Bioresource Engineering Department.

BREE 495 – Design III.

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Engineering Design Assessment Report

Rainwater Purification System for a Multi-Story Building

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Client:

Mr. Philippe St-Jean, Sustainability Construction Officer at McGill Facilities Management and Ancillary Services

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Abstract.

The use of rainwater for domestic purposes has become increasingly popular in the developing and the developed world. The rainwater harvesting is being done to make full use of natural water that has an immense potential of being collected and treated to potable levels. The buildings that do not require any external water supplies and are self-sufficient in their use of water can qualify for Living Building Challenge standards. The Living Building Challenge is a green building certification program and sustainable design framework that promotes the ideal built environment. Living buildings have the potential to collect and treat all the water used on site. They help creating a positive and a mutually beneficial interaction between humans and the natural ecological systems. This technical engineering design report focuses on designing a rainwater purification system for a multi-story building, complying with the Living Building Challenge standards, to treat the rainwater to the potable levels. In order to adhere to the standards, it is ensured that the filtration products do not contain any of the LBC red listed materials. The design is broken down into pre- and post-storage filtration schemes.The components of the design involve sand and sediment filters accompanied by devices containing granular and powdered activated charcoal as filtration media. The final product in both the filtration schemes is a UV sterilizer. The purification technologies used in this project are thoroughly analyzed and evaluated based on their social, environmental, economic, ergonomic and health and safety aspects. It is recommended to incorporate all of the suggested technologies in the water purification system as the limitations of one would be compensated by the strengths of the other.

List of Tables and Figures.

List of Acronym and Abbreviations.

ANSI = American National Standards Institution

BNQ = Bureau de normalisation du Québec

BPA = Bisphenol A

FDA = US Food and Drug Administration

GAC = Granulated Activated Charcoal

LBC = Living Building Challenge

MSE = McGill School of Environment

PAC = Powdered Activated Charcoal

THM = Triahalomethane

USEPA = US Environmental Protection Agency

UV = Ultraviolet

VOC = Volatile Organic Compound

Introduction.

Rooftop rainwater harvesting systems have become popular with the increase in climate change awareness among the population. They are being used worldwide in regions that are experiencing erratic precipitation events, groundwater level reduction and/or contamination. People living in these areas have no choice but to invest in different approaches to obtain clean, safe drinking water.

The idea of capturing rainwater and using it for ourselves is not new, we've been doing it for centuries. In recent years, with the increased information obtained on global warming, trends are emerging which consist of using existing rainwater harvesting systems and retrofitting them to filter water for domestic household use.

By capturing rainwater, there is less of a water stress put on the natural resources by homeowners. It reduces or completely eliminates the dependence of the household to the water distribution system and it also reduces the volume of water sent for treatment to the wastewater treatment facility. In other words, the facility receives a reduced volume of water for treatment. Subsequently, the facility would, therefore, be able to handle overflows during storm events without having to dump untreated wastewater into the river system.

These systems have also increased the awareness of many looking to reduce their ecological footprint and adopt a more sustainable lifestyle without sacrificing any luxury. A benefit is that people who are actively using these systems are more conscientious of their water usage.

Our Company.

We at FILTR Tech ™ are committed to solving water quality problems with our filtration products. Our aim is to recycle rainwater to potable levels using low maintenance filtration techniques leading to reduced consumption of water in multi-story buildings. We can only achieve our mission statement with the development and use of our filtration systems.

We specialize in filtration systems for homeowners or businesses wanting a rainwater recuperation system. Our clients have existing structures built for rainwater harvesting for outdoor irrigation use. They come to us for a tailored solution to their current systems. We analyze the existing arrangement of the harvesting system to efficiently integrate our filtration system. Our arrangements are compact, low maintenance, chemical free and relatively inexpensive for the average homeowner. They include the following technologies depending on the application, activated charcoal, sediment filtration and ultra violet (UV) radiation filtration.

Living Building Challenge Compliance.

Our filtration system works in tandem with a rooftop harvesting system. The water collected on the roof gets plumbed indoors to a "filtration room" before being distributed to the interior water fixtures. This filtration step is needed because rainwater accumulates contaminants during its time in flight and when it gets into contact with the roofing material. There are contaminants in the collected rainwater that would make it extremely unhealthy for consumption purposes. A properly designed filtration system would address these concerns by removing the harmful particles through a multiple stage process to provide clean potable water as the product.

Our client is Mr. Philippe St-Jean, the sustainability construction officer at McGill's Facilities Management and Ancillary services. Mr. St-Jean is working on a project to convert an existing rooftop rainwater harvesting system for domestic purposes. It is located on top of McGill's School of Environment building in downtown Montreal. The McGill School of Environment (MSE) is refurbishing their building with the aim of attaining the Living Building Challenge (LBC) certification. There are certain criteria that must be respected to comply with the LBC standards. The first one is the recycling of rainwater for domestic use using non-chemical approaches (LBC, 2016). LBC standards also set up the guidelines for the materials that cannot be used to manufacture the products. The guidelines clearly provide detailed information on Red Listed materials and chemicals that are banned. There is a specified criterion for the transportation of products. Manufacturer location for materials and services must adhere to the following restrictions:

- 20% or more of materials construction budget must come from within 500 km of construction site.
- An additional 30% of materials construction budget must come from within 1000 km of the construction site or closer.
- An additional 25% of materials construction budget must come from within 5000 km of the construction site.
- 25% of materials may be sourced from any location.

Our client has called upon us to design a water filtration system to properly clean the rainwater in order for it to get distributed throughout the building's water fixtures. He is asking us to prioritize the system's performance over maintenance and costs. The overall size of the filtration system cannot be too large, our client plans on using existing closet spaces to install the filtration system throughout the building.

