Project P1-3: Livable High Rise for Extended Blackouts

P1 Final Report

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Sunday, January 26th, 2020

Statement of Originality

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Executive Summary

The following report addresses the need of development for sustainable emergency systems in high-rise in Victoria, British Columbia in order to support up to 200 people in the event of a power blackout due to extreme weather conditions. The primary goal of the report is to determine and quantify the problem, evaluate and address the needs of all stakeholders, reiterate background research conducted to justify the selection criteria selected, and to develop and determine the final systems chosen to address all stakeholder needs. The project will prioritize public and resident safety, take into consideration ethical, cultural, and economic considerations, and will fulfill all project goals. The system must be able to function completely off grid while meeting all requirements laid out by the British Columbia building codes for safety, accessibility, fire and structural protection, and efficiency.

The final design of all systems seeks to modify new building plans to raise the first floor and will use rooftop generators to reduce risk of service interruption. Water will be supplied for all critical systems through additions to preexisting plumbing. Ongoing building safety and emergency planning sessions will be utilized to educate residents on refuge procedures and the blackout systems that have been put in place. Additional insulation will be implemented to the building to reduce load on climate control systems to improve thermal efficiency and reduce carbon emissions. The final design solution uses a combination of diesel generators, gas furnaces, ultraviolet water purification, and improved insulation systems to temporarily replace all systems affected by the power interruption. A stockpile of first aid and sleeping supplies, food, and hygiene products will be available in the case that residents do not have personal supply available

Table of Contents

Statement of Originality .... ***i***

Executive Summary .... ***ii***

List of Tables .... ***v***

Table of Figures .... ***vi***

1 Introduction ***1***

1.1 Problem Statement **1**

1.2 Stakeholder Needs **1**

1.3 Design Criteria **3**

1.3.1 Cost 4

1.3.2 Lifetime and Reliability 5

1.3.3 Social and Ethical Considerations 5

1.4 Scope **6**

2 Background Research ***7***

2.1 Potable and Nonportable Water Resources **7**

2.2 Power Generation and Heating for Residential Buildings **7**

2.3 Extreme Weather Conditions Affecting Building Design **8**

3 Preliminary Designs ***9***

3.1 Idea Generation and Preliminary Idea Selection **10**

3.1.1 Potable and Non-potable Water Systems 10

3.1.2 Heating and Cooling Systems 12

3.2 Design Selection **13**

3.2.1 Potable and Non-potable Water Systems 13

3.2.2 Power Generation and Heating and Cooling 15

3.2.3 Building Insulation and Energy Efficiency 16

4 Considerations for Final Design ***17***

4.1 Sustainable Engineering **17**

4.1.2 People and Social Considerations 17

4.1.3 Profit and Corporate Requirements 18

4.1.4 The Planet and Environmental Consciousness 18

4.2 Safety and Regulatory Issues **19**

5 Final Design ***20***

5.1 Final Design Solution **20**

5.2 Assessment of Solution **20**

6 Conclusions and Recommendations 22

6.1 Conclusion 22

6.2 Recommendations 22

References.......... 24

Appendix A: Individual Contributions 30

Appendix B: Additional Figures 31

Appendix C: Additional Tables 32

List of Tables

Table 1: Summary of the stakeholders involved in the project, and their needs. 3
Table 2: Summary of design criteria and specifications that the solution must meet. 4
Table 4: An outline of each team members contributions to the P1 Interim Report. 30
Table 4: Final cost breakdown and for necessary supplies for 200 building occupants over seven days. 32
Table 5: Long-term costs of implementing systems, maintenance, emergency plans. 32
Table 6: Daily water consumption for various gender and age demographics [10]. 33
Table 7: Daily human caloric intake for various age groups and activity levels from the NHLBI [12]. 34
Table 8: Decision making table defining excellent, competent and marginal aspects of design solution. 34

Table of Figures

Figure 1: A summary evaluation of the final solution based on project design criteria in Table 2. 20
Figure 2: Expenses deemed eligible and ineligible for cost sharing under the DFAA [5]. 31
Figure 3: Apartment unit floor plan, design company unknown. 32
Figure 4: Water use, including correction for peak usage. 32
Figure 5: "What is Head" (Pump Fundamentals.com). 32
Figure 6: Booster Pump Typical Installation (Little Giant). 33
Figure 7:VIQUA-POE-IHS-schematic-home (Viqua). 33
Figure 8: Gravity feed water basin. 33
Figure 9: Chlorine House of Quality. 25
Figure 10: Ultraviolet House of Quality. 26
Figure 11: Water Tank House of Quality 27
Figure 12: Water Pump House of Quality. 28
Figure 13: Evaluation matrix for water supply options. 29
Figure 14: Energy use and heating in medium urban residential buildings. 29
Figure 15: QFD for Diesel Generators 30
Figure 16: Evaluation matrix for UV filtration versus tablet chlorination. 31
Figure 17: Preliminary idea selection mind map for brain storming. 31
Figure 18: Example of the possible Emergency Preparedness Booklet [54] 31

1 Introduction

This section of the report addresses the need for urban infrastructure development to sustain long-lasting power outages during unpredictable weather events. Stakeholder needs, design criteria such as costs, lifetime, reliability and efficiency of possible design solutions will be discussed. Background research explores energy generation options, extreme weather events affecting infrastructure, and potable water filtration system.

1.1 Problem Statement

Occupants of a residential high-rise in Victoria, British Columbia, require design solutions to sustain livable building conditions during a municipal blackout, caused by an earthquake or extreme flooding. According to the Center for Climate and Energy Solutions, the "growing frequency and intensity of extreme weather events", over the last fifty years, is the "most visible consequence of a warming world" [1]. The social and economic burdens on government factions to repair the destruction caused by such disasters is minimized through adapting urban infrastructure and preparing emergency procedures and supplies for those affected. Occupants of residential high-rise buildings will be provided with safe, economically feasible, and sustainable emergency relief solutions. This includes UV filtered potable water for hydration, livable levels of heating and cooling, and toilet and bathing facilities for sanitation. As defined by the Canadian Red Cross, relief centers provide clean water, safe shelter, and three daily meals for occupants [2]. This project will provide such fundamental human needs for 200 building occupants, residents, guests, and building employees, over a seven-day emergency period. The project's budget does not exceed $300 000 CAD, as outlined in Appendix C **Table 4** and **Table 5**. This budget includes the costs of implementing a diesel generator, gas heating system, ultraviolet water filtration devices, and preparing emergency medical, nutritional, and hygiene supplies. Ensuring the accessibility of basic living requirements and the safety of all entrapped residents with diverse needs is of utmost priority. Gender privacy, racial and religious sensitivities are considered. All elements of the project ensure public safety, address ethical and economic considerations, while producing environmentally conscious, energy-efficient design options.

1.2 Stakeholder Needs

Emergency preparedness plans for extreme weather events, such as earthquakes and floods, are of great concern to residents, having a direct impact on personal safety. Those effected during a municipal blackout include the building's residing families and landlord, the City of Victoria, the Government of British Columbia, and the Government of Canada, construction companies and all forms of emergency personnel. The proposed building will consist of ten residential floors, each with four, three-bedroom family apartment units, housing a total of 160 residents. The resident's safety is the most important stakeholder consideration.

Occupants will require an emergency protocol plan, available nutritional, medical, and hygiene supplies, and a method to contact external resources and emergency services. An emergency plan will be implemented and taught to occupants, to alleviate confusion and distress during an emergency. Each person will require three liters of drinking water, and an additional three liters of water for sanitation and hygiene practices daily. [3]. Building employees consist of plant services, overseeing daily operation and maintenance of the residential high-rise. These individuals require methods to contact family members separated in the surrounding city. Staff will need to be trained to assist residents in remaining calm and following protocol in an emergency setting. Building guests include additional family and friends of residents, tourists and local civilians who will require basic living necessities of heating, water and food, hygiene and medical supplies, shelter and allocated sleeping areas, as outlined in Appendix C **Table 4**.

The landlord and building manager will need to ensure that their building meets the infrastructural and safety standards of the British Columbia Building Code [4]. The landlord will be concerned about what the building is enduring, the cost of building repair, and the wellbeing of occupants. He or she will need to contact residents who were not on the residential premise while the emergency occurred, informing them on the latest situation. Resident safety should be of utmost importance to the landlord at the time of emergency.

The municipal, provincial and federal government, namely the City of Victoria, the Government of British Columbia, and the Government of Canada, respectively, will assist in managing unexpected emergency events. BC Hydro will need to restore municipal electricity and cleanse municipal water reservoirs. All levels of government will need to attend to injured civilians, repair infrastructure, and provide compensation for economic losses.

Construction, architecture and engineering companies responsible for constructing this residential high-rise will be concerned about their building licenses and the needs of entrapped individuals. Prior to the event, such companies will retrofit the existing building to achieve increased thermal efficiency standards. After the emergency, these companies need to prepare for reconstruction of the complex. Emergency personnel need to ensure the safety and health of entrapped occupants.

Table 1: Summary of the stakeholders involved in the project, and their needs.

Stakeholder	**Needs of Stakeholder**
Residing families	Ensure safety and implement emergency protocol
Employees	Ensure safety of themselves, residents and their family members
Guests	Basic living necessities provided
Landlord	Ensure safety of residents, consider cost of repairs of the building
City of Victoria	Assist injured civilians, repair infrastructure and economic loss
Government of British Columbia	Assist injured civilians, repair infrastructure and economic loss
Government of Canada	Repair infrastructure and provide compensation for economic loss
The engineer	Retain building license and ensure building safety
Emergency Personnel	Ensure the safety and health of entrapped occupants

1.3 Design Criteria

The objective of the design criteria is to minimize system costs, while maximizing the resiliency and efficiency of the final product. A summary of all design criteria in **Table 2**, serves to improve the safety and living conditions of entrapped occupants. It offers a framework to measure the viability of solutions based on a five-level scale. Environmental considerations are an overarching aspect of all criterium.

The twelve-story residential complex consists of ten residential floors, a ground level entrance, and a basement with storage lockers, a mechanical room and water filtration systems. Each residential floor includes four three-bedroom family apartment units. Building occupants account for an average family size of four people per unit and ten building maintenance and managing personnel. Supplies and mechanical systems support a total of 200 residents, guests, and building employees. Each occupant is provided six liters of potable water for basic hydration and sanitation, a daily necessity outlined by the World Health Organization [3]. Existing power generators provide lighting, elevators, and an adequate level of safe air circulation through ducts. Retrofitting the pre-existing building with additional insulation optimizes efficiency and increases building resilience in extreme weather events.

Table 2: Summary of design criteria and specifications that the solution must meet.

Criteria	**Level 1**	**Level 5**
Economic Feasibility	the cost of implementing the design is unreasonable and requires expensive outsourced generators, filters, and systems	the cost of implementing the design is reasonable and requires local generators, filters, and systems
Durability and Lifetime	systems will require replacement, will not last for a reasonable amount of time, require much maintenance	systems will be made of durable, long-lasting materials and systems that will require little to no maintenance
Environmental Impact	the overall design has a negative impact on the environment and does not provide an energy efficient solution for power generation, water purification, and sanitation	the overall design has a positive impact on the environment, providing an energy efficient solution for power generation, water purification, and sanitation, using locally sourced materials and systems
Social Considerations	the design will not provide fundamental living requirements of food, water, shelter, medical supplies to occupants, ignores social and cultural diversity of occupants	the design will support necessary refuge living requirements outlined by the World Health Organization, address gender, religious and racial privacy and sensitivity
Complexity	the design is complex and will require a lot of education for occupants to be comfortable using the emergency plan	the design is simple to use, and the residence will need only basic education for the use of systems in an emergency

1.3.1 Cost

This project provides construction companies, The City of Victoria, and the Government of Canada with an accessible and marketable emergency solution. The cost analyses in Appendix C **Table 4** and **Table 5** outline supplies required for emergency storage, energy generation, potable water filtration, facility maintenance, and implementing an emergency preparedness plan. Supplies such as nonperishable food, clothes, sleeping, and personal hygiene items, potable water, and medical supplies have been considered in the cost breakdown. As seen in Appendix C **Table 4** and **Table 5,** the project budget for emergency supplies and power generation is $300 000 CAD. The Government of Canada will provide economic relief through the Disaster Financial Assistance Arrangements (DFAA), administered by Public Safety Canada [5].

In the case of an emergency, Public Safety Canada would work with the Government of British Columbia to reimburse recovery costs. Since this program began in 1970, the Government of Canada has provided $5 000 000 000 CAD towards "returning infrastructure and personal property to pre-disaster condition" after floods, wildfires, and earthquakes [5]. Provincial emergency relief expenses, eligible and not eligible for cost sharing under the DFAA are outlined in Appendix B **Figure 2** [5]**.**

1.3.2 Lifetime and Reliability

All systems support occupant life under extreme environmental conditions, increasing the importance of design durability. Engineering fail-safe techniques and monthly maintenance tests will be implemented. Decreasing the lifetime of systems to increase reliability will be considered if necessary. For example, an ultraviolet water purification system has an expected lifespan of 10 000 hours with particle filters needing replacement for every six to 12 months of continuous usage [6] [7]. The water pump will require maintenance including changing of lubricant, oil or grease, every 2000 operating hours [8]. Practice emergency drills will be held monthly for occupants, similar to those outlined in the City of Vancouver's Business and Employer Emergency Preparedness Guide (BEEP Guide), and Metro Vancouver's Emergency Preparedness Tenant Information Housing Guide.

