uOttawa

GNG 5140 Engineering Design

Project Deliverable H: User Manual and Video
Sustainable food storage B
Under the guidance of Professor David Bruce

Submitted by

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List of Acronyms and Glossary

Acronyms	Definition
VAWT	Vertical axis wind turbine
PV	Photo voltaic
HVAC	Heating, Ventilation, and Air Conditioning
RPM	Revolution per minute
AC	Alternating Current
DC	Direct Current
PLA	Polylactic Acid
DRFH	Deep Roots Food Hub

1 Introduction

One of the many far-reaching repercussions of climate change is the emergence of unusual plants and insects. The impact of air conditioning and heating on our lifestyle is significant, even for those of us who live in houses with these amenities. Take food, for instance. It's a luxury we often take for granted. We always have easy access to food; we just need to make a quick trip to the grocery store to get what we need. We can also eat these things without worrying about contamination or infections because they are normally safe. However, climate change poses a major threat to these aspects of human life. It immediately impacts primary production, which encompasses agriculture, cattle, and fisheries, putting food security—also referred to as the availability of food—in jeopardy. Concerns about food storage are widespread, particularly in Canada and other northern regions where climate change may impede this vital function (1).

Canada's environment makes it challenging to grow and distribute food responsibly all year long, especially in the warmest months. This study explores the challenges that reputable, cost-effective food storage facilities face during the winter months and emphasizes the need for tailored solutions. Winter-specific issues need to be addressed to establish sustainable food storage technologies that guarantee a dependable supply chain despite changing climatic conditions. This off-grid storage facility and raised cellar offer small-scale vegetable growers an affordable and sustainable post-season storage option. It allows root crops to be kept fresher for longer, which increases the opportunities for distribution and sales. Before this prototype was introduced, West-Carleton had no community-based root crop storage. This inventive Quonset-style metal house uses ground-sourced geothermal heat to keep the root storage chamber at a nearly constant +2°C and 90–95% humidity (2).

The climate of Canada makes it difficult to produce and deliver food sustainably throughout the year, particularly during the warmest months. This study examines the difficulties dependable, reasonably priced food storage facilities confront in the winter and highlights the necessity for solutions that are specific to these intricacies. Establishing sustainable food storage methods that ensure a reliable supply chain despite changing climatic conditions requires addressing winter-specific concerns.

Figure 1 Food Cellar

2 Overview

2.1 Existing Problems and Importance

Humidity control in the root cellar is not very good, and the humidifier is not strong enough. Solar power powers the root cellar, but in the winter, it is insufficient, unstable, and unreliable. To heat the root cellar, the client occasionally had to run the gas generator. The electricity system's initial cost of connection to the utility is high. The root cellar isn't usable in the summer. The "Icehouse Straw pile" system that is in place now works well in the spring, but there isn't enough ice because it usually melts in two to three days. The temperature in the root cellar can get up to nine centigrade during extended warm spells, which is higher than usual. The root cellar lacks a chilly temperature at night, thus controlling the temperature during prolonged warm spells is difficult.

Understanding the restrictions and inefficiencies in the current system is crucial because it can have a big impact on how food is stored, how much energy is used, and how useful it is overall. Let's examine the main ideas:

- Problems with Humidity management: Inadequate humidity management can affect the freshness and durability of produce that is kept in storage. For best preservation, fruits and vegetables frequently need to be at particular humidity levels.
- Limitations of Solar electricity: Although solar electricity is ecologically benign, it might be insufficient, unstable, and unreliable in the winter. This has an impact on the root cellar's overall energy supply as well as its capacity to control humidity and temperature.

- Gas Generator Usage: Relying on a gas generator to provide extra power is a sign of using non-renewable energy sources, which can have a negative influence on the environment and raise operating expenses.
- High Initial Cost of Utility Connection: Getting access to a more dependable and consistent power source is significantly hampered by the high initial cost of connecting to the utility grid.
- Summer Usability: During the summer, the root cellar is unusable, which could result in a waste of space and a restricted amount of storage during the warmer months.
- Icehouse Straw Pile System: Although the existing system performs well in the spring, it is not as successful during prolonged warm spells due to the problem of ice melting too quickly.
- Difficulties with Temperature Control: Warm spells cause temperature surges in the root cellar, which can harm products that have been stored. Controlling the temperature becomes more difficult when it's not cold at night.

It is essential to comprehend these difficulties in order to create practical solutions that deal with the underlying causes of the problems. It draws attention to the need for enhanced humidity and temperature management systems, a more dependable and sustainable energy supply, and possibly even investigating alternate cooling strategies like improving the ice storage system. In addition to the user's convenience, these problems must be resolved for the effective and long-term preservation of stored items.

2.2 User Needs

- The root cellar ought to be expandable.
- Steady, dependable power sources are needed for the root cellar.
- You can use the root cellar for an extended amount of time.
- The humidity and temperature in the root cellar need to be kept constant.

2.3 Key Product Differentiator

As we know from our previous deliverables, our solution to the problem involves two phases:

Phase 1: Renewable Energy Integration.

The proposed source of power is VAWTs, which will eliminate the need to rely solely on the PV panels. The wind regime is quite high and stable near the location of the root cellar, which makes wind turbines a perfect choice to use as a power source.

Phase 2: Small room with Heat Pump

A tiny room will be built inside the root cellar itself which would help the cellar operate all year round. It will also have a heat pump for heating and cooling purposes. The size of the tiny room and the heat pump depends upon the power generated by the renewable energy power source.

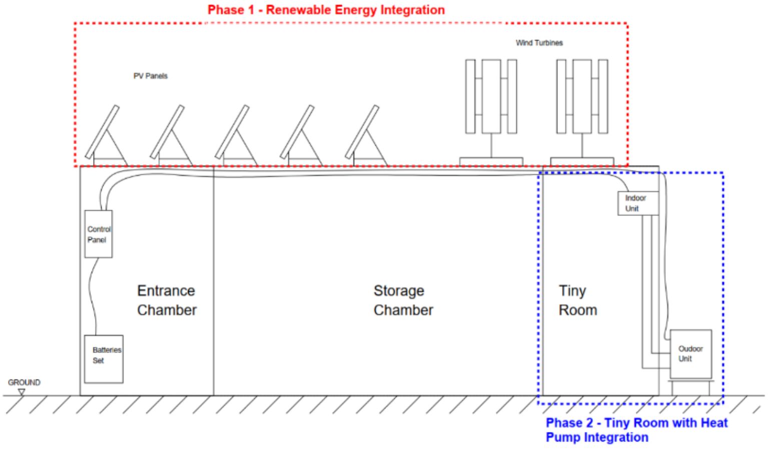

Figure 2 Final Prototype Design Consideration

3 Getting Started

3.1 Set-up Considerations

The pictures show the structure and dimensions of the root cellar. A dividing wall separates the inner space into two sections, the front is an antechamber for equipment storage, and the back is the produce chamber.

