An Investigation into Developing a Net-Zero Water Management Strategy for the New Student Union Building

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An Investigation into Developing a Net-Zero Water Management Strategy for the New Student Union Building

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Abstract

To achieve net zero water consumption for our new SUB, the report first identifies the methods for capturing clean water such as rainwater harvesting and dew water collection. These two methods can greatly reduce the portable water usage. Suggestions for reducing water consumption such as different fixtures and reusing grey water are investigated. According to literature review, grey water reuse can save significant clean water usage; thus, making net zero consumption feasible. In order to utilize rainwater and greywater, both water types need to go through different water treatments such as an in-Line Filtering, Activated Carbon Filtering and chemical treatments such as coagulation, ultra membrane filtration (UF) system, and ozonation.

This report also covers a triple bottom line assessment involving water collection and filtration. From the economic aspect, a large initial cost must be invested. From the environmental aspect, reducing potable water consumption and capturing clean water locally implies less power consumption. From the social aspect, the idea of reusing grey water may cause some concerns but can also promote sustainability and raise awareness within a community.

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Glossary

Glossary	Definition
Biochemical Oxygen Demand (BOD)	"is the amount of oxygen required by microbes, mainly bacteria, in the stabilization of organic materials under aerobic conditions" (Reynolds p.106).
Catchment Area	Surface area dedicated to dew and rainwater harvesting
Chemical Oxygen Demand (COD)	is a measure of the organic materials in a wastewater in terms of the oxygen required to oxidize the organic materials chemically. It is measured by boiling and refluxing the sample with a strong oxidizing agent and determining the amount of oxidizing agent used" (Reynolds p.104)
Coliforms	"Species that exist in large numbers in the intestines of humans and other warm-blooded animals, so they are present in large numbers in municipal wastewaters" (Reynolds p. 30).
Distillation	The volatilization or evaporation and subsequent condensation of a liquid, as when water is boiled in a retort and the steam is condensed in a cool receiver
Halogen	Any of the electronegative elements, fluorine, chlorine, iodine, bromine, and astatine, that form binary salts by direct union with metals
Halophenols	Halogen elements (group 7 elements) that are a derivative of a phenol compound (contains at one hydroxyl group –OH and is attached to a benzene ring).
Oxidize	To convert (an element) into an oxide; combine with oxygen
PH	Degree of how acidic or basic a solution is
Radative Cooling Rate	The process in which heat is loss by radiatation
Rainwater Harvesting (RWH)	Method of collecting rainwater
Reverse Osmosis	Water pressure is used to force water molecules through a membrane that has extremely tiny pores, leaving the larger contaminants behind. Purified water is collected from the "clean" side of the membrane, and water containing the concentrated contaminants is flushed down the drain from the "contaminated" side.
Scraping	The act of "wiping" a surface
Total Organic Carbon (TOC)	"A measure of the organic materials in a wastewater in terms of the amount of carbon in the organic materials. It is measured by removing the carbon dioxide present, combusting the sample, and measuring the amount of carbon in the carbon dioxide evolved" (Reynolds p.104).
TP	Total phosphorus content.
Total Suspended Solids (TSS)	Solids that are "separated by filtering a sample and drying and weighing the residue" (Reynolds p. 103).
Turbidity	"Is mainly due to suspended organic solids, which range in size from colloidal to coarse suspensions. Municipal wastewater is about 99.95% water, but the organic solids present have a pronounced effect in that they exert a biochemical oxygen demand" (Reynolds p. 102)
UV	Radiation lying within the Ultraviolet Spectrum
World Health Organization (WHO)	An agency of the UN that specializes in coordinating and monitoring standards of international public health.

List of Abbreviations

Abbreviations	Expansions
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
GAC	Granular Activated Carbon
HDPE Pipe	High-Density Polyethylene Pipe
KSI System	Kodan Skelton Infill System
RWH	RainWater Harvesting
SBAC	Solid Block Activated Carbon
TN	Total nitrogen content.
TOC	Total Organic Content
TP	Total phosphorus content.
TSS	Total Suspended Solids
UV	Ultra Violet
WHO	World Health Organization

1.0 Introduction

In this investigation, a water management plan is proposed for the new SUB with the ultimate goal of promoting sustainability and therefore earning credit towards a LEED Platinum status. The water management strategy proposed is outlined from the collection to the treatment procedure and finally the distribution of the treated water. The objective is to nullify the new SUB's water consumption by managing the availability of fresh water and proposing a storage strategy and treatment techniques. More specifically, rainwater will be collected and treated. The treatment goes as follows: pre-storage treatment or in-line filter, post-treatment filters with activated carbon and finally through a disinfection step with ozonation. This rainwater will be used in all sectors' taps. The treated rainwater after usage will become grey water, going through a sequence of physical and chemical treatments. The proposed sequence goes as follows, screening pretreatment step, a dual-media filter, coagulation, flocculation, ultra membrane filtration (UF) and optional disinfection treatment, photocatalysis. This treated grey water can then be potentially used in toilet flushing, laundry, air conditioning landscape irrigation, fire protection and street washing. An evaluation of the proposed management strategies is made via a triple-bottom line assessment and finally a conclusion is made of whether net-zero water is achieved.

2.0 Dew Collection

Our atmosphere contains an abundant reservoir of water. Dew collection is one method that provides a viable solution for tapping into this free, clean and 'unlimited' source of water. Water sources based around dew collection has proven to be relatively clean and sometimes even satisfies the average requirements set by the W.H.O [1]. However, the quality of dew water is very dependent on the surrounding air quality and the location where the dew is collected.

2.1 Dew collection System and Concepts

This method of collecting moisture trapped in our atmosphere occurs naturally and does not need any external energy input making the process 100% environmentally friendly. The water quality obtained is relatively clean and very low in metal and mineral content. A detailed list of advantages for dew collection can be found in Appendix A. The concept of dew collection is very simple and figure 1 outlines the basic idea and concept of the system. A real-life implementation of this system can also be seen in figure 2

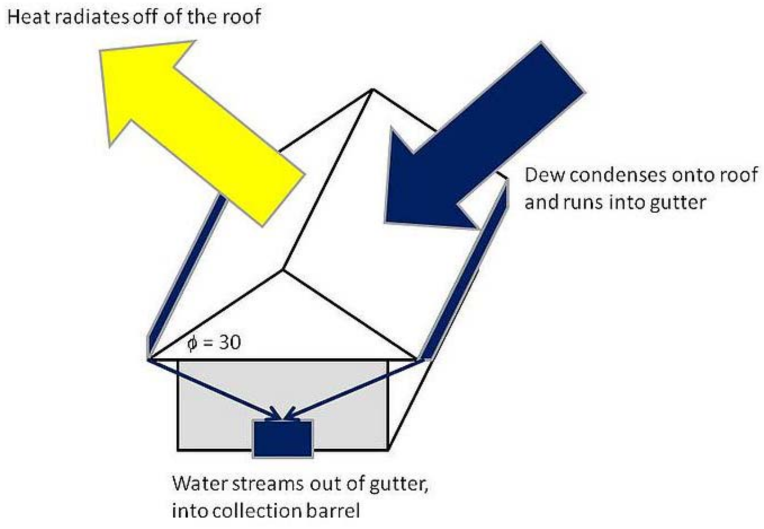


Figure 1: Simple dew collection system

Source: http://www.appropedia.org/Dew_collection_roof_retrofit

Figure 2: Real life implementation of a dew collection system

Source: http://www.appropedia.org/Dew_collection_roof_retrofit

To implement a dew collection system, the system itself would have to take advantage and optimize the factors which influence dew collection. The main physical and environmental factors contributing to dew collection can be seen in appendix B and the dew collection system should be built and modeled based on these factors [2].

2.2 Calculating Dew Yields

The climate in Vancouver falls under the Oceanic climate category. This zone usually exhibits relatively warm winters and cool summer and is comparable to the Mediterranean climate category. Instead of taking into consideration each individual atmospheric factor, the similarities in climate conditions allow us to use dew collection results performed from experiments conducted in the Dalmatian Coast, Croatia to predict our theoretical dew yields for Vancouver.

The dew experiment was carried out in two different sites Zadar and Komi□a, with Zadar having favorable climate conditions and Komi□a having unfavorable climate conditions for dew collection [2]. Both locations used identical dew condenser systems, see Figure 3 [2]. From these results, we can use the data collected from Zadar as our maximum expected yield and data from

Komi□a as our minimum expected yield to predict collection values for the new SUB. A summary of results obtained in Komi□a and Zadar can be seen in table 1. From these results we can calculate the mean expected maximum and minimum yield.

Figure 3: Dew condenser system used in Croatia

Source: M. Muselli, D. Beysens, M. Mileta & I. Milimouk, 2009

Dew collection results				
Year	Zadar		Komi□a	
	Yield (mm)			
	Before scraping	After Scraping	Before Scraping	After Scraping
2004	8.622	19.029	8.144	10.366
2005	10.672	20.688	5.452	8.302
Mean	9.647	19.859	6.798	9.334

Table 1: Summary of dew collection results from Croatia

Source: M. Muselli, D. Beysens, M. Mileta & I. Milimouk, 2009

Assuming we are including scraping in our dew collection system, the yield from our dew collection system in the new SUB can be found by the follow formula:

$$Dew\ collected\ (l)\ = Expected\ yeild\ (mm) \times Condensation\ Area(m^2)$$

If we assume that the entire roof of the new SUB (251,000 $ft^2 \approx$ 23318.663 m^2) is used for dew collection, the maximum expected value would be 463,085 liters/year, the minimum expected value to be 217,656 liters/year and the average to be 340,371 liters/year [3].

These expected values are only for a single sheet of foil spread over an area of 251,000 ft^2. We could further improve the system by having multiple layers of foil evenly spaced from one another. Moreover, considering that we are implementing this system in an oceanic climate condition, our yields for summer would be higher than that of the expected values due it is cooler on average.

3.0 Rainwater Harvesting

Rainwater provides a free and clean source of water and the implementation of rainwater harvesting (RHW) systems integrates well into the dew collection system mentioned in the previous section. The collection and storage of rainwater is encouraged due to the new SUB having a roof space of about 251,000 ft^2 which can be utilized towards RWH [3]. Moreover, Vancouver's weather makes this collection method viable as we experience a high level of annual rainfall.