1.3.3 Social and Ethical Considerations

Alongside technical design considerations, system success is evaluated on the premise of addressing social and ethical concerns of all building occupants. The World Health Organization outlines fundamental living requirements as basic nutrition and water supplies, toilets and hygiene stations for sanitation, all of which will be provided for occupants [9]. Women and adolescent girls commonly seek private sanitation facilities and sleeping quarters to avoid sexual and gender-based marginalization and violence [9]. Mothers with young children or infants will be allocated space for changing and nursing. The project will promote gender acceptance, respect and diversity. Ensuring access to professional health services and prenatal care is out of the scope of this project, as necessary resources such as prescribed medication for chronic diseases and vaccinations are solely provided by emergency personnel at medical treatment facilities. It will be recommended that all occupants with known health complications have additional medication on their person to prepare for emergency events. There is an accessible environment for those with physical disabilities, including wheelchair access to each refuge floor through elevators and bathrooms with support bars.

The Department of Health and Human Services of the State Government of Victoria, Australia outlines daily water consumption requirements for children and adults of various ages, found in Appendix C **Table**

6 [10]. Necessary daily water consumption is variable based on individual lifestyles. It is noted that necessary water consumption is reduced for individuals who are sedentary, have fruit and vegetable-based diets or live in a cold environment [10]. While others that have high-protein and high-fiber diets, remain physically active or live in warm environments consume greater amounts of water [10]. The Canadian Food Guide is a resource from the Government of Canada, classifying nutritional food groups of whole grains, protein and vegetables and fruits. Average portion sizes for each group are based on filling a plate, half with fruits and vegetables, a quarter with whole grains, and a quarter with protein [11]. Appendix C

Table 7 outlines the number of calories required for children and adults of various ages and activity levels from the National Heart, Lung, and Blood Institute (NHLBI) [12]. Water consumption and nutritional requirements for children and adult occupants are overestimated in supply calculations. The building is equipped with three meals a day for each occupant, with enough food to last ten days. Daily caloric consumption of both children and adults is taken into consideration as the project is subject around a family-based residential high-rise.

1.4 Scope

The proposed solution provides livable conditions for residents of a high-rise building, over a seven-day blackout period where there is an interruption from the municipal electrical grid. This causes inoperability of municipal water treatment and pressurization systems. The high-rise will be in Victoria, British Columbia, where there is a risk of possible flooding and earthquakes [13]. The building currently has a backup generator installed for lighting and elevator use however it lacks the capacity to power appliances, including refrigerators, ovens, stoves, or microwaves. Outlets are not included within power allotment from the backup generator. Provision of power for electronic appliances or to operate portable heaters is out of the project scope. There is water available at ground level, however there is a risk of contamination in this supply, due to an interruption in municipal sanitation systems.

The high-rise has ten residential floors, a common ground floor, and a basement with laundry facilities and a mechanical room. The residential floors each have four apartments, one unit of which can be seen in Appendix B **Figure 3**. In the case of an emergency, residents will be expected to temporarily relocate to residential floors two through five, minimizing heating costs. This will also concentrate relief efforts for first responders that will need to enter the building. Each refuge floor will have a storage closet with supplies, highlighted in Appendix C **Table 4**. Supplies will remain in the building and will be maintained by the building manager.

For the purpose of this solution, livable conditions have been defined as maintaining a building temperature of 16 degrees Celsius, providing six litres of water daily to each occupant and sleeping quarters, and general construction in accordance with British Columbia building and fire codes [14]. Sleeping spaces, heat, first aid, food, drinking water, and emergency planning are within the scope, however personal needs such as electronic device usage remains outside of the scope.

2 Background Research

The location and climate of Victoria, British Columbia, societal expectations of emergency resources, and the provincial and municipal economy was researched to design a project that satisfies the fundamental needs of high-rise occupants

2.1 Potable and Nonportable Water Resources

To understand drinking water requirements, the Department of Health and Human Services of the State Government of Victoria, Australia**,** has published that the amount of water required by one individual in a single day is between 0.7 liters and 2.6 liters, as seen in Appendix C **Table 6** [10]. The amount of water required daily per individual will be rounded to three liters. This equates to 21 liters of water a week per person, bringing the total drinking water requirements for 200 people in seven days to 4200 liters. This figure is independent of all other water requirements, such as those for washing and sanitation. Hand washing uses approximately two liters per wash and the average person washes their hands 8.6 times per day in total using about 17 liters of water per day [15] [16]. Toilet flushing will require another 30 liters per day assuming that all toilets in use meet or exceed the ULF (ultra-low flush) standard of six liters per flush [17]. The calculations used for water usage can be viewed in Appendix B **Figure 4**. For the purposes of this research “peak hours” are being taken as between seven AM to seven PM and the assumption is being made that two-thirds of usage will occur within this time frame [18]. Thus, the maximum flow rate that should be expected of the system will be 9.57 liters per minute with a head of 20 meters [19].

2.2 Power Generation and Heating for Residential Buildings

Power generation is required to support building habitability. Air conditioning and heating systems contribute to over half of the power consumed in the high-rise building [20]. In the case of a blackout, it is vital for such systems to keep in working order to support livable building conditions. According to BC Hydro, the internal temperature of the high-rise must range between 16 to 20 degrees Celsius [21]. Internal temperatures cannot exceed 22 degrees Celsius.

The climate of Victoria, British Columbia is mild and temperate, with low temperature fluctuations and high annual rainfall. During the summer, the temperature ranges between 20 to 25 degrees Celsius and rarely exceeds 30 degrees Celsius [22]. During the winter, the temperature averages between one and two degrees Celsius, rarely dropping below zero degrees Celsius. Power consumption is highest during the month of February, as this is the coldest month of the year on the West Coast of Canada.

Residential buildings are generally heated via several different methods. Electric and gas heating sources are combined commonly in buildings depending on their age and geographic location. Type and quality of wall and window insulation determines how much energy is used by the heating and cooling system. Of the total energy used by residential buildings on the West Coast in 2015, only 38% was in the form of electricity, while 21% of that electricity was allocated to powering HVAC and heating systems [23]. The remaining amount was for powering electric appliances, lighting etc.

Natural gas, used primarily for heating, is the biggest source of energy used in buildings of the West Coast accounts for 54% of energy use. A study in 2009 of the energy consumptions for heating and cooling systems on the West Coast of Canada concluded that out of the 39 high-rises observed, 13 were gas dominant, 13 were electrically power and another 11 were combined. The 13 electrically dominant buildings had no less than 40% of their heating coming from gas. The gas dominant high-rises varied significantly in their consumption of electricity [20]. Approximately 37% of all energy consumed by a mid-sized apartment building in Victoria is used for heating, 69% of which is in the form of natural gas. These systems are most commonly in the form of Make-Up Air (MUA) ventilation units or boilers, which run on gas but need electricity to move heat through the building.

Due to the mild summers on the West Coast, the AC and cooling systems in high-rises do not take as much energy in the form of electricity as heating systems do [24]. The primary focus of this project needs to be the powering of the back-up heating system.

2.3 Extreme Weather Conditions Affecting Building Design

Victoria, British Columbia remains primarily susceptible to increased flooding due to its coastal location. With record-breaking increases in annual rainfall and glacier melting rates, sea levels continue to rise, increasing the probability of coastal storms and urban flooding [25]. As the content of water vapor in the atmosphere increases with air temperature, severe precipitation events are forecasted [26]. With pavement covering urban areas, stormwater runoff is lead into sewer systems due to a lack of absorption from natural vegetation. Combined sewer systems can become overwhelmed, posing a great threat to human and ecosystem health, while pathogens and pollutants including nitrogen, phosphorous, and heavy metals contaminate the environment [27]. Flood control infrastructure should be built on higher ground or raised. Non-permeable ground surfaces, such as pavement and concrete, should be replaced with green infrastructure that allow surface water to penetrate the ground below [28]. Municipalities should implement separate sewage and stormwater treatment systems to avoid untreated products entering waterways.

Furthermore, Victoria, British Columbia is situated in a coastal region of tectonic instability. The oceanic Juan de Fuca Plate continues to subduct under the continental North American Plate in the Cascadia subduction zone, increasing the likelihood of an overdue megathrust earthquake [29]. Studies in building science and technology focus on minimizing the structural damage caused by an earthquake, accounting for vertical and lateral loading. Engineering and architectural design serves to minimize the risk of building collapse through binding walls, floors, roofs, and foundation together, avoiding the use of unreinforced brick or concrete blocks in cladding, and minimizing roof weight on the walls and building foundation [30]. Multiple-story complexes have used the concept of 'base isolation' with shock absorbers such as springs, ball bearings, padded cylinders, and tuned mass dampers to minimize the effect of swaying and shaking on the building [31]. These infrastructural solutions cannot be installed into pre-existing buildings; however, they should be considered in future high-rise construction.

3 Preliminary Designs

Preliminary building designs which were considered, establish an off-grid energy supply, improve building insulation and filtrate potable water for sanitation purposes. The building will meet the standards of the British Columbia Building Code for areas of "public safety, health, accessibility, fire, structural protection, and energy and water efficiency" [1]. Emergency access and exit routes will be outlined for residents and emergency response personnel, drills and educational seminars will be hosted to ensure occupants and building employees are prepared for cirucmstantial events. Preliminary design ideas for heating and cooling systems include heat pumps, utilizing existing municipal natural gas systems, or electric heating. ultraviolet filtration devices and chlorination tablets are possible options for water pruifications systems. Increasing building energy efficiency through use of cellulose insulation with a thermal resistance value of R-3.5 per inch of thickness, will impove building efficiency by up to 89% [32].

3.1 Idea Generation and Preliminary Idea Selection

To fulfill requirements for optimal idea generation, preliminary solutions were found through brainstorming using a mind map in Appendix B **Figure 17**. Once ideas had been discussed, specifically for heating and cooling systems, potable and non-potable water systems, and building insulation and appliances, a democratic vote was conducted. A group of 20 second-year Mechanical Engineering students at Queen's University wrote their top three design solutions from the given list. This process was used to avoid bias in design selection. The votes were conducted anonymously, while the winning three ideas for each design were selected as preliminary design options.

The criteria for each symbol in Quality Functional Development or "House of Quality", (QFD) decision making tools used for preliminary idea selection can be seen in Appendix C **Table 8.** The "Houses of Quality" for heating and cooling, and water systems are found in Appendix B **Figure 9, Figure 10, Figure 11**, and **Figure 12**. Specified criteria have been used to determine which preliminary design best addresses stakeholders needs, project scope and the design criteria.

3.1.1 Potable and Non-potable Water Systems

Water will be available at the ground level but must also be accessible on all refuge levels. Thus, there must be a way to carry the water as high as the fifth floor. For this purpose, a booster pump can be installed to flow water through pre-existing plumbing in the structure. At a height of five stories the pump will have a head of approximately 20 meters that it must drive water to [19]. The head is defined as the height of the column of water located above the fluid pump. See **Figure 5** in Appendix B for a visual representation. At this height it must be able to provide a minimum flow rate of 9.57 litres per minute as per the calculations in Appendix B **Figure 4**. For this purpose, a pump such as the Little Giant Inline 400 can be implemented at a cost of $860 CAD [33]. According to the manufacturer supplied specification sheet it can provide in excess of 50 liters per minute at a 20 meter head, more than adequate for the purpose of this project [34]. A typical install case for this system can be found in Appendix B **Figure 6**. This reference includes a pressure regulation tank however the installation of such is optional and unnecessary for this install case [35].

An alternative to ensuring adequate quantity of water is available is using a large water basin that would be kept full and circulated during normal, non-emergency scenarios. This basin would be mounted on the roof or in an upper floor. A reference image of a similar system can be seen in Appendix B **Figure 8,** where rather than relying on a powered pump, water flows to the lower refuge floors via gravity assist, again utilizing the building's already-existing plumbing. The total volume of the basin would need to be adequately sized to provide a minimum of 73 080 liters for the week period as determined in Appendix B **Figure 4.** A tank like the N-43825 from The Tank Depot would suit well for this purpose. It has a capacity of 75 000 liter and would cost about $30 600 CAD [36].

Sanitation needs are defined as water needed for washing and plumbing. This has been included in the water requirements calculations for both above supply methods as to simplify installation all water will be supplied via the building's existing plumbing. The assumption is being made that city black water systems are still operational and can accept all drained water. Black water is defined as wastewater carrying human solid or liquid waste and poses a risk as a carrier of bacteria or pathogens [37]. By the same source, grey water is wastewater that contains contaminants that need to be filtered or processed before it can be safely released back into the environment. Both wastewater sources, however, will be flushed out via city sewers which are assumed to be operational.

To filter and purify drinking water there are two possible systems that would serve this function. Both systems can effectively be implemented with either a pumped or tank-fed water supply. One involved an ultraviolet and five-micron filtration combination system, and the other utilizes chlorination tablets to effectively sterilize drinking water.

The UV filtration and purification system works via combining a particle filter and an ultraviolet light bulb to purify contaminated water and make it safe for drinking. As the ultraviolet light can only effectively function on particles smaller than five microns the inline filter works to pre-process the water and remove any larger particulate to ensure proper function of the UV treatment. Together they can remove and neutralize 99.99% of contaminants in a water supply. It would draw only 35 Watts of 120 Volts AC electricity and can provide nine gallons per minute or thirty-four liters per minute, this equates to a maximum capacity of 48 960 liters per day of safe drinking water [38]. As a fail-safe, in case of system failure, two of these will be installed. One on the second floor and one on the fourth floor. This will allow for two points where residents can get drinking water as well as simultaneously acting as a fail-safe in case one experiences an interruption of operability. System maintenance is minimal as the only maintenance item is bulb replacement, and that is only needed every 10 000 hours of use, more than fifty times necessary for the 168 hours of the blackout period [6]. The cost to install the system would be $750 CAD per unit, or $1 500 CAD total for the two proposed. See Appendix B **Figure 7** for a sample system diagram.

