140 Engineering Design

Project Deliverable C: Design Requirements and Project Plan

Group 4 – Sustainable Food Storage

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Abstract

This report investigates and analyzes an existing prototype for food storage in Eastern Canada: an above-ground vegetable root cellar designed by a local grassroots organization called Deep Roots Food Hub. The report examines the design features, flaws, and user test results. From the aforementioned, the team proposed intended fixes to the flaws. Based on these proposals and looking at alternative solutions, the team outlined a revised project requirement, an updated problem statement, and a new prototype definition.

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List of Acronyms

Acronym	Definition
DRFH	Deep Roots Food Hub
HVAC	Heating, Ventilation, and Air Conditioning

1 Introduction

Higher temperatures, water scarcity, extreme events like droughts and floods, and greater CO_2 concentrations in the atmosphere have already begun to impact staple crops around the world [1]. Maize (corn) and wheat production have declined in recent years due to extreme weather events, plant diseases, and an overall increase in water scarcity [1]. The threat of the varying global climate has greatly driven the attention of scientists, as these variations are imparting negative impact on global crop production and compromising food security worldwide [2].

As discussed, climate change poses an eminent threat to growing our crops and sustaining our population's food consumption. With climate change reducing harvests, this means that the lean period (skipping one or more meals a day to reduce food consumption) may be extended if there are fewer supplies, or if it takes longer to get an adequate harvest. In many food-insecure areas, such as Eastern Canada, agriculture and food production is seasonal (during the Summer and Fall seasons); leaving the population to rely on the harvests for the Winter and Spring seasons. However, the harvests from our local farmers are not enough to sustain the current population of Easter Canada during these seasons. Therefore, a lot of the food we consume has to be imported from warmer climates.

The aforementioned factors are motivators for a working, all-year round crop storage. Providing long-term storage for crops in a well-designed environment will decrease the likelihood of having to extend the lean period, and thus, have enough crops available. This will sustain a controlled population during foreseeably harsher climate conditions and moments of uncertainty, which can include an increase in food prices due to a lower production and higher demand.

The Deep Roots Food Hub (DRFH) is a grassroots, West Carleton-based non-profit organization that aims to create a secure, sustainable food system in West Carleton, Ontario [3]. This system is in the form of a prototype root cellar (see Figure 1).

Figure 1. Root cellar exterior (February 2020).

This above-ground cellar and off-grid storage structure provides small-scale vegetable growers with a post-season sustainable and energy-efficient storage facility, providing longer root crop storage and extended sales and/or distribution possibilities [3]. Prior to bringing this prototype design to life in the West-Carleton area, there wasn’t a community-based storage space for local root crops. This innovative Quonset-styled metal building is designed to capture and circulate ground-sourced geothermal heat to maintain a near-constant + 2°C temperature and 90-95% humidity within the structure's root storage chamber [3].

There are other more traditional methods of prolonging root crops such as: freezing, canning, and dehydrating. However, these methods involve having to thaw them in order to be readily edible (in the case of freezing), or are laborious in practice (such as the case of canning, which must be done to some root vegetables because of their low acid content).

The controlled environment in the root cellar is better at providing fresher and readily-available foods (no waiting for food to thaw – which could take hours depending on the environment), and extending the life of root crops.

The main objective of this report is to summarize and analyze the existing prototype test results to refine our design requirements, problem statements, and prototype definition. This will help us better understand the prototype’s performance and flaws. This report will discuss in detail the main features of the root cellar’s subsystems, the shortcomings of the subsystems, user test results of the prototype, intended design fixes to overcome the flaws, revised design requirements, updated problem statements, and a new prototype definition.

2 Prototype Test Results and Analysis

2.1 List of Metrics

Each metric has its own importance value, with larger ones being more important.

Table 1. Critical Metrics.

#	Metric	Importance Value	Unit
1	Size of each storage chamber area	1	ft^2
2	Total storage area after shelves being installed	2	ft^2
3	Total chamber volume	2	ft^3
4	Target indoor temperature	4	°C
5	Target indoor humidity	4	%
6	Wall insulation material heat resistance	4	k/W
7	Total heat exchange with the outside	3	W
8	Heat distribution within the storage chamber	3	List
9	Maximum power usage	5	W
10	Power source output rating	4	W
11	Electricity storage capacity	4	Ah
12	Heat source output rating	3	Btu/kW
13	Heat gains from gravel floor	3	btu/kW
14	Time required to heat up the chamber	2	Min
15	Time required to stabilize the humidity	2	Min
16	Straw bale heat resistance	3	k/W
17	Time for snow/ice to melt in straw bale	1	h

18	Time required to cool down the chamber	3	min
19	Cooling system capacity	4	btu/kW
20	Autonomous control of the backup generator	1	Binary
21	Weather forecast integration	2	Binary
22	Wireless connection stability test	1	Binary

2.2 Existing Design Features and Flaws

2.2.1 HVAC system

The HVAC system consists of heating, cooling, and ventilation elements.

- **Ventilation**

The root cellar has a simple duct system to bring in fresh air from outside and exhaust air from inside to outside.

Above the main doors in the antechamber, there is an external intake vent that connects to an insulated flexible duct, which then connects to the main chamber fan assembly. The main assembly has a manual damper installed that can be used to restrict extremely cold or hot air from entering the root cellar.

In the main chamber there is a lower duct assembly. This assembly has a simple flap that opens when there is minimal air pressure built up in the main chamber that requires to be exhausted. This air goes into the antechamber.