3.1 Rainwater Harvesting System and Concepts

Due to the uncertainty in the viability of utilizing ground water around the new SUB, the proposed RWH system focuses on the "roof catchment" method (see Figure 4). Since the RWH system will use the same catchment area as the dew collection system, the system for both processes is essentially the same [4].

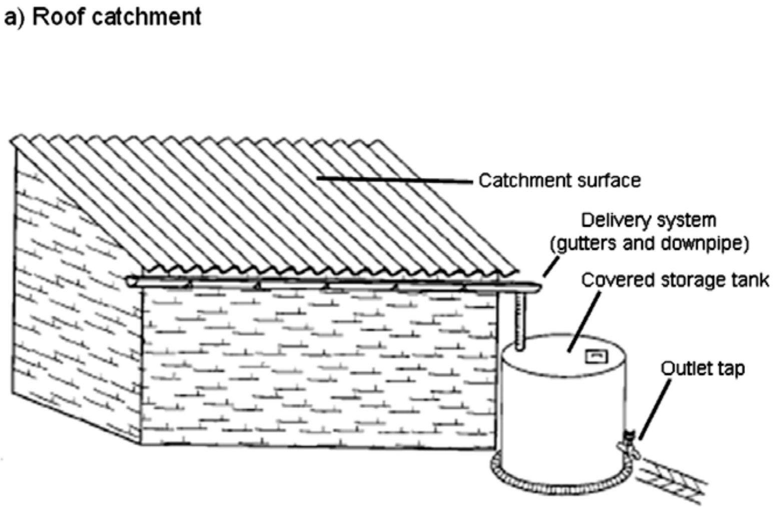


Figure 4: Simple Roof Catchment Design

Source: M. Sturm, M. Zimmermann, K. Schütz, W. Urban, H. Hartung, 2009

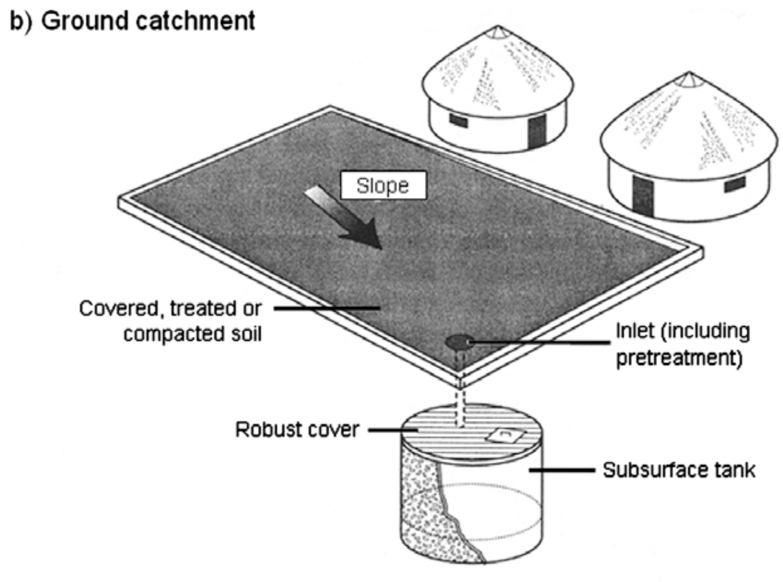
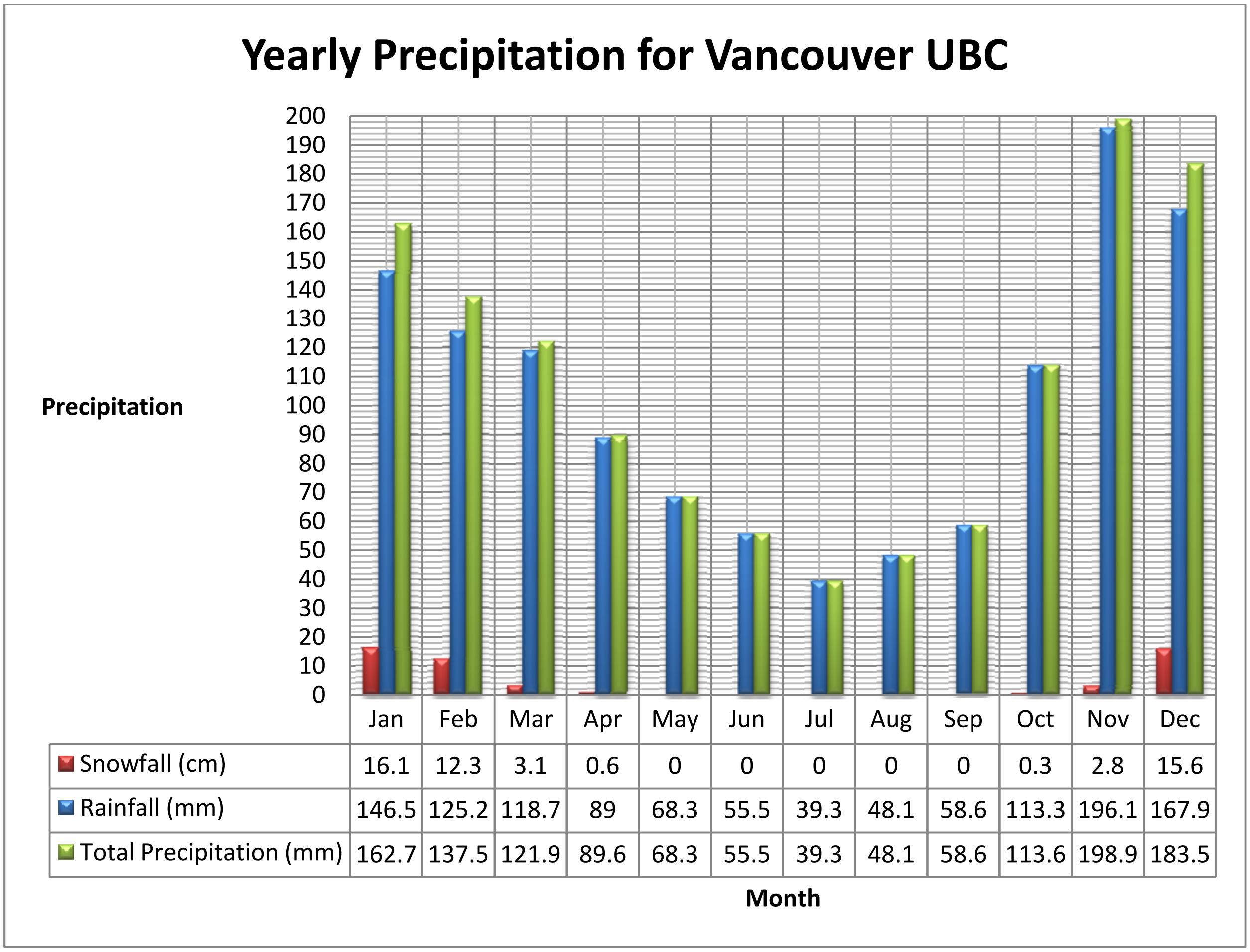


Figure 5: Simple Ground Catchment Design

Source: M. Sturm, M. Zimmermann, K. Schütz, W. Urban, H. Hartung, 2009

3.2 Calculating Rain Yields

Statistical figures of UBC's annual precipitation levels will be used when calculating the expected yield for rainfall collection.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟥 Snowfall (cm)	16.1	12.3	3.1	0.6	0	0	0	0	0	0.3	2.8	15.6
🟦 Rainfall (mm)	146.5	125.2	118.7	89	68.3	55.5	39.3	48.1	58.6	113.3	196.1	167.9
🟩 Total Precipitation (mm)	162.7	137.5	121.9	89.6	68.3	55.5	39.3	48.1	58.6	113.6	198.9	183.5

Figure 6: Yearly Precipitation for Vancouver UBC

Source: http://www.climate.weatheroffice.gc.ca/Welcome_e.html

Using the entire roof, (251,000 $\text{ft}^2 \approx 23{,}318.663\ \text{m}^2$) and the numerical figures from figure 6, the total amount of rain collected per unit area can be calculated by the following equation:

The table below shows the amount of rainwater collected if the entire roof space of the new SUB were to be used.

Collection Period	Months	Total Precipitation (mm)	Total Collected amount ($x10^6$ l)
Fall	Jan – Apr	511.7	11.93
Summer	May – Aug	211.2	4.92
Winter	Sept – Dec	554.6	12.93
Total	**Yearly**	**722.9**	**16.86**

Table 2:Estimated Rainwater Yeild using 100% of the roof space

4.0 Water Management

There are two main water cycles in our water system: clean water cycle and grey water cycle. The first cycle deals with clean water usage such as drinking and shower. This will be maximized by utilizing rainwater and dew water to reduce potable water usage and therefore achieve net zero water.

The second water cycle involves the use of grey water. There are two ways to reducing water consumption: implementing fixtures and systems which consume less water and recycling grey water, lessening the overall building's water consumption. This is especially important for the new SUB since the amount of water used in a restaurant is greater compared to other buildings (See Figure 7).

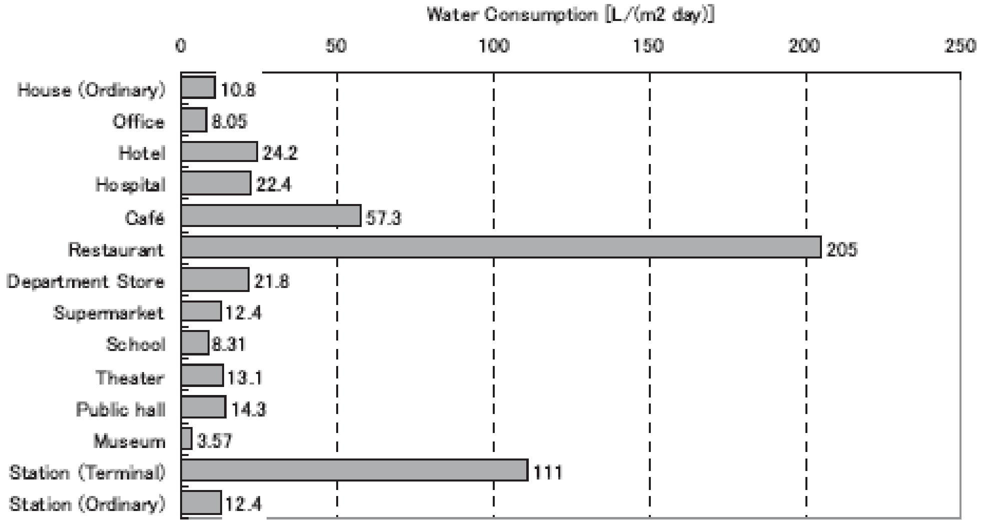


Figure 7: Water consumption in public and residential buildings

Source: Library for Sustainable Urban Regeneration, 2008

4.1 Fixtures

Kitchens and washrooms will have the largest water usage in the new SUB. Therefore, reducing the water usage of fixtures from these two places will have a significant impact on the water consumption.

