November 10, 2014

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Dear Commissioner McAllister, Mr. Singh and Mr. Ngo:

The Alliance for Water Efficiency and Plumbing Manufacturers International both filed comments in the CEC Appliance Efficiency Pre-Rulemaking, Docket 14-AAER-1, on Title 20 Plumbing Standards. Both sets of comments supported the staff recommendation. One specific issue raised in the Alliance for Water Efficiency's comments is the potential for pathogen growth where there are extremely low fixture flow rates in premise plumbing systems.

While we support the desire of the California Energy Commission to improve the efficiency of plumbing standards in California, we urge that any new standards be based on proven performance of fixtures in the field. This concept of "proven performance" includes the achievement of the efficiency goals set in the standard, demonstrable cost-effective product performance, and avoidance of related critical issues such as unintended impacts on public health and safety. Our concern on the public health question comes from observations of the consequences of extremely low flow rates on total building systems and the difficulty of maintaining the disinfection residual in drinking water necessary to protect public health.

The Water Research Foundation has undertaken scientific research that clarifies what is known about this issue in green buildings, specifically addressing the issue of pathogen growth in end-use premise plumbing fixtures. Unfortunately, the report on Project 4379 will not be publicly released until early 2015. However, in view of the importance of your upcoming regulatory proceeding, the Foundation has graciously consented to share a preliminary draft of the report's conclusions. Attached is a draft of the final report which is not meant for general circulation, but is provided as a pre-publication version specifically for CEC's consideration. It identifies what is known and not known about this emerging issue of legionella and pathogen growth in efficient premise plumbing systems. We have also attached a one-page excerpt of some of the relevant issues.

Should you have any questions about the project report or its conclusions, we recommend that you contact John Whitler of the Foundation at JWhitler@waterrf.org for further information.

We stand ready to provide whatever information or assistance you may need for this important regulatory proceeding. Please feel free to contact us.

Sincerely yours,

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Excerpts from Water Research Foundation Report 4379: State of the Science and Research Needs for Opportunistic Pathogens in Premise Plumbing

- As more water conservation-specific devices enter the market, despite being NSF/ANSI certified for different health criteria, similar concerns are likely to arise. Fundamental research will be necessary to understand and resolve these problems before such devices can be used with confidence. Results/Conclusions, pg. xxv

- Opportunistic premise plumbing pathogens (OPPPs) are now the leading cause of water borne disease in developed countries (CDC, 2011). Section 3.2.1, pg. 11

- The effects of continuous versus intermittent flow, regardless of overall water age, and the effects of high versus low flow rate are unclear. Section 3.6.1.4, pg. 49

- Adding another layer of complexity, intermittent high and low flow could further alter how microorganisms grow and are released from biofilms. Clearly, studies examining stagnation versus flow, and high versus low flow rate, have shown contradictory results thus far. There is a need for more research in this area to help explain these discrepancies. Section 3.6.1.4, pg. 50

- While achieving water conservation is an important and noble goal, for reasons that are not yet clear – perhaps because of lower flow or specific components of these devices, these devices may pose a health concern to some individuals. Section 3.6.2.2, pg. 52

- The low flow through water-reducing faucets is linked to low pressure and an increased stagnant volume of water in the pipes leading to the tap. This could provide ideal growth temperatures (35oC) for Legionella spp. And Pseudomonas aeruginosa (Halabi et al, 2001). The reduced flow and pressure could be incapable of providing enough water volume or turbulence to properly flush and "clean" the faucet (Chaberny and Gastmeier, 2004; Yapicioglu et al, 2011), which has implications for biofilm attachment and release rates that are not well understood. Section 3.6.2.3, pg. 52

5.4. FIELD SITE #2

5.4.1 Background

The second field site (FS#2) is an experimental single-family dwelling that simulates hot water demand of a family of four (65-85 gpd). Water is supplied to FS#2 by a large eastern surface water drinking water utility (Utility #2), which uses a free chlorine disinfectant residual and orthophosphate corrosion inhibitor. The purpose of the experimental building is to evaluate the feasibility of achieving net-zero energy in a typical residential setting using various energy-conserving technologies. For the hot water system, an 80 gallon "pre-heat" tank is installed upstream of an 80 gallon electric heat pump water heater to decrease the electrical demand for the entire hot water system (Figure 5.9). The pre-heat tank uses a glycol heat exchanger from the solar panels. Copper pipes are used upstream of the water heaters and hot and cold water distribution manifold. All plumbing downstream of the manifold is $^{3}/_{8}$" diameter flexible cross-linked polyethylene (PEX) tubing.

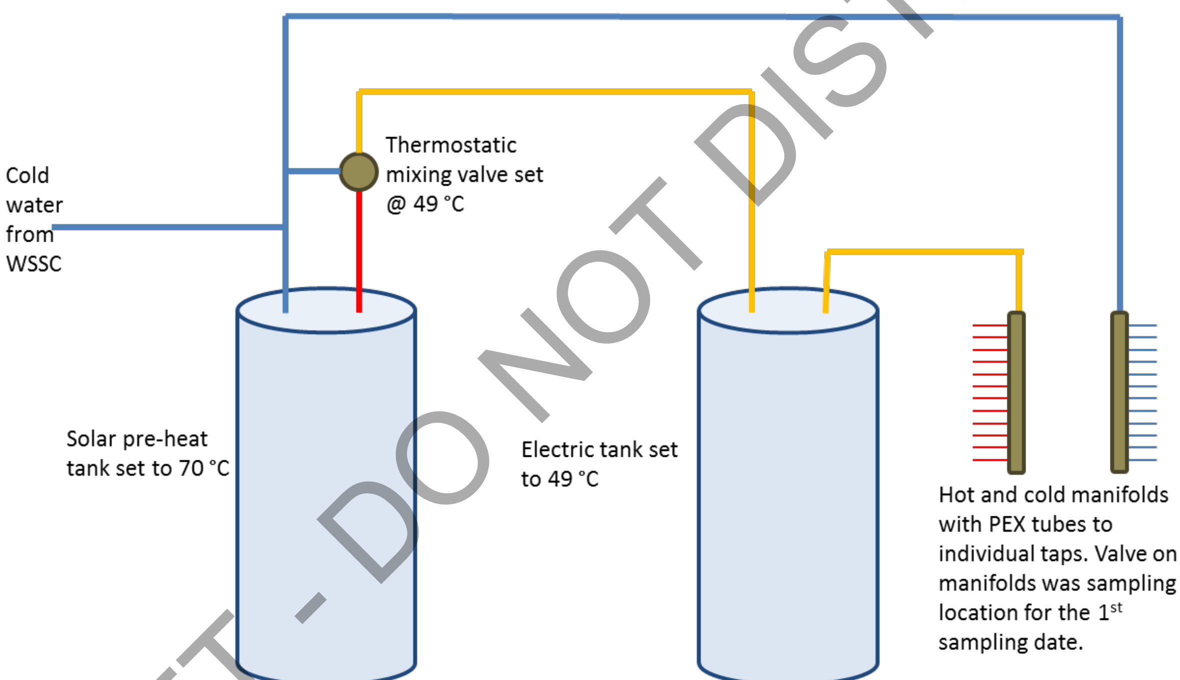

Figure 5.9. Schematic of solar pre-heat and electric water heater setup (all plumbing is copper up to the manifold systems).

5.4.2 Context

After construction was completed in early 2013 and all water systems were tested, they sat stagnant for several months while the research team was outfitting the house with monitoring equipment. In March of 2013, the hot water system was turned back on to begin testing the monitoring equipment associated with the solar pre-heat tank. At that time, a foul (rotten egg) odor was originating from the hot water during flushing. The heaters were increased to 60 °C for several hours and flushed thoroughly, after which the smell was no longer present. The smell was attributed to sulfate reducing bacteria growing in the stagnant water, which were remediated by high temperatures and flushing. However, the presence of the 80 gallon preheat storage tank posed additional concerns due to the increased hot/warm water storage and resulting increased water age within the hot water system. The purpose of sampling this building was to assess the extent to which the water storage was increased versus a conventional building and to determine if any risk factors resulted.

5.4.3 Methods

Sampling occurred on two separate dates. During the first date, a profile of the hot and cold water quality in the building before the experiment started was obtained. To accomplish this, flushing from the cold and hot lines were conducted downstream of the water heaters at the cold and hot manifolds. Stagnant and flushed samples were collected and analyzed for metals, major anions, water chemistry (temperature, pH, chlorine, total organic carbon), and selected bacterial and opportunistic premise plumbing pathogens (OPPP). Samples were also collected directly from the bottom of the solar and electric water heaters. After flushing had occurred, temperature recovery times of the electric and solar water heaters were quantified.

During the second day of sampling, the experiment was fully underway with well-defined daily water use patterns (e.g., Table 5.6). To collect samples without interfering with the energy testing associated with using hot water, samples were taken from a tap during the three automated showering events. All water collected during the shower events was tempered to 40 °C. After the three sampling events, additional samples were taken directly from both the solar and electric water heater.

Table 5.6
Timing of water flow events. The three 8.75 gallon events were the simulated showing events sampled during the second sampling visit.

Friday		
Start time	FixtureID	Volume (gallons)
3:33 AM	SinkMastBath	0.52
4:02 AM	SinkMastBath	0.52
6:04 AM	KitchenSink	0.52
6:05 AM	Simulated Shower 1	8.75
6:12 AM	SinkMastBath	0.52
6:25 AM	KitchenSink	0.52
6:32 AM	KitchenSink	0.52
6:33 AM	Simulated Shower 2	8.75
6:39 AM	SinkMastBath	0.52
6:40 AM	KitchenSink	0.52
6:42 AM	SinkMastBath	0.52
6:44 AM	Simulated Shower 3	8.75
6:51 AM	KitchenSink	0.52

For comparison, samples were collected from a conventional house that has no green features located within the same distribution system. Only hot and cold water samples were taken as a function of flushing from the kitchen sink.

5.4.4 Results and Discussion

After reviewing profiles of hot and cold water during flushing events and comparing these data to a conventional home with no green features, results from the simulated showering events are presented. A final section presents and discusses qPCR results.

5.4.4.1 Cold tap flushing profile. The total chlorine residual in both the net-zero test house and the conventional house verified concerns about effects of storage and water age (Figure 5.10). The conventional baseline house reached a steady residual within three minutes of flushing at 1.5 gpm, whereas it took >20 minutes of flushing to attain a similar residual at the net-zero house at 2 gpm. The net-zero energy house has a longer service line, has newer a service line and pipes, and had stagnant conditions associated with construction prior to sampling, all of which tend to decrease chlorine residuals to the building despite purposeful and very thorough flushing the of lines 1-3 days before sampling.

The pH of stagnant samples was about 0.5 pH units greater than the rest of the flushed of the samples, likely due to the high amount of stagnation in the tap that was sampled. Similarly, ATP, an overall indicator of biomass, was extremely high in stagnant samples vs flushed samples (215 pg/mL vs <2 pg/mL). There were no significant fluctuations in TOC, a basic measurement of the total amount of carbon nutrient potentially available for microbiological growth (range 1.29-1.44 mg/L).

Stagnant samples from this visit indicated there was elevated lead in some samples. For instance the first flush sample for the cold tap had 14.3 μg/L total lead. However, the sample port available was a brass hose spigot on the manifold that was rarely, if ever used. Copper and zinc were also elevated in that sample (0.61 mg/L and 0.29 mg/L, respectively), which is consistent with the notion the stagnant brass sample port caused the high lead. No other inorganic constituents appeared to be elevated or change significantly of the course of flushing.

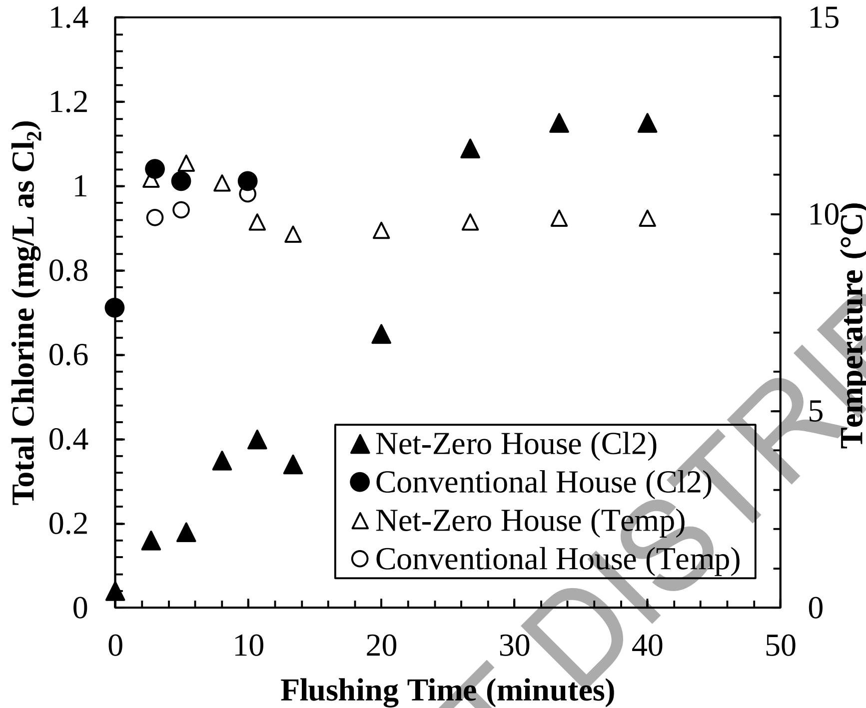

Figure 5.10. Chlorine residual and temperature measurements at cold taps as a function of flushing time for the net-zero energy house and an ordinary household with no green features (all flushing times normalized to 1.5 gpm flow rate).

5.4.4.2 Hot tap flushing profile. The temperature setting of the solar water heater at the net-zero house was different from the temperature setting for the electric water heaters at both the net-zero and conventional houses. At the net-zero house, the solar heater was set to 70 °C, but reportedly never exceeded about 60 °C (personal communication). Water exiting the solar heater and entering the electric water heater is tempered to 49 °C using a thermostatic mixer (Figure 5.9), and the electric heater is set to 49 °C. The conventional household targets 49 °C as well. It is apparent that neither household consistently hits the thermal target (Figure 5.11). The net-zero house water temperature decreased from 50 °C to 35 °C within five minutes of flushing at 2 gpm. The conventional household maintained temperatures in the 40 °C range for approximately 20 minutes at 1.5 gpm, then gradually decreased as more cold water entered the heater, but never reached 49 °C.

After 20 minutes of flushing, chlorine residuals in both systems began to increase markedly. The conventional house chlorine residual increased at a faster rate than the net-zero house, presumably due to the lower overall hot water storage volume (75 gallons vs 160 gallons). It was expected that the net-zero house would require two times the amount of flushing as the conventional house to achieve a chlorine residual comparable to the main distribution system because the storage was doubled. However, both systems reached concentrations of about 1 mg/L as Cl_2 after about an hour of flushing. Because both the solar and electric water heaters at the net-zero house had no disinfectant residual in them at the time sampling began, it would be expected that the entire 160 gallons of storage would need to be flushed in order to measure a residual at the hot tap. However, a significant residual (1 mg/L as Cl2) appeared after about 100 gallons of water had been flushed. This suggests that cold water in the solar pre-heat tank might be short circuiting the solar tank volume. In any regard, it seems unlikely that either system has a consistent chlorine residual in it during regular use, given that it took 30 minutes of flushing to obtain significant disinfectant residuals in both systems.

After the system in the net-zero house had been completely flushed such that there was no hot water in the tanks, and water temperatures in both the solar and electric water heaters were similar to temperatures observed of the cold water distribution main (15-17 °C), temperature recovery profiles of the two heaters were examined. One hour after flushing, the electric water heater had recovered to 90% of the initial temperature of 50 °C. The solar water heater temperature did not increase during this one hour period, with a 47% difference between the temperature one hour after flushing and the heater set point. Although the temperature and chlorine residual profiles of the net-zero and conventional household hot water systems were not strikingly different as a function of flushing, the solar water heater did not recover quickly, allowing the system to remain at non-optimal temperatures for controlling pathogen growth.

Similar to the cold water tap, the hot water tap at the net-zero house did not have out-of-the-ordinary chemical profiles. ATP was consistently higher in the hot water samples than the cold water, but only by about 2 pg ATP/mL. The highest concentration of ATP in the hot water flushing profiles was only 3.5 pg/mL, which is well within recommended upper limits of low ATP water (10 pg/mL as defined by LuminUltra, Ontario, Canada). TOC was also slightly elevated compared to the cold water samples (1.51 mg/L vs 1.41 mg/L). Although assimilable organic carbon (AOC) was not measured, levels as low as 10 μg/L have been shown to limit *Legionella* growth (van der Wielen and van der Kooij, 2013). If a fraction of the measured 0.1 mg/L difference was AOC, it has the potential to support bacterial regrowth.

The hot water samples had elevated lead, copper, and zinc. Lead and copper levels were above the action limit of 15 μg/L and 1.3 mg/L, respectively, in first draw samples. As flushing continued, all levels gradually deceased (Figure 5.12). Because there were very strong correlations between lead and copper (Pearson's $R^2 = 0.83$) and lead and zinc (Pearson's $R^2 = 0.98$), it is likely that the high level of inorganic contaminants at this tap was a product of the infrequently used brass sampling port . This conclusion is supported by results presented in the next section, where samples taken from a shower head fixture had lead levels < 3 μg/L.

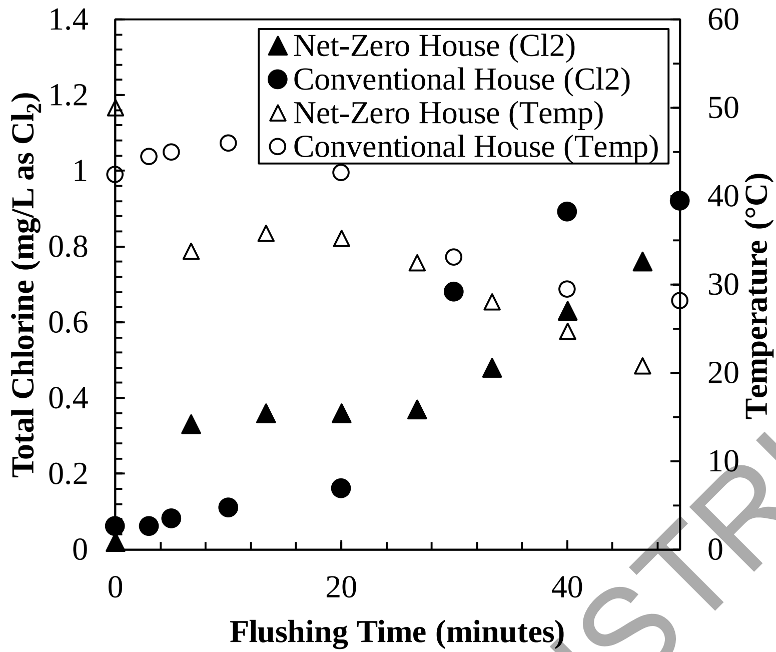

Figure 5.11. Chlorine residual and temperature measurements at hot taps as a function of flushing time for the Net-Zero Energy house and an ordinary household with no green features (all flushing times normalized to 1.5 gpm flow rate).

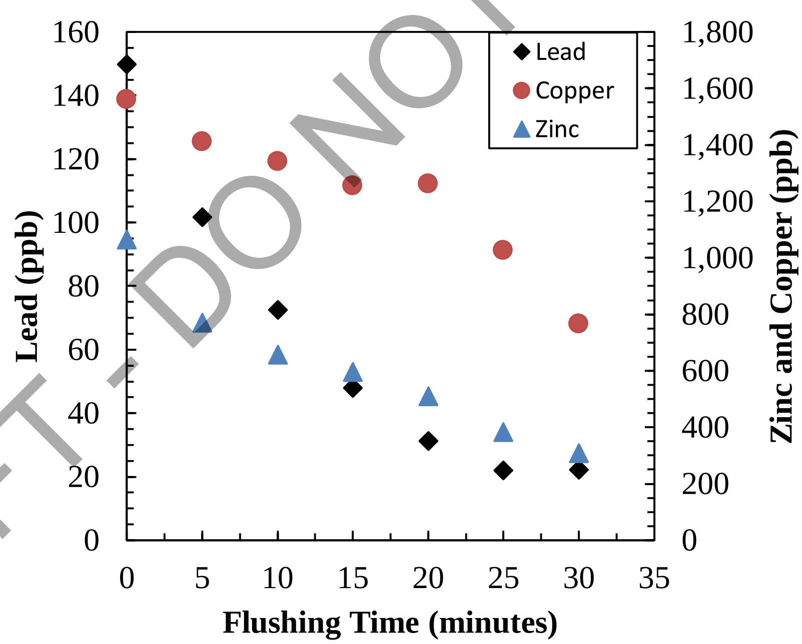

Figure 5.12. Lead, copper, and zinc concentrations as function of flushing at the hot tap

5.4.4.3 Simulated showering events. The temperature during all three showers was targeted to 40 °C, which is a markedly higher than the maximum temperatures observed during flushing of the hot water tap during the previous sampling visit (33-35 °C; Figure 5.11). However, excluding the first sample at the start of the first shower event, which was <30 °C (probably stagnant water in the line), the thermal target was consistently met (Figure 5.13). The total chlorine delivered to the water heaters never exceeded 0.1 mg/L as Cl_2, which is consistent with expectations based on hot flushing results up to 20 minutes (Figure 15.3). Because these three showering events represent the highest water usage in this experimental home a significant disinfectant residual is never observed in the shower.

With the added hot water storage volume to accommodate the solar preheat tank, the net zero system turns over 3.12 times weekly, as opposed to 6.25 times weekly in the conventional house for the same demand (500 gallons per week). The lower turnover and increased water age decreases the likelihood of maintaining the chlorine residual in distal sites.

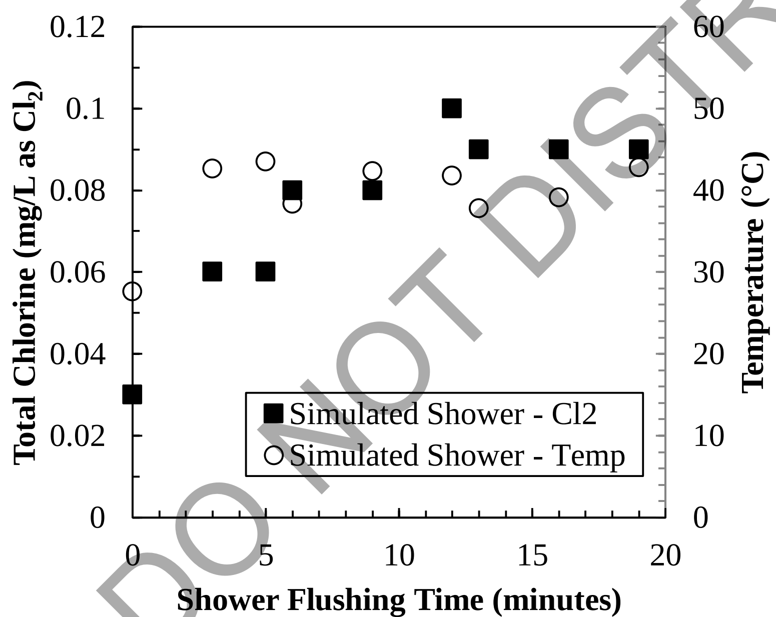

Figure 5.13. Total chlorine and temperature profiles during three simulated showering events (shower #1 from 0-7 minutes of flushing; shower #2 from 7-14; shower #3 from 14-19). Water was turned off and on again between events (refer to Table 5.6)

5.4.4.4 qPCR results. Exploratory biological sampling revealed several insights. First, it appeared there was regrowth within the hot and cold temperature water systems downstream of the water heaters. There was approximately 2 logs more overall bacteria (as measured by 16S rRNA; Table 5.7) and up to a 2 log increase in *Legionella* spp. at the manifold sampling locations, but not in the simulated showering events. This supports the idea presented earlier that the higher water age at these infrequently used sampling ports could be the cause of bacterial regrowth as well as the elevated lead and copper observed at these taps. In addition, there was clear regrowth of *V. vermiformis* within the plumbing system. Samples downstream of the water heaters had higher concentrations (~3 log increase in gene copies/mL) and prevalence of *V. vermformis* than the samples taken from the heaters themselves, where samples were consistently below the quantification limit of the assay.

The opposite was true for *Legionella* spp. or *M. avium*. *M. avium* occurred and at a lower frequency than *Legionella* spp. Anecdotally, this supports observations of other researches where water in one system using free chlorine residual was more resistant to *Mycobacterium* growth than *Legionella* growth, whereas the opposite trend was observed when the residual was switched to a chloramine (Moore et al., 2006). It is again noteworthy that the concentrations of *Legionella* spp. were very high as compared to the OSHA standards of 10,000 CFU/L and 100,000 CFU/L. These results, as well as the comprehensive work by the U.S. EPA referenced in Section 1.3.1, highlight the gap between standards and the prevalence and concentration of *Legionella* occurring in practice. (OSHA, 1999; U.S. EPA, 2014).

Table 5.7
Quantitative polymerase chain reaction results for both sampling dates at the net-zero house.

Sample Description	Flushed/ Stagnant	log 16S rRNA (gene copies/mL)	log V. vermiformis (gene copies/mL)	log M. avium (gene copies/mL)	log L. spp. (gene copies/mL)
Cold Manifold Trip 1	Stagnant	7.81	0.50	0.50	4.67
Cold Manifold Trip 2	Stagnant	6.68	3.44	0.50	3.73
Hot Manifold Trip 1	Stagnant	7.59	2.88	3.16	4.30
Hot Manifold Trip 2	Stagnant	7.69	0.00	0.00	5.97
Shower event	Stagnant	5.44	2.86	0.50	3.11
Shower event	Flushed (10 gal)	4.16	2.40	0.50	0.50
Shower event	Flushed (30 gal)	3.60	0.50	0.50	2.57
Water Heater Trip 1	N/A	5.40	0.50	3.11	3.54
Water Heater Trip 2	N/A	5.03	0.00	0.50	0.50
Solar Heater Trip 1	N/A	5.08	0.50	2.98	3.81
Solar Heater Trip 2	N/A	4.18	0.00	0.50	0.50

*A value of 0.5 indicates the genes were detected, but not in quantities above the quantification limit of the method.