Our design must be compact, low maintenance and effective in removing the contaminants to ensure the building water quality guidelines are met. Our filtration system will incorporate 3 different filtration technologies. To ensure our client is able to meet his goal, our system will not use any chemicals. We have selected sediment filtration to filter medium to coarse particles, activated charcoal for more finer sediment and to remove any unpleasant taste in the water and lastly UV light radiation to eliminate any pathogenic microorganisms.

Design Considerations and Restrictions.

While we are doing our best to come up with the best solution possible, there exists with everything in life restrictions on potential applications. Since we are using only non-chemical filtration techniques, we are limited to our filtration ability. Our system will filter the water for short-term use only. This is because there is no chemical being added to the water for long-term use which is the case with the current municipal wastewater treatment protocol.

Also, in terms of potential applications to our filtration system, it can only be used in conjunction with an already existing rainwater harvesting system. This also holds true for our potential customers that aren't necessarily interested in following the LBC standards.

We started our project aiming to combine three different technologies, namely, slow sand filtration, activated charcoal and UV radiation. During our thorough product research in the latter half of our project, we found a compelling reason to substitute a bio sand filter with vortex fine sand and sedimentation filter. The bio sand filter offers an extremely low flow rate, making it a less suitable option for our design. Besides offering a low flow rate, bio sand filter needs approximately 30 days to form a bio film that acts as primary filtration media. This makes the maintenance of the product highly inconvenient and time consuming. Furthermore, the product is not quite robust and does not offer hassle free operation. These were some of the reasons that lead us dropping bio sand filter from our design.

Each of our technologies is limited to addressing a specific range of chemical and biological contaminants. Each technology individually targets different types of impurities and pollutants and therefore tend to have a narrow scope. For example, the activated carbon can address the removal of the taste and odor as well as the elimination of Volatile Organic Compounds (VOCs) whereas, the UV treatment is able to effectively reduce the number of pathogenic organisms (HPP, 2018). Each of these techniques have their own limitations as well. The UV radiation and activated charcoal technologies can only be used when the water has been treated and the size if particles has been brought down to a certain level. It is recommended that the water passing through the UV radiation and activated charcoal filters should be purified by a sediment filter having a size of 5 microns.

Therefore, it can be concluded although each of the technology has its own benefits, there are also some limitations associated that cannot be overcome if it is functioning alone. However, when working in conjunction, the drawbacks of one technology can be compensated by the benefits of the other.

Our whole concept of filtering rainwater with a filtration device is mostly aimed at people conscientious of their impact on the environment. That being said, our system doesn't economically pay for itself. Although some may view payback in terms of a reduced collective eco-footprint, the reality in Montreal is that water doesn't cost very much. Therefore, there is less of an incentive for people to invest their money into a product like ours.

Lastly, our system is designed to be long-lasting and as low maintenance as possible. However, there will be filters to change and cleaning to be done as with any watering system. This is to ensure no build-up of unwanted substances occurs along the pipe walls and the system itself. The drawback is that it leads to increased maintenance of the building whereby the roof must be cleaned on a weekly basis. This preventative maintenance will help extend the life of our product and keep the plumbing clear and cleaner for longer service intervals by significantly reducing the sediment accumulation in the filtration system. For our system to be long lasting, we must carefully consider the choice of materials. We can only use materials that are safe in contact with water and will not release toxins or heavy metals. We will look at different plastic composites that are Bisphenol A (BPA) free, UV stable and cannot oxidize or corrode throughout the lifetime of the product.

Review of Different Filtration Techniques Used in Our Product.

Vortex Fine Sand Filter.

The extent of the industrial and agricultural activities highly impacts the type and the load of contaminates present in the area. The rooftop of a building can contain a wide range of contaminants including leaves, twigs, atmospheric dust, pollens, pesticide residues and bird droppings. In our case, the McGill School of Environment (MSE) building is located in the downtown of the city of Montreal. Although the building is far away from industrial and agricultural sites, there are still high chances of accumulation of large sediments, leaves, debris and bird droppings on the roof of the building.

Prefiltration devices are commonly used in order to remove large size contaminants and particles. These devices are usually installed in the drainage system of the building before any filtration products. It is highly recommended to install a pre- filtration device right after the rooftop drain so as to avoid the blockage of the water pipeline system (CMHC, 2013).

The prefiltration device chosen in this project comprises of multiple downspout filter connected to a single pipe. This device is known as a vortex fine sand filter. This filter is installed in the water pipeline system of the building. The rainwater enters through an inlet pipe attached to the top end of the filter. It works by diverting up to 95% of the clean water to a pipe, attached to one end of the device, that carries away the filtered rainwater. The debris, along with the rest of storm water, flows through the storm water pipe attached to the other end of the device (RMS, 2016).

The device consists of a stainless-steel mesh screen that can filter particles down to a size of 280 microns. The filter housing is made of pure polypropylene. This avoids the rusting of the product when in contact with water. This is a self-maintained, robust and long-lasting device that requires manual cleaning only a few times a year (RMS, 2016). The Vortex filter does not restrict the flow of water and can work with very high flow rates. The product is made by WISY, a company located in Germany. We assume that the product is manufactured in North America as the distribution facilities are present in United states.

Figure. 1. Schematic of a Vortex Fine Sand Filter (RMS, 2016).

Sedimentation Filter.

Most modern sedimentation type water filtration products are made out of a spun polypropylene fiber matrix. The material's fibers are tightly bound which is beneficial for filtration but also for structural stability. Depending on their manufacturing process and gradient density, they are able to trap particles all across their accessible surface area. The arrangement of fibers allows the coarser particles to get trapped at the outer edge of the filter cartridge, whereas the fine particles are immobilized in the inner layers closest to the core of the cartridge (PP, 2012)

This dual gradient technology is capable of sequestering more contaminants and has longer service intervals than standard sedimentation filters. These filters are also designed to be adapted to a wide variety of filtration systems, they have special integrated seals to eliminate the more conventional "loose" gaskets that are prone to leaks. They can be used in different situations requiring different flow rates and temperatures (PP, 2012).