4.2 Urinals

By carefully designing the shape of the bowl and flushing, Falcon Waterfree Technology has developed waterless urinals [5]. The major issue with waterless urinals is the smell of urine. To seal the smell of urine, waterless urinals use an Eco-trap system (See Figure 8). Urine passes though the drain where it flows through a floating layer of Blue Seal [5]. Blue Seal is a liquid that is less dense than urine forming a barrier that prevents the smell of urine from coming out of the pipes. However, this technology requires replacement of cartridges three to four times a year [5].

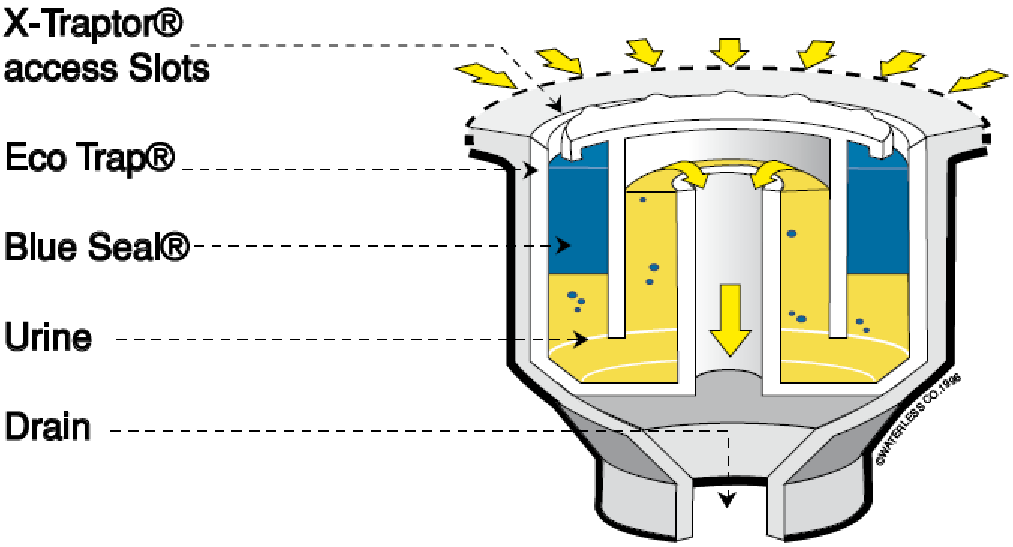


Figure 8: Cross section of Eco Trap system

Source: An Investigation into Net Zero Water Usage and Water Reduction for the Proposed Student Union Building, 2010

4.3 Faucets

In the washroom, the traditional taps tend to waste a significant amount of water. The most common situation is that people are careless when it comes to turning off the taps, leading to water losses. To prevent unnecessary flowing, automatic faucet using sensors is strongly recommended.

In the kitchen, there are two options: automatic faucet and the foot-touch faucet. Washing dishes uses the most water in the kitchen. Besides automatic faucet, foot-touch faucet is also an ideal choice. It is very convenient to stop water by your foot while both of your hands are occupied [6]. Figure 9 shows the saving rate of the traditional taps, automatic faucet and the foot-touch faucet. The foot-touch faucets can save water by approximately 10% [6].

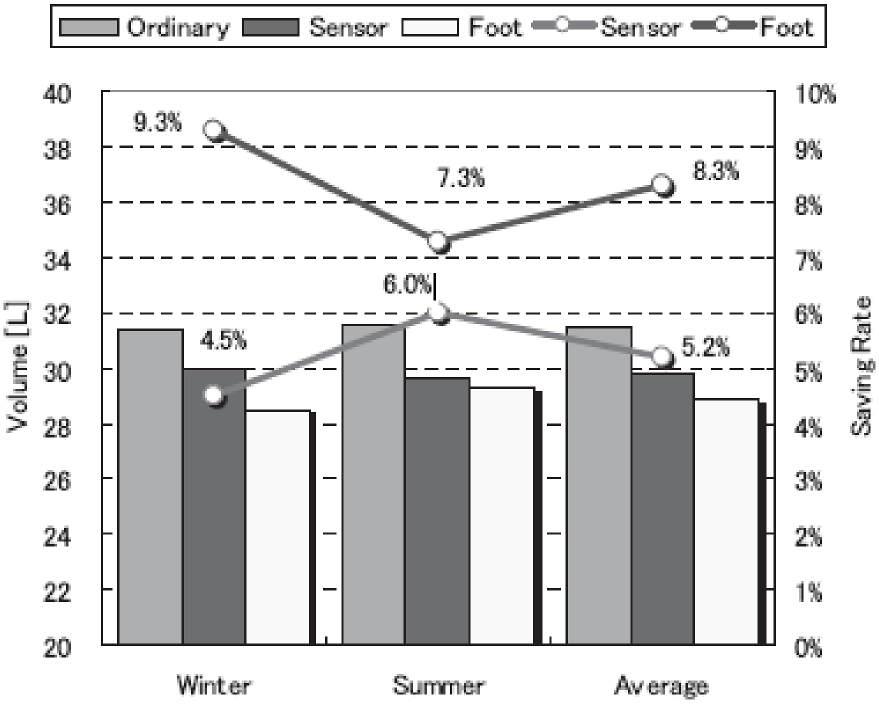


Figure 9: Water saving rate of different kitchen faucets

Source: Library for Sustainable Urban Regeneration, 2008

4.4 Sewage pipes

A sustainable building often is made so that it can last more than 100 years. As a result, pipes must be replaced several times in a building's total lifespan even with the most durable piping. In many buildings, pipes are rarely replaceable, especially sewage pipes, since they are installed in the central part of the buildings [6]. To make replacement easier, Kodan Skelton Infill system

(KSI) can be implemented in the new SUB. In KSI systems, vertical pipes are located outside. Sewage piping is designed using a header and replaceable horizontal pipes to assure the sewage system last longer [6]. Figure 10 and 11 show a sample of KSI system.

Regarding to the water efficiency, high-density polyethylene (HDPE) pipe is a good option comparing to other materials for several reasons. HDPE pipes have very smooth interior surface, providing exceptional hydraulic characteristics [7]. It prevents the biological or chemical constituent being carried from adhering to the pipe surface. Their inner surfaces do not deteriorate like other types of materials; therefore, their flow capacity will remain the same throughout their life cycle. Furthermore, HDPE pipes have virtually no water leaks due to their fused joints. Other types of materials typically have 10 to 20% water leakage rates [7].

Figure 10: Sewage system of KSI

Source: Library for Sustainable Urban Regeneration, 2008

Figure 11: Sewage header of KSI

Source: Library for Sustainable Urban Regeneration, 2008

4.5 Grey water

In a drinking water stream, majority of water that has been used in bathtubs, showers, hand-washing basins, laundry machines, and kitchen sinks forms grey water. The remaining water is used to flush toilets, which creates black water. Grey water and black water are different in their composition. Black water is highly contaminated and can hardly be reused. On the other hand, grey water can be reused with proper treatment depending on the application [8].

Generally, 50 to 80% of wastewater in a household is grey water [9]. In order to reuse grey water, we have to separate grey water and black water. This requires a dual plumbing system for separate collection (See Figure 12) [8].