5.4.5 Conclusions

- The solar preheat tank doubled hot water storage and water age within the net-zero house.
- The large hot water storage volume likely contributes to the lack of chlorine residuals in the building, though there may be cold water short circuiting during high flow events.
- Exploratory OPPP data reveals regrowth downstream of the water heaters in the infrequently used sample ports, at least with 16S rRNA and *V. vermiformis* assays. In addition, *V. vermiformis* was elevated in the firsts two showering samples, indicating regrowth in the pipes downstream of the manifold.
- Both *M. avium* and *Legionella spp.* were detected at a high frequency at infrequently used taps in both hot and cold water systems.

- Overall, this case study provides additional evidence that long stagnation events, lack of chlorine residual, and large storage volumes can trigger problems with microbial growth and inorganic contaminants.
- There is a need for recommendations in standards and guidelines that tie specific levels of *Legionella* collected via a defined sampling protocol, with specific remedial actions and responses.

5.5. FIELD SITE #3

5.5.1 Background

The third field site (FS#3) is a small net-zero energy and net-zero water office building that houses 3-5 full time employees. Rainwater is collected via rooftop (1,000 ft^2) with a first-flush diverter and then stored in a 3,000 gallon cistern for all potable and non-potable uses. To avoid stagnant water within the cistern, solar-powered pumps automatically recirculate 600 gallons of the rainwater in the cistern through the cold water plumbing system, including the treatment system, twice daily. The water treatment system includes a 20 µm filter, a 5 µm filter, and a granular activated carbon (GAC) filter followed by ultra violet light irradiation at 253 nm. At potable taps (in bathrooms and a kitchenette), an additional 1 µm final filter is installed. The filters are changed semi-annually or when there is a high pressure drop through the system as they become clogged. Twice a year the water is treated with a high concentration of bleach (> 50 ppm) and continuously recirculated for 24 hours. After this period the water is drained and the cistern is primed (i.e., filled halfway) with groundwater from a nearby building supplied by local groundwater. Thus, this net-zero building is not actually net zero, because it regularly uses groundwater for recharge and maintenance. In addition, there is some concern that these maintenance practices may cause or facilitate other water quality issues (Table 5.8).

Table 5.8
Potential negative effects of routine maintenance procedures.

Treatment	Potential Issue
GAC filtration	Act as a sink for contaminants such as Pb and metals; Constant supply of dissolved oxygen; Infrequent replacement may facilitate sloughing of biofilm, potential shielding from UV disinfection
UV irradiation	Regrowth potential downstream of UV not addressed
1 µm filter at potable tap	Act as a sink for contaminants
Recirculation of water	Creates completely mixed system; Assists accumulation of contaminants on GAC filters
50 ppm chlorination*	Pitting corrosion in copper pipes; May be ineffective against organisms protected in biofilms; Regrowth potential after reducing biofilm (necrotrophic growth) not addressed

*the facility reduced the concentration of bleach to 10 ppm after the sampling visit

As part of the effort to reduce overall water demand in the building, composting toilets were installed and outdoor irrigation was not installed on the property. All grey water effluent is land-applied to an infiltration field adjacent to the building. In addition, all sink faucets in the building are equipped with a low flow restrictor with a 1 gpm flow rate. Half-inch copper pipes supply individual faucets while ¾" copper pipes are used elsewhere in the system. There were no consumer complaints or other known issues with this water system before sampling. In fact, the water quality was regarded by some users as the highest quality of water they have tasted.

5.5.2 Methods

Stagnant and flushed water samples from hot and cold taps in the men's restroom, the kitchenette, and a janitor's closet (not considered potable) were collected to generate a profile of water quality data. In addition, samples were taken directly from the rainwater cistern and directly after the GAC filters and UV tube.

5.5.3 Results and Discussion

After reviewing general information about the use and daily operations of the system, a section on the water quality in the building is presented. A third section discusses qPCR results, followed by general comments on the scalability of this model of water system.

5.5.3.1 Water use. Although there were no water meters on this system to determine the exact demand, the facility estimates that an average of 13,000 gallons is used annually. If this were the case, the 3,000 gallon cistern would be turned over only 4.3 times per year, resulting in an average water age within the system of a little less than 3 months. This water age is unprecedented in convention buildings using municipally supplied tap water. However, upon sampling it was discovered that alkalinity, calcium, and magnesium were much higher than concentrations found in rainwater (~110 ppm as $CaCO_3$, ~12 ppm Mg^{2+}, and ~30 ppm Ca^{+2}) and the water sampled in the cistern was more representative of the local groundwater. The groundwater was pumped into the facility, using on-the-grid electricity, during routine maintenance conducted nearly four months prior to sampling. Based on conversations with facility staff and observations made during sampling, the total annual demand of this facility is probably closer to about 5,000-8,000 gallons, which indicates that 38-60% of total water use in the facility is actually groundwater used for routine maintenance purposes. Indeed, using the calcium and magnesium as a tracer, and assuming that the rainwater have zero hardness and would dilute the groundwater, approximately 40-50% of the water in the cistern at the time of sampling was groundwater. In addition, there is a fire suppressant system that is supplied by the same groundwater and a small firefighting pond located directly adjacent to the building as an on-the-grid emergency backup.

5.5.3.2 Water quality profiles. The pH measured in most of the samples of 7.6 (Figure 5.14) in samples was also inconsistent with typical rainwater levels (pH ~5.5). Stagnant samples from potable taps generally had lower pH, yet a stagnant sample from a janitor's closet, which was not considered potable water and thus did not have an additional 1 μm filter, did not have a lower pH. It is possible that microbial activity on the 1 μm filters contributed to the decrease in pH, but this was not confirmed with BARTs run that were inconclusive.

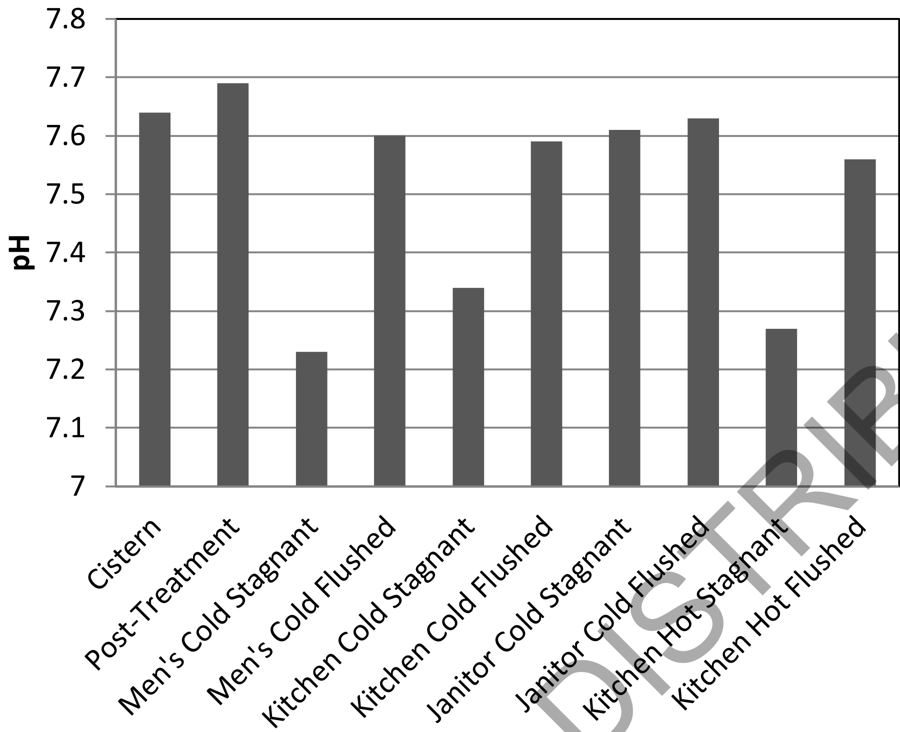

Figure 5.14. pH readings for samples taken at FS#3

In a similar trend, ATP was higher at the potable men's room and kitchenette taps compared to at a non-potable taps and directly downstream of the GAC filters and UV system or the janitor's closet (Figure 5.15). The potable taps had 7 to 17 times more ATP than treated water, again suggesting a high amount of regrowth occurred at or downstream of the1 μm filters.

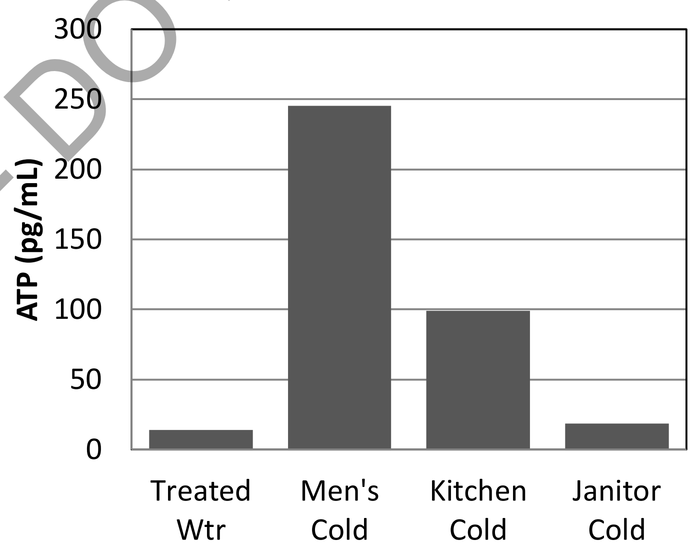

Figure 5.15. ATP concentrations at various locations in the building

Temperatures in the cold water taps were considerably higher than what is encountered in municipally supplied systems. The temperature in the cistern and in both stagnant and flushed water samples was on average 26.5 °C (standard deviation = 1.3 °C), or indoor room temperature. This was to be expected, however, given that the cistern is effectively indoors. While stagnant samples would likely have elevated temperatures regardless of system type, higher temperatures throughout the system could be problematic. It is suggested that remaining below 20 °C in cold water systems helps to minimize growth of bacteria in general and OPPPs in particular (ASHRAE, 2000). For more conventional systems, periodic flushing may assist with achieving this target; however, water temperatures are dependent on the climate and frequency of flushing.

Metal concentrations in all cold water taps were less than half the U.S. EPA action limits for lead and copper. For example, the ranges for total lead and copper concentrations were 0.1 – 7.7 ppb and 0.02 – 0.57 ppm, respectively. If rainwater was the primary water in the cistern as advertised, the pH and alkalinity would have been significantly lower than the pH and alkalinity measured (pH 7.6 and 110 mg/L as $CaCO_3$) and the water would have been much more corrosive. Since the majority of the water in the cistern was leftover water from the semiannual maintenance, the water is not considered corrosive, and therefore it is not surprising that the amount of lead and copper in the water was not higher. If the system were operated as truly off-the-grid, it is possible and even likely that a higher concentration of lead and copper would be detected. Low pH waters (<6) and low alkalinity (<20 mg/L as $CaCO_3$), similar to typical rainwater quality, would be expected to be the most corrosive (Edwards et al., 1999; Dodrill and Edwards, 1995; Gardels and Sorg, 1989).

Hot water was supplied using 2.5 gallon water heaters with the thermostat set to 50 °C. Although the stagnant water temperatures were at room temperature (25 °C), the thermal target was met within 10 seconds of flushing due to the proximity of the heaters to the taps. Metal concentrations in hot water samples were also well below U.S. EPA action limits (average of 4.2 μg/L for lead and 0.51 mg/L for copper).

5.5.3.3 qPCR results. There were no significant differences in overall bacterial concentrations as measured by 16S rRNA, even directly downstream of the UV treatment (Table 5.9). This is not unexpected, as the qPCR assays pick up both live and dead organisms. No regrowth was observed for *M. avium* or *Legionella* spp. in potable hot and cold water piping and no *L. pneumophila* was detected, but there was nearly a 2-log increase in *V. vermiformis* in both hot and cold taps. Importantly, *V. vermiformis* is an amoeba host for *Legionella*, and it is logical that enhanced growth of this host could sometimes lead to more *Legionella* in some circumstances. *Legionella* spp. was present at very high levels at FS#3 as well.

Table 5.9

Quantitative polymerase chain reaction results for FS#3.

Sample Description	Flushed/ Stagnant	log 16S rRNA (gene copies/mL)	log V. vermiformis (gene copies/mL)	log M. avium (gene copies/mL)	log L. spp. (gene copies/mL)
Cistern Storage Tank	N/A	6.96	2.60	2.00	4.36
Post-Treatment	Flushed 3 min	6.36	3.43	2.61	4.26
Men's Cold	Stagnant	6.77	4.49	2.73	4.58
Men's Cold	Flushed 3 min	6.51	3.00	0.50	3.48
Men's Hot	Stagnant	6.90	4.20	2.65	4.28
Men's Hot	Flushed 3 min	6.52	2.26	3.32	3.34
Janitor's Cold	Stagnant	6.95	2.93	3.69	3.32

5.5.3.4 Scalability. From a practical standpoint, the facility must routinely monitor for coliform and overall heterotrophic bacterial growth to ensure that the facility is compliant with drinking water quality standards. Instead of sampling and analyzing data on-site, as would any municipal water treatment facility, the building staff collects samples and sends them to a certified national lab for analysis to gather data on heterotrophic plate counts and coliform bacteria. This is time and resource restrictive, and the ability for this approach to be scaled to all private water users that treat their water onsite is low. This suggests that as the practice of treating water on-site for buildings seeking complete or partial water independence gains popularity, methods for monitoring water quality at these locations will have to be rethought.

5.5.4 Conclusions

This case study offers several insights into the net-zero energy and net-zero water building approach to potable water:

- This building is not truly off-the-grid, as it uses on-grid electricity and groundwater for routine maintenance and fire-fighting protection. Because this location is generally supplied by well water, the responsibility for maintaining the water connections is simplified. If this building were located where the municipal water utility provided backup, emergency connections, the situation is more complicated. If the majority or even just a large number of buildings in a municipality seek to be off-the-grid, municipal rate structures would have to be adjusted accordingly to maintain the connections for the backup water supply.
- Calcium and magnesium concentrations of the water in the cistern suggest that 40-50% of the water in the cistern at the time of sampling was groundwater. Therefore, the cistern may have been drastically over-sized for the water demand of this facility.

- The additional 1 μm filter might be adversely impacting the quality of the water in stagnant samples. Increased levels of OPPPs and their host organisms, as well as higher concentrations of ATP were detected in potable taps with the additional 1 μm filter.
- High levels of OPPPs and host organism *V. vermiformis* were detected in nearly all rainwater samples, despite the routine water recirculation that occurs twice daily. Although long periods of stagnation are avoided by this approach, the overall water age in the facility is likely on the order of months.

CHAPTER 6: USGBC INSIGHT TECHNICAL REPORT: GREEN BUILDING WATER EFFICIENCY STRATEGIES

6.1 ABSTRACT

This chapter describes compliance paths for projects earning water efficiency credits under LEED for New Construction v2.2. A stratified random sample was taken of all non-confidential certified projects earning these credits under this version of the rating system, and compliance forms for Water Efficiency credits (WEc) 1, 2, and 3 were analyzed. Frequency in use of water efficient landscaping, non-potable water sources, on-site wastewater treatment, and selection of plumbing fixtures and tap fittings were calculated. For WEc1: Water Efficient Landscaping, projects most often avoid permanent irrigation altogether. Rainwater was the most common non-potable water source for those that selected that compliance path. For WEc2: Innovative Wastewater, wastewater reduction was selected over on-site grey- or blackwater treatment. High efficiency toilets and non-water urinals were most often used to meet the high reduction necessary to earn the credit. Dual flush and high efficiency urinals were most often selected for lower (20+% or 30+%) water use reduction needs for WEc3: Water Use Reduction.

6.2 INTRODUCTION

Water use in the built environment is a very important aspect of human civilization. Public supply and domestic use accounts for about 12% of all fresh water withdrawals in the US (Barber, 2009). The energy alone used to run the drinking water and wastewater plants in the US costs about $4 billion each year (Energy Star, 2012). Societally, this water use affects municipal water supply and treatment facility loads. Economically, it affects utility bills and municipal spending. Environmentally, it affects fresh water sources both in terms of volume extracted and pollution added. Because of these impacts, it is beneficial to reduce building water usage rates. There are many different facets of this issue, and many ways of addressing it in buildings, including water efficient fixtures and fittings such as toilets and sinks, collection of non-potable water sources such as rain, and treatment and reuse of wastewater.

The Energy Policy Act of 1992 (EPAct) took a step towards reducing the impacts of building water use by imposing flow restrictions on bathroom fixtures. Since then, many technological advances have been made which can further reduce water impacts while delivering the same level of service expected by building occupants. As a leader in the movement to create built environments that meet the needs of people and life on Earth without sacrificing the long term viability of either, the U.S. Green Building Council has sought to promote these technologies by including their use in the Leadership in Energy and Environmental Design (LEED) rating system for built environments.

In order to achieve certification, applicants must earn credits for inclusion of features in their building that achieve the goals of the rating system. LEED devotes an entire category of credits to efficient water use, covering several aspects of water efficiency. This report aims to describe how projects achieved credits for this category in LEED for New Construction v2.2 through an analysis of compliance paths and choices. Factors investigated include water efficient landscaping, non-potable water sources, on-site wastewater treatment, and flush fixture and tap fitting selection.

6.3 METHODOLOGY

6.3.1 Sample

The research team began with the public LEED project directory from the USGBC website, and a list of all non-confidential projects earning Water Efficiency (WE) 1, 2, and 3 credits under LEED NC v2.2. Non-US and confidential projects were not included in the sample. Owner types were obtained from the public database and statistics were generated to describe their distribution. A stratified random sample was then taken of the WE credit-earning projects based on owner type. The result was a sample of 448 projects earning at least one of WE credits 1, 2, and 3. Credits 1 and 3 were earned much more frequently than credit 2 (Figure 6.1).

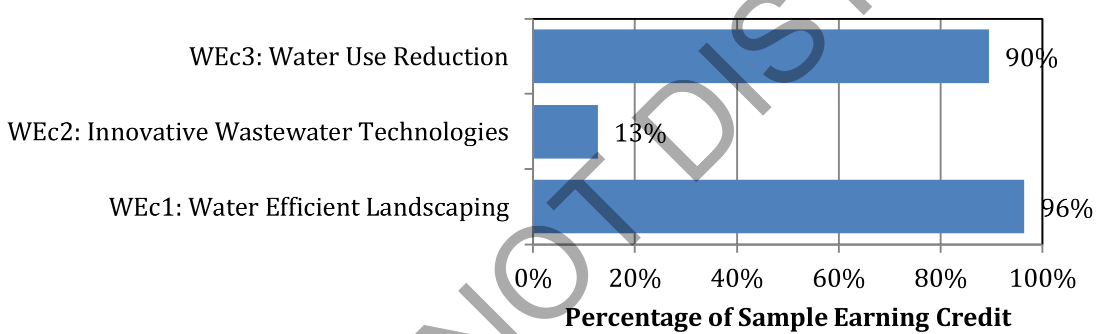

Figure 6.1 Counts of projects earning WEc 1, 2, and 3 in sample

For data validity, credit earning and owner type mentions were analyzed. The percentages of projects earning each credit are approximately equal in the population and the sample. Project teams specified one or more owner types as part of project documentation, and this selection was the basis for owner type classification (Figure 6.2). This stratified random sampling meant that the percentages of projects mentioning each owner type were equal in the population and the sample.

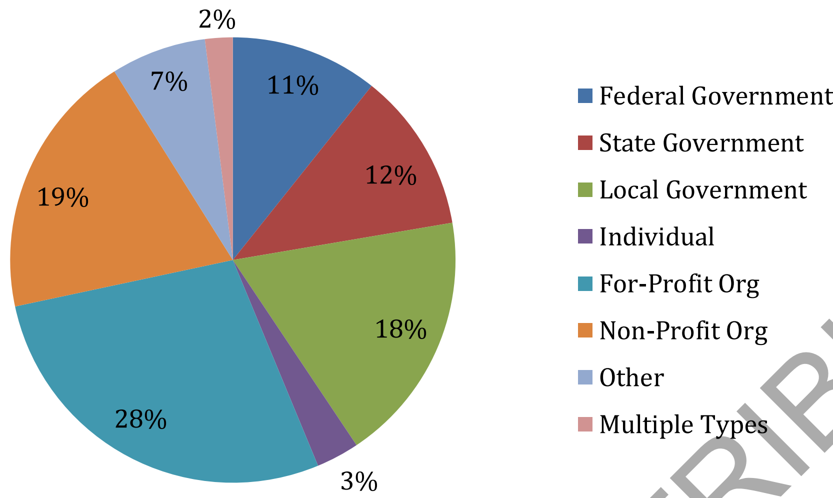

Figure 6.2 Percentages of projects mentioning each owner type

6.3.2 Measures

The data used in this study were drawn from LEED credit submittal forms and from the USGBC list of non-confidential certified projects. LEED credit submittal forms accept input in three different ways: radio buttons, check boxes, and text input fields. Each was treated and displayed differently.

Radio buttons allow a user to select only one of several options. These are presented in this report as pie charts, with data as percentages of projects earning that credit making each selection. This type is used for compliance paths for WEc1 and WEc2.

Check boxes allow a user to select more than one option. Because they are not mutually exclusive, these results are presented as bar charts, with data as percentages of projects with the ability to make a choice selecting each option. This type is used for non-potable water sources in WEc1.

Text field form entry is used to describe and specify flush fixtures and tap fittings in WEc2 and WEc3. Text fields allow manual entry of a description. These are by nature not standardized. The research team generated a list of all unique values, and assigned a standardized value to each. These standardized values are normalized and presented in this report in bar charts, with data as percentages of projects using the flush class of fixtures that used that particular type of fixture, or percentages of tap fittings using a particular flow rate. Projects typically use more than one type of fixture and fitting. For instance, a building might have different types of urinals in different bathrooms. Tap fittings and flush fixtures were categorized by classes and types, as many different brands and flow rates were mentioned. The water closet class included dual flush, high efficiency, compressed air, and composting toilet types. High efficiency toilets are defined as water closets that use a maximum of 1.28 gallons per flush (GPF), which is 20% less water than the current U.S. maximum of 1.6 GPF. Urinal class fixtures were placed in one of two major types: High efficiency and non-water. High efficiency urinals are those that use no more than 0.5 GPF, half of the current U.S. maximum of 1 GPF. Non-water urinals have no flush. Tap fittings include sinks and showers.

These are categorized by type and flow rate. Flow comparisons for water use reduction towards credit compliance are based on EPAct standards.

6.4 RESULTS

6.4.1 WEc1: Water Efficient Landscaping

This credit covered landscaping water use. 401 out of 448 projects (89.5%) in the sample earned this credit. There were four paths to compliance (Figure 6.3), by some combination of reduced irrigation and non-potable water sources, or by removing permanent irrigation altogether. The most commonly selected option was no permanent irrigation. Reduced irrigation consumption is part of options 1 and 3, and between them the technique almost rivaled the lack of permanent irrigation in popularity.

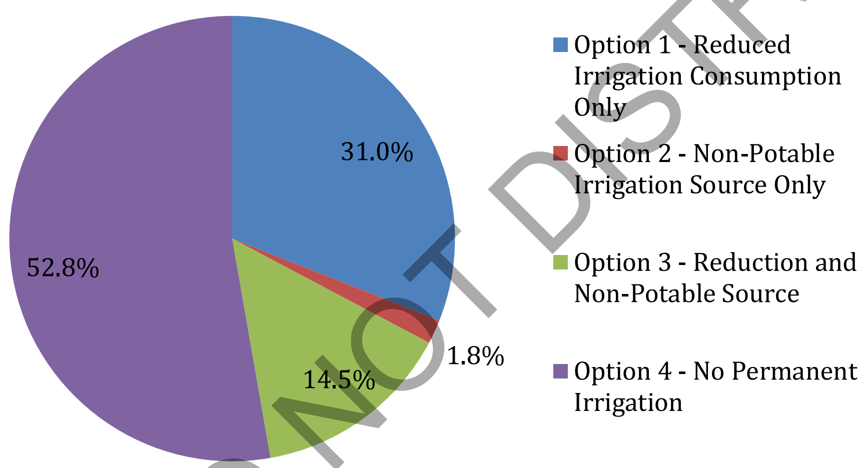

Figure 6.3 WEc1 Compliance path for sample

For those projects selecting option 2 or 3, at least one non-potable water source was listed. Of the 401 projects earning WEc1 in the sample, 65 made this choice. The categories on the forms were rainwater, greywater, wastewater, and publicly supplied non-potable water (reclaimed municipal wastewater that has been treated, but not up to drinking standards), also known as purple pipe. Some projects used more than one source. Rainwater was the most popular choice, followed by public sources (Figure 6.4).

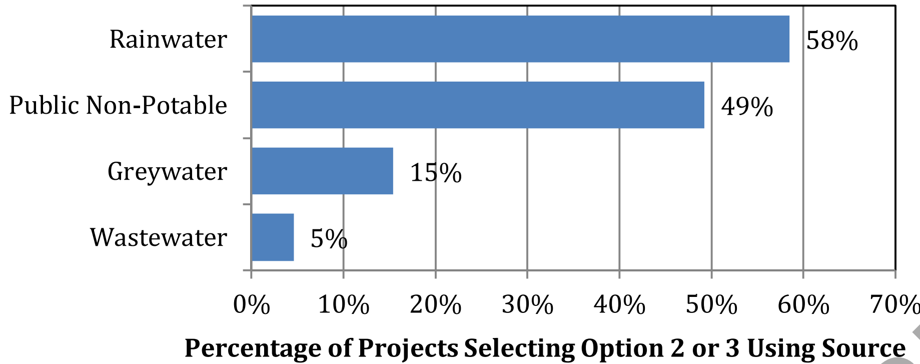

Figure 6.4 WEc1 Non-potable water source for projects selecting option 2 or 3

6.4.2 WEc2: Innovative Wastewater Technologies

This credit addresses generation and treatment of wastewater, and can be achieved either through on-site wastewater treatment or a sewage conveyance water savings of at least 50%, both of which reduce the demand placed on public wastewater treatment facilities by a project. This 50% reduction can be achieved with the use of efficient water closets and urinals. Of the 57 (12.7%) projects in the sample that achieved this credit, most projects selected reduced sewage conveyance based on water savings calculation for their compliance path (Figure 6.5).