The manufacturer's specification will identify the maximum flow rates and temperatures that they can be used in to respect the filtration performance and manufacturer's warranty if applicable. Filters manufactured for usage in North America are required to meet the ANSI-NSF standards in terms of manufacturing and material selection (PP, 2012).

Our filtration scheme uses PENTEK's Dual Gradient sedimentation filter which is highly effective at eliminating particles greater than 5 microns. This ensures that the water leaving the sedimentation filter is purified enough to avoid the sediment loading in the Powdered Activated Charcoal (PAC) filter, increasing the effectiveness of the PAC filter (HPP, 2018).

The PAC filter is highly expensive and must be protected from sediment loading in order to achieve the required performance. The manufacturing material for the dual gradient sedimentation filter is polypropylene. Products made with polypropylene are not only environmentally sustainable but also resist bacterial growth (HPP, 2018).

This sedimentation filter comes with the block carbon filtration package and does not have to be separately bought. However, to achieve maximum efficiency, the filter cartridge needs to be replaced every 4 – 8 months as part of the maintenance requirements (HPP, 2018).

Activated Carbon.

Carbon is a highly porous material that has great potential to hold a variety of harmful contaminants (Dvorak, 2013). Activated carbon is carbon having a slight electro-positive charge, adding to the attraction of chemicals and impurities (HPP, 2018). The passage of water over the positively charged carbon surface draws the negative ions of the contaminants to the surface of the carbon granules (HPP, 2018).

Water purification by activated carbon works on principles of adsorption and catalytic reduction. The contaminants are adsorbed onto the surface of the activated carbon particles (Dvorak, 2013). Whereas, the catalytic reduction involves attraction of negatively-charged ions of the contaminants to the positively-charged activated carbon. Among all the available sources of carbon, activated carbon made by coconut shell is considered as the most effective (Arena et al.,2016). Our filtration systems would use carbon extracted from coconut shell.

The finer the size of the particles, the higher the effectiveness of the removal impurities. The size of the carbon particles used in our system will be 0.5 microns which is considered to be the most effective (HPP, 2018). The amount of carbon and the contact time of contaminants with carbon highly influences the efficiency of the filtration. An increased efficiency of purification is obtained when the quantity of carbon in the system is high (Dvorak, 2013). A wide range of contaminants are removed as the amount of carbon is increased. An increase in the quantity of carbon also increases the life cycle of the filter by increasing its saturation capacity (Dvorak, 2013). This is due to the fact that there are more adsorptive sites present for the attachment of contaminants (Dvorak, 2013).

The greater the length of time for which the contaminants are in contact with carbon, the higher the efficiency of their removal. This allows time for the contaminants to adsorb to the surface of carbon particles (HPP, 2018).

The production of activated carbon from the coconut shells has lesser environmental impact than from carbon-based compounds (Arena et al., 2016). However, there is still some environmental impact associated with the overall manufacturing of powdered activated carbon. The coconut shells are crushed and dried before being sent to the carbonization unit. The electric energy consumed by the crusher as well as by the activated carbon tumbling machine values around 2160 MJ per ton of activated carbon produced (Arena et al., 2016). Pyrolysis is carried out at extremely high temperatures to produce activated carbon in powdered form. This generates heat, $CO2$ and other potentially hazardous compounds such as acids and tar as the byproducts of the process (Arena et al., 2016). These by-products have a high potential of escaping into the atmosphere and leading to acidification, global warming and human toxicity if not handled properly by the plant (Arena et al., 2016).

Powdered Activated Carbon.

Powdered Activated Carbon can effectively reduce most of the odor and taste generating compounds. It can significantly reduce the concentrations of several organic compounds present in water. This treatment system is able to eliminate some nuisance compounds, radon and volatile organic compounds (VOCs) (Dvorak, 2013). Lead from the corrosion of some older pipes may be deposited in water. It can also reduce, to some extent, the concentration of lead in water (HPP, 2018).

The activated carbon filtration device provided by HPP will consist of two cartridges (2018). The first cartridge will comprise of dual-gradient sediment filter to remove fine sediment particles down to a level of 5 microns (HPP, 2018). This would be followed by 0.5-micron carbon block filter to avoid the sediment loading in the more expensive and effective carbon filter (HPP, 2018).

The filter package offered by HPP is complete in itself (2018). It is highly effective at removing ultra-fine sediments, particulates, cryptosporidium and giardia cysts, chlorine, bad tastes and odors, and VOCs (HPP, 2018).

An important drawback of the product is its restriction of the flow rate. A flow rate of less than 15 litres per minute needs to be maintained at all times (HPP, 2018). This is to ensure that enough time is provided for the purification process to take place. The PAC cartridge has to be changed every 12 months to ensure proper functioning of the filter (HPP, 2018). Clear Plus WHC+ filter package is NSF certified and exceeds all the required codes and standards (HPP, 2018). Moreover, the product is manufactured inside North America and hence meets the LBC distance criteria.

The following diagram shows the schematic of the filtration device. The design of device will be scaled in the next phase of this project to integrate it into the plumbing system of the building.

Figure. 2. An illustration of the sediment filter cartridge (on the left) accompanied by the block carbon filter cartridge (on the right) (HPP, 2018).

Granular Activated Carbon.

This specific type of filter media is mainly used to remove "natural organic compounds, taste and odor compounds, and synthetic organic chemicals" that are found in water destined for potable use. The carbon absorbs these compounds and sequesters them in its porous matrix until it has reached saturation and must be replaced with a new unit. The granulated variant of the activated carbon family is differentiated by its particle size (US EPA, n.d).

Typical granulated carbon particles range from 1.2 to 1.6mm in diameter. Its uniformity coefficient is roughly around 1.9 allowing backwashing to occur without damaging the composition or structure of the filter unit (US EPA, n.d).