The other possible water treatment method proposed involved the use of thin paper filters and chlorination tablets. These chlorination tablets are inexpensive and can purify one liter of water each [39]. The paper filters (such as the type found in coffee machines) are necessary because like the ultraviolet light, they cannot affect larger particulate matter and failure to pre-filter may result in the consumption of contaminated water [40]. This system can be easily implemented into pre-existing structures only requiring storage space until they're needed. One notable downside to this system is that the tablets have a shelf life of only five years at which point they must be discarded and replaced with new tablets. This quinquennial replacement cycle is both costly and creates unnecessary environmental waste and a possible risk of damage to animal and plant life [41]. The tablets are sold for $20 CAD for a pack of 100, and as 4200 liters of water is required plus a 20% safety margin, the cost of tablets every five years will be $1008 CAD, plus an additional $16 CAD for coffee filters [39] [42].

3.1.2 Heating and Cooling Systems

In the case of a prolonged blackout, heating will be provided through a backup generator system. There are several options for a backup heating system, depending on the age, location and existing systems. The first method of heating would be with the use of heat pumps. Being reliable and efficient to use, heat pumps are often used to both heat and cool building spaces. Air-source heat pumps could be installed on the outside of the building and provide heating in an emergency. These heat pumps can also be used as additional heating or cooling units for use at any other time. The advantages of this system lie in the efficiency of the ASHPs, being three to four time more efficient at supplying heat than most furnaces or boilers, which means that less electricity would have to be generated [43]. Additionally, the heat pumps do not have any needs besides power, and the whole system would be contained in the building. The limitations of this system include the bulkiness and initial cost to set up this system. Depending on the unit, prices range from $3000 to 10 000 CAD, and up to four units would have to be installed per floor. Each unit is also quite bulky and requires space on the outside, either on the side or roof of the building. While useful in the emergency and the relatively high efficiency, the use of such a system requires electricity, which in non-emergency situations is less cost effective than natural gas [24].

The second type of system relies on existing natural gas heating systems within the building. In Victoria and the lower mainland, each high rise is at a minimum 40 percent reliant on gas energy to heat [20]. Powering the system with an internal source of electricity would prove to be efficient. The advantages of a backup like this would be that an existing system carries little to no additional costs, apart from the source of power generation. However, this system relies on the maximum possible heat generation of the system and whether the gas heating is strong enough on its own to heat the living space. This varies from highly from building to building.

The third type of heating system would be a pure electrical heating set up. This set up would use a very large power generator located on the roof of the building to power electrical heating units located in the desired locations. The entire system would be set up and contained within the building, assuring high reliability and work ability in any situation. However, to power all electric heaters in a space occupied by the estimated number of people, a very large electric generation unit is required. This runs with extremely high initial costs and is much less cost efficient than other solutions.

3.2 Design Selection

3.2.1 Potable and Non-potable Water Systems

To evaluate both water supply and water purification systems a combination of House of Quality and evaluation matrixes were created. For the water purification systems House of Quality, the following criteria and limits/goals were selected. 'Flow Rate', greater than 10.5 liters per minute, 'Ability to Neutralize Bacteria', greater than 99%, 'Ability to Filter Particulate', five microns or better, 'Solution Purchase Price', less than $2000 CAD, 'Reusable Solution' , zero waste, 'Time to Implement' , one day, 'Compact', no additional space in building, and 'Available On-Demand', zero-delay. Some of these options are self-explanatory; however, to expand on others, 'Time to Implement' refers to the expected installation time for the system, 'Available on Demand' refers to the length of time that elapses between a resident wanting water, and them being able to consume water. In the House of Qualities for Tablet Chlorination and Ultraviolet Purification as seen in Appendix C **Figure 9** and **Figure 10** respectively, ultraviolet filtration and purification appears to come out ahead of chlorination. While chlorination tablets appear to have a lower entry cost, they have repeating costs for every five years that they aren't used. This also affects the maintenance metric. While chlorination tablets will require removal from storage, disposal, reordering and restocking, the ultraviolet system will need only to be tested periodically which can be as simple as filling a sample of water to ensure functionality. Additionally, the environmental concerns of chlorine disposal are of note here. While they may have expired at the end of five years and are not strong enough to purify water, there will still be a large amount of free active chlorine that, if not disposed of correctly, run a risk of contamination of natural environments [41]. Both systems have a similar capacity to filter and neutralize contaminants, both are reasonably compact although ultraviolet has an edge as it can be contained within a wall while chlorination tablets require storage space. Both are available on demand however chlorination tablets have a processing period of thirty minutes, whereas the ultraviolet filtration systems operate on an on-demand basis [40]. As for customer qualities, most are like the Quality Characteristics, however 'Taste' is a quality worth mentioning. Consumers of water do not like excessive processing flavors, ultraviolet purification doesn't add anything to the water however chlorination may add a mild taste, even if it is not unpalatable to most [40]. This ends up being another point in favor of ultraviolet purification.

The evaluation matrix used to determine between these two options has a similar result, see Appendix C **Figure 16**. Categories of 'On Demand', 'Compact', 'Convenience', 'Safety', 'Taste', 'Maintenance', and 'Cost' were used. Weighting was used that favored functionality like 'Safety' and cost metrics over 'nice to haves' like small size and effect on water taste. In this matrix chlorination tablets scored 86 out of 130 possible points, whereas ultraviolet filtration scored 116. The largest discrepancies were found when it came to maintenance and ability to be accessed on demand. Both of which have already been explained in the House of Quality section. The only section in which chlorination stood out over ultraviolet was in the cost section, which for the purpose of the evaluation matrix was only concerned about initial setup costs, not long term in which the replacement cycle of chlorination tablets would shortly outweigh the slightly higher initial setup cost of ultraviolet filtration.

House of Quality and evaluation matrixes were also used for help in the decision-making process of the issue of water supply. Due to the simplicity of these systems the list of required qualities for the House of Quality is much smaller. Functional requirements of 'Volume', 73,000 liters per week, 'Flowrate', 9.57 liters per minute, 'Connection to Critical Systems', Supplies all, 'Reliable', Maximize, and 'Maintenance', Minimize, were used. Again, to clarify some possibly less-clear terms, 'Connection to Critical Systems' is a metric which ensures that all sinks, toilets, and drinking water systems will be adequately supplied by the supply in question. 'Reliable' and 'Maintenance' attempt to objectively look at how likely a system is to fail and how much preventative or reparative maintenance will be needed over time. Both Water Tank and water pump systems scored quite evenly in this test, as seen in Appendix C **Figure 11** and **Figure 12** respectively. The only notable differentiating factor was in maintenance as a tank will need regular invasive inspection to ensure that no cracks are forming, and water samples taken to ensure that there is no bacteria buildup within. The water pump on the other hand can be tested simply by turning it on briefly and ensuring that there is adequate water pressure to service up to the fifth floor.

An evaluation matrix was also created, see Appendix C **Figure 13**, including factors such as 'Volume', 'Flowrate', 'Compact', 'Reliable', 'Environmentally Responsible', and 'Ease of Install'. 'Volume' refers to the capacity that it can supply over a seven-day period. 'Flowrate' refers to the maximum throughput of the system at a given time. 'Reliable' was explained in the House of Quality section. 'Ease of Install' refers to how large a change to pre-existing structures is needed, or how much consideration must be made in a new building in order to implement it. The greatest weight was placed on 'Volume', 'Flowrate', and 'Ease of Install', with the lowest concern being how compact it was. Utilizing a water tank scored 91 points out of 125, and a water pump scored 102 out of 125. Both solutions were found to have equal volume and flowrate capacity, however there was a large discrepancy in favor of a pump in the 'compact' and 'Ease of Install' categories. This is due in large part to the size of a sufficiently large water tank, and the need to locate it in a high location within the building. A pump on the other hand can be installed in-line on the wall in an equipment room and can be retrofit or planned into a project with relative ease. As such, the Water Pump is selected to supply water to the building.

Use of a Water Pump and combination Ultraviolet Filter has subsequently been selected as the best solution to this problem. A water pump will be able to drive an on-demand limitless quantity of water from the municipal water supply to upper floors whenever needed, and the ultraviolet filters will ensure that clean, fresh, tasteless water is available on-demand as well to provide for the residents. Compared to a water tank which would take up a large amount of space and require structural consideration, a water pump is a safer, less expensive, and more reliable option. It also has a side benefit of avoiding any fears of water running out during an emergency as the selected pump can provide a much higher volume than required, whereas a water tank will contain a finite volume of water which may create undue additional stress during a scenario in which user comfort is paramount and stresses are already high. Chlorination and Ultraviolet would both work equally well, however when the cost, flavor quality, and environmental concerns of chlorination tablets are taken into consideration an ultraviolet purification system appears by far to be the better option. Additionally, the on-demand nature of an ultraviolet purifier is another benefit for the safety of dependents as there can be no temptation to drink chlorinated water too soon and run the risk of drinker illness since the water will leave the tap clean and safe to drink.

3.2.2 Power Generation and Heating and Cooling

The simplest and most efficient heating and cooling system would be to power the existing gas heating and AC systems within the building with an internal source of electricity. The electrical power for the AC system is much less than is required to power the heating system [24].

In the event of a black out, gas heating systems within a high-rise would shut down and remain idle until electricity is provided to circulate heat in the building, as seen in Appendix B **Figure 14**. To power this system, electricity has to be generated within the building, moments after the beginning of the black out and up until the power grid is up and running once again. The power generation system will connect directly to pre-existing heating and cooling systems within the building.

A diesel generator capable of providing 220 kWh of electricity is sufficient for powering the heating or cooling systems, and the water filtration system for an extended period of time in a black out [44]. A priority for power is the reliability and quick response time of the back-up power generation, both attributes that a diesel generator maximizes. A Cummins Triton 220 kWh diesel generator that will be used as an example of a mid-line generator that is required for the project [45]. Other similar generators can be used depending on the available products or for budget adjustments.

The generator in question will be 2.7 metric tons with an additional 1.5 metric tons added with the sound attenuated cover [45]. The cover is 4.25 meters in length, 1.5 meters in height and 2.25 meters wide. The generator is positioned on a heavy-duty steel frame with anti-vibration pads to reduce stress when the generator is powered on. The cover on the generator is a powder coated steel that protect against the elements and reduce noise while the generator is powered on. An additional housing for the generator to increase the lifetime of the sound attenuated cover can be put in place but is not necessary. To conserve space in the building and to provide easy disposal of emissions, the generator will be placed on the roof of the building.

While the generator is highly efficient due to the 15 to one compression ratio, at 100% power load it consumes 54 liters of diesel an hour [45]. An additional 10 000 liter diesel fuel tank will have to be placed on the roof to accommodate the maximum power generation of the diesel engine for over 185 hours or 7.7 days. This diesel fuel tank will be an additional 5-meter-long and 2 meter in diameter cylindrical tank, that will connect to the generator [46]. It will need minimal maintenance as diesel can be stored for 12 months at a time, longer with additional treatment of diesel.

The generator will be connected to the power supply of the building with the internal breaker that is built into the generator. In the case of a blackout the generator will power on within ten seconds, before the heating system is cooled, to increase efficiency. For QFD of diesel generators Appendix C, Figure 15.

3.2.3 Building Insulation and Energy Efficiency

Heating and cooling systems, potable water filtration devices, and sanitary facilities will maintain adequate efficiency ratios. Thermal performance of the building is increased through air sealing and moisture control. Installation of energy efficient windows and doors, and increasing insulation R-values, reduces the transfer of thermal energy between the interior and exterior of the complex. Less generated energy is required to maintain the internal temperature of the building. Ceiling, floor, and wall insulation R-values used in a net-zero building envelope are specific to the climate of the chosen building location, type of cladding materials, as well as the established heating and cooling systems [47]. Victoria, British Columbia is located in a temperate sub-Mediterranean climate zone, with mild winters, constant offshore breezes and a low humidity ratio offering comfortably dry summers [48]. The ceiling, floor, and wall insulation must have approximate thermal resistance values of R-60, R-40, and R-30, respectively [32]. Blown-in, closed cell spray foam insulation made of cellulose will be used. By focusing on conservative energy design and building construction, the cost of utilizing generator power is reduced. ENERGY STAR certified windows and doors will be installed, to increase the average fenestration energy efficiency by 25% to 89% [49]. Proper maintenance and inspection and minimizing machine rest time during repairs will increase efficiency and ensure functionality of mechanical systems.

4 Considerations for Final Design

Sustainability in the P1 Project design was achieved through addressing: (1) people and social considerations, (2) profit and financial requirements, and (3) the planet and environmental consciousness. Sustainability is defined as the practice of meeting present needs in design requirements without affecting future generations ability to support those needs. The timescale of design reliability is described in years and decades rather than upcoming weeks. The following three report sections explain how sustainable practices were integrated in design considerations. Project design criteria clearly address each aspect of the Triple Bottom Line (TBL), outlined in **Table 2.**

4.1 Sustainable Engineering

4.1.2 People and Social Considerations

All stakeholders require a safe shelter for seven days during an environmental emergency. Emergency response systems are highlighted in **Section 4.2**, for the benefit of occupant safety. Each individual has their own methods of handling stress in a state of emergency. Separated living quarters ensure gender privacy and account for individual racial and religious practices. As a result, additional room heating is required, increasing the cost of the system. The landlord will provide safety resources for his or her clients, creating a sustainable ownership system [50]. Residents must accept the implementation of each system into their building prior to moving in. The cost of occupant rent should increase no more than ten percent to ensure that all residing families can afford safety insurance in their homes. The ten percent increase in rent is to compensate the landlord for additional safety regulation costs. Private benefits will be recognized by occupants and the landlord, proud to be living in an apartment building which sustain life in an emergency situation. Other civilians will recognize a greater sense of security in retrofitting their own homes with adequate emergency relief plans, providing external benefits.

