Livable High Rise
P1 Final Report

Presented to:

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Our signatures below attest that this submission is our original work. Following professional engineering practice, we bear the burden of proof for original work. We have read the Policy on Academic Integrity posted on the Faculty of Engineering and Applied Science web site https://engineering.queensu.ca/policy/academic-integrity and confirm that this work is in accordance with the Policy.

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Executive Summary

The goal is to design an emergency system for a high-rise building, capable of sustaining life for up to five days without access to external resources. When a natural disaster creates a situation that prevents a high-rise building from having electricity or an abundance of food and water, it can be life threatening to the occupants of the building, which is the issue that the report addresses. In order to sustain livable conditions in a high-rise building, the occupants must have access to food, potable water, a waste removal system (i.e. toilets), and basic medical supplies.

For water there are multiple different storage options including tanks, jugs, or sealed water bottles. Each one has different advantages. After scoring each option, sealed water bottles are shown to be the most viable options.

For the decision regarding nutrition, various food groups were compared against several criteria including cultural and dietary acceptance, preparation difficulty and lifespan. Dry Cereal was the most successful with dried fruit, legumes, nuts and grains having similar final scores. In future testing, the best combination of food groups based on their volume will be finalized.

For heating and cooling, the solution proposed was meant to be the most energy efficient and environmentally friendly. The comfort of the residents, amount of fuel and cost was considered. After doing research, Geothermal heat pumps was the main solution considered as it can provide heating and cooling and uses renewable options. Wall cladding and double-panel windows was also considered. The best option was to combine all the solutions together for maximum efficiency and more economically feasible.

For the decision regarding the electricity source, several options were considered. Fossil fuel generators and backup batteries were found to be the two most viable options. Those two categories were narrowed down to batteries connected to solar panels, and natural gas generators, which were then compared using a table, outlining their pros and cons, to find the ideal source.

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1. Introduction

1.1 Problem Statement

An emergency system must be developed for a Vancouver high-rise building that can sustain life for up to five days without access to external resources. This system must provide adequate drinking water and food that accommodates different dietary needs. It must provide waste removal and designate resources for personal hygiene. Furthermore, the system must have a source that provides enough electricity for basic lighting, to power elevators and to allow a safe level of fresh air circulation without any heating or cooling.

1.2 Stakeholder Needs

The stakeholders involved in this project are the residents, the government, engineers and high-rise owners. The residents living in the high-rise building, they are significant as the execution of the new systems may affect their living condition. For example, the new systems may take up space so the residents would be restricted from a few floors or even inside the apartment. They need to have temperatures which are comfortable to live in, sterile water, functioning sewage and a proper heating and cooling system.

The government needs a system which is environmentally sustainable and ensure that the building owners are following the safety regulations. They also want to guarantee that the high-rise building owners are following the building codes and property standards. Sometimes the government will help in funding for building the new system, therefore the system should be economically feasible. To also be considered livable to the residents, the building must comply with the Tenancy Laws and Rules.

The engineers are also considered stakeholders because they are involved with the implementation of the system. The engineers need to put safety first and ensure that the system will not affect the building and the residents inside it.

Furthermore, the high-rise owners are also a significant stakeholder as they will be the ones that will be implementing the system to their buildings and providing most of the budget. Therefore, they need the most economically feasible solution possible and the solution should ensure that no residents would leave the building for good as it can affect the owners economically. The owners need to also ensure that the safety requirements of the residents are met.

1.3 Design Criteria

Below is a brief description of the three criteria that will be considered in the design. The quantitative requirements are summarized in Table 1.

Cost

The High-Rise must provide disaster proof housing at a competitive price in the current real estate market as well as against other disaster proof housing solutions. The stockpiled resources will have to be exchanged for fresh goods as they expire adding to the maintenance cost of the High-Rise. All resources in the High-Rise must have long a lifespan to decrease running costs.

Sustainability

The High-Rise must last five days completely isolated from the municipal systems. Therefore the building must supply shelter, food, water and proper temperature controls all while maintaining proper hygiene and sanitation for public health. For Hydration, each person will require 20L of water for the five days as well as 50% of their daily recommended caloric intake [1]. When looking at nutrients, the High-Rise must provide each resident with 100% of the 14 most important micro and macro nutrients including protein, fats, Vitamins A to E and Calcium [2]. All nutritional options must be able to be prepared with less than 20 minutes of prep time and must not require any appliances. The foods must be accepted by most major cultures and dietary restrictions. The High-Rise must also keep the temperature as close to 20C or provide additional clothing when below for the entire five days regardless of the external temperature [3]. Any resource within the High-Rise must last longer than two years to decrease waste and extra costs.

Efficiency

Spatial Efficiency

There is a finite area within the High-Rise to store enough resources to last the five days. Therefore, it is essential that the food and water are packaged and stored such that the total required food and water is available without taking up too much space. Examples include water tanks instead of water bottles, and food that is denser and of higher calories.

Energy Efficiency

The high-rise building will be off the grid in the event of natural disaster, thus the available electricity will be supplied by generators and back up batteries. In order for the electricity to last 5 days, all emergency backup equipment must use low levels of power to achieve necessary tasks. For example, this means that pumping water to all floors of the building may not be an efficient use of power, and an alternative solution may be required.

Table 1: Outlines the specifications of cost, sustainability and efficiency.

Criteria	Specification
Cost	• Must be an affordable compared to alternative emergency solutions • Maintenance and expired resource replacement costs must be kept low • Project costs must be kept in reasonable price range when compared to the competitive value and rent of similar properties
Sustainability	• Must store 4L of clean drinking water per person per day for 5 days • Must store enough food to satisfy caloric and nutritional needs for up to 5 days • The total quantity and volume of resources must include a factor of safety, as to account for unexpected situations
Efficiency	• The equipment installed must be energy efficient with respect to the total power reserve and generator capacity • Resources and equipment cannot use too much space, as to not interfere with existing pre-existing building requirements

1.4 Scope

The scope of this project is to design an emergency system that can be implemented into an existing seven story building that can sustain liveable conditions for five days without access to external resources. It was determined that the building must be located in Vancouver, British Columbia. Moreover, the system must provide adequate resources to support the following assumptions:

- No one in the building has enough food and water of their own to maintain liveable conditions for themselves.
- All the necessary electricity must be sourced from independent generators in the building.
- The apartments do not have access to running water.
- The wiring and ducts still function properly to provide electricity and fresh air circulation respectively, throughout the building when power is supplied.

Sanitation was not addressed as it was considered out of scope for this report. Nutrition and water supplies, heating and cooling and electricity were all chosen so there could be a greater focus on those four elements.

1.5 Constraints

Storage is a major constraint as it limits the amount of equipment and resources the system may have. As well, the budget should not exceed an amount that would cause the cost of living to be unaffordable relative to other housing options. Electricity consumption is another constraint as limited power can be stored in the building without an external source. Moreover, the building must be in a Canadian city and at least seven stories.

2. Background Research

The following background research was gathered to create a working knowledge of nutrition, water use, temperature control and electricity generation. This strengthened the process of idea generation, design selection and the final product.

2.1 Nutrition

What is NNR?

The Naturally Nutrient Rich score ranks foods based on their nutrient content. Overall the index compares at 14 different essential nutrients such as protein, vitamins A-E and Iron, then scores them based on the nutrient per serving divided by the recommended daily amount. These 14 individual scores are then averaged for the final NNR score [3] [1].To clarify, the NNR score does not have any relationship to calories. What many call the 2000 calorie per day diet also provides recommendations for daily nutrient and mineral recommendations. Therefore, the NNR [1] score does not have any relationship to calories but rather uses those recommended nutrient quantities to determine a percentage of the daily requirement for each food group.