Granulated Carbon filtration systems are typically placed after the primary filtration system. This filter excels at removing the dissolved organic compounds that are not absorbed by the primary filtration steps. It is not to be used as a primary means of filtration, this will only result in poor water filtration efficiency and premature servicing of the unit. Lastly, in large scale filtration systems, the disposal of the carbon media requires careful planning as it can leach contaminants into the environment. Often it is regenerated through a heat process to remove the organic contaminants before being re-used in the water treatment process (US EPA, n.d).

The granulated activated charcoal component of our design is a product of Environmental Water Systems Inc. The filtration media used in this case is Granulated Activated Charcoal (GAC) . The GAC used has a very high iodine number and therefore can be deemed as of highest quality. It is capable of effectively removing and reducing chlorine, VOCs, trihalomethanes (THMs), pesticides, herbicides and pharmaceutical residues from the incoming water (EWS, 2018).

The product requires least manual interruption in terms of maintenance, making it hassle free, robust and user-friendly. The automatic backwashing feature of the product ensures that the filtration media is always clean in order to provide maximum adsorption surface area to capture contaminants (EWS, 2018). This is highly beneficial in preventing bacterial growth and avoids clogging of the filter.

The GAC filtration media is free of all chemical additives, fillers, metal resins or any kind of silver impregnation. The product does not contain any chemicals, salts or corrosive softeners. This makes the filter meet or exceed all FDA, ANSI-NSF, and California State standards and compliances (EWS, 2018).

EWS-1354 model from the company offers a very high flow rate (132 liters per minute) and a filter life of 10 years. The tank cover is made from BPA-free, phthalate-free white plastic. The filtration media is ANSI-NSF compliant 100% pure proprietary blend of biodegradable and compostable activated carbon. An automatic drain valve is present in the system and can be connected to a pipe to collect the backwash drain (EWS, 2018).

Figure. 3. A component of the GAC filter with inlet and outlet pipe valves (EWS, 2018).

Figure. 4. The GAC filter by EWS used in this project (EWS, 2018).

UV Radiation Treatment.

The treatment of water with ultraviolet rays has been quite well known for purifying the drinking water to the potable levels. Ultraviolet radiation is an energy band within the electromagnetic radiation (Mounaouer and Abdennaceur, 2012). UV radiation is generally characterized as the colorless, odorless and chemical free method of treating water to eliminate germs and any microorganisms that are resistant to other filtration techniques. UV is not able to remove the sediments, particulates and other mineral contaminants (AC, 2017). Hence, it must be ensured that the water coming to the UV filtration device has been screened of all those impurities. UV energy works by penetrating the outer cell membrane of microorganisms and disrupting their DNA which disables their replication (ESPWP, 2017).

The UV radiation is provided through the special low-pressure mercury vapor lamps that emit the radiation at the wavelength of 254 nm, optimum wavelength for disinfection. In order to avoid any contact of water with the UV lamp, it is enclosed in the quartz dome or sleeve (RF, 2016). The untreated water flows inside the stainless-steel disinfection chamber where microorganisms like bacteria, viruses, fungi, algae etc. in the water are exposed to the UV light emitted by the lamp. This causes inactivation of the microorganisms leading to their destruction (AC, 2017). The water flowing out of the chamber is disinfected and safe for consumption. This device is mounted horizontally to avoid any disruption on the flow.

This technology has the least environmental impact in terms of global warming potential and ozone depletion as long as it is contained in the filtration device. It is recognized by regulators including USEPA as being one of the environmentally friendly technologies. Although the UV lamp requires electricity to operate, its energy consumption is very low (ESPWP, 2017).

Ultraviolet treatment involves a special lamp protected by a quartz glass sleeve inside the stainless-steel chamber. As the water flows through the stainless-steel chamber, UV lamp produces ultraviolet spectrum of light. This exposure of UV light to the incoming water destroys the microorganisms present in water. The two factors that determine the dosage of UV are intensity and exposure time (TTG, 2018).

The UV-Max Pro20 ultraviolet sterilizer manufactured by Viqua Inc. consists of a special UV sensor. This sensor keeps on regulating the intensity of UV light in the chamber. The sensor is connected to an audible alarm which rings when the UV intensity drops below a certain threshold. It is a sign that the UV light and the sleeve are not effective anymore and the consumer should replace the UV light and sleeve as soon as possible (TTG, 2018).

It is recommended by the manufacturer of the product to change the UV lamp and sleeve once every year. A high dose of 40 mJ/cm2 is provided by this UV lamp. This is to ensure optimum protection from pathogenic organisms (TTG, 2018).

This specific model of UV sterilizer is made for large homes having up to 7 bathrooms. A high flow rate of 75 litres per minute is provided by the product. The premium features include UV intensity monitor and alarm, flow based dosed monitoring and lam dimming system. It can work with different pipe sizes and has to be installed vertically. The product meets NSF-55 Class A validation requirements (TTG, 2018).

Figure. 5. A UV sterilizer with LCD controller (TTG, 2018).

Chlorination.

The other alternative to our system would be one that uses chemicals for filtration and preservation. Chlorine is dissolved into the water as a disinfectant in water to kill remaining contaminants that haven't been removed during filtration. It is also a means of prevention to keep the plumbing clean, preventing any buildup of bacteria or pathogens along the inner pipe wall (Dvorak, 2013). Chlorine will not be used in our treatment system primarily due to the LBC standards stipulating that chemical filtration is not permitted. There are also some other drawbacks associated with chlorine.

Unfortunately, the addition of chlorine in water gives the water an unpleasant taste and odor. It has not been shown to cause health problems if the recommended concentrations are followed for drinking water purposes (Dvorak, 2013). In addition, a system that requires chemical filtration will have an additional consumable that needs to get replenished depending on the volume of water being filtered. One of the major drawback is the potential of disinfection from by-products. Addition of excessive chlorine in water can combine with organic material in the water to form substances such as THMs, which are known to cause liver, kidney, or central nervous system problems (Dvorak, 2013).

Table 1. Weighted factor chart summarizing the evaluation scheme.

