UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Assessment of Alternative Water Systems

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APSC 598G

May 30, 2014

Final Report

Project Title: Assessment of Alternative Water Systems

Sustainable Building Science Program (SBSP) Project Course

APSC 598G

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2014

Contents

List of Figures

Executive Summary

Given the increasing demands for water conservation, some water systems have been designed to allow the use of rainwater and wastewater streams for non-potable uses within a building. Unfortunately, these alternative water systems usually encounter issues that led to them being shut off. This assessment examines the challenges and issues of several alternative water systems within the region around the University of British Columbia to inform the university on future building projects on campus.

The alternative water systems were analyzed from interview questions from four case studies based on six factors that are believed to be influential to the successful implementation of an alternative water system. These factors include cost, reliability, commissioning, operations and maintenance, occupant education, and occupant perception of the water system.

While the main operation (water treatment) was done very well due to regulatory pressure, many other aspects of the implementation of the alternative water system that supports the operation is somewhat lacking. Together, these factors lead to large issues that irritated occupants, or major cost in repairs to bring the system back to expected operational parameters. From the analysis, appropriate recommendations are given to support future implementation of alternative water systems at the University of British Columbia.

Introduction

The increasing need for water conservation as well as rising water cost and waste water disposal have resulted in the development of alternative water systems such as rainwater harvesting, greywater and blackwater reuse systems. The purpose of these systems is to provide an alternative to potable water for appliances and processes which do not require high quality water such as flushing toilets and urinals and irrigation. This results in reduced potable water consumption. In recent years, a number of these alternative water systems have been designed and installed, but have not been sufficiently and effectively operated, leading to these systems being shut off. Inappropriately operated systems may lead to economical losses, public health risks, people disruption and other unexpected issues as well.

Rainwater gets contaminated by atmospheric and surface runoff pollution that makes the water non-potable. Grey water and black water contain a wide range of contaminants which highlights the importance of correct and adequate treatment procedure to prevent serious health hazards in alternative water systems.

In its quest to become a leader in sustainability, UBC is interested in considering such alternative water systems to help meet sustainable building objectives. There are recent projects at UBC that have included these alternative systems, such as CIRS and Buchanan, which have experienced technical challenges in commissioning and operation. Therefore, this study is aimed to investigate the uncertainties about these systems such as cost, successful commissioning, regulatory barriers, reliability, operational and maintenance challenges and other effective aspects to inform UBC's strategy on water management.

This project is conducted by studying and assessment of alternative water systems installed in the region (e.g. city of Vancouver and Victoria) which were in comparative building type and scale as the ones in UBC campus considering the list of factors developed by reviewing relevant literature and interviewing experts in the field. Research methodology, introduction of the studied buildings, results of assessment and identification of top issues and barriers as well as a list of recommendations to UBC mentioning the lessons learned from this study are presented in this report.

Research Methodology

In order to assess alternative water systems, a literature review was conducted to examine what factors may be important to the implementation of rainwater harvesting systems and wastewater reuse systems. Using these factors interview questions were developed (shown in Appendix A and B). Several potential case studies fitting the university's criteria were contacted for interviews and site visits. The details surrounding these two processes will be elaborated in the following two sections.

Once the interviews and site visits are conducted, the data was analyzed by those questions to find similarities and differences to their challenges and successes. Recommendations were given based on the data.

Factors for Assessing Alternative Water Systems

After a literature review, six factors were considered to be likely important to the successful implementation of an alternative water system. From these factors, interview questions were generated that would explore and assess the influence of each of these factors for a given alternative water system. These six factors include 1) cost, 2) reliability, 3) commissioning and compliance, 4) operation and maintenance, 5) occupant training and education, and 6) occupant perception.

1) Cost

Cost refers to the resources used to design, install, operate, and maintain the alternative water system. Cost includes finances, time, and manpower to do each of those steps. Cost may influence the implementation of an alternative water system from the burden to the owner that the system imposes (Li, Wichmann, & Otterpohl, 2009). Liedl, Farahbakhsh, and FitzGibbon (2010) has found that the cost of the rainwater harvesting technology in Ontario homes may hinder the owners and designers from installing such a system when the benefits is comparatively small. An alternative water system that has a higher cost than the benefit it generates may cause the owner to discontinue the use of the water system.

2) Reliability

Reliability refers to the failures of the alternative water system. This includes the frequency, the severity, and the types of failures. The reliability also involves the ease of resolving the failures. Zhang, Grant, Sharma, Chen, and Chen (2009) examined the proportion of water supply and demand and the storage capacity needed to process all of the wastewater. In order for a system to perform efficiently, these factors have to be well determined so that the alternative water system can store the amount of water to supply the demand at the appropriate time.

Alfiya, Gross, Sklarz, and Friedler (2013) has examined 20 water reuse systems in single-housing units in the Middle East region. They found that half of the failures occurred in a quarter of the systems, and 45% of the systems did not experience any failures. Most were due to clogged or broken pumps bringing greywater into the system, electrical issues, and physical blockages to the treatment system. These issues may occur frequent or severe enough that the owners may abandon the alternative water system after it has been installed.

3) Commissioning and compliance

Commissioning is a necessary part of the building project process. During this phase, the installation of the alternative water system is reviewed to see if it meets the design specifications. As the system is operating, the commissioning process continues to ensure that the system is operating as designed. If the system is not installed or operated as designed, it is likely that the system may not be able to achieve the design criteria that allow the system to treat and distribute the water as desired. This check may detect many of the issues that burden the owners to stop using the alternative water system. Due to the public health risk from improperly functioning wastewater reuse systems, the BC government deems it imperative that the Ministry of Environment to check the design and the commissioning process is adequate, as stated in the 2012 Municipal Wastewater Regulation.