This ranking system does have the limitation of being too general with the single score. If an entire diet was to be chosen just based on the top NNR scores, there is a possibility that individual nutrients could be completely missing. [3] If the NNR Score was to be used to choose a diet for the High-Rise, secondary dietary accounting must be competed and if necessary; extra dietary supplements should be added [4]. In Table 2, the NNR scores are summarized for 12 food groups provided by the BMC Nutrition Journal.

Table 2 - NNR Score per food Group from the BMC Nutrition Journal which featured an article containing 12 studied food groups specific for emergency response in urban environments. [1]

Nutrient	Dry cereal	Nuts	Dried fruit	Grains	Legumes	Dried meat/fish	Dry milk	Fresh vegetables	Fresh fruits	Fresh milk	Eggs	Fresh meat/fish
NNR Score	28.1	7.3	6.8	10.6	9.2	8.5	12.4	13.9	2.1	13.4	7.1	12.2

Research for Immediate Disqualification Criteria

All research can be summarized in Table 5 , where a failure indicates it did not achieve greater than a score of one based on the Criteria in Table 12 - Rubric for the Nutrition Design decision matrix.

Total Dietary Recommendations for Macro Nutrients

Table 1 demonstrates the breakdown of macro nutrients in the average 2000 calorie diet.

Table 2 - Macro Nutrient Breakdown [5]

Macro Nutrient	Protein	Fats	Carbohydrates
Recommended Daily %	~25%	~15%	~60%

Necessary Nutritional Intake During Disaster Scenarios

When considering a five day disaster response nutrition program, it is important to determine what nutritional intake is absolutely necessary and what can be made up for after the lockdown. Ketosis; the oxidations of proteins could be considered a danger for low calorie diets especially in lean individuals occurs after 1-3 days during low calorie diets [6]. To avoid ketosis and hyperketonemia response, individuals must provide their bodies with enough energy [7]. If there are not enough calories digested, the body will begin using fat stores and proteins as energy causing a buildup of nitrogen in the urine [6].

Nutrition is also incredibly important for disease and sickness prevention. For a large quantity of people in an enclosed space, contraction of the flu, a virus or the common cold can become incredibly easy. Vitamins C, D and Zinc are all found to lower the risk of contraction against an infectious agent [8].

Supplements

Supplementing common vitamins and minerals can be done through pills or chewable tablets with one or two small tablets providing the full daily recommended requirement [8]. For macro nutrients such as protein, powders that are mixed with water could be provided. In the case of protein deficiencies, vegetarian based powders would be chosen to decrease the possible nutritional conflicts. In the case where a resident cannot eat the provided food due to allergies, personal texture or taste issues or cultural reasons, meal replacement could be provided. Meal replacement are often shakes, drinks or powder that contains macro and micro nutrients similar to a meal [2]. For example, the Ensure Regular meal replacement drink has approximately 30% of daily required vitamins and minerals and contains 10g of protein and 70g of carbohydrates [2].

2.2 Water

Why is water important?

Besides oxygen, water is one of the most essential substances for survival. The human body is reliant on water as it necessary for most bodily functions including digestion, excretion, temperature regulation, and many more [9]. Without access to drinking water, dehydration will occur and the chances of surviving more than 3 days become greatly reduced [10]. This makes it important that the high-rise building is well stocked with enough drinking water for the occupants in the event of a natural disaster. An insufficient supply will cause dehydration which depending on the severity can have numerous consequences; fatigue, constipation, and seizures are a few side effects [11].

How much water is needed?

The rate of water consumption for an individual can vary based on multiple factors such as age, physical activity, sicknesses, and other medical conditions. For example, individuals with diabetes could require a larger water intake due to the effects of their medications [11]. According to the United States Federal Emergency Management Agency, it is recommended that 3.8 liters of water is stored per person per day [12]. This amount accounts for cooking and sanitation needs that may require water [12]. There must also be water stored for pets. Animals generally need a minimum of 30 mL per kilogram of body weight per day [13]. Water is important in maintain health and survival of the building's occupants, therefore, ensuring a sufficient volume of water will be essential.

Treatment methods for water?

When water is sitting in a container for a long period of time, contaminants can interact with the water, thus reducing the quality of the water. Although municipal drinking water is expected to be safe, pathogens can enter the water system. [14] It is important that the water is treated properly in order to prevent health complications for the occupants. One of the simplest treatment methods involves bleach, as it contains chlorine which is effective at killing germs such as salmonella or the norovirus. [15] However, because bleach can be toxic in high concentrations, the amount of bleach added to the water must be monitored closely. Safe levels of chlorine are 4 mg per liter of water. [15] This will kill off the pathogens while maintaining water quality that will not threaten one's health. The bleach must contain 5.25% sodium hypochlorite or else solid calcium hypochlorite should be added instead. [13] Another alternative are purification tablets, which range in chemical composition but usually consist of either chlorine, sulfate, or iodine [16]. These tablets are put into the water 30 minutes to an hour before consumption so that they decrease the chances of active viruses and bacteria [16]. Both of these treatment options are simple and effective in ensuring safe drinking water for the building's occupants.

2.3 Heating and Cooling

Depending on the time of year and the natural disaster, temperature will have a significant impact on the health and survival of the building's occupants. Humidity also influences the comfort of the occupants.

Impact of Extreme Heat Conditions

In the event of a heat spell, the residents would be susceptible to discomfort and health issues. When the human body is exposed to temperatures above 32 degrees Celsius for an extended time, this can cause heat cramps and exhaustion. If the temperature rises greater than 40 degrees Celsius then the residents may experience numerous symptoms of heat stroke including heavy sweating, fatigue or blacking out, dizziness, nausea, and vomiting. Hydration is an essential part of reducing these symptoms, but because water is a limited resource in the event of a natural disaster, it is important that multiple solutions are found for maintaining a stable body temperature [17].

Impact of Extreme Cold Conditions

Extreme cold temperatures can also be detrimental to one's health. Unlike hot temperatures, the effects of cold temperatures are greater influenced by humidity and other factors. Therefore, body temperature is a better indication of the severity of the coldness experienced. As body temperature lowers, the effects of heat loss can have a greater impact, and chances of survival rapidly decrease. Body temperatures below 37 degrees Celsius will result in shivering and rising heart rate, and upon reaching 30 degrees Celsius the human body will experience an inability to walk, feelings of drowsiness, and a further increased heart rate. As the body temperature gets even lower, low levels of functionality are reached and digression into a comatose state may occur, eventually leading to death. These effects can be more catastrophic especially for the elderly or people with medical conditions. The consequences of extreme temperatures must be accounted for in the high-rise emergency design in order to greatly decreased the chances of casualties and generally sustain the health of the occupants [17].

2.4 Electricity

2.4.1 Power Source

The system must provide power for the entire building without access to the grid's power. Many larger buildings make use of fossil fuel generators as their independent source of power. There are two fossil fuel generators that are typically used; natural gas or diesel generators. Natural gas generators are preferred to diesel generators as they have reduced operational emissions, simpler maintenance and do not have to be refueled [18]. Another viable source of power for a building of this size are backup batteries, which are better for the environment and require little to no maintenance. As well, when connected to a solar energy system, there are no energy costs and they often have federal incentives [19]. The main drawbacks to using the batteries compared to fossil fuel generators is the upfront cost, lower power output and lower storage capacity [18].