	Weight Factor	***Sedimentation Filtration***	***Activated Carbon***	***Ultraviolent Radiation***	***Chlorination***
Removal of Bad Taste and Odor	***5***	2	9	3	9
Removal of Microorganisms	***6***	2	4	9	8
Removal of Turbidity	***7***	8	6	2	3

Removal of Organic& Inorganic compounds	***5***	2	8	2	3
Environmental Impact	***8***	9	6	8	6
Initial Cost	***4***	9	7	6	6
Operation and Maintenance Cost	***7***	9	8	7	7
Ease of Installation	***6***	8	7	8	6
Functionality	***8***	7	8	9	7
Lifespan	***7***	6	7	8	6
Social acceptability	***6***	8	8	9	8
Occupational Health & Safety Risks	***9***	8	8	9	7
LBC Qualification	***10***	9	9	9	0

Key:

1 – Least Feasible

10 – Most Feasible

Design Approach.

The proposed rainwater filtration system design approach is shown below. The design approach, in this case, can be broken down into two portions:

1) Pre storage filtration
2) Post storage filtration

Pre- Storage Filtration.

The filtration process starts right from the top of the roof drain. Our client has planned to install a mesh screen (several inches in height) on top of the drain. This would prevent large particles such as leaves from blocking the drain. As the rainwater passes through the drain, it runs along a 10.16cm diameter pipe where a vortex fine sand filter is installed. The water flows from the filter inlet and passes through the stainless-steel screen present inside. A swirling effect allows the rainwater to get filtered to a level of 280 microns. The filtered water, constituting 95% of the total volume, flows through a pipe connected to the bottom end of the filter. The rest of storm water, along with the debris, passes through another pipe attached to the opposite end of the device.

The next component in the pre-storage filtration scheme is a dual gradient sedimentation filter. The pipe sizing changes as the water passes through the vortex fine sand filter. All of the potable water pipes from this point onward are 2.54cm in diameter. The sedimentation filter further purifies the water and reduces particle size to 5 microns. This avoids the blockage of the following PAC device, ensuring effective and hassle-free operation. It is highly recommended to install a sedimentation filter to fulfil the incoming particle size requirements of the PAC filter.

Following sediment filter, we have our powdered activated charcoal filter which is highly effective at purifying water to potable levels. The contaminant removal range of the PAC filter has already been described in the previous section of this report. This filter removes all the particles that are greater than 0.5 microns in size.

The next component in the design is the UV sterilizer. Water entering the UV chamber gets exposed to UV light which inactivates the microorganisms by disintegrating their DNA. The

UV sterilizer comes with an electric controller having LCD display. A cooling fan is attached on top of the casing to maintain the internal temperature. Water flowing out of the UV chamber is considered safe to drink.

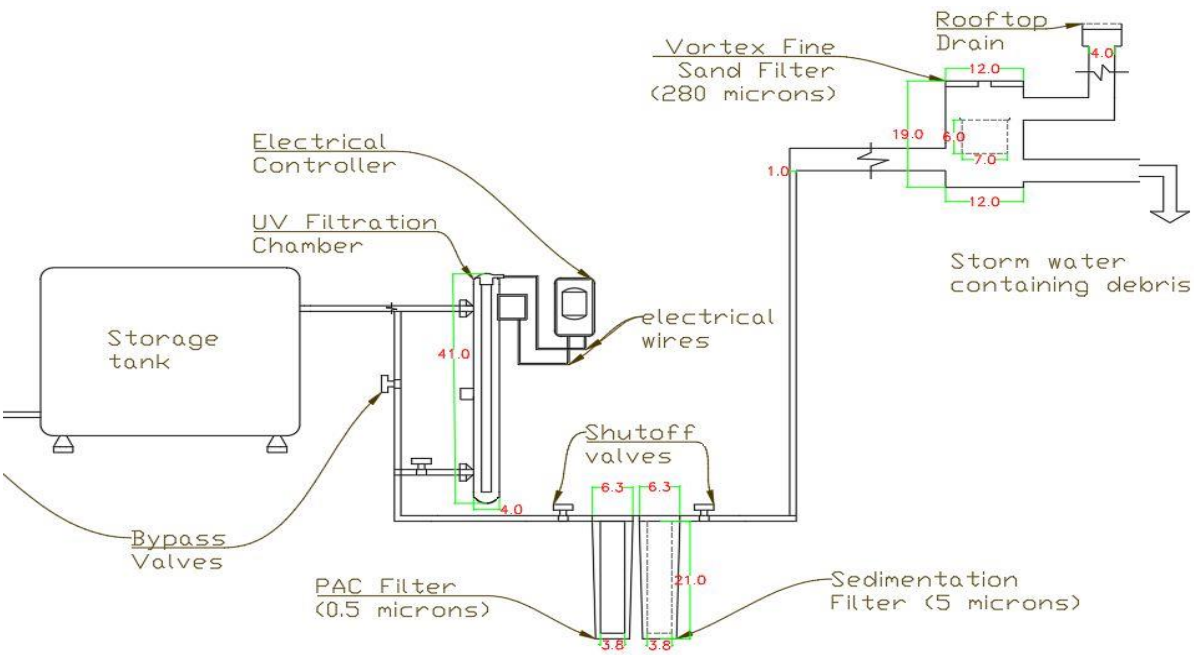

Figure. 6. An annotated diagram of pre- storage treatment scheme.

Post Storage Filtration.

Water coming out of the UV chamber is stored into a tank. This tank is large enough in size to meet potable water requirements of the whole MSE building, assuming enough amount of rain. The water stays in the tank until it is required by the water fixtures inside the building. The water flowing out of the tank is treated again by two other filtration devices before flowing to the fixtures.

The first filtration device in the post storage treatment is the granulated activated charcoal filter. Since a GAC filter can work with very high pressures and flow rates, it can be placed immediately after a pumping device. A pumping device will be placed after the tank to meet the pressure requirements of the fixtures.