In the antechamber there is a lower duct assembly. This assembly has a manual duct, to prevent extreme cold or hot air to enter the antechamber. Also, there is a duct flap on the exhaust vent that allows air to be exhausted from the antechamber to outside. This duct flap requires minimal air pressure to be allow air to be exhausted.

- **Heating**

Heating is mostly supported by a simple floor system. The flooring system is comprised of a raised insulated floor sitting on top of concrete blocks at a height of eight (8) inches. The purpose of the floor is to control the amount of warmed air that is available from the warmth of the ground that can be circulated within the main chamber. At the start of the storage season, it is possible that the ground temperature can prevent the temperature in the main chamber to drop to the desired storage temperature, thus the need to insulate it. Also, the captured warm air can be used to warm up the main chamber when temperatures outside drop significantly so that the main chamber temperature is maintained between 2 to 4C. Warm air can be circulated using the fans. However, if the solar system fails to store enough power throughout the day, and cold temperatures are looming, it is possible to remove some of the floor panels to let the warm air to circulate naturally throughout the main chamber.

- **Cooling**

There are two ways to cool down the chamber. The first to open the vents at night to cool down the chamber with outside air because the temperature at night is low. The second method is to utilize Icehouse Strawpile, which is invented by the client. It consists of a straw bale and 3.78 antifreeze containers, which is equivalent to a device that can perform convection heat transfer. 260 of which is equivalent to 1 ton of water. Divide them into 4 layers and make with chlorine paste. Insulating and inert. The user first uses the cold air in the environment to cool the water in the container, freezing them into ice. And then closes the vents that bring in ambient air and opens the vents that bring in cellar air. The air in the cellar can be cooled by ice cubes, and then returns to the cellar to achieve the purpose of cooling.

- **Flaws of current HVAC**

The insulation is R40 for the rear wall and the wall dividing the main chamber from the antechamber. The front wall and side walls are R20 in the antechamber. The spray foam (8 inches thick) is about R 48, on the side walls of the produce chamber only. This insulation combined with the floor heating is not enough to keep the chamber temperature above 2C, a record by the client shows that main chamber temperature decreases from 3C to 1C within 3 hours when the outside temperature drops from 0C to -12C. Two 250W electric heaters are required to be turned on when outside temperature is below 15C.

Although the Icehouse Strawpile has not ran at all since last fall due to the extreme cold of this winter, the stored ice usually melts in 2-3 days when outside temperature is on average of 5C which is too short for spring time.

2.2.2 Power system

In existing root cellar energy generation is dependent only on solar power. A more diversified energy generation is required.

The current root cellar has 6 solar panels which is 100W each. Energy generation:

- On bright sunny day: 500W
- On cloudy days: 200W

Current OVERNIGHT energy consumption is 300W

So, assuming total energy consumption will be 800W (at max)

Due to Canadian weather, sun is not bright 60% of times in a year and hence solar energy will fall short of matching the power demand.

2.2.3 Storage

The current DRFH project consists of three above-ground storage structures, all off-grid and on NCC land close to the Federal Government's Communication Research Centre's campus on the western portion of Carling Avenue. The three structures are: the root cellar (Figure 2), storage container (Figure 3), and storage shed (Figure 3).

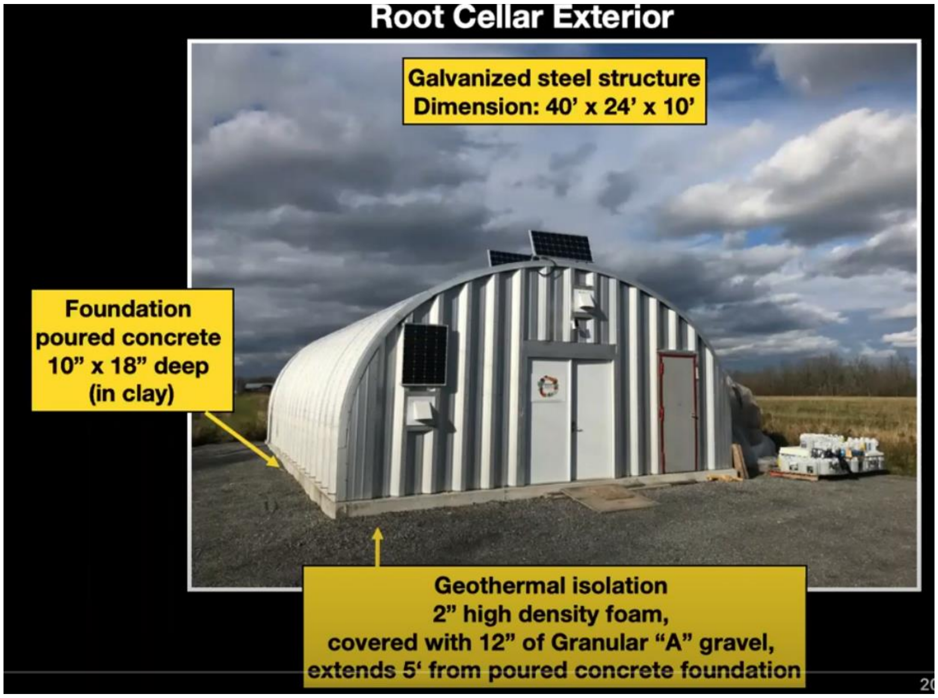


Figure 2. Exterior of the root cellar with dimension estimates

Figure 3. Storage shed (left) and 20’ steel storage container (right)

The root cellar is the largest structure on the property. According to an informative video by Barry Bruce [5], the entire root cellar measures 37’ by 24’ by 12’ high, which is equivalent to 10,656 sqft. This value is slightly higher than the value obtained from the dimensions stated in Figure 2, which is 9,600 sqft. Because of the different values, we know that there is a flaw in the numbers stated in the sources or a flaw in the measurements. A summary of the dimensions obtained from 3 different sources is summarized in Table 2.