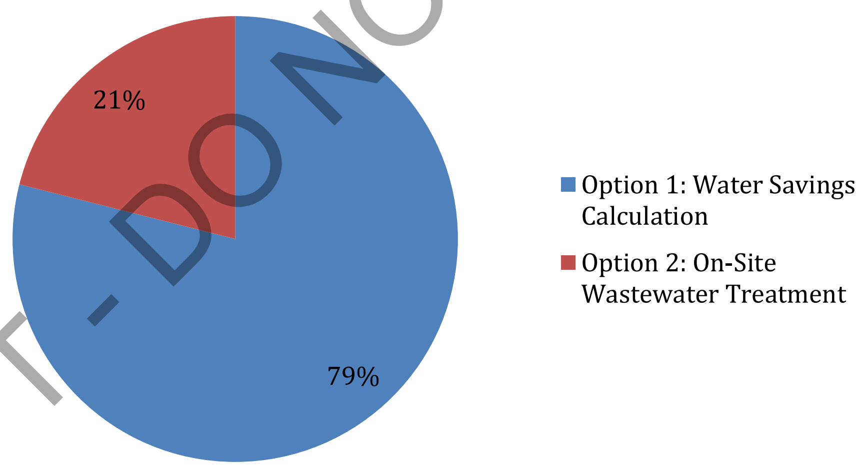

Figure 6.5 WEc2 Compliance path for sample

Although only the projects pursuing the water savings compliance path were required to specify flush fixture types, 54 of 57 (95%) projects achieving the credit provided a description of flush fixtures for the project. Therefore, flush fixtures are given as a percentage of these 54 projects that described flush types (Figure 6.6). Among these, high efficiency toilets and non-water urinals were the most common.

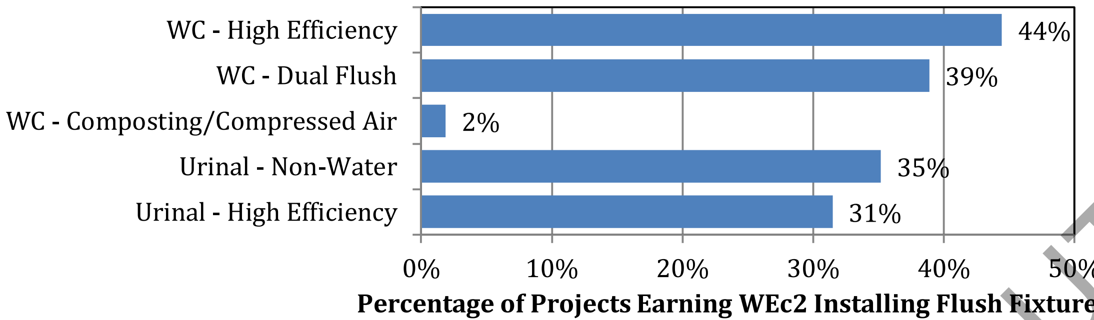

Figure 6.6 WEc2 Flush fixture type usage

6.4.3 WEc3: Water Use Reduction

Water efficiency credit 3 can be earned by reducing water use through efficient tap fittings and flush fixtures to reduce water use in the building by at least 20% for one credit or at least 30% for two credits. These classes are limited to water closets, urinals, lavatory faucets, showers, and kitchen, classroom, lab, or janitor sinks. Projects used some or all of these classes, and some used more than one type within a class. Flush fixture use is given as a percentage of the projects earning WEc3 that used each fixture type for compliance (Figure 6.7). Dual-Flush was the most common type of water closet used, and high efficiency urinals were more commonly used than non-water.

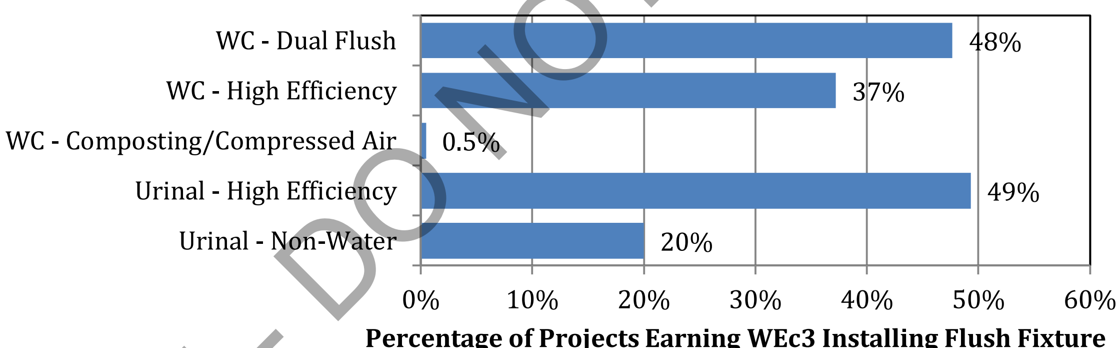

Figure 6.7 WEc3 Flush fixture type usage

Tap fittings described on forms include showers and several classes of sinks. Projects may have multiple taps, so results are presented by type. Use is given as the five most common design flow rates for each fitting type, as a percentage of the type. The average reduction of flow rate from EPAct baseline to design is also given (Table 6.1). The greatest average reduction was in lavatory sinks, at about twice that of the other types.

Tap fitting types were analyzed to find the most common flow rates for each. Projects may have multiple taps, so results are presented by type. Each fitting type had a different distribution of commonly used flow rates (Table 6.2). The most pronounced preference was for 0.5 GPM faucets in lavatory sinks.

Table 6.1

WEc3 Tap fitting average flow reductions.

Tap Fitting Type	Number of Fittings Examined	Average Percent Flow Reduction
Shower	249	35%
Sink - Lavatory	474	73%
Sink - Kitchen	322	35%
Sink - Janitor	48	34%
Sink - Class/Lab	19	43%

Table 6.2
WEc3 Most utilized flow rates for each tap fitting type.

Tap Fitting Type	Fitting Examined	Most Common Flow Rates (GPM)	Percent of Fittings Using Flow Rate
Shower	249	1.5	43%
		2	15%
		1.8	12%
		1.75	10%
		Other	21%
Sink - Lavatory	474	0.5	78%
		1.5	8%
		1	3%
		2.2	2%
		Other	8%
Sink - Kitchen	322	2.2	32%
		1.5	26%
		0.5	14%
		1.8	8%
		Other	20%
Sink - Janitor	48	2	29%
		2.2	23%
		1.5	17%
		0.5	13%
		Other	19%
Sink - Class/Lab	19	1.5	32%
		0.5	21%
		2.2	16%
		1.6	11%
		Other	21%

Results were compiled for all sink fittings, and 0.5 GPM faucets were the most commonly used (Figure 5.8).

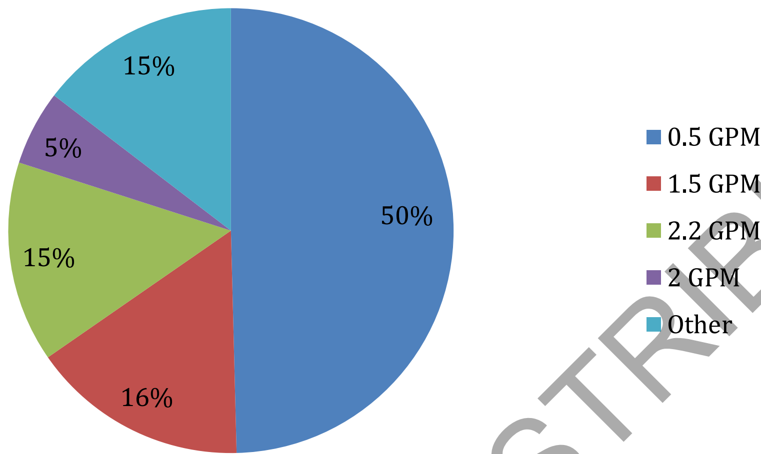

Figure 6.8 WEc3 Most common flow rates for sink fittings

6.5 DISCUSSION

The analysis of WEc1: Water Efficient Landscaping forms showed that non-potable water sources were not used nearly as much as irrigation reduction or elimination. This might be related to the availability of municipal non-potable water, local restrictions on rain or grey water collection, or the simplicity of not having an installed irrigation system. A study of these choices by climate and municipal non-potable availability could be a useful future study. Of the sources mentioned, the heavy skew away from grey and wastewater also bears investigation, perhaps into local ordinance patterns.

With WEc2: Innovative Wastewater Technologies, on site wastewater treatment did not see much use, possibly because the other option of sewage conveyance reduction was partially already covered by flush fixtures used to earn WEc3: Water Use Reduction. This might have provided an easier path to compliance with WEc2 than installing water treatment on-site, as the sewage conveyance reduction was already mostly met for WEc3. There is a difference to be noted between the flush fixture selections, specifically that WEc2, which required a greater wastewater flow reduction, showed majorities for high efficiency water closets and non-water urinals. On the other hand, WEc3, with its lower requirements, tended towards dual-flush water closets and high efficiency urinals. This could indicate that non-water urinals and pure high efficiency water closets are less desirable than the other options when water use restrictions are not as high.

6.6 CONCLUSIONS

While it is true that projects employ many different techniques to earn each water efficiency credit, it is clear from the results of this study that some are much more common than others. WEc1 earners tended towards removing permanent irrigation altogether, and when non-potable water sources were used, they preferred rainwater and public non-potable sources. WEc2 earners tended to avoid on-site wastewater treatment in favor of conveyance reduction, and used non-water urinals and high efficiency water closets to that end. WEc3 earners selected high efficiency urinals over non-water urinals, and tended to select dual-flush water closets over high efficiency water closets. Efficient tap fittings were most commonly used in lavatory sinks, and typically used 0.5 GPM faucets.

As the use of water efficiency techniques in the built environment becomes more common, it becomes even more important to study how it is being achieved by projects. By doing so, practices can be analyzed and improved. This report provides a starting point for future research, pointing to the most commonly used techniques on LEED projects. In this way, research can be directed towards the most useful questions first. Why is rainwater the preferred non-potable water source? What makes projects select dual flush toilets over low-flow? Why are waterless urinals less used than low-flow? Answering these questions could make it easier for future builders to make selections of their own, and for more projects to include water efficient features.

CHAPTER 7: CLIMATE FACTORS

7.1 ABSTRACT

The variation of water efficiency measures in green buildings as a function of climate regions was quantified using project certification documents from the Leadership in Energy and Environmental Design (LEED) for New Construction v2.2 system. These documents included design decisions about landscape irrigation and toilet selections. The distributions of decisions were compared across two climate region classification systems: those used by the National Oceanic and Atmospheric Administration (NOAA) and the US Department of Energy's Energy Efficiency and Renewable Energy (EERE) office. Significant differences were demonstrated in several decisions, including landscape irrigation water reduction choices, which varied in both systems. Water closet choices showed some difference, with dual flush toilets being selected significantly more in the EERE Marine and NOAA Northwest region. High efficiency toilets were selected significantly less in the EERE Marine and NOAA Northwest regions than at least one other region. High efficiency urinals showed differences in only one climate classification system, being selected significantly more in the EERE Marine region than in the Hot-Dry and Mixed-Humid regions. Non-water urinals showed no significant differences.

7.2 INTRODUCTION

Water use in buildings accounts for about 11% of fresh water withdrawals in the US (Barber 2009). Utility scale water extraction, treatment, and distribution are all major operations with significant environmental and public health impacts. To make the most of scarce water resources, a number of strategies have been employed over the years in the building industry.

The Energy Policy Act of 1992 (EPAct) took a step towards reducing the impacts of building water use by imposing federal flow restrictions on new bathroom fixtures. Since then, many technological advances have been made which can further reduce water impacts while delivering the same level of service expected by building occupants.

More recently, policy and habits in environmentally conscious construction and maintenance have been influenced by green building rating and certification systems, such as the US Green Building Council's (USGBC's) Leadership in Energy and Environmental Design (LEED) program. The LEED certification system has been adopted by some of the largest agencies in the US Federal Government, including the General Services Administration (US General Services Administration, 2013), and is by far the most used building certification system that includes water issues in the US with over 25,000 certified projects (US Green Building Council, 2014). LEED promotes water efficiency by giving projects credits toward certification through several avenues, including efficient toilets, sinks, and landscape irrigation strategies.

There are a number of rating systems within LEED, designed to cover different types of construction, renovations, or operations. This paper focused on the version designed for new construction. In order to achieve LEED certification, projects earn credits for including sustainable features and practices in their designs. To earn these credits, they must submit documentation describing design details related to whichever credits are being sought.

The first few iterations of LEED were meant to be broadly applicable to encourage participation, and as such did not have any region or climate specific guidelines. They did, however, allow participants freedom in selection of options for reduction of water use. Water issues vary markedly by region in the U.S., with very high stress in deserts and little stress in less populated and high rainfall regions. Projects therefore had the ability to be climate specific in their selections, but had no explicit incentive or suggestion in the certification system to do so. Starting in LEED version 3, regional priority credits were included to promote this behavior, and water use reduction became mandatory.

The USGBC has published information about trends in LEED participation in its Green Building Information Gateway (GBIG) project (US Green Building Council, 2013)as well as a number of details about the size, location, and function of individual projects. GBIG provides a credit-level resolution, showing what goals have been achieved by projects. However, for confidentiality reasons, it is not able to provide details about how credits are earned, i.e., with which specific technologies or practices conservation is achieved. For this investigation, the USGBC provided data that are not part of the GBIG. This was possible because the results are presented in aggregate. Before this investigation, the only precedent for analysis of USGBC data at this resolution was a report relating green building design goals and energy performance to technology selection (Brennan, 2012).

Prior to this investigation, no studies had been done on LEED water efficiency credits at a resolution that showed what technologies were employed to earn them. The first stage of this investigation was a study published as a report on the USGBC website that described design choices made by projects to earn water efficiency credits (Chambers et al., 2013). The project data from that study were used to perform the study presented in this paper. The goal of this research was to identify the differences in the types of technologies (in the case of toilets and urinals) and strategies (in the case of landscape irrigation) used to achieve LEED water efficiency credits across different climate regions in the continental United States.

7.2.1 Research Scope

The researchers selected LEED NC v2.2 for study because it had the largest number of projects and date range at the time of sample selection, and because the data format and content of project documentation for this version was most suitable for the type of analysis sought. This study examined certification documents for Water Efficiency credits 1 and 3 from this version of LEED. These certification documents describe how projects intend to comply with LEED requirements. The first credit examined was WEc1: Water Efficient Landscaping. It requires projects to reduce the use of potable water in landscaping, either by reducing the need for water or by using non-potable sources. This study compared the four basic options for compliance: reduced irrigation consumption only, non-potable irrigation source only, reduction and non-potable source, and no permanent irrigation. The other credit examined was WEc3: Water Use Reduction. It requires projects to reduce the use of water within the building through efficient plumbing fixtures and fittings within structures. This study compares the use of the most common categories of toilets in LEED NC v2.2 buildings: high-efficiency and dual flush water closets, and high efficiency and non-water urinals (Chambers, 2013). High-efficiency is defined for water closets as 1.28 gallons per flush or less and 0.5 gallons per flush or less for urinals. WEc2: Innovative Wastewater Technologies was omitted from this study because of the relatively low number of projects earning it (13% of the sample), and because the most common means of compliance is the use of efficient toilets, which overlaps with WEc3.

Within the framework of these data, the question became: For projects achieving LEED NCv2.2, how did landscape irrigation choices used to earn WEc1 and flush fixture choices used to earn WEc3 vary by climate region?

7.3 RESEARCH METHODOLOGY

Water use reduction choices for a sample of LEED certified projects earning water efficiency credits under LEED for New Construction v2.2 were analyzed for differences using two climate classification schemes. LEED credit application forms were provided by USGBC. Researchers cleaned and compiled choices on these forms indicating irrigation schemes and toilet and urinal types. Contingency and pairwise statistical tests were used to find significant differences in choices on the forms between climate regions.

7.3.1 Sample Selection

Green buildings were defined as structures intended to be environmentally responsible. There are multiple sets of guidelines and certification programs used to help designers achieve this goal, but not all projects are actually registered with the programs. As such, it is difficult to determine how many such buildings exist. The USGBC was selected as a large source of project information, with over 12,000 projects certified at the time of sample selection. Within the USGBC's LEED program, one specific rating scheme was selected for comparison, LEED for New Construction v2.2. This version was chosen because of the number of projects earning it and because its certification data formatting was in an easier form than the other versions offered. The USGBC provided a list of all non-confidential projects earning Water Efficiency (WE) credits 1 and 3 under LEED NC v2.2 in the continental United States.

Certification data were provided by USGBC using a stratified random sampling approach, wherein the sample has a distribution of a characteristic that is similar to that of the population. Sampling was stratified based on owner type for projects. This was done to evenly represent the different decision making strategies in different types of organizations. The opportunity to stratify by location was not available. The result was a sample of 448 projects earning at least one of WE credits 1 and 3, including 391 WEc1 projects and 422 WEc3 projects. The USGBC provided completed certification forms for these credits from these projects, which contained the information used in this study.

Due to confidentiality requirements, nothing that might be used to identify specific projects used in the study can be disclosed. Therefore, only very low resolution information about project locations (i.e., their climate region) is included in this paper.

7.3.2 Water Efficiency Choices

Within WEc1, the certification documents covered potable water use in landscaping. This was shown through the ability to select one of four options:

- A: Reduced Irrigation Consumption Only

- B: Non-Potable Irrigation Source Only
- C: Reduced Irrigation and Non-Potable Irrigation Source
- D: No Permanent Irrigation

Credit documentation forms also offered some additional details describing water quantities and non-potable sources, depending on the design team's selections. These details were given as annual volumes of water use and check boxes for a list of different non-potable sources. The design team's choice of option was the best indicator of landscape irrigation water efficiency techniques employed in the project, and the only characteristic given for all projects, so it was selected as the WEc1 data field to analyze.

To earn WEc3, projects were asked to describe a number of details about fittings and fixtures. These included product types, makes, models, and flow rates, as well as information about intended user types and genders. The ubiquitous use of toilets and urinals to earn this credit, the common classification of each in two main categories, and the nature of the data led to their selection as the characteristics from WEc3 to analyze. The toilet types examined were dual flush toilets and high efficiency toilets, while the urinal types selected were high efficiency urinals and non-water urinals.

It should be noted that due to the nature of this version of LEED, these data represent design intent only. As-built data were not available, as their collection was not a part of the certification process for LEED NCv2.2.

7.3.3 Climate Regions

Two separate climate classification systems were examined to relate LEED water saving features to climate, including a system used by the National Oceanic and Atmospheric Administration (NOAA) (Figure 7.1a) and a system used by the US Department of Energy's Energy Efficiency and Renewable Energy (EERE) office for their Building Technologies program (Figure 7.1b). The NOAA system is based on research done by the National Climatic Data Center (Karl and Koss 1984), and consists of nine groups of states. The EERE system is based on heating degree days, average temperatures, and precipitation (US Department of Energy, 2010). It divides the continental United States into five regions and two sub-regions, with boundaries following county lines.

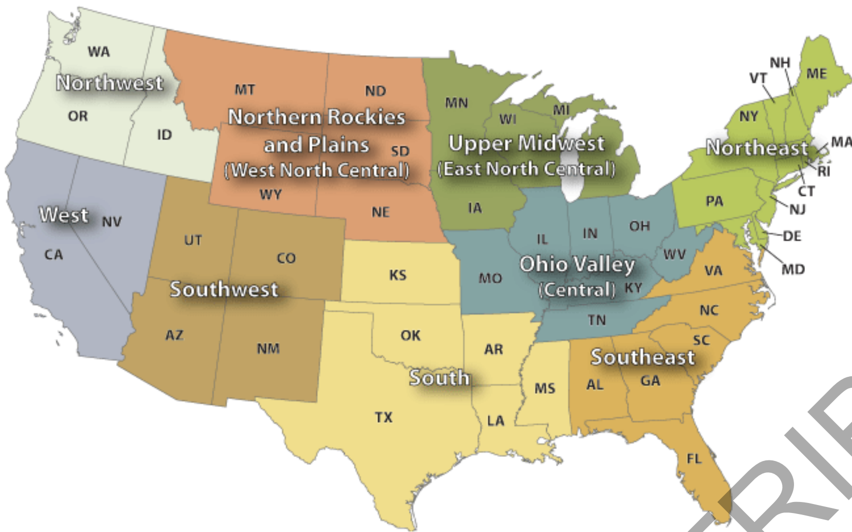

Figure 7.1a NOAA Climate Regions (National Oceanic and Atmospheric Administration, 2013)

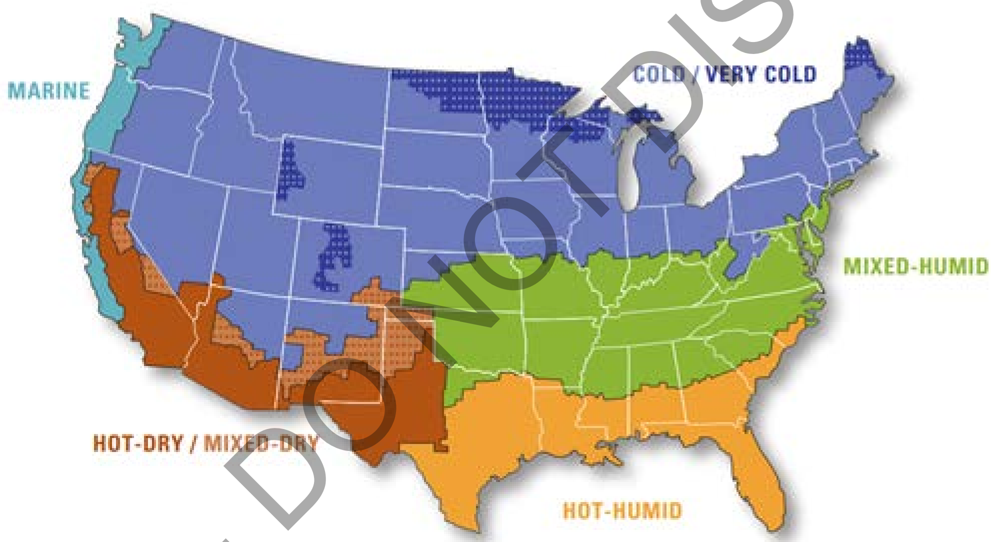

Figure 7.1b EERE Climate Regions (U.S. Department of Energy, 2010)

7.3.4 Data Analysis

To verify sample representativeness, credits earned and owner types were analyzed. The percentages of projects earning each WE credit were approximately equal in the population and the sample. The stratified random sampling by owner type was verified with the percentages of projects mentioning each owner type being equal in the population and the sample.

The data source was forms filled out by project representatives. These documents only indicate design choices, and so represent the intentions that are the focus of this study. The design of the forms allowed for the flexibility in compliance that the USGBC intended, by giving text boxes for the representative to fill out describing the technologies used. As a consequence of this flexibility, there was significant variability in how technologies used to achieve compliance with WEc3 were described on the forms. Information about such things as type, make, model, and flow rate had spaces for input, but these spaces were not always used. For example, one form might have been filled out with “High Efficiency Toilet, [Brand], [Model], 1.28 GPF” while another might just have said “Dual Flush”.

Where possible, toilet makes and models as described were used as the defining characteristic for these fixtures, and fixture types and flush rates entered on the forms were standardized, verified, and updated as necessary to achieve consistency with product specifications for the models on the forms. When no make or model was provided, provided fixture types and flow rates were taken as correct. WEc1 did not have this problem for the characteristic examined, as it allowed projects to select one of four mutually exclusive options on the form indicating a reduction in potable water use, a non-potable water source, a combination of the two, or no permanent irrigation whatsoever.

In order to assign climate regions, project presence in each had to be determined. Locations in the USGBC project database are entered by project representatives. They provide cities and states for each project. The cities were given county designations by geographical locations using ArcGIS, and these counties along with state designations were used to assign climate regions from NOAA and EERE classification systems.

Contingency analysis was performed on the data, to determine whether differences existed in distributions for each characteristic across climate regions under each system. Where significant differences were found, Tukey pairwise comparison was performed for that characteristic and climate classification system to determine which regions differed from each other under a rigorous test. This test identified groups of regions that were not statistically different from each other, and assigned regions to all groups that they fit into. For all tests, an alpha of 0.05 was used for a confidence of 95%.

7.4 RESULTS

The tests of characteristic variations within each climate region classification system indicated that significant differences likely existed for all but two cases (Table 7.1), non-water urinals in the EERE system and high efficiency urinals in the NOAA system. Details for each characteristic examined are presented below. Tukey’s pairwise analysis was performed for a rigorous test of characteristic-region combinations. These tests show which regions differ from each other for each characteristic.

Table 7.1
Results of statistical analysis of differences within each climate region classification system

Characteristic	EERE		NOAA	
	Result	**P-Value**	**Result**	**P-Value**
WEc1				
Option	Difference	<0.0001	Difference	<0.0001
WEc3				
Urinal - High Efficiency	Difference	0.0473	No Difference	0.3582
Urinal - Non Water	No Difference	0.2612	Difference	0.0413
WC - Dual Flush	Difference	0.0005	Difference	<0.0001

WC - High Efficiency	Difference	0.0379	Difference	0.0031

Figures 7.2-7.6 are mosaic plots. In these plots, the X-axis shows the proportion of the total sample in each climate region. The width of each bar, therefore, represents how much of the total sample was in that region. The Y-axis shows the percentage of projects in that particular region that selected the toilet, urinal, or irrigation type presented in that plot. These mosaic plots allow for visual examination of the data. Where one bar is much taller or shorter than the others, there are often, but not always, statistically significant differences. The statistical methods used identified these statistically significant differences where they existed.

7.4.1 WEc1: Option for Water Efficient Landscaping

The analysis showed that option selection differences between climate regions in both classification systems were statistically significant (Table 7.1). Mosaic plots (Figure 7.2 a, b) were generated to illustrate this graphically. Pairwise analysis (Table 7.2 a, b), which compares two regions to each other at a time, proves this with most comparisons showing a p-value below 0.05, indicating a greater than 95% confidence in the result. Differences were shown to exist between all EERE regions, and most NOAA regions.