The UV sterilizer is also present in the post storage treatment, following the GAC filter. This is to eliminate any microorganisms that might have developed during the storage of water. Although the growth of microorganism is less likely at this point, the UV component is added be risk free and give a sense of confidence to the consumers in terms of water quality.

Once the water has passed through the last component of the filtration system i.e. UV sterilizer, it is ready to be pumped to the fixtures. Shutoff and bypass valves need to be installed at the places shown in the figures. These valves ensure that the flow of water can be easily diverted or turned off in case of any repairing and maintenance. This also provides an alternative path for water to flow in case of any emergency.

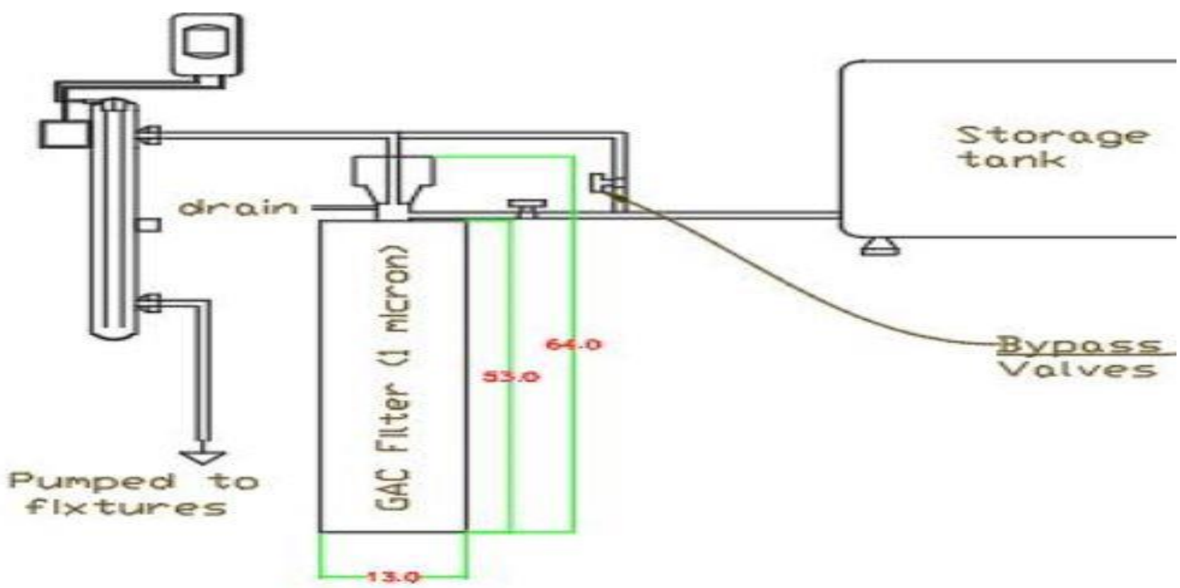

Figure. 7. An annotated diagram of post storage treatment scheme.

Building Codes and Standards.

Since our design will be applied in a real-world context, it is important that it follows applicable codes, regulations and standards imposed by the relevant authorities. In our case, we had to familiarize ourselves with the relevant standards applicable to potable water distribution in buildings with an occupancy. We made sure to choose products that were certified by independent, accredited organizations that are recognized by government authorities. Specifically, we learned about the American National Standards Institution (ANSI) and their collaboration with NSF International in testing and certifying products available to consumers worldwide. They also work on establishing standards for a multitude of products available worldwide. NSF International was founded just before the end of the second world war in 1944 and was known as the National Sanitation Foundation. Today they are very well known and their certification carries a very strong importance for the recognition of products in different applications. The ANSI-NSF certification is unique in that it is recognized throughout North America. More precisely the ANSI-NSF 61 series standards are relevant to our design project because they cover a wide range of products that are in contact with potable water. This standard can be applicable to something as simple as a protective coating all the way to a complex rubber washer or seal. These items must be certified if they are in contact with potable water destined for human consumption (ANSI-NSF, 2018).

Similarly, we understood that there also exists an independent organization in the province of Quebec that issues standards for the similar context. Known as the Bureau de Normalization du Quebec (BNQ), they are accredited by standards Canada and have issued standards regarding the authorized materials that can be in contact with potable water. The BNQ 3660-950 series of standards is very similar to the one issued by the ANSI-NSF organization in that it ensures that specific products are certified for use in contact with potable water (BNQ, 2018).

Regarding our filtration system design, we were very careful in our product selection as to prioritize products that were certified by the ANSI-NSF standards. This selective choice was done to facilitate the negotiating process that will have to be done to circumvent legally the existing municipal building codes regarding the retro-fitting of our novel water supply system into the McGill School of Environment building.

Living Building Challenge Red List.

The Living Building Challenge organization has listed all the different types of building materials that are toxic to the environment and also directly toxic to humans through bio-accumulation in the environment. A pre-requisite for the LBC certification is that no materials listed on the Red List be used in the construction or renovation of any building applying for certification. Exemption is possible, but it is difficult to achieve and substantial evidence is needed to demonstrate that alternative materials cannot be used. The list compiles around twenty different categories of toxic materials of which another ten to twenty specific materials are listed in each category (LBC, 2018).

In regard to our water filtration design, we had to ensure that no material on the Red List was used in the manufacturing of the filtration products. We were mostly concerned with Bisphenol A, Polyethylene and Polyvinyl chloride categories. Polyethylene and Polyvinyl chloride are commonly used building materials and they are most often used in piping for plumbing of different utilities within a building. In addition, BPA is used to manufacture a wide range of plastic products and can still be found in re-usable water bottles. For these reasons, we disregarded any potential product containing any variants belonging to the mentioned categories (LBC, 2018; TT, 2017).

The products that we have chosen are either made out of corrosion resistant stainless steel or out of polypropylene. Polypropylene is a compound that is not listed on the Red List. It is very robust and resistant to bacterial growth and is not prone to chemical leaching. It is not considered as a harmful substance and is used in many consumer applications (CMB, 2016).