2.4.2 Power Consumption

Money can be saved if less electricity is used. To limit power usage, electricity could only be available for certain necessities. It is common for larger buildings to limit power usage throughout the apartments and have temperature controlled common refuge areas that are designated for residents to do things such as cook and charge their phones [20].

The minimal required power output for everything stated above to function properly, the power source should provide around 100killoWatt [21]. Some generators are capable of providing this power if fueled sufficiently, however backup batteries typically have a max power output of 5-10killoWatts each. This means that powering a building of this size might require up to 20 batteries. Fortunately, these batteries are compact, and a sufficient amount could be implemented onto the roof of most buildings [22].

3. Preliminary Designs

3.1 Idea Generation

A variety of idea generation tools were used including sticky-note brainstorming, a mind map and several group discussions to create a multitude of potential design solutions.

3.1.1 Nutrition

Potential design options began with brainstorming common groupings of food. After researching the topic further, the BMC Nutrition Journal featured an article containing 12 studied food groups specific for emergency response in urban environments [1].

After these food groups were created, a second idea generation phase occurred where the team accumulated a list of foods that fit in each food group through a mind map. In Table 3 below is a summarized version of this idea generation tool. Then their nutrition facts were compiled on MyFoodDiary.com with the recommended serving size. A representation of the idea generation phase is represented below in Table 3.

Table 3 - Idea Generation for food groups developed by a research paper published by the BMC Nursing Journal. Extra food examples were added by the team to the initial suggestions by the paper.

Food Group	Example
Dry Cereal	Cornflakes®, Cheerios® (3/4 cup); Shredded Wheat® (1/2 cup); granola (1/4 cup), granola bars (2 bars), Just Right, Fiber One
Nuts	almonds, walnuts, cashews, pecans, pistachios (1/2 cup), almond butter, peanut butter (1 tbsp)
Dried Fruit	apricots, figs, raisins, apples, dates, Mango, Pineapple, mixed Berries (1/4 cup each),
Grains	cooked quinoa, cooked white rice (1/3 cup); 6 saltine crackers; cream of wheat, enriched pasta (1/2 cup cooked), full grain bread (two slices)
Legumes	raw peas, raw soybeans (1 cup); canned kidney beans, cooked chick peas, cooked lentils (1/2 cup), roasted chickpeas
Dried Meat/Fish	beef, cod (1 oz)
Dry Milk	carrots, tomato, spinach, celery, bell pepper (1 cup)
Fresh Vegetables	apple, orange, banana (1 piece); seedless grapes, cantaloupe (1 cup)
Fresh Fruits	ground beef, pork roast, cod, chicken, salmon (3 oz)
Fresh Milk	Dairy, Soy, Almond
Eggs	Eggs (2)
Fresh Meat/Fish	beef, cod (1 oz)

3.1.2 Water Management

Design Options

In order to have enough accessible water in the event of a crisis, there must be a constant storage of water. The following solutions were obtained using both background research and group sticky note brainstorming which can be seen in the Appendix. After the idea generation, the list of options was reduced to the top 3. For storing water, tanks, jugs, and water bottles are all valid solutions, however, there are different advantages and restrictions that must be accounted for.

Storage Tanks

Water tanks are the largest of all the storage methods, and as a result they can hold a considerable amount of water depending on their size. Plastic tanks are commonly used for this application because they are inexpensive compared to steel tanks. Plastic can range from $130 for a 208 liter barrel to $1200 for a 984 liter tank, while it costs $1150 for a 379 liter steel tank. [23] Even though steel is more expensive, both options will be considered for this project. An advantage of large tanks is that they have a reduced ability to freeze up. In the event that they are exposed to extremely low temperatures, the water inside will want to freeze, but the increased volume to surface area ratio means that it will take significantly longer for the tank to freeze compared to other storage options. [24] If necessary, the tanks can also be equipped with a heating system or a system that maintains motion in the water to ensure that the tank does not freeze. [24] A disadvantage to large water storage is that any contamination within the water tank will result in a large portion of the drinking supply water being contaminated, especially when compared to smaller containers like jugs or water bottles.

Jugs

By going with smaller containers for water storage, it will increase the portability of the water supply, allowing for the water to be moved throughout the building. Additionally, distribution of the water can be made simple as jugs of smaller volume could be used to give out rationed amounts to the occupants. For example, each building resident could receive a jug of water equal to their portion of the water supply. A downside to this is that many jugs would need to be stored in order to have enough water, and spatial efficiency of water jugs is often less than water tanks.

Sealed Water Bottles

Store bought sealed water bottles are also a possible option. Not only are water bottles easier to distribute, but they are sealed, thus reducing the chance of contamination. Water bottles are also easy to store as they are often organized into rectangular flats, which can make it easy pack them into small spaces. The disadvantage is that as the storage container sizes decrease, the chances of freezing in cold temperatures will be greater.

3.1.3 Heating and Cooling

There are three systems for heating and cooling being considered for implementation. The first option is the geothermal heating and cooling system. The geothermal system can be used as a heat source and sink. It uses Earth as a source of energy; therefore, it is considered a renewable resource which implies that it is energy efficient and eco-friendly [25]. For this high-rise building we will be using the ground source heat pumps which uses pipes or loops which are usually underground for circulation. There are four types of ground loop systems, but the best option would be a vertical closed-loop system. A horizontal closed-loop system required more land area than the vertical closed-loop system. However, for a vertical system, holes are drilled from 100 to 400 feet deep [26] ; therefore, it can negatively affect the environment. The vertical loops are then connected to a heat pump in the building which can also be retrofitted into an existing HVAC system. As a result, it can be also economically favorable as minimal HVAC systems need to be installed.

Another option is having energy-efficient wall cladding which can reduce heating and cooling loads. They have higher thermal resistance and fewer thermal breaks, so less energy is required for cooling and heating [27]. The type of cladding that will be used is exterior insulation and finish system which is cost-effective. However, if there are defects beneath the cladding, there will be failures and loss of efficiency. Furthermore, Double-panel windows are another option. They will maintain room heat in the winter and prevent heat entering in the summer. Increasing the number of panels is better for harsher climates and they are not expensive.

3.1.4 Electricity

To power the building, solar panels could be set up on the roof and connected to backup batteries. The backup batteries could charge fully from the grid's power before the emergency occurs. Once it has occurred, the diminishing power supply in the batteries could be replenished from the solar panels. The fossil fuel system could be implemented by using natural gas generators as the primary backup source, while having diesel generators as a secondary source in the event of a natural gas disruption [20].

To limit power usage, it should be considered that only basic lighting and fresh air circulation be provided to each apartment. As well, electricity could be used to pump water to one designated area on every floor rather than to every apartment. Common refuge areas could also be implemented to every floor to efficiently provide more necessary resources.

3.2 Design Selection

The design process began with identifying the functional requirements and the demanded qualities requested by the customer. These criteria were related using the QFD section in the found in the APPENDIX which produced relative weightings of each criteria; ranking which was most important for the final plan. In initial drafts of the QFD table, the Functional design elements overlapped and were combined into one category. After the design criteria were finalized, a rubric was developed for each criteria with qualitative and quantitative goals to determine the success of each design option. Each food group was ranked with the rubric criteria with a score of either 1, 3 or 9 to emphasize the difference between failure, mediocre and perfect. These individual scores were then multiplied by the weightings developed in the QFD then totaled for a final score in the Informed Decision Matrix found for all designs in the APPENDIX.