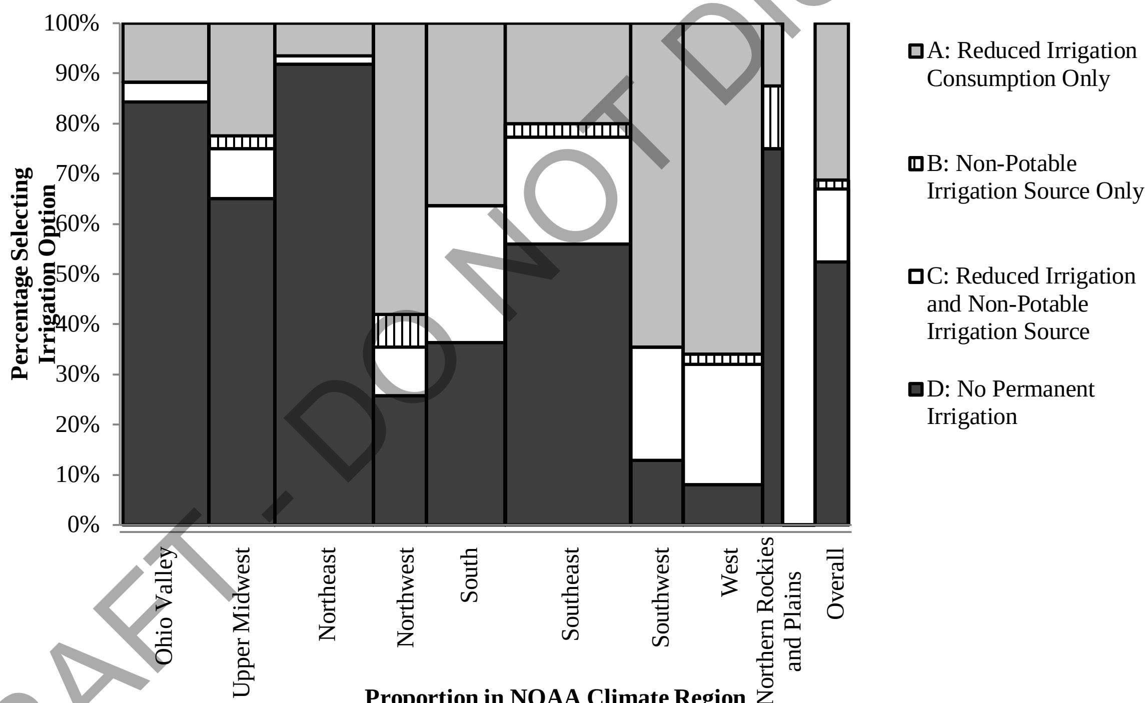

Figure 7.2a NOAA Irrigation Option Mosaic Plot

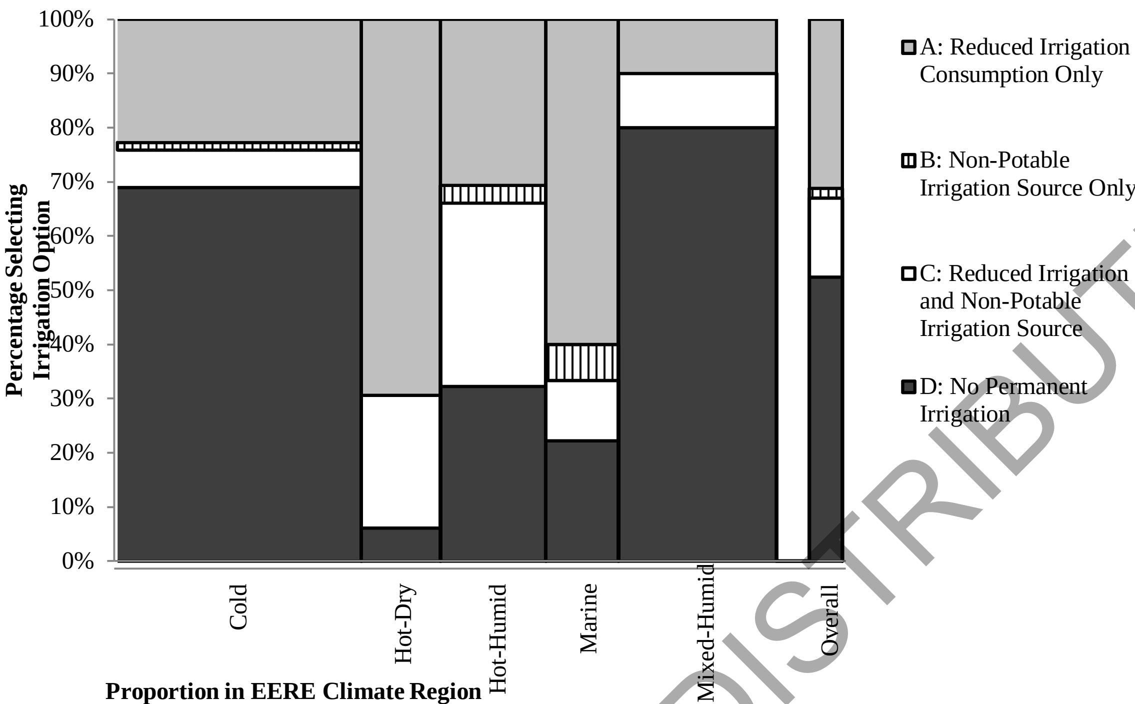

Figure 7.2b EERE Irrigation Option Mosaic Plot

Table 7.2a
NOAA Irrigation Option comparison p-values

	East North Central	Northeast	Northwest	South	Southeast	Southwest	West	West North Central
Central	0.1346	0.4583	<0.0001	<0.0001	0.0022	<0.0001	<0.0001	0.1988
East North Central		0.0070	0.0060	0.0206	0.4676	<0.0001	<0.0001	0.3773
Northeast			<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.1660
Northwest				0.0277	0.0009	0.1175	0.0586	0.0320
South					0.0632	0.0270	0.0021	0.0104
Southeast						<0.0001	<0.0001	0.1602
Southwest							0.6961	0.0004
West								<0.0001
Key:	>99.99% Confidence	>95% Confidence						

Table 7.2b
EERE Irrigation Option comparison p-values

	Hot-Dry	Hot-Humid	Marine	Mixed-Humid
Cold	<0.0001	<0.0001	<0.0001	0.0294
Hot-Dry		<0.0001	0.0362	<0.0001
Hot-Humid			0.0049	<0.0001
Marine				<0.0001
Key:	>99.99% Confidence	>95% Confidence		

7.4.2 WEc3 Characteristics

Some differences in WEc3 existed between regions in both climate systems (Table 7.3), but these were not as pronounced as within WEc1. Within the NOAA system, only the water closets showed some inter-regional differences. The Northwest region showed this the most, differentiating itself from all but the Northeast and Southwest regions with dual flush water closets. The Northwest also differed to a lesser extent with high efficiency water closets, showing differences only with the Southeast and West North Central regions. Within the EERE system, more differentiation was shown. The Marine region differed from all others with dual flush water closets. With high efficiency water closets, the Marine and Hot-Humid regions differed only from each other. This system, unlike the other, showed some difference in high efficiency urinals, with the Hot-Dry region differing from the Mixed-Humid and Marine regions.

Table 7.3a
Summary of groupings from pairwise analysis in NOAA regions

Feature Selection	**Statistically Significant NOAA Region Differences**		
	Selected Feature	**More Than**	**Selected Feature**
Toilet - Dual Flush	Northwest	>	Ohio Valley
		>	Upper Midwest
		>	South
		>	Southeast
		>	West
		>	Northern Rockies & Plains
Toilet - High Efficiency	Southeast	>	Northwest
	Northern Rockies & Plains	>	Northwest
Urinal - Non Water	(None)		
Urinal - High Efficiency	(None)		

Table 7.3b
Summary of groupings from pairwise analysis in NOAA regions

Feature Selection	Statistically Significant EERE Region Differences		
	Selected Feature	**More Than**	**Selected Feature**
Toilet - Dual Flush	Marine	> > > >	Cold Hot-Dry Hot-Humid Mixed-Humid
Toilet - High Efficiency	Hot-Humid	>	Marine
Urinal - Non Water	(None)		
Urinal - High Efficiency	Hot-Dry	> >	Marine Mixed-Humid

7.4.3 WEc3: Water Closet – Dual Flush

Contingency analysis (Table 7.1) showed that dual flush water closet use differs between NOAA climate regions, as well as between EERE climate regions. Mosaic plots (Figure 7.3 a, b) present this visually. Pairwise analysis identified differences. For the NOAA system, the Northwest region had the highest inclusion rate, and showed statistically significant difference from all but the Northeast and Southwest regions (Table 7.3). Other differences existed, such as the low selection rate in the West North Central region, but these were not statistically significant. For the EERE system, the Marine region was shown to differ from the rest, using dual flush water closets more than the other regions (Table 7.3).

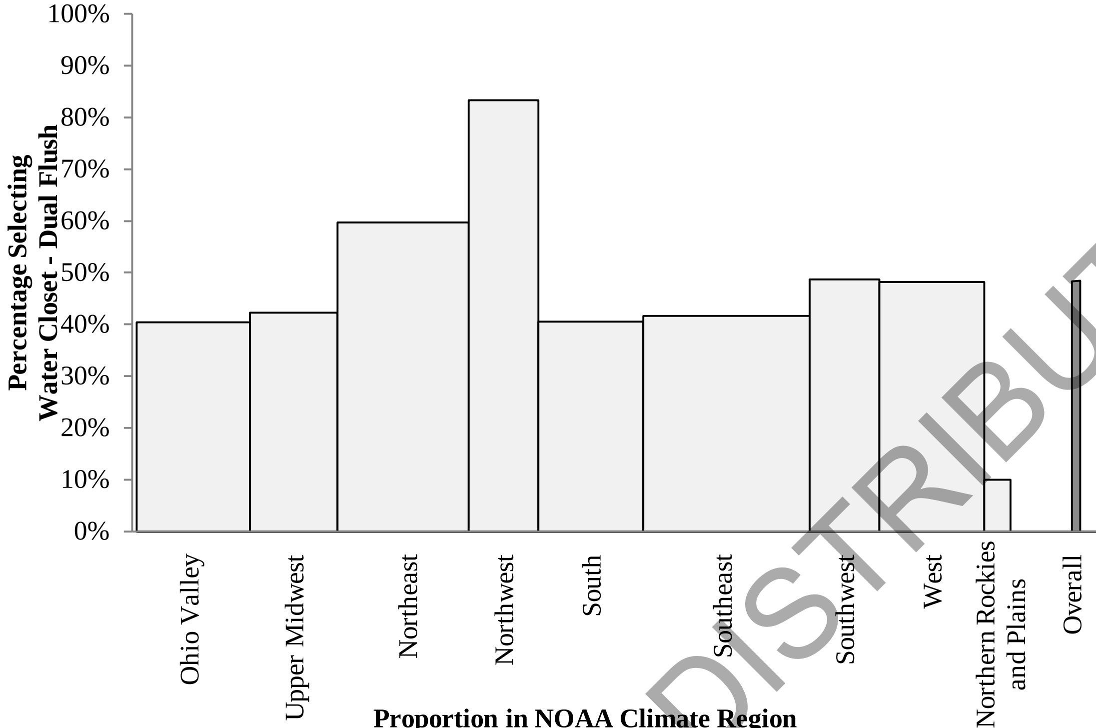

Figure 7.3a NOAA Dual Flush Water Closet use

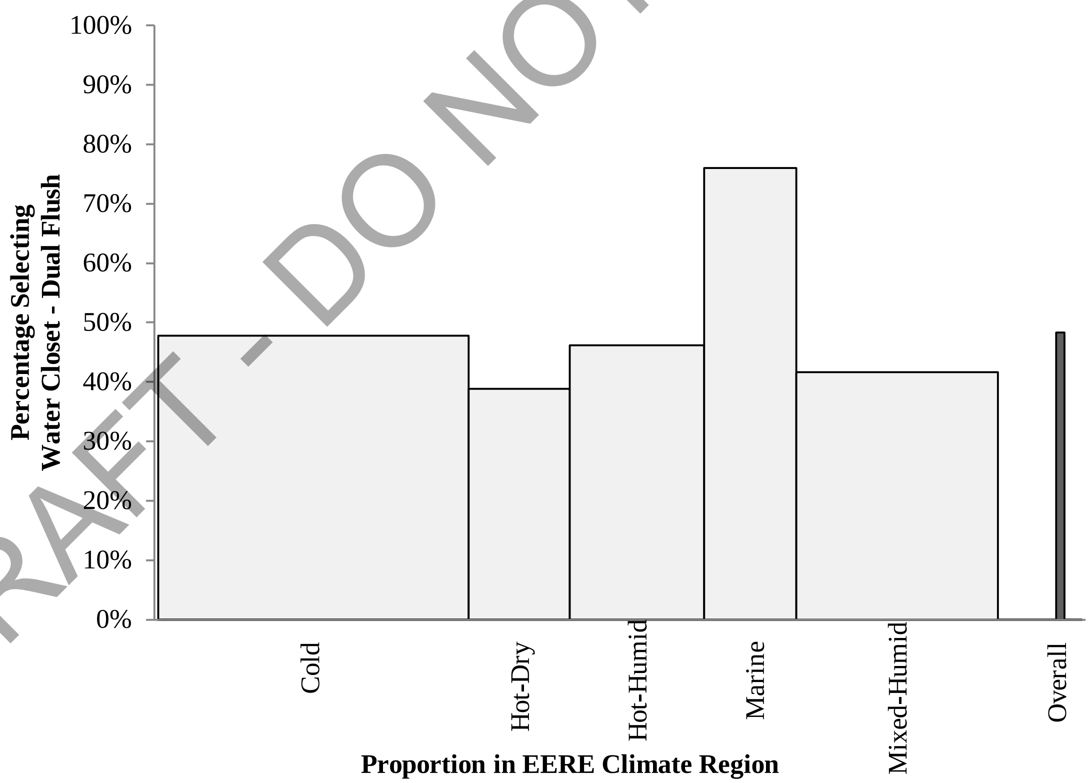

Figure 7.3b EERE Dual Flush Water Closet use

7.4.4 WEc3: Water Closet – High Efficiency

Contingency analysis (Table 7.1) showed that high efficiency water closet use differs between NOAA climate regions, as well as between EERE climate regions. Mosaic plots (Figure 7.4 a, b) represent this visually. Pairwise analysis identified the differences. For the NOAA system, the Northwest region selected these features significantly less than the Southeast and West North Central regions, but did not differ in a statistically significant degree from the other regions (Table 7.3). The EERE system showed differences between the Hot-Humid region's high selection rate and Marine region's low selection rate.

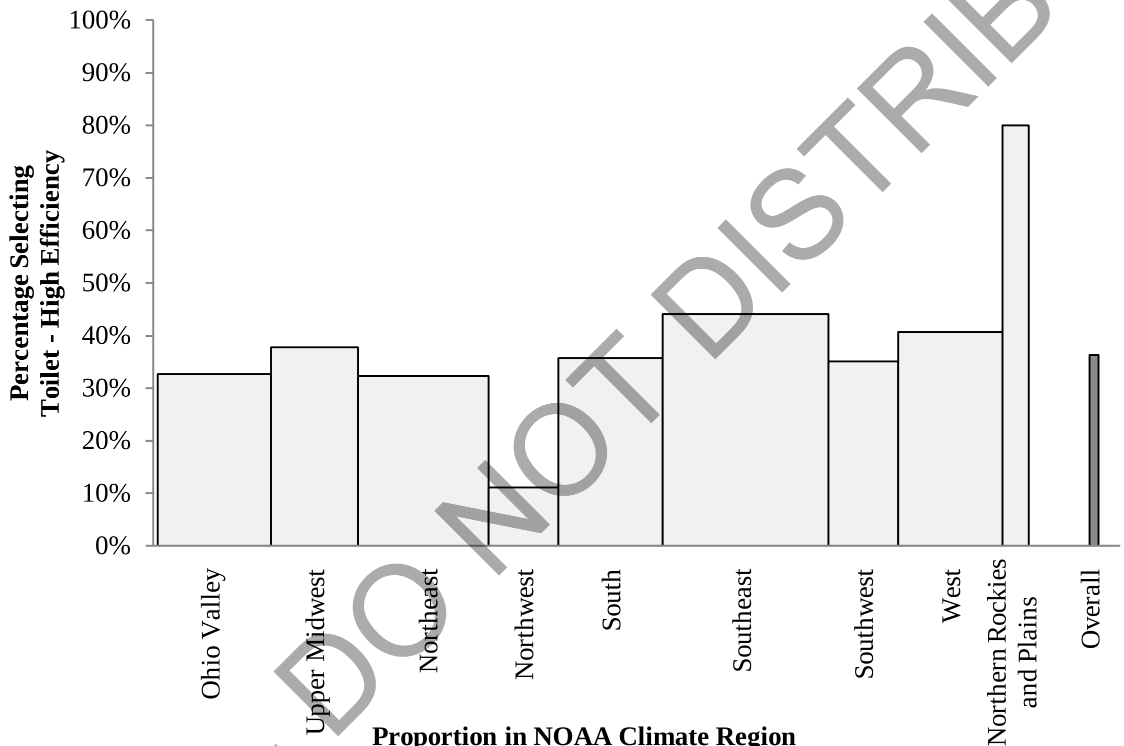

Figure 7.4a NOAA High Efficiency Water Closet use.

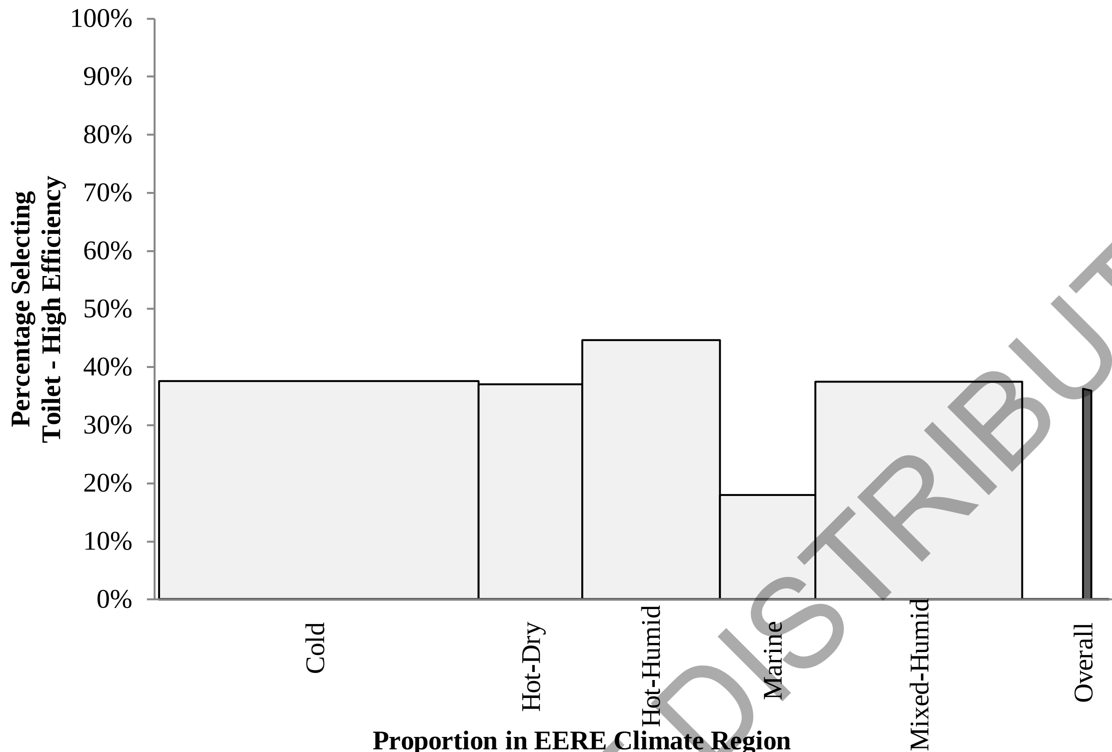

Figure 7.4b EERE High Efficiency Water Closet use.

7.4.5 WEc3: Urinal – High Efficiency

Contingency analysis (Table 7.1) showed that high efficiency water closet use differs between EERE climate regions but not NOAA regions. Mosaic plots (Figure 7.5 a, b) represent this visually. Pairwise analysis identified the differences in the EERE system (Table 7.3) but found none in the NOAA system. The Mixed-Humid and Marine regions showed statistically significant difference from the Hot-Dry region.

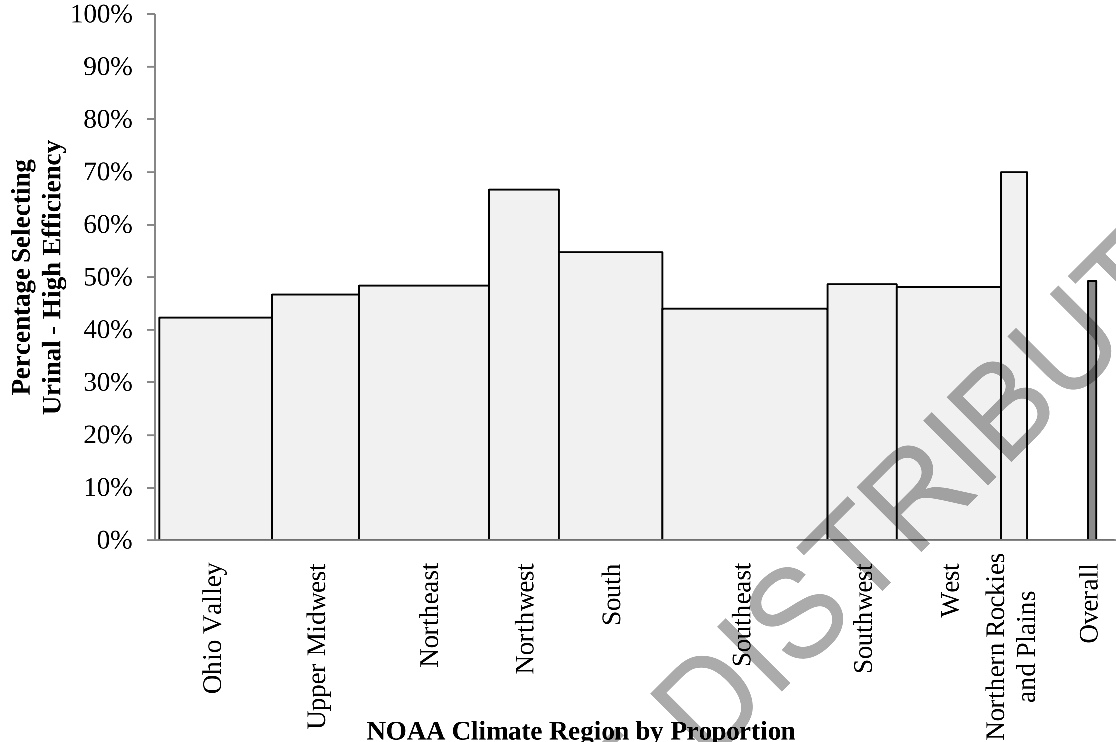

Figure 7.5a NOAA High Efficiency Urinal use

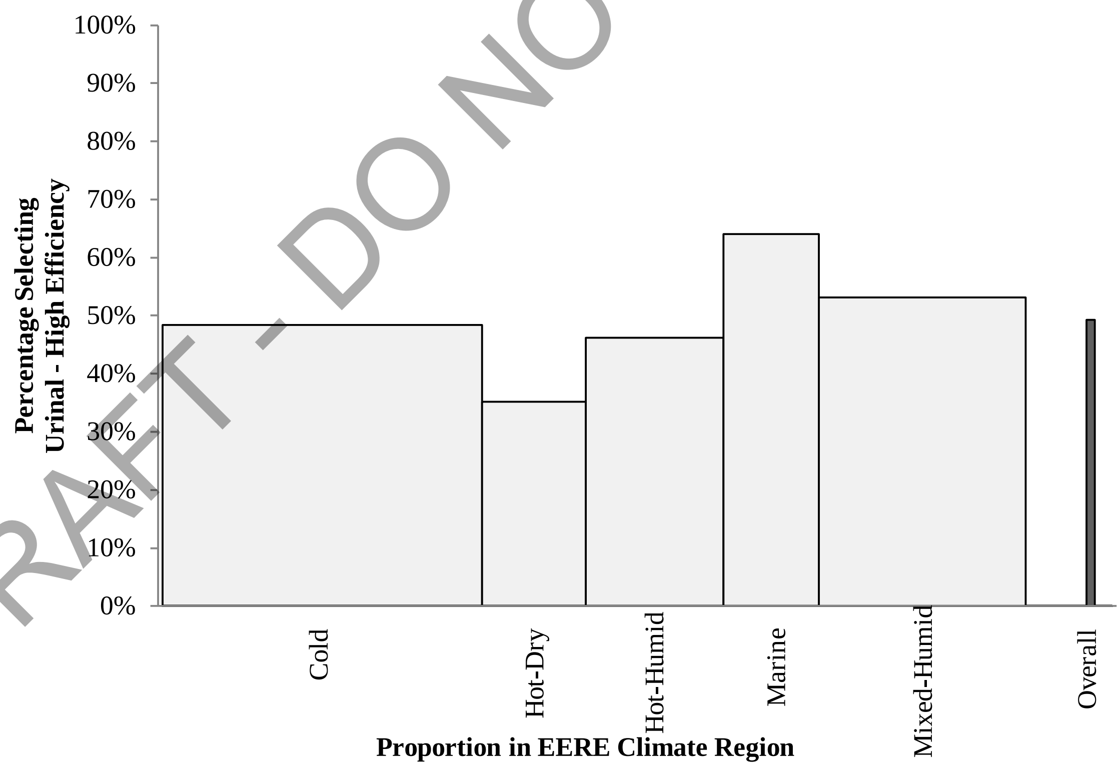

Figure 7.5b EERE High Efficiency Urinal use.

7.4.6 WEc3: Urinal – Non Water

Contingency analysis (Table 7.1) suggested that high efficiency water closet use differs between NOAA climate regions but not EERE regions. Mosaic plots (Figure 7.6 a, b) represent this visually. The more conservative pairwise analysis (Table 7.3) did not identify differences, indicating that this conclusion about differences in NOAA regions is not strong enough to call significant under a rigorous test. The lack of significant difference in EERE regions is repeated under the pairwise test.