There is a social implication of moving all occupants to four floors during an emergency. There must be a form of compensation for the individuals who have purchased the 12 apartment units which exist on these four floors. In order for the landlord to rent out these units, he or she will have to lower the rent and ensure compensation for any damage caused by fellow occupants within their apartment. The following 12 residents must sign a contract, agreeing to this emergency policy prior to signing onto the lease.

4.1.3 Profit and Corporate Requirements

The emergency system must generate a source of revenue to be classified as a sustainable design [50] . If the government decides to cover the cost of implementing emergency systems, profit will be generated by design owners. If governmental funding is not available, building owners would assume the cost of implementing emergency systems. Building owners would increase the rent for current or future residents to create equitability. Residents and landowners must support system reliability and development through financial investment. Private effects of implementation include fostering a sense of security in the daily life of an occupant. A resident will choose to live in a retrofitted building for its ability to financially and physically reciprocate for them in the case of an emergency. This will create an external effect, where local residential high rises surrounding Victoria and Vancouver, British Columbia will install similar systems. Market competition will arise, and other construction companies will implement similar protocol in future building design. Employment rates and revenue generated by construction companies will increase.

4.1.4 The Planet and Environmental Consciousness

The final aspect of a sustainable engineering design considers the environment. The premise of the “cradle to grave” effect was taken into consideration, where the environmental impact of a product or activity from the beginning of its life cycle to its end disposal is analyzed [51]. Renewable energy sources and ecofriendly waste disposal and sanitation procedures were considered. The private effects of development include raising awareness on the need for renewable and energy efficient building design, reducing fossil fuel consumption and mitigating climate change. When considering energy efficiency and resource consumption, following the building and safety standards under the British Columbia Building Codes and from National Resource Canada was completed. Latest regulations for the construction of residential complexes improve insulation and increase energy conservation through wall cladding [52]

[53]. Serious environmental consideration must be addressed for heating and cooling systems. Options include solar energy generation or implementing a gas or diesel generator. Both ideas quantify to zero land use since it is being retrofitted into an existing building. When considering solar, the design company must consider the disposal of chemicals used in the manufacturing and disposal of solar panels [51].

4.2 Safety and Regulatory Issues

Safety and regulatory issues are taken into consideration throughout the P1 Project. Economic feasibility is one of three major design criteria chosen for the implementation of an emergency system into the high rise in Victoria, British Columbia. The regulations of implementing a number of different emergency plans and resources within each resident will increase the cost of the project, however, is a mandatory project asset. The safety of the residents is of utmost important consideration throughout a blackout. An emergency booklet will be distributed to each occupant, when they become a tenant. The emergency booklet as shown in Appendix B **Figure 18**, consists of instructions for a number of test and drills to be conducted throughout the year. There will be an explanation on how to practice safe exit routes and will cover all forms of possible emergencies that could occur within the area like earthquakes and fires [54].

For example, a monthly fire test will be conducted, tenants are required to know two escape routes from their apartment, and tenants must know their designated room if a blackout were to occur. An emergency kit for a blackout will be given, however the emergency booklet will emphasize the importance of having your own and how to create one [54].

The safety and health of occupants is one of the defining criterium for the project. Defining the required survival heating, water consumption and sanitation is the bulk of the cost and design for the implementation of the emergency system. Research was conducted to ensure that tenants would be receiving six liters of water daily for drinking and sanitation and a consistent building temperature of 16 degrees Celsius throughout the blackout [55] [56].

The final safety factor and regulation taken into consideration throughout the design process was the number of floors that are going to be used. As stated in the scope, the plan was for all residents to move to four condensed floors. This was determined by the set regulation of how many people can be in a 2000 square foot apartment and still follow safety requirements [57].

5 Final Design

The final design solution is the culmination of all successful design elements. The final design solution addresses the problem statement, fitting all the requirements set out by the scope and satisfies the needs of the stakeholders to the greatest possible extent.

5.1 Final Design Solution

The final design solution consists of fundamental systems to sustain living conditions for all occupants of the residential high-rise in Victoria, British Columbia. Located in a temperate coastal environment with influx in seasonal temperatures, the building will always maintain and internal temperature of 16 degrees Celsius. In addition to the current backup power generator for lighting and elevator usage, an additional diesel generator capable of providing 220 kWh of electricity will be implemented. This system generates enough power for heating and cooling in a 185-hour emergency. Existing gas heating and air conditioning systems within the building will be powered with this internal source of electricity. An ultraviolet water filtration system will be used to purify six litres of water daily for each occupant of the building. This water allotment is evenly divided between consumption for basic hydration and sanitation purposes. Pressurized, non-potable water pump systems are included as a final design solution. As such, toilets have water and pump systems to remove untreated sewage from the building. Drains and pipes remain operable during the emergency for handwashing and basic bathing. Walls, floors, and ceilings within the high-rise will be retrofitted with blown-in, closed cell spray foam insulation made of cellulose. ENERGY STAR certified windows and doors will be installed to reduce thermal transfers across wall cladding, and certified low-flush toilets will reduce the building's overall water consumption. With such insulation and ENERGY STAR appliance additions, energy efficiency of the building will increase by up to 89% [49]. Across the entirety of the final design solution, diversity of gender, racial and religious sensitivities, practices and beliefs are addressed through private living spaces. There is elevator access to all areas of the building to provide accessibility for those with disabilities.

5.2 Assessment of Solution

Assessment of the final solution, combining power generation, water purification and pump systems, and retrofitting solutions is based on level ranking for each design criteria found in **Table 2.** Explanations for overall project evaluation, based on economic feasibility, durability and lifetime, environmental impact, social considerations, and system complexity, on a five-level scale, can be found in **Figure 1.**

Figure 1: A summary evaluation of the final solution based on project design criteria in Table 2.

Criteria	Level Ranking
Economic Feasibility	LEVEL 3
Durability and Lifetime	LEVEL 4
Environmental Impact	LEVEL 2
Social Considerations	LEVEL 4
Complexity	LEVEL 5

Economic feasibility of the final project received an evaluation of level three. Purchasing of all systems, implementation practices, and necessary emergency supplies is within the allotted budget of $300 000 CAD outlined in the problem statement. The project aims to source local materials for systems to support the Canadian economy. Social considerations and durability of the system were prioritized over the cost of the final solution. A level four rating was given to durability and lifetime of the system. Although annual maintenance is required for power generation and water filtration and pump systems, both systems will remain in operable order for the lifetime of the building. The final solution addressed all stakeholder needs, receiving a level four evaluation. One aspect of the design which diminishes the evaluation for social considerations is the idea that all occupants must move to four condensed floors in an emergency. Fellow occupants may not be satisfied with opening their apartment to other residents, at the time of signing rental agreements. Furthermore, residents must understand that the primary purpose of this project is to meet basic living requirements of all occupants and must not expect luxury accommodations. The system is easy for occupants to utilize and understand. Emergency preparedness plans will be provided, and practice drills will be conducted, in order to receive the optimal level five evaluation for solution complexity. The environmental impact of the final solution received a low evaluation of level two. Aside from power requirements and the manufacturing of water filtration devices, there are no negative environmental impacts as a result of implementing this system. Retrofitting the building through addition of cellulose insulation has a positive impact on the environment, increasing energy efficiency and reducing the amount of energy required to heat the building. However, the power generation system will utilize up to 10 000 litres of diesel over the seven-day emergency period [45]. This amount is equivalent to generating 2.68 kg of CO_2 per litre of consumption, or 144.72 kg of CO_2 per hour of system usage [58]. This system clearly has a detrimental effect on the environment, being a large contributor to greenhouse gas emissions.

6 Conclusions and Recommendations

To get to the final design solution, the proposed ideas were changes and the project went through several iterations to fit all the initial criteria set forth in the proposal. Due to the time and space constraints, several ideas were under designed and not researched thoroughly enough to make it into the final solution. These ideas are put into the recommendation section.

6.1 Conclusion

Throughout the project, design criteria were established outline to optimize the final solution. The final design was determined by creating an evaluation matrix and House of Quality for water filtration and pump, heating and cooling systems. The chosen final design consists of an ultraviolet filtration device, a water pump and a diesel power generator. Design criteria and project specifications in **Table 2** provide a level-based evaluation system for the final solution. For example, the final project achieved an evaluation level of three and a half, just above the neutral level of a three. The final project score was hindered by its negative environmental impact. The use of 10 000 litres of diesel for power generation lowers the overall score of the project [45].

Overall stakeholder needs were met, ensuring the safety of all building occupants. Residents must agree to all emergency plans prior to moving into an apartment. Building employees must sign a working contract to agree to similar terms. Occupants must be satisfied with the amount of supplies provided in an emergency situation. The social, economic and environmental requirements of the engineering companies involved in building the high-rise, the Government of British Columbia, and the City of Victoria is hard to justify within the scope. Their needs are based off the effects of the extreme weather event which is out of the project designer's control. This project was established to understand the increasing effects of climate change on weather patterns. Such extreme weather events have an effect on the future of infrastructure development. As climate change progresses, human must adapt to new lifestyles.

6.2 Recommendations

Given more time to develop the P1 Project there would be a greater expectation and emphasize on the finalizing an accurate emergency booklet that is sufficient for this specific high rise in the city of Victoria. To be able to do that, a phone call to the city of Victoria would have to be conducted to see what resources they currently have installed and compare the cities ideas to the P1 project.

As for the projects long term goals, to sufficiently finalize the project a CAD model would be created to represent the 4 floors set out for the purpose of a blackout. With a CAD model design the project for a restoration of an existing high rise could be created which consist of the CAD floor plan and the emergency booklet that could be implemented in any building.

References

[1] Centre for Climate and Energy Solutions, "Extreme Weather and Climate Change," [Online]. Available: https://www.c2es.org/content/extreme-weather-and-climate-change/. [Accessed 25 January 2020].

[2] American Red Cross, "Disaster Relief," [Online]. Available: https://www.redcross.org/about-us/our-work/disaster-relief.html. [Accessed 25 January 2020].

[3] World Health Organization, "How much water is needed in emergencies?," [Online]. Available: https://www.who.int/water_sanitation_health/publications/2011/tn9_how_much_water_en.pdf . [Accessed 24 January 2020].

[4] The Governement of British Columbia , "The Codes," 10 December 2018. [Online]. Available: https://www2.gov.bc.ca/gov/content/industry/construction-industry/building-codes-standards/the-codes. [Accessed 6 February 2020].

[5] Government of Canada: Public Safety Canada, "Disaster Financial Assistance Arrangements (DFAA)," [Online]. Available: https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/rcvr-dsstrs/dsstr-fnncl-ssstnc-rrngmnts/index-en.aspx. [Accessed 6 January 2020].

[6] Ultraviolet.com, "Frequently Asked Questions - Ultraviolet Technology," [Online]. Available: https://ultraviolet.com/ultraviolet-frequently-asked-questions/. [Accessed 7 February 2020].

[7] Livpure, "What is the Average Life of a Water Filter," 25 May 2018. [Online]. Available: https://www.livpure.com/blog/what-is-the-average-life-of-a-water-filter. [Accessed 9 February 2020].

[8] Plant Services, "Preventative Maintenance Schedule for Centrifugal Pumps," [Online]. Available: https://www.plantservices.com/articles/2017/fh-preventive-maintenance-checklist-centrifugal-pumps/. [Accessed 9 February 2020].

[9] World Health Organization, "WHO Health Emergencies," [Online]. Available: http://www.emro.who.int/eha/information-resources/public-health-priorities-in-emergencies.html?fbclid=IwAR2IThm9zvL9RBCghkxmU1NhD5KL5T2qU4ZiO-rHsa7rDXkAHH-_6EmzfmQ. [Accessed 25 January 2020].

[10] Department of Health and Human Services, State Government of Victoria, Australia, "Water- a vital nutrient," [Online]. Available: https://www.betterhealth.vic.gov.au/health/healthyliving/water-a-vital-nutrient. [Accessed 6 Febraury 2020].

[11] Government of Canada, "Canada's Food Guide," Government of Canada, 2019.

[12] National Heart, Lung and Blood Institute, "Parent Tips: Calories Needed Each Day," National Heart, Lung and Blood Institute, 2010.

[13] City of Vancouver, "Hazards that could Affect our City," [Online]. Available: https://vancouver.ca/home-property-development/prepare-for-other-disasters.aspx. [Accessed 9 February 2020].

[14] British Columbia, "The 2018 BC Codes," 2018. [Online]. Available: http://www.bccodes.ca/index.html. [Accessed 9 February 2020].

[15] South Staffs Water, 2010. [Online]. Available: https://www.south-staffs-water.co.uk/media/1539/waterusehome.pdf. [Accessed 7 February 2020].

[16] Cleaning Institute, 21 September 2009. [Online]. Available: https://www.cleaninginstitute.org/newsroom/surveys/92109-summary. [Accessed 7 February 2020].

[17] Home Water Works, "Toilets," Alliance for Water Efficiency, 2011. [Online]. Available: https://www.home-water-works.org/indoor-use/toilets. [Accessed 7 February 2020].

[18] Ontario Energy Board, [Online]. Available: https://www.oeb.ca/rates-and-your-bill/electricity-rates/managing-costs-time-use-rates. [Accessed 7 February 2020].

[19] City of Victoria, [Online]. Available: https://www.victoria.ca/assets/Departments/Planning~Development/Community~Planning/Local~Area~Planning/Fairfield~Gonzales/Fairfield~Growth~Survey/PDF%20How%20tall%20is%20a%20building%20storey.pdf. [Accessed 7 February 2020].

[20] G. Finch, "(PDF) Energy Consumption in Mid and High Rise Residential Buildings in British Columbia," [Online]. Available: https://www.researchgate.net/publication/305347772_Energy_Consumption_in_Mid_and_High_Rise_Residential_Buildings_in_British_Columbia. [Accessed 25 01 2020].