4) Operation/Maintenance

Like any other water system, there are procedures that are required to operate and maintain the system. Li et al. (2009) has set out 4 guideline criteria to which any water reuse system should meet, one of which includes hygienic safety. These concerns are mirrored in other studies as well (Friedler, Kovalio, & Galil, 2005; Lazarova, Hills, Birks, 2005; Liedl et al., 2010). In any water system, a certain amount of treatment is required to keep the water clean and safe enough for non-potable use, which depends on the level of contaminants of the water entering the system. Water quality measurements or inspection items are done to ensure that the treatment is adequate. In traditional wastewater facilities, there is a list of items that must be measured (Günther, 2000; Lazarova et al., 2005) and is detailed in the 2012 Municipal Wastewater Regulation. Due to the public health risk involved with wastewater reuse systems, the regulation also requires a certified wastewater system operator to run greywater/blackwater reuse systems. While rainwater is relatively benign, rainwater harvesting system would require some kind of treatment to remove large objects and biological matter that may proliferate inside the system. In order to do the work efficiently, procedures regarding all aspects of operating and maintaining the system should be laid out for the operators to follow.

Besides the issues of public safety, it is possible that the difference of the operation and maintenance of an alternative water system from a traditional water system may be more complex. Hennessy (2009) has found, from interviews with stakeholders, that some of the challenges of implementing the system include maintenance and creating the infrastructure, concerns of possible contamination of groundwater, and damage to plants and soil from contaminated water. The regulatory burden to deal with the health risks, the complexity of the system, along with the cost of operating and maintaining the system, may lead the system to be discontinued.

5) Occupant training and education

The 2012 Municipal Wastewater Regulation has categorized the treated wastewater use into three categories, which ranges from the greatest exposure potential to a low exposure potential. The change in exposure potential depends partly on the access of those who know about the system. Liedl et al. (2010) found that there is confusion among Ontario homeowners regarding the difference among the different types of water that may be used in an alternative water system. It is possible that the occupants may be more accepting to the alternative water system with greater education and training, by understanding the function of the system, the risk from the system, and the role of the occupants in using the system.

6) Occupant perception

The acceptance of any new technology by its users dictates whether it will be received well. Issues regarding the aesthetics of the system or the discomfort caused by the system would hinder the implementation of an alternative water system (Lazarova et al., 2005; Li et al., 2009). These issues may include odour problems, noise problems, the system as a visual nuisance, the complexity dealing with an alternative water system on the occupant’s way of life.

Analysis of the factors

Besides these factors, questions were asked of those interviewed to determine their overall satisfaction of the alternative water system based on their role, and the changes they think would improve the system. By examining the answers to the questions, the factors that have an impact on the successful implementation and operation of the alternative water system in general are evaluated. From these answers, recommendations will be given on future buildings that install rainwater harvesting systems and greywater/blackwater reuse systems. The interviews yielded little information that can be used to evaluate cost and regulatory compliance on its own, and is considered within each of the other criteria.

Introduction to Case Studies

In order to find case studies which are in comparative building types found at UBC, several factors were considered. Since UBC has academic, institutional and residential buildings, case studies were chosen from similar type of building application and relative scale (e.g. single family houses were not considered for this study). Moreover, water source was another factor which was taken under consideration in the process of choosing case studies. Rainwater, grey water and black water are the water resources which UBC consider for recycling processes. Therefore, equal number of case study buildings was chosen from those with similar sources of water. Treatment method and type of application (e.g. toilet flushing, irrigation and mechanical heating and cooling systems) were other factors which were considered in the process of choosing appropriate and meaningful case studies.

Furthermore, similar climatic condition was another significant factor for choosing the case studies. Average amount of precipitation, temperature and humidity of the region were considered as effective factors in the choice of alternative water systems and their optimal designs.

After conducting desk studies, reviewing recent reports of the region and asking experienced people in the field, 6 different potential projects were chosen for this study are as follows:

- Vancouver Convention center, Vancouver, BC
- Buchanan Building, UBC , Vancouver, BC
- University of Victoria, Saanich, BC
- Errington Lab Building, Errington, BC
- The False Creek Olympic Village, Vancouver, BC
- Quayside Village, North Vancouver, BC

Due to the several reasons, such as political issues, technical problems, non-interested project designers and operators, difficulties in finding relevant people and lack of time, the first 3 buildings in the above list were managed to be visited and analyzed and system designers and/or operators were interviewed. Moreover, as Errington project which interestingly has similar water treatment system as CIRS building could not be studied, CIRS building was replaced for conducting the studies, analysis and interviews. In the following sections of the report these 4 studied buildings are introduced and described.

Vancouver Convention Centre (Vancouver, BC)

Figure 1 : Vancouver Convention Centre, West Building

This building which is located in north east side of Vancouver is one of Canada's largest's convention center which is divided into two separate buildings, west building and east building. The west building was chosen for this study which is directly adjacent to the east building and consists of convention space, retail space and parking space. The overall area of the west building is 30,980m^2 (VCC, 2010).

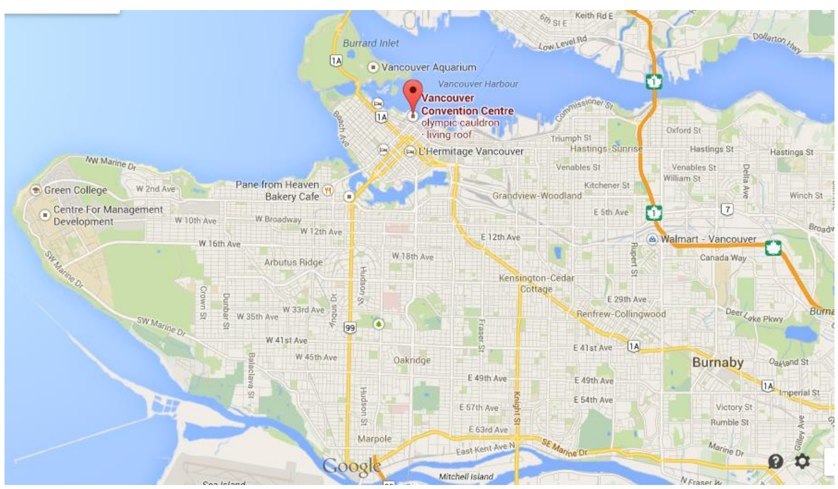

Figure 2: Location of Vancouver Convention Center in City of Vancouver-Source: Google Maps

All the water used in the kitchens and the washrooms of this building (grey water and black water) is treated in the wastewater treatment facility of the building and used for flushing toilets and urinals and summer time irrigation of the green roof.