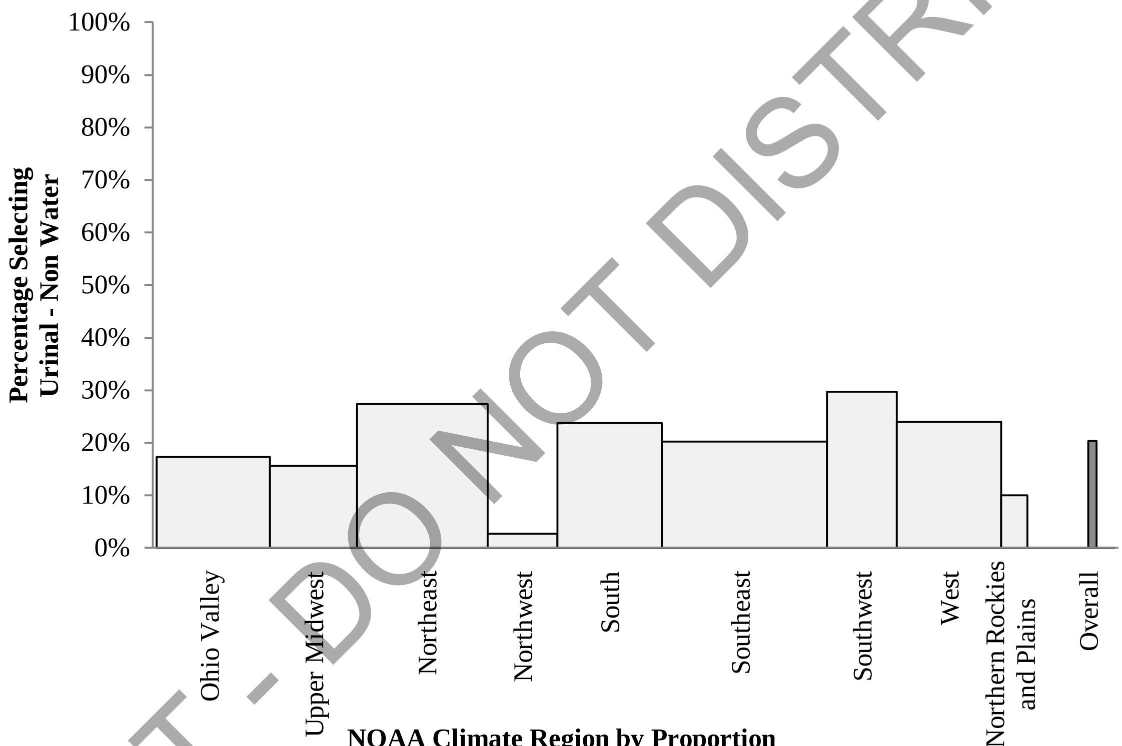

Figure 7.6a NOAA Non Water Urinal use.

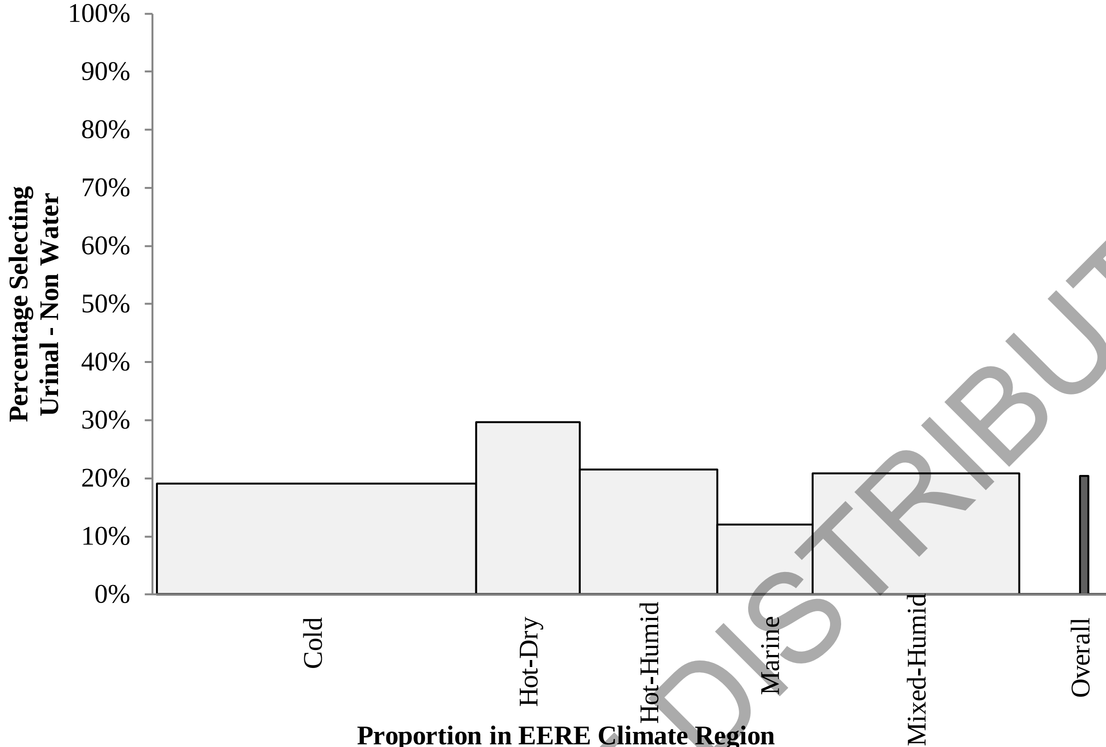

Figure 7.6b EERE Non Water Urinal use.

7.5 CONCLUSIONS

These results support the hypothesis that landscape water use design decisions for LEED NC v2.2 projects vary between climate regions. This may have to do with practices already in place in those regions, or because the impact of regional rain water availability is most visible outside in the landscaping.

While irrigation selections showed differences between most regions under both climate systems, it should be noted that the choice of no permanent irrigation was least used in the Hot-Dry EERE region and three western NOAA regions. This may be related to societal expectations for landscaping that require more water than is naturally available in that region, or it may be because of the availability of rain reducing the need for these features in other regions.

Toilet and urinal type selections showed differences between fewer regions than did irrigation selections, and in fact were not significant in non-water urinals. The higher selection rates of dual flush water closets and lower selection rates of high efficiency water closets in the NOAA Northwest and EERE Marine environments suggests that in these water rich regions, there is a preference for dual flush toilets. With non-water urinals, the name clearly indicates lower water usage, so one might expect them to be significantly more popular in water-sensitive regions. The distribution graphs indicate that they are included in designs in the hot-dry climate region more often than other EERE regions, but the difference is not statistically significant.

These results indicate that while some LEED v2.2 water efficiency design decisions were different between climate regions, there was still room for further climate specificity. The inclusion of climate specific guidelines within the newer green building rating systems could make climate specificity more prevalent in green building water efficiency strategies, especially with regard to plumbing fixtures.

7.6 FUTURE RESEARCH

This research demonstrated that differences existed in some water efficiency design choices, but the data examined did not include any information about why these design choices were made. Future research is needed to identify these reasons. Some possible influences to investigate are the input of various stakeholders in the design process, local and regional water efficiency legislation, and local water sensitivity related to non-climate factors such as demand.

Another limitation of this study was that no comparison was made with projects where regional climate needs were mentioned in the rating system. As climate specificity is implemented in green building guidelines and certification programs, it would be interesting to learn whether projects are actually making a point of selecting water efficiency measures appropriate for the climate and the region’s water resource sensitivity.

CHAPTER 8: GREEN BUILDING SURVEY

8.1 ABSTRACT

An internet survey was developed to synthesize experiences of green building professionals with water conservation related innovations. The survey was distributed by the US Green Building Council and other venues, including LinkedIn and several mailing lists. Participants rated their experiences with 33 types of innovations, and indicated problems they had experienced. Participants were also asked to check off experiences from a short list of common issues. The most common problems were due to pipe leaks and clogs, insufficient hot water, premature system failure, and complaints about taste, odor, or coloration. A majority of respondent ratings were not negative (i.e., positive or neutral). Green landscaping innovations were overwhelmingly positive in all categories. Non-water urinals and toilets had the most negative response distributions, followed by blackwater and greywater recovery systems. Payback expectations were different from outcomes in both positive and negative directions for many of the innovations examined.

8.2 INTRODUCTION

Many green buildings utilize innovations that reduce dependency on external resources by reducing the use of potable water or limit the production of wastewater. Multiple environmental, ethical, and financial factors are involved in implementation of such systems, but an important incentive is criteria for green building certifications such as the US Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) program, which has certified over ten thousand projects in the United States (US Green Building Council, 2013).

The paths to compliance in contemporary green building rating systems typically allow for a wide range of techniques and technologies to be employed in a project. Because the requirements for water use in these green buildings are different from traditional buildings, the water solutions used may of necessity be atypical or new innovations.

The reactions of early adopters to these innovations can greatly influence public opinion and future adoption of the innovations (Rogers, 2003). Anecdotal evidence exists to support the conclusion that some systems are creating negative experiences. These include pipe corrosion and bad smells associated with non-water urinals (Guevarra, 2010; Shapiro, 2010), increased water usage from long showers (Walker, 2009), and site inappropriate system installation (Bray and McCurry, 2006). Some technologies have been studied systematically, especially with regard to opportunistic pathogens in water heater systems (Bagh et al., 2004; Brazeau and Edwards, 2012; Codony et al., 2002; Mathys et al., 2008). However, a review of the literature yields no comprehensive study of water systems in green buildings or any scholarly synthesis of water system experiences and satisfaction.

This research addressed this issue by collecting green building professionals' perceptions of innovations related to water conservation in buildings through an internet survey. Participation was open to any green building professional that had experience with water conservation related systems. The USGBC's network of these professionals was initially utilized, and several other professional and government organizations were added to increase participation.

Innovations considered included anything intended to assist in water conservation in green buildings. A comprehensive list of innovation types was created by the researchers, in order to help participants describe their experiences. The survey identified which of these innovation types were generating positive and negative experiences, as well as the most common problems.

8.3 RESEARCH METHODOLOGY

An internet survey queried adopters about known problems, gave participants the opportunity to rate their satisfaction with various systems, and allowed them to describe these experiences.

8.3.1 Distribution

The survey was initially distributed by the US Green Building Council (USGBC) through several of their internet-based social networking tools (USGBC Yammer, USGBC Chapter Newsletters, USGBC Education Portal, USGBC National Newsletter), as well as through their contact for an official post at LEEDUser.com. To gather additional responses, several contacts were used to distribute the survey to a list of federal facility managers through the US General Services Administration, the US Department of Energy, and the US Interagency Sustainability Working Group. Distribution was also made through the Society of Building Science Educators listserv, the Water Research Foundation mailing list, the Green Building Alliance newsletter, and direct email to a list of members of the Associated General Contractors (AGC). Several postings were also made to LinkedIn on various green building boards. It is impossible to know how many individuals saw or received the invitation, as membership in most of these mailing lists is confidential, as is the number of reads the pages receive. What is known is that the AGC mailing list used was 4008 members strong, and that the USBGC and LinkedIn forums are active. The survey link was opened by 166 distinct IP addresses.

8.3.2 Survey Content

Because of the length and breadth of the survey, respondents were first taken to a ‘short’ overview page, where they were asked whether they had experienced any of the problems that researchers suspected might be most common. These known problems were based on the literature and the experiences of the researchers. Nine general issues were described (Table 8.1).

Table 8.1
Known problems asked about on survey

One or more water-related systems have had to be replaced before the end of their design life.
There have been user complaints about water taste, odors, or coloration.
There have been user complaints about water temperature.
There have been complaints about insufficient hot water.
A significant number of building users drink bottled water instead of tap water.
There have been leaks or clogging of pipes.
There have been capacity problems, including inability to handle water demand or undesired accumulation/diversion of wastewater/stormwater.
Building occupants have perceived illness (or other health concerns) as being related to green water systems.
Water tests show contamination.

To get the breadth of water conservation related innovations, a comprehensive list of innovation types was created (Table 8.2). This list contained 33 innovations, divided into 9 categories. The list was based on facility features mentioned in LEED documentation and the professional experience of the research team.

8.3.3 Survey Format

In order to gather information on professional experiences with water systems in green buildings, an internet survey was created using the tools provided by Qualtrics. The survey was broken into several sections, with a 'short form' at the beginning asking about the known problem types (Table 8.1), to help with classification of negative experiences. Respondents were asked to check boxes for each problem experienced, and were given an opportunity to describe other problems. This was followed by questions about the 33 innovations (Table 8.2), with a page for each of the nine categories. Respondents were asked to rate experiences with innovations in each category on a five point Likert scale, with the options Extremely Disappointing, Somewhat Disappointing, Indifferent, Satisfying, and Far Exceeded Expectations. Respondents were able to select more than one rating for each innovation in case they had varied experiences. Negative responses were followed with open ended questions about the types of innovations, the problems, and their resolution. Responses of Far Exceeded Expectations were followed with open ended questions about the types of innovations and their success.

Table 8.2
Categories of innovations included in user satisfaction portion of survey

Category	Innovation
Toilet and Urinal	Water Conserving Toilets Non-Water Toilets Non-Water Urinals Alternative Flushometer Valves
Shower and Faucet Fixtures	Low Flow Fixtures Alternative Controls Self-Powering
Plumbing	Alternative Piping Manifold Distribution Cured-in-Place Pipe Lining High Performance Epoxies
Water Heating	Recirculation On-Demand Solar Heat Recovery
Appliances	Water-Efficient Dishwashers Water-Efficient Clothes Washers Water-Efficient Icemakers
Alternative Water Sources	Rainwater Harvesting Greywater Reuse Blackwater Reuse Process Water Recycling/Reuse Condensate Recovery Municipal Nonpotable
Landscaping	High Efficiency Irrigation Water Conserving Plant Selection Green Stormwater Retention and Infiltration Grey Stormwater Retention and Infiltration
Performance Monitoring	Water Audits Sub-Metering
User Education	Feedback on Water Use Signage and Educational Materials Behavioral Policies and Incentives

8.4 RESULTS

The survey link was opened by a total of 166 distinct IP addresses. Of those that opened the link, 95 individuals went past the introductory pages to report problems with green water systems, and 76 of those continued on to respond to some or all of the remaining innovation ratings pages. Response counts are provided in the data summary section. The predominant professional roles of respondents are presented in Table 8.3. Professional experiences with green building water systems are presented in Table 8.4.

Table 8.3
Predominant professional roles of the 95 respondents

Role	Percentage
Constructor	3%
Designer	34%
Educator	13%
Facility Manager	5%
Inspector	7%
Occupant/User	4%
Operator/Maintainer	3%
Owner	4%
Planner	3%
Product Manufacturer	3%
Utility Service Provider	3%
Other	18%

Table 8.4
Experience questions

Question	% Yes
Are you involved in building operations or maintenance?	38%
Have you ever been involved in the design, construction or operation of a building utilizing green water innovations?	84%
Have you ever been an occupant of a building utilizing green water technologies?	76%

8.4.1 Known Problem Types

Of the 95 respondents summarized in this report, nine did not provide any answers after the demographics page, suggesting that their responses should be omitted. However, other respondents did not indicate experience with any of the known water problems, but did share other experiences later. For this analysis it is assumed that the nine respondents did not experience the known water problems, and thus they are included in the total for this section. These responses for known water problems are collected below (Table 8.5). Problems with leaks or clogging of pipes were most reported, followed closely by complaints about hot water supply, early failure of systems, and complaints about water taste, odors, or coloration. Very few respondents reported occupants perceiving health concerns as related to green water systems, and fewer reported contamination in water tests.

Table 8.5
Known problem type results

Problem Description	Percentage (of 95)
There have been leaks or clogging of pipes.	32%
There have been complaints about insufficient hot water.	31%
One or more water-related systems have had to be replaced before the end of their design life.	29%
There have been user complaints about water taste, odors, or coloration.	29%
A significant number of building users drink bottled water instead of tap water.	22%
There have been user complaints about water temperature.	21%
There have been capacity problems, including inability to handle water demand or undesired accumulation/diversion of wastewater/stormwater.	14%
Building occupants have perceived illness (or other health concerns) as being related to green water systems.	6%
Water tests show contamination.	2%
Other	18%

8.4.2 Innovation Ratings

When asked to describe their experiences with specific water-related innovations in buildings, respondents reported a variety of satisfaction levels and experiences. The nine categories of innovations are presented separately here, with charts describing the distribution of ratings for each innovation type. Not all respondents had experience with each innovation, so some innovations had relatively low rating counts. The count of ratings for each type is provided in the charts with type titles, as well as the number of respondents that viewed the category. There were 19 instances where a responder gave two ratings for a particular innovation. In line with the survey instructions, these were treated as separate experiences. Summaries paraphrasing free response data are also included to illustrate the experiences respondents had. Explanations of innovation types which were provided through mouse-over text on the surveys are also included in the summary tables.

8.4.2.1 Toilets. The Toilet category contained classes of toilets, urinals, and flushometer valves. Toilet responses (Figure 8.1) show a large share of negative experiences for non-water options, with 46% for non-water toilets and 58% for non-water urinals. Results were generally positive for water conserving toilets, as well as alternative flushometer valves.

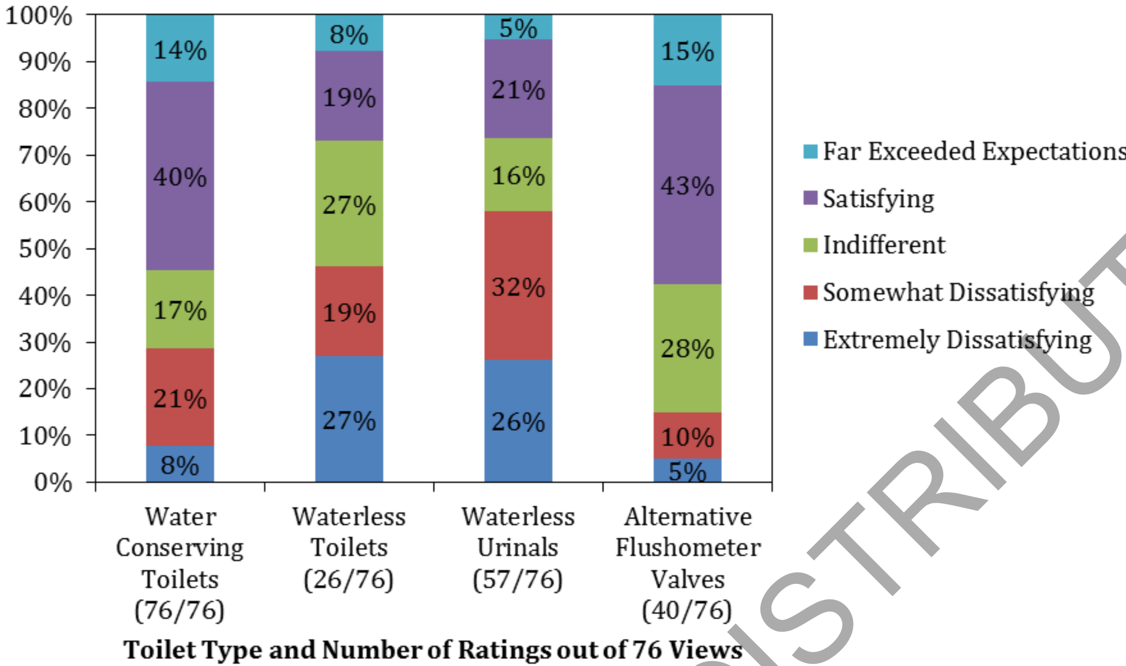

Figure 8.1 Response breakdown for Toilet category

With toilet innovations, positive experiences reported by respondents focused mainly on effective function of the innovation in saving water (Table 8.6

Table 8.6). Those that described them said they were pleased that the toilet worked well or as intended, and that they were happy about their ability to save water. Negative experiences were slightly more varied. Some respondents said that their water conserving toilets did not have sufficient flow to clean the bowl, or to carry waste through the lines, and required multiple flushes. Non-water options received negative responses related to odor, cleanliness, and difficult maintenance. Non-water urinal negative responses reported maintenance staff being unable or unwilling to deal with maintenance procedures. Clogging from salts was also reported. Alternative flushometer valves also received complaints. Respondents perceived that dual-flush valves were often used on the higher volume flush when a low volume would suffice, either through habit or ignorance. Automatic flush valves were triggered by mistake, either from poorly calibrated sensors or non-elimination uses of stalls, such as changing clothes.

Table 8.6
Experiences described for toilet category

Type & Alt Text	Positive Experiences	Negative Experiences
Water Conserving Toilets Low-flow, high efficiency toilets (HETs), dual-flush toilets, pressure-assisted toilets, etc.	• Worked well or as intended • Easy way to conserve water	• Insufficient flushing power to clear bowl • Insufficient water for line carry
Non-Water Toilets Composting, incinerating, foam-flush, vacuum-flush, etc.	• Worked well or as intended	• Odor • Difficult to maintain • Cleanliness
Non-Water Urinals	• Worked well or as intended • Water conservation	• Improperly trained maintenance staff led to failures • Odor • Line clogging from salts • Cleanliness
Alternative Flushometer Valves Dual-flush, automated flush, self-powered, timed, solar-powered, etc.	• Worked well or as intended • Water conservation	• Automatic flush sensors are triggered more than necessary • Dual flush valves often used on the wrong flush option

7.4.2.2 Shower and faucet fixtures. The Shower and Faucet Fixtures category included low flow fixtures, as well as controls and self-powering control mechanisms. Responses for shower and faucet fixtures (Figure 8.2) show similar degrees of positivity for each type. Low flow fixtures showed 33% dissatisfaction, with about twice as many ratings given as the other two types in this category. Alternative controls were met with 45% indifferent ratings.

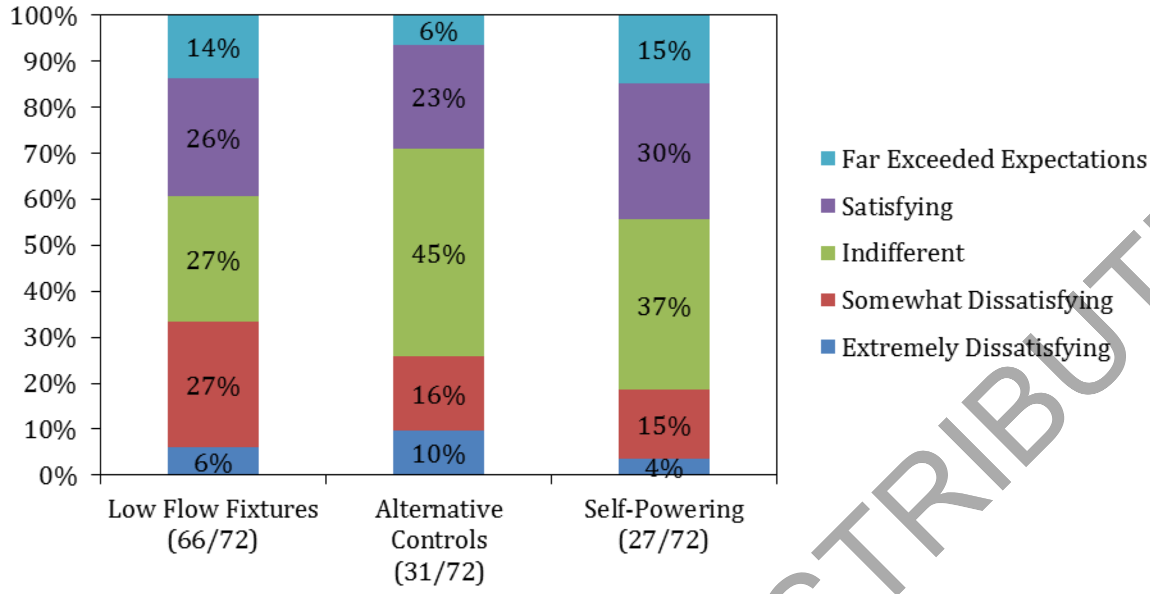

Figure 8.2 Response breakdown for Shower and Faucet Fixture category

With low flow shower and faucet fixtures, positive experiences described mostly involved the fixtures working well, and pleasure at the ability to easily conserve water (Table 8.7). One respondent was happy to note that their customers did not notice a switch to high efficiency bathroom sink faucets. Negative experiences involved inconsistent or too little flow, and extended waits for hot water. Respondents also indicated that the lower flow can be insufficient to clear and clean the drain pipes. In buildings requiring high water pressure or fire suppression systems, there were complaints about excessive splashing. Positive alternative control experiences involved the controls working well, and users being happy to not touch controls in public bathrooms. Complaints were about cycle length and sensor mechanisms that were difficult to trigger. For self-powering fixtures, positive experiences given only described fixtures working well. Negative experiences involved early battery failures.

Table 8.7
Experiences described for shower and faucet fixture type

Type & Alt Text	**Positive Experiences**	**Negative Experiences**
Low Flow Fixtures Restricted, aerated, laminar flow, etc. Better than code requirements	• Worked well or as intended • Users did not notice switch • Water conservation	• Increased hot water delivery time • Too little flow in shower • Inconsistent flow • Splashing in buildings that maintain high water pressure for fire suppression system • Insufficient water for line carry
Alternative Controls Metered, timed, trickle valves, sensor-activation, foot activation, etc.	• Worked well or as intended • Enjoyed not having to touch controls	• Cycle too short • Automatic sink sensors difficult to trigger or keep triggered
Self-Powering Microturbine powered, solar powered, etc.	• Worked well or as intended	• Early battery failures

8.4.2.3 Plumbing. The plumbing category included alternative piping materials, manifold distribution, cured-in-place pipe lining, and high performance epoxies for joints and sealing. The lining and epoxies types had the lowest number of ratings of any innovation type in this study. Plumbing responses (Figure 8.3) were largely positive or indifferent for alternative piping and manifold distribution, with all types having over 40% indifferent responses. Very few respondents reported experience with cured-in-place pipe lining or high performance epoxies.