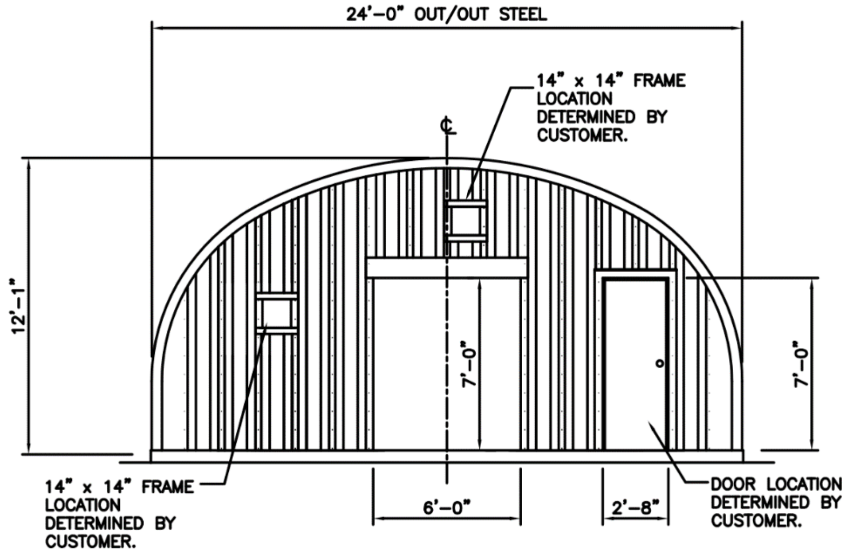

Figure 3 Front Elevation of Root Cellar

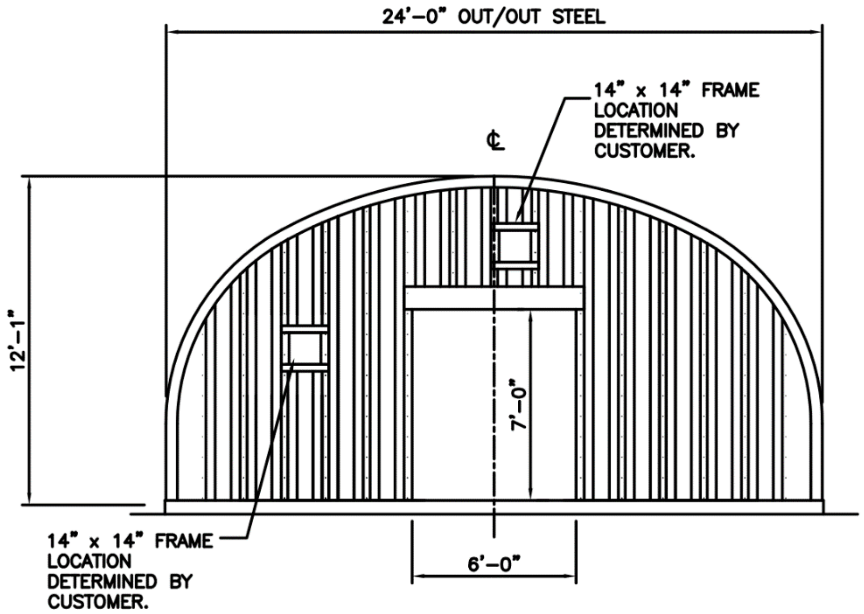

Figure 4 Partition wall elevation of Root Cellar

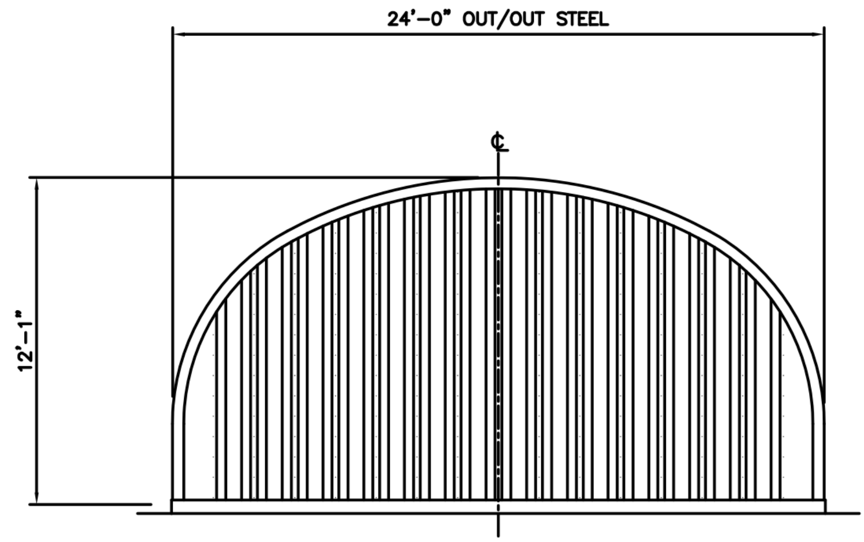

Figure 5 Rear elevation of Root Cellar

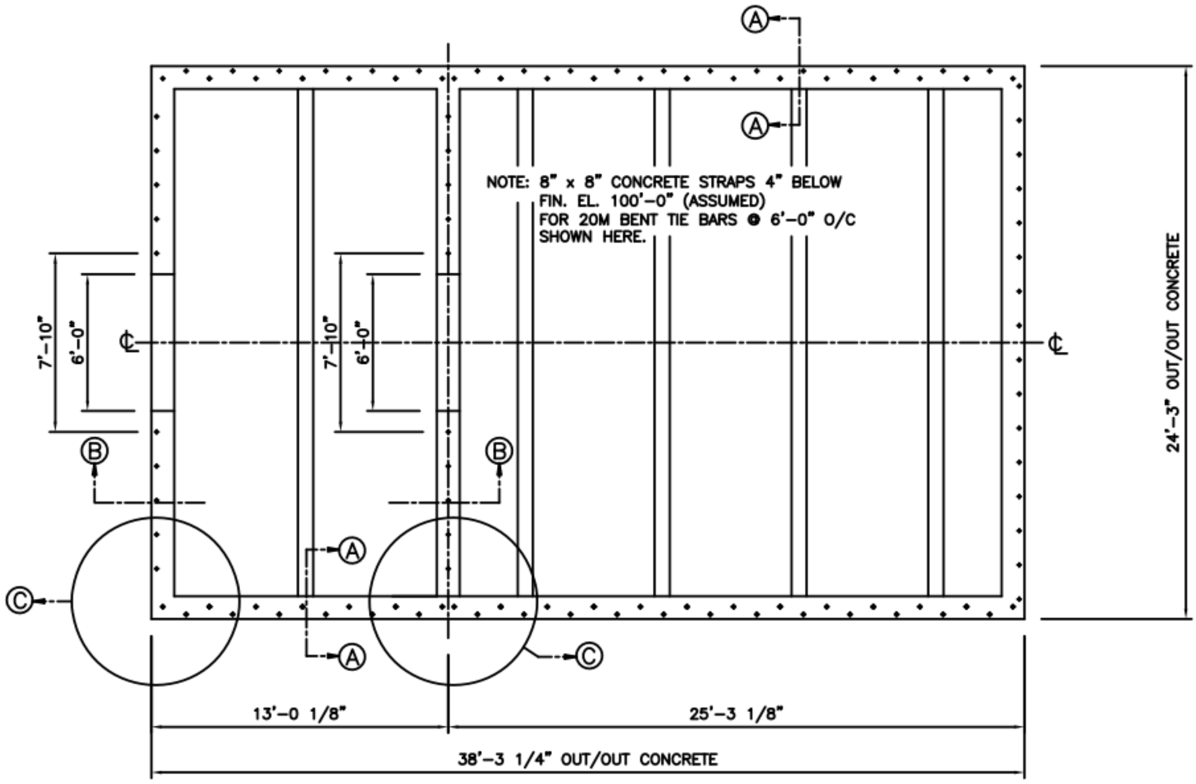

Figure 6 Foundation Plan of Root Cellar

The Current Temperature Controlling System

A microprocessor is installed on the front wall to regulate the fans, outlet, intake, and all the sensors within the chamber. To prevent tangling, all electrical lines are taped to the wall. If the outside air is colder than the inside air, the outside air intake fan will operate; otherwise, the outlet fan will only run when the inside air temperature rises above the target range and the warm interior air will be expelled. Only when the underfloor temperature is within or above the targeting range and the indoor temperature is below it are the floor fans activated. Therefore, the system relies on outdoor conditions and experienced many issues. Root cellars' inability to accurately regulate humidity, reliance on unreliable winter solar power, high initial utility hookup costs, limited summer availability, insufficient ice storage, unstable temperatures during warm periods, and lack of funds compromise their effectiveness in preserving food., affecting food security and sustainability.

Our Proposed Prototype

The prototype should be able to make the root cellar operational all year round. The off-grid supply makes it impossible to power a heat pump system for the entire root cellar for all seasons. Therefore, this idea entails creating a tiny, energy-efficient cold room inside the root cellar to handle temperature regulating issues. It uses heat pump technology to keep the temperature steady all year round. The room volume is based on how much power can be generated to run the heat pump system.

For the existing power supply, PV panels are installed and stored in vehicle batteries for supplying power to all equipment including the lighting, and fans. The reliance on solar power, particularly during winter, presents operational challenges due to its inadequacy, instability, and unreliability. Specifically, installing more possible alternative power generation applications such as wind turbines, and extra solar panels can increase the amount of power available.

The combination of PV panels and VAWT will generate around 2000W which is sufficient to run the Heat Pump system and Existing equipment.

To build the tiny room (6X2 = 12sqm), the R40 double batt insulation is required from one side. The heat pump system with a 5kW cooling capacity was installed along with 2 – 1750 CFM fans for proper ventilation and temperature control.

Powering a heat pump system directly from a combination of PV panels and VAWT eliminates the grid connection. Photovoltaic panels and wind turbines generate electricity, controlled by a charge controller, ensuring optimal energy transfer. An inverter converts the generated DC electricity into AC electricity suitable for the heat pump system. In this off-grid setup, a battery bank may store excess energy, though it's optional. The heat pump system directly connects to the inverter, utilizing the combined power of solar and wind sources for continuous operation. Safety measures include disconnecting switches and circuit breakers. This self-sufficient system is designed to provide reliable and sustainable energy for heating and cooling without relying on the electrical grid.

3.2 User access Considerations

The system's users can be categorized into categories based on how they engage with the communal root cellar. These groups consist of the DRFH employees and volunteers who look after the root cellar facility, as well as the farmers and agricultural professionals who use it to store and retrieve their harvests.

Farmers and individuals who use the community root cellar to store and retrieve crops must have access to the storage chamber and tiny room, but likely should not have allowed access to the roof to affect the operation of PV panels and wind turbines. Ideally, with the indoor unit of the heat pump system placed in the tiny room, perhaps in an elevated position, it will prevent any intentional or accidental tampering with the cooling system.

DRFH volunteers and staff who are responsible for maintaining the root cellar facility must have access to the indoor unit in the tiny room, and the outdoor unit installed at the back of the root cellar, in order to perform maintenance and checks of the system and determine if trained technicians must be hired to make repairs or address issues.

3.3 Accessing the System

To access the root cellar, you need to make an appointment for a visit via the DRFH website: https://www.deeprootsfoodhub.ca/contact.html

3.4 System Organization and Navigation

The 3D model reveals the overview of the system.

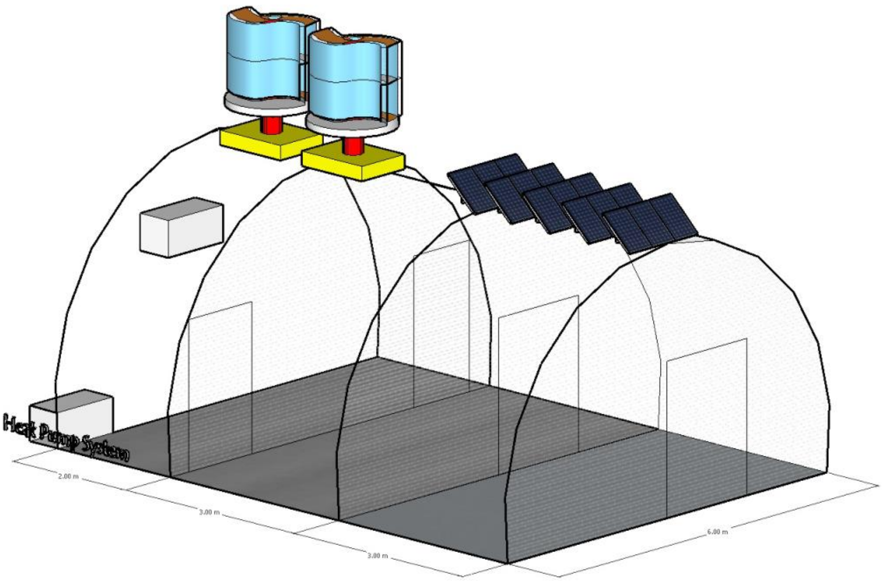

Figure 7 3D model of Root Cellar

Activating the off-grid heat pump system, powered by a combination of PV panels and VAWT, involves a sequential process ensuring efficient and continuous energy generation. The initiation begins with the installation and physical connection of PV panels, VAWT, charge controller, and safety devices. Activation of the VAWT and exposure of PV panels to sunlight kickstart electricity generation. The charge controller is configured to optimize energy transfer and prevent overcharging. The inverter is then powered on to convert the generated DC electricity into AC electricity suitable for the heat pump system. Optionally, a battery bank can store excess energy for backup use. Direct connection of the heat pump system to the inverter completes the setup, allowing for continuous heating and cooling. Safety measures like disconnect switches and circuit breakers provide safeguards, and regular monitoring ensures optimal performance. Periodic maintenance checks maintain system integrity. This self-sufficient and sustainable off-grid system offers reliable energy for heating and cooling needs without reliance on the electrical grid, exemplifying a green energy solution.

3.5 Existing the system.

To properly exit or turn off the off-grid heat pump system, a systematic approach is crucial for safety and efficiency. Begin by initiating the shutdown sequence for the heat pump system, adjusting temperature controls, or activating a designated shutdown mode. Power off the inverter to cease the conversion of DC to AC electricity, ensuring no power is supplied to the heat pump. Deactivate the PV panels and VAWT to stop electricity generation, and adjust the charge controller to halt energy transfer. If a battery bank is present, implement a controlled shutdown process for energy storage. Ensure all safety measures like disconnect switches and circuit breakers are in the off position, isolating system components to prevent electrical hazards. Verify the monitoring dashboard reflects the system's safety and off-state. Physically inspect components for any signs of malfunction and consider environmental factors during shutdown. Maintain documentation of the process for reference and secure the site if needed.

This comprehensive approach ensures a secure and efficient shutdown, promoting both the safety and the longevity of the off-grid heat pump system.

4 Using the System

The following sub-sections provide detailed, step-by-step instructions on how to use the various functions or features of the Power System & Heat pump system. We require a broader range of renewable energy generation alternatives.

4.1 Renewable Energy Integration

Solar panels: In Canada, solar panels produce considerably greater amounts of electricity during the spring and summer months compared to the fall and winter. This discrepancy in solar power generation is not solely due to variations in daylight hours; it is also influenced by seasonal fluctuations in cloud cover, alterations in snowfall patterns, and other climate-related disparities. Therefore, one potential solution could involve installing additional solar panels. The actual requirement of the solar panels is 600W.