By using the Qualitative Functional Design Table to develop the weightings used in the Decision Matrix increased the accuracy of the final scores. This is because the QFD table uses a quantitative method to develop these scores rather than qualitative approaches like group discussion or assigning an arbitrary value based on other criteria.

3.2.1 Nutrition

Immediate Disqualification Criteria

Failing certain criteria was demined unacceptable and resulted in immediate disqualification for that design. If the solution scored a one in preparation requirements, it would conflict with the initial problem statement; requiring no appliances to be used due to energy consumption restrictions. If any food group conflicted with a major diet or culture it would be immediately removed from consideration, for example; Milk and Lactose Intolerance or beef for Hinduism [28] [29]. Finally, if the food would last less than six months in a room temperature storage facility, it would become too expensive to continually replace and the added waste would increase the High-Rise's effect on the environment [30].This process is shown in Table 3.

Informed Decision Matrix Results

After using the QFD, success criteria and the final decision matrix, it was determined that dry cereal was the out-right best option. Although a properly designed nutrition plan does not just incorporate one food or one meal, it's the combination of several high-quality foods that will sustain the residents for the five days. As discussed in the above background information it is important to identify other factors

Daily Meal Plan Analysis

Now that the top five food groups have been identified, a single day meal plan should be created and all the nutrients totalled. Then, nutrients that are significantly lower than the their suggested daily values should identified and extra supplements or meal replacement should be provided. Finally, fulfilling the daily intake for important vitamins and minerals identified in the Background Research should be emphasized and supplements recommended. A suggested meal plan is shown in the appendix as Figure 4.

Adding Supplements

According to the totals at the bottom of Figure 4, the suggested dietary plan is low in vitamin A, C and Iron. The protein intake is also very close to the lower limit and will not suffice for a larger person (protein intake is recommended by grams per kg of body weight) [4]. Therefore, it is recommended for the residents to have access to vegetarian protein supplements and a daily supply of vitamin supplements listed above, as well as zinc for sickness prevention [2]. Quantities would be the maximal daily dose as per the bottle (typically 1-2 tablets per day).

3.2.2 Water Management

In order to compare the different options for water storage, organized criteria are used. A Quality Function Deployment (QFD) chart seen in Table 6 was used to assist in this process. First, a list of functional requirements was added to the chart to outline the most important characteristics that a water storage method should have. Next a list of requirements was created based on the possible needs of the building's occupants. By scoring the importance of the occupants' requirements as 1 (less important), 3 (somewhat important), or 9 (extremely important), the more essential requirements are able to have a large impact in the overall weightings. Additionally, the strength of the relationships between each functional requirements and the occupants' requirements are also scored. The QFD takes these relationships into account and generates relative weightings for each of the functional requirements. These weighting are then used to assess each of the design options, as seen in Table 12. Also an in-depth criteria was created for each functional requirement, ensuring a structured assessment of each water storage option. This can be seen in Table 10.

3.2.3 Heating Cooling

When deciding the solution, the stakeholder's needs, and the design objectives will have to be considered. A QFD table and rubric was done to see relationship between what the customer requirements and its functional requirements. The results can be seen on Figure 2 and Table 5. If the solution scored a one for amount of time of heating and cooling supplied, it would be unacceptable as residents should at least have livable levels of heating and cooling. The wall cladding and double-panel windows would do a difference if combined as it would cut costs and be more energy efficient. The scores can be done on the QFD and a decision matrix. In conclusion, the best option to go for is the wall cladding combined with double-panel windows.

3.2.4 Electricity

Based off the background research and idea generation, backup batteries or natural gas generators with backup diesel generators should be used to provide power for the building. To simplify the designs, the comparison will be against backup batteries and natural gas generators without the fail-safe diesel generators design as having a secondary backup power source is out of the scope of this report. Table 9 outlines pros and cons of the two power sources.

To quantitatively compare the two designs, a QFD (Figure 3Table 9 - Outlines the pros and cons of different power sources.

Power Source	Pros	Cons
Backup Batteries	-Environmentally friendly -Little to no maintenance -No refueling required -No energy cost when connected to solar panels -Can use the solar panels as a source of power when not in a state of emergency to reduce utilities in the building	-Upfront cost -Lower storage capacity -Lower power output -Require more space
Natural Gas generators	-Commonly used in larger buildings -No refueling required -Higher power output -Cheaper upfront costs	-Uses fossils fuels -Maintenance requirements -May not work in the event there is a natural gas disruption

Figure 3 – Quality Functional Design Table for Electricity) and decision matrix were created. The QFD helped determine what the most important characteristics for the design are and weighted them based of importance. Fuel requirements and capacity were found to be the most important characteristics, which makes sense as they are the two functional requirements for the system to work properly. Environmental effect and maintenance scored lower as while they are beneficial for the environment and cost respectively, they are not essential for providing the livable conditions required for this report. Table 11 outlines the criteria for the scoring of each design. The scores are then multiplied by the relative weighting for each characteristic in Table 12 showing the total scoring to determine the ideal design.

4. Considerations for Final Design

4.1 Sustainable Engineering

When implementing water storage, the Triple Bottom Line needs be taken into account. The stored water must be replaced every 6 months to a year to be considered potable and not pose a health risk in the event of a crisis. This results in the disposal of an immense amount of unused water and plastic. However, there are some possible solutions that will benefit everyone. Firstly, the water bottles can be donated to a food bank assuming that the bottles are not past their best before date. Additionally, the water could be used in other ways such as watering plants or kept in storage for cleaning and sanitation applications. Recycling would be used to dispose of all plastic waste that is generated by the implementation of this project, reducing the environmental impact. This will increase the sustainability of this project by reduce both health risks and negative effects on the environment while having a positive impact in the community.

Potential food waste is an extremely negative result of the livable High-Rise and must be considered when developing the triple bottom line. Not only will it raise costs to change the food supply regularly, but it is also incredibly wasteful if done improperly. In order to lower financial costs, it should be a priority to choose food with a long lifespan. To lower societal and environmental costs, all stored food that is about to expire should be removed and donated while it is still edible.

Using backup batteries instead of fossil fuel generators is much more sustainable for the environment as they can be used in a way that they produce no direct emissions. Backup batteries can be charged by the grid power or by a solar panel system, whereas a generator would rely on fossil fuels. It would be ironic to use fossil fuels in this project considering they contribute to the effect of global warming, which is likely to impact future natural disasters [31].

For heating and cooling, all the solutions suggested are sustainable and environmentally friendly. The geothermal system uses renewable resources for energy; however, the installation of the geothermal system pipes and tubes may affect the environment because of the drilling underground. The wall cladding and double-panel windows will help reduce the load on the HVAC system and therefore will make it more energy efficient. The wall cladding and double-panel windows will also prevent the sound from outside from entering the building. By having more energy efficient solution, it will cut down costs as less fuel will be needed.

4.2 Safety and Regulatory Issues

In order to maintain potable water, the water bottles cannot be kept for longer than a year [13]. Chemicals from the bottle can seep in to the water making it unhealthy to consume. Therefore, all the water bottles must be replaced once a year.

For heating and cooling, safety regulations required that no harmful chemicals or gases leave the system. Wall cladding and double-panel windows do not have the ability to produce chemicals that may affect the residents or the water in the building. Therefore, it is safe and complies with the safety regulations. However, the geothermal system is underground and needs drilling so it is harmful for the environment and can affect water beside it. Thus, it is considered to be a safety hazard and that's why the wall cladding, and double-panel windows is a safer solution.