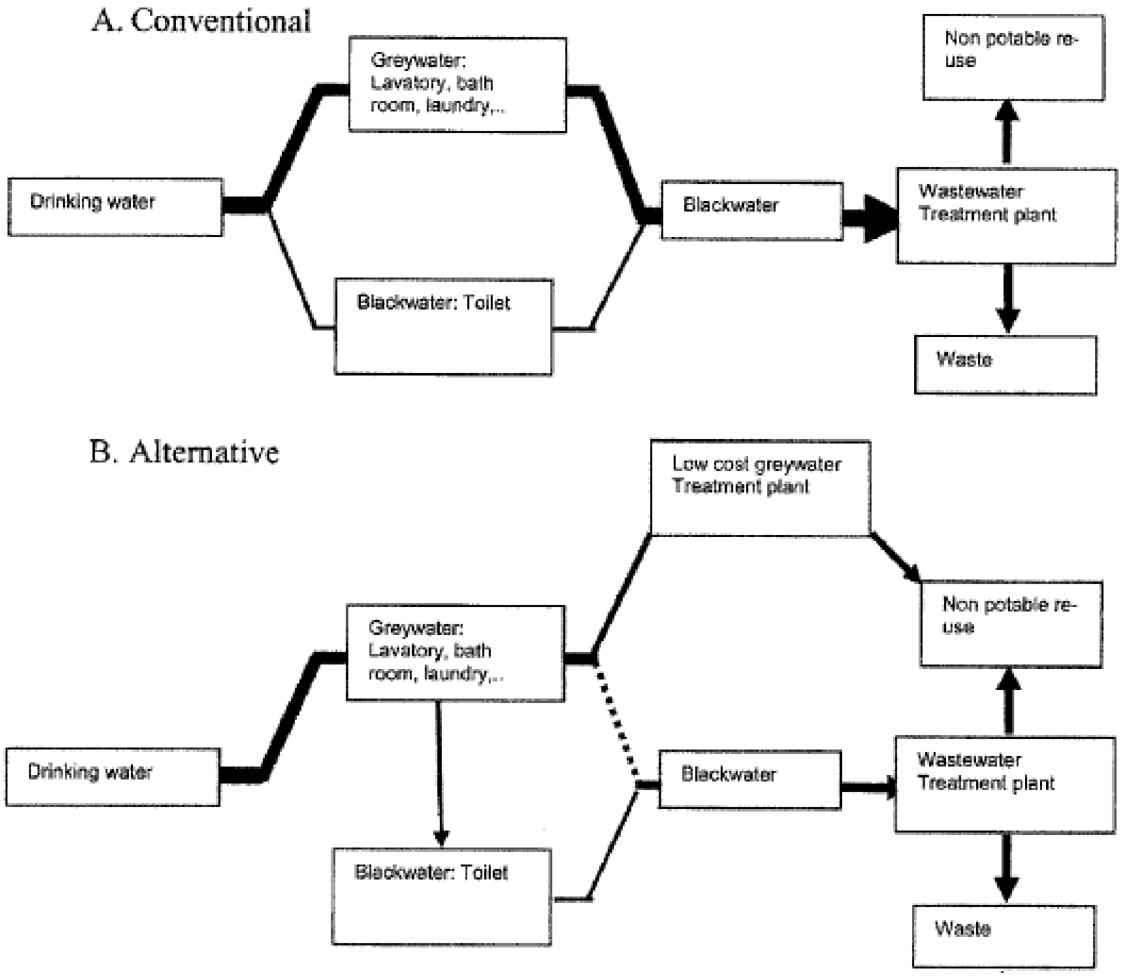
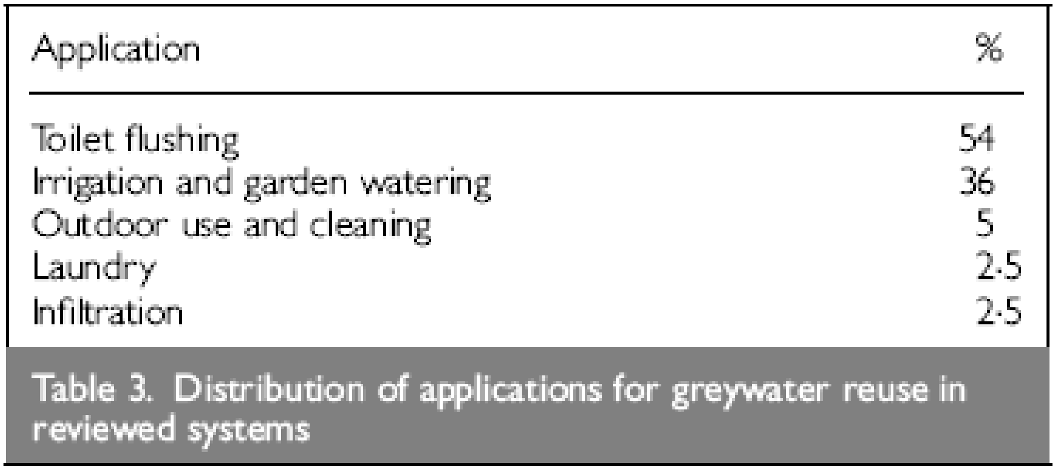


Figure 12: Conventional and alternative schemes for urban water use and treatment

Source: Desalination, 2004

There are several reuse options including toilet flushing, irrigation, fire suppression and cooling. Among them, toilet flushing and irrigation are the two main focuses for grey water distribution due to their water consumption. It is been reported that reusing grey water alone in toilet flushing can save potable water resources up to 60-70%. Also, using grey water for irrigation can result in savings of 12-65% of fresh water usage [9]. Table 3 shows a sample of the distribution of application for grey water reuse.



Application	%
Toilet flushing	54
Irrigation and garden watering	36
Outdoor use and cleaning	5
Laundry	2·5
Infiltration	2·5

Table 3. Distribution of applications for greywater reuse in reviewed systems

Table 3: Distribution of applications for grey water reuse in review systems

Source: https://dspace.lib.cranfield.ac.uk/.../Greywater_recycling-A_review_of_treatment_options-2007.pdf

5.0 Rainwater Treatment

The main objective for the treatment method of cycle one of our water usage management is to treat rainwater. Our goal is to provide potable water for usage in washrooms, sinks and kitchens. Another goal is to be able to treat the collected rainwater quickly and efficiently. There are three main types of contaminants that can be found in water: biological, organic, and inorganic [10]. Figure 13 is a diagram of the complete treatment system aimed to treat these contaminants. Rainwater from the rooftop passes through a screen which then enters the storage tank. After that, water is pumped into the ozone system and filtered. Lastly, the filtered water is treated with UV light. Below is a more detailed explanation of the technologies and why these were chosen.

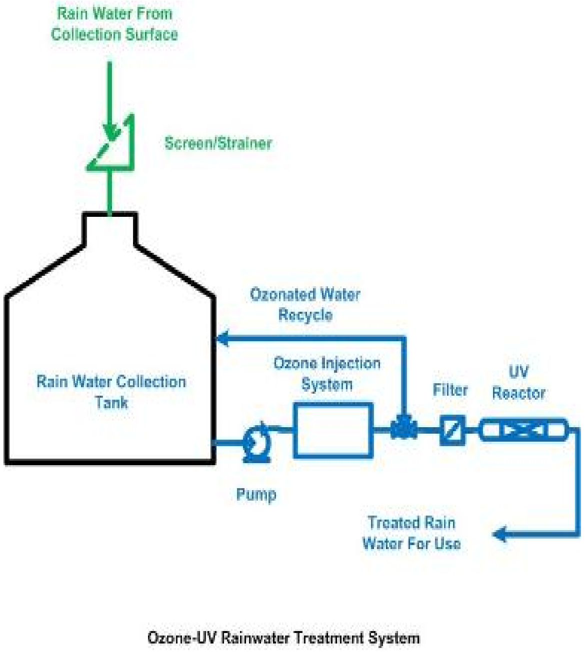


Figure 13: Rainwater Treatment System

Source: http://www.spartanwatertreatment.com/rainwater-harvesting-water-treatment.html

5.1 Pre-Storage Treatment - In-Line Filter

The process of pre-storage treatment of water is very important. The main goal for pre-treatment is to prevent the larger contaminants from entering the storage tank. The in-line filter is a device specifically designed for RWH. This powered independent filter effectively prevents larger contaminants such as dust, leaves, twigs, and rocks from entering the storage system [11]. Figure

14 and 15 shows an in-line filter system (for a 32000 cubic ft roof) which filters out particles larger than 380 micron and needs to be replaced twice a year. It can handle a load up to 60 tons and operate at 90% efficiency [11]. Figure 16 shows how the inline filter can be connected to smaller rainwater collection pipes coming from different parts of a roof.

Figure 14: In-line Filter

Source: http://www.jrsmith.com/green_building/select_rainwater_filter.htm

Figure 15: In-line Filter Connection

Source: http://www.jrsmith.com/green_building/select_rainwater_filter.htm

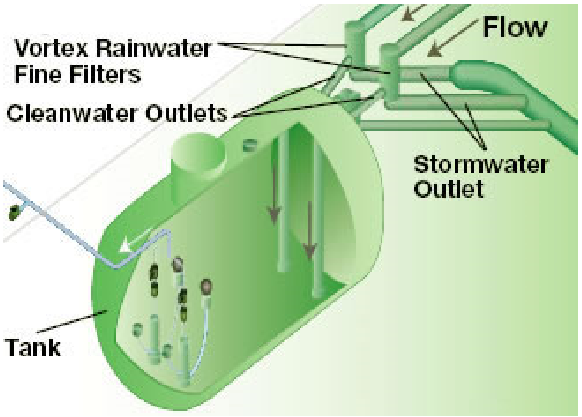


Figure 16: Post Treatment Filters: Activated Carbon Filter

Source: http://www.jrsmith.com/green_building/select_rainwater_filter.htm

5.2 Post Treatment Filters: Activated Carbon Filter

The main advantage of the activated carbon filter (AC) is its ability to absorb organic compounds. This means it is very effective in removing bacteria and also improves the taste and odour of the water [12]. Figure 18 shows how an activated carbon works. Depending on the type of activated carbon, it can be very effective in eliminating organic contaminants of 0.1 micron to 30 micron [12]. The filters need replacements every several months [12]. The two main technologies of carbon filters are: granular activated carbon (GAC) and solid block activated (SBAC) [12]. Even though SBAC is better at contaminant reduction and has a higher water output efficiency rate [13], GAC is recommended. GAC's main disadvantage compared to SBAC is its ability to filter out the smaller contaminants. GAC will filter out contaminants larger than 30 microns compared to SBAC's 1 micron [12]. Ozonation will destroy the contaminants GAC missed. The main reason we recommend GAC is because of its ability to output filtered water at a higher rate than SBAC. This factor is a crucial component in the proposed strategy due to the SUB's high demand for water. Figure 17 shows a GAC system hooked up to a control system.

Figure 17: Filter Connected to a Control System

Source: http://www.aquamasterwater.co.uk/commercial%20reverse%20osmosis%20systems.html

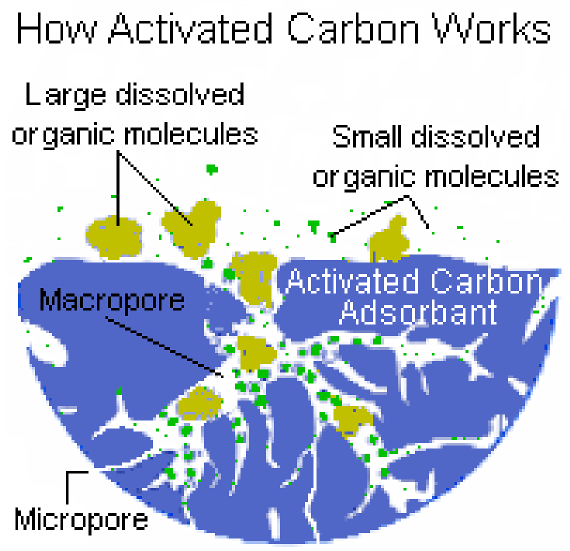


Figure 18: How Activated Carbon Works

Source: http://www.cyber-nook.com/water/Solutions.html

5.3 Post Treatment Disinfection: Ozonation

Ozone is an unstable gas composed of three oxygen atoms (O_3). Due to its reactive nature, the extra oxygen atom will oxidize with other unwanted contaminants such as mold, yeast spores, organic material, and viruses [14]. The advantage of using ozone is that the treatment process does not need to introduce chemicals into the water to eliminate a wide variety of inorganic, organic, and microbiological compounds. Also, ozonation is more effective than chlorination at eliminating doors [14].