To access to the sunlight, we need to place solar panels in an area that receives the most sunlight throughout the year. With increasing the count of solar panels to 8 we get 100W each. With considering all the losses which affect the overall power generation, 8 solar cells can produce minimum of 300W. Considering all the data we need to install solar panels on the roof of root cellar. In Canada, since the sun angle changes significantly between seasons, so adjustable mount that tilts the panels to match the sun’s angle would be beneficial. Panels angled closer to the perpendicular to the sun’s rays generate more power.

VAWT: Canada's geographical features are well-suited for harnessing significant wind energy, allowing us to produce electricity year-round using wind turbines. The country boasts some of the world's most robust wind patterns, ensuring a continuous energy source unlike solar power, which is dependent on daylight. Our team's collaborative project focuses on harnessing wind energy to develop a Vertical Axis Wind Turbine (VAWT) specifically designed for the Root Cellar.

For this root cellar we used 2 Numbers of Ugrinsky Vertical Axis Wind Turbine. Vertical axis turbines are less sensitive to turbulent airflow, making them potentially more efficient in confined spaces. We need to Place the VAWT strategically to capture the maximum airflow so with respect to that we need to place the VAWT on the Top of root cellar. With considering the average wind speed in the location, the sweep area of the turbine is 0.9sqm & the available wind power is 116W.

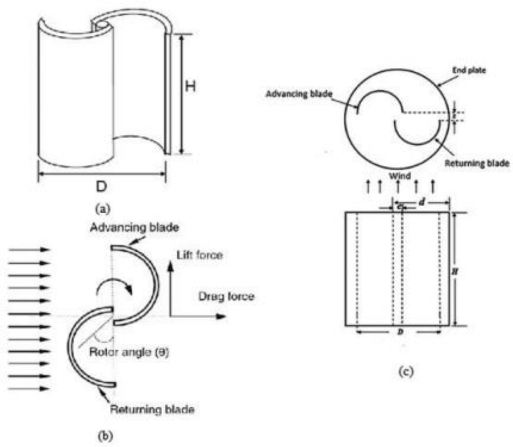

Figure 8 Wind turbine

Features-

- Orientation: Unlike HAWTs, which have blades rotating around a horizontal axis, VAWTs have blades that rotate around a vertical axis. This design allows VAWTs to capture wind from any direction without the need for repositioning or facing into the wind.
- VAWTs often have a more unique and aesthetically pleasing appearance compared to traditional HAWTs. This feature might make them more acceptable in certain environments where visual impact is a concern.

4.2 Heat pump integration

We are going to design a tiny room with heat pump integration for the contouring the indoor conditions. We were planning to enhance our utilization of geothermal energy for heating, primarily because the heat beneath the floor is insufficient to adequately warm the primary chamber. To improve the transfer of heat through convection between the warmer air under the floor and the cooler air in the cellar, our intention is to install fans. Currently, we have four fans in place, but we may increase this number. Operating six fans simultaneously will significantly increase the circulation of indoor air, leading to faster heating. During extremely cold weather, geothermal heat alone may not meet the heating requirements of the room, necessitating the use of multiple heaters with power rating 600W.

This tiny room with heat pump system can be used in 3 different ways. 1) During summer, the outdoor temperature in summer is high & summer is the most critical period to store the food. During this season we use tiny room with colling mode to keep the humidity & temperature in a proper condition. 2) During Fall / Spring season. The outdoor temperature is low compared to the summer season. We can use this tiny room with colling mode & the two doors can be open & using circulating fans we can control the temperature in the tiny room, because of this the air can circulate through the whole storage chamber. 3) During Winter season, the outdoor temperature in cool. Similar to the fall & spring operation, but in winter we need to switch the heat pump to heating mode & we have kept the doors open to circulate warm air throughout the chamber.

5 Troubleshooting and support

This section documents the possible errors that may happen during the operation, and how the errors can be resolved or avoided.

5.1 Error or Behaviours

The main areas for potential errors/breakdowns include the assembling the VAWT, and the fan & heat pump system within the storage chamber.

(a)VAWT

- If wind speed exceeds the turbine’s design limits, it can cause an over-speed error. Because of this the turbine might shut down or employ braking mechanisms to prevent damage.
- VAWT’s might generate lower than expected power due to various factors like low wind speed, improper installation pr mechanical issues. This could trigger Under-performance alerts.
- VAWTs might produce less noise than their horizontal counterparts but can still create vibrations and some operational noise, especially if not properly maintained or if the design is flawed.
- Errors related to maintenance needs such as damaged blades, bearings, or electrical components may indicate the need for immediate attention.

(b) Heat Pump System

- Problems with the compressor or motor can result in error codes or alerts. These components are vital for the heat pump's functionality, and issues with them can significantly impact performance.

- During colder temperatures, heat pumps may enter defrost cycles to remove ice buildup on the outdoor unit's coils. This temporary switch to cooling mode can cause a brief period of colder air to be circulated inside.
- Heat pumps can produce operational noise, especially the outdoor unit when it's running.

Faulty temperature sensors or other monitoring devices can lead to erroneous readings and trigger error messages, affecting the system's operation.

5.2 Maintenance and support

(a) VAWT

- Monitoring Performance: Regularly monitor the turbine's power output, especially during varying wind conditions. A sudden drop in power generation could indicate a problem.
- Blade Maintenance: Regularly inspect the turbine blades for damage, erosion, or wear. Clean the blades to remove debris or dirt that could affect their aerodynamic performance.
- Mechanical components: Check bearings, shafts, and other mechanical parts for lubrication, wear, or any signs of malfunction. Lubricate moving parts as per manufacturer recommendations.
- Safety checks: Prioritize safety during maintenance. Use appropriate safety gear when working at heights or around moving parts. Follow manufacturer guidelines for safe maintenance procedures.

- Electrical System: Inspect the electrical components, including wiring, connections, and inverters, for any signs of damage, corrosion, or loose connections. Ensure the system is well-grounded.

(b) Heat Pump System

- Check Thermostat Settings: Ensure the thermostat is set correctly for heating or cooling. Sometimes, incorrect settings can lead to perceived malfunctions.
- Check Air Filters: Clogged or dirty air filters can hinder airflow and reduce efficiency. Regularly clean or replace filters according to the manufacturer's recommendations.
- Regular Servicing: Schedule annual maintenance by HVAC professionals to inspect and service the heat pump. This includes checking refrigerant levels, cleaning coils, and verifying electrical connections.
- Clean Coils: Both indoor and outdoor coils should be cleaned regularly to maintain efficiency. Dirt buildup can hinder heat transfer.
- Professional Maintenance: Engage certified HVAC technicians for regular maintenance and troubleshooting. They have the expertise to identify and resolve complex issues.

6 Product Documentation

This represents our ultimate prototype. Through careful calculations, we have determined that each photovoltaic (PV) panel generates approximately 100W of energy, while each wind turbine produces around 650W of energy. These outputs are deemed adequate to power both the heat pump system and the current infrastructure.

Our decision to acquire the PV panels was guided by meticulous calculations, and our vision for the future includes a compact room equipped with a heat pump system. In our prototype, we have incorporated the design of the Ugrinsky wind turbine, and all detailed calculations can be found in the testing and validation section.

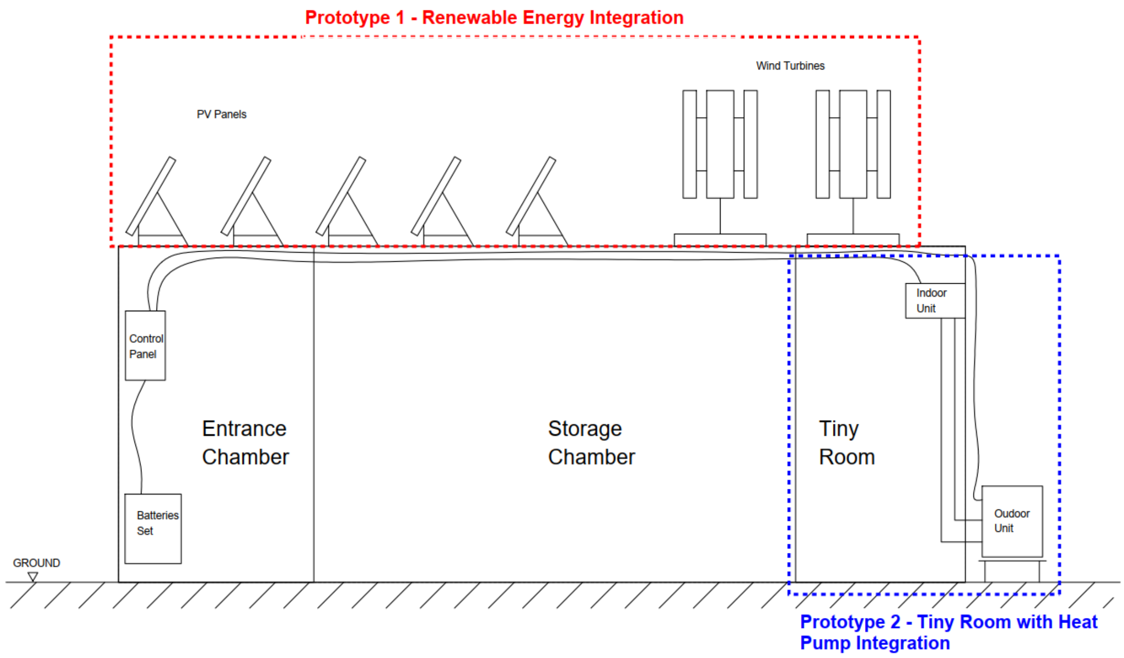

Figure 9 Final Prototype

Ugrinsky Wind Turbine

Given the increasing emphasis on renewable energy sources, there is a growing need to enhance the efficiency of vertical axis wind turbines (VAWTs), including the Savonius wind turbine. While the Ugrinsky wind turbine, a specific type of VAWT, has not been extensively studied, it is believed to outperform the Savonius wind turbine in generating positive torque across all rotational angles. The Ugrinsky turbine features two smoothly connected blades—a semicircle and a circular arc.

As indicated by research, the Savonius model exhibits a maximum output power coefficient of 0.110, which is 43.0% lower than that of the Ugrinsky wind turbine with a superior maximum output power coefficient of 0.170. Furthermore, the Ugrinsky turbine maintains a consistently high-power coefficient across a broad range of tip speed ratios (TSR). This noteworthy performance is attributed to both semicircular blades providing positive torque during the advancing blade, while the larger radius blade, due to its overlapping pattern, generates negative torque during the returning blade.

In the design process, theories and calculations correlated in finding the best dimension for the Ugrinsky wind turbine prototype. For this project, there are four stages in the design process. The first stage is the wind turbine design parameter. The second stage is the Ugrinsky wind turbine drawing and 3D views. The third stage is the dimensional analysis of the design, and the last stage will be the fabrication of the prototype with specified dimensions and materials. The experiment for Ugrinsky wind turbine was done after the fabrication of the wind turbine was complete and the data from the experiment was used to determine the performance of the mixed wind turbine. This project focuses on two Ugrinsky blades to operate. The variables that would be used to determine the performance of the wind turbine were the dimensions of the blades and the radius of the curve of the blades that will differentiate the swept area.