Brief System Description

The treatment facility uses a membrane bioreactor process, manufactured and supplied by General Electric, consisting of two bioreactor tanks and an ultrafiltration (hollow fibre) membrane tank, followed by chlorination to remove colour and disinfect the reclaimed water. The treatment system is designed for maximum flows of up to 150 cubic metres per day (40,000 gallon per day) an average daily flow of 75 cubic metres per day (20,000 gallon per day). With the City of Vancouver 2012 commercial metered water and sewer rates at $2.803 and $1.754, respectively, the convention centre is able to save over $21,000 monthly in utility fees through water reuse. Maintaining the treatment plant bacteria in a healthy condition during the period of no or limited wastewater generation in the building is considered as one of the main operating challenges in Vancouver Convention Centre (VCC, 2010).

Figure 3: Water treatment Facility of Vancouver Convention Centre

Figure 4 shows samples of water in different stages of treatment in Vancouver convention center. (From left to right: Black water before filtration, water after filtration and before disinfection, water after filtration and disinfection process)

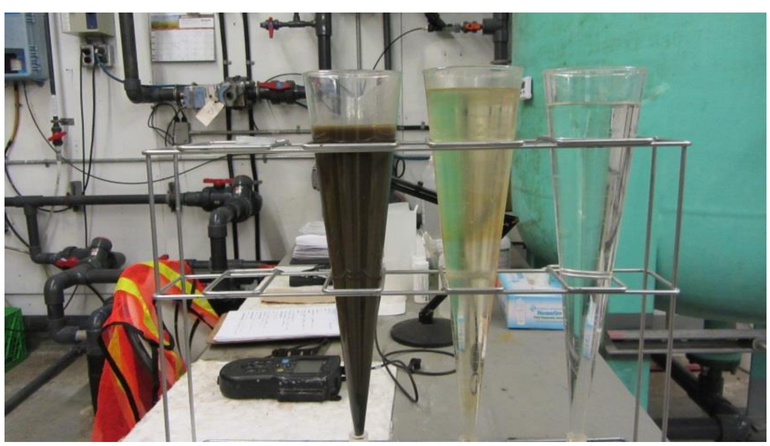

Figure 4: Samples of water in different stages of treatment in Vancouver Convention Centre-Source: self-taken photo

Buchanan Building Courtyard (UBC Vancouver Campus, BC)

Figure 5: Buchanan Building Courtyard (UBC Vancouver Campus)-Source: UBC Website

This building which is located in North west side of Vancouver consists of five blocks (A, B, C, D, and E) and a tower. The Buchanan courtyard site water harvesting/ recycling system entails the collection, conveyance, storage and reuse of site storm water for the purpose of irrigation and water feature recharge. No potable water will be used for these purposes and the system will not be connected to a potable water source as a backup measure. Cistern stored water will be used for landscape irrigation and reflecting pool recharge. According to the project Manual, The cistern capacity of approximately 28,000 gallons was based on below average 10 year rainfall rates and above average evaporation rates (anticipating future drought conditions) (Crowdis, 2013).

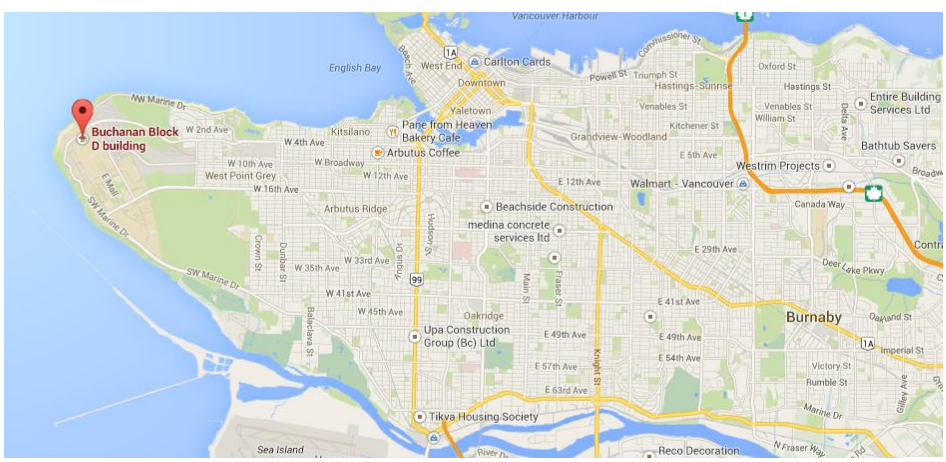

Figure 6: Location of Buchanan building courtyard in the city of Vancouver-Source: Google Maps

Buchanan outdoor space area which was recently renovated is 7432 m^2 in total and approximately 4,000 m^2 (for collection and irrigation area) of that is allocated to the water system. Rainwater is the source of water system at Buchanan which is used for irrigation and water feature recharge after being treated. While the cost specific to the water system cannot be determined, the overall project cost was $2.8M and spanned two years from conception to completion (including all the renovation costs). A new storm water management system, including a water harvesting, filtration and recycling in the form of a naturalistic "rain-garden", a new pavilion and reflecting pool are some examples of the renovation improvements (Crowdis, 2013).

Brief System Description

Collection Method: Rainwater falling on the reflecting pool, hard paved areas and the pavilion roof will overflow into the water channel to the east where it will be carried to the rain garden. Storm water from the east plaza hard surfacing will also flow to the rain garden.