Since water demands are high and rainwater is not plentiful, a slow and wasteful water treatment processes such as distillation and osmosis will not keep up with the demand of water for the SUB. Though it provides a much faster treatment method, ozonation is an expensive technology to maintain [15]. Cheaper technologies such as UV light can be used to replace ozonation with the sacrifice of some treatment effectiveness against certain contaminants.

5.4 Post Treatment Disinfection: UV Light

Ultraviolet light is another water treatment method used to destroy bacteria and viruses. Water is pumped through a clear chamber where it is exposed to UV light. The UV rays efficiently remove various organic contaminants, such as humid acid (HA), herbicides, pesticides and halophenols [16]. The more energy dosage given to the UV light, the more effective it will be at removing contaminants. UV treatment require only seconds of contact time with water therefore becoming a good final treatment method before usage [17]. Figure 19 shows the components of a UV system.

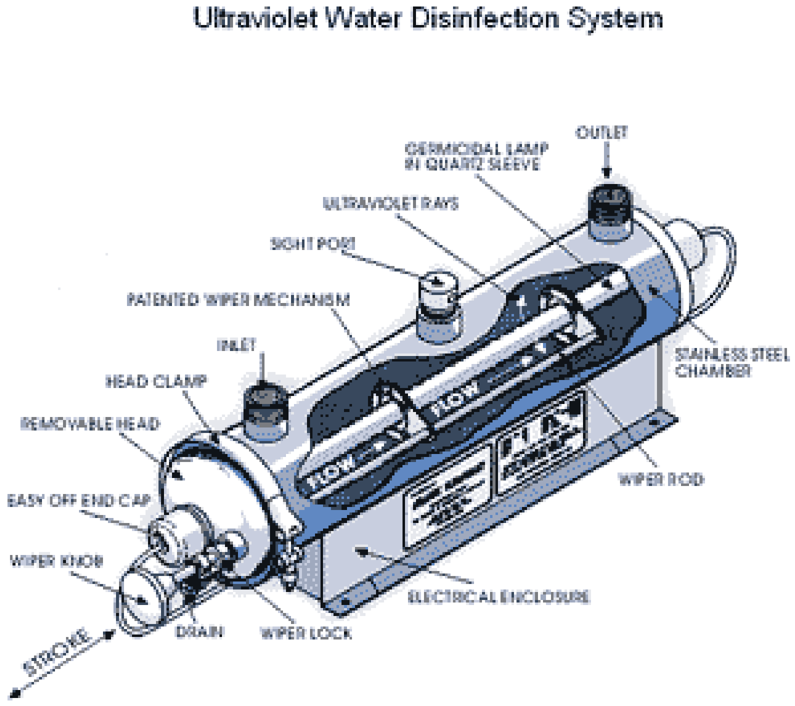
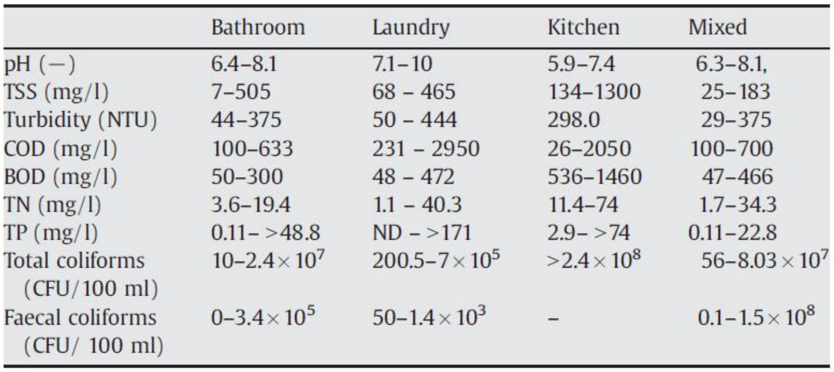


Figure 19: Ultraviolet Water Disinfection System

Source: http://www.rahawater.com/uv.htm

6.0 Grey Water Treatment

Grey water has been receiving more and more attention with the demand in water. Reuse and recycle of grey water has been seen as an attractive alternative for reaching sustainability standards as it constitutes 50 to 80% of the total household wastewater [18]. Also, the typical volume of grey water varies from 90 to 120 L/day. This is an average amount as this value depends on factors such as living standards, customs and habits, water installations and the abundance of water [18]. “Grey water is defined as the urban wastewater that includes water from baths, showers, hand basins, washing machines, dishwashers and kitchen sinks, but excludes streams from toilets [18]. Moreover, grey water is known to consist of low levels of contaminating pathogens and nitrogen. Table 4 below demonstrates the quality of grey water; however, as mentioned earlier, it is important to note that there are many variables in such characterization.



	Bathroom	Laundry	Kitchen	Mixed
pH (−)	6.4–8.1	7.1–10	5.9–7.4	6.3–8.1,
TSS (mg/l)	7–505	68 – 465	134–1300	25–183
Turbidity (NTU)	44–375	50 – 444	298.0	29–375
COD (mg/l)	100–633	231 – 2950	26–2050	100–700
BOD (mg/l)	50–300	48 – 472	536–1460	47–466
TN (mg/l)	3.6–19.4	1.1 – 40.3	11.4–74	1.7–34.3
TP (mg/l)	0.11– >48.8	ND – >171	2.9– >74	0.11–22.8
Total coliforms (CFU/100 ml)	10–2.4×10^7	200.5–7×10^5	>2.4×10^8	56–8.03×10^7
Faecal coliforms (CFU/ 100 ml)	0–3.4×10^5	50–1.4×10^3	–	0.1–1.5×10^8

Table 4: Quality of grey water different categories

Source: Fangyue Li, Knut Wichmann and Ralf Otterpohl, 2009

Another consideration that has to be accounted for the treatment for grey water is the standards for such water source recycling. Although there are not such specific guidelines to be found, the reclaimed municipal wastewater guidelines will be used (Table 5) as a basis for the proposed scheme.

	Unrestricted reuses	Restricted reuses
Treatments Goals	BOD5: ≤10 mg/l Turbidity: ≤2 NTU pH: 6–9 Faecal coliform: ≤10 / ml Total coliforms ≤100/ ml Residual chlorine: ≤1 mg/l	BOD5: ≤30 mg/l TSS: ≤30 mg/l pH: 6–9 Faecal coliforms ≤10/ml Total coliforms ≤100/ml Residual chlorine: ≤1 mg/l
Applications	Toilet flushing; laundry; air conditioning, process water; landscape irrigation; fire protection; construction; surface irrigation of food crops and vegetables (consumed uncooked) and street washing	Landscape irrigation, where public access is infrequent and controlled; subsurface irrigation of non-food crops and food crops and vegetables (consumed after processing)

Table 5: Reclaimed municipal wastewater guidelines

Source: Fangyue Li, Knut Wichmann and Ralf Otterpohl, 2009

The table above divides the non-potable reuses of grey water into restricted and unrestricted reuses. Obviously, the water quality for the unrestricted non-potable is of better quality than the restricted one.

The flow diagram below outlines the steps in treating grey water.

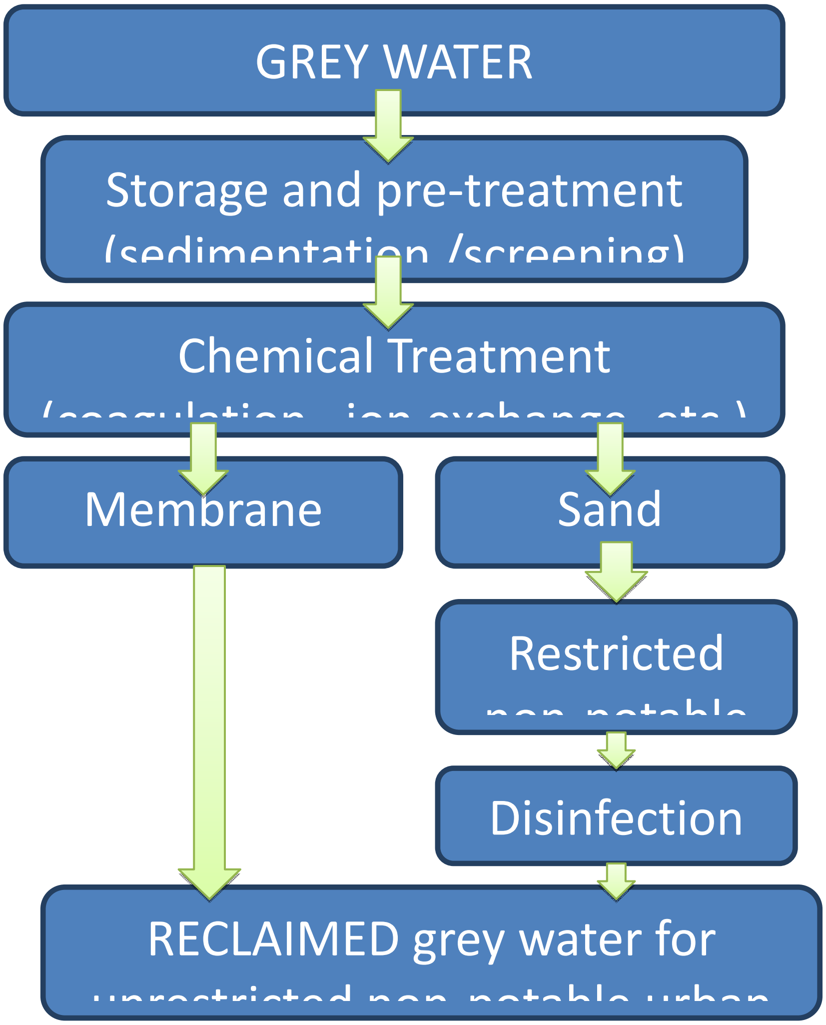


Figure 20: Flow Diagram of Grey Water Treatment

Firstly, the grey water should undergo a pretreatment such as a septic tank, filter bags or screen, removing larger particles, oil and grease which can damage other finer physical treatments. The treatment begins with a dual-media filter. As the name denotes, the solid-liquid separation occurs with the liquid, in this case, grey water, passing through a porous material, crushed anthracite and sand, to remove fine suspended solids. A dual-media is chosen over a single-media since the available pore volume will be greater. In other words, it has a greater gradient in pore volume (the top layer having a pore volume greater than the bottom with a gradual decrease in between). Also, dual-media filter has a higher filtration rate than just a sand media filter. The commonly used dual-media filter comprises of 457 to 610mm layer of crushed anthracite and 152 to 305mm layer of sand [19].