Furthermore, the wind speed will be varied to determine the power that the turbine can produce at a specified wind speed. From these variables, the rotation speed of the turbine, torque, and power generated by the turbine can be determined. The main purpose of the experiment is to determine the performance of the mixed wind turbine and focus more on the Ugrinsky wind turbine section. The experiment was conducted in the Makerspace Lab.

Details of the first prototype -

Dimensions R = 100mm (Sweep Area Radius), H = 100mm

3-D Printing parameters Layer Height –

The height of each layer in mm: 0.4mm

Wall Thickness – The thickness of the walls in the horizontal direction: 0.3mm

Top Thickness – The thickness of the top layers int the print: 0.3mm

Bottom Thickness – The thickness of the bottom layers in the print: 0.3mm

Infill Density – Adjusts the density of infill of the print: 5%

Infill Pattern – The pattern of the infill material of the print – Cubic 3.2

Details of the Revised Prototype -

Dimensions R = 150mm (Sweep Area Radius), H = 100mm

3-D Printing parameters Layer Height - The height of each layer in mm: 0.2mm

Wall Thickness – The thickness of the walls in the horizontal direction: 0.6mm

Top Thickness – The thickness of the top layers int the print: 0.6mm

Bottom Thickness – The thickness of the bottom layers in the print: 0.6mm

Infill Density – Adjusts the density of infill of the print: 10%

Infill Pattern – The pattern of the infill material of the print – Grid

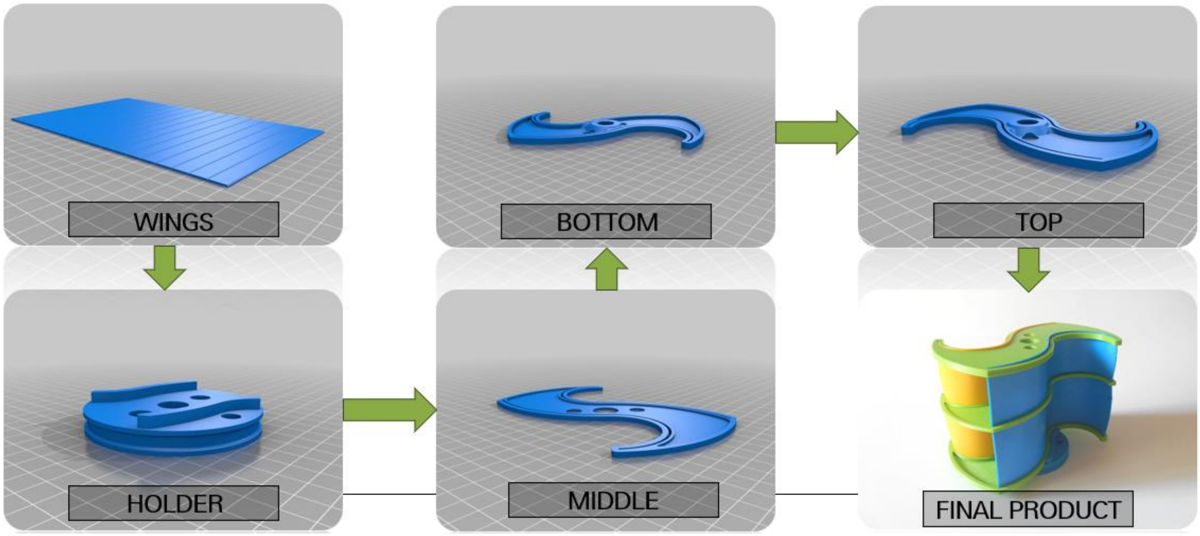

Figure 10 3D model images of prototype

The following requirements were considered while designing the prototype –

• Strength (Material and Durability)

• Safety Standards

• Bird Protection Design

• Noise Cancellation and Aesthetic

The following assumptions were made while designing the prototype –

• Steady Wind Conditions

• Neglecting Structural Dynamic

• No Wind Shear

• Neglecting Vibration and Fatigue

But for practical use we need to consider the above assumptions

For the prototype, we used PLA material which is used in a 3D printing. The PLA have hight tensile strength and inexpensive than other materials. Apart from that, we can use following materials.

Material		Printing with enclosure	Dry box recommended	Hardened nozzle required	Nozzle temperature (+-10 °C)	Bed temperature (+-10 °C)	Printable on powder coated sheet	Printable on smooth PEI sheet	Soluble with common solvents	Heat deflection temperature (avg. °C)	Impact resistance Charpy (kJ/m²)	Tensile strength (Mpa)	Price
PLA	(12)	No	No	No	210 - 215 °C	60 °C	✓	✓	✗				
PETG	(7)	No	No	No	240 - 270 °C	90 °C	✓	✓ with window cleaner	✗				
PETG HT	(1)	No	No	No	270 °C	110 °C	✓	✓ with window cleaner	✗				
ASA	(2)	Yes recommended	No	No	260 - 265 °C	95 - 110 °C	✗ not recommended	✓	✓				
ABS	(5)	Yes recommended	No	No	240 - 255 °C	110 °C	✗ not recommended	✓	✓				
PC (Polycarbonate)	(2)	Yes recommended	No	No	270 - 275 °C	115 °C	✓ with glue stick	✗ not recommended	✗				
CPE	(1)	No	No	No	275 °C	90 °C	✓	✓ with window cleaner	✗				
PVA / BVOH	(2)	No	Yes	No	195 - 215 °C	60 °C	✓	✓	✓				
HIPS	(1)	No	No	No	220 °C	110 °C	✓	✓	✓				
PP (Polypropylene)	(1)	Yes	Yes	No	220 °C	100 °C	✗ not recommended	✓ with PP tape	✗				
Flex	(4)	No	No	No	230 - 260 °C	50 - 85 °C	✓	✓ with glue stick	✗				
nGen	(1)	No	No	No	240 °C	90 °C	✓	✓ with window cleaner	✗				
Nylon	(1)	Yes recommended	Yes	No	250 °C	90 °C	✓ with glue stick	✗ not recommended	✗				
Carbon filled	(1)	No	No	Yes	260 °C	90 °C	✓	✓	✗				
Wood / metal filled	(7)	No	No	-	190 - 220 °C	60 °C	✓	✓	✗				

Figure 11 Type of material used in 3D Printer.

Traditionally, small wind turbine blades were constructed using wood due to its availability and ease of manufacturing. However, advancements in materials science and engineering have led to the emergence of innovative materials that offer improved performance characteristics. Fiberglass composites and carbon Fiber composites, for instance, have gained popularity due to their high strength-to-weight ratios, corrosion resistance, and enhanced aerodynamic properties. These materials offer the potential for lighter, more efficient blades capable of capturing more wind energy. The selection of materials for small wind turbine blades involves a careful consideration of their mechanical properties, such as stiffness, strength, and fatigue resistance, as well as their suitability for manufacturing processes. Additionally, environmental factors, such as the impact on the carbon footprint and recyclability, are increasingly becoming important criteria for material selection. Optimizing the material selection process for small wind turbine blades requires a multidisciplinary approach, involving expertise from materials science, engineering, aerodynamics, and sustainability. For the small wind turbine, we took following materials in consideration.

Attributes Alternatives	**Tensile Strength (MPa)**	**Production Rate**	**Flexural strength (MPa)**	**Corrosion resistance**	**Blade Cost (USD)**	**Setup Cost (USD)**	**Density (kg/m^{3})**
Wood	70	0.3	147	0.3	90	7000	625
Aluminum	229	0.8	299	0.7	150	24000	2700
CFRP_{EP}	440	0.7	286	0.9	160	3000	1400
GFRP_{EP}	190	0.7	252	0.9	30	3000	1700
GFRP_{PP}	150	0.5	199	0.7	26	3000	1350
CGFRP_{EP}	165	0.7	218	0.8	22	3000	1300
CGFRP_{PP}	135	0.4	179	0.7	20	3000	1200
FGFRP_{EP}	88	0.3	122	0.5	30	3000	1320
SGFRP_{EP}	80	0.3	113	0.5	24	3000	1340
plastic	40	1	75	0.8	10	18000	1250