Treatment Method: Water in the rain garden will be bio remediated as it passes through the bed of littoral vegetation such as bulrushes. Water will also be filtered as it moves through a layer of filter fabric and underlying granulars.

Water Distribution: a portion of the water will be captured in a subsurface piping system and will be pumped to the cistern located under the pavilion. Water that is not captured will be used to recharge the groundwater table.

Storage: Cistern stored water will be used for landscape irrigation and reflecting pool recharge. The cistern capacity of approximately 28,000 gallons was based on below average 10 year rainfall rates and above evaporation rates (Crowdis, 2013).

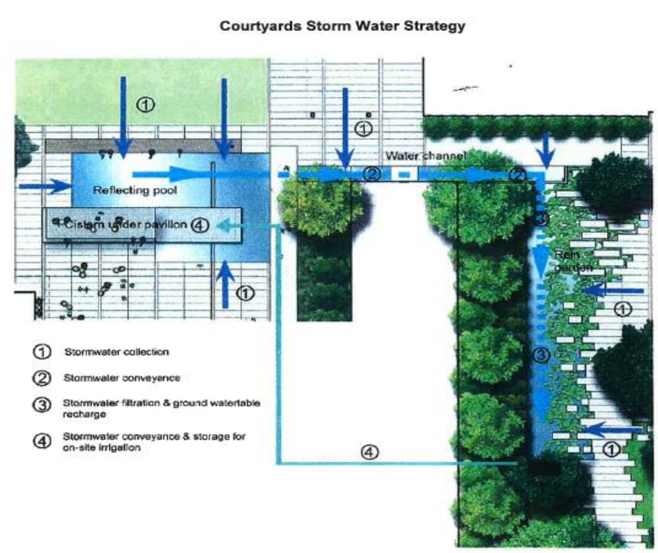

Figure 7: Buchanan Courtyard Water Diagram-Source: Buchanan Courtyard project Manual

University of Victoria (Victoria, Vancouver Island, BC)

Figure 8: Outdoor Aquatic Facility, University of Victoria, Saanich, BC

The University of Victoria (UVIC) is located within the District of Saanich in Vancouver Island, BC.UVIC water audit reviewed specific water uses within the Outdoor Aquatic Facility (OAF).The OAF consists of laboratories, aquatic animal holding facilities as well as a water treatment building. The OAF is the largest water consumer within UVIC, with approximately 18% of all water consumed within the main campus (Reilli, 2013).

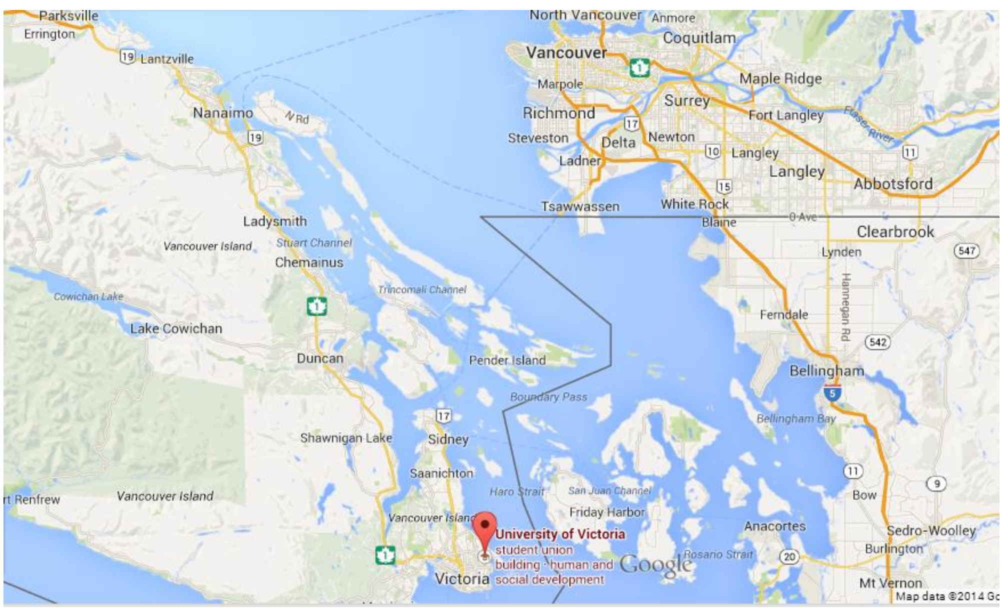

Figure 9: University of Victoria, Saanich, BC-Source: Google Maps

Currently, UVIC treats a portion of the grey water produced from the OAF, city wastewater and seawater for toilet and urinal flushing in number of buildings in the campus.

Brief System Description

Water taken from the grey water holding tank is disinfected with chlorine and ozone prior to use within the ECS and First Nations Buildings and 186 residences. Based on water consumption monitoring between October 23, 2011 and November 15, 2011, the water reuse system used a total of 4,514 m^3 of grey water, or 196 m^3/day(Reilli,2013).