Table 2. Dimensions of the root cellar according to three sources

Source	Main produce chamber (usable food storage area)				Entrance/Antechamber (utilities, air inlet and outlets, and storage batteries housed here)				Entire root cellar (main produce chamber + antechamber)			
	W	L	H	Total (sqft)	W	L	H	Total (sqft)	W	L	H	Total (sqft)
DRFH website [3]	21	20		400	25	12		300				
Informative video speech [5]		24				12			37	24	12	10,656
Slides from informative video [6]						10			40	24	10	9,600

Note: Some cells are empty because the value was not stated in the source(s).

The team hasn't been able to visit the root cellar in person to re-measure these dimensions. However, based on the data from Table 2, we can assume an average value for all three dimensions (width, length, and height). The average height of the entire root cellar structure is set as 11', the length is 24', and the width is 38.5'. The dimensions of the entrance/antechamber are set as 11' for the height, 11.4' for the length, and 25' for the width. The dimensions of the main produce chamber are set as 11' for the height, 22' for the length, and 21' for the width. These values are summarized in Table 3.

Table 3. Average dimension values for the main produce chamber, entrance/antechamber, and entire root cellar.

Main produce chamber (usable food storage area)				Entrance/Antechamber (utilities, air inlet and outlets, and storage batteries housed here)				Entire root cellar (main produce chamber + antechamber)			
W	L	H	Total (sqft)	W	L	H	Total (sqft)	W	L	H	Total (sqft)
21	22	11	**5,082**	25	11.4	11	**3,135**	38.5	24	11	**10,164**

From Table 3, it can be observed that the total square footage from the main produce and the entrance/antechamber does not match/add up to that of the entire root cellar. This can be due to dimension inconsistency in the three sources from Table 1. To obtain the actual dimensions of the two chambers, we will have to either go to the root cellar in-person and measure or ask our client, Barry Bruce, for confirmation of the actual dimensions.

It is important to note that there is a height difference between the main chamber and the antechamber. This difference is brought on by fans in the floor that help pull warm air up from the floor-to-ground gap to heat up the produce/storage chamber (see Figure 4). These fans are activated when geothermal heat is needed to maintain storage chamber temperature if temperature drops below a target threshold of +2 °C.

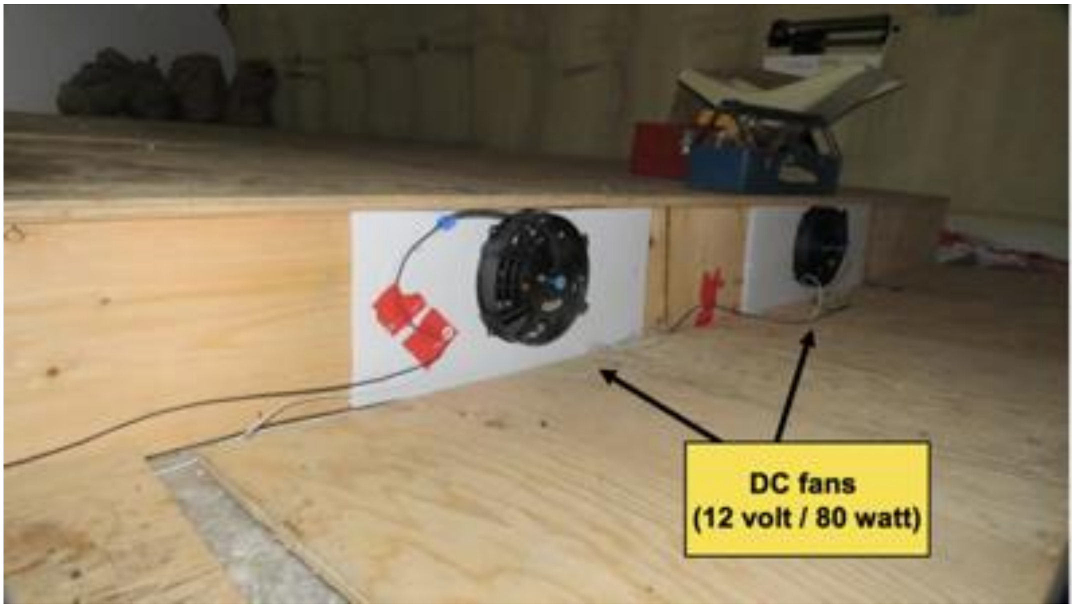


Figure 4. Storage Chamber **Floor fans in the root cellar.**

As for the extra storage structures, the storage shed dimensions are unknown. Items such as the generator and gasoline are stored in the shed and not in the root cellar because it is illegal to run and store them in an enclosed space. The metal storage contained measures 20’ in length but the width and height dimensions are unknown. This metal container is used to store clutter from the antechamber, construction and building materials, and more.

The main chamber is lacking the framework (such as shelving units) to maximize the quantity of produce that can be stored. When DRFH started storing produce for the first time since the launch of the cellar, there was no additional storage structure (such as racks) other than the floor surface area and a prototype box made of 4 mm coroplast and plywood (see Figure 5). In November 19, 2020, the cellar contained about 5,000 pounds of various root vegetables in storage. The latter makes up for about 10% capacity of the main chamber space. As shown in figure 5, The blue boxes are plastic storage boxes from a local farmer, who asked DRFH to store her produce there (boxes on left side). The plywood boxes in the center isle and right-side house smaller boxes made of coroplast. These coroplast boxes hold between 18-24 kg of produce in an efficient use of space. One layer (between two plywood sheets) can hold 16 of the coroplast boxes. The coroplast provides additional insulation.