Table 1 Material selection for small wind turbine

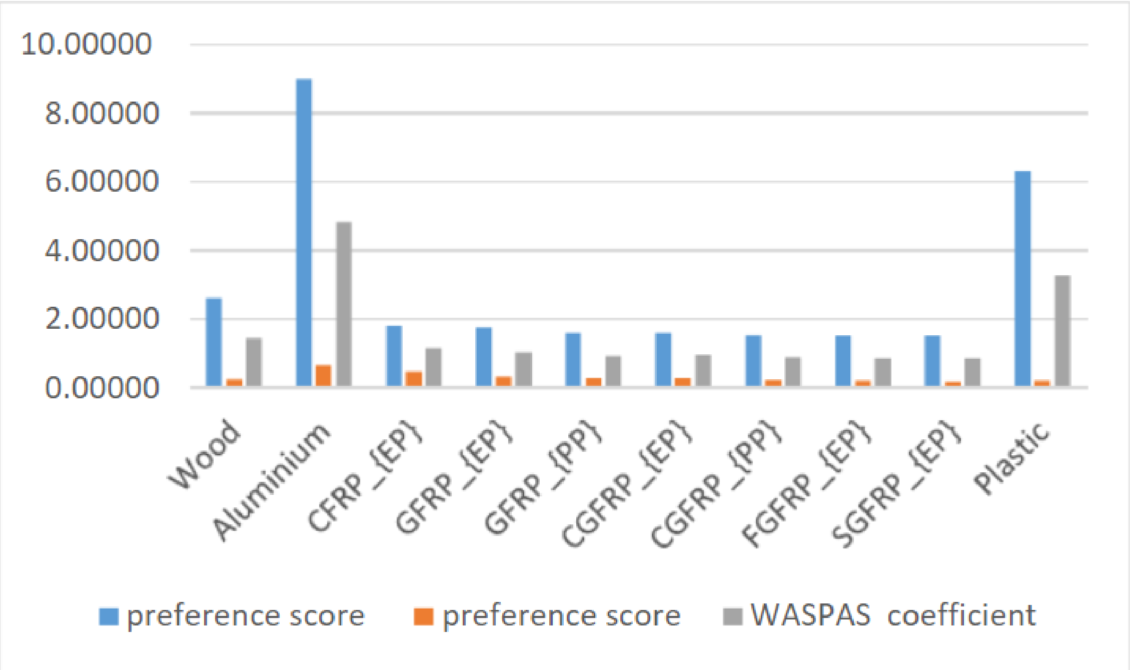

Figure 12 WASPAS Score

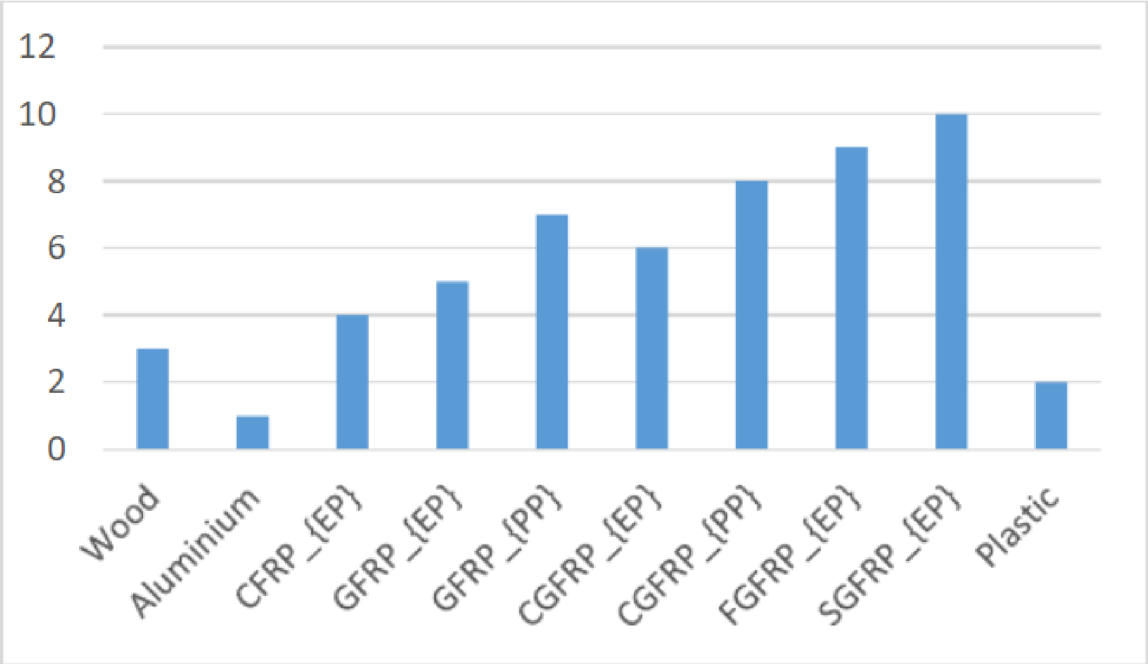

Figure 13 Rank of selection

6.1 Bill of material

Name	Amount	Unit cost (CAD)	Total cost (CAD)
PV Panels	5.00	120	600
R40 double batt	315 ft2	133 / 48 ft2	931.00
Heat Pump Unit (5KW)	1.00	2100.00	2100.00
1750 CFM fans	2.00	50.47	100.00
PLA	1.00	22.95	23.00
Generator	1.00	455.00	455.00
Wire	40 ft	142.00	142.00
Inverter	1.00	955.00	955.00

Table 2 Bill of materials

Name	Link
PV Panels	https://www.amazon.ca/ECO-WORTHY-Watts-Volts-Monocrystalline-Solar/dp/B00V4844F4/ref=asc_df_B00V4844F4/?tag=googleshopc0c-20&linkCode=df0&hvadid=292939506956&hvpos=&hvnetw=g&hvrand=3457035515893710603&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000662&hvtargid=pla-314250919320&th=1
R40 double batt	https://www.homedepot.ca/product/owens-corning-r-40-pink-next-gen-fiberglas-insulation-24-inch-x-48-inch-x-11-inch-48-sq-ft-/1000524955
Heat Pump Unit (5KW)	https://senville.ca/36000-btu-mini-split-air-conditioner-senl-36cd/?sku=SENL-36CD-16&gad_source=1&gclid=CjwKCAjw7oeqBhBwEiwALyHLM5qMsUeO1AX1kkDcjqLXCw4PTA5teFjLqqVqPlqTetAD3utv_b3EgBoC1DQQAvD_BwE
1750 CFM fans	https://www.amazon.ca/CTOCH-Electric-Radiator-Cooling-Universal/dp/B09XB1ZC8T?th=1
PLA	https://3dprintingcanada.com/products/black-1-75mm-pla-filament-1-kg
Generator	https://www.amazon.ca/Generator-Gearless-Permanent-Alternators110v-Turbine/dp/B0B2ZZ7KM9/ref=asc_df_B0B2ZZ7KM9/?tag=googleshopc0c-20&linkCode=df0&hvadid=580610331085&hvpos=&hvnetw=g&hvrand=16560452047233232652&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000662&hvtargid=pla-2084071487454&th=1
Wire	https://www.amazon.ca/Southwire-68579223-Type50-Feet-Conductors-Insulated/dp/B000BPDBAA/ref=asc_df_B000BPDBAA/?tag=googleshopc0c-20&linkCode=df0&hvadid=335174690103&hvpos=&hvnetw=g&hvrand=11313460831908193829&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000662&hvtargid=pla-597647393714&psc=1
DC Motor (12V)	https://www.amazon.ca/Torque-Motor-3000RPM-Permanent-Magnet/dp/B078F7M8R8/ref=asc_df_B078F7M8R8/?tag=googleshopc0c-20&linkCode=df0&hvadid=578829734382&hvpos=&hvnetw=g&hvrand=13745689692276027588&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000662&hvtargid=pla-578736573083&th=1
Rectifier	https://www.amazon.ca/Voltage-Regulator-rectifier-Electrical-Motorcycle/dp/B07L94NTSB/ref=asc_df_B07L94NTSB/?tag=googleshopc0c-20&linkCode=df0&hvadid=335592758565&hvpos=&hvnetw=g&hvrand=49354975608383223337&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000662&hvtargid=pla-897793317491&psc=1
Inverter	https://www.amazon.com/18000watts-Inverter-Battery-Charger-Frequency/dp/B09VYPNKFR/ref=sr_1_1_sspa?keywords=wind%2Bturbine%2Binverter&qid=1698867648&sr=8-1-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&th=1

Table 3 Purchase link of material.

6.2 Equipment list

1. Tower:

- Structural components for the tower, including materials like steel or composites.

2. Blades:

- Prototype wind turbine blades designed for testing.

3. Nacelle:

- The housing that contains the gearbox, generator, and other key components.

4. Generator:

- A generator to convert mechanical energy into electrical energy. Permanent magnet generators are commonly used in small-scale wind turbines.

5. Gearbox:

- If applicable, a gearbox to adjust the rotational speed of the turbine to the optimal speed for the generator.

6. Yaw System:

- Mechanism to allow the turbine to turn into the wind. This can include a yaw drive and yaw motor.

7. Control System:

- Sensors and control electronics to optimize the turbine's performance and direction based on wind conditions.

8. Anemometer:

- Instruments to measure wind speed at the turbine location.

9. Data Acquisition System:

- Hardware and software for collecting and analysing data from various sensors on the turbine.

10. Tower Foundation:

- The foundation for the tower, which could include a concrete base or other suitable support structure.

11. Inverter:

- If the turbine generates AC power, an inverter may be needed to convert it to a usable form for the electrical grid.

12. Transmission System:

- Cables and wiring to transmit the generated electricity from the turbine to a storage system or the electrical grid.

13. Safety Systems:

- Emergency braking system and other safety features to protect the turbine in case of extreme wind conditions or other issues.

14. Monitoring and Maintenance Equipment:

- Tools and equipment for regular maintenance and monitoring of the turbine.

15. Environmental Monitoring Equipment:

- Instruments to measure environmental factors like temperature, humidity, and other conditions that might affect the turbine's performance.

6.3 Instructions

1. Define Goals and Specifications:

- Clearly define the goals of your prototype, such as power output, rotor diameter, and target wind speed.

- Establish specifications for key components, including the blades, generator, and tower.

2. Research and Design:

- Conduct a thorough literature review and research on existing wind turbine designs.

- Use this information to inform the design of your prototype.

- Create detailed engineering drawings and plans for the turbine components.

3. Material Selection:

- Choose materials for the tower, blades, nacelle, and other components based on your design and budget.

- Consider factors such as strength, weight, and cost.

4. Fabrication of Components:

- Manufacture or fabricate the tower, blades, nacelle, and other structural components based on your design.

- Ensure precision and quality in the fabrication process.

5. Assembly:

- Assemble the tower, nacelle, and blades according to your design specifications.

- Incorporate safety features and ensure proper alignment of components.

6. Electrical System Integration:

- Install the generator, gearbox, and other electrical components in the nacelle.

- Connect wiring and test the electrical systems.

7. Yaw System Installation:

- Integrate the yaw system to allow the turbine to turn and face into the wind.

- Test the yaw drive and motor for functionality.

8. Control System Integration:

- Install sensors and control electronics to optimize the turbine's performance based on wind conditions.

- Set up the control algorithms and test the system.

9. Testing and Calibration:

- Conduct initial tests to ensure the turbine operates correctly.

- Calibrate sensors and fine-tune control parameters for optimal performance.

10. Safety Testing:

- Perform safety tests, including emergency braking system tests, to ensure the turbine can respond appropriately to extreme conditions.

11. Data Acquisition System Installation:

- Set up a data acquisition system to collect and analyse data from various sensors on the turbine.
- Implement a monitoring system for ongoing performance evaluation.

12. Environmental Monitoring Equipment Setup:

- Install instruments to measure environmental factors that might affect the turbine's performance.

13. Commissioning:

- Commission the wind turbine by systematically testing and verifying its functionality and safety features.

14. Installation:

- Erect the turbine on its foundation, ensuring that the tower is securely anchored.

15. Operational Monitoring and Maintenance:

- Implement a system for monitoring the turbine's performance during operation.
- Develop a maintenance plan for regular inspections and necessary repairs.

16. Documentation:

- Create comprehensive documentation that includes design specifications, assembly instructions, and operational guidelines.

6.4 Testing and Validation

Phase 1 – Renewable Energy integration

For the existing power supply, PV panels are installed and stored in vehicle batteries for supplying power to all equipment including the lighting, and fans. The reliance on solar power, particularly during winter, presents operational challenges due to its inadequacy, instability, and unreliability. Specifically, installing more possible alternative power generation applications such as wind turbines, and extra solar panels can increase the amount of power available.

It is possible and realistic to provide a more dependable and continuous supply of electricity by combining different renewable energies, such as solar panels and wind turbines. For example, by addressing the fluctuation of both solar and wind energy sources, this hybrid system can guarantee a more reliable power supply. Wind and solar energy sources frequently have complementing qualities. In contrast to solar energy, which is at its peak during the day and under sunny conditions, wind is typically greater at night and during specific seasons. The energy supply will be more plentiful throughout the day and year if more sources are combined.

The combination of PV panels and VAWT will generate around 2000W which is sufficient to run the Heat Pump system and Existing equipment.

Future Results-

By combining the two renewable power sources, the power generation will increase.

Powering the heat pump system directly from the power generation to reduce the number of batteries required. Dump load can be stored in the batteries.

PV Panels -

In Canada, there is a notable disparity in electricity production from solar panels between the spring and summer months, as opposed to the fall and winter. This difference in solar power generation is not solely attributed to changes in daylight duration but is also affected by seasonal shifts in cloud cover, variations in snowfall patterns, and other climate-related differences. Consequently, a potential remedy could involve the installation of extra solar panels.

Calculation:

Actual Requirement – 2000 W

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

On average we get 4 hours of Sunlight in Winter Season and in summer, we can get around 8 hours of sunlight. We must also consider some losses which affect the overall power generation.