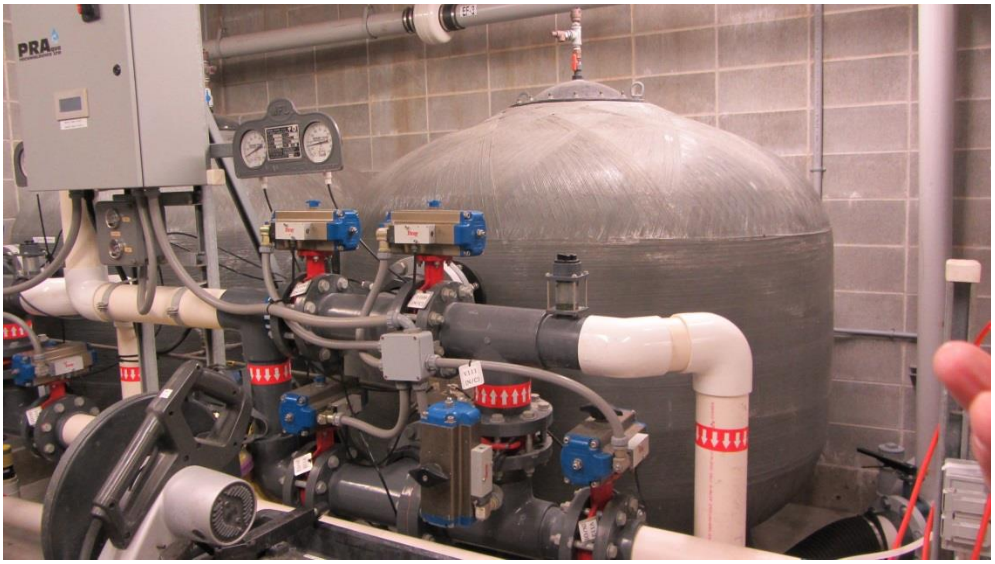

Figure 10: Part of the water treatment system of Outdoor Aquatic Facility (UVIC)-Source: self-taken

Based on OAF's average daily consumption of 330m^3/day, further water reuse opportunities of approximately 134 m^3/day are available to UVIC. These opportunities include toilet flushing, subsurface irrigation practices, fountain use (pending applicable approvals) or for cooling purposes. Utilization of this additional grey water can provide significant cost savings to UVIC. Based on current water charges to UVIC for this water volume, an annual cost savings of approximately $110,000 (water and sewer charges as well as sewer use bylaw discharge fees) could be realized.

OAF uses three different water systems to complete its day to day operations. These systems are:

Freshwater Flow Through System (FWFT): This system provides water to the pathology labs and supplies "make-up" water to the Freshwater Recirculation System. The FWFT filters potable water through 3 Sand filters and 2 activated carbon filters. Chlorine is removed from the city water using sodium thiosulphate and the water temperature can be controlled for use within the pathology labs. Water that is used within the pathology labs is not used within the recirculation system

Freshwater Recirculation System (FWR): Like the FWFT, the FWR uses granular media filtration to remove particulate from the water. The FWR also uses a bio-reactor fluidized sand bed to remove biological waste prior to disinfection with ozone and UV. Water within the FWR is also temperature controlled.

OAF Seawater Recirculation System (OAF-SWR): Seawater brought to site by truck is stored within the seawater reservoir. The seawater is pumped from the reservoir, treated with sand filtration and disinfected with UV prior to use within the facility (Reilli, 2013).

CIRS Building (UBC Vancouver Campus, BC)

Center for Interactive Research on Sustainability (CIRS) building at the University of British Columbia (UBC), opened in late 2011, is a relatively new building that was built with ambitious and aspirational goals with respect to its intended sustainability performance. CIRS was built as a living laboratory for sustainable practices and was designed while keeping in mind the campus' goal of creating a fully integrated energy and water system.

Figure 11: CIRS Building, UBC Vancouver Campus-Source: UBC Website

CIRS was designed to be net positive on environmental performance such as: energy, water, structural carbon and operational carbon as well as on human well-being which could be noted as their health, happiness and productivity.

According to the CIRS Technical Manual Chapter 12, CIRS is designed to be entirely water self-sufficient. In order to achieve this objective, rainwater harvesting system and reclaimed water system were designed and built for this building. In this study we focus on the reclaimed water system at CIRS which has similar concept of the system in Errington LabBuilding that was one of the potential case studies for our research (Vassos, n.d.).

Brief System Description

Reclaimed water system at CIRS is the Solar Aquatic System which is an ecologically engineered system working based on natural processes to consume human biological waste for generating clean water. Purification process in this system is similar to the ones in the wetlands and streams. This system consists of collection tank, blending tank, aeration tank, gravity clarifier, sand filter, constructed wetland, ultra-filter and chlorination step (Rink, n.d.).

All the waste water produced in the building is collected in the collection tank and then is directed to the blending tank and aeration tanks. The nutrients in the water leaving the aeration tanks is more available for reuse process due to the conversion of ammonia to nitrate and more solvable phosphorous. In gravity clarifier which is a cone bottomed tank, all the bacteria settle in the bottom of the tank being separated from clarified water. After that, the clarified water moves through a sand filter and constructed wetlands where tiny particles, fecal coliform and some metals get removed from the water. Then, the water gets disinfected through a two-step process: ultra violet light and adding residual chlorine. The reclaimed water is then channeled to the storage tanks for re-use purposes (Rink, n.d.).

Evaluation:

Reliability:

From these case studies, it was found that they have some failures that occurred during their operation. Many of these failures were regular issues associated with traditional water systems, such as clogged filters, and water quality issues. Regular maintenance and troubleshooting was effective at resolving these failures. The exception was due to frequent vandalism in water features (by blocking openings into the water system using objects in the pool), which, undetected, has caused a dramatic decrease in the flow to the water systems. While easy to resolve, this has caused damaged many components downstream of the vandalized area.

There were some issues experienced by the alternative water systems that were not common to the traditional water systems. These include lack of flow into the systems, unforeseen design issues that affected the system performance, and the system was not built as designed. The first issue, depending on the treatment process involved in the system, may yield undesirable conditions and performance of the system, and ultimately reduce the amount of water available for the end application. In one case, not having enough water stopped the system from irrigating. This issue was resolved by creating a secondary system to add water into the system (at the appropriate location upstream of the problem area). The second issue was due to an unknown parameter that caused issues within the system. However, having a redundant component of the system allowed continued service with unnoticeable interruption to the users.

Commissioning:

As mentioned previously, the last issue relating to the reliability of alternative water systems is the system's congruity with the design, which relates to the commissioning process. While all of the case studies appeared to have undergone commissioning, most of the work has followed the traditional framework. One of the main issues that are not examined during commissioning of alternative water systems includes the balance of flow into and out of the system. When one of the case study water system was initially installed, the system was not functioning as expected. The reason was due to the lack of water supplying the system, causing the nutrient removal process to produce malodourous gases that annoyed the occupants of the building. While efforts were made to minimize the effect, the problem was only resolved once the water supply into the alternative water system was increased dramatically (by increased occupancy), which took another year or so to achieve.

