The Impact of Water-Energy Feedback on Water Conservation at Residence Halls

Seung Hyo Jeong

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
in
Civil and Environmental Engineering

John E. Taylor, Committee Chair

Annie Pearce

Sunil Sinha

August 8, 2013

Keywords:

Residential Halls, Water Consumption, Water-Energy, Water-Saving Behavior, Water Use Feedback

The Impact of Water-Energy Feedback on Water Conservation at Residence Halls

Seung Hyo Jeong

ABSTRACT: Demand for potable water and energy is increasing with growing populations and economies and many fear that scarcity of such resources will become a significant worldwide problem in the future. As such, promoting water and energy conservation in residential building environments has become an important focal area for research. Providing feedback of water or energy consumption to residential building occupants has been demonstrated to be effective in promoting water and energy conservation separately. However, although water and energy are inexorably connected, we lack research that investigates the bridge between water and energy in the representation of feedback to promote water conservation. In this paper, we describe a study that was designed to investigate the impact of two different representations of water consumption feedback on water conservation. Water consumption was represented to consumers in one of two different ways: 1) gallons and 2) gallons along with the estimated embodied energy of water consumption. The study was conducted in 18 residential halls at Virginia Tech and lasted approximately six weeks. The outcome of the study suggests that representing water consumption in terms of gallons together with the embodied energy associated with water consumption can lead to a statistically significant reduction in water conservation while representing water consumption only in terms of gallons may not. This has significant implications for future water feedback designed to promote water conservation and the study indicates that non-monetary approach can be taken.

Acknowledgements

I would like to thank my committee Dr. John E. Taylor, Dr. Annie Pearce and Dr. Sunil Sinha for their input into this research and extend my thanks to Rimas Gulbinas, Virginia Tech Housing Office, Virginia Tech Electric Services and Virginia Tech Office of Sustainability for enabling this research.

Table of Contents

List of Figures

List of Tables

Introduction

A six-week study was conducted at Virginia Tech residential halls, with permission from both Virginia Tech Electric Services and the Housing Life Office of Virginia Tech, to promote water conservation utilizing two different feedback representations. The residents in these halls do not directly pay for water and this study explores if feedback can be utilized to induce water conservation in the absence of direct monetary incentive.

The results of the study was determined to be significant, and the thesis is formatted in preparation for a possible journal submission. Two details that were excluded to correspond with the word limit for a journal submission can be found in the appendix section of the thesis. Appendix section will discuss and provide the concept of feedback loop, the water-energy calculation, and the raw data.

Review of Literature

The demand for potable water is expected to increase with increasing population and globalization, while access to freshwater supplies will remain restricted[1]. Only approximately 0.007% of the earth's water is considered to be freshwater and potable and it is estimated that by 2030, 40% of the global demand for potable water will not be met[2]. Without significant changes in potable water consumption patterns, an estimated $50 to $60 billion will be required over the next two decades to close the gap between the supply and demand for potable water[2].

The increasing gap between the supply and demand for potable water is already observable throughout the world as various regions already suffer from potable water shortages brought about by consumption, drought and water pollution[3]. For example, reduced inflows due to drought and increased outflows due to population increase in Australia have triggered potable water consumption restrictions, and freshwater water storage levels have declined to 4% of the original capacity in some areas[4]. It is estimated that by the end of 2013, even under non-drought conditions, at least 36 states in the United States will anticipate local, regional, or statewide water shortages due to over consumption and climate change[5, 6].

Water is an essential component of life, and its scarcity is a major challenge that humans face in the 21st century[7]. The World Health Organization defines reasonable access to water as having at least 5.3 gallons of potable water per person available within one kilometer in a given day. However, while many developing nations struggle to meet this definition for their citizens, relative ease of access to potable water in many developed countries has resulted in misperceptions of potable water availability and its general overuse at the end-user level[8]. Perceptions and beliefs pertaining to potable water have been shown to have significant influence on potable water consumption behaviors[7, 9]. For example, the United States is estimated to have among the highest rates of natural resource consumption in the world; an average family of four in the United States consumes approximately 400 gallons of potable water per day[10]. Such excessive water use threatens freshwater resources in the United States; e.g., aquifers located in North Carolina are in danger of saltwater intrusion due to the voids created in the aquifers by excessive pumping of water[11]. As potable and freshwater sources becomes scarcer, water conservation will play an increasingly important role in ensuring water security.

Equally vital to personal, environmental, and economic health, energy production and consumption has become an important topic of research in recent years. Energy related emissions account for more than 80 percent of the carbon dioxide released into the atmosphere each year and anthropogenic greenhouse gases resulting from energy production have been shown to have a significant impact on the global climate[12]. Energy should be conserved to prevent increased atmospheric carbon concentrations and to assist in global climate stabilization.