That’s why energy generation would range from 400W – 1000W.

Worst Case Scenario: 400W.

Ugrinsky Wind Turbine -

In the design process, theories and calculations correlated in finding the best dimension for the Ugrinsky wind turbine prototype. For this project, there are four stages in the design process. The first stage is the wind turbine design parameter. The second stage is the Ugrinsky wind turbine drawing and 3D views. The third stage is the dimensional analysis of the design, and the last stage will be the fabrication of the prototype with specified dimensions and materials. The experiment for Ugrinsky wind turbine was done after the fabrication of the wind turbine was complete and the data from the experiment was used to determine the performance of the mixed wind turbine.

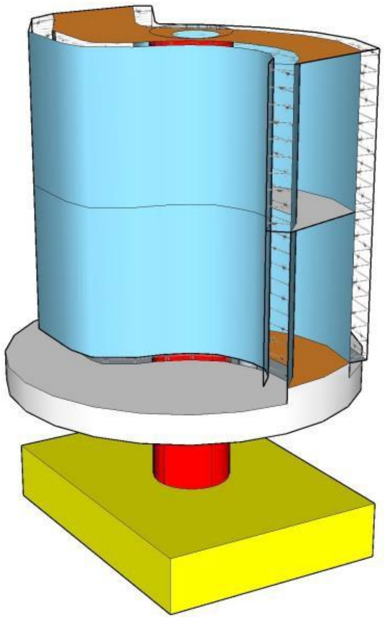

Figure 14 3D model of Ugrinsky wind turbine

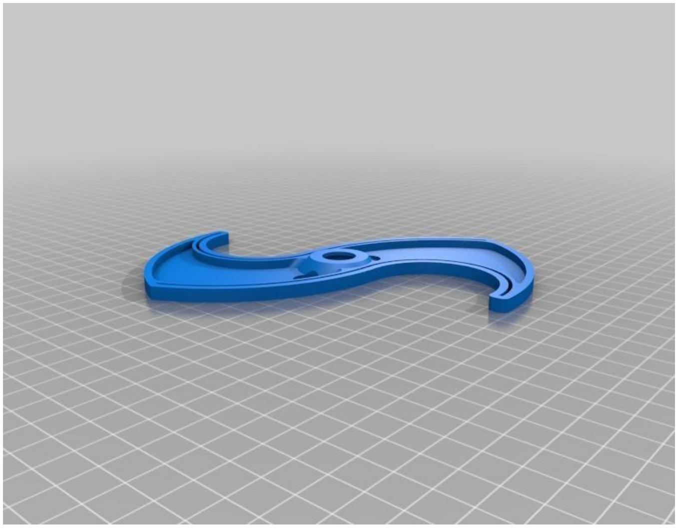

Figure 15 Bottom

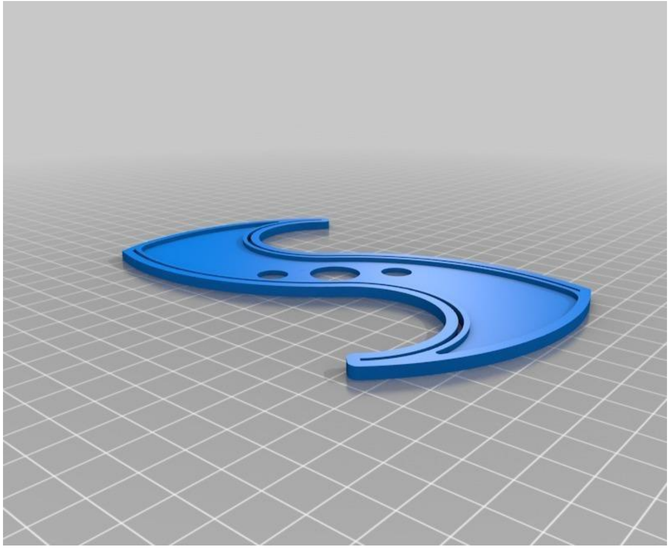

Figure 16 Middle

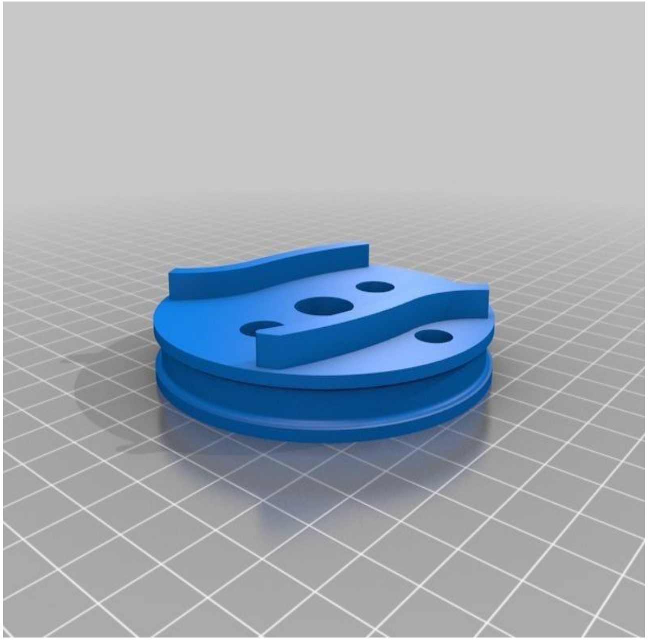

Figure 17 Holder

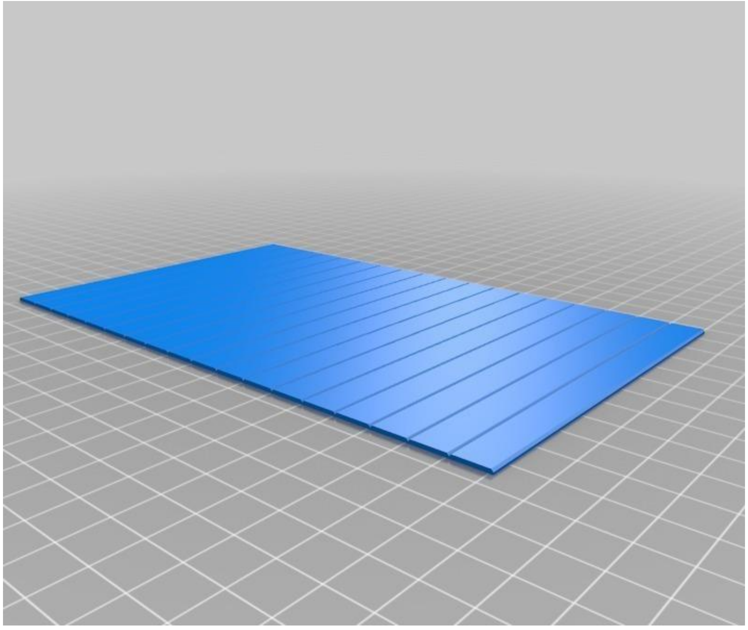

Figure 19 Wings

Figure 18 Top view of final product

Figure 20 Final Product

Test Procedure:

The first variable that was most important in this experiment was the wind speed. The wind speed from the wind tunnel was adjusted based on the distance of the turbine from the wind tunnel. The wind speed from the wind tunnel was adjusted using an anemometer and the ground was marked or pointed after the required wind speed was achieved. The wind speed that was used in the experiment was 21km/hr, 22 km/hr which are average wind speed of the Root Cellar location. The second variable examined was the angle of the curve from the centre of the blades for the wind turbine.

Data Collection and Equipment:

For the experimental work, tools, and equipment for measuring, calibration, and data collection must be determined for a smoother operation during experimental work. Data was collected through observation and documentation of images, videos, and government websites as reporting and evaluation material. The turbine is placed at different distances on the roof of the root cellar determined by measured wind speed using an anemometer. Besides that, the amount of rotation per minute produced from the rotating wind turbine section can be determined by using a bicycle rotation sensor. Mobile video recorders would be used if there is difficulty taking readings from the sensor. The RPM would be counted properly based on the slow-motion turbine rotation from the video. The power generated from the wind turbine motor can be calculated using a wind turbine controller. A digital multimeter is used in case the controller malfunctions. The wiring circuit is used as an alternative in case the power generated from the motor is not sufficient for the controller to work. The wiring circuit included a rectifier, capacitor, wires, wiring hub, and light bulb with 5 W of power.

Design Calculation –

<u>For Revised Prototype-</u>

Diameter – 0.15 m

Height – 0.1 m

Wind Speed – 10 km/ hr

Turbine Efficiency – 30%

Wake Losses – 5%

Losses-

Mechanical – 0.2%

Electrical – 1.5%

Electrical Losses (Transmission) – 5% Maintenance – 3%

Output – 0.06 Wph

1.543 W in 24 hrs.

After scaling up (1:10) the prototype, we will get the following output.

<u>For Actual Turbine –</u>

Diameter – 1.5 m Height – 1 m

Wind Speed – 22 km/ hr

Turbine Efficiency – 30%

Wake Losses – 5% Losses-

Mechanical – 0.2%

Electrical – 1.5%

Electrical Losses (Transmission) – 5% Maintenance – 3%

Output – 66 Wph

- 1584 W in 24 h

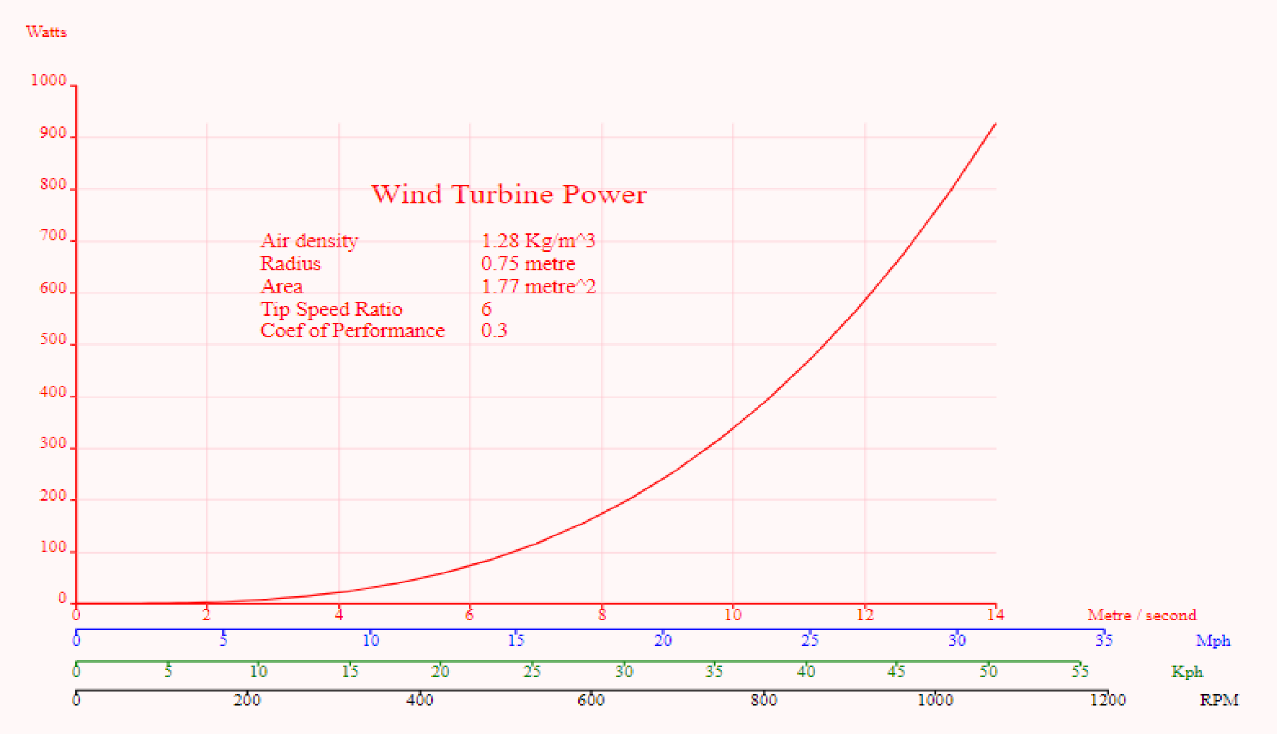

Figure 21 Power generated vs Wind speed plot.