Secondly, the proposed treatment involves the soil-filtered grey water to undergo a chemical treatment: coagulation. The chemistry behind this process is very complex. In simple terms, coagulation is the "addition and rapid mixing of a coagulant, the resulting destabilization of the colloidal and fine suspended solids, and the initial aggregation of the destabilized particles" [19]. In other words, a coagulant, or iron salt, is added to the wastewater, destabilizing the colloids and forming flocs of coagulants. In the water, the coagulant salt dissociates, the metallic ion hydrolyzes, yielding positively charged hydroxo-metallic ions. As these possess high positive charges, they have the tendency of adsorbing to the surface of the colloid, which are negatively charged. There is an interparticle attraction between the destabilized particles and the hydroxo-metallic complexes due to Van der Waals forces. The constant agitation of the system aids in the aggregation of the destabilized particles. The flocs are then left to settle, facilitating their removal. It is important to note that the variables here are: settling velocity of the flocs, the type of coagulant used, and type of mechanical agitator [19].

The next step would be to have the water undergo an ultra membrane filtration (UF) system. This consists of a series of tubes with fine pores on their walls. The water is left to pass through the clustered tubes, specifically through the pores. Membrane filtration is seen as an attractive technique due to its quick and selective removal of suspended solids as well as pathogenic agents. Li et al. (2008), has conducted a study in which TOC from the influent dropped from 161mg/L to 28.6/L, that is an 83.4% elimination rate. Also, the total nitrogen and total phosphorus has decreased to 16.7mg/L and 6.7mg/L, respectively [18]. In addition, the permeate was low in turbidity and free of suspended solids and E.coli, not to mention the physical appearance.

To guarantee that the grey water can be reclaimed and reused for unrestricted uses, a process of disinfection should be incorporated. Photocatalysis is seen as a promising method. It uses a semiconductor photocatalyst and UV radiation for the degradation of organic pollutants. It has been reported that various organic contaminants, such as humic acid (HA), herbicides, pesticides and halophenols can be efficiently removed using this technique [20].

7.0 Total Yield

The process of collection, filtering and treatment is not 100% efficient. The total net water yield from dew, rain and grey water reuse can be calculated based on the efficiency table below [5].

Losses and Efficiency (%)			
Process	Rain	Dew	Grey Water
Average Collection	100.00	80.00	65.00
Loss from evaporation	20.00		Evaporation are accounted for in collection
Treatment Process	25.00	25.00	48.75
Prelimary Filtration	10.00	10.00	43.875
Efficiency	54.00	67.50	43.875

Table 6: Total Yield's Losses and Efficiency
Source: CIRS team, 2008

As 50-80% (average of 65%) of waste water in a building falls under the category of grey water, the total amount of grey water collected can be calculated base on our initial water yield from rain and dew collection [9, 18]. Table 7 shows the calculation based on the efficiency levels of table 6 and our results from section 2 and 3.

Roof Area used (%)	**Yield after filtration and treatment process (10^6 L)**			
	Dew	Rain	Grey	Total
100	0.230	9.104	4.095	13.430
75	0.172	6.828	3.072	10.072
50	0.115	4.552	2.048	6.715
30	0.069	2.731	1.229	4.029
25	0.057	2.276	1.024	3.357
20	0.046	1.821	0.819	2.686
10	0.023	0.910	0.410	1.343
5	0.011	0.455	0.205	0.671

Table 7: Net Yield and roof space correlation

Comparing the calculated net yield to the new SUB's yearly water demand, net-zero water consumption has successfully been achieved, but the calculation assumes that the entire 251,000 ft^2 of roof space is used for water collection [3]. However in reality, only a portion of roof space will be dedicated to water collection which will linearly decreases our calculated yearly yield. On the other hand, it is highly unlikely that the SUB will constantly operate at full capacity as shown in appendix C and the average expected operation level of the SUB is approximately 25% to 37.5% (500 – 750 occupants out of a maximum of 2000 occupants) and table 8 shows a change in yearly water demand based on the average operation level of the SUB [3].

Average Operation Level (%)	Yearly Water Demand ($\times 10^6$ l)
100.00	9.60
75.00	7.20
50.00	4.80
37.50	3.60
31.25	3.00
25.00	2.40
10.00	0.96
5.00	0.48

Table 8: Yearly water demand and average operation level correlation

Comparing tables 7 and 8, if we were to assume that the SUB would be operating at an average rate of 31.25%, to achieve net-zero water the minimum roof size needed as a dew and rainwater collection system would be approximately 25%.

However, 25% of the roof space dedicated to rainwater and dew collection may still be a lot in the real scenario. One solution to maintain the required yield while limiting the collection area is to build protruding/external roofs. This will not only provide shelter for students but also increase out catchment/condensation area. Figure 21 shows an example of this solution.

Figure 21: Protruding Roof

Source: http://www.builderbill-diy-help.com/butterfly-roof.html

8.0 Triple Bottom

8.1 Social Aspects

Since the new SUB aims to achieve net-zero water its water consumption will impose responsibilities not only on the students, but also kitchen staff, cleaners and other workers. This requires education for workers and staff members and the need for awareness to be created among students

Among the fixtures suggested, the one with greatest concern is water-free urinals and its odors. Although the technology can stop the smell of urine from coming out of the pipes, there will still be the some coming from the surface of the urinals. To solve this, windows should be kept open in the washroom to keep the air flow. Furthermore, the surface of the urinals needs to be cleaned regularly to eliminate the smell.

The implementation of this water management strategy can be seen negatively from the new SUB users' perspective. The water collection and treatment systems will have to either sacrifice the roof space or underground/basement space of the new SUB, which could potentially be used for other purposes. Sacrificing such spaces could also impact the building's design and infrastructure, which can also be aesthetically not appealing for the users (student body).

Regarding the usage of rainwater and grey water, there is another social concern: the skepticism of such practice. In other words, awareness would have to be raised within the community about the different treatment methods, showing their reliability in meeting acceptable quality standards. Using grey water for irrigation and garden watering for instance can be seen as unreliable. Some are afraid that the contaminants will accumulate in the plants. This requires the new SUB to have strict standard of its water treatment and to present the results to the public.

8.2 Economic Aspects

The main economical factor of dew and rainwater harvesting system mainly composes of the implementation of the storage tank(s) and catchment area. Appendix D gives two suggested water storage techniques as well as their advantages and disadvantages. Maintenance cost would include annual cleaning of the tank, replacement of the condensation sheets and regular inspections of the catchment area, gutters and pipes. An estimate maintenance price cannot be calculated due the price being heavily dependent on the size of the system and the type of materials used to construct the system. For example, the condensation surface material can vary from glass to corrugated steel which will only need to be cleaned and not replaced, to plain aluminum and specialized OPUR foil which needs to be replaced once a year. Appendix E gives the prices of some possible building/maintenance material.

To obtain a net zero building, we need to have a huge initial cost to implement more expensive equipment in order to do so. However, most of the equipment can last longer than the one being replaced and can save significant water usage and power consumption in the long term. The equipment proposed also reduces the amount of money needed for maintenance.

The cost of rainwater treatment varies with the types of technology used. The table in appendix H shows the cost for a specific technology. Although ozone is shown to be very expensive, it is a very effective treatment method. Ozone is an attractive option for larger systems such as the SUB. Ozonation can be replaced by a SBAC filter instead of a GAC filter or by an increase of water contact time with UV radiation. This method will reduce the overall cost, but will slow the treatment process.

As water in BC is not charged based on consumption rates, water collection methods and treatment would increase the cost of water usage in operating the technologies being proposed as well as the maintenance required by such technologies. In other words, it is all dependent on the consumption rate of water in the new SUB.

8.3 Environmental Aspects

Using fixtures with new technologies and reusing grey water aid in reducing the usage of potable water and contamination in effluents. Reducing potable water usage also implies reduction in power consumption. Even though implementation will cost more, being environmentally friendly promotes sustainable practices for others to follow.

The rainwater treatment system has barely any negative environmental impact. The in-line filter does not require power to operate. There are no chemicals introduced to the water in the treatment cycle. The ozone system does require a significant amount of electricity to operate, but it not comparable to the energy the SUB uses overall.

The proposed treatment method for grey water is environmentally sound as it does not use any hazardous chemicals which could pose any health risk to the community or its effluents. The management strategy proposed focuses on minimizing the water requirement from the utility provider. By making use of the water that would be discarded, grey water will substitute in some sectors of the SUB the use of clean municipal water that could be used for drinking water. In other words, conserving natural resources in the long run will benefit the environment and compensate for the disturbance caused by the construction of the new SUB.

9.0 Conclusion

In conclusion, net zero water can be achieved by using at least 30% of the total roof area (≈7000 m^2) and assuming the SUB will operate on average around 30% of maximum its capacity. The two rainwater collection methods are dew collection and roof catchment. In order to maximize the rainwater usage, the water will be used for two cycles. The first usage cycle involves using the treated rainwater for cleaner purposes such as sinks and the second usage cycle will reuse the drainage water from the sinks (greywater) for toilets. Our treatment method for rainwater involves using an in-line filter, ozonation, carbon filtration, and UV disinfection. Our treatment method for grey water involves a septic tank, dual-media filter, coagulation, ultra-membrane filtration, and UV disinfection.

The rainwater treatment system is a major investment. Because water is free in British Columbia, it does not make sense in an economic point of view to build such a system. However, because the main goal of the new SUB is to achieve LEED Platinum, a net zero water system will help achieve this goal. Also, the net-zero system will help in a social standpoint in that it will promote for a greener planet. Furthermore, the rainwater system has very little negative environmental impact. Based on the SUB's goals for LEED Platinum, positive social effect, and small environmental impact it is recommended to implement the net-zero rainwater system.