Potable water and energy conservation are critical and inextricably related; energy is required to transport and distribute water, and is also used in the construction, operation and maintenance of all water facilities. Water related energy consumption in the United States in 2005 was estimated to be approximately 521 million MWH, which is approximately 13% of all electricity consumption in 2007[13]. Wasteful water consumption will result in wasteful energy usage and, likewise, reducing unnecessary water consumption will reduce unnecessary water related energy usage.

The extended effects of water consumption are not limited to impacting energy consumption. Potable water production has been shown to have a large carbon footprint[14]. Water related energy consumption accounts for approximately 290 million metric tons of carbon dioxide emissions annually, about 5% of all U.S. carbon dioxide emissions in 2005[13]. Assuming continuous economic and population growth and current potable water consumption trends, it is estimated that the energy used in the production of water and the carbon dioxide emissions of water production will increase by 58% by 2035[15]. Conserving potable water by reducing the demand for water at the residential end-user level will both assist in reducing excessive and unnecessary water related energy consumption and water related carbon dioxide emissions[16].

Residential end-users have high level of control over their water and energy consumption, and can be good subjects to promote water conservation[17]. Multiple studies have investigated ways of mitigating the impact of potable water and energy mismanagement and misperceptions by inducing pro-environmental behaviors[18-21]. The purpose of many of these studies was to determine the effectiveness of different intervention approaches on inducing pro-environmental behaviors.

Household retrofitting, e.g., installing high efficiency showerheads and low-flow toilets, have been shown to effectively increase water consumption efficiency, but such approaches have also been shown to cause offsetting behaviors[22, 23]. Studies have demonstrated that users sometimes increase water consumption frequency and/or duration following retrofits, partly offsetting the increased water efficiency provided by retrofits. Therefore, the water conservation rate by the residential end-users is often less than the expected water conservation rate of the installed household water retrofits[22]. While retrofitting still represents an effective method for conserving water, building owners often cannot justify the cost of retrofitting existing buildings because many of the household retrofits require high initial investments and have a long payback period[24-26].

Promoting pro-environmental behavior at the residential end-user level is an alternative approach to realizing water and energy conservation. Feedback and/or education have been used as common intervention approaches to promote pro-environmental behavior, as consumption feedback and environmental education can be tailored to meet the several conditions that are required for the residential end-users to adopt pro-environmental behaviors**.** The residential end-user must initially identify the issues relating to water and energy and realize that their current consumption behaviors have negative impacts on the identified issues, such as declining freshwater sources due to excessive water consumption. Once the residential end-users link their current behaviors with the identified issues, proper subjective and social norms of water and energy conservation can promote adaptation of pro-environmental behaviors. Furthermore, the end-users need to realize that they have the power to change their current consumption behaviors for the better and also realize that they can have positive impact on the issues surrounding water and energy[27, 28].

Environmental education, e.g., education on the issues of excessive water and energy consumption, provide some means for inducing pro-environmental behaviors by identifying the needs and the methods for water and energy conservation. However, it has been shown that even though environmental education results in increased knowledge on the needs and methods of water and energy conservation, the increased knowledge does not directly result in pro-environmental behaviors[22]. It is possible to combine education with other intervention methods to more effectively induce pro-environmental behaviors. One such complementary intervention method is the communication of relevant feedback.

Even though water and energy are closely related, feedback representations of the relationship between the two is lacking[22, 29]. This is a missed opportunity, because representing water consumption in terms of water and energy consumption creates an opportunity to take advantage of both established social norms of water and energy conservation. Water and energy conservation related behavior have increasingly become social norms, as water and energy conservation are promoted and encouraged throughout the United States by state and local government campaigns[30, 31]. The relationship between water and energy will become more transparent to the feedback recipients, and the recipients may attempt to reduce water consumption in efforts to meet the social norm of both water and energy conservation.

In this study we explore the effects of the two different representations of water feedback in an environment where residential end-users have little direct incentives to conserve water, i.e., residential end-users do not directly pay for water, and to compare the relative effectiveness of water-only and water-energy feedback in promoting water conservation.

Method

The study was conducted in 18 Virginia Tech residential halls and water consumption data were collected weekly at a building level. Weekly baseline readings were taken between August 27, 2012, and September 24, 2012, by Virginia Tech Electrical Services. The feedback period lasted six weeks, from September 24, 2012 through October 29, 2012. All of the water readings for the study were performed utilizing a handheld device that wirelessly and synchronously read water meters and ensured that the frequency and the rate of water data collection was consistent throughout the study.

Three groups were created to formulate testable hypotheses that can be used to investigate the impact of water-only and water-energy feedback on water conservation. The three groups in the study were as follows:

Water-Only Feedback Group: The water-only feedback group was provided with education on the issues of excessive water consumption, such as decreasing freshwater sources and increasing potable water demand. The group was also provided with general water conservation tips. Some water conservation tips suggested that residents turn off the faucet when brushing and shaving and recommended the residents to take shorter showers. The water-only feedback provided building level and per capita weekly total and daily average water consumption in gallons. Cumulative water consumption at a building level and cumulative water consumption per capita were also provided in the feedback.