Occupational Health and Safety.

With our product, concerns about occupational health and safety will be kept to a minimum. Our product will not be dangerous to use. It is designed to improve water quality. It will be lightweight to reduce installation injury with clearly labeled mounting locations. We will provide color-coded plumbing to reduce the chance of incorrectly installing the filtration system. In our installation booklet, we will recommend a team of two adults for the filtration system installation to prevent any type of physical injury from happening. Our product has to be safe to touch. It cannot have any sharp edges or any type of residue left over from the manufacturing process. We don't want to use materials that will degrade or dissolve over time releasing unwanted contaminants in or onto the filtering system.

There will be a risk with any proposed engineering design solution. The objective is to understand the risks and minimize their chance of occurring. Throughout our design process in creating the filtration arrangement that we have proposed, we came to the conclusion that the most important human risk involved is the possibility of water contamination causing important human health problems. We ensured that our arrangement is capable of filtering the water collected from the rooftop to potable levels, however there remains the possibility of a device malfunctioning and compromising the water quality. This risk will be mitigated by ensuring that routine maintenance be carried out on a adequate frequency to ensure the proper working order of the filtration system. Additionally, water tests will be mandatory and prescribed by the authorities to ensure that the quality is within the specified acceptable range.

Secondly, in the case of our project there will not only be potable water circulating in the building but also grey water and black water. To that effect, it is extremely important to identify the quality of water by affixing proper attractive labeling near water fixtures, toilets and in other restrained locations. The labeling will be used as a means of raising awareness to the individual using different water fixtures. This will inform occupants of the potential risks associated with using each different water fixture.

Environmental and Social Factors.

Our filtration product combined with a rainwater harvesting system aims at reducing the negative human impact on the environment. By implementing our filtration system, we believe that there will be fewer amounts of synthetic toxic chemicals released into the environment. There will be significantly less rainwater wasted onto the ground or sent to wastewater treatment facilities. With our system in place, water is collected and filtered naturally. Our system is built following an environmentally friendly approach. For example, we are going to source the powdered charcoal through coconut shells. We've also designed it to be incorporated inconspicuously into any building requiring the least amount of modifications possible. The geographic area that our product is used in will have to be considered to ensure that enough water can get filtered based on known precipitation information.

Socially, our product will raise awareness among the population about water use. Our customers will slowly adapt to this system by re-evaluating the amount of water they really need for a particular task. There will be a change in mentality because it will get people to reflect and think about what happens to the water after it is dumped down the drain or flushed out of a toilet. On the other hand, depending on the location, secondary health effects will have to be taken into consideration. Certain dissolved minerals found in spring water or that are added to the treated drinking water, are absent in the rainwater. The consequence would entail that extra supplements be taken aside to compensate for its absence in the filtered water. Most notably is fluorine that is added currently in our drinking water for good dental health and to prevent tooth decay.

Economic Analysis.

The purpose of this section is to present the capital and operating costs associated with our system. We have limited the scope of the analysis to only include the filtration products. We are not including the plumbing and the infrastructure, that will be constructed to display our filtration system to the building's occupants and visitors.

Table. 2. List of costs associated with filtration arrangement.

	Type of Filter		Unit price CAD$		Serviceable parts price CAD$
Pre-Storage	WISY Vortex WWF100		770		n/a
	ClearPLus WHC (Sediment and Charcoal)		335		130
	Viqua UVMax Pro 20 UV sterilizer		2,765		285
Post-Storage	EWS 1354 (Granulated Charcoal)		6,450		2,500
	Viqua UVMax Pro 20 UV sterilizer		2,765		285
		Total:	13,085		3,200

The cost of each filtration product along with the cost of the servicing parts where applicable are presented in Table 2. Our most expensive product is the granulated charcoal component. It has the longest service interval of all filtration products of approximately ten years depending on the water quality. It is important to note that our client Mr. St-Jean had informed us that cost was not a limiting factor in the project. We used this flexibility to our advantage by sourcing products that were robust, manufactured following high-quality standards, certified by ANSI-NSF standards and that had extended service intervals. In other words, we did not compromise on the selection of products because of a restrained budget allocated for this design.

The system is not intended as a means to generate revenue, it will not payback for itself. Instead, McGill is using this pilot project to determine the effectiveness of implementing a water harvesting system in its faculty buildings on both campuses.

Depending on the ease of the retro fit and its overall efficiency, McGill may consider implementing this strategy in all its buildings as part of its effort to become more sustainable and environmentally friendly in the years to come. We see this as an opportunity to invest in the future.

Conclusion.

Throughout the course of our design process, we made sure to consult often with our mentor and our client. This was to ensure that we remain focused and on the right path to solve the problem we had at hand. We are very pleased with our final result. Our client has expressed his gratitude towards us for our design. The next step in the near future, will be to incorporate our renderings into the plans that will be approved by the engineers working on the MSE project. We would like to thank our mentor for this project, Professor Madramootoo for his valuable guidance and feedback throughout the project.