One of the requirements for water reuse systems in the 2012 Municipal Wastewater regulation is the completion of an environmental impact assessment. This involved examining the health risk of the treated water to the occupants and the general public at the point of application, given the design of the alternative water system. Since the local jurisdictions would require certain criteria to be met, this process is likely done as a part of commissioning, even though none of the people interviewed are sure. While it may be useful to detect big flaws in the water reuse system that may undermine the general public's safety, the water quality monitoring process (mentioned later) appeared to have a greater impact on regulatory requirements during the installation and operation of the system.

Another requirement for water reuse systems in the regulation is the operation of the system by a person certified by the Environmental Operators Certification Programs (EOCP). For the operation of water reuse systems at a university, it is likely that an operator with at least level 3 or level 4 is required. The operator would have to have at least 5-10 years of experience working in a wastewater treatment facility under certified personnel of a higher level (usually another level 4), along with the course requirements at that level. This is not a person that would usually be already hired as a part of the university staff. At UVIC, due to the complexity of the system, those interviewed were confused with the requirements of the EOCP to the requirements of the laboratory (the former is for the water reuse system, the latter is the source of the greywater). This is likely related to the current situation at that facility, where the decrease in water from the supply source is causing certain requirements to become more lax (from a change in laboratory work process which did not require as much treatment), and may not necessarily be attributed to the knowledge for those who were interviewed. In the other case studies, only the operator appears to be cognizant of the EOCP requirement. When the owner of the water reuse system is looking to operate the system, it is likely that the owners do not realize this requirement and have to delay the operation of the water reuse system.

Operations/maintenance:

In order for the system to be operated efficiently, a document that details the procedures during operation is required. For all of the case studies, the main procedures relating to daily operation activities are known to the operators of the alternative water system, most of which involves the water quality monitoring. As required by the regulatory agency for water reuse systems, the measurements for water quality indicators taken is taken at least once a week and is kept almost within the drinking water guideline (except for a higher residual chlorine content that makes the water less palatable). In one case study, the testing for some certain indicators occurs several times over a single day. There are procedures in place to deal with any exceedances quickly to each of the water quality indicators.

However, there are few, if any, maintenance procedures set out for the operators in most case studies. In one case study, the operator received the procedure from the designer regarding the operation of the system (that explains what switches are needed to turn the system on and off). Unfortunately, when mechanical problems arose, the operator had no idea where the problem is coming from, and cannot troubleshot most of the problems until the operator made a diagram of how different components intersected with other components of the alternative water system to make the system function. Due to these issues, it became hard for the operator to inspect the system to make sure that maintenance work can be done before critical failure occurs.

Another issue for the operation and maintenance of alternative water system in the case studies came from the lack of manpower dealing with the issues. At one of the case study, one person is responsible for the operation and maintenance of the alternative water system. On the days when the operator is not working, only small issues may be resolved by the plumbers with the aid of a simple operating procedure that the operator drafted. Larger issues would have to rely on external contractor to examine the problem. Due to the lack of manpower, the maintenance work in one case study became reactive.

Occupant training/education:

There was very little information given to the occupants at most of the case studies. At most, signage was placed near the end application (which was only for toilet and urinal flushing). In one case study, the operator allowed occupants to visit the alternative water system so that the occupants can become more familiar with it, which may allay their fears regarding the safety of the alternative water system. Their acceptance of the system allowed the outrage that follows the reliability issues to be better communicated and managed.

Since water is treated very close to drinking standards (with slightly higher residual chlorine), it may not be a concern to notify and educate the occupants. Mainly, the water is not used for potable reasons, making signage seem awkward when occupants already do not drink the water coming from toilet and urinal flushing. However, there was a huge resistance from the regulatory agency regarding irrigation from treated wastewater. While it is desirable to do so, it is not clear to those interviewed. They have attributed this to the idea that treated wastewater may contain harmful substance that can become airborne and pose a risk to the general public.

Occupant perception:

Although the interviews only examined occupant complaints, it appears that there were few complaints, if any, at these case studies. One of those interviewed likened these complaints to be "more like questions" about the system. In one of the case study, occupants were complaining of the smell, which was due to the improper functioning of the treatment system from the lack of flow. In another, there was an error during installation that was not found until later, which, when compounded with other installation and design issues, allowed an offensive odor to reach the occupants.

When the occupants realize an issue with the alternative water system and complain, it appears to be the result of many reliability issues that are not resolved. It does not seem likely that occupants have a huge effect on whether the system's use is continued.

Recommendations to UBC (lessons learned)

To Work Collaboratively:

- One of the main lessons learned is the importance of communication between all the stakeholders at all stages of project life. Architects, environmental engineers, mechanical engineers, operators, regulators and all the other stakeholders involved in any stage of the project: pre-design, design, construction, commissioning and operation should work collaboratively and have shared understanding of the system. In addition, operational feedback during the ongoing system operation should be circulated among all the involved stakeholders in order to understand the actual condition of the system, control the efficiency and consider any required improvements.
- Another lesson learned from this study is the importance of understanding not only one operational sequence but all the sequences and components of water flows in networked water systems. In order to move towards integrated water systems in built

environment all the components should be seen together. The relationship between each of the components, their influences on each other and how they affect the larger system are needed to be intelligently articulated and conceptualized for optimizing the operation. Considering this point during all the life cycle of a project would be advantageous in maximizing the efficiency of the whole system.