Food safety must be closely regulated to stop the spread of preventable illness, especially in an enclosed building with minimal cleaning and sanitation supplies. Since the food has been chosen to be stored without refrigeration, the staff must only pay attention to the best before dates. During food prep, gloves and hairnets should be worn to prevent bacteria spreading and all cutlery should be sanitized after every use. All surfaces involved in food prep should be cleaned to avoid cross contamination. To avoid the possibility of allergic reactions, all residents should be required to submit any potential allergens to avoid. In this scenario, they will either be provided with a different meal, a meal replacement, or if it is severe enough, that allergen will be removed from the diet completely.

5. Final Design

5.1 Final Design of Solution

5.1.1 Nutrition

The final nutrition plan for one day is outlined in Figure 4 in the appendix. It outlines the final foods and supplements planned for one day in the High-Rise. Extra Vitamin A, C, zinc, calcium and protein were added as supplements in the breakfast time-slot but these could be taken at any point throughout the day [2]. The final daily nutritional statistics can be found in **Error! Reference source not found.**. For a breakdown of every food in the day refer to Figure 4.

This nutrition plan achieves the daily nutritional requirements for the identified vitamins, minerals and macronutrients in the background information and also includes over 2000 calories. Achieving this quantity of energy will stop the body from entering ketosis as the caloric intake is above the average base metabolic rate [6].

These foods have been selected as they require no extra appliances to cook or store as well as have minimal conflicts with cultural or dietary restrictions. For preparation, these provided foods will require limited preparation time, equipment and skill [28].

Figure 1 - Final Nutritional Statistics for one day.

Expand all	Cal	Fat	S Fat	T Fat	Chol	Sod	Carbs	Fib	Sug	Prot	Vit A	Vit C	Calc
+ Breakfast	332	1.0 3%	0.5 1%	0.0 0%	0	440	55.5 69%	6.7 8%	24.2 30%	23.0 28%	4300	627.0	900
+ Morning Snack	248	7.3 26%	1.1 4%	0.0 0%	0	184	39.5 63%	5.7 9%	15.1 24%	7.0 11%	550	29.1	20
+ Lunch	642	22.0 29%	1.8 2%	0.0 †	0	284	104.8 62%	11.2 7%	65.4 39%	14.8 9%	0	0.0	200
+ Afternoon Snack	430	7.0 14%	1.0 2%	0.0 0%	0	200	91.0 81%	6.0 5%	69.0 62%	5.0 4%	0	0.0	40
+ Dinner	481	8.1 15%	1.5 3%	0.0 †	4	966	81.1 66%	17.9 15%	5.5 †	23.0 19%	0 †	1.8 †	85 †
+ Evening Snack	140	2.0 13%	0.0 0%	0.0 0%	0	260	24.0 68%	6.0 17%	3.0 8%	7.0 20%	0	0.0	80
Totals Percentage of Calories	2,273	47.4 18.3%	5.9 2.3%	0.0 †	4	2334	395.9 68%	53.5 9%	182.2 †	79.8 13.7%	4850 †	657.9 †	1325 †

5.1.2 Water Storage

Individual sealed water bottles will be the primary source of all water. Due to the lighter mass of each bottle, it will be easier for people of all physical abilities to transport their own water throughout the building. The ability to transport the bottles will also make replacement of the water supply easy when the bottles need to be swapped at the end of their lifespan. Additionally, it will simplify the process of distributing rations, as each individual would receive a select number of water bottles. This will reduce the chances of uneven distribution. For example, if 1 liter water bottles are used, then each individual will be provided 4 water bottles per day. Regardless of the size of each bottle, all building occupants will be provided 4 liters, as this ensures that they have enough water for their drinking, cooking, and sanitation needs. While water bottles are not as spatially efficient as a water tank, they can still be organized effectively as flats of water bottles can be stacked. It is the simplicity of distribution and transportation that makes sealed water bottles the primary solution for water storage.

Although sealed water bottles should be free of all contaminants, chlorine tablets will be stored as a precautionary measure. This will allow for the water to be treated if deemed necessary.

5.1.3 Heating Cooling

The final design for the heating and cooling of the system involves adding insulating wall cladding and adding double or more panel windows. These reduce heating and cooling loads for the HVAC in the building and can maintain and control the temperature inside the building [27]. Therefore, less power is used to power the HVAC which is more economic, and the power saved can be used for other applications in the building. For the wall cladding, both the interior and exterior of the building will be insulated; this is to have maximum efficiency. The windows added can be also sealed shut so that there is no risk of heat leaving or cold wind entering the building. The windows can be sealed by either drilling them shut or by adding a low thermal conductive foam. However, this system does not provide heating and cooling for the building, but it would maintain the temperature in the building before the blackout. Thus, the building does not need to be drastically cooled or heated during the blackout. These meet the stakeholders needs as it is environmentally friendly, cost-effective and the building can be kept in livable temperatures for 5 days. To have maximum efficiency, blankets, fans and dehumidifiers can be added too. This can increase the resident's comfort and is more cost effective as less energy is used.

The geothermal heating and cooling system were disregarded for more than one reason. The main reason was the construction constraint. The geothermal system needs to be underground and therefore drilling and lots of space is required. The holes are from 100 to 400 feet deep so it cannot be placed under the building due to structural concerns [26]. Drilling would also negatively impact the environment and a geothermal system is not cost effective.

5.1.5 Electricity

The best system to power the building based off the weighted decision matrix, Table 11 - Final weightings tables, was determined to be the backup batteries connected to solar panels system. This system would include about 20 backup batteries on the roof as well as solar panels covering the rest of the available roof space. The batteries could be fully charged from the grid's power while it is still working, and additional charge could be provided from the solar panels when the grid is no longer providing power to the building. The combined batteries would be enough to provide the building with basic lighting, fresh air circulation and power an elevator. Additionally, it would be capable of powering common refuge areas and pumping water to designated areas.

5.2 Assessment of Solution

5.2.1 Nutrition

Overall the solution provides exactly what the criteria outlined; a meal plan that requires minimal prep, storage requirements and minimal conflicts with consumption while still being nutritious and providing enough energy to sustain the residents throughout the five days. Where it may fail is the actual quality of the food and how it tastes. For example; a mixture of quinoa, kidney beans and chick peas may be incredibly nutrient dense, but isn't known to be extremely delicious without condiments or spices. There is the back-up of meal replacement and supplements but these were meant to compliment the meal plan rather than completely replace. Therefore, by the definition of 'livable' this diet succeeds but certain residents may be left expecting more in terms of flavor and taste.

5.2.2 Water

In a crisis, water bottles will be an effective water storage solution. The quality of living must be up during a crisis, so it is important that they have easy access to water. Water bottles will allow for this as each individual will be able to receive their portion of water bottles in a convenient and organized manner. Additionally, the water bottles are sealed against contamination, which helps maintain the potability of the water. This will reduce the chances that a building occupant may be exposed to waterborne diseases or illnesses.

5.2.3 Heating Cooling

The wall cladding and double-panel window is an overall cost-effective, environmentally friendly and most comfortable solution. This solution can be implemented throughout the whole building; however, for the existing building it might be a constraint to remove the existing windows and adding the new windows and to add new wall claddings as the existing structure might not support this solution. This solution might fail too because it depends on the temperature inside the building before the blackout. The wall cladding and windows insulate the previous temperature so that there are no huge changes that can affect the residents.

5.2.4 Electricity

While the solution is not cost effective upfront, it meets the requirements for what needs to be powered in the building, which is outlined throughout this report. The battery system is not efficient relative to the natural gas generator however, it has many benefits. If charged by the solar panels, it would use entirely renewable energy. Additionally, it has no refueling requirements and could save money in the long run as energy from the solar panels is costless.