[21] BC Hydro, "BC Hydro sets record for highest February power load," 01 March 2019. [Online]. Available: https://www.bchydro.com/news/press_centre/news_releases/2019/february-power-load.html. [Accessed 25 January 2020].

[22] Weather Spark, *Average weather in Vancouver,* Vancouver: Weather Spark.

[23] "Households and the Environment: Energy Use: Analysis," Statistics Canada, 27 11 2015. [Online]. Available: https://www150.statcan.gc.ca/n1/pub/11-526-s/2013002/part-partie1-eng.htm. [Accessed 25 01 2020].

[24] BC Hydro, "High-powered high-rise," Vancouver, April 2019.

[25] C. Nunez, "Sea Level Rise, Explained," Natinoal Geographic, 19 February 2019. [Online]. Available: https://www.nationalgeographic.com/environment/global-warming/sea-level-rise/. [Accessed 9 February 2020].

[26] US Global Change Research Program, "The National Climate Assesment: Extreme Weather," [Online]. Available: https://nca2014.globalchange.gov/highlights/report-findings/extreme-weather.. [Accessed 11 January 2020].

[27] Centre for Climate and Energy Solutions, "Extreme Precipitation and Climate Change," [Online]. Available: http://www.c2es.org/content/extreme-precipitation-and-climate-change/. [Accessed 11 January 2020].

[28] E. Matlovich, "How Permeable Pavements Help To Prevent Urban Flooding," True Grid, [Online]. Available: https://www.truegridpaver.com/permeable-pavements-help-prevent-urban-flooding/. [Accessed 9 February 2020].

[29] Natural Resources Canada, "Questions and Answers on Megathrust Earthquakes," 11 March 2019. [Online]. Available: https://earthquakescanada.nrcan.gc.ca/zones/cascadia/qa-en.php. [Accessed 9 February 2020].

[30] Imagination Station, "Earthquake-Proof Buildings," [Online]. Available: https://www.imaginationstationtoledo.org/educator/activities/can-you-build-an-earthquake-proof-building. [Accessed 11 January 2020].

[31] I. Station, "Earthquake-Proof Buildings," [Online]. Available: https://www.imaginationstationtoledo.org/educator/activities/can-you-build-an-earthquake-proof-building. [Accessed 11 January 2020].

[32] The Home Depot, "How to Choose Insulation," [Online]. Available: https://www.homedepot.ca/en/home/ideas-how-to/home-repair-and-maintenance/how-to-choose-insulation.html. [Accessed 11 January 2020].

[33] Water Pumps Direct, [Online]. Available: https://www.waterpumpsdirect.com/Little-Giant-92061503-Water-Pump/p16621.html. [Accessed 7 February 2020].

[34] Little Giant, "Inline 400 pressure Booster," [Online]. Available: https://www.waterpumpsdirect.com/manuals/little-giant-1b187de34a06cc77f17ec76728376eec.pdf. [Accessed 7 February 2020].

[35] J. Woodard, "What is a Water Booster Pump and How Does It Work?," FreshWaterSystems.com, 12 June 2019. [Online]. Available: https://www.freshwatersystems.com/blogs/blog/what-is-a-water-booster-pump-and-how-does-it-work. [Accessed 7 February 2020].

[36] The Tank Depot, "20000 Gallon Vertical Liquid Storage Tank - 43825," [Online]. Available: https://www.tank-depot.com/productdetails.aspx?part=N-43825. [Accessed 7 February 2020].

[37] R. Lamb, "How Grey Water Reclamation Works," How Stuff Works, [Online]. Available: https://science.howstuffworks.com/environmental/green-science/gray-water-reclamation1.htm. [Accessed 7 February 2020].

[38] Viqua, "VH-200-F10 UV System for Home," [Online]. Available: https://viqua.com/product/vh200-f10/?productDetails. [Accessed 7 February 2020].

[39] ELUA, "Aquatabs Water Purification Tablets 49 mg Canadian Pack," [Online]. Available: https://elua.com/collections/aquatabs-canada/products/aquatabs-49-mg-canadian-pack?variant=231616636. [Accessed 7 February 2020].

[40] Aquatabs, Global Hydration, 2013. [Online]. Available: https://www.aquatabs.ca/faq.html. [Accessed 7 February 2020].

[41] Lenntech, [Online]. Available: https://www.lenntech.com/periodic/elements/cl.htm. [Accessed 8 February 2020].

[42] Bulk Office Supply, "Wholesale - BUNN 12-Cup Regular Filters," [Online]. Available: https://www.bulkofficesupply.com/Products/BUNN-12-Cup-Regular-Filters__BUNREGFILTER.aspx. [Accessed 7 February 2020].

[43] M. Neuberger and M. Lang, "Documentation of heat pump retrofits in multi-unit residential buildings," Sustainability Group, City of Vancouver, 2017.

[44] BCHydro, "Cost Calculator," [Online]. Available: https://www.bchydro.com/powersmart/residential/tools-and-calculators/cost-calculator.html. [Accessed 11 January 2020].

[45] TRITON POWER CORP, "Triton 220 KW / 275 KVA," [Online]. Available: https://www.americasgenerators.com/uploads/docs/220%20kW%20Cummins%20Diesel%20Generator%20Set%20-%20Non%20EPA%20-%2060Hz%20%20TP-C220-T1-60.pdf. [Accessed 08 February 2020].

[46] "Horizontal Bulk Fuel Tank 10000 Litre," Pumps Direct 2U, [Online]. Available: http://www.pumpsdirect2u.com/diesel-fuel-tanks-376/horizontal-bulk-fuel-tank-10000-litre-6665.htm. [Accessed 08 February 2020].

[47] Zero Energy Project, "Extremely Energy Efficient Homes," [Online]. Available: https://zeroenergyproject.org/build/twelve-steps-affordable-zero-energy-home-construction-design/. [Accessed 11 January 2020].

[48] City of Victoria, "Climate," [Online]. Available: https://www.victoria.ca/EN/main/residents/about/climate.html. [Accessed 11 January 2020].

[49] Natural Resources Canada, "Windows, doors, and skylights," [Online]. Available: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-products/product-information/windows-doors-and-skylights/13739. [Accessed 11 January 2020].

[50] M. Grant, "Sustainability," Investopedia , 25 June 2019. [Online]. Available: https://www.investopedia.com/terms/s/sustainability.asp. [Accessed 23 Jaunary 2020].

[51] Encyclopedia of Materials: Science and Technology, "Cradle-to-Grave," ScienceDirect , 2001. [Online]. Available: https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/cradle-to-grave. [Accessed 23 January 2020].

[52] Natural Resources Canada , "Canada's national energy code," Governement of Canada , 27 Novemeber 2019. [Online]. Available: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-buildings/energy-efficiency-new-buildings/canadas-national-energy-code/20675. [Accessed 23 January 2020].

[53] Building and Safety Standards Branch , "New Energy Requirements," Goverment of British Columbia , 22 May 2013. [Online]. Available: https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/construction-industry/building-codes-and-standards/bulletins/b13-05_new_energy_requirements.pdf. [Accessed 23 Janaury 2020].

[54] Metro Vancouver, "Emergency Preparedness: Tenant Information".

[55] World Health Organization, "How much water is needed in emergencies".

[56] Candian Centre of Occupational Health and Safety, "Temperature," 30 January 2020. [Online]. Available: https://www.ccohs.ca/topics/hazards/physical/temperature/. [Accessed 6 February 2020].

[57] Governement of British Columbia , "Fire Safety & Occupant Load," [Online]. Available: https://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery/fire-safety/legislation-regulations-codes/occupant-load. [Accessed 8 February 2020].

[58] "Calculation of CO2 Emissions," [Online]. Available: https://people.exeter.ac.uk/TWDavies/energy_conversion/Calculation%20of%20CO2%20emissions%20from%20fuels.htm. [Accessed 08 February 2020].

[59] Walmart, "Walmart," [Online]. Available: https://www.walmart.com/. [Accessed 8 February 2020].

[60] "220 kW Cummins Diesel Generator Set - Non EPA - 60Hz," Americas Generators, [Online]. Available: https://www.americasgenerators.com/220kW-Cummins-Diesel-Generator-Non-EPA.aspx. [Accessed 06 February 2020].

[61] Portland Energy Conservation, "Operation and Maintenance in Office Buildings: Defining Baseline," p. 9, 1996.

[62] Governement of British Columbia , "Finanical Management of emergency Response Costs during Provincial Activations," March 2013. [Online]. Available: https://www2.gov.bc.ca/assets/gov/public-safety-and-emergency-services/emergency-preparedness-response-recovery/provincial-emergency-planning/financial-management-of-emergency-response-costs.pdf. [Accessed 8 February 2020].

[63] Canadian Red Cross, "Get Help: Disaster Relief and Recovery," [Online]. Available: https://www.redcross.ca/how-we-help/emergencies-and-disasters-in-canada/get-help-disaster-relief-and-recovery. [Accessed 6 January 2020].

[64] City of Vancouver, "BEEP Guide".

[65] Ontario Energy Board, [Online]. Available: https://www.oeb.ca/rates-and-your-bill/electricity-rates/managing-costs-time-use-rates. [Accessed 7 February 2020].

[66] Water Quality Association, [Online]. Available: https://www.wqa.org/Learn-About-Water/Common-Contaminants/Bacteria-Viruses. [Accessed 7 February 2020].

[67] Capital Regional District, "Water Treatment in Greater Victoria Supply," 28 September 2008. [Online]. Available: https://www.crd.bc.ca/docs/default-source/Partnerships-PDF/water-in-our-community-learning-resource/water-treatment-in-greater-victoria-slides.pdf. [Accessed 7 February 2020].

[68] J. Woodard, "What is a Water Booster Pump and How Does It Work?," Fresh Water Systems.com, 12 June 2019. [Online]. Available: https://www.freshwatersystems.com/blogs/blog/what-is-a-water-booster-pump-and-how-does-it-work. [Accessed 7 February 2020].

[69] Hydro-Québec, "Breakdown of a household's electricity use," [Online]. Available: http://www.hydroquebec.com/residential/customer-space/electricity-use/electricity-consumption-by-use.html. [Accessed 25 January 2020].

[70] Government of Canada, "Power Outages — What to do?," 01 February 2018. [Online]. Available: https://www.getprepared.gc.ca/cnt/rsrcs/pblctns/pwrtgs-wtd/index-en.aspx. [Accessed 06 01 2020].

[71] Bell Performance, "Guidelines For Long Term Fuel Storage of Diesel and Storage Tanks," 09 May 2013. [Online]. Available: https://www.bellperformance.com/blog/bid/114020/guidelines-for-long-term-fuel-storage-of-diesel-and-storage-tanks. [Accessed 08 February 2020].

[72] Portland EAnergy Consercation, Inc, "Operation and Maintenance in Office Buildings," p. 9, 1996.

Appendix A: Individual Contributions

Table 3: An outline of each team members contributions to the P1 Interim Report.

Team Members	Content	Write-up	Editing
Emma Christie-Gallop	Introduction (Problem Definition, Design Criteria), Background Research (Extreme Weather Conditions Affecting Building Design), Design Selection (Building Insulation and Energy Efficiency), Final Design (Final Design Solution, Assessment of Solution)	Introduction (Problem Definition, Design Criteria), Background Research (Extreme Weather Conditions Affecting Building Design), Design Selection (Building Insulation and Energy Efficiency), Final Design (Final Design Solution, Assessment of Solution)	Each Component
Alexandra MacDuff	Introduction (Stakeholders), Preliminary Design (Idea Selection), Considerations for Final Design (Sustainable Engineering, Safety and Regulatory Issues), Conclusions and Recommendations (Conclusion, Recommendations)	Introduction (Stakeholders), Preliminary Design (Idea Selection), Considerations for Final Design (Sustainable Engineering, Safety and Regulatory Issues), Conclusions and Recommendations (Conclusion, Recommendations)	Each Component
Alexander Parks	Background Research (Power Generation for Residential Buildings), Preliminary Designs (Heating and Cooling Systems), Design Selection (Power Generation and Heating and Cooling)	Background Research (Power Generation for Residential Buildings), Preliminary Designs (Heating and Cooling Systems), Design Selection (Power Generation and Heating and Cooling)	Each Component
Adler Grienke	Executive Summary, Introduction (Scope), Background Research (potable and Nonportable Water Resources),	Executive Summary, Introduction (Scope), Background Research (potable and Nonportable Water Resources),	Each Component

	Preliminary Designs (Potable and Non-potable water systems), Design Selection (Potable and Non-potable Water Systems)	Preliminary Designs (Potable and Non-potable water systems), Design Selection (Potable and Non-potable Water Systems)	

Appendix B: Additional Figures

Examples of provincial/territorial expenses that may be eligible for cost sharing under the DFAA

- Evacuation, transportation, emergency food, shelter and clothing
- Emergency provision of essential community services
- Security measures including the removal of valuable assets and hazardous materials from a threatened area
- Repairs to public buildings and related equipment
- Repairs to public infrastructure such as roads and bridges
- Removal of damaged structures constituting a threat to public safety
- Restoration, replacement or repairs to an individual's dwelling (principal residence only)
- Restoration, replacement or repairs to essential personal furnishings, appliances and clothing
- Restoration of small businesses and farmsteads including buildings and equipment
- Costs of damage inspection, appraisal and clean up

Examples of expenses that would NOT be eligible for reimbursement

- Repairs to a non-primary dwelling (e.g. cottage or ski chalet)
- Repairs that are eligible for reimbursement through insurance
- Costs that are covered in whole or in part by another government program (e.g. production/crop insurance)
- Normal operating expenses of a government department or agency
- Assistance to large businesses and crown corporations
- Loss of income and economic recovery
- Forest fire fighting

Figure 2: Expenses deemed eligible and ineligible for cost sharing under the DFAA [5].