Figure 5. Items stored in the main chamber of the root cellar on November 19, 2020.

The client mentioned that some issues with the storage were 1) the lack of organization, 2) the lack of shelving units, and 3) division of the space to house different root vegetables that prefer different climates. There definitely needs to be an increase of surface area available to increase the amount of produce stored. Once shelving units are installed, we'll be better able to estimate the ultimate storage capacity of the storage chamber.

2.3 Testing Results

This section contains the testing results captured by the user.

- HVAC

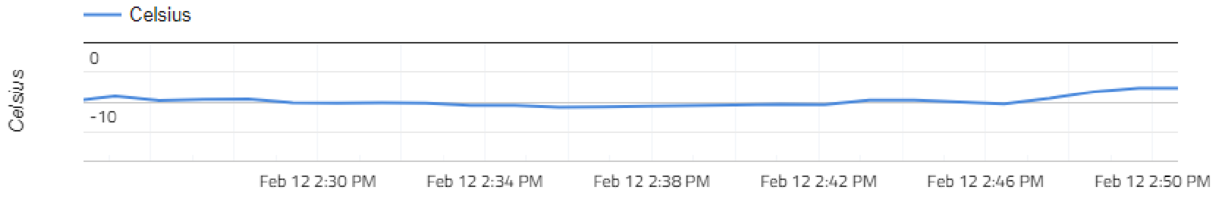


Figure 6. External temperature captured by DS18B20 sensor

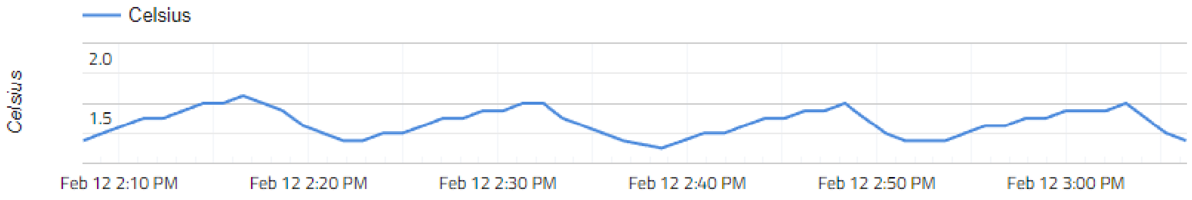


Figure 7: Main chamber temperature captured by DS18B20 sensor

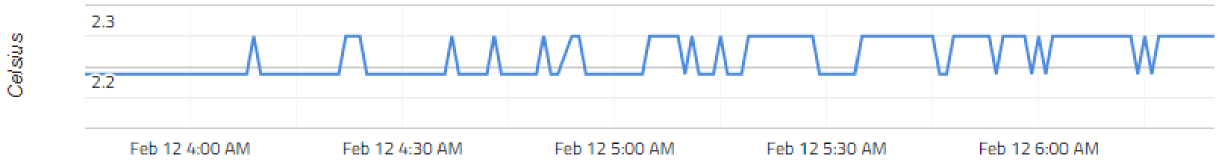


Figure 8: Under floor temperature captured by DS18B20 senor

The above three figures are the temperatures captured by sensor DS18B20 on Feb 12th, note that there was rapid outdoor temperature decline on that day due to snowing and strong wind. The main chamber temperature was consistently below 2C which was lower than the targeted 2-4C. And the under-floor temperature was also below 2.5C, the fluctuation was due to the fans being turning on and off to warm up the main chamber. This test shows that the current heating method is insufficient when temperature rapid declines.

- Power system

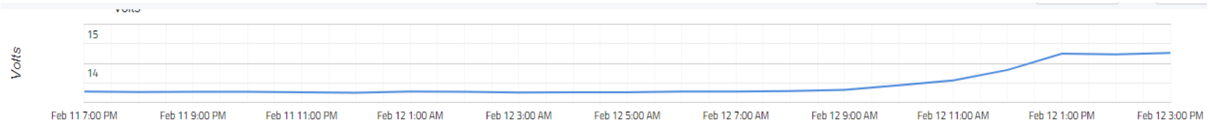


Figure 9: Battery level recorded by Raspberry Pi

The above figure shows the battery level from Feb 11th 7PM to Feb 12th 3PM, the battery level remained low until the next day when solar panel restarts. It also shows that the battery level was over 13 V for the whole night which means it was not completely drained through this time. Therefore, the power system is sufficient to support the root cellar's electronics for at least 24 hours while the heaters were remaining turned off.

- Storage size

Client estimated that the chamber can store 50,000 kilograms of food based on the current storage he had.

3 Revised Prototype Requirements, Problem Statement, and Prototype Definition

3.1 Intended Design Fixes

3.1.1 HVAC

- A better method to collect geothermal energy shall be investigated, **Figure 8** shows that the under-floor temperature is too low to keep the main chamber warm. To better facilitate convective heat transfer between the warmer air under the floor and the cooler air in the cellar, fans need to be installed. There are currently four fans, and the number of fans can be doubled. If there are eight fans rotating together, it will increase the rate of indoor air flow and achieve the purpose of rapid heating.
- In particularly cold weather, geothermal heat alone cannot meet the heating needs of the room. We need to add multiple heaters artificially. The power of the heater can be between 250 and 1000 watts.
- When cooling is required, we want to be able to isolate the heat from the floor. At the start of the storage season, it is possible that the ground temperature can prevent the temperature in the main chamber to drop to the desired storage temperature. Therefore, another layer of insulating material can be laid on the original floor. The insulating material may consist of thick foam pads that are easy to install and remove. The heat transfer coefficient of the foam pads can be 4.26m2•CW [4].