6. Conclusions and Recommendations

6.1 Conclusion

Initially the project goal was to design a high-rise that would be “liveable” for five days independent of the municipal systems. In reality, the actual objective was to determine what “liveable” meant and what was required to achieve this. The team broke it down into four main categories. Water for hydration and sanitation, food for energy and nutrients, temperature control to maintain homeostasis and electricity for emergency systems.

Ideas were generated, potential designs were identified and then were selected through a process using QFDs, a criteria table and a decision matrix. Final design ideas were chosen and implemented. Water will be stored in bottles, the temperature will be controlled by a geothermal system, the electrical system stores energy in batteries and a complete daily nutrition plan was developed.

Therefore, with these systems in place, the residents will live in a warm, lit building and have access to clean drinking water and nutrients. All of these services combine to produce a “livable” building.

6.2 Recommendations

6.2.1 Nutrition

A storage analysis should be conducted on the building to determine how much space there is for extra food items. Once this is complete, it could be determined whether extra condiments or spices could be added for improve the flavor of the food.

It is also recommended that a cost analysis is performed for the food to determine the cost of restocking each item once it is past its best before date. Once this is determined, building owners will have a better understanding of the cost of the nutrition program for the building and what to charge the residents.

One final project proposed for the future include designing a food distribution system. This way residents can access food without needing to prep anything. By having a few staff do this it will greatly reduce the risk of any food safety issues.

6.2.2 Water

While the water bottles are a good solution, optimizations should be made. Firstly, water bottles will produce a large volume of plastic waste, so biodegradable plastics should be investigated as they could reduce the environmental impact of this project. Secondly, by buying water bottles of larger volumes there will be less plastic waste per liter of water. Overall, this will reduce the negative environmental impact, make this project more sustainable.

6.2.3 Heating and cooling

To know the best solution possible, a building must be chosen with all the dimensions and space available known. The best solution would be to combine all the design options together for maximum energy efficiency and eco-friendly. To have the geothermal heating and cooling system combined with the wall cladding and double-panel windows would save up a lot of energy; however, it wouldn't be cost effective. The solution can also be helpful when there is no blackout as the wall cladding and double-panel windows can still be functional and be more thermal and energy efficient.

6.2.4 Electricity

For a more accurate design solution, it a recommended that a specific building be chosen. This would allow for more accurate estimates of power necessary to determine correct amount batteries required. As well, the amount of solar panels that could fit on the roof could be determined and the resulting energy produced from the solar panels could be calculated. Moreover, if specific solar panels and backup batteries were chosen, an accurate cost analysis could be implemented.

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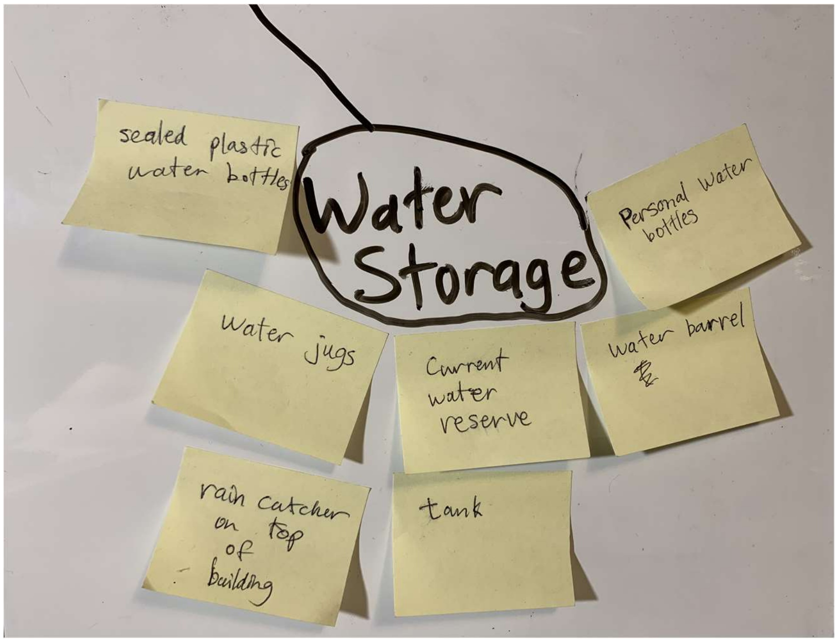
Appendix A: Individual Contributions

Table 4 - Outlines the contributions of each group member.

Name	**Content**	**Write-up**	**Editing**
Josh Block	Background Research on Water, Temperature		Edited Document
Cristiano Iacobelli	Scope/constraints, problem statement, Team planning, Everything on electricity consumption	Scope/constraints, problem statement	Edited document
Waleed Shehadeh	Stakeholders, Everything on heating and cooling	Stakeholders, Research sanitation	Edited document
Noah Simms	Everything on Nutrition	Everything on Nutrition	Edited Document

Appendix B: Background to Section 3



Appendix C: The Garbage Bin for Figures & Table

Table 5 Immediate Disqualification of Design Ideas for Nutrition [5][4][3][2]

Food Group	Food Storage	Cultural/Dietary Acceptance	Life Span
Dry Cereal	✓	✓	✓
Nuts	✓	✓	✓
Dried Fruit	✓	✓	✓
Grains	✓	✓	✓
Legumes	✓	✓	✓
Dried Meat/Fish	✓	X	
Dry Milk	✓	X	
Fresh Vegetables	X		
Fresh Fruits	X		
Fresh Milk	X		
Eggs	X		
Fresh Meat/Fish	X		

Nutrition QFD

Table 4 - Quality Functional Design Table for the Nutrition Design Ideas

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▼	▼	▲	▲	▲									
				Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / **Demanded Quality** (a.k.a. "Customer Requirements" or "Whats")	NNR/L	Preperation Time	Preperation Requirements	Cultural Acceptance	Dietary Acceptance	Life Span									
1	3	32.1	9.0	Consumed Calories	▲	O													
2	9	32.1	9.0	Nutrient Qualities	Θ	▲	▲	▲	▲	▲									
3	3	10.7	3.0	Food Quality	O	▲	▲	▲	▲	▲									
4	9	10.7	3.0	Preperation Difficulties		Θ	Θ	▲	▲	▲									
5	3	10.7	3.0	Food Variation	▲	▲	▲	O	O	▲									
6	3	3.6	1.0	Cost	O		O	▲	▲	O									
7																			
8																			
9																			
10																			
				Target or Limit Value															
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)															
				Max Relationship Value in Column	9	9	9	3	3	3									
				Weight / Importance	375.0	246.4	160.7	89.3	89.3	75.0									
				Relative Weight	36.2	23.8	15.5	8.6	8.6	7.2									

Table 6 - QFD for water

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Portability	Spatial efficiency	Ease of replacement	Ability to ration
				Column #	1	2	3	4
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)				
1	9	60.0	9.0	Distribution speed	Θ	O	O	Θ
2	9	20.0	3.0	Water source on each floor	Θ	Θ	Θ	O
3	9	20.0	3.0	Ability to possess rations	Θ	Θ	▲	Θ
4								
5								
6								
7								
8								
9								
10								
				Target or Limit Value				
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	2	5	4	3
				Max Relationship Value in Column	9	9	9	9
				Weight / Importance	900.0	540.0	380.0	780.0
				Relative Weight	34.6	20.8	14.6	30.0