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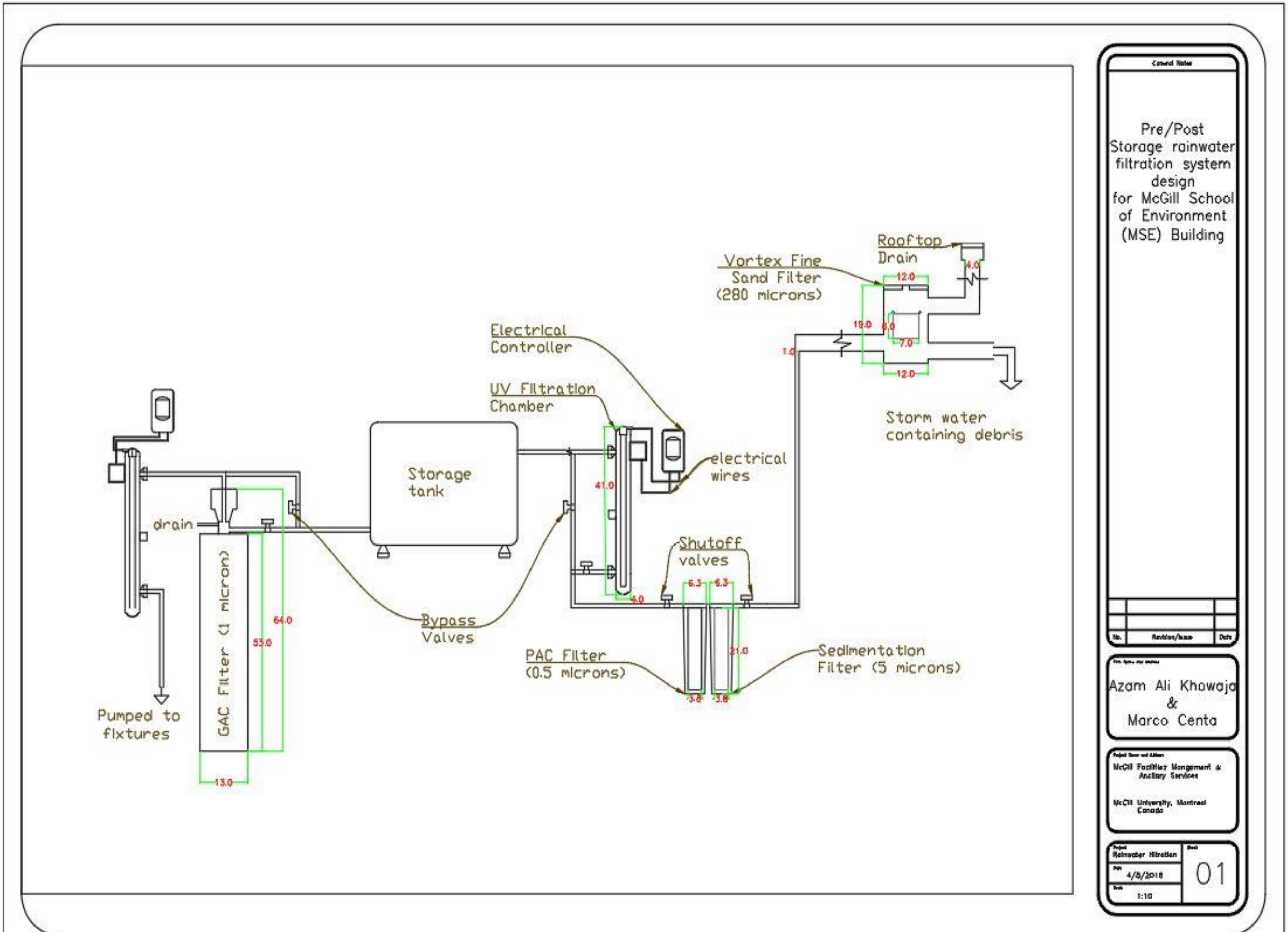
Appendices.

Options	Treatment	Materials	Flow rate	Pipe Sizings	Pressure	Maintainence	Cost	Details
Pre Storage								
WISY Vortex Fine Filter WFF100	Vortex Fine Sand Filter	Polypropylene/ Stainless steel	No more than 60 gal/min	4"	No specifc requirement	~1 every 4months	$600	280 microns, good for roofs with 2200sqft area
ClearPlus WHC+ Whole House Premium 0.5 Micron	Sedimentation Filter	Polypropylene	4 gal/min	1" MNPT	<90 psi	every 14-8 months	See in PAC	5 micron sediment filter comes with PAC
ClearPlus WHC+ Whole House Premium 0.5 Micron	Powdered Activated Charcoal	Polypropylene	150,000 gallons @4 gal/min	1" MNPT	<90 psi	every 150,000 gallons	$350	Pressure drop <9psi, 0.5 micron filter, can be used with 3/4" or 1/2" pipes.
Viqua - commercial	UV Filter	Stainless steel	up to 30 gallons per minute	1" NPT	<90 psi	Every 9000 hours	~$2000 - $3000	Light commercial application Advanced monitoring systems
Post Storage								
EWS 1354	Granulated Activated Charcoal	Fiberglass + Polypropylene	15 gal/min	3/4" to 1"	>35 psi <75 psi	every 10 years	see retailer	automatic backwash mechanism bypass valve required, backwash drainline required
Viqua - commercial	UV Filter	Stainless steel	flow rates up to 30 gallons per minute	1" NPT	<90 psi	Every 9000 hours	~$2000 - $3000	Light commercial application Advanced monitoring systems



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LBC RED LIST.

- Alkylphenols
- Asbestos
- Bisphenol A (BPA)
- Cadmium
- CHLORINATED POLYETHYLENE AND CHLOROSULFONATED POLYETHYLENE
- CHLOROBENZENES
- CHLOROFLUOROCARBONS (CFCS) AND HYDROCHLOROFLUOROCARBONS (HCFCs)
- CHLOROPRENE (NEOPRENE)
- CHROMIUM VI
- FORMALDEHYDE (ADDED)
- HALOGENATED FLAME RETARDANTS (HFRS)
- LEAD (ADDED)
- MERCURY
- POLYCHLORINATED BIPHENYLS (PCBs)
- PERFLUORINATED COMPOUNDS (PFCs)
- PHTHALATES

- POLYVINYL CHLORIDE (PVC), CHLORINATED POLYVINYL CHLORIDE (CPVC), POLYVINYLIDENE CHLORIDE (PVDC)
- SHORT CHAIN CHLORINATED PARAFFINS (SCCPs)
- VOLATILE ORGANIC COMPOUNDS (VOCS) IN WET APPLIED PRODUCTS
- WOOD TREATMENTS CONTAINING CREOSOTE, ARSENIC OR PENTACHLOROPHENOL