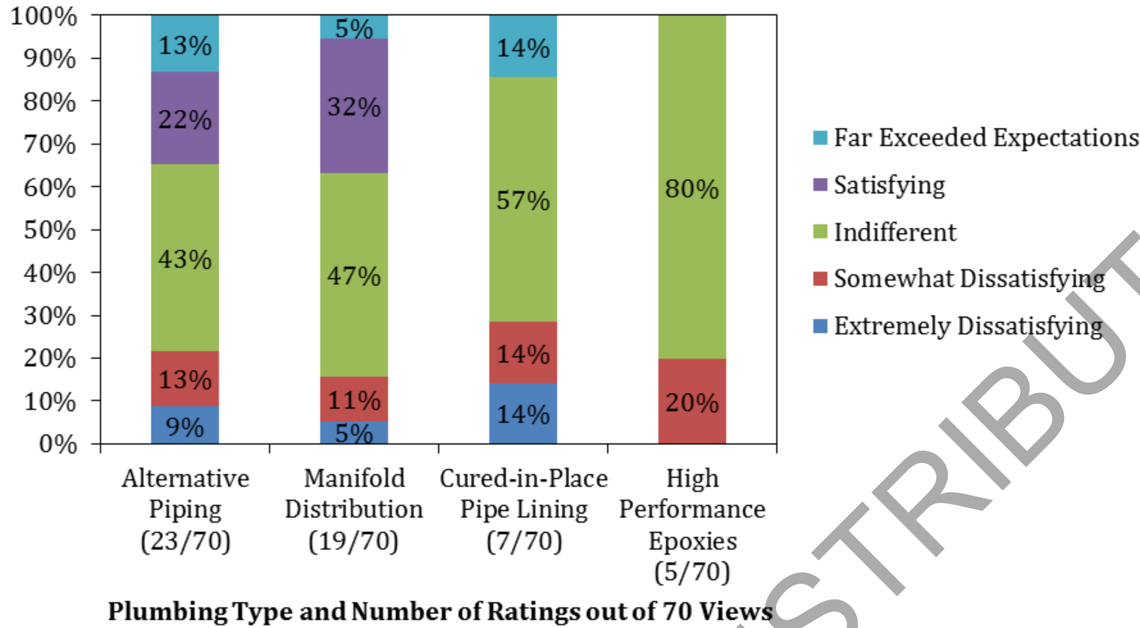

Figure 8.3 Response breakdown for Plumbing category

For alternative piping (Table 8.8), all experiences described were about PEX. Respondents indicating positive experiences described PEX as having improved pressure and flow over copper, and respondents were pleased with the ease of installation and repair. One respondent reported leaking in their PEX piping, and another complained of air and dirt pockets forming from slag in their PEX piping. Manifold distribution was perceived as easy to install, manage, and repair. One respondent complained of leaking. Positive reports said cured-in-place pipe lining was more durable and had better flow than the original pipes. The negative experiences involved an epoxy lining project being expensive and lacking quality control. No experiences were described for high performance epoxies.

Table 8.8
Experiences described for plumbing type

Type & Alt Text	Positive Experiences	Negative Experiences
Alternative Piping PEX, Aluminum-Plastic composite, Recycled PVC, fused polypropylene, etc. Also includes alternative types of pipe insulation	• PEX had better pressure and flow than copper. • PEX easy to install and repair	• PEX with slag creating air and dirt pockets • PEX leaking
Manifold Distribution	• Easy to install and manage	• Leaking
Cured-In-Place Pipe Lining	• Improved durability and flow characteristics over original pipe	• Lining for copper pipe was expensive and lacked quality control
High Performance Epoxies	• None given	• None given

8.4.2.4 Water heating. The Water Heating category included recirculating systems, on-demand (instant) heating, solar heating, and heat recovery systems. Responses for water heating innovations were very positive across the board (Figure 8.4).

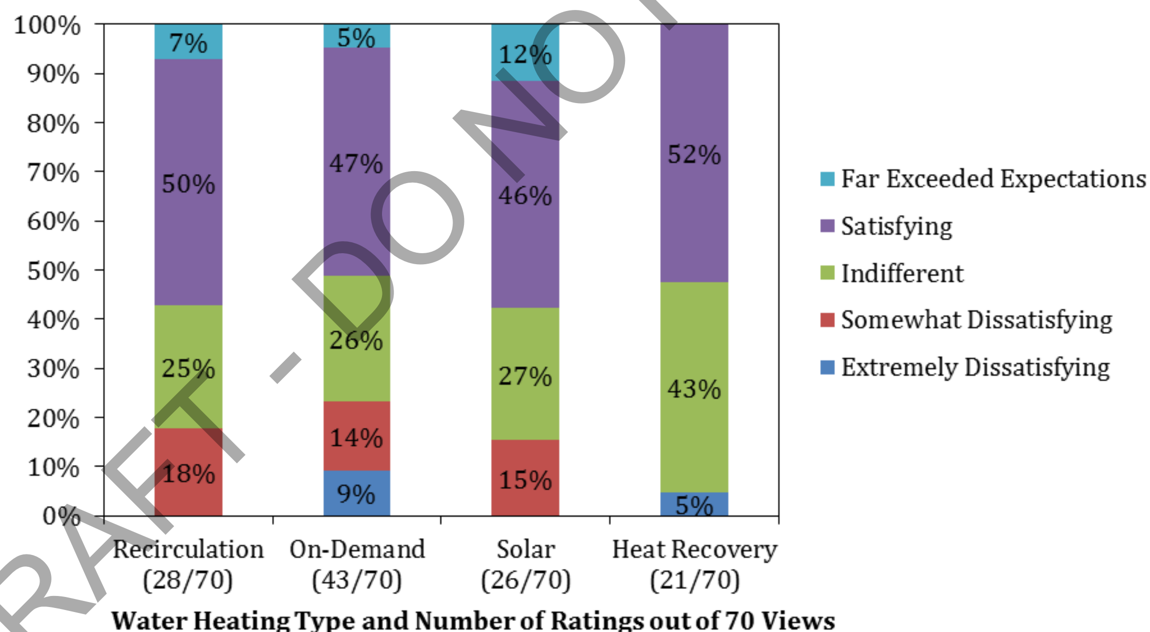

Figure 8.4 Response breakdown for Water Heating category

Positive experiences with recirculation systems (Table 8.9) included installations that worked well or as intended, with users happy not to have to wait for hot water. In one case, pipe leaks due to cavitation occurred possibly because of the constant flow. Positive experiences with on-demand water heating systems described respondents pleased by quick supplies of hot water that did not run out. The negative experiences involved insufficient heating capacity, which forced users to choose between heat and flow rate. Systems in cold environments, such as basements, were reported to be excessively noisy when coming up to temperature. Positive solar water heating experiences involved systems working well, or as intended. The short payback period was also mentioned. Negative experiences involved expense and long payback periods for the larger, more advanced systems.

Table 8.9
Experiences described for water heating type

Type & Alt Text	Positive Experiences	Negative Experiences
Recirculation Hot water recirculation systems	• Worked well or as intended • No wait for hot water	• Pipe leaks due to cavitation
On-Demand Centralized or point of use, instantaneous	• Worked well or as intended • Quick supply of hot water • Hot water does not run out	• Insufficient heating capacity • Inconsistent temperature • Excessive noise in cold environments
Solar Solar water heating	• Worked well or as intended • Short payback period	• Long payback period
Heat Recovery Water heat recovery systems, from greywater, geothermal, HVAC, etc.	• Worked well or better than intended • Energy savings	• Hot water demand and wastewater generation not always synchronized

8.4.2.5 Appliances. The Appliances category included dishwashers, clotheswashers, and icemakers. Icemakers had the third lowest number of ratings in this study. Responses for appliances were largely positive or indifferent (Figure 8.5).

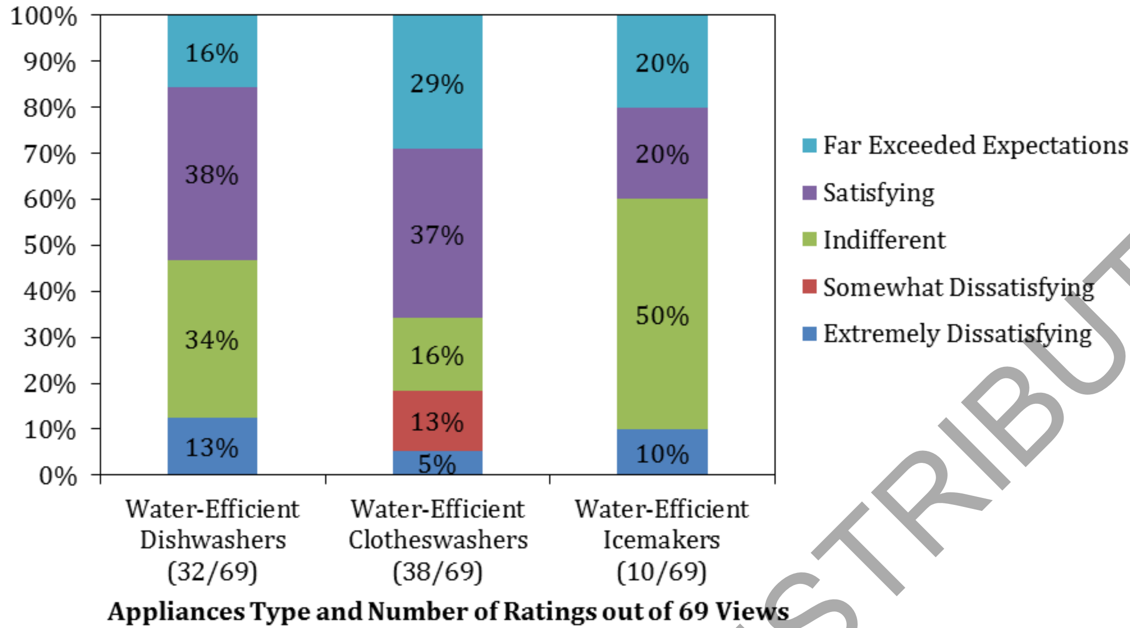

Figure 8.5 Response breakdown for Appliances category

For all appliance types, respondents were pleased with the savings that they experienced (Table 8.10). Positive experiences for water-efficient dishwashers mostly said that the dishwashers worked well and were quiet. The negative experiences were with dishwashers that failed to properly wash dishes. Water-efficient clothes washers worked well or better than expected for positive responders. Negative experiences included user error with front loading machines, where clothes were dropped. Respondents indicated that some machines did not wash clothes well, and developed a mildew odor, likely due to inadequate rinse and draining. Water efficient icemakers created positive experiences with better taste than respondents were used to, though there was a complaint about lengthy ice-making cycles.

Table 8.10
Experiences described for appliances type

Type & Alt Text	Positive Experiences	Negative Experiences
Water-Efficient Dishwashers	• Worked well or as intended • Water and energy savings • Quiet	• Dishes not washed well
Water-Efficient Clothes Washers	• Worked well or better than intended • Water and energy savings	• Mildew odor from inadequate rinse or draining • Clothes fell to floor out of front-loading machine • Clothes not washed well
Water-Efficient Icemakers	• Better taste than conventional • Energy savings	• Lengthy cycle

8.4.2.6 Alternative water sources. The Alternative Water Sources category covered sources of non-potable water, including rainwater, greywater, blackwater, process water, condensate, and municipal supply. Responses for alternative water sources varied somewhat, but were largely satisfactory (Figure 8.6). Municipal nonpotable sources met with a large amount of indifference. Process water and condensate recovery were very well liked, with 77% and 73% positive responses, respectively. Greywater and blackwater reuse both had 15-25% proportions of strong responses on both ends of the spectrum.

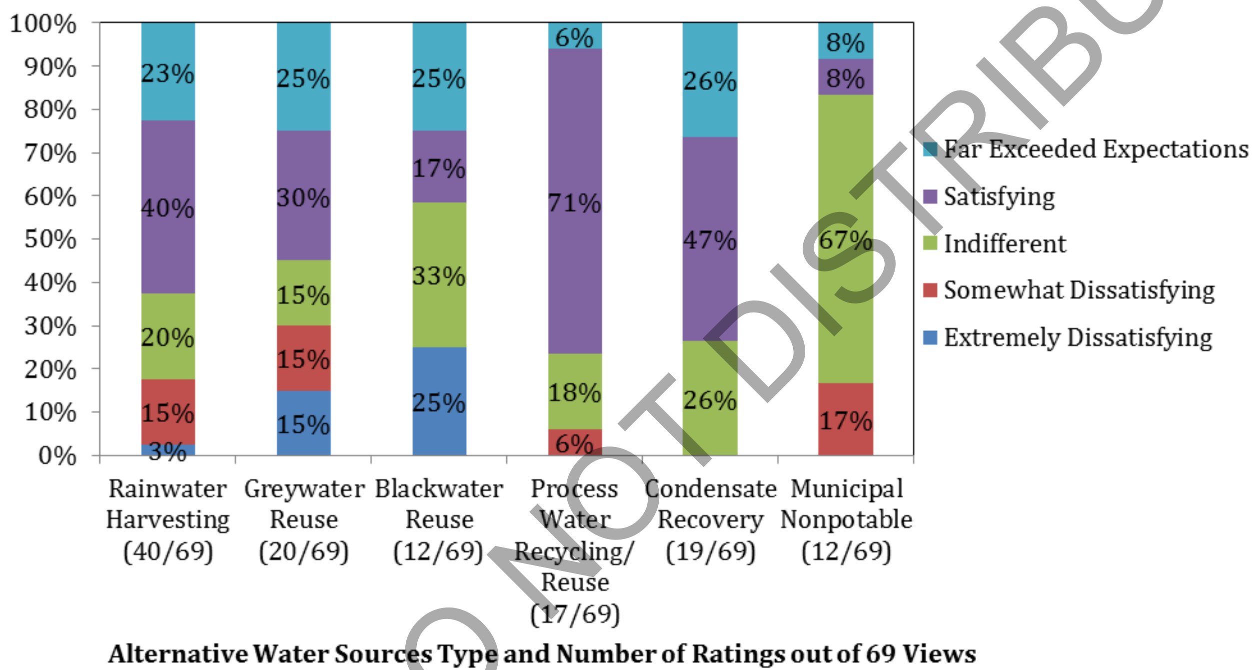

Figure 8.6 Response breakdown for Alternative Water Sources category

Positive experiences reported for alternative water sources often included mention of water savings, and systems performing well or better than intended (Table 8.11). Negative experiences with rainwater harvesting included expensive maintenance and treatment, freezing failures, the difficulty of finding turnkey systems, and issues where the lack of pressurization required addition of pumps, sometimes post-installation. Negative experiences with greywater reuse revolved around poor designs and bad filters that caused odors, sepsis, and complete system failure. Blackwater reuse was seen very positively by respondents whose systems were automated or remotely controlled by the installer. Negative experiences indicated high costs and poor process design. Chlorine treatment was also reported to cause pipe failures due to treatment process design flaws. Process water use gave positive experiences with water savings and a reduced need for chemical treatment. Condensate recovery gave positive experiences for similar reasons, by providing users with very clean water. Negative experiences with municipal non-potable water sourcing included the necessity of polishing on site, as well as complaints about the cost of infrastructure installation.

Table 8.11
Experiences described for Alternative Water Sources type

Type & Alt Text	Positive Experiences	Negative Experiences
Rainwater Harvesting Rainwater and stormwater collection	• Water savings • Worked well or as intended	• Expensive to maintain • Lack of pressurization required addition of pumps • Freezing related failures • Hard to find turnkey systems
Greywater Reuse Greywater treatment and reuse	• Worked well or better than intended	• Systems went septic quickly • Bad filters • Odors
Blackwater Reuse Blackwater treatment and reuse	• Automated and remotely controlled systems make life easy • Worked well or better than intended	• Water treatment causes pipe failures elsewhere in building • High operating costs • Poor process design
Process Water Recycling/Reuse Industrial process water	• Water savings • Reduced need for chemical treatment	• None given
Condensate Recovery HVAC condensate recovery	• Water savings • Cleaner water	• None given
Municipal Nonpotable Municipal Nonpotable sources (purple pipe)	• None given	• Cost of infrastructure • Required polishing

8.4.3 Landscaping

The Landscaping category included efficient irrigation, plant selection, and green and grey (living and non-living) stormwater management. Landscaping innovations were very well received at 75% or more positive responses (Figure 8.7). Only green stormwater retention and infiltration had any dissatisfying experiences reported, with 6% of responses.

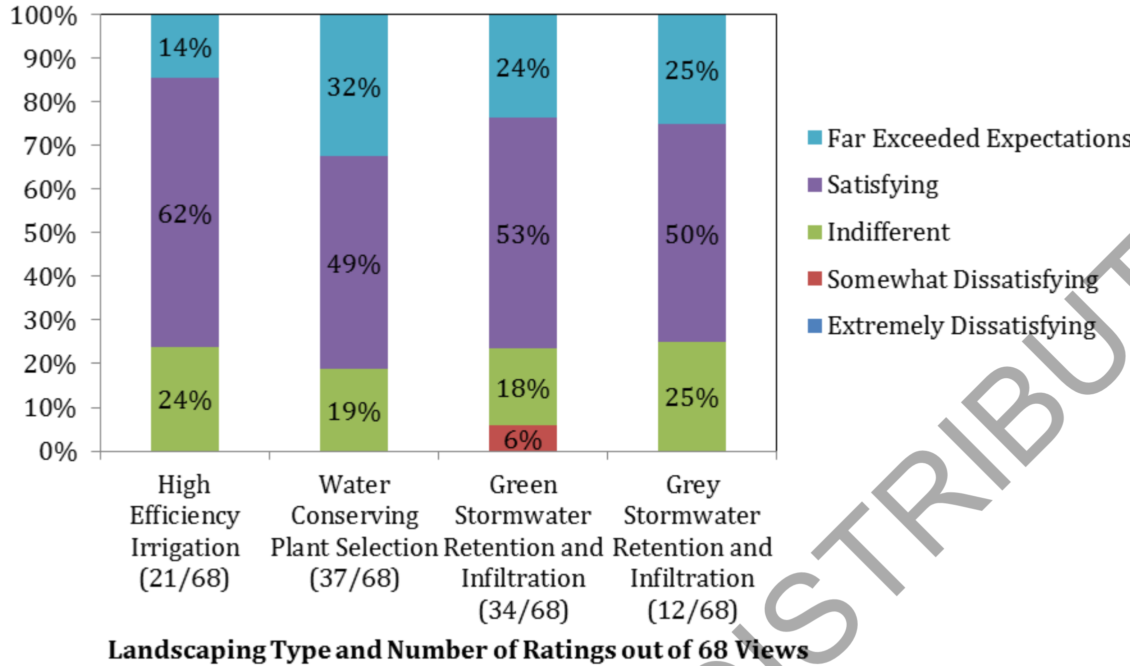

Figure 8.7 Response breakdown for Landscaping category

Landscaping innovations were very positively received (Table 8.12). High efficiency irrigation created positive experiences by saving water, and also improving the perception of landscape management by not watering areas that don't need water, like sidewalks. Positive experiences with water conserving plant selection involved water savings, minimal upkeep, and excitement at the use of native plants. Green stormwater management created positive experiences associated with low maintenance and aesthetics, and by working well. This is the only landscaping type to mention negative experiences, which resulted from water gardens often being built incorrectly by unqualified contractors. Grey stormwater management systems were positively perceived for working well, and because respondents enjoyed watching porous pavement drain.

Table 8.12
Experiences described for landscaping type

Type & Alt Text	Positive Experiences	Negative Experiences
High Efficiency Irrigation Alternative controls, high efficiency distribution, tailwater reuse, etc.	• Water savings • Reduced perception of wasted water by not spraying sidewalks, etc.	• None given
Water Conserving Plant Selection Native plants, xeriscaping, etc.	• Water savings • Minimal upkeep • Native plants	• None given
Green Stormwater Retention and Infiltration Biological systems such as vegetated roofs, Bioswales, rain gardens, infiltration basins, etc.	• Low maintenance • Aesthetically pleasing • Worked well or as intended	• Water gardens often built incorrectly by non-experts
Grey Stormwater Retention and Infiltration Non-biological systems such as pervious paving, storage, etc.	• Porous pavement fun to watch drain • Worked well or as intended	• None given

8.4.3.1 Performance monitoring. The Performance Monitoring category included water audits and sub-metering of water use. Performance monitoring innovation experiences were mostly rated as satisfying or indifferent (Figure 8.8), with under 20% negative experiences for both types.

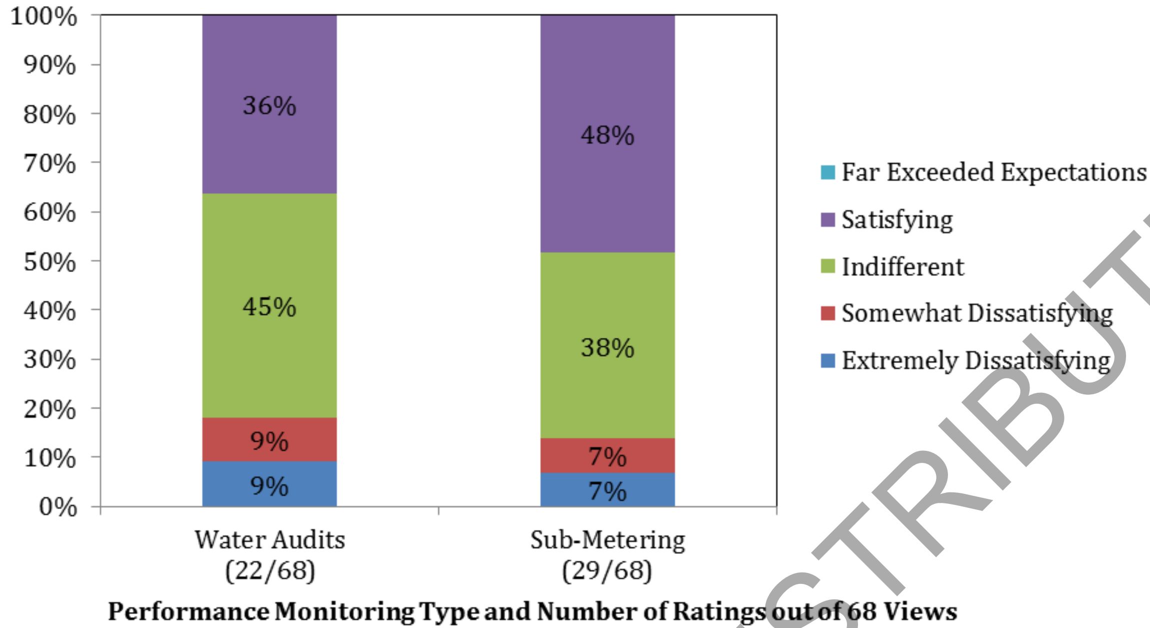

Figure 8.8 Response breakdown for Performance Monitoring category

Positive experiences described for water audits involved good return on investment, and a sense of becoming informed (

Table 8.13). In one case, a dissatisfied respondent had an audit with very poor return on investment. Sub-metering created positive experiences where demand was reduced, and firm documentation was available for questions of use and billing. The complaints included a high initial cost and difficult installation.

Table 8.13
Experiences described for performance monitoring type

Type & Alt Text	Positive Experiences	Negative Experiences
Water Audits Audits of building water use, water bill analysis, etc.	• Informative about waste • Good return on investment	• Poor return on investment
Sub-Metering Sub metering of occupants and rooms for detailed usage data	• Reduced demand • Firm documentation for use and billing	• High initial cost • Difficult installation

8.4.3.2 User education. The User Education category included feedback, signage and educational materials, and behavioral policies and incentives. User Education innovation experiences were mostly described as satisfying or indifferent (Figure 8.9).

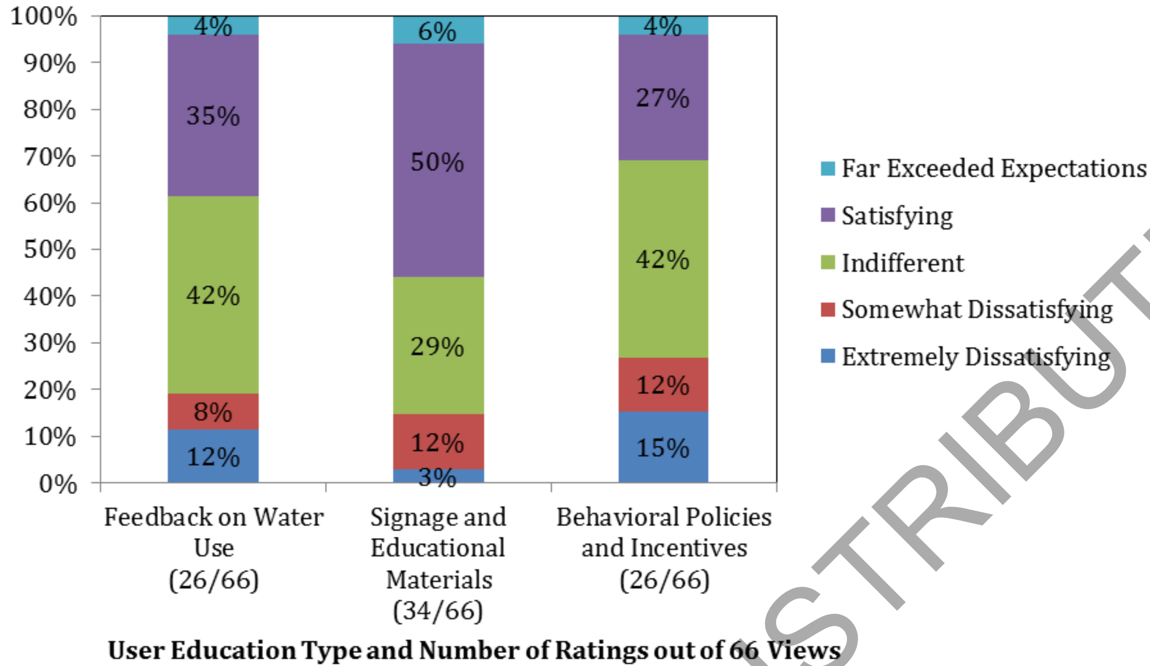

Figure 8.9 Response breakdown for User Education category

Feedback on water use was successful in creating water and power savings, and respondents suggested that in their experience, tracking was very effective when an average or benchmark was provided (Table 8.14). Negative experiences involved lack of engagement with leadership and facilities managers. Some respondents were also upset when feedback was only provided for negative behaviors. Respondents reported positive experiences with signage and educational materials related to easy implementation and scalability, as well as positive influences on user perceptions. Negative experiences involved the lack of useable data, and cases when users ignored signage, continuing in their old habits. Behavioral policies and incentives were reported as very effective where rebates were concerned, but were ignored in the experience of other respondents.