Figure 2: QFD Figure for Heating and Cooling

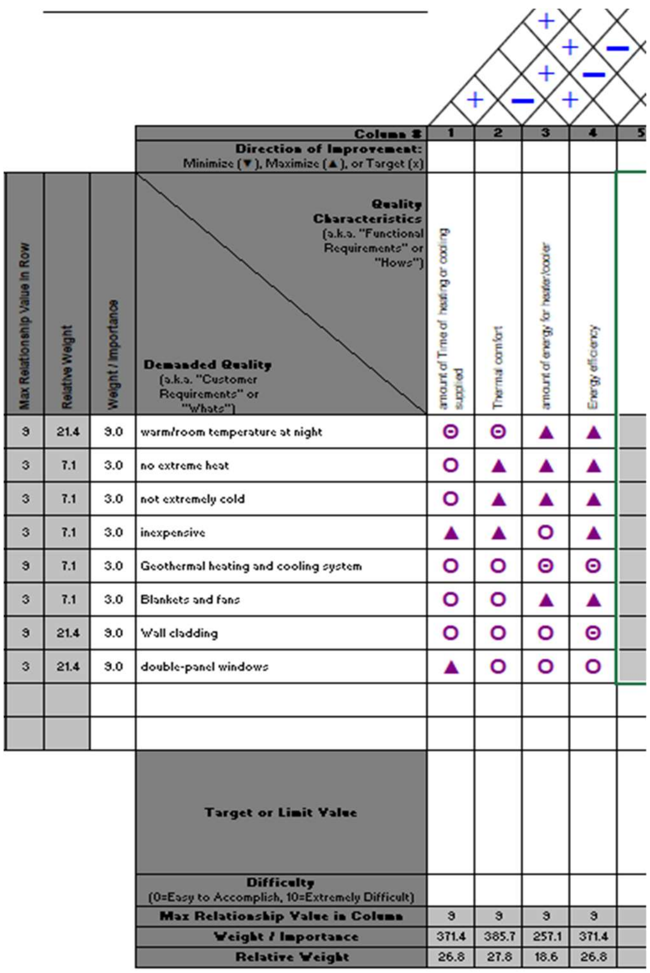


Table 7: Rubric for the Heating and cooling Matrix

Functional Requirements	1.0	3.0	9.0
Amount of time of heating and cooling supplied	Heating and cooling can only be supplied for 1-2 hours per day	Heating and cooling can only be supplied at night	Heating and cooling can be supplied all day and night

Amount of energy needed for heater/cooler	Energy barely enough for 5 days	Energy can be enough for 5 days but is not on for all day and night	Energy enough for all 5 days without stopping
Wall cladding	Wall cladding available for only certain floors and apartments and is only able to either reduce load on heating or cooling	Wall cladding available for only certain floors and apartments and can reduce load on heating and cooling	Wall cladding available for the entire building and apartments and can reduce load on heating and cooling
Geothermal heating and cooling	Energy supplied barely enough for the building and only enough for a couple of days	Energy supplied barely enough for the building but supplied for 5 days	Energy supplied enough for the building and supplied for 5 days
Blankets and fans	Blankets and fans barely enough for all residents	Blankets and fans enough for majority of residents	Blankets and fans available for all residents
Double-panel windows	Double-panel windows available for only certain floors and apartments	Double-panel windows only for a few floors	Double-panel windows available on every floor

Table 8: Informed Decision Matrix for Heating and Cooling

Design Options	Thermal comfort		Efficiency		Time of heating and cooling supplied		Amount of energy required by heating and cooling		Totals
	21.8		21		21		14.5		
	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	
Geothermal	1	21.8	6	126	6	126	9	130.5	404.3
Blankets and fans	9	196.2	1	21	3	63	3	43.5	323.7
Wall cladding and double-panel windows	3	65.4	9	189	9	189	9	130.5	573.9

Table 9 - Outlines the pros and cons of different power sources.

Power Source	Pros	Cons
Backup Batteries	-Environmentally friendly -Little to no maintenance -No refueling required -No energy cost when connected to solar panels -Can use the solar panels as a source of power when not in a	-Upfront cost -Lower storage capacity -Lower power output -Require more space

	state of emergency to reduce utilities in the building	
Natural Gas generators	-Commonly used in larger buildings -No refueling required -Higher power output -Cheaper upfront costs	-Uses fossils fuels -Maintenance requirements -May not work in the event there is a natural gas disruption

Figure 3 – Quality Functional Design Table for Electricity

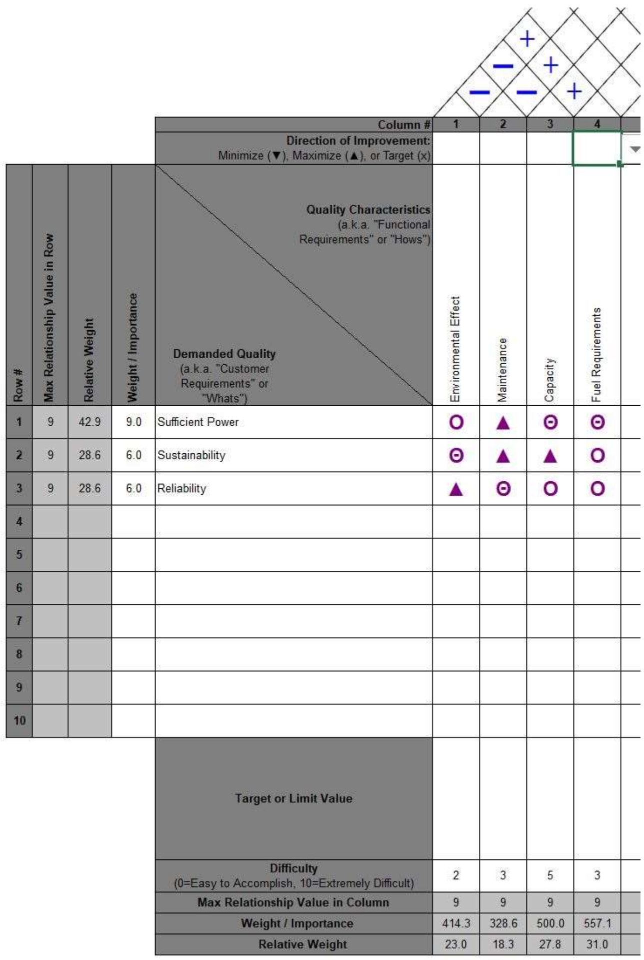


Table 10 - Criteria for the design weightings.

Functional Requirements	1.0	3.0	9.0
Environmental Effect	Uses external fuels that have negative effects on the environment.	Uses external fuels as well as benefits from the grid's power while it's in effect.	Uses entirely renewable energy.
Maintenance	Not reliable and has a large chance of	Reliable enough to have no concerns for short periods of times but	Requires no maintenance unless damaged.

	malfunctioning in an emergency.	requires some routine maintenance.	
Capacity	The source cannot efficiently generate required energy relative to the other source.	The source can deliver sufficient energy however, it requires more space and resources relative to the other source.	The source can efficiently generate sufficient energy using minimal space relative to the other source.
Fuel Requirements	Frequent refueling required during the emergency.	No refueling required during the emergency but the source of the fuel could fail.	No refueling required and no problems should arise unless due to an external force.