3.1.2 Power System

More diversified renewable energy generation options are needed. Here are some proposed solutions for more energy generation:

1. Adding solar panels:

Addition of a few more solar panels can be done. If the space on roof of root cellar is not enough then the solar panels can be installed on the space around root cellar.

- **Calculation:**

  Increasing the count of solar panels to 10 (100W each)

  Hence, energy generation would range from 350W – 850W.

  Worst Case scenario: 350W

- **Result:**

  10 Solar cells can produce a minimum of **350W** in worst case scenario.

2. Wind energy:

Canada's geography makes it ideally suited to capitalize on large amounts of wind energy. It has one of the highest wind flows in the world. Unlike solar energy, wind energy can be collected 24/7.

- **Calculation:**

  Q = Qty

  W = Watt of wind turbine

  H = Hours of operation

  C = Capacity factor

Two 800W wind turbine running only 2 hours per day at 15% efficiency can produce:

Q * W * H * C = 2* 800 W x 2 Hours x 15% (0.15) = **240W**

Two 800W wind turbine running only 8 hours per day at 15% efficiency can produce:

Q * W * H * C = 2* 800 W x 8 Hours x 25% (0.15) = **960W**

- **Result:**

2 Wind turbine in worst case scenario can produce minimum **240W**

3. Micro hydro energy (Optional):

Locating root cellar near a flowing water can be of a greater advantage. Micro hydro energy can be harvested from the flowing water.

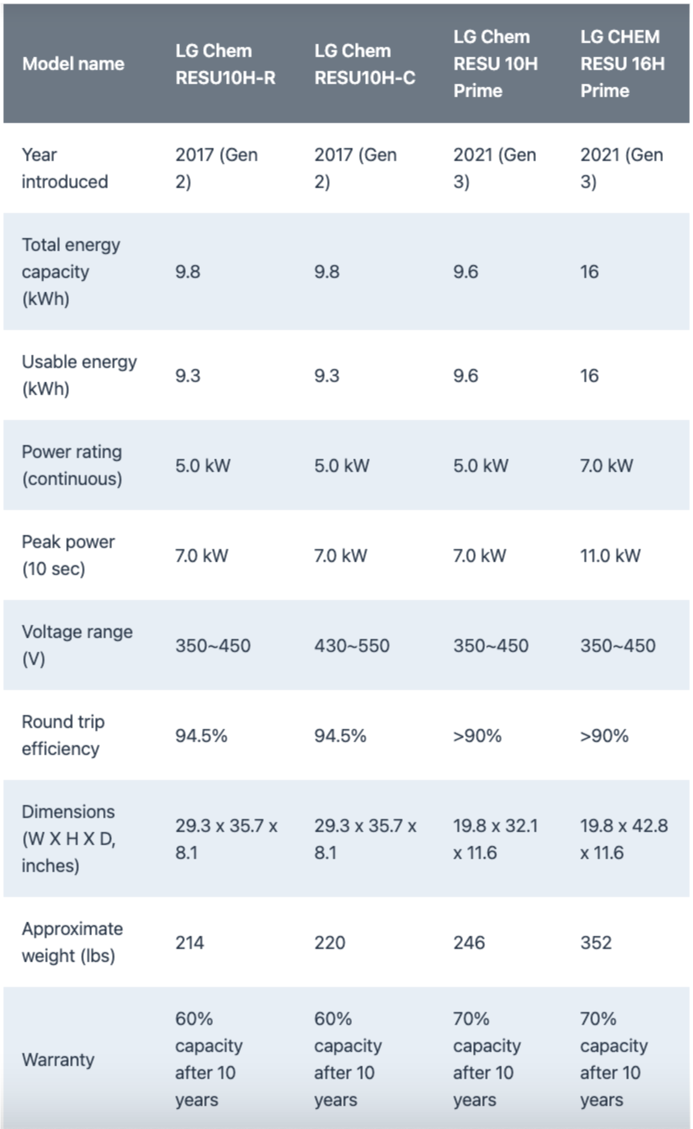
Using Jack Rabbit turbine or Waterotor that can generate power from a stream with as little as 13 inches of water and no head. Output from the Jack Rabbit is a maximum of 100 Watts, so daily output averages 1.5–2.4 kilowatt-hours.

In worst case scenario a water turbine can produce 20 Watts per hour i.e., 20W*24 hr = **480W**

4. Battery- Power storing capacity:

Using a better battery that can store the large amount of power would be beneficial. Summer is usually time where more energy will be generated. That extra power can be stored in a battery and used in winter when energy generation is low.

LG CHEM RESU 10H is the suggested battery backup option. Here’s the detailed specification:



Model name	LG Chem RESU10H-R	LG Chem RESU10H-C	LG Chem RESU 10H Prime	LG CHEM RESU 16H Prime
Year introduced	2017 (Gen 2)	2017 (Gen 2)	2021 (Gen 3)	2021 (Gen 3)
Total energy capacity (kWh)	9.8	9.8	9.6	16
Usable energy (kWh)	9.3	9.3	9.6	16
Power rating (continuous)	5.0 kW	5.0 kW	5.0 kW	7.0 kW
Peak power (10 sec)	7.0 kW	7.0 kW	7.0 kW	11.0 kW
Voltage range (V)	350~450	430~550	350~450	350~450
Round trip efficiency	94.5%	94.5%	>90%	>90%
Dimensions (W X H X D, inches)	29.3 x 35.7 x 8.1	29.3 x 35.7 x 8.1	19.8 x 32.1 x 11.6	19.8 x 42.8 x 11.6
Approximate weight (lbs)	214	220	246	352
Warranty	60% capacity after 10 years	60% capacity after 10 years	70% capacity after 10 years	70% capacity after 10 years

Figure 10. Specification of LG CHEM RESU 10H

5. Stand by generator:

Having a back-up propane generator for emergency situations where the battery backup is not enough to maintain the temperature inside the root cellar. This generator should automatically be triggered via IOT system when the power backup inside battery is not sufficient. Hence, eliminating the need for any person to rush to the root cellar to start the generator.