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Appendix

Appendix A: Advantages and Disadvantages of Dew collection

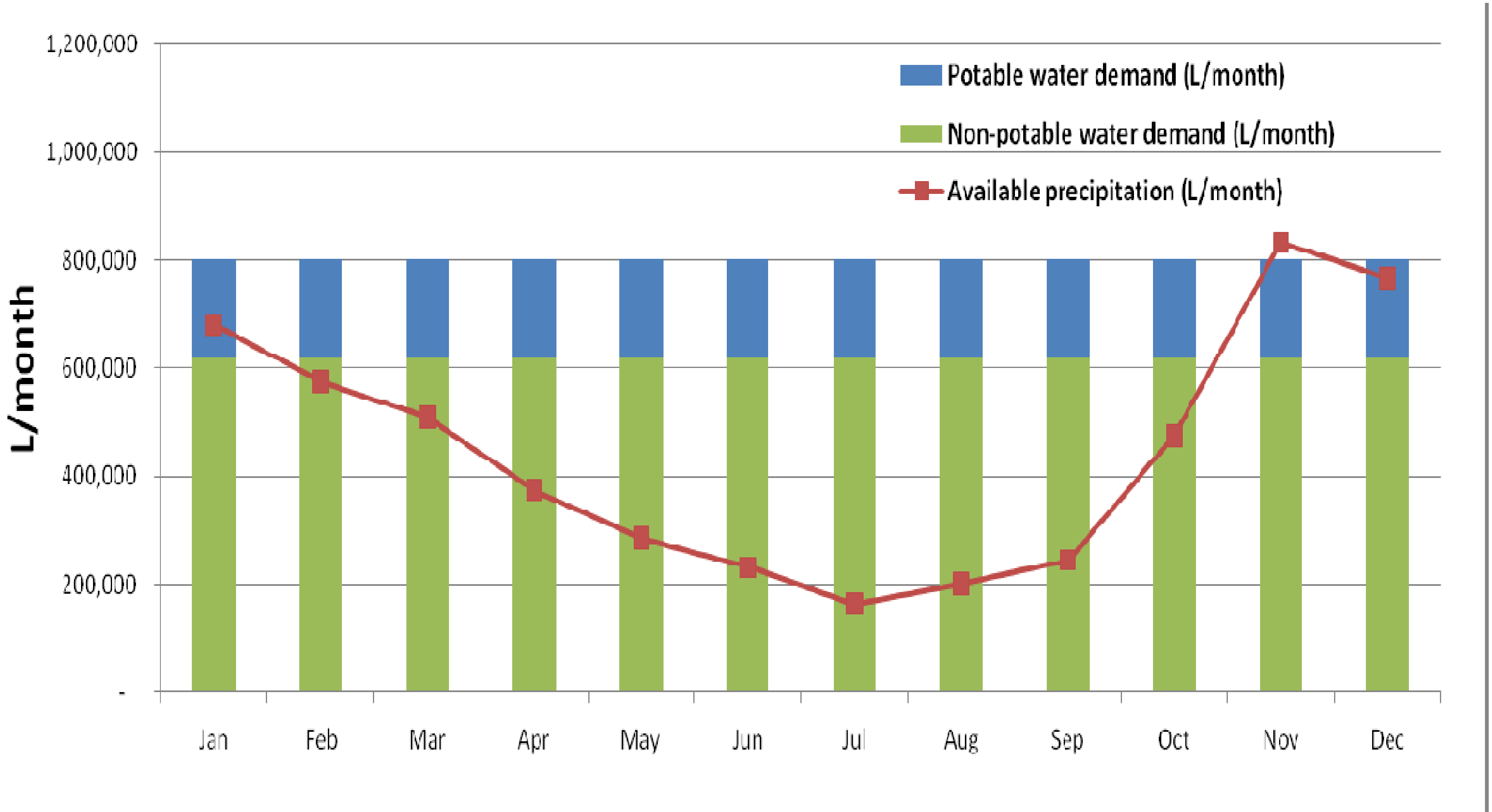
Advantages	Disadvantages
Formation of dew occurs naturally and does not need any external energy inputs	N/A
The process of dew formation is environmentally friend	N/A
Water quality obtained from dew is usually expected to contain low amount metal and mineral content	The water quality of dew has a strong relation to the air quality. The dew composition is determined the by the dissolution of surrounding gas and particles which settle on top of the condensing surface. As a result, dew collection in urbanized or heavily industrialized location will lead to a poor water quality. In extreme cases dew water itself can be corrosive.
Dew formation is dependent on multiple atmospheric conditions. This makes its availability higher and more dependent (e.g. compared to rain)	Although dew collection will still occur, the amount of dew collected will deteriorate in unfavorable climate conditions
The location of dew collection is flexible and can occur in a variety of locations	N/A
The cost of setting up a simple dew collection system is relatively cheap	Materials used as a condensation surface may not be environmentally friendly (e.g. plastic)
Collection systems can easily be integrated into pre-existing houses or buildings	Used up roof space
Low maintenance cost	May require yearly maintenance check for larger and more efficient dew collection systems.

Appendix B: Factors Affecting the Condensation and Yield of Dew

System factors	Dependency	Maximization	Suggestions
Radative Cooling Rate	The radiative cooling rate is the rate at which heat is dissipated from the surface. When the surface drops below the dew point of water, moisture in the air will start to condensate onto the surface	To maximize the condensation rate of dew, materials with high radian cooling properties will be used as the surface for dew collection	Suggested materials are materials that are smooth and impervious. For example, tiles, a sheet of corrugated steel, Cement, plastic and glass. The material used at Dalmatian Coast experiment was a condensing foil made up of TiO_2 and $BaSO_4$ microspheres embedded in low-density polyethylene.
Humidity	Humidity plays an important role in dew collection. Relative humidity represents the amount of moisture in the surrounding air. The higher the relative humidity, the higher the rate of dew formation.	The dew system will have to be set up in a way to keep humidity levels around the collection surface as high as possible	As UBC is located on the coast of Vancouver, the most common and strongest winds are expected to come from the direction of the sea (blowing from west to east). The dew systems collection surface should be slanted facing the east to avoid as much direct wind contact. This setup will allow high dew yields with incoming winds from that direction.

System factors	Dependency	Maximization	Suggestions
Scraping	Scraping with the respect to dew collection is a process of removing water droplets from the surface (much like the windscreen wiper of a car). For the automatic collection of dew to occur, the water droplets formed on an angled surface will have to be big enough so that the gravitational pull on the droplet can overcome the cohesion forces between the water and the condensation surface.	Scraping allows smaller water droplets to be harvested from the condensation surface before the droplets evaporate. Scraping also re-exposes the condensation surface to the atmosphere which allows quicker dew formation. Experimental data has shown that scraping increases the amount of dew yield by about 25-50%.	Scraping should be incorporated into the dew collection system. The evaporation rate of water increases with atmospheric temperature (e.g. when the sun rises). In order to maximize the dew yield, an automated scraping system could be set to scrape the condensation surface in the early hours of the morning (much like the windscreen wiper on a car). If scraping occurs too frequently, the movement of scraping disturbs humidity levels between the condensation surface and the atmosphere resulting in the opposite effect, a decrease in dew condensation rate.
Condensation Surface Area	Heat dissipation and condensation are both related to the surface area. The larger the surface area, the more heat can be dissipated. The surface area of the cooled material also provides a larger condensation site for dew.	To maximize the dew yield, we will have to maximize the surface area of the dew collection system.	Ideally the dew collection system would span across the whole roof of the new SUB. However, the drawback is that the roof would be unusable for anything else. Another suggestion is to have multiple thin layers of collection foil equally spaced from one another. This would allow dew condensation to occur on each sheet.
Surrounding temperature	For condensation to occur, the temperature of the surface will have to be below the dew point of water.	The condensation surface will have to be thermally insulated from any heat sources present in its surrounds. However, the surface area has to still have the ability to dissipate heat into its surroundings	As the dew collection system will be taking place on the roof of the new SUB, the major heat source would be the SUB itself. The foil of the condenser will have to be thermally insulated from the SUB. One way to do this is to place insulation layer between the foil and the frame of the condenser.

Appendix C: Estimated Water Demand VS Months for the New SUB



Graph showing the water demand rate of the new SUB operating at 100% and the estimated available precipitation given a 5,200m^2 catchment area on the roof.

Appendix D: Advantages and Disadvantages of Suggested Water Storage Techniques

Water Storage			
Underground Tank		Above Ground Tank	
Advantages	Disadvantages	Advantages	Disadvantages
Saves physical space	Hard to clean and Maintain as they tank is located underground. Drainage of the water for cleaning will also be a hassle	Easier to maintain and clean	Takes up Physical Space
Keeps water cool and at a relative constant temperature	Requires a pump to distribute stored water	Easy to detect cracks and leaks	Subjected to weather conditions
Keeps algal and other organisms from growing due to there being no light	Risk of contamination from groundwater	Possibility of using gravity to help the distribution of water	Requires strong Anchoring to support the Tank
Possibility of the collection collection process uses gravity to direct water to the tank	Significantly more costly than a tank located above ground	Cost of implementing is significantly less than that of a tank underground	
Tank is protected from Weather conditions	Risk of taking damage from growing tree roots		
Can be easily integrated with the ground catchment technique for rainwater collection			

Appendix E: Approximate Price of Possible Building Materials

Parts	Specifications	Price (CAD)	Use
Gutters	Approx 3.25"x2.5"x120" - 9.6"x9.6"x120.4" (Material Plastic, Aluminum, Vinyl)	11.00 -15.00	Water Management
Leaf Guards	Approx 5.25"x72"x0.5" (Material Vinyl/ Aluminum	8.00 – 10.00	Filtration
Pipes/Spouts	Approx 34.75"x3"x3" to 120"x3.25"x3.25" (Material Vinyl, Aluminum, Plastic)	11.00 – 14.00	Water Management
Glass Sheet	Approx 3"x6" to 4"x4"	1.00 – 3.00	Collection Area
High Performance Aluminum Foil	Approx 47.25"x2165.36"	550.00 – 650.00	Collection Area
OPUR Condensation Foil	Specialized condensing foil made up of TiO_2 and $BaSO_4$ microspheres embedded in low-density polyethylene.	Unknown Price	Collection Area