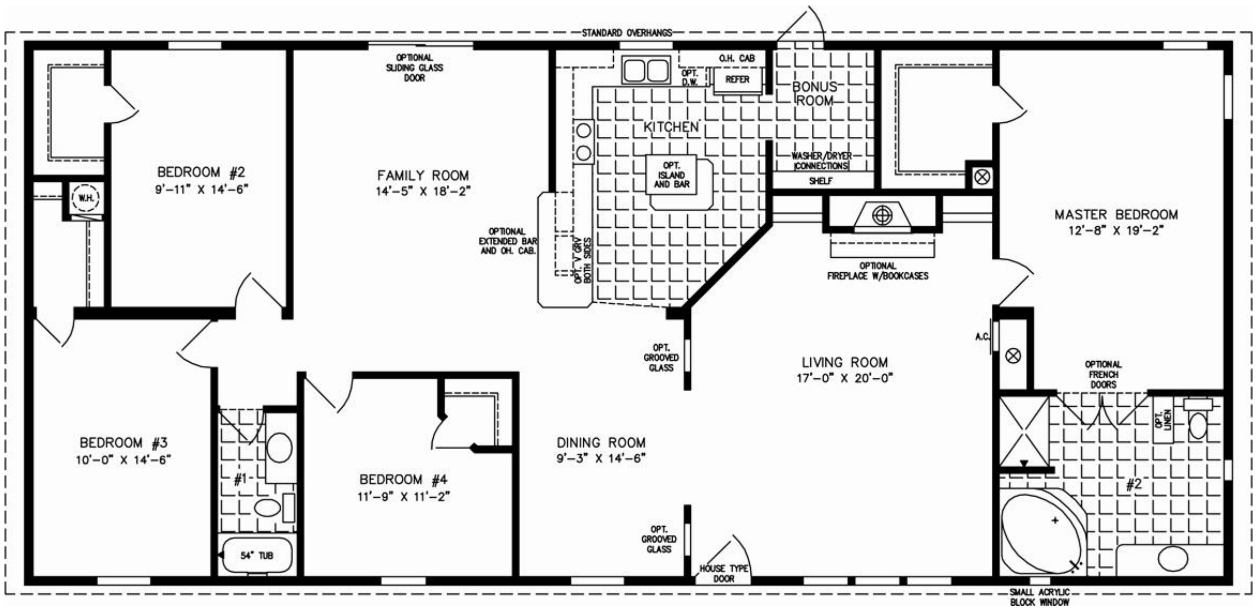


Figure 3: Apartment unit floor plan, design company unknown.

lumbing Fixture Water Use plus Drinking Water (Including Peak Usage Correction where 66.66% of usage occurs between 7:00am a						
Use Case	**(L/use)**	**(uses/day/person**	**Water Use (L/min)**	**Water Use (L/day)**	**Water Use (L/wk**	**Water Use (Peak) (L/min**
Toilet	6	5	0.0208	30	210	0.0275
Bathroom Sink (washing	2	8.6	0.0119	17.2	120.4	0.0158
Sink Bathing (capacity)	4	0.5	0.0014	2	14	0.0018
Drinking/Hygiene	x	x	0.0021	3	21	0.00275
		Total (per person)	0.0363	52.2	365.4	0.04785
		Total (200 ppl):	7.2500	10440	73080	9.57

Figure 4: Water use, including correction for peak usage.

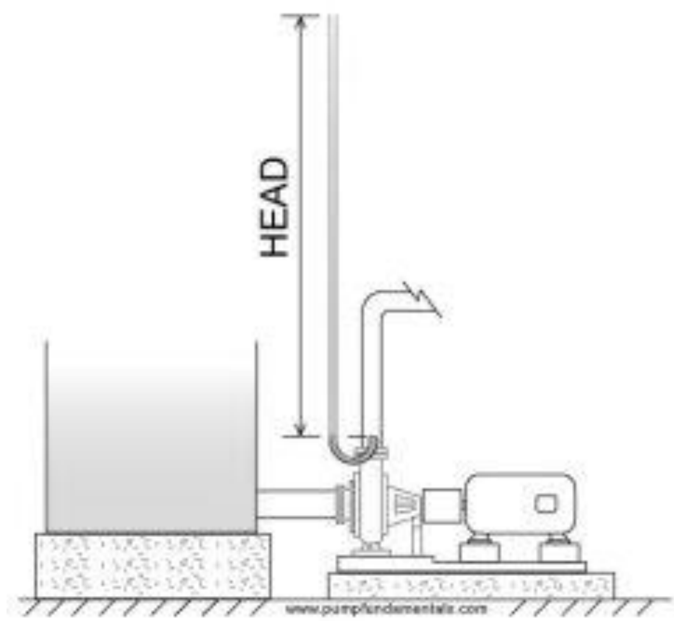


Figure 5: The Water Head (Pump Fundamentals.com).

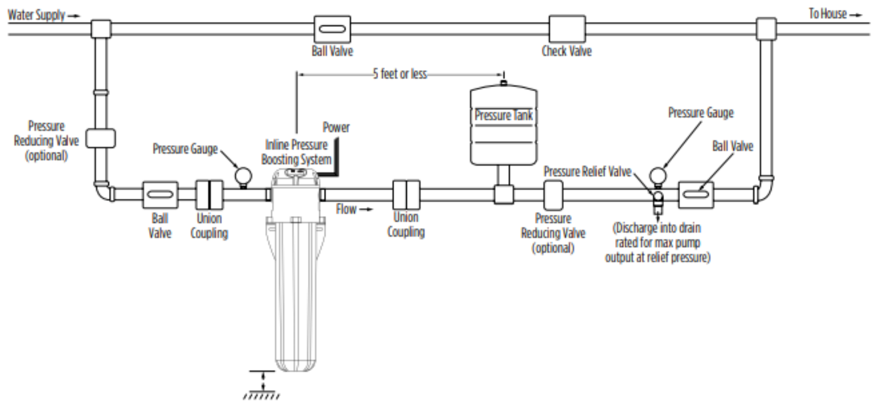


Figure 6: Booster Pump Typical Installation (Little Giant).

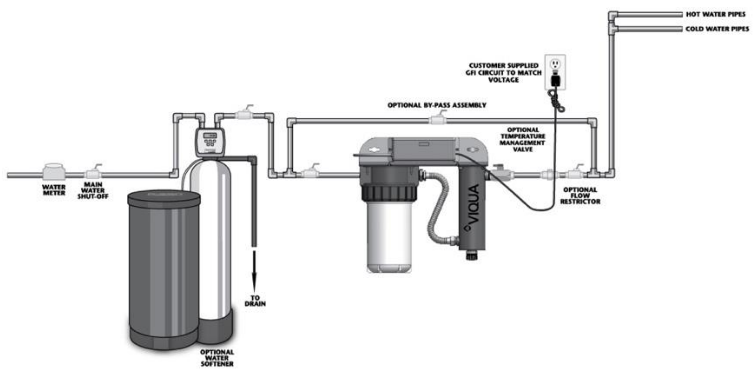


Figure 7:VIQUA-POE-IHS-schematic-home (Viqua).

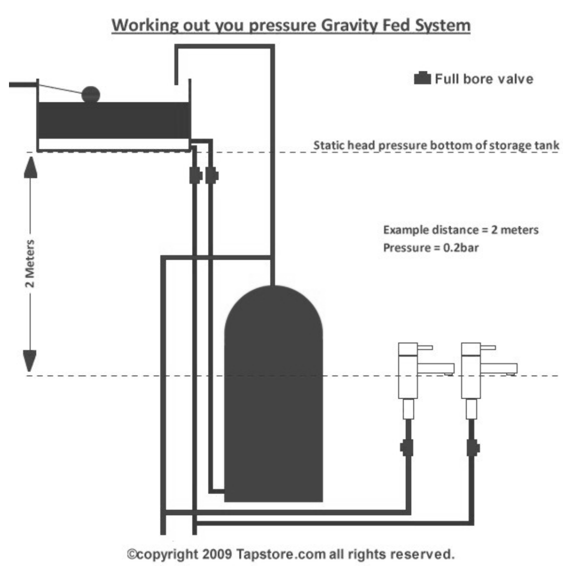
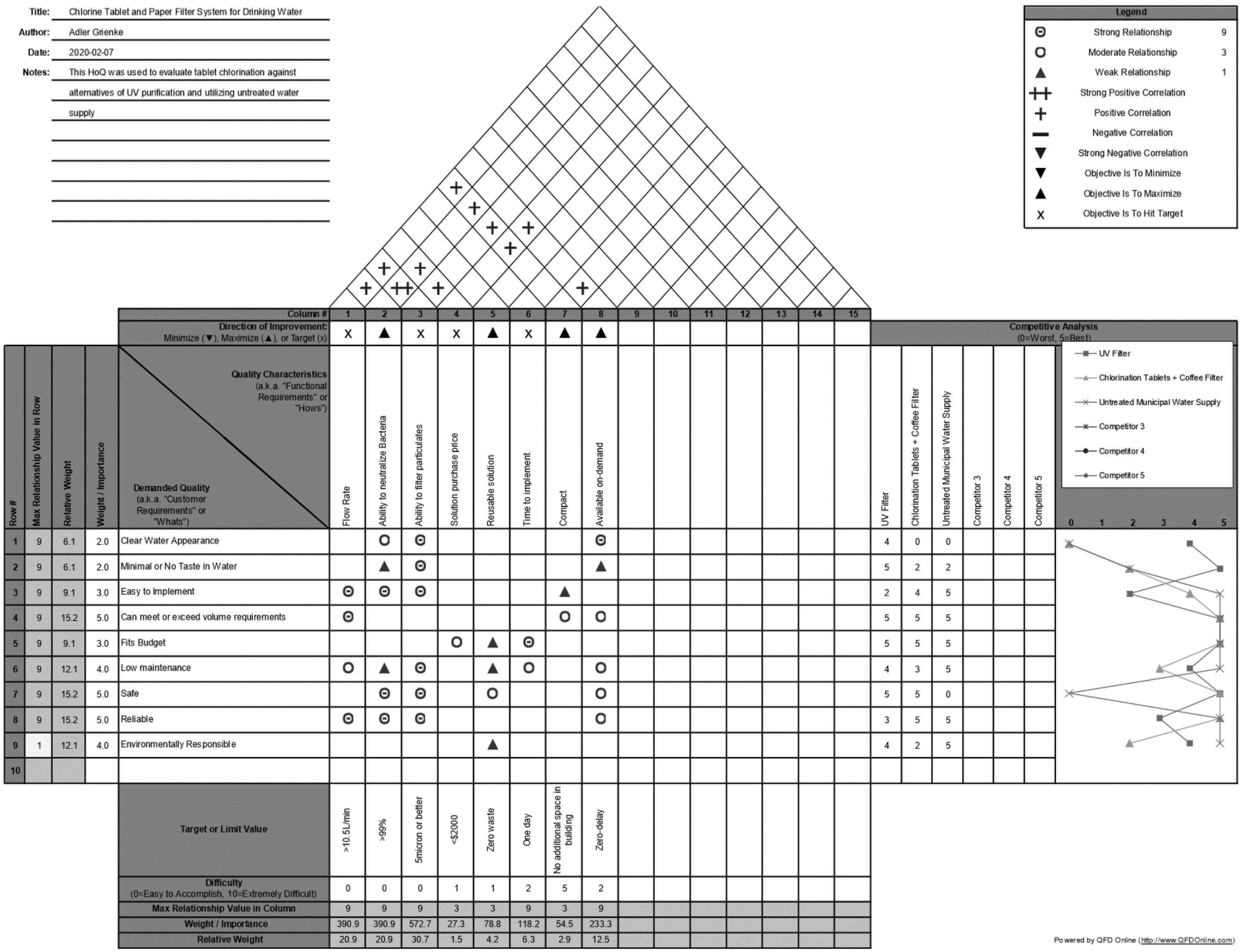


Figure 8: Gravity feed water basin.

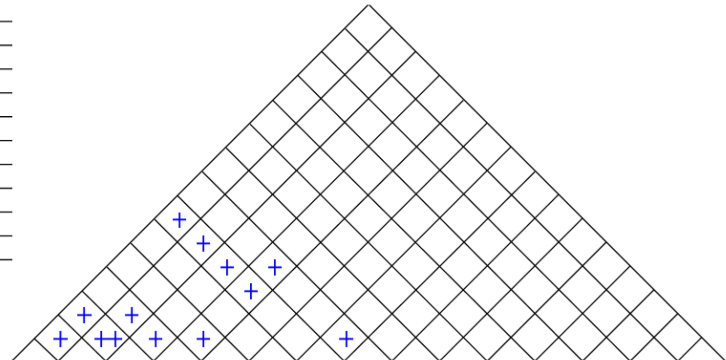


Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality	UV Filter	Chlorination Tablets + Coffee Filter	Untreated Municipal Water Supply
1	9	6.1	2.0	Clear Water Appearance	4	0	0
2	9	6.1	2.0	Minimal or No Taste in Water	5	2	2
3	9	9.1	3.0	Easy to Implement	2	4	5
4	9	15.2	5.0	Can meet or exceed volume requirements	5	5	5
5	9	9.1	3.0	Fits Budget	5	5	5
6	9	12.1	4.0	Low maintenance	4	3	5
7	9	15.2	5.0	Safe	5	5	0
8	9	15.2	5.0	Reliable	3	5	5
9	1	12.1	4.0	Environmentally Responsible	4	2	5
10							

Column #	1	2	3	4	5	6	7	8
Difficulty	0	0	0	1	1	2	5	2
Max Relationship Value in Column	9	9	9	3	3	9	3	9
Weight / Importance	390.9	390.9	572.7	27.3	78.8	118.2	54.5	233.3
Relative Weight	20.9	20.9	30.7	1.5	4.2	6.3	2.9	12.5

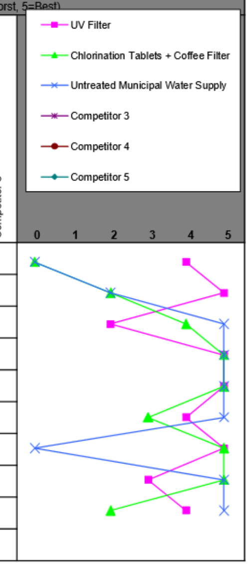
Figure 9: Chlorine House of Quality.