Summary:

Total renewable power generation without hydro energy:

- Worst case scenario: 600W
- Best case scenario: 1810W

Total renewable power generation with hydro energy:

- Worst case scenario: 1080W
- Best case scenario: 2810W

Required energy by root cellar is average 800 W / day.

Excess energy generation will be stored in batteries that will be used on worst weather conditions. Automated propane generated will be triggered in worst scenario where backup power in batteries is not enough.

3.1.3 Storage

The client mentioned that some issues with the storage were 1) the lack of organization, 2) the lack of shelving units, and 3) division of the space to house different root vegetables that prefer different climates.

To address the first point, the lack of organization, an inventory system is recommended. This system involves logging in what comes into the cellar by filling out a SharePoint Excel document or a physical paper log. A robust SharePoint Excel is recommended as it can be accessed remotely by anyone with access to the link. A sticker/label system can also be implemented to group the produce in different categories, such as: by owner, by expiry date, by and type of produce. The boxes that house the produce can include this label/label system, so it is easier for people to identify what is in the boxes. This will make finding items easier for anyone entering the cellar. After all, the idea is that the community can store their produce there, so it is very important that everyone’s items are classified and organized. This will avoid mishaps and produce getting lost or misplaced. It will also avoid having to be inside the cellar for long periods of time looking for items/produce; spending time in an environment as cold as the chamber (2-4 °C) can be quite uncomfortable and even dangerous at long exposures.

Barry and his team came up with an innovative idea of a rectangular hollow box made up of two plywood sheets that can hold up to 16 individual coroplast boxes. Each of these boxes can store about 18-24 kg of produce. The 4 mm coroplast was leftover material from the building stage and so Barry and his team reused this material to simple boxes that could store food. The coroplast layer provides some insulation as well as a sturdy structure to package the produce (see Figure 6).

Figure 6. Plywood box with coroplast boxes near the back of the root cellar.

Assuming that the dimensions of the box are about 8’ in length, 5’ in width, and 1’ in height, the total square footage per plywood box is 40 sqft. If we limit the maximum height of the stacked shelf units at arm’s reach (which is 6’ for most people), the height used to calculate the number of plywood boxes that can fit in the space will be 6’. We also need at least 3’ of clearance between the boxes for people to walk. The produce chamber has a width of 21’. If we divide this by the size that one box occupies in width, which is 5’+ 3’ (clearance on one side) + 3’ (clearance on the other side) = 11’. The latter means that in a length of 21’, we can just fit 2 boxes comfortably. The produce chamber measures 22’ in length, so if we apply the same logic, a box occupies 8’ + 1.5’ (clearance on one end) + 1.5’ (clearance on the other end) = 11’. So, we may be able to just fit 2 boxes if we compromise on 1.5’ on the clearances. There can be 6 boxes stacked on top of each other given that the height of each box is 1 foot (see Figure 7). This brings the total number of boxes to 24. Since each plywood box can hold 16 coroplast boxes, that brings the total coroplast boxes to 384. Each coroplast box can store 18-24 kg of produce. If we take the average (21 kg), all the coroplast boxes can hold up to 8,064 kg of produce. Barry has mentioned that he estimates the cellar can hold 50,000 kg of food. So, this current design is not sufficient as it can only support about 16% of the aforementioned. More innovative ideas will be researched in order to increase this percentage and get closer to 100% (which represents 50,000kg, or full capacity).

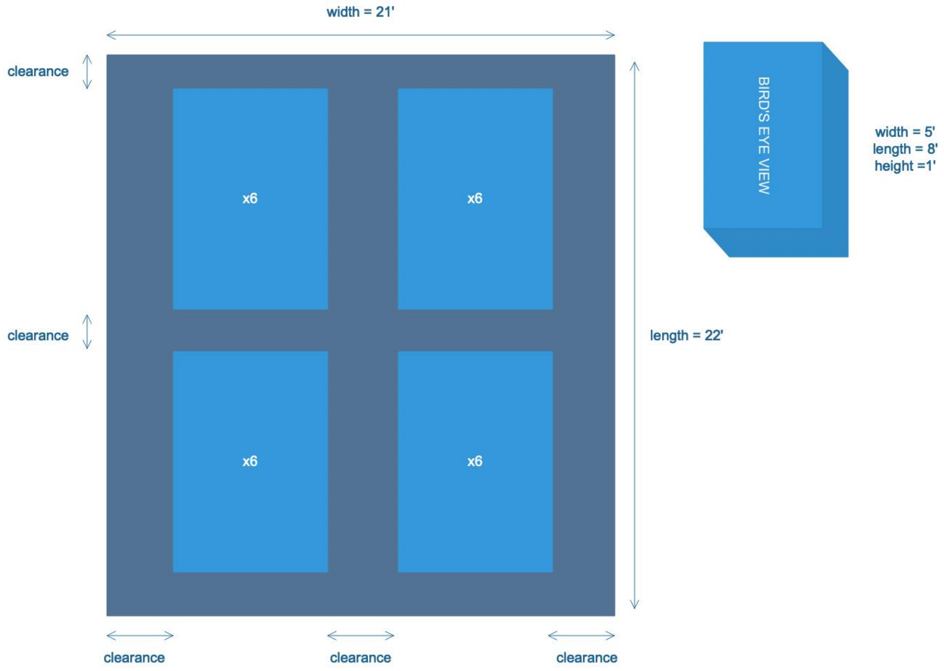


Figure 11. Bird's eye view of the produce chamber. The light blue boxes with ‘x6’ are 6 individual plywood boxes stacked. The dimensions of 1 plywood box are on the right of the diagram.