Phase 2 – Tiny Room with Heat Pump Integration

To build the tiny room (6X2 = 12sqm), the R40 double batt insulation is required from one side. The heat pump system with a 5kW cooling capacity was installed along with 2 – 1750 CFM fans for proper ventilation and temperature control. There are 3 ways to operate the tiny room.

Way 1 - High outdoor temperature the tiny room size: 6m (W) x 2m (L)

Only the tiny room operates with cooling mode.

Assumption

The outdoor peak temperature is 35 oC. Mainly used for storing potatoes Storage capacity: 10000 kg

Product exchange rate: 1000 kg per day

After calculation, the cooling load is around 4.49 kW. (Details see Appendix 1)

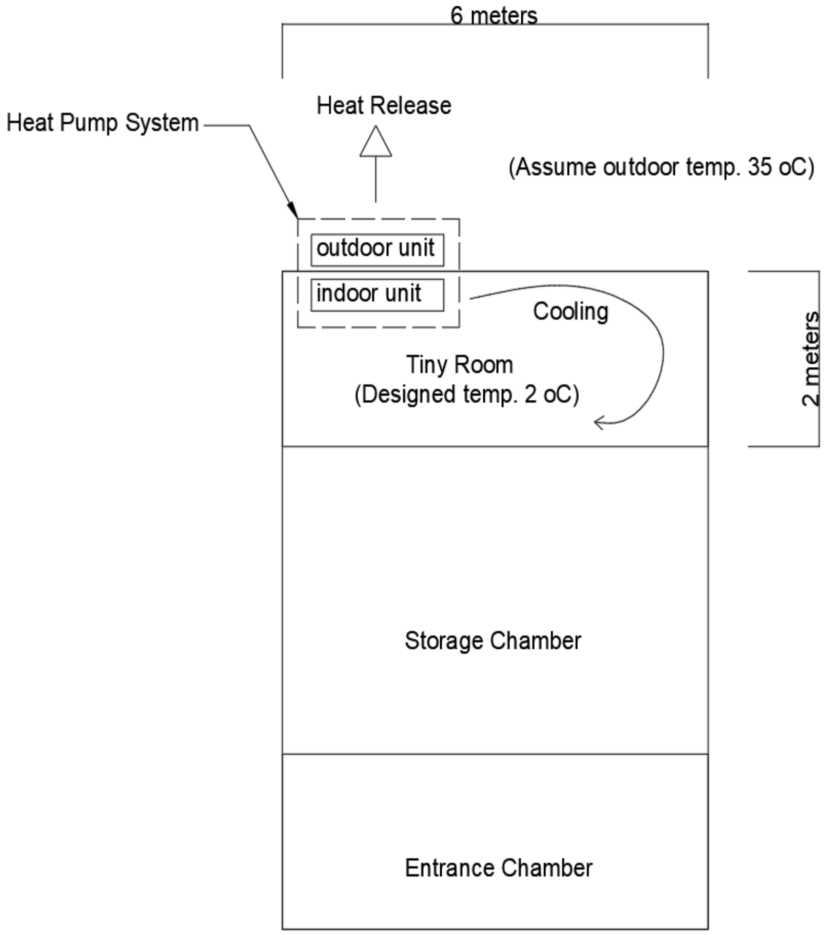

Figure 22 Tiny room operation in summer

Way 2 - Low outdoor temperature

The tiny room + Storage Chamber size: 6m (W) x 6m (L)

The tiny room operates with cooling mode and doors are opened to circulate chilled air throughout the whole storage chamber.

Assumption-

The outdoor peak temperature is 10 ^{0}C. Mainly used for storing potatoes Storage capacity: 25000 kg

Product exchange rate: 2500 kg per day

After calculation, the cooling load is around 4.44 kW. (Details see Appendix 2)

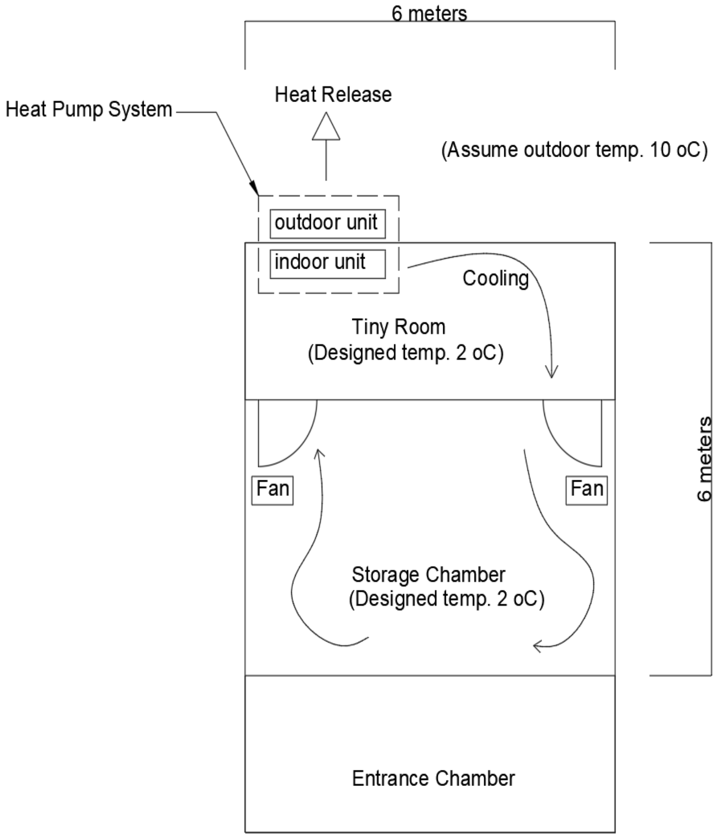

Figure 23 Tiny room operation in Fall/Spring

Way 3 - Cold outdoor temperature

The tiny room + Storage Chamber size: 6m (W) x 6m (L)

The root cellar operates normally. The heat pump switches to heating mode and doors are opened to circulate warm air throughout the whole storage chamber.

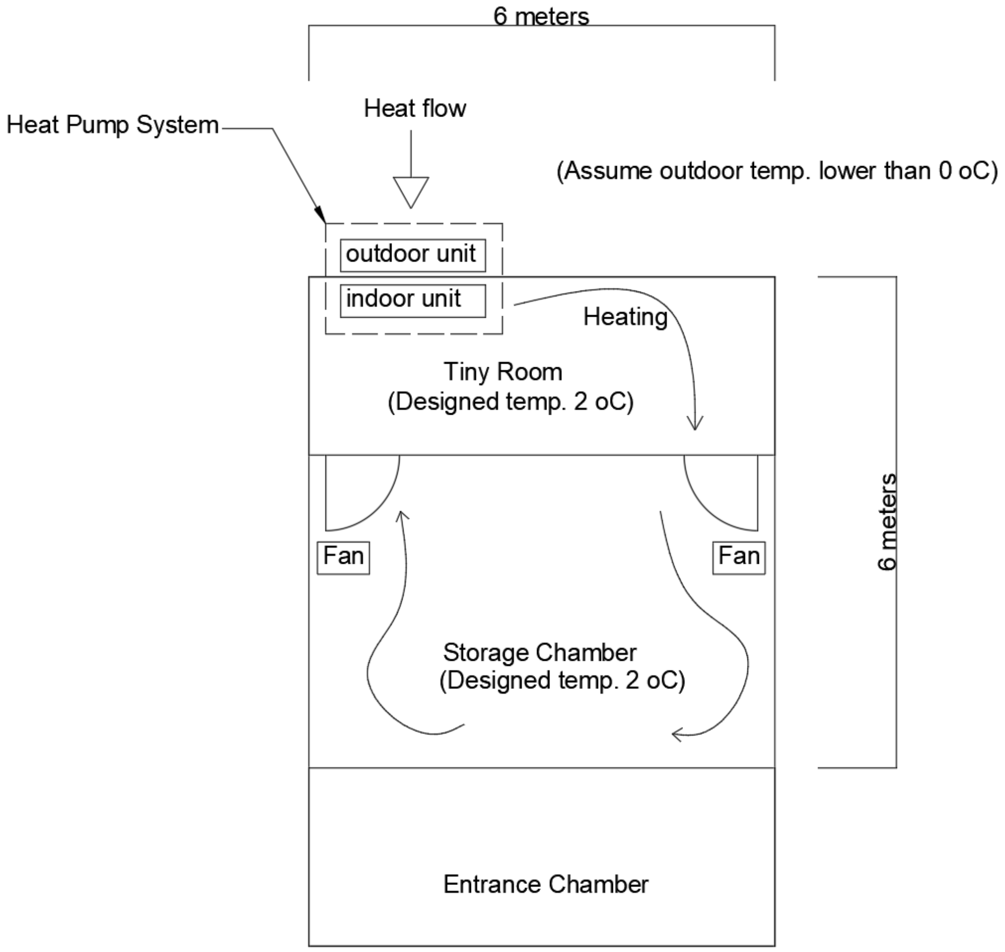

Figure 24 Tiny room operation in winter

To monitor and record the performance of a heat pump, as well as check power consumption and cooling performance, you can use various sensors and data logging equipment. Here's a list of equipment and sensors that are needed.

Temperature Sensor (Thermometer):

-Use temperature sensors to measure the temperature at different points in your heat pump system. You may need both indoor and outdoor temperature sensors to assess the system's efficiency and performance. Thermocouples or digital temperature sensors like DS18B20 can be suitable choices.

Humidity Sensor (Humidity Monitor):

Humidity can impact the efficiency of your heat pump. A humidity sensor can help you monitor indoor and outdoor relative humidity. Sensors like the DHT22 or SHT series are commonly used for humidity measurements.

Power Meter:

A power meter or wattmeter can be used to measure the power consumption of your heat pump. This will help you track the energy usage and efficiency of the heat pump system. Different types of power meters are available, including clamp meters or plug-in power meters.