Table 11 - Final weightings tables

Design Options	Environmental Effect		Maintenance		Capacity		Fuel Requirements		**Totals**
	23.0		18.3		27.8		31.0		
	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	
Backup batteries with solar panels	6	138.0	6	109.8	3	83.4	6	186.0	517.2
Natural gas generators	1	23.0	3	54.9	6	166.8	6	186.0	430.7

Criteria and Rubric

Table 12 - Rubric for the Nutrition Design decision matrix

Nutrition Functional Requirements	1.0	3.0	9.0
NNR/L	5th lowest NNR/L Value when compared to other foods	3rd or 4th lowest NNR/L Value when compared to other foods	Top two highest NNR/L Value when compared to other foods
Preparation Time - Total time from unpacking to consuming	Requires 20+ minutes of preparation time	Requires 5+ minutes of preparation time	Preparation is instantaneous. (ex. Pouring cereal into a bowl)
Preparation Requirements - With building limitations (no stoves, ovens, microwaves), the food must be able to be safely consumed with limited equipment.	Food requires one of the ‘out-of-use appliances’ to be cooked and therefore cannot be consumed.	Food requires no appliances but requires extra equipment such as cutting boards, large knives, etc.	Food requires no appliances and no extra equipment other than a plate/bowl and personal cutlery.
Cultural Acceptance - If food is accepted within certain	Food is rejected by several major groups	Food is accepted by most major groups staying within the	Food is accepted by all groups staying within the facility

cultures, religions, etc.	with members staying within the facility	facility but there are some minor conflicts that could be solved with dietary substitutions	
Dietary Acceptance - If food is accepted by common dietary restrictions such as lactose Intolerant, Celiac, etc.	The food's ingredients conflict with common dietary restrictions	The food provides limited conflicts (less than 5) within the facility and could be solved with dietary substitutions.	The food provides no conflicts with any common dietary restrictions
Life-Span - Time before food becomes inedible at room temperature	Has a storage life less than 6 months	Has a storage life less than 2 years	Storage life is indefinite

Informed Decision Matrix

Table 13 - Informed Decision Matrix for the potential Nutrition design ideas with the weightings produced by the QFD in Table and the Criteria for each ranking in Table 12

		NNR	Preparation Time		Preparation Requirements		Cultural/Dietary Acceptance		Life-Span		totals
Weighting		36.2	23.8		15.5		8.6		7.2		
	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	
Dry Cereal	9	325.8	9	214.2	9	139.5	9	77.4	3	21.6	778.5
Nuts	3	108.6	9	214.2	9	139.5	3	25.8	3	21.6	509.7
Dried Fruit	1	36.2	9	214.2	9	139.5	9	77.4	9	64.8	532.1
Grains	9	325.8	3	71.4	1	15.5	9	77.4	9	64.8	554.9
Legumes	3	108.6	3	71.4	9	139.5	3	25.8	9	64.8	410.1

Table 14 - Functional requirements criteria for water

Functional Requirements	1.0	3.0	9.0
Portability	Water storage containers are static and cannot be moved around	Can be moved around but with some difficulty or physical exertion	Can be moved around easily with minimal effort
Spatial Efficiency	Cannot pack with other identical units	Reasonably tight packing with other identical units	Can be packed tightly with other identical units
Ease of Replacement	Replacement of water or containers is difficult and requires extensive effort and equipment	Replacement of water or containers may require equipment but	Replacement of water or containers requires minimal effort and no equipment

		not any extensive effort	
Ability to Ration	Difficult to keep track of rations, may result in unequal distribution of water	General water ration sizes can be estimated and distributed accordingly	Equal water portions can be calculated and distributed easily

Table 15 - Water storage design scoring matrix

Design Options	Portability		Spatial Efficiency		Ease of Replacement		Ability to Ration		**Totals**
	34.6		20.8		14.6		30		
	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	
Tanks	1	34.6	9	187.2	1	14.6	3	90	326.4
Jugs	3	103.8	6	124.8	9	131.4	9	270	630
Sealed Water Bottles	9	311.4	6	124.8	9	131.4	9	270	837.6

Final Design – Nutrition

Expand all / Collapse all	Cal	Fat	S Fat	T Fat	Chol	Sod	Carbs	Fib	Sug	Prot	Vit A	Vit C	Calc	Iron
- Breakfast	210	0.0 0%	0.0 0%	0.0 0%	0	225	49.0 94%	4.7 9%	21.7 42%	3.0 6%	800	7.2	0	8.5
Kellogg's Corn Flakes Cereal 1 cup	100	0.0	0.0	0.0	0	200	24.0	0.7	2.7	2.0	500	6.0	0	8.0
Amport Foods Dried Mixed Fruit 6 pieces	110	0.0	0.0	0.0	0	25	25.0	4.0	19.0	1.0	300	1.2	0	0.5
- Morning Snack	248	7.3 26%	1.1 4%	0.0 0%	0	184	39.5 63%	5.7 9%	15.1 24%	7.0 11%	550	29.1	20	1.8
Nature Valley Oats 'n Honey Crunchy Granola Bar 2 bars	190	7.0	1.0	0.0	0	180	29.0	2.0	11.0	3.0	0	0.0	0	0.7
Green Peas 0.5 cup	58	0.3	0.1	0.0	0	4	10.5	3.7	4.1	4.0	550	29.1	20	1.1
- Lunch	642	22.0 29%	1.8 2%	0.0 †	0	284	104.8 62%	11.2 7%	65.4 39%	14.8 9%	0	0.0	200	5.5
Sun-Maid Raisins 0.5 cup	240	0.0	0.0	0.0	0	20	62.0	4.0	58.0	2.0	0	0.0	40	2.2
100% Whole Wheat Bread 2 slices	200	3.0	0.0	0.0	0	260	36.0	6.0	6.0	8.0	0	0.0	80	2.2
Almond Butter w/ No Salt Added 2 tbsp	202	19.0	1.8	–	0	4	6.8	1.2	1.4	4.8	0	0.0	80	1.1
- Afternoon Snack	430	7.0 14%	1.0 2%	0.0 0%	0	200	91.0 81%	6.0 5%	69.0 62%	5.0 4%	0	0.0	40	2.9
Nature Valley Oats 'n Honey Crunchy Granola Bar 2 bars	190	7.0	1.0	0.0	0	180	29.0	2.0	11.0	3.0	0	0.0	0	0.7
Sun-Maid Raisins 0.5 cup	240	0.0	0.0	0.0	0	20	62.0	4.0	58.0	2.0	0	0.0	40	2.2
- Dinner	481	8.1 15%	1.5 3%	0.0 †	4	966	81.1 66%	17.9 15%	5.5 †	23.0 19%	0 †	1.8 †	85 †	4.6 †
Red Kidney Beans 1 cup	207	0.9	0.1	0.0	0	655	37.9	11.0	4.7	13.4	0	1.8	70	3.2
Quinoa 0.5 cup	112	1.8	0.2	0.0	0	6	19.5	2.5	0.8	4.0	0	0.0	15	1.4
Cooking Light Marinated Chickpeas 0.5 cup	162	5.4	1.2	–	4	305	23.7	4.4	–	5.6	–	–	–	–
- Evening Snack	140	2.0 13%	0.0 0%	0.0 0%	0	260	24.0 68%	6.0 17%	3.0 8%	7.0 20%	0	0.0	80	1.4
The Good Bean Roasted Chickpeas ~ Cracked Pepper ¼ cup	140	2.0	0.0	0.0	0	260	24.0	6.0	3.0	7.0	0	0.0	80	1.4
Totals **Percentage of Calories**	2,151	46.4 18.9%	5.4 2.2%	0.0 †	4	2119	389.4 70%	51.5 10%	179.7 †	59.8 10.8%	1350 †	38.1 †	425 †	24.7 †

Figure 4 - Nutrition plan for one day using the food groups identified in the Decision Matrix