Title: Ultraviolet and 5 Micron Filter System for Drinking Water
Author: Adler Grienke
Date: 2020-01-25
Notes: This HoQ was used to evaluate the Ultraviolet filter against alternatives of tablet chlorination and utilizing untreated water supply



Legend		
⊙	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
—	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

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")	Flow Rate	Ability to neutralize Bacteria	Ability to filter particulates	Solution purchase price	Reusable solution	Time to implement	Compact	Available on-demand								UV Filter	Chlorination Tablets + Coffee Filter	Untreated Municipal Water Supply	Competitor 3	Competitor 4	Competitor 5
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Competitive Analysis (0=Worst, 5=Best)					
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	x	▲	▲	▼	▼	▼	▼	▲													
1	9	6.1	2.0	Clear Water Appearance		O	⊙					⊙								4	0	0			
2	9	6.1	2.0	Minimal or No Taste in Water		⊙	⊙					⊙								5	2	2			
3	9	9.1	3.0	Easy to Implement	⊙	O	⊙				O									2	4	5			
4	9	15.2	5.0	Can meet or exceed volume requirements	⊙						⊙	⊙								5	5	5			
5	9	9.1	3.0	Fits Budget				⊙	O	O										5	5	5			
6	9	12.1	4.0	Low maintenance	O	⊙	⊙		⊙	⊙		⊙								4	3	5			
7	9	15.2	5.0	Safe		⊙	⊙		⊙			⊙								5	5	0			
8	9	15.2	5.0	Reliable	⊙	⊙	⊙					⊙								3	5	5			
9	9	12.1	4.0	Environmentally Responsible					⊙											4	2	5			
10																									



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Target or Limit Value	>10.5L/min	>99%	5micron or better	<$2000	Zero waste	One day	No additional space in building	Zero-delay							
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	0	0	0	1	1	2	5	2							
Max Relationship Value in Column	9	9	9	9	9	9	9	9							
Weight / Importance	390.9	481.8	572.7	81.8	381.8	136.4	163.6	627.3							
Relative Weight	13.8	17.0	20.2	2.9	13.5	4.8	5.8	22.1							

Figure 10: Ultraviolet House of Quality.

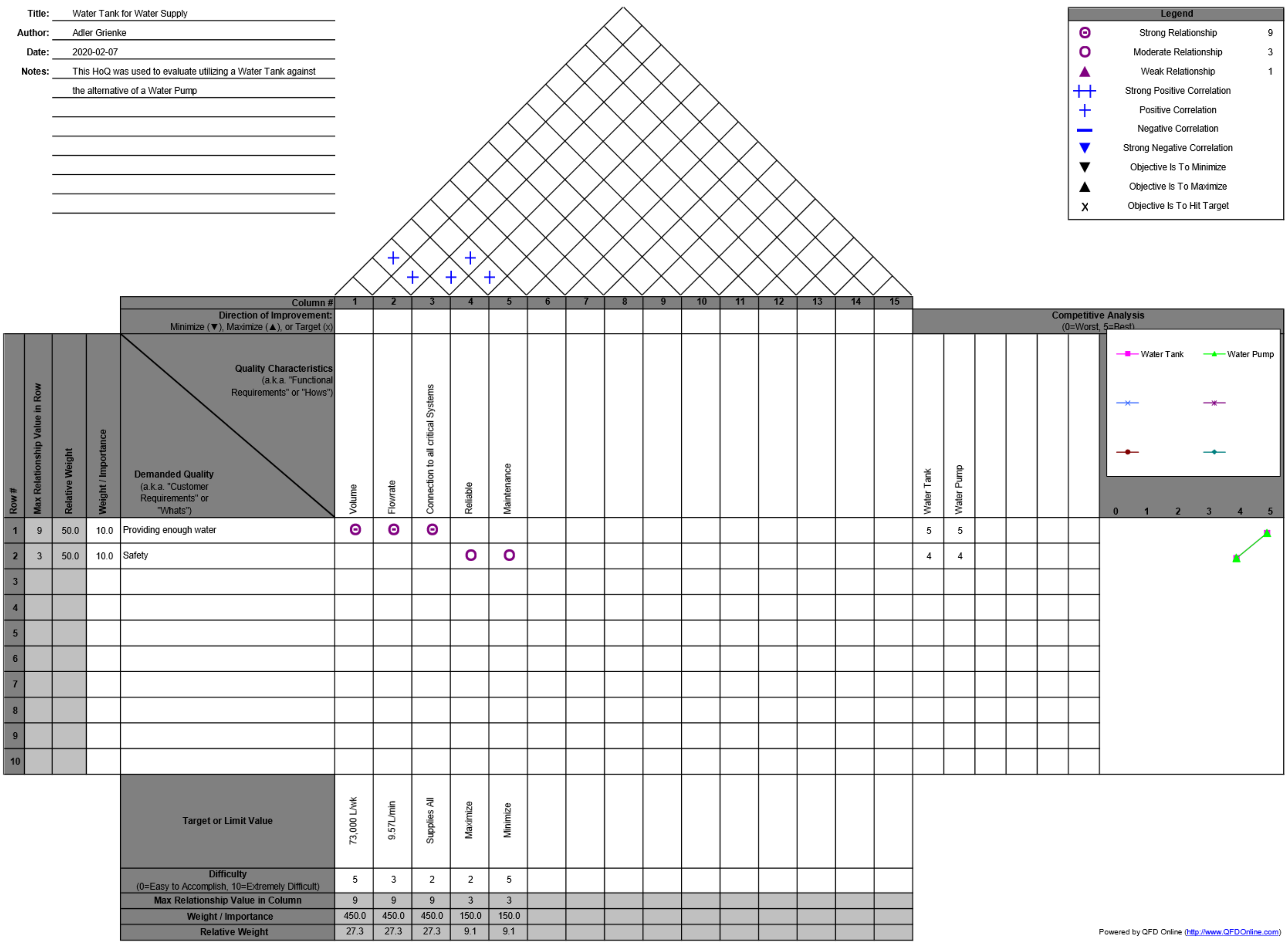


Figure 11: Water Tank House of Quality

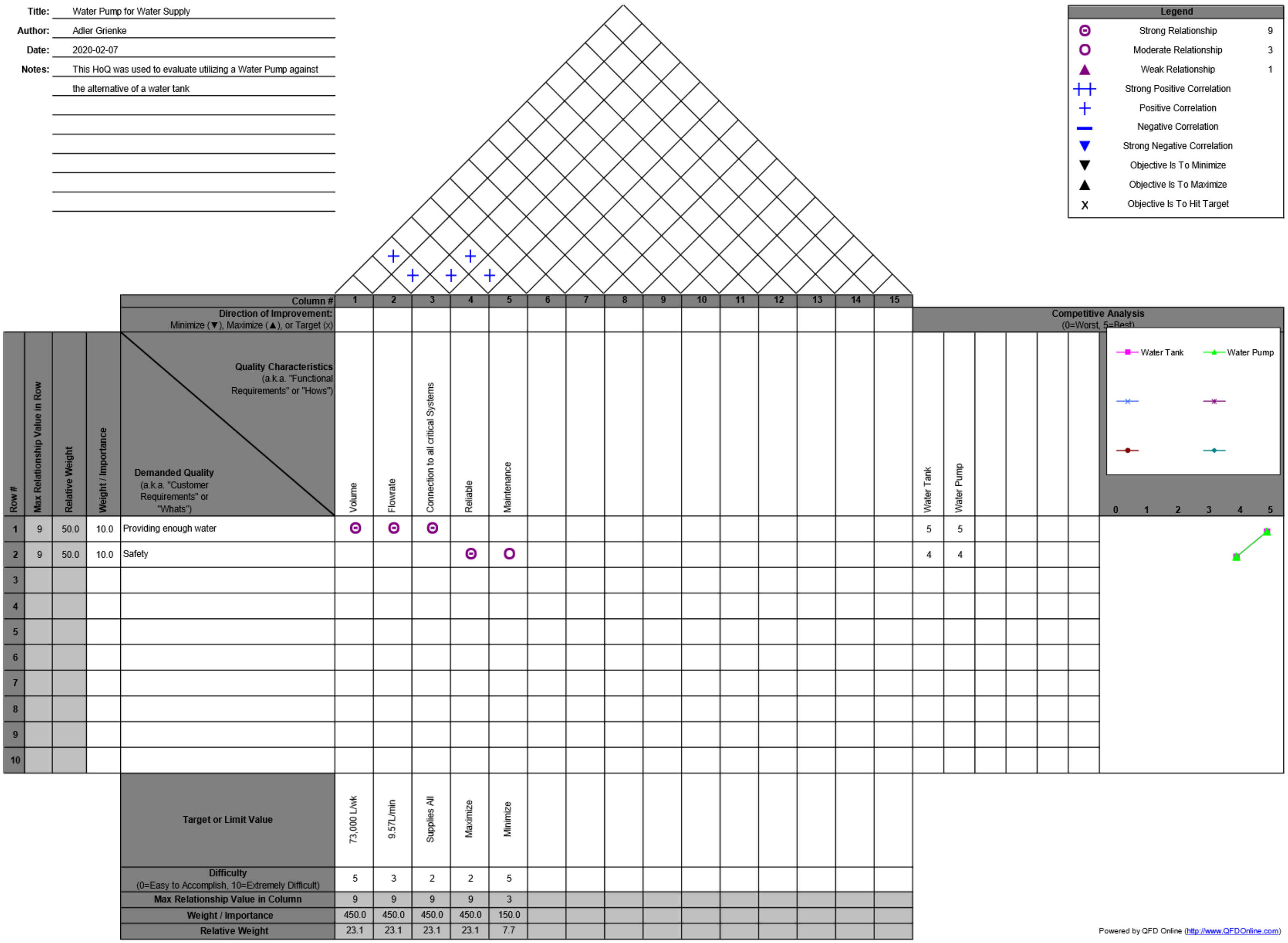


Figure 12: Water Pump House of Quality.

Water Tank vs Water Pump for Water Supply Evaluation Matrix							
Option:	Volume	Flowrate	Compact	Reliable	Environmentally Responsible	Ease of Install	Totals
Weight	5	5	2	5	3	5	
Water Tank	5	5	1	4	3	2	91
Water Pump	5	5	4	3	3	4	102

Figure 13: Evaluation matrix for water supply options.

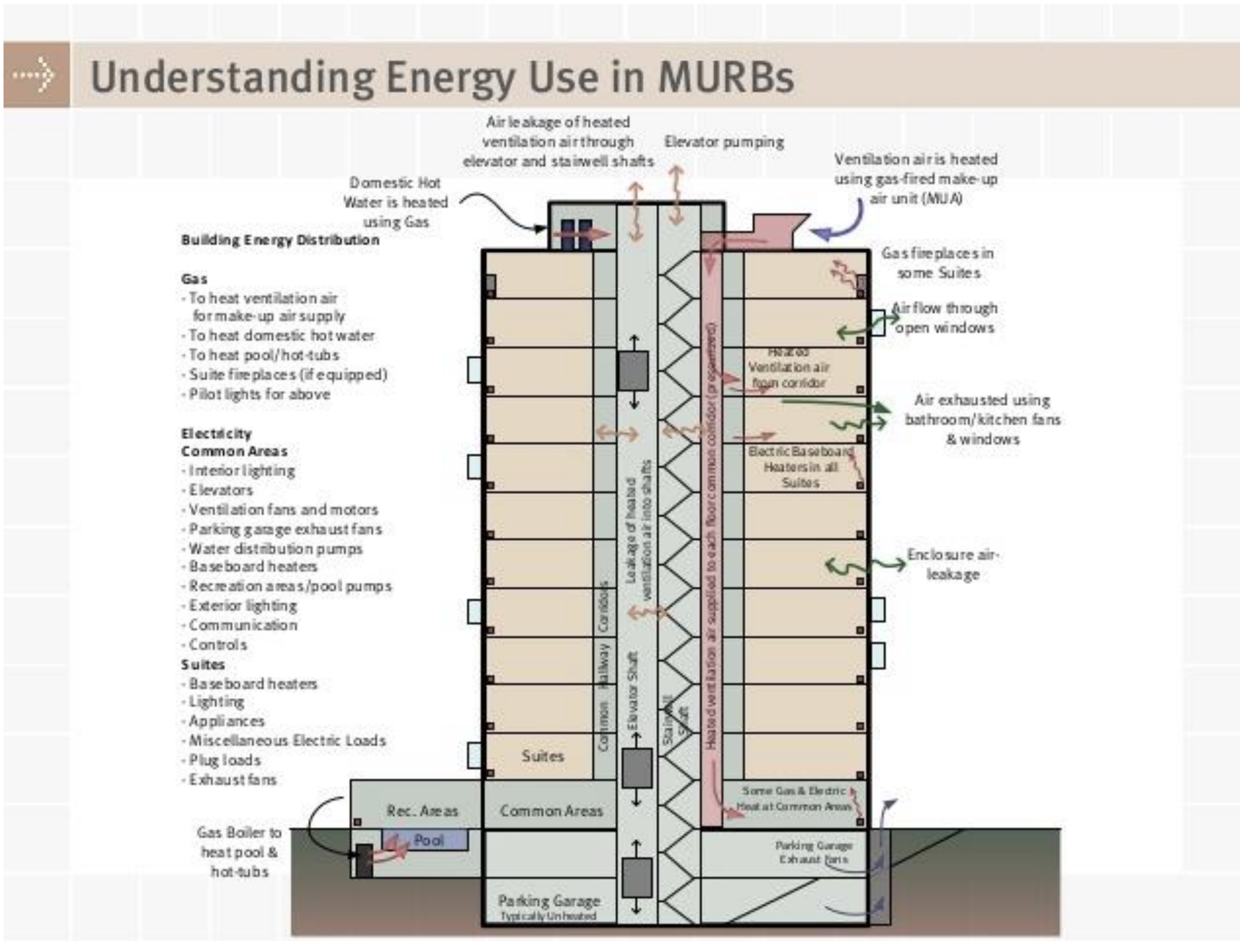


Figure 14: Energy use and heating in medium urban residential buildings.