- Moreover, any changes to the project scope, regulations, boundaries and components occur in any stage of the project should be announced to all the teams such as design team or operation team who are involved in the project. Because in case of any changes in the whole process, all new ways in which system components could affect each other or the larger system should be understood and the required adjustments should be investigated.
- Moreover, even in the buildings with high sustainability goals, major operational savings and improvements are still possible. Thus, the system efficiency could increase by better processes of construction, commissioning, monitoring and operation.
- Developing a shared understanding of the goals and incentives among all the stakeholders is important to provide a framework and communication link leading to more efficient building operations. The process of specifying and planning strategies to achieve the shared goals could create opportunities for collaboration among the stakeholders and finding creative and efficient ways of operation. In this way, a culture of learning could be created which results in more successful system operation and better team work. It is important to trust in that systems fail and people make mistakes. Therefore, not only failure of a system or human errors does not cause people to blame each other, destroy their relationships and get disappointed at the system, but also motivate them to capitalize on opportunities for improvement.
- Another main finding of this study is the importance of creating a cycle between system design and construction specifically in the case of using novel technologies with high level of complexity. Allocating time to take feedback, circulate among the entire stakeholders and establish a conversation between them to investigate the lessons learned from each phase is an important factor needed to be considered in each project.
- If the proposed system is designed for more than one building, defining system boundaries is important. It may also require redefining the concept of ownership over project responsibilities. When system operational boundaries includes more than one building, it is important to highlight that all the analysis need to be conducted considering the requirements of all the corresponding buildings.
- If monitoring and control points are decided to be installed in a system, accurate operational understanding of the system is required to be developed to identify the reasonable and practical quantities and locations of those points. Without this

understanding, monitoring and control strategies may not deliver accurate reports due to misrepresentation or insufficient information. Having access to high quantities of data is not necessarily helpful. It is important to deeply understand the system operation and investigate which sort of data is useful to be monitored and why. Otherwise, excessive monitoring and control points may cause more problems and confusion in system operational understanding. Moreover, it is important to realize who is going to use those collected data and how easy it is for that person to interpret the data. Considering this point helps to facilitate the data availability and better design of monitoring strategies. Operational data should be accessible and easy to understand.

- The flexibility of the system to new technologies and future improvements and replacements is another important factor. Perhaps it is thought that design phase is the only stage where better system can be developed. However, many improvement opportunities could occur during construction, commissioning and operation phases. Thus, the flexibility of the system is important which provides the opportunity for changes, modifications and adaptation in the system during all the life cycle of a project.
- For the projects in which more than one firm is involved at design, construction and commissioning phase, clarification of the responsibilities and the related costs among them are significantly required.

To highlight the importance of open-door policy and community engagement

- The importance of community engagement is another lesson learned in this study. Buildings' occupants should know where does the water come from, how it becomes available for them and how the water system works in their building. In that case they will realize the importance of their consumption behavior on water and energy resources utilization which hopefully results in more careful consumption behavior. Therefore, having the open door policy is significantly important. System operational data should be available for the occupants and presented in a meaningful and understandable way.

To conduct cost benefit analysis and sizing determination of the system before making any decision

- Cost benefit analysis and sizing determination of the system before making any decision is so important. The stakeholders need to assess the capacity of the supply and know the quantity of the demand to make sure the system selected is economically and operationally reasonable. This would include understanding the frequency of the water demand and water supply, whether it is continuous for certain periods of time, the effect of occupancy on water supply and demand. The designers should also consider the storage required to deal with the possible amount of excess net water supply from the alternative water system during different times of the day, ways to deal with low flow or high flow that may damage the system or cause it to function improperly. Different choices of systems should be considered at the beginning and these feasibility studies and calculations should be conducted for each of them. Then all those systems should be compared with each other to make sure all the different factors and options were considered in the decision process.

- Cost effectiveness of the water treatment system should be analyzed. Proximity of collection points and relative proximity of distribution points are important. If large scale of plumbing and embedded energy is needed to collect and distribute the water, then the system may not be cost effective. It is important to investigate how much the institution pays for purchasing and disposing water and how much cost may be recovered from the operation of the alternative water system. Each case has to be studied in individual basis and business case studies should be done on a case-by-case basis.
- Checking the scalability of the system and its corresponding efficiency is so important. By doing this study it can be understood if the system should be sized for one building, a cluster of buildings or a bigger community.
- Conducting climatic studies of the site (e.g. precipitation data and indoor and outdoor temperature) before choosing, designing and sizing rainwater harvesting systems and wastewater treatment systems is highly recommended. It is important to make sure the amount of rainfall on the site is enough to run the rainwater harvesting system efficiently. It is also important to know what the required temperature for the biological activities is in the grey water treatment system. This information helps the designers to know if outdoor treatment facility works properly considering the average, maximum and minimum site temperature or all the parts of the treatment system are needed to be located indoor with controlled temperature.
- Checking the compatibility of all the sub-systems as well as the wiring system and piping system with the rest of the components is highly recommended. This point is important especially if there are more than one firm involved in the design and construction of the system.
- The amount of water needed for flushing toilets and urinals are easier to be estimated in comparison with the water required for irrigation. Moreover, large amount of water is needed for irrigation during summer time which means the water treatment system should be sized accordingly. However, during winter time, less amount of water is required for irrigation. It is important to consider how to deal with the excess amount of water which will not be used for irrigation in winter time. In the case of toilet and urinal flushing small reservoir may be enough for a building where as for irrigation purposes

large reservoir will be required that will increase the infrastructure cost. Moreover, the aesthetic aspect of storage tanks should be considered as well.

Create partnerships with regulators

- Creating partnerships with regulators is another significant factor. Consulting with regulators early and often during the design process and working collaboratively to address their concerns and requirements are very important notes to be considered.
- It is highly recommended to review all the policy documents and future developing plans of the region (e.g. place and promise, Vancouver campus plan) in order to make sure the intended project is integrated with any other plans.
- Checking all the regulations from the senior levels of government before making any final decision is important in order to make sure there will not be any regulatory barriers for the intended project.