Table 8.14
Experiences described for user education type

Type & Alt Text	Positive Experiences	Negative Experiences
Feedback on Water Use User/occupant feedback on water use	• Water and power savings • Tracking especially effective with points of comparison	• Lack of engagement with leadership • Only supplied for negative problems
Signage and Educational Materials Signage and educational materials explaining how and why to conserve water	• Easily implemented • Scalable • Promotes positive views in users	• No useable data • Ignored in favor of habit
Behavioral Policies and Incentives Incentives for users to conserve water	• Rebates very effective	• Ignored by users

8.5 SUMMARY AND CONCLUSIONS

Though the survey was distributed to thousands of individuals, only 95 reported problems. There are many possible explanations for this being so low. One is that a majority of the target population is very satisfied with their systems, or is not aware of problems, so felt no need to participate.

The known problems most reported were noted by about a third of respondents. These included leaks and clogging of pipes, user complaints about insufficient hot water, early system failure, and water taste, odor, or color. These are all symptomatic issues, but do give indicators for managers to focus monitoring efforts on, and to use for other studies.

For all categories of innovations, negative satisfaction ratings were reported by a minority of respondents, indicating that these technologies are perceived to be working effectively in the majority of cases. These experiences are likely to support further diffusion of these technologies given what we know about experiences of early adopters. Some innovation types, such as landscaping measures, had little or no negative experiences reported. Toilets and Urinals, especially the non-water varieties, had the most negative response. The largest proportions of severe negative experiences also seem to have occurred in these non-water toilet innovations, followed by blackwater and then greywater reuse. It may be that these sewage related innovations inspire the strongest negative feelings because of humanity's evolved aversion to bodily waste. However, blackwater and greywater systems also have amongst the highest percentage of extremely positive responses.

Negative experiences were described for most of the innovations considered, and positive experiences were described for all but one. These experiences involve design, process, and human behavior, and suggest many topics for improvement and future research. Positive experiences tended towards systems working as intended, few surprises were reported. Respondents were pleased with cost and water savings for many innovations. The negative experience descriptions had several common themes. Water conserving fixtures and fittings failed to clear waste or to carry it through wastewater pipes, due to insufficient flow. Maintenance difficulties were also reported for many innovations, either through difficulty with the innovation itself, or through failures to communicate with maintenance staff. Negative perceptions about high costs were also reported for innovations in several categories.

In addition to offering green building professionals some information about what to look out for, these results suggest several areas of future research. Quantifying the impacts of these experiences on adoption rates would be very relevant to designers and vendors. The prevalence of both unmet and exceeded payback expectations suggests future research into understanding and improving the accuracy of financial expectations for these innovations. Furthermore, research could be done to develop more robust innovations that leverage the positive responses identified in this study, as well as address negative responses.

CHAPTER 9: INTERVIEWS WITH GREEN BUILDING PROFESSIONALS ABOUT THEIR EXPERIENCES WITH WATER CONSERVATION MEASURES

9.1 ABSTRACT

Phone interviews were conducted with a sample of green building professionals from multiple disciplines including, but not limited to, facility managers; architects; and engineers; about their experiences with water conservation measures in green buildings. Subjects were asked about their successes with water conservation measures, as well as difficult experiences. They were also asked to give advice based on their experiences for other professionals attempting their own conservation measures. Interview transcripts were analyzed using thematic analysis to identify successes and difficulties and evaluate frequency of occurrence, which were sorted by type of water conservation measure. Some themes emerged, including non-water urinal clogging and odors, line clogs where insufficient pipe slope was given for high-efficiency toilets, and difficulty educating maintenance personnel about procedures. Multiple subjects also shared the sentiment that water is underpriced and undervalued, and prices should and will go up in the future.

9.2 INTRODUCTION

Water conservation measures are frequently employed in buildings, in efforts to save money, promote sustainability, and improve public image. These measures are present in a large number of certified green buildings, as certification programs promote or require their inclusion. There are many different types of measures employed in these buildings, ranging from user interface products like high-efficiency water closets and faucet aerators to building-scale wastewater treatment plants. What these measures have in common is that they are meant to reduce the use of externally treated potable water, and they are innovative in the sense that they are unfamiliar to the adopter (Rogers, 2003).

Because the outcomes of the implementation of these innovative practices can have major consequences on the future adoption of similar innovations by others (Ash et al., 2007; Rogers, 2003), it is in the interest of those impacted by their success to understand what happens when they are installed. A fair amount of anecdotal evidence exists already, such as negative experiences with non-water urinals (Guevarra, 2010; Shapiro, 2010). There have also been several scientific studies, particularly related to opportunistic pathogen growth in water heating systems (Bagh et al., 2004; Brazeau and Edwards, 2012; Codony et al., 2002; Mathys et al., 2008). The most comprehensive formal study to date examined the results of an internet survey given to green building professionals, and identified multiple areas of potential future study.

This paper reports the next step of that exploratory study, where a series of in-depth phone interviews was conducted with a multi-discipline sample of green building professionals about their experiences with water conservation measures.

Participants were initially drawn from a pool of internet survey respondents that opted in to this portion of the study. After this pool was exhausted, the researchers expanded the pool by purposively sampling institutional owners and facility managers regionally with multiple green buildings in their portfolios, to maximize exposure to possible outcomes of interest.

The survey was designed to take about 30 minutes, and consisted of a series of questions about the respondents and their organizations, their experiences with water conservation measures both good and bad, and their thoughts on the future, including advice for others who might be interested in implementing similar measures.

9.3 RESEARCH METHODS

This was an exploratory study into professional experiences with water conservation measures in green buildings. An interview process was designed to elicit experiential data from participants' professional practice.

9.3.1 Subject Sources

The initial sample consisted of respondents to the internet survey from a previous phase of this study who had opted in to this phase. Of the 27 who expressed interest on the survey, 13 ultimately completed the interview. In order to expand the number of participants and buildings represented, the researchers sought institutional facility managers with multiple facilities in their portfolios. Virginia universities and city and county governments with LEED (Leadership in Energy and Environmental Design) certified buildings in their portfolios as included in the LEED directory (US Green Building Council, 2014) were contacted. This effort brought the number of respondents who completed interviews up to 25.

Because of the sensitive nature of some of the stories shared, any information that could be used to identify participants has been removed.

9.3.2 Interview Process

Interviews were conducted over the phone, and recorded by researchers. The process was designed to take approximately 30 minutes. Interviews began with an informed consent script (Appendix A) and a brief statement re-iterating the purpose of the interview. A series of open ended questions, broken down into four different parts, were then asked (Appendix B). The first section determined job functions and building portfolios. The second section determined organizational goals and behaviors regarding water conservation. The third section dealt with professional experiences, asking specifically about difficulties and major successes with water conservation. The fourth section inquired about perspectives on the future of water conservation in green buildings, in general and within their organization. The interviews ended with a question requesting advice for others trying to implement water conservation measures in their own buildings.

9.4 RESULTS

This was an exploratory study, seeking experiential data such as practitioner perspectives and outcomes of innovation adoption and implementation as the basis for future studies. Given the nature of the sample and the interview process, the aim of the study was not to undertake statistical analysis for the purpose of generalization. Instead, results are presented as a series of statements, first of successes, then of difficulties, and finally of advice given. They have been paraphrased and re-ordered by the types of systems involved, in order to protect the identity of interviewees. Categories are the same as those used in the previous study, consisting of 9 categories of 33 innovations (Table 9.1) (Chambers, 2014). Because the interview design measured self-reported experiences, not all of these innovation types were represented in the results. Additionally, counts have been included for experiences mentioned by multiple interviewees to give an indication of the frequency of occurrence across the sample.

Table 9.1
Categories and types of innovations (Chambers 2014)

Category	Innovation
Toilets and Urinals	Water Conserving Toilets Water Conserving Urinals Non-Water Toilets Non-Water Urinals Alternative Flushometer Valves
Shower and Faucet Fixtures	Low Flow Fixtures Alternative Controls Self-Powering
Plumbing	Alternative Piping Manifold Distribution Cured-in-Place Pipe Lining High Performance Epoxies
Water Heating	Recirculation On-Demand Solar Heat Recovery
Appliances	Water-Efficient Dishwashers Water-Efficient Clothes Washers Water-Efficient Icemakers
Alternative Water Sources	Rainwater Harvesting Greywater Reuse Blackwater Reuse Process Water Recycling/Reuse Condensate Recovery Municipal Nonpotable
Landscaping	High Efficiency Irrigation Water Conserving Plant Selection Green Stormwater Retention and Infiltration Grey Stormwater Retention and Infiltration
Performance Monitoring	Water Audits Sub-Metering
User Education	Feedback on Water Use Signage and Educational Materials Behavioral Policies and Incentives

9.4.1 Participation

A total of 25 interviews were conducted. The interview subjects represented multiple professional roles. While the largest percentage were facility managers, individuals with other roles such as plumbers, engineers, utility managers, architects, vendors, scientists, executives, and financial professionals were represented by one or more participants. All of these individuals had in common that their professional roles involved water conservation measures in green buildings. The subjects also represented multiple different types of organizations, including local government, armed services, private industry, non-profit, and higher education.

9.4.2 Successes

Interviewees were asked to talk about their greatest successes with water conservation measures. Responses were sorted by relevant water conservation measure categories and innovation types. They were then paraphrased for clarity and identity protection, and similar responses were combined and summarized in a table (Appendix C). Each type of success was given a reference number for ease in using the Appendices. The count of interviewees stating similar successes was also recorded. Results were ordered by category and innovation, then by amount of repetition.

Interviewees described 34 distinct successes. These successes largely involved systems working as well as or better than intended. Several others described successful programs and policies that reduced waste and user difficulties through recycling (S32), free products (S16), or creating accountability (S29).

9.4.3 Difficulties

Interviewees were asked to describe difficulties and challenges they had faced with water conservation measures. Responses were sorted by categories and types of relevant water efficiency measures. They were then paraphrased for clarity and identity protection, and similar responses were combined and summarized in a table (Appendix D). Each type of difficulty was given a reference number for ease in using the table. The count of interviewees stating similar difficulties was also recorded. Results were ordered by category and innovation type, then by amount of repetition.

Interviewees described 51 distinct difficulties. These difficulties varied widely. Recurrent themes included a lack of knowledge amongst users and owners (D4, D10, D14, D36, D50), and inaccurate manufacturer claims (D5, D9, D33).

9.4.4 Advice Given

Interviewees were given the opportunity to provide any advice they might have for others in their position seeking to implement water conservation efforts. Responses were paraphrased for clarity and identity protection, and similar responses were combined and summarized in a table (Appendix E). Each distinct piece of advice was given a reference number for ease in using the table. The count of interviewees giving similar advice was also recorded. Results were ordered by amount of repetition. This table was not organized by type of water efficiency measure because many of the pieces of advice are general or cover multiple types.

Interviewees described 29 distinct pieces of advice, covering many different things. Most commonly, they made statements about how water was undervalued and underpriced (A1) and that efforts for conservation needed to expand beyond bathrooms into recycling and recovery (A2). Education (A3) and policy involvement (A4) were also repeatedly encouraged.

9.4.5 Summary of Response Categories

Counts of successes and difficulties were tabulated for the categories of water conservation measures reported on in the interviews (Table 9.2).

Table 9.2
Summary of response types for categories reported on

Category	Successes	Difficulties
Alternative Water Sources	9	12
Blackwater Reuse	2	3
Condensate Recovery	3	
Greywater Reuse		4
Rainwater Harvesting	4	5
Landscaping	2	6
Green Stormwater Retention and Infiltration	1	1
High Efficiency Irrigation		3
Water Conserving Plant Selection	1	1
Other		1
Shower and Faucet Fixtures	3	10
Alternative Controls	1	3
Low Flow Fixtures	2	7
Toilets and Urinals	7	18
Alternative Flushometer Valves	3	5
Low Flow Urinals		
Non-Water Urinals	1	3
Water Conserving Toilets	1	9
Non-Water Toilets		1
Performance Monitoring	2	0
Sub-Metering	1	
Other	1	
User Education	8	0
Signage and Educational Materials	6	
Other	2	
Other	3	5
Total	34	51

9.5 DISCUSSION AND CONCLUSIONS

The successes reported by interviewees in many cases involved systems or features working as intended or expected. These results may help provide encouragement for future adopters or current proponents. The less commonly utilized successes discussed, such as recycling toilets (S32), offering products to commercial entities (S16), or requiring sign-offs on product manuals (S29) suggest future studies or changes in policy that could improve the success of water efficiency efforts.

While the nature of this investigation makes drawing statistical conclusions difficult, there were some things that were experienced by many of the interviewees. These, especially, may deserve future attention. Some, like issues with non-water urinals (D34), are highly visible and have gained notoriety within the industry. Plumbing issues from high efficiency water closets related to line slope and length that cause clogs (D37) are less visible to people who are not plumbers or facility managers, and need to be addressed in the design phase. That this was the most repeated difficulty suggests a need for further investigation to determine whether it is indeed common, and if solutions other than slope adjustment exist.

A repeated theme in the difficulties reported was lack of knowledge by owners or maintenance persons (D4, D10, D14, D36, D50). Some interviewees had attempted to mitigate these issues with policy changes requiring sign-offs (S29), reducing conflicts, but not significantly reducing failures. This suggests a need for investigation into how to improve education about maintenance procedures for these water efficiency products, as some of the advice given also attests (A6).

The advice given by interviewees also showed some common themes. Over a third of respondents commented that water is undervalued and underpriced (A1), that prices need to go up, and that they will. Multiple interviewees also suggested that water efficiency focus should shift from bathrooms where a point of diminishing returns is being reached towards water recycling and recovery, where large gains still remain to be made (A2).

One repeated piece of advice was to do thorough investigation into water efficiency measures before adopting them (A3). This echoes a theme from the difficulties that manufacturer claims may not always be accurate (D5, D9, D33) or that designers may lack expertise (D6). Programs such as MaP Testing (MaP, 2014) already exist to assist to identify products that do not work, so finding ways to improve the visibility of these programs might be the most fruitful research pursuit.

That the interview sample was geographically concentrated in Virginia suggests the possibility of biases related to this location. Future research into this subject might include studies in other geographical regions.

9.6 SUMMARY

This chapter presented the results of a series of interviews with green building professionals about their experiences with water conservation related measures. They were asked about their successes and difficulties, and then to provide advice for others. These stories and bits of advice may help other adopters avoid problems or attain greater success. Some areas of possible future research were also identified, particularly into issues related to line carry with water-conserving toilets and insufficient slope, and into educating maintenance personnel on proper care of unfamiliar fixtures and features.

CHAPTER 10: LESSONS LEARNED

10.1 INTRODUCTION

Each of the water quality issues described in this report is linked in some way to the water age within the plumbing system. Water age is increased by installing low flow devices and implementing potable water-saving technologies and seeking to use alternative water source for potable and non-potable uses such as rainwater collection, water reuse, and reduced use campaigns, among other strategies. While plumbing codes developed for green buildings identify the best strategies to reduce water use in buildings, and standards to protect buildings against the regrowth of harmful waterborne pathogens, there are not specific warnings, suggested strategies to maintain low water use, or frameworks for selecting desirable controls while ensuring there are not problems with rapid disinfectant residual decay, pathogen growth, and corrosion of premise plumbing. Decreasing pipe diameters seems like a promising choice to help decrease water age, but restrictions on in-pipe velocity, minimum pipe diameter requirements for fire demand, and minimum pipe diameter requirements based on the number of fixtures may limit the ability for designers to decrease the overall volume of the system to levels that are capable of maintaining adequate water age. For now, the most effective solution for buildings that implement green water strategies that are supplied by a public water utility may be to simply implement flushing at the farthest point from the entry point to introduce "new" water to the building plumbing system regularly. The amount and frequency of water to be flushed will like vary depending on various factors; however, the goal is to achieve and maintain a disinfectant residual in the plumbing system. For new buildings, it is recommended to minimize plumbing system volume and complexity. Unfortunately, there are not specific recommendations for buildings seeking off-the-grid status. Even with flushing, the source water quality may not change appreciably. Solutions for off-the-grid buildings are problematic because each building is unique and there is not currently sound science to aid in understanding all problems

10.2 RAPID LOSS OF DISINFECTANT

Abiotic and biotic reactions increase the rate at which residuals disappear. Water residence times, temperature, and nitrification seem to have the largest impact on decay, which may also have secondary impacts including causing pH fluctuations, microbial (re)growth, increased corrosion, and taste and odors problems. While several strategies exist for maintaining disinfectant residuals, none are effective for all systems all of the time (Table 10.1). It should be noted that many of these strategies have disadvantages and limitations. For example, varying the chloride to sulfate ratio in chloraminated systems is complex and cannot easily be done. Relative effectiveness should be taken into consideration for each strategy. For premise plumbing, the easiest and most straightforward solution to maintaining a residual is decreasing water age by implementing flushing (<1% of total daily flow has been effective in one building) if water is supplied by a utility that meets all U.S. EPA drinking water regulations at the building point of entry.

Table 10.1
Stakeholder responsibilities for maintaining adequate disinfectant residuals

Strategy	Stakeholder(s)
Limit the use of material with high chlorine demand	Designer Material manufacturer to some degree
Increase the chlorine: ammonia ratio in chloraminated systems	Utility, Building disinfection system manager
Increasing overall concentration of residuals applied	Utility, Building disinfection system manager
Raising pH	Utility, Building disinfection system manager
Controlling microbial growth	Combination of efforts
Flushing the system	Utility if problem is widespread, Building owner/operator if it is localized, Consumer

10.3 IN-BUILDING DISINFECTION SYSTEMS

Many building operators do not have the staff or expertise to properly maintain and operate all in-building disinfection systems. To the extent possible, it is better to rely on the expertise and experience of the utility plant operators. The site-dependent efficacies of many commercially available in-building treatment systems are not well understood. Most data is produced in field studies that have different overall goals, different methods for water quality analysis, sampling protocols, vigor of study, and parameters measured; therefore, it is difficult to make comparisons and draw over-arching conclusions. In some instances, how the system will react with the existing premise pluming is not well defined. For example, the pH dependent metal ion speciation of copper in copper-silver ionization systems could render the ions ineffective at eradicating microorganisms. However, as green buildings seek to become more independent (i.e. "net-zero"), they will like have to turn to in-building disinfection systems to ensure their water quality.

Regulating in-building disinfection will pose a new challenge. ASHRAE Standard 188, a new standard still in public review at the time of writing, is a step forward because it assigns responsibility to a specific stakeholder (the building owner/manager) in cases of *Legionella*-related outbreaks. However, various parts of how the standard will be implemented, and the legal and water quality repercussions that might result, are not well defined. There are three specific areas that need improvement:

- A protocol for measuring influent chlorine residuals should be a specified protocol in the standard and should be designed to maximize the likelihood of identifying systems with low chlorine residuals throughout the plumbing system.

- A framework for identifying potential long-term detrimental effects of thermal disinfection with regards to efficacy of the treatment and physical integrity of the plumbing system should be provided.
- A framework for selection between different disinfectant system types should be provided. The current *Legionella* control guidelines and standards do not provide this. When selecting a system, the engineer must consider the integrity of existing plumbing, safety of consumers, and ability to properly maintain and monitor the system over long periods of time in the face of considerable knowledge gaps and uncertainties.

An initial iteration of such frameworks is presented in Chapter 3. Other standards are needed for the control of other opportunistic pathogens because controls that work for *Legionella* may not be effective for other pathogens.

10.4 CORROSION

10.4.1 Blue Water

The occurrence of blue water (Type III pitting) is more common at the end of distribution systems and is often characterized by low chlorine residuals, less overall water use (high water age), and dead ends. Waters where soluble copper is the dominant form of copper in blue water are typically lower in pH, and problems usually dissipate over time. If they do not, pH can be raised above 7.6 or orthophosphate corrosion inhibitor can be dosed. Problems with blue water where particulate copper is the dominant form of copper usually develop after an initiation time and usually do not dissipate over time. Increased levels of chlorine can also be effective in inhibiting particulate copper release in high pH, low alkalinity waters. In these cases, water age and maintenance of chlorine residual can be key to solving problems.

10.4.2 Pinhole leaks

For waters that are known to form pin hole leaks, very low overall use and low chlorine residuals can exacerbate problems, especially when the leaks are microbiologically driven. Sulfate reducing bacteria play an important role in some cases of pitting. They produce a micro-anaerobic environment beneath tubercles. While flushing and increased disinfectant residual might help, replacement of the plumbing is sometimes necessary when SRB are involved. There are no proven remediation techniques that are effective for all systems.

10.4.3 Lead leaching

While the relative corrosivity of utility water is probably most important factor for causing lead leaching, even mildly corrosive waters that routinely pass Lead and Copper Rule sampling can have problems when water age is high. The highly corrosive nature of rainwater is of particular concern when it is used in potable water systems with lead bearing plumbing components. For very corrosive waters, some level of treatment is required. The new definition of lead-free brass per ANSI/NSF standards (60, section 8 and 9) will help reduce issues with lead in water, but until all buildings are rid of lead-laden brass devices, lead remains an on-going concern.

10.5 TASTES AND ODORS

Consumers are good indicators of water quality problems occurring in the distribution and building plumbing system. High water age and low disinfectant residuals are key causes factors for taste and odors; however, consumers also voice complaints about chlorine odor as well, which is necessary to identify and resolve many water quality and microbial problems. Some practitioners have reported consistent problems with sulfate reducing bacteria (rotten egg odor) in hot water systems, even if the water heater set point is above 60 °C where extensive flushing and disinfection have been implemented. New materials being developed and used in green buildings are ANSI/NSF rated for health. These tests do not address aesthetics and some synthetic materials being implemented could eventually contribute to taste and odor issues. To the extent taste and odor problems are isolated in a particular building, possible solutions (in order of likely increasing complexity) include flushing, designing and reducing water residences times, minimizing dead ends, using point of use filtration, booster chlorination, or other disinfectant.

10.6 RAINWATER HARVESTING

The corrosive nature of rainwater makes leaching of metals a concern. Rainwater quality and quantity varies greatly between regions. Rainwater can absorb contaminants from the air and roofing materials – including volatile organic compounds, heavy metals, and nutrients for biological growth. In some areas rainwater quality may not be adequate to drink (e.g. areas with high industrial activity) without additional treatment. Proper materials selection in rainwater systems is paramount, especially when used for potable water. Standards such as NSF 14, 60, and 61 as well as international green plumbing codes should be followed for material selection and installation practices. Research into rainwater quality in potable rainwater systems is needed to fully assess the safety and aesthetic implications of using this alternative water source.

10.7 MICROBIOLOGICAL CONTAMINANTS

10.7.1 Microbiological regrowth

Low water residence times and maintaining chlorine residual play key roles in preventing microbial growth. Although other strategies such as limiting nutrients entering the distribution system (e.g. assimilable organic carbon) also play a key role, many nutrients can be produced in the distribution system, decreasing the likelihood this strategy will be successful in controlling re-growth. Premise plumbing, in general, provides conditions such as intermittent flow, moderate temperatures, lower disinfectant residuals, and higher surface area to volume ratios that are ideal microbial growth. Maintaining temperature and disinfectant targets, and low water age, are viable strategies to avoid regrowth.

10.7.2 Metered Faucets

Increased incidence of *Legionella* and other opportunistic pathogens in metered faucets have raised concerns with installing these water-saving devices in plumbing systems. Although the cause for higher pathogen occurrence in these faucets is not fully understood, hypotheses for the cause(s) include water age, overall flow rate, materials used in the manufacturing process, testing and shipping of the faucets, and poor installation practices. The issues observed with these green devices bring into question other untested green building water conservation strategies.

10.8 GREEN BUILDING PLUMBING CODES

Standards, codes, and guidelines provide information about how to achieve reduced water demand in buildings, but infrequently provide information on potential changes to water quality that result from their use. A more integrated approach to reducing water demand would be beneficial to make the designers and building owners/operators more aware of the ways in which these green technologies and strategies can change the water quality within a building.

10.9 CASE STUDIES

The three case studies illustrated a range of water (and energy) conservation techniques that are being implemented to achieve a reduction in water demand. The solutions ranged from simply using low flow devices to using alternative water sources. In many cases, the effectiveness of treatment strategies applied to green building water systems are largely untested. For example, Field Site #3 with the use of GAC filtration and UV irradiation for treatment of rainwater, resulted in high concentrations of *Legionella* spp. and opportunistic pathogen host organisms. As a result, there appears to be a shift in responsibility for the safety of drinking water in green buildings, intentionally or unintentionally, away from utilities to individual home and building owners/operators. A better understanding of the chemistry and microbial ecology of green building plumbing systems is needed, along with efficacy studies of disinfectant approaches.

10.10 USGBC INSIGHT REPORT

Trends in pathways for achieving Leadership in Environmental Engineering Design (LEED) certification for water efficiency credits were examined. Projects pursing WEc1: Water Efficient Landscaping, projects most often pursue the use no permanent landscape irrigation as means to decrease their overall potable water use. Rainwater was the most common non-potable water source used to replace potable water used for landscaping. In order to reduce the amount of wastewater effluent for buildings in WEc2, high efficiency toilets and non-water urinals were more common than on-site treatment and reuse of the effluent. Overall, identifying the most common ways building designers are achieving these water conservation goals will help direct future research and efforts to further reduce water use.

10.11 CLIMATE FACTORS

Differences in pathways to achieving LEED water efficiency credits between climate regions defined by EERE and NOAA climate systems were examined. Irrigation selections showed differences between most regions under both climate systems. The choice of no permanent irrigation was least used in the Hot-Dry EERE region and three western NOAA regions. Water closet choices showed some differences, with dual flush toilets being selected significantly more in the EERE Marine and NOAA Northwest region. High efficiency urinals showed differences in only one climate classification system, being selected significantly more in the EERE Marine region than in the Hot-Dry and Mixed-Humid regions.

Results may be related to societal expectations and cultural norms. For instance, landscaping that requires more water than is naturally available in a particular region is common if there is cultural emphasis given to ornate lawns and gardens. The inclusion of climate specific guidelines within the newer green building rating systems could make climate specificity more prevalent in green building water efficiency strategies. Specifically, use of potable water resources for irrigation could be specifically discouraged in some regions of the U.S.

Further study of why the decisions that were made were made could also influence future certification guidelines. For instance, some possible influences on decisions that need further investigation are the input of various stakeholders in the design process, local and regional water efficiency legislation, and local water sensitivity related to non-climate factors such as demand. In addition, understanding if, or when and how, water feature decisions are made because of specific climatic region and water source sensitivity would useful to help influence future buildings design process to be more sustainable to the entire region, and not just the energy and water efficiency of that particular building. The main concern is that while some water conservation practices are overall more "efficient" they might not be ideal in every climate region.