Barry had mentioned an interest in eventually storing fruits in the cellar. However, different fruits prefer different temperatures, and this would require the complete isolation of those items from the rest of the population (as they would need their own temperature and humidity control). This goal will be put aside as the first 2 objectives (organization and increase in storage) are higher in the client’s priority list.

3.2 Revised Project Requirements

Table 4. Revised Project Requirements.

#	Requirements	Importance Value
1	The root cellar stays off-grid.	1
2	The root cellar needs eco-friendly backup power.	2
3	The root cellar needs more renewable power sources.	2
4	The root cellar needs an efficient heating and cooling method.	2
5	The root cellar needs better insulation	3
6	The root cellar has different chambers to keep stuff separately.	3
7	The root cellar can store a large variety of crops, vegetables, and fruits.	4

*Lower the value higher the importance

3.3 Updated Problem Statements

3.3.1 Insufficient Heating and Cooling

- Ideal:

The cellar can be kept at 2-4 degrees Celsius in extreme cold or extreme heat.

- Reality:

According to monitoring data, in winter, the temperature of the cellar often drops below 2 degrees Celsius; in summer, the cellar is often unavailable due to the high temperature.

- Proposal:

Users can make the most of or avoid geothermal energy. When geothermal energy is not needed, lay a thick foam insulation layer on the floor; when geothermal energy is needed, install multiple fans near the floor to enhance convection heat transfer. In addition to this, multiple heaters can be installed to directly heat the room.

3.3.2 Insufficient Solar Energy

- Ideal:

The root cellar has enough power, and the solar energy can match the power demand all the time.

- Reality:

The current root cellar has 6 solar panels which is 100W each. But the assuming total energy consumption will be 800W. Due to Canadian weather, sun is not bright 60% of times in a year and hence solar energy will fall short of matching the power demand.

- Proposal:

The root cellar needs more diversified renewable energy generation. Wind and hydro energy would be a good option. Canada's special climatic conditions will facilitate the use of wind energy; if the cellar is built near the water source, hydroelectric power can be used. In the case of sufficient roof space in the cellar, several more solar panels can be installed to absorb solar energy. In extreme conditions, when none of these sources of energy are sufficient for the cellar, the presence of a backup battery is also important.

3.4 New Prototype Definition

There are individual prototypes that each team member will be working on. Each prototype aims at improving one of the aforementioned issues that our client had.

Regarding the HVAC improvements, to test the theory that the quantity of fans needs to be doubled in order to achieve more rapid heating, the 4 additional fans need to be installed in the cellar and monitored for their activity. Once their activity has been measured, the data can be analyzed. Calculations can be made beforehand to estimate how fast the space can be heated with additional fans. The latter would be the theoretical value and once the fans have been implemented, then the actual value can be measured and evaluated.

The insulating material will need to be installed in order to measure its efficacy. There is no other way around that in terms of estimating how much insulation it would provide. However, calculations can be made based on the R values, thickness, heat capacity, and more.

In terms of power, more specifically increasing the number of solar panels and implementing wind power can increase the amount of power available to run the motored equipment. This is something that does not need to be prototyped as we can get a very good estimate of the power that solar panels and wind energy could provide. If we want to get the actual values of power generated, they will need to be installed. This is dependent on the budget that the client is willing to spend, as both of those items can be costly. This is also the case for battery improvements.

Hydro energy can be tested (Barry mentioned they do have a reservoir full of water they collect during the rainy season). A prototype of using this water as energy to power the motored equipment or even batteries can be done on-site at the root cellar. More in-depth innovation on how to achieve this with the current water reservoir will need to be brainstormed. The IoT (Internet of Things) can be implemented to control the generator, but this may still require human interference given the dangers involved with running such a machine.

The client's existing concept of plywood boxes with coroplast boxes can store a significant amount of food, but not nearly as much as he would like. Therefore, a more in-depth analysis of how to efficiently use the root cellar space will need to be performed.

4 Task Planning

This section contains the updated task list and gantt chart for the next deliverable and client meeting.