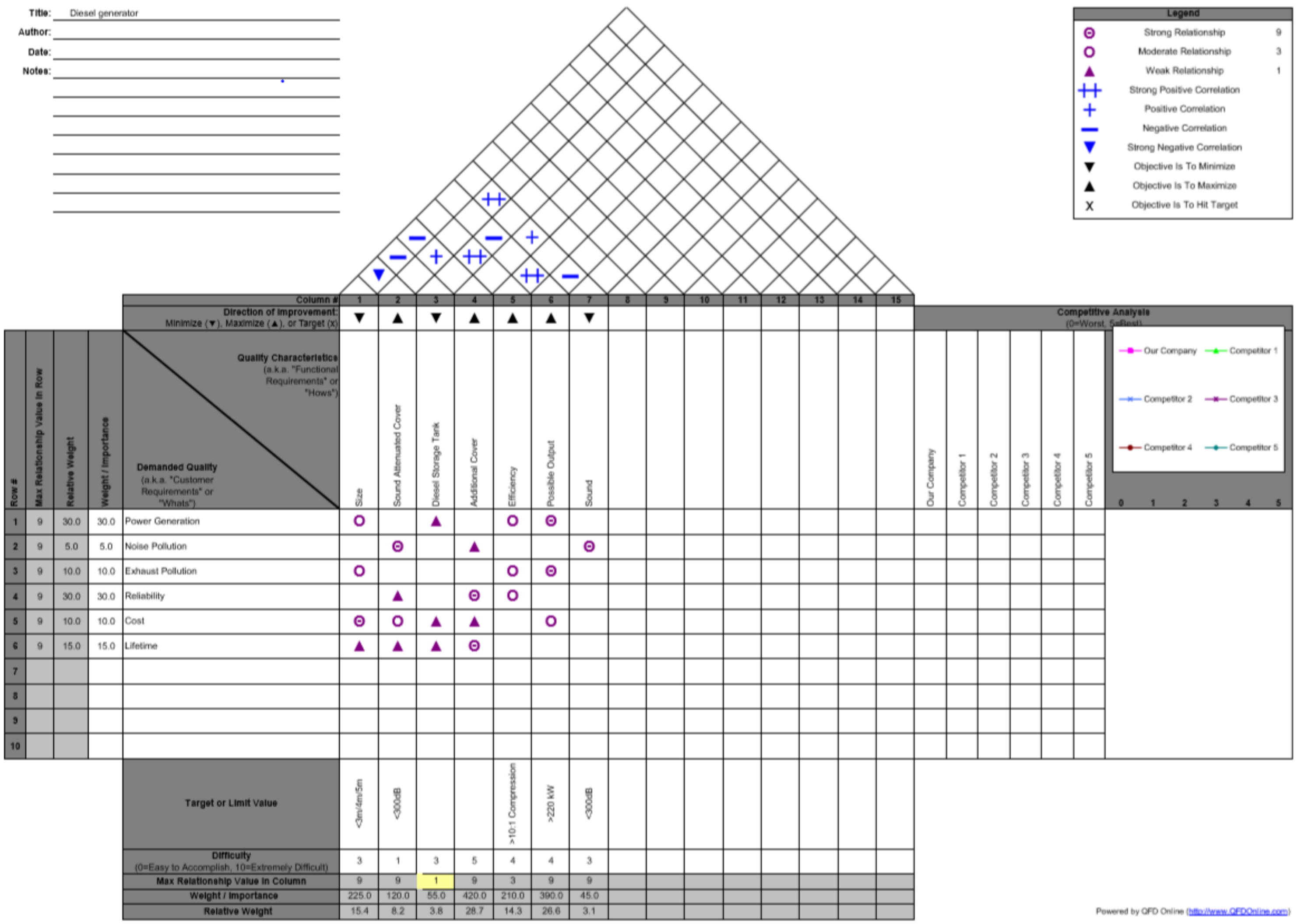


Figure 15: QFD for Diesel Generators

UV Filtration vs Chlorination Evaluation Matrix								
Option:	**On Demand**	**Compact**	**Convenience**	**Safety**	**Taste**	**Maintenance**	**Cost**	**Totals**
Weight:	5	2	4	5	2	4	4	
UV Filtration	5	4	5	5	5	4	3	116
Chlorination	3	3	3	5	2	2	4	97

Figure 16: Evaluation matrix for UV filtration versus tablet chlorination.

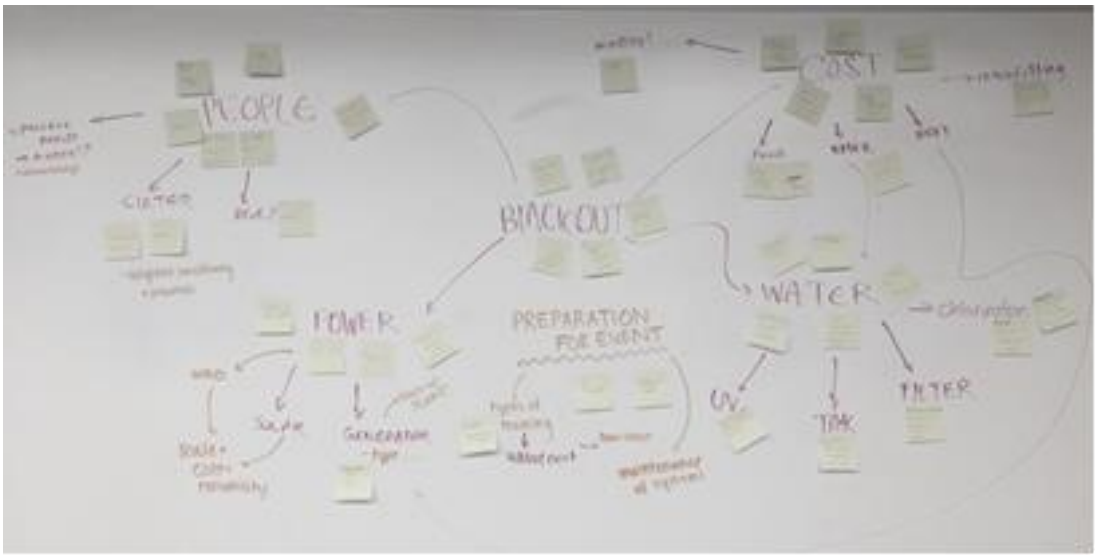


Figure 17: Preliminary idea selection mind map for brain storming.

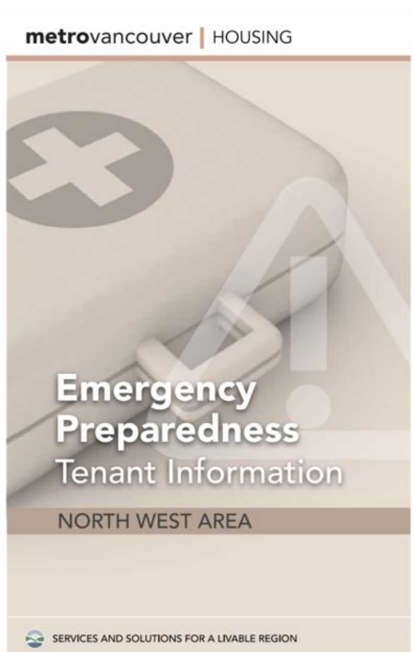


Figure 18: Example of the possible Emergency Preparedness Booklet [54]

Appendix C: Additional Tables

Table 4: Final cost breakdown and for necessary supplies for 200 building occupants over seven days.

Necessary Supplies	**Solution**	**Amount**	**Cost**
Food	nonperishable food items, not requiring power generation for cooking (canned beans, chickpeas, corn)	three canned items per person each day, including vegetable and barley soup, beans, peas, corn	$12 600 ($3 per can of food) [59]
Clothes	obtain clothes from individual apartments, additional clothes provided for cold temperatures	one thermal shirt, pants, socks, sweater, and toque per person, in additional to personal resources	$10 400 ($10 shirt, $15 pants, $20 sweater, $2 socks, $5 toque) [59]
Sleeping Items	use items from individual apartments, additional blankets	two space blankets and a foam mattress provided per person	$14 000 ($30 foam mattress, $20 space blanket) [59]
Personal Hygiene Items	products obtained from own apartment, additional supplies to avoid possible shortage	toothbrush, toothpaste, soap, towel, hairbrush for each individual	$2 600 ($2 each for toothbrush, toothpaste and soap and hairbrush, $5 towel) [59]
Medical Supply	Necessary medical supplies available for occupants in cases of sickness or injury	Advil and Tylenol (300 tablets each), Benadryl (100 servings), Bandages (1000), first aid kit (every second floor), sterilization (four liters of peroxide), AED (every second floor)	$3 250 ($200 Advil, $200 Tylenol, $200 Benadryl, $150 Bandages, $100 Peroxide, $1700 AED, $700 First Aid Kits) [59]

Table 5: Long-term costs of implementing systems, maintenance, emergency plans.

Necessary Systems	**Solution One**	**Solution T** [60]**wo**	**Solution Three**
Systems Maintenance	system is checked on once every six months ***Cost:*** $500 ($250 per visit, for a year) [61]	system is checked on by supplier once every three months ***Cost***: $1000 ($250 per visit, for a year) [61]	system is checked on once a month by supplier ***Cost***: $3000 ($250 per visit, for a year) [61]

Emergency Plans	enforced once by owner or staff towards residents ***Cost***: $120 ($120 per session, for 10 years) [62]	enforced once a year by owner or staff towards residents ***Cost***: $1200 ($120 per session, for 10 years) [62]	enforced once every 6 moths towards residents ***Cost***: $2400 ($120 per session, for 10 years) [62]
Water Filtration	buying a Tank with enough drinking water ***Cost***: $1100 (4200L water tank) [36]	UV and particle filter ***Cost***: $1560 ($780 each, two used for redundancy) [38]	chlorination tablets ***Cost***: $924 ($0.22 each, 4200 needed for 200 people) [39]
Power Generation	Heating for approximately $4m^2$ of area per person, for approximately 220 kWh daily, initial setup cost maximum price: 150,000 to 250,000 USD, cost to run systems for one week estimated from BC Hydro: $150 [60]		

Table 6: Daily water consumption for various gender and age demographics [10].

Age and Gender Demographic	**Average Daily Water Consumption**
• Infants (up to 12 months)	• 0.8 litres
• Girls and Boys (one to three years)	• 1.0 litres
• Girls and Boys (four to eight years)	• 1.2 litres
• Boys (nine to thirteen years)	• 1.6 litres
• Boys (fourteen to eighteen years)	• 1.9 litres
• Girls (nine to thirteen years)	• 1.4 litres
• Girls (fourteen to eighteen years)	• 1.6 litres
• Men (19 years and over)	• 2.6 litres
• Women (19 years and over)	• 2.1 litres
• Pregnant Women (19 years and over)	• 2.3 litres

Table 7: Daily human caloric intake for various age groups and activity levels from the NHLBI [12].

Calories Needed Each Day for Boys and Men

Age	Not Active	Somewhat Active	Very Active
2–3 years	1,000–1,200 calories	1,000–1,400 calories	1,000–1,400 calories
4–8 years	1,200–1,400 calories	1,400–1,600 calories	1,600–2,000 calories
9–13 years	1,600–2,000 calories	1,800–2,200 calories	2,000–2,600 calories
14–18 years	2,000–2,400 calories	2,400–2,800 calories	2,800–3,200 calories
19–30 years	2,400–2,600 calories	2,600–2,800 calories	3,000 calories
31–50 years	2,200–2,400 calories	2,400–2,600 calories	2,800–3,000 calories
51 years and older	2,000–2,200 calories	2,200–2,400 calories	2,400–2,800 calories

Calories Needed Each Day for Girls and Women

Age	Not Active	Somewhat Active	Very Active
2–3 years	1,000 calories	1,000–1,200 calories	1,000–1,400 calories
4–8 years	1,200–1,400 calories	1,400–1,600 calories	1,400–1,800 calories
9–13 years	1,400–1,600 calories	1,600–2,000 calories	1,800–2,200 calories
14–18 years	1,800 calories	2,000 calories	2,400 calories
19–30 years	1,800–2,000 calories	2,000–2,200 calories	2,400 calories
31–50 years	1,800 calories	2,000 calories	2,200 calories
51 years and older	1,600 calories	1,800 calories	2,000–2,200 calories

Table 8: Decision making table defining excellent, competent and marginal aspects of design solution.

Symbol	**House of Quality Design Criteria**
Excellent ⊝	• Supports all stakeholder needs • Supports all design criteria • Inside of scope • Solution is clearly defined
Competent ○	• Supports some stakeholder needs • Supports some of the design criteria • Moderate solution definition • Missing some scope requirements
Marginal ▲	• Minimal consideration of stakeholder needs • Unrelated to design criteria • Not in defined scope • Irrelevant or incorrect solution