To facilitate system operation

- It is important to note that system operators need to have enough expertise to run and troubleshoot the systems. If the people in charge of system operation are not knowledgeable enough about the system functionality and troubleshooting, designers should be in close collaboration with them since the initial phases and provide them with required amount of training to understand the basics of the system and find an operational expert who would be able to provide the operation team with adequate training sessions onsite.
- It is recommended to prepare a manual of the system operation and making it available and easy to follow in case the main operator is not available. In this way other people can follow the manual step by step and troubleshoot the problems.
- One of the other lessons learned is to make sure the system operators have required qualification (in the case of water reuse systems) considering the requirements of the involved regulatory organizations.
- The storage tank needs to be cleaned from time to time that slime does not stay there for a long time which weakens the disinfection process.
- Any type of operational error should be fixed immediately (e.g. leaking) to prevent major issues to occur.
- Considering a large tank for filtering large objects in the water (such as twigs and branches) specifically in the case of rainwater harvesting systems is important. This tank is used in many wastewater treatment centre to allow these objects to settle out of the water stream, and prevent the filter from clogging up as often to save on maintenance cost.

Future work:

Based on the findings of this project, conducting following studies is recommended in order to gain deeper and more complete understanding of alternative water systems.

- To determine water use activities and the amount associated with the occupants of buildings at UBC. As mentioned in the recommendations, knowing the amount and schedule of reusable water supply and non-potable water demand can assist in the efficiency operation and reliability of a future alternative water system on campus.
- To conduct occupants survey
- To study the relationship between the alternative water systems and energy use and recovery

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Appendix A: Interview Questions to the building owners

General Information of the building owner:

Building:

Part A: Design Information

1) How much water can the alternative water system handle in a day according to the original design?
2) How much water can the alternative water system design store according to the original design?
3) How many permanent and temporary occupants can the building allow?
4) Where does the water entering the alternative water system come from?
5) How is the water treated?
    a. Who was in charge of designing the system?
    b. Were there other building projects using the same system of which you are aware?
6) What is the water used to do after treatment?
    Prompt: Toilet flushing, Irrigation, Laundry water, Dishwasher water

Part B: Operating Information

Commissioning

7) Was a review conducted to ensure that the alternative water system was installed as designed?
8) Was a review conducted to ensure that the alternative water system is operating as designed?
    a. Who is in charge of doing this review?
    b. How often does this occur?
9) Was an environmental impact assessment regarding the installation of the alternative water system completed prior to installation?
10) Were there approvals from the health authority, and building inspectors for the operation of the alternative water system as intended?
11) Does the building meet LEED certification?

Operation

12) Is there a written procedure for operating and maintaining the alternative water system?
13) What is the qualification and training of the person who is operating and maintaining the alternative water system?
14) What is the recommended frequency for taking the water quality measurements and its reporting?

15) What is to be included in the water quality measurements?
16) What is the level to be achieved in these water quality measurements?
17) How many times, during the system's operation, have the water quality measurements gone above the operational levels?

Occupant's training/education

18) Was information told to the occupants regarding…
    a. The function of the alternative water system?
    b. The risks associated with using the system?
    c. The roles and responsibilities occupants have regarding the system's proper use?

Reliability and maintenance

19) How frequent are maintenance done on the alternative water system?

    Once every day | Once every week | Once every two weeks
    Once every month | Longer

20) How frequent do issues with the alternative water system come up?

    Once every week | Once every two weeks | Once every month
    Once every year | Longer

21) What are the issues that occur?
22) How long and how many people does it take to resolve these issues?
23) Which issues are usually found during maintenance? Which are not?

Cost

24) What is roughly the cost of the… (may have to find through documents)
    a. Alternative water system components: ______________________
    b. Installation: ______________________
    c. Environmental impact assessment: ______________________
    d. Commissioning process: ______________________
    e. Operating the system: ______________________
    f. Maintenance on the system: ______________________
25) How long did it take to complete each of these processes? (from documents)
    a. Alternative water system components: ______________________
    b. Installation ______________________
    c. Environmental impact assessment: ______________________
    d. Commissioning process: ______________________
    e. Operating the system: ______________________
    f. Maintenance on the system: ______________________
26) How many people did it take to complete each of these processes?
    a. Alternative water system components: ______________________
    b. Installation ______________________

c. Environmental impact assessment: ______________________________
d. Commissioning process: ______________________________
e. Operating the system: ______________________________
f. Maintenance on the system: ______________________________

Overall

27) What was the objective of installing the alternative water system?
Prompt: reducing water use, becoming LEED gold
    a. Did you believe the alternative water system achieve the intended objective? Why?
28) Given your experience with this alternative water system,
    a. Would you install another one in a future project?
    b. What are the reasons for doing or not doing so?
    c. In what type of building and application would this alternative water system be most appropriate?
    d. What would you change in this system to make it more appropriate for future projects?

Appendix B: Interview Questions to the system operators

General Information

Building:

Water System Information:

1) How much water does the alternative water system handle in a day?
2) How much water can the alternative water system design store?
3) Where does the water entering the alternative water system come from?
4) How is the water treated?
5) What is the water used to do after treatment at this moment?
   Prompt: Toilet flushing, Irrigation, Laundry water, Dishwasher water

Operating Information:

6) What is your qualification and training for working with water systems?
7) How long have you worked on this system?
8) How frequent do you take water quality measurements?
9) What is included in the water quality measurements?
10) How many times, during the system's operation, have the water quality measurements gone above the operational levels?
11) How frequent are maintenance done on the alternative water system?
12) How frequent do issues with the alternative water system come up?
    Once every week   Once every two weeks   Once every month
    Once every year   Longer
13) What are the issues that occur?
14) Which issues are usually found during maintenance? Which are not?
15) How much does it cost to do these repairs?
16) How long does it take to do these repairs?
17) How many people and who (if specific expertise is required) is needed to do these repairs?
18) How easy is it to use this system compared to the traditional water system (only potable water)?
19) Given your experience with this alternative water system,
    a. Would you recommend it be used in another building?
    b. What are the reasons for doing or not doing so?
    c. In what type of building and application would this alternative water system be most appropriate?
    d. What would you change in this system to make it more appropriate for other buildings?