Sustainable Food Storage				Rushi Patel, Abubakar Irfan, ...
1. Initiation	12/01/2022	17/01/2022		Lotty Pontones, Can Cui, Zhi...
3. Execution	12/01/2022	15/03/2022		Lotty Pontones, Can Cui, Zhi...
3.5 PD C	08/02/2022	15/02/2022		Rushi Patel
3.6 PD D		01/03/2022	8FF	Lotty Pontones
3.6.1 Detailed design	16/02/2022	18/02/2022		Zhi Zheng
3.6.1.1 Power system update	15/02/2022	18/02/2022		Rushi Patel
3.6.1.2 HVAC update	15/02/2022	18/02/2022		Can Cui
3.6.4.3 Storage	23/02/2022	28/02/2022		Lotty Pontones
3.6.2 Prototype 1	19/02/2022	24/02/2022	19FS	Rushi Patel
3.6.2.3 Storage	15/02/2022	24/02/2022		Lotty Pontones
3.6.2.1 Power system	19/02/2022	24/02/2022		Rushi Patel
3.6.2.2 HVAC	19/02/2022	24/02/2022		Can Cui
3.6.2.2.1 Heating system mo...	18/02/2022	21/02/2022		Can Cui
3.6.2.2.2 Cooling system mo...	18/02/2022	23/02/2022		Zhi Zheng
3.6.3 Testing	25/02/2022	27/02/2022	23FS	Can Cui
3.6.3.1 HVAC	25/02/2022	25/02/2022		Can Cui
3.6.3.2 Power	25/02/2022	25/02/2022		Rushi Patel
3.6.3.3 Storage	25/02/2022	25/02/2022		Lotty Pontones
3.6.4 BOM	28/02/2022	01/03/2022	29FS	Can Cui
3.6.4.1 HVAC	23/02/2022	28/02/2022		Zhi Zheng
3.6.4.2 Power	23/02/2022	28/02/2022		Rushi Patel
3.6.4.3 Storage	23/02/2022	28/02/2022		Lotty Pontones
3.7 PD E	02/03/2022	21/03/2022	18FS	Can Cui
3.4 Client meet 2	08/02/2022	14/02/2022		Lotty Pontones
3.8 Client meet 3	01/03/2022	01/03/2022		Rushi Patel

Figure 12. Updated task list for the next deliverable and client meeting

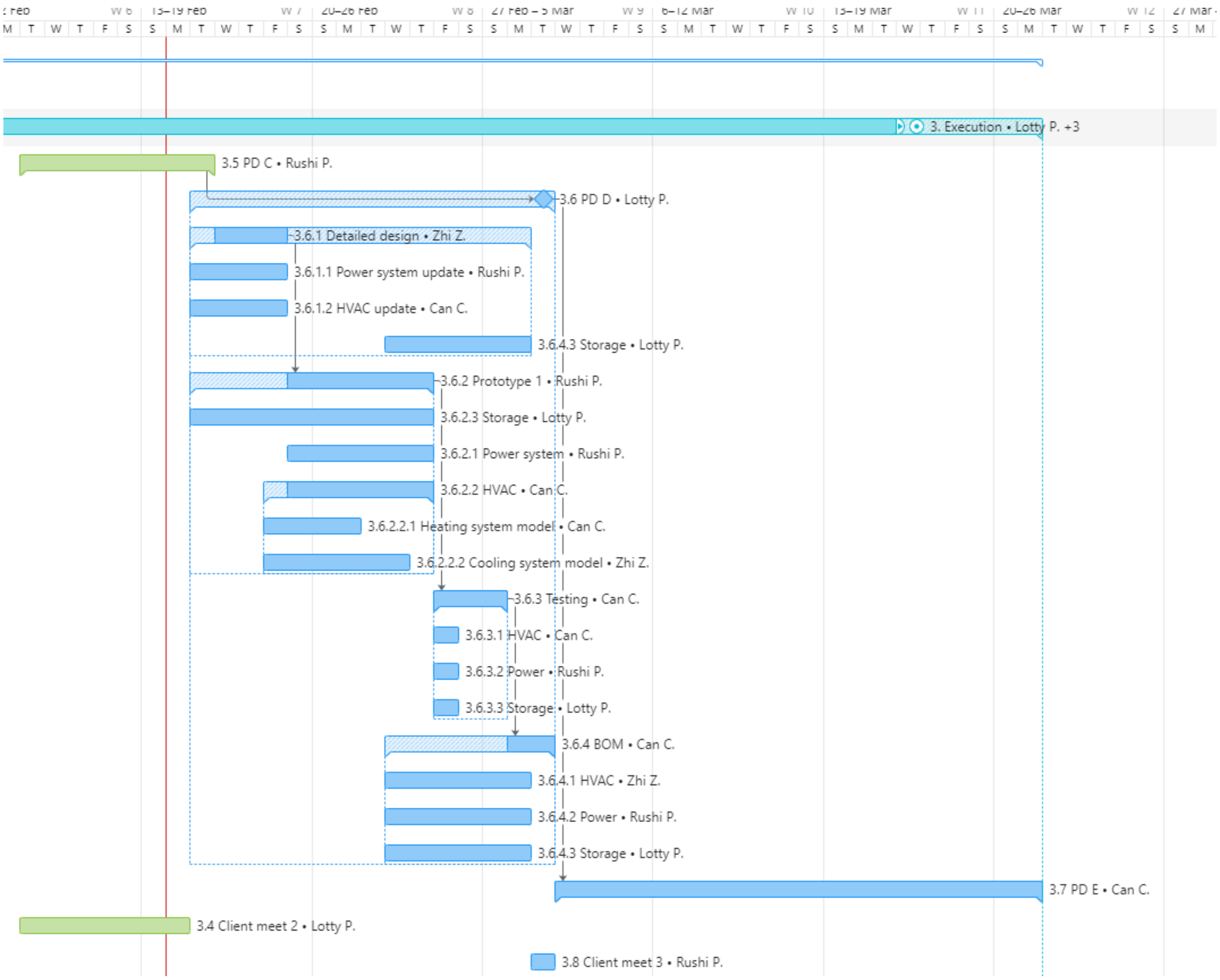


Figure 13. Updated gantt chart with dependencies for each task

5 Conclusions and Recommendations for Future Work

This report helped us narrow down possible solutions in three areas: HVAC improvements, increasing the power available, and designing an efficient storage space. The project plan is to meet again with the client and present the results from our calculations and estimates. This will give him an idea of what he would like to further investigate. Once he determines which area he would like to pursue (HVAC, power, or storage), the team can converge into a problem and continue developing a solution(s) for this.

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