Appendix F: Summary of domestic fresh water use in an experiment

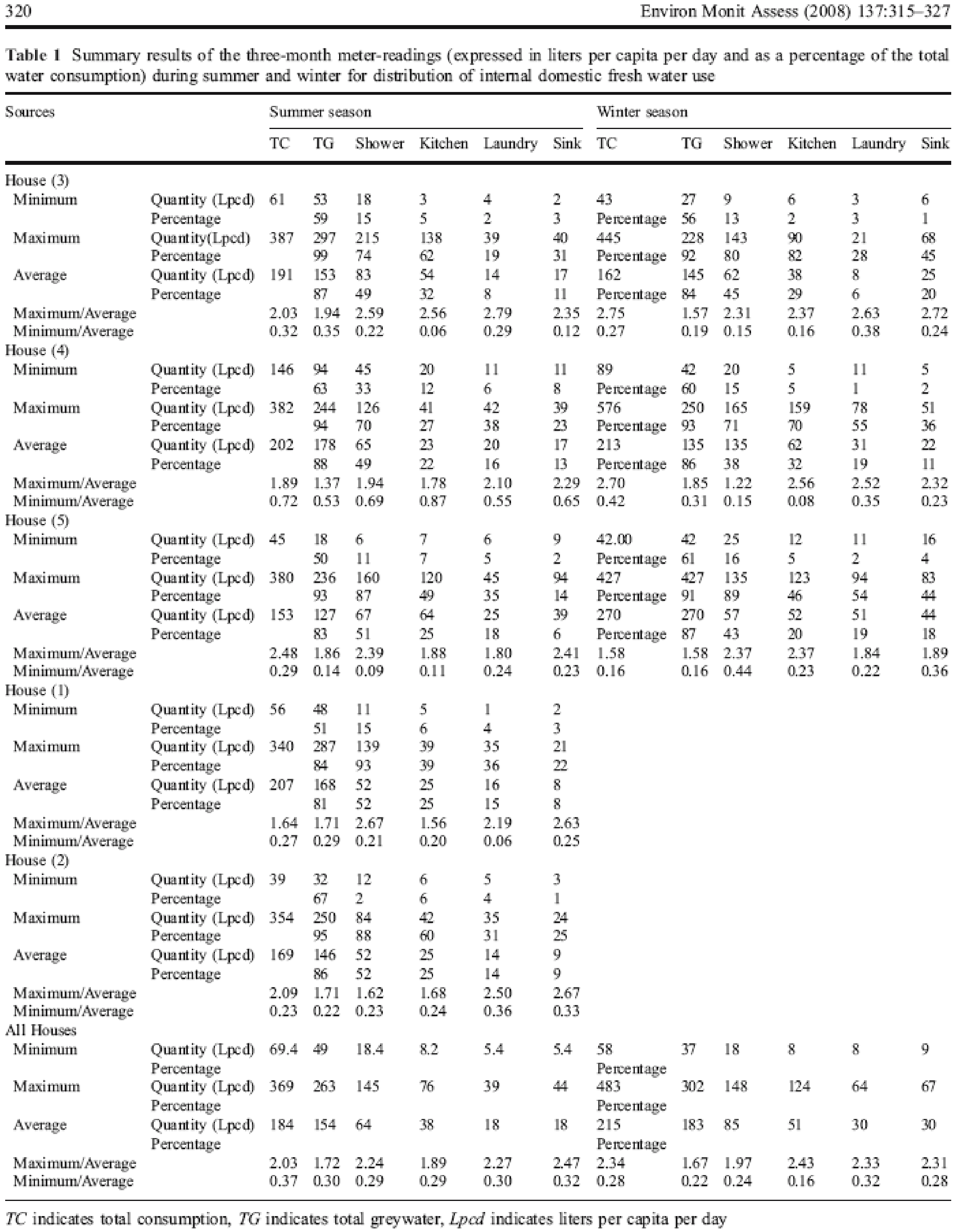


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Table 1 Summary results of the three-month meter-readings (expressed in liters per capita per day and as a percentage of the total water consumption) during summer and winter for distribution of internal domestic fresh water use

Sources		Summer season						Winter season					
		TC	TG	Shower	Kitchen	Laundry	Sink	TC	TG	Shower	Kitchen	Laundry	Sink
House (3)													
Minimum	Quantity (Lpcd)	61	53	18	3	4	2	43	27	9	6	3	6
	Percentage		59	15	5	2	3	Percentage	56	13	2	3	1
Maximum	Quantity(Lpcd)	387	297	215	138	39	40	445	228	143	90	21	68
	Percentage		99	74	62	19	31	Percentage	92	80	82	28	45
Average	Quantity (Lpcd)	191	153	83	54	14	17	162	145	62	38	8	25
	Percentage		87	49	32	8	11	Percentage	84	45	29	6	20
Maximum/Average		2.03	1.94	2.59	2.56	2.79	2.35	2.75	1.57	2.31	2.37	2.63	2.72
Minimum/Average		0.32	0.35	0.22	0.06	0.29	0.12	0.27	0.19	0.15	0.16	0.38	0.24
House (4)													
Minimum	Quantity (Lpcd)	146	94	45	20	11	11	89	42	20	5	11	5
	Percentage		63	33	12	6	8	Percentage	60	15	5	1	2
Maximum	Quantity (Lpcd)	382	244	126	41	42	39	576	250	165	159	78	51
	Percentage		94	70	27	38	23	Percentage	93	71	70	55	36
Average	Quantity (Lpcd)	202	178	65	23	20	17	213	135	135	62	31	22
	Percentage		88	49	22	16	13	Percentage	86	38	32	19	11
Maximum/Average		1.89	1.37	1.94	1.78	2.10	2.29	2.70	1.85	1.22	2.56	2.52	2.32
Minimum/Average		0.72	0.53	0.69	0.87	0.55	0.65	0.42	0.31	0.15	0.08	0.35	0.23
House (5)													
Minimum	Quantity (Lpcd)	45	18	6	7	6	9	42.00	42	25	12	11	16
	Percentage		50	11	7	5	2	Percentage	61	16	5	2	4
Maximum	Quantity (Lpcd)	380	236	160	120	45	94	427	427	135	123	94	83
	Percentage		93	87	49	35	14	Percentage	91	89	46	54	44
Average	Quantity (Lpcd)	153	127	67	64	25	39	270	270	57	52	51	44
	Percentage		83	51	25	18	6	Percentage	87	43	20	19	18
Maximum/Average		2.48	1.86	2.39	1.88	1.80	2.41	1.58	1.58	2.37	2.37	1.84	1.89
Minimum/Average		0.29	0.14	0.09	0.11	0.24	0.23	0.16	0.16	0.44	0.23	0.22	0.36
House (1)													
Minimum	Quantity (Lpcd)	56	48	11	5	1	2						
	Percentage		51	15	6	4	3						
Maximum	Quantity (Lpcd)	340	287	139	39	35	21						
	Percentage		84	93	39	36	22						
Average	Quantity (Lpcd)	207	168	52	25	16	8						
	Percentage		81	52	25	15	8						
Maximum/Average		1.64	1.71	2.67	1.56	2.19	2.63						
Minimum/Average		0.27	0.29	0.21	0.20	0.06	0.25						
House (2)													
Minimum	Quantity (Lpcd)	39	32	12	6	5	3						
	Percentage		67	2	6	4	1						
Maximum	Quantity (Lpcd)	354	250	84	42	35	24						
	Percentage		95	88	60	31	25						
Average	Quantity (Lpcd)	169	146	52	25	14	9						
	Percentage		86	52	25	14	9						
Maximum/Average		2.09	1.71	1.62	1.68	2.50	2.67						
Minimum/Average		0.23	0.22	0.23	0.24	0.36	0.33						
All Houses													
Minimum	Quantity (Lpcd)	69.4	49	18.4	8.2	5.4	5.4	58	37	18	8	8	9
	Percentage							Percentage					
Maximum	Quantity (Lpcd)	369	263	145	76	39	44	483	302	148	124	64	67
	Percentage							Percentage					
Average	Quantity (Lpcd)	184	154	64	38	18	18	215	183	85	51	30	30
	Percentage							Percentage					
Maximum/Average		2.03	1.72	2.24	1.89	2.27	2.47	2.34	1.67	1.97	2.43	2.33	2.31
Minimum/Average		0.37	0.30	0.29	0.29	0.30	0.32	0.28	0.22	0.24	0.16	0.32	0.28

TC indicates total consumption, *TG* indicates total greywater, *Lpcd* indicates liters per capita per day

Appendix G: Estimated Rainwater Treatment Efficiency

Rainwater Treatment Output Efficiency	
Treatment Technology	Percentage
In-Line Filter	90%
Ozone System	95%
Activated Carbon Filter (GAC)	90%
UV	100%
Total Output Water for Usage	76.95%

Appendix H: Estimated Price of Water Treatment Equipment

	Initial Cost ($) Details	Maintenance Cost ($) Annual
In-line Filter	-$1.57 per m^2 of roof space -Assuming using whole roof space 23000m^2 , it cost approximately $36000	-$200-$400 per replacement filter -Assume filter needs to be replaced 3 times a year: $600-$1200
Ozone	-$20000-$80000 -more expensive require less maintenance and more efficient	-Assuming electricity rates at $0.06/KWh we get $8 per day plus $3 for plumbing and plus $20 for capital we get $31 for O&M cost per day -it comes to $11315 per year
GAC Filter	-$3000-$6000 per unit -depends on the quality and size of filter	-$0.50 to $3.00 per 1,000 gallons (3785 L) depending on the quality filter -Assume in one year SUB collect 17 million liters of water per year, so the cost can range from $2200-$13474 per year
UV	-$700-$1500 per unit -depends on quality of unit such as: -flow restrictors-(capacity of unit is not exceeded -solenoid-shut of the water if power is down -intensity meter-close down system if bulb is not strong anymore -treatment speed from 4L per minute to 150L per minute	-$100-$200 bulb replacement per unit -Assume bulb needs to be replaced twice every year which comes to $200-$400