10.12 GREEN BUILDING SURVEY

An internet survey was developed to synthesize experiences of green building professionals with water conservation related innovations. Participants rated their experiences with 33 types of water efficiency innovations, and indicated problems they had experienced. The most common problems were due to pipe leaks and clogs, insufficient hot water, premature system failure, and complaints about taste, odor, or coloration. The majority of respondent ratings of technologies were positive or neutral. Green landscaping innovations were overwhelmingly positive in all categories. Non-water urinals and toilets had the most negative response distributions, followed by blackwater and greywater recovery systems. Attempts to change consumer behavior related to how water is used had mixed results. In general, the lack of negative responses related to specific devices suggests people are overall satisfied with the perceived performance of these innovations. Areas for improvement for this area include lack of engagement with leadership, lack of useable data, or people ignoring behavioral policies that were outside regular norms.

10.13 INTERVIEWS

Phone interviews were conducted with green building professionals from multiple disciplines about experiences with water conservation measures in green buildings. Subjects were asked about their successful and challenging experiences. They were also asked to give advice based on their experiences for other professionals attempting their own conservation measures. Several themes appeared, including clogging and odors associated with non-water urinals, line clogs where insufficient pipe slope was given for high-efficiency toilets, and system problems and failures resulting from difficulties educating maintenance personnel about procedures. Multiple subjects also shared the sentiment that water is underpriced and undervalued, and prices should and will go up in the future.

In the future, achieving effective water conservation in buildings will not be limited to optimizing specific devices, but instead will likely incorporate design of whole water systems. This not only includes potable water supply systems, but consideration of wastewater systems as part of a larger green building design strategy as well. However, a way to mitigate concerns with adverse effects caused by these systems on potable water quality will be needed. For example, in high-efficiency system designs where flushing is necessary to reduce water age, the flushed water could be recovered for non-potable uses. Considering the design of the building water system as a whole, both upstream and downstream of the point of use, will be essential to ensure high water quality while achieving conservation goals in the green buildings of the future.

APPENDIX A – INFORMED CONSENT SCRIPT

Green Building Design: Water Quality and Utility Management Considerations
Interviews
Consent Script

As this study will be done over the phone, verbal consent will be obtained. The script follows:

Thank you for participating in Green Building Design: Water Quality and Utility Management Considerations. Before we continue, I need to read you a consent script to ensure you are fully aware of what you are participating. At the end, I will ask you to give verbal consent before we continue.

This study is being performed by Virginia Tech in conjunction with the Water Research Foundation. Researchers include Dr. Marc Edwards, Dr. Annie Pearce, both professors at Virginia Tech, and Ben Chambers and William Rhoads, graduate students at Virginia Tech.

The study is designed to identify and understand unanticipated consequences of green water technologies and practices on water use in buildings. It is a multi-phase research study with internet surveys, phone interviews, and site visits. Subjects are green building professionals in the United States, and there are expected to be about 50 participants in this phone interview phase.

This portion of the study will take approximately 30 minutes of your time, all over the phone. I will ask you a series of open-ended questions about your experiences, and allow you to respond to your satisfaction. We will be recording and transcribing your responses, but all identifying information will be removed and replaced with an ID code to protect your privacy, and the only individuals with access to this information will be the four research workers. It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research. We will not quote you or use identifying information without express written consent from you. Data will be destroyed three years after publication of results.

There are no expected risks to this study. Benefits are the knowledge of common problems with green water systems that they might be studied and fixed, which could improve your professional life.

There is no compensation for this interview. You are free to withdraw at any time without penalty. You are free to not answer any questions if you choose without penalty.

Do you have any questions?

If you have any further questions, the contact information for the investigators and IRB have already been provided by email.

Have you heard and understood the consent language for this study? Have you had all of your questions answered? Do you give your voluntary consent?

Thank you. We can now begin.

APPENDIX B – INTERVIEW QUESTIONS

Green Building Design: Water Quality and Utility Management Considerations
Interviews
Data Collection Instruments

Interview Question Worksheet

Demographics - Understanding the Interviewee and their Organization (5 min)

1. What is your Job Title? What did you do before this?	
2. Tell us about your building portfolio or buildings with which you are involved. a. Types of buildings, number b. Special functions, if any, with respect to water	
3. What are your job tasks and responsibilities? What role do you play with respect to <organization’s> buildings?	

Organizational Choices about Water Technologies (10 minutes)

4. What are your organization’s goals with regard to building water conservation and use? a. General impression - important? Ambitious? b. Links to any explicit written goals or policies c. Verification of any policies we learned about on the web	

5. How have these goals influenced the <u>types of water technologies</u> used in your projects?	
6. What else (e.g., <u>external policies, incentives, programs</u>) has affected the technologies and systems used?	
7. What have been your <u>major successes</u> with innovative water-related technologies over the past 5-10 years? a. What has been tried? b. What has been <u>routinized</u>?	

Unanticipated Consequences of Innovations (10 min)

8. What innovations have resulted in unexpected or undesirable outcomes? a. Project details b. Technologies used c. Causes of problems d. Resolution <Provide prompt from survey if completed>	
9. What types of building water problems have you heard about but not experienced personally?	
10. Have these experiences changed how you approach future projects? In what way?	

11. What is the most challenging innovation (water or not) you have undertaken on a project? a. Why was it challenging? b. What was the outcome?	

Perspectives on the Future of Water-related Innovations (5 min)

12. What do you see as the future of <organization's> buildings with respect to water? a. How do you see things changing in the next five years? b. Ten or more?	
13. What will be driving those changes? a. Internal factors b. External factors	
14. How successful is the field of 'green' water technologies now? How does it need to change in the future?	
15. What advice would you have for others trying to innovate in their building water systems?	

APPENDIX C – INTERVIEWEES' GREATEST SUCCESSES WITH BUILDING WATER CONSERVATION MEASURES

Reference	Category	Innovation	Count	Description
S1	Alternative Water Sources	Blackwater Reuse	1	Users expressed pleasure upon realizing that the plant beds they had been admiring were part of the treatment system.
S2	Alternative Water Sources	Blackwater Reuse	1	Pleased with the functioning of blackwater treatment systems.
S3	Alternative Water Sources	Condensate Recovery	2	Recovering condensate and stormwater resulted in significant savings on water use.
S4	Alternative Water Sources	Condensate Recovery	2	Because sewerage rates were based on water draw, using non-utility sources such as condensate recovery for non-sewer applications such as evaporative coolers and landscaping removed the problem of paying for sewerage that was not being used.
S5	Alternative Water Sources	Condensate Recovery	1	Cooling tower water management was a significant source of savings at low investment cost.
S6	Alternative Water Sources	Rainwater Harvesting	2	Using rainwater for landscaping irrigation resulted in cost savings.
S7	Alternative Water Sources	Rainwater Harvesting	2	Pleased with the functioning of rainwater harvesting systems.
S8	Alternative Water Sources	Rainwater Harvesting	1	Pleased with functioning of vortex upright filters.
S9	Alternative Water Sources	Rainwater Harvesting	1	Using rainwater as a source for ultra-pure industrial or lab water significantly reduced the costs for treatment, as it is more pure than tap water.

Reference	Category	Innovation	Count	Description
S10	Landscaping	Green Stormwater Retention and Infiltration	2	Pleased with the functioning of green stormwater retention and infiltration systems.
S11	Landscaping	Water Conserving Plant Selection	3	Pleased with reduced irrigation cycling allowed by drought resistant plant selection.
S12	Performance Monitoring	Other	2	Leak surveys have been successful in dramatically reducing fault-related water waste.
S13	Performance Monitoring	Sub-Metering	1	Individual building bills for a large facility created internal competition and awareness that led to many users and personnel searching for ways to reduce water use.
S14	Shower and Faucet Fixtures	Alternative Controls	3	Automatic cutoff sinks have worked well, and have prevented multi-day discharge from people leaving sinks on in little used bathrooms over weekends.
S15	Shower and Faucet Fixtures	Low Flow Fixtures	2	Low-flow sinks and showers have consistently proven cost effective, particularly because of hot water energy savings.
S16	Shower and Faucet Fixtures	Low Flow Fixtures	1	By going to restaurants and offering to install a water saving version of a dishwashing nozzle product for free, a utility reduced stress on their water supply while giving significant annual savings to the restaurants.
S17	Toilets and Urinals	Alternative Flushometer Valves	3	Dual-flush toilets have been well received and worked well.
S18	Toilets and Urinals	Alternative Flushometer Valves	1	Pressure assisted flush toilets have worked well.
S19	Toilets and Urinals	Alternative Flushometer Valves	1	Customers appreciate touch free sensors on toilets and sinks, and are asking for them on other features, like towel dispensers.

Reference	Category	Innovation	Count	Description
S20	Toilets and Urinals	Water Conserving Urinals	2	Pint flush urinals have been well received and worked well.
S21	Toilets and Urinals	Water Conserving Urinals	1	Half-gallon flush urinals have been well received and worked well.
S22	Toilets and Urinals	Water Conserving Toilets	2	High efficiency toilets have worked well.
S23	Toilets and Urinals	Non-Water Urinals	1	High visibility of non-water urinals has made many users notice them and get excited.
S24	User Education	Other	1	Pleased with the success of LEED criteria at promoting water efficiency and making it mainstream, accepted practice.
S25	User Education	Other	1	Pleased with the success of WaterSense at promoting water efficiency and making it mainstream, accepted practice.
S26	User Education	Signage and Educational Materials	2	User education has helped to reduce water usage.
S27	User Education	Signage and Educational Materials	1	By setting up demonstration gardens, involving gardening clubs, and making educational materials accessible at points of sale, xeriscaping was successfully promoted in the community by the utility.
S28	User Education	Signage and Educational Materials	1	WaterSense was successfully promoted for new homes in an area, easing strain on the water utility.
S29	User Education	Signage and Educational Materials	1	Providing new owners and maintenance staff manuals and maintenance logs and requiring them to sign papers off on having received and read them has reduced conflict and litigation, though it has not significantly reduced failure incidence.
S30	User Education	Signage and Educational Materials	1	Teaching plumbers about MaP testing and other certifications has stopped wholesale rejection of efficient toilets after bad experiences.

Reference	Category	Innovation	Count	Description
S31	User Education	Signage and Educational Materials	1	MaP testing and other certifications have helped to reduce the spread of greenwashing and ineffective products.
S32	Other	Other	1	All the toilets being replaced were recycled for building materials, utilizing a waste stream and saving landfill space.
S33	Other	Other	1	Centralized treatment systems for lab or process water significantly reduced waste and maintenance costs.
S34	Other	Other	1	Successful codification of water softening saved water heater efficiency and plumbing fixtures from scaling.

APPENDIX D – INTERVIEWEES' DIFFICULT EXPERIENCES WITH BUILDING WATER CONSERVATION MEASURES

Reference	Category	Innovation	Count	Description
D1	Alternative Water Sources	Blackwater Reuse	1	Blackwater system was very susceptible to whole system failure due to minor malfunctions such as blown fuses or loose contacts.
D2	Alternative Water Sources	Blackwater Reuse	1	Facility did not budget for major maintenances of blackwater system, and a plumbing failure could not be repaired. The system has been sitting unused for years.
D3	Alternative Water Sources	Blackwater Reuse	1	Lack of incentives in some rating systems for blackwater treatment directed focus away from it in spite of the significant water savings possible.
D4	Alternative Water Sources	Greywater Reuse	3	Lack of proper maintenance by uninformed or unwilling maintenance staff caused greywater systems to go septic. Reducing maintenance load with measures such as adding backwashing filters has reduced problems.
D5	Alternative Water Sources	Greywater Reuse	1	Greywater systems have not performed to manufacturer claims.
D6	Alternative Water Sources	Greywater Reuse	1	Greywater systems have failed because they were designed by people without the proper expertise.
D7	Alternative Water Sources	Greywater Reuse	1	Greywater systems were blamed for all bad odors in buildings, regardless of actual fault.
D8	Alternative Water Sources	Rainwater Harvesting	2	Poor installation jobs for rainwater harvesting systems by novices caused failures including tank contamination, pump bun-out, plumbing cross-contamination, discolored water, and systems going septic.
D9	Alternative Water Sources	Rainwater Harvesting	1	Rainwater harvesting systems or components did not perform consistently with manufacturer claims.

Reference	Category	Innovation	Count	Description
D10	Alternative Water Sources	Rainwater Harvesting	1	Lack of proper maintenance of rainwater harvesting systems by owners, particularly regarding pre-filters, has caused systems to go septic.
D11	Alternative Water Sources	Rainwater Harvesting	1	Water discoloration from green roof substrates discouraged the use of toilets containing the water.
D12	Alternative Water Sources	Rainwater Harvesting	1	Rainwater corroded copper pipes.
D13	Landscaping	Green Stormwater Retention and Infiltration	1	Bio-retention system took more maintenance than was budgeted, and undesired species took over.
D14	Landscaping	High Efficiency Irrigation	2	Users superseded high efficiency irrigation system technology intent or did improper maintenance due to lack of understanding of the systems.
D15	Landscaping	High Efficiency Irrigation	1	High efficiency irrigation systems were not life cycle cost effective individually. Grouping buildings for economies of scale fixed this.
D16	Landscaping	High Efficiency Irrigation	1	In green roof systems, drip irrigation did not work with highly porous substrate as water just fell through, leaving many areas dry. Porosity also made moisture sensors ineffective. With spray systems, significant amounts of water were lost to evaporation and the breeze.
D17	Landscaping	Other	1	Architects did not understand the implications of their landscape decisions on stormwater discharge to the neighborhood, causing flooding of some areas.
D18	Landscaping	Water Conserving Plant Selection	1	Xeriscaping saved on water and O&M, but proved not to be cost effective due to the low cost of water.
D19	Shower and Faucet Fixtures	Alternative Controls	1	Automatic faucets regularly failed, and replacement parts were difficult or expensive to obtain.

Reference	Category	Innovation	Count	Description
D20	Shower and Faucet Fixtures	Alternative Controls	1	Users complained about automatic faucets making tooth brushing and other non-hand washing actions difficult.
D21	Shower and Faucet Fixtures	Alternative Controls	1	Automatic faucets made it difficult or impossible to get hot water out of sinks.
D22	Shower and Faucet Fixtures	Low Flow Fixtures	2	Low flow faucets made it difficult to get hot water out of sinks.
D23	Shower and Faucet Fixtures	Low Flow Fixtures	2	Faucet aerators were found to grow bacteria. They were replaced with antimicrobial models.
D24	Shower and Faucet Fixtures	Low Flow Fixtures	1	Users removed faucet and shower aerators to increase flow.
D25	Shower and Faucet Fixtures	Low Flow Fixtures	1	Users removed faucet aerators for use in construction of drug paraphernalia (bongs or water pipes). Aerators were replaced with locking models.
D26	Shower and Faucet Fixtures	Low Flow Fixtures	1	Users complained about low flow faucets increasing the time necessary to fill containers.
D27	Shower and Faucet Fixtures	Low Flow Fixtures	1	Faucet aerators were found to have significant scale buildup and required undesirable extra maintenance.
D28	Shower and Faucet Fixtures	Low Flow Fixtures	1	Low flow showerheads in old buildings provided inconsistent pressures and flow rates.
D29	Toilets and Urinals	Alternative Flushometer Valves	2	Automatic flush toilets had significant numbers of false flushes.
D30	Toilets and Urinals	Alternative Flushometer Valves	1	Automatic flush toilets regularly failed, and replacement parts were difficult or expensive to obtain.
D31	Toilets and Urinals	Alternative Flushometer Valves	1	Remote operated flushometer controls have been promoted by salespersons as an easy way to get LEED certification and easily increase toilet flow afterwards.
D32	Toilets and Urinals	Alternative Flushometer Valves	1	Dual flush toilets were unnecessarily placed in bathrooms with urinals.

Reference	Category	Innovation	Count	Description
D33	Toilets and Urinals	Alternative Flushometer Valves	1	Dual flush toilet valves were not accurate.
D34	Toilets and Urinals	Non-Water Urinals	7	Non-water urinals caused drain clogging and foul odors.
D35	Toilets and Urinals	Non-Water Urinals	1	Non-water urinal cartridges were repeatedly destroyed by chewing tobacco expectoration from users.
D36	Toilets and Urinals	Non-Water Urinals	1	Non-water urinal cartridges were destroyed by janitorial staff emptying mop buckets containing cleaning products into them.
D37	Toilets and Urinals	Water Conserving Toilets	10	High efficiency toilets created plumbing problems due to the water content and pipe slope, possibly compounded by line length.
D38	Toilets and Urinals	Water Conserving Toilets	2	High efficiency toilets created problems with sewer lines due to the water content, requiring extra flushing.
D39	Toilets and Urinals	Water Conserving Toilets	2	Users complained about odors in high efficiency urinals.
D40	Toilets and Urinals	Water Conserving Toilets	1	Pipe roughness created problems with high efficiency toilets in older buildings.
D41	Toilets and Urinals	Water Conserving Toilets	1	After encountering problems with high efficiency toilets, plumbers have refused to consider them ever again.
D42	Toilets and Urinals	Water Conserving Toilets	1	Water conserving toilets and urinals were not life cycle cost effective when implemented only in low usage buildings. Combining them with high usage buildings for large design or retrofit projects made them financially justifiable.
D43	Toilets and Urinals	Water Conserving Toilets	1	Water conserving toilets over strengthened wastewater stream to sewage treatment facility, necessitating major upgrades.
D44	Toilets and Urinals	Water Conserving Toilets	1	Users tampered with high efficiency toilet valves to increase flow, causing damage.

Reference	Category	Innovation	Count	Description
D45	Toilets and Urinals	Water Conserving Toilets	1	Construction or project managers insisted upon the installation of standard flow fixtures despite specifications.
D46	Toilets and Urinals	Non-Water Toilets	1	Mistakes during construction caused vent clogging on a composting toilet system that caused foul odors for a long time before being caught and repaired.
D47	Other	Other	2	Lower water use in some areas has increased water age and decreased chlorine residuals, creating water quality issues. Fire codes mandated fire sprinklers in new homes, requiring larger supply lines and meters, further compounding this problem.
D48	Other	Other	1	Experience with problems with early water efficiency technologies made during the 1990s has caused people to refuse to try or even consider new versions.
D49	Other	Other	1	Self-priming traps did not fill due to the combination of low-use and low-volume fixtures, allowing sewer odors to escape. Regular flushing of drains was required.
D50	Other	Other	1	Owners and operators lacked good information about the maintenance and use of their water conservation features. They did not seek information due to the undervaluing of water.
D51	Other	Other	1	Contractors who are used to operating in a particular way and already have established supplier relationships have been difficult to convince to make water conservation changes.

APPENDIX E – ADVICE GIVEN BY INTERVIEWEES TO OTHERS IN THEIR FIELDS SEEKING TO IMPLEMENT WATER CONSERVATION EFFORTS

Reference	Count	Advice
A1	9	Water is currently undervalued and underpriced. Prices should or will increase, making these measures more cost effective and popular.
A2	6	Water efficiency in bathrooms is nearly at its peak. It is time to shift focus to recycling and recovery in areas such as condensate, HVAC, and process water.
A3	5	Make sure that fixture options are well researched before making selections. Talk to people who have used them. Do not rely on price, manufacturer specs, or aesthetics alone, and be aware of possible parts supply issues.
A4	5	Get involved in the policy decision making process for codes and standards, and make sure that government makes features like green architecture and rainwater and greywater recovery legal and easy to accomplish in all jurisdictions. Meeting criteria like WaterSense could become required.
A5	3	When installing toilets with low volume flushes, avoid long line carry and make sure there is sufficient grade.
A6	3	Always lead with a strong education program. Following instructions and manuals is extremely important. Make sure that your maintenance people read them. If you are passing a project off, make sure the new owners or managers sign a statement that they have received and read the instructions. Including log books may also help.
A7	2	When designing or implementing water conservation efforts, be sure to take a holistic look at the facility. This will help to find the areas where the biggest difference can be made.
A8	2	Do thorough cost-benefit analyses to ensure that plans make sense. Be aware of energy efficiencies, materials, plumbing schemes, and possible future add-ons. The minute energy savings from things like self-powering auto-flush or faucet systems alone are not sufficient reason to install them.
A9	2	Sustainability decisions should be made in the first part of the design process for maximum impact and minimum cost. Structural differences are likely to help more than the details of what is selected inside, and won't cost any extra if made early in the design phase.
A10	1	If drawing water from a well, be aware that grit from the well may impact the function of plumbing fixtures.
A11	1	If you are an early adopter of an innovation, start with a small scale test.

Reference	Count	Advice
A12	1	Investigate the cleaning capabilities of sinks with reduced flow before implementing them in highly sensitive buildings such as hospitals.
A13	1	Completely waterless technologies meet resistance because of human perceptions of the necessity of water for cleaning things. When up against this, get the lowest flow possible with suitable performance.
A14	1	Long term studies (10 years or more) need to be done on the effects of water efficient fixtures on pipes.
A15	1	The industry would benefit greatly from regional benchmarks for water conservation. Standards, codes, and the like could be dramatically improved with this information.
A16	1	Try to install wastewater treatment systems that have some built-in redundancy and partial function if minor parts fail.
A17	1	Don't think of greywater systems as add-ons. When designing buildings, imagine that they will be installed eventually, and plan accordingly.
A18	1	Don't forget to look for leaks and check plumbing fixtures for proper function.
A19	1	Make sure to do water and stormwater calculations in the context of the neighborhood as well as the building, especially in flood-prone areas.
A20	1	Rainwater, greywater, and blackwater treatment systems would benefit greatly from true turnkey systems.
A21	1	Don't forget that low water use plants need extra attention the first year or two to get established, or you'll lose a lot of them.
A22	1	Stagger Y joints in sewage plumbing at least a few feet, to avoid 'perfect storms' of paper out of low-flow toilets catching and clogging.
A23	1	Look for other sources of water for evaporators to save on sewage bills if you pay sewage based on draw. Wells are one source.
A24	1	Don't tell occupants about minor changes, especially in flow rates on sinks and toilets. They tend not to notice on their own, and then they don't complain about having to make changes to their routine.
A25	1	Trying to turn a desert into an oasis doesn't work. Use climate appropriate landscaping. Try to get past the east coast idea that green is good and brown is bad.
A26	1	We should all be using water that is 'fit for purpose', but most people have a hard time accepting or understanding that. There needs to be a matchup between end uses and water source and treatment. You don't need drinkable water to flush a toilet.
A27	1	Larger water recycling projects tend to be more economically viable. Think big.
A28	1	When dealing with wastewater treatment systems, don't let your manufacturer only provide the equipment. Make sure they work with you to develop a whole working system. These systems take a lot of collaboration.

Reference	Count	Advice
A29	1	Try not to work with too many subcontractors, as doing so increases the chances of confusion, miscommunication, and mistakes.

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ABBREVIATIONS LIST

Ag – Silver (ions, metal, could refer to particulate and/or soluble).
ANSI – American National Standards Institute.
AOC – assimilable organic carbon.
ASHRAE – American Society for Heating, Refrigeration, and Air-conditioning Engineers.
ATP – Adenosine triphosphate.
AWT – Association of Water Technologies.
BART – Biological activity reactivity test.
BCV – Blacksburg-Christiansburg-VPI Water Authority.
CCPP – Calcium Carbonate Precipitation Potential.
CDC – Center for Disease Control.
CFU – colony forming unit.
CPVC – Chlorinated polyvinyl chloride (premise plumbing pipe material).
Cu – Copper (ions, metal, could refer to particulate and/or soluble).
DBPR –Department of Business and Professional Regulation.
DGGE – Denaturing gradient gel electrophoresis.
DN – Denitrifying bacteria.
DNA – deoxyribonucleic acid.
DO – Dissolved oxygen.
DOH – Department of Health.
DWS – Maui Department of Water Supply.
EDC-IS – Epidemiology Disease Control, and Immunization Services.
EERE – US Department of Energy's Office of Energy Efficiency and Renewable Energy.
EF – electronic faucet.
G6PD - Glucose-6-phosphate dehydrogenase.
GAC – Granular activated carbon (filter).
HAB – heterotrophic aerobic bacteria.
HACCP – Hazardous Analysis Critical Control Point.
HDPE – High density polyethylene.
HPC – heterotrophic plate count.
IES – Illuminating Engineering Society.
IgCC – International Green Construction Code.
LCR – Lead and Copper Rule.
LD – Legionnaires' disease.
LEED – Leadership in Environmental Engineering Design.
LSI – Langelier Saturation Index.
MAC – Mycobacterium avium complex.
MC – monochloramine.
MCCP – Measured Calcium Carbonate Precipitation.
MDCHD – Miami-Dade County Health Department.
MDPE – Medium density polyethylene.
MPW – Marshall pitting water.

MRDL – Maximum Residual Disinfectant Level.
NAHB – National Association of Home Builders.
NB – Nitrifying bacteria.
NI – Nucleation Index.
NOAA – National Oceanic and Atmospheric Administration.
NOM – Natural organic matter.
NRC – National Research Council.
NSF – National Science Foundation.
NTM – Non-tuberculosis Mycobacteria.
OPPP – Opportunistic pathogen in premise plumbing.
OR – odds ratio.
OSHA – Occupational Safety and Health Administration.
PAH – Polycyclic aromatic hydrocarbons.
Pb – Lead (ions, metal, could refer to particulate and/or soluble).
PCR – polymerase chain reaction.
PCU – Pinellas County Utility.
PEX – Cross-linked polyethylene (premise plumbing pipe material).
PVC – Polyvinyl chloride (premise plumbing pipe material).
QA/QC – Quality Assurance/Quality Control.
qPCR – Quantitative polymerase change reaction.
rRNA – ribosomal ribonucleic acid.
SRB – Sulfate reducing bacteria.
TOC – total organic carbon.
t-RFLP – terminal restriction fragment length polymorphism.
U.S. – United States.
U.S. EPA – United States Environmental Protection Agency.
UNC – University of North Carolina.
USGBC – United States Green Build Council.
UV – ultraviolet (light, disinfection).
VOC – Volatile organic carbon.
WHO – World Health Organization.
WQRC – Water Quality Research Council.