Data Logger:

A data logger is essential for recording and storing the data from your temperature sensors, humidity sensors, and power meter over time. Data loggers can vary in complexity, from simple USB loggers to more advanced devices with cloud connectivity and remote monitoring capabilities. Examples include Arduino-based data loggers, Raspberry Pi data loggers, or commercial data logging systems.

Pressure Sensors (optional):

Pressure sensors can be useful for monitoring refrigerant pressure within the heat pump system. This data can be critical for assessing the cooling performance and ensuring the heat pump is functioning within the optimal range.

Flow Sensors (optional):

Flow sensors can help monitor the flow of the heat transfer fluid within the heat pump system, which is crucial for evaluating performance and efficiency. Flow sensors can be ultrasonic or mechanical in nature.

Remote Monitoring and Control (optional):

For more advanced monitoring and control, consider incorporating a remote monitoring and control system. This can be achieved using IoT devices or a central control system that allows you to access real-time data and adjust remotely.

By combining these sensors and equipment with appropriate data logging and analysis tools, we can effectively monitor and record the performance of heat pump system, check power consumption, and assess cooling performance. This data can help you optimize the system's efficiency and identify any issues that may require maintenance or adjustments.

	Metrics	Unit	Expected Value	Tested Value and Comments
1	Temperature	Celsius (^0C)	2-4	Able to maintain proper temperature in the tiny room for all seasons. Also helping for heating in wintertime.
2	Humidity	Percentage (%)	90-95	Able to maintain proper humidity in the tiny room for all seasons.
4	Power Generation	Watts (W)	2500	With the 10 PV panels and VAWT, the power generation will increase up to 2720 W.
5	Storage Capacity	Pounds (lbs)	110000	22000 lbs for the tiny room during summer. 55000 lbs for Spring and Fall 110000 lbs for winter
6	Cost	CAD	20000	The cost is lower than the expectation.
7	Max Power Consumption	Watts (W)	2000	1400W for heat pump, 600W for other equipment > 300W for heaters in Winter if necessary

Table 4 Table result comparison.

The implementation of our design will last for a long time because phase 2 must be started after phase 1. Additionally, the assessment for phase 1 needs to span the entire year to facilitate comprehensive data collection on renewable power generation. Consequently, the user or the contractor is advised to perform the specified tests during each respective phase.

Table 5 Tests for real product in the future

PV Panels	VAWT	Tiny Room with the Heat Pump System
Visual Inspection	RPM Test	Humidity & Temperature Test
Insulation Resistance Test	Actual Power Generation Test	Power Consumption Test
Open Circuit Voltage Test	Safety Test	
Short Circuit Current Test		
Shade and Obstruction Test		
Temperature Coefficient Test		

The implementation of our design will last for a long time because phase 2 must be started after phase 1. Additionally, the assessment for phase 1 needs to span the entire year to facilitate comprehensive data collection on renewable power generation. Consequently, the user or the contractor is advised to perform the specified tests during each respective phase.

7 Conclusion and recommendations for future work

At the project's inception, our team possessed limited comprehension of farm-level food insecurity and waste. However, through our interactions and meetings with the client, we gained insight into his innovative solution: an off-grid root cellar designed to preserve farmers' produce. To improve sustainability, it is of key importance to have sustainable food storage that meets the needs of the UN goals and satisfies the needs for the future.

The client brought up a few important issues, including difficulties he had. The root cellar can only be operated in winter. It was difficult to maintain a constant temperature with humidity which was one of the problems associated with the cellar along with a stable power source. While understanding all the challenges and requirements of the client we designed our project in two phases.

The first phase was a renewable energy integration. The PV panels that were already installed by the client were not sufficient to keep the cellar operating stably and commence any system upgrade. So, while designing this part we decided to keep the UN sustainability goals for which we decided to use wind energy. Wind electricity is one of the reliable and constant sources of energy as it helps to get enough energy from it. Based on our location the wind speed and the data collected will be sufficient to generate the electricity. For, the wind turbine we also used the skills that we learned during the course and 3D printed the shaft and made a model which replicated the study which was done for the root cellar.

Moreover, phase two was making a small room with a heat pump that would provide heating and cooling all year round, and the adjustments could be made every season which makes heating and cooling. And to counter the problem of heat dissipation we can provide insulation in the tiny room which serves the purpose. The sizes of the heat pump system and the dimensional of the tiny room are depended on the power generated by the renewable power source. Therefore, the system is possible to scale up or down.

Overall, our participation in this project has been a thrilling experience, and the knowledge we've gained from Dr. Barry Bruce is invaluable. We extend our best wishes to the succeeding team and hope they enjoy their time on this project as much as we did! This project, focused on making the root cellars functional, is indeed a remarkable one, contributing significantly to a sustainable future and promoting better health for all.

8 Bibliography

(1) Content Engine LLC. “Climate Change Threatens Food Security.” CE Noticias Financieras, English ed., Content Engine LLC, a Florida limited liability company, 2022, 2674751786” rb.gy/u06ct.

(2) Deep Roots’ Root Cellar. (2020 February). Retrieved from http://www.deeprootsfoodhub.ca/community-root-cellar.html

Appendix 1 (Calculation for operation in summer)

Transmission Load

Temperature		
Outdoor	35	°C
Storage Chamber	30	°C
Ground	17	°C
Cold room	2	°C
U value (roof)	0.0167	W/m^2 · K
U value	0.025	W/m^2 · K
Area		
Outer Wall	16.08494	m^2
Inner Wall	16.08494	m^2
Roof	20.10618	m^2
Floor	12.8	m^2
Q		
Outer Wall	0.318482	kWh/day
Inner Wall	0.270227	kWh/day
Roof	0.265932	kWh/day
Floor	0.1152	kWh/day
Total	0.969841	kWh/day

To calculate the transmission load we will be using the formula

Q = U x A x (Temp out – Temp in) x 24 ÷ 1000.

- Q= kWh/day heat load
- U = U value of insulation (we already know this value) (W/m^2.K)
- A = surface area of walls roof and floor (we will calculate this) (m^2)
- Temp in = The air temperature inside the room (°C)
- Temp out = The ambient external air temperature (°C)
- 24 = Hours in a day
- 1000 = conversion from Watts to kW.

Product load

Product Exchange		
Specific heat capacity (assume potato)	3.39	kJ/kg.°C
Mass exchanged	1000	kg
Arriving temperature	35	°C
Storage temperature	2	°C
Q	31.075	kWh/day

Q = m x Cp x (Temp enter – Temp store) / 3600.

- Q = kWh/day
- CP = Specific Heat Capacity of product (kJ/kg.°C)
- m = the mass of new products each day (kg)
- Temp enter = the entering temperature of the products (°C)
- Temp store = the temperature within the store (°C)
- 3600 = convert from kJ to kWh.

Product Respiration		
Respiration heat	1.9	kJ/kg
Total mass in storage	10000	kg
Q	5.277778	kWh/day

Q = m x resp / 3600

- Q = kWh/day
- m = mass of product in storage (kg)
- resp = the respiration heat of the product (1.9kJ/kg)
- 3600 = converts the kJ to kWh.

Total Product Load	36.35278	kWh/day

Infiltration load

Air changes per day	5	volume
Volume	32.16988	m^3
Air per cubic meter kJ/°C	2	kJ/°C
Q	2.948906	kWh/day

Q = changes x volume x energy x (Temp out – Temp in) / 3600

- Q = kWh/d
- changes = number of volume changes per day
- volume = the volume of the cold store
- energy = energy per cubic meter per degree Celsius
- Temp out is the air temperature outside
- Temp in is the air temperature inside
- 3600 is just to convert from kJ to kWh.

Transmission Load	0.969841	kWh/day
Product load	36.35278	kWh/day
Infiltration load	2.948906	kWh/day
Assumed Equipment Load	10	kWh/day
Total	50.27152	kWh/day
Safety factor	1.25	
Total Cooling Load	62.83941	kWh/day
14-hour operation for the compressor	4.488529	kW
estimated COP (Coefficient of Performance) for Heat Pump System	4	
Power consumption for heat pump outdoor unit	1.122132	kW
Power consumption for heat pump indoor unit	0.15	kW

Table 6 Calculations for operation in summer

Appendix 2 (Calculations for operation in Fall/Spring)

Transmission Load

Temperature		
Outdoor	10	°C
Entrance Chamber	10	°C
Ground	10	°C
Storage Chamber	2	°C
U value (roof)	0.0167	W/m^2 · K
U value	0.025	W/m^2 · K
Area		
Outer Wall	16.08494	m^2
Inner Wall	16.08494	m^2
Roof	60.31853	m^2
Floor	38.4	m^2
Q		
Outer Wall	0.077208	kWh/day
Inner Wall	0.077208	kWh/day
Roof	0.193405	kWh/day
Floor	0.18432	kWh/day
Total	0.532141	kWh/day

To calculate the transmission load we will be using the formula

Q = U x A x (Temp out – Temp in) x 24 ÷ 1000.

- Q= kWh/day heat load
- U = U value of insulation (we already know this value) (W/m^2.K)
- A = surface area of walls roof and floor (we will calculate this) (m^2)
- Temp in = The air temperature inside the room (°C)
- Temp out = The ambient external air temperature (°C)
- 24 = Hours in a day
- 1000 = conversion from Watts to kW.

Product load

Product Exchange		
Specific heat capacity (assume potato)	3.39	kJ/kg.°C
Mass exchanged	2500	kg
Arriving temperature	10	°C
Storage temperature	2	°C
Q	18.83333	kWh/day

Q = m x Cp x (Temp enter – Temp store) / 3600.

- Q = kWh/day
- CP = Specific Heat Capacity of product (kJ/kg.°C)
- m = the mass of new products each day (kg)
- Temp enter = the entering temperature of the products (°C)
- Temp store = the temperature within the store (°C)
- 3600 = convert from kJ to kWh.

Product Respiration		
Respiration heat	1.9	kJ/kg
Total mass in storage	25000	kg
Q	13.19444	kWh/day

Q = m x resp / 3600

- Q = kWh/day
- m = mass of product in storage (kg)
- resp = the respiration heat of the product (1.9kJ/kg)
- 3600 = converts the kJ to kWh.

Total Product Load	32.02778	kWh/day

Infiltration load

Air changes per day	5	volume
Volume	96.50964	m^3
Air per cubic meter kJ/°C	2	kJ/°C
Q	2.144659	kWh/day

Q = changes x volume x energy x (Temp out – Temp in) / 3600

- Q = kWh/d
- changes = number of volume changes per day
- volume = the volume of the cold store
- energy = energy per cubic meter per degree Celsius
- Temp out is the air temperature outside
- Temp in is the air temperature inside
- 3600 is just to convert from kJ to kWh.

Transmission Load	0.532141	kWh/day
Product load	32.02778	kWh/day
Infiltration load	2.144659	kWh/day
Assumed Equipment Load	15	kWh/day
Total	49.70458	kWh/day
Safety factor	1.25	
Total Cooling Load	62.13072	kWh/day
14-hour operation for the compressor	4.437909	kW
estimated COP (Coefficient of Performance) for Heat Pump System	4	
Power consumption for heat pump outdoor unit	1.109477	kW
Power consumption for heat pump indoor unit	0.15	kW

Table 7 Calculations for operation in Fall/Spring