Water–Energy Feedback Group: The water-energy feedback group was provided with education on the issues of excessive water consumption and the relationship between water and energy. Statistics, such as a faucet running for 5 minutes equates to a 60 watt light bulb running for 14 hours, were emphasized to highlight the connection between conserving water and conserve energy. The water-energy group was also provided with general water conservation tips like the water-only study group. Building level weekly water consumption feedback in gallons and alternate units such as the estimated amount of energy (kWh) embodied in the water consumption, as well as the equivalent energy in terms of light bulb hours, was provided to the water-energy group. Light bulb hours represent the number of hours a 100 watt light bulb can stay lit utilizing the estimated embodied energy in water consumption, e.g., 1kWh of water-energy can light a 100 watt light bulb for approximately 10 hours. The purpose of introducing light bulb hours was to make estimated energy easier to comprehend for the residents, as residents may not be able to easily quantify and realize the significance of kWh. The feedback also communicated weekly, daily average (per week) and cumulative water consumption in gallons, calculated water-energy in both kWh and 100 watt light bulb hours at a building level and per capita.

Each group formulated for the study consisted of six residential halls. The groups were selected so that the average water consumption per capita across the three groups over the previous year was commensurate. This ensured that residential halls that may consume more or less water than the average residential halls due to externalities, such as the age of the residential hall, were controlled and distributed equally throughout all the groups involved in the study. Furthermore, the number of residents and the distribution of males and females per residence hall were used in the formation of the study groups and the control group to ensure that they had similar demographics. Males and females have been shown to have different water consumption behaviors and different water conservation behaviors, resulting in different water conservation rates[32]. The purpose of having similar numbers of males and females for the water-only, the water-energy and the control group was to control for any group possibly conserving more water due to gender differences in the study population and to directly compare the relative effectiveness of water-only, water-energy and no feedback on water conservation.

All groups were located in the same geographical area (Virginia Tech, Blacksburg campus), ensuring consistent temperature and weather for the groups. This ensured that the externalities that may have impacted water consumption, such as weather changes, were consistent across the study groups and the control group. Basing the study in residence halls at only Virginia Tech also ensured that the residents were in similar facilities; e.g., all residence halls were confirmed to have laundry rooms and shared restrooms. The summary of factors and the values of the study groups and the control group can be found in Table 1.

Table 1. Study Groups and Control Group Parameters

Groups	**Daily Water Consumption Per Capita**	**Average Number of Males**	**Average Number of Females**
Control	11.8	148	109
Water-Only	13.4	153	119
Water-Energy	12.6	146	112
Groups	**% Variance (Water Consumption)**	**% Variance (Males)**	**% Variance (Females)**
Control	0	0	0
Water-Only	12	3	8
Water-Energy	7	-1	3

The parameters used to determine study groups are summarized in this table. The table also highlights the percent variance of the parameter between the study groups.

Two testable hypotheses were formulated based on the study groups and the control group to test the impact of water-energy feedback and water-only feedback on water consumption.

Null Hypothesis 01: There will not be a statistically significant difference of water conservation relative to baseline level, between the control and the water-only study group over the course of the study. [The purpose of this null hypothesis is to determine if water-only feedback, in gallons, is sufficient to promote water conservation in an environment where the residents do not have direct incentives to conserve water.]

Null Hypothesis 02: There will not be a statistically significant difference in water conservation between the control and the water-energy study group. [The purpose of this null hypothesis is to determine if water-energy feedback can be utilized to induce water conservation, when an alternative incentive to conserve water, energy conservation, is introduced.]

Feedback was delivered to the residents through emails, specially designed websites and posters placed throughout the residence halls. Three feedback mediums were utilized to increase the chance of exposure to feedback. The feedback was facilitated through the Virginia Tech Housing Department to provide validity of the feedback to the residents. The water-only and the water-energy group had distinct email, poster and website templates, in an effort to prevent cross-over of feedback.

The emails utilized in the study were sent to the study participants every two weeks, and in addition to water consumption feedback, the emails contained information on the issues of water security, water conservation tips and reminders to check residents' respective feedback websites and posters. The emails designated for the water-energy group had an extra information pertaining to the relationship between water and energy.

The posters were generally placed in hallways and in the restrooms of residential halls that were in the water-only and the water-energy study groups. The posters contained conservation tips, a URL and associated Quick Response (QR) Code of the feedback website, and respective water-only or water-energy consumption feedback. The poster template designated for the water-energy group also had extra information pertaining to the relationship between water and energy. The posters were updated weekly, usually the day after recording the respective building's water consumption data. The QR Codes were included in an effort to increase resident interaction and participation through added convenience.

The feedback websites utilized for the study were updated within hours of the weekly data collection and communicated the most comprehensive educational material, conservation tips and feedback. The websites displayed weekly cumulative and per capita consumption feedback. The residents were able to see their residence hall's total water consumption level as well as the average water consumption per person. Sample of the websites and the posters used in the study can be found in Figures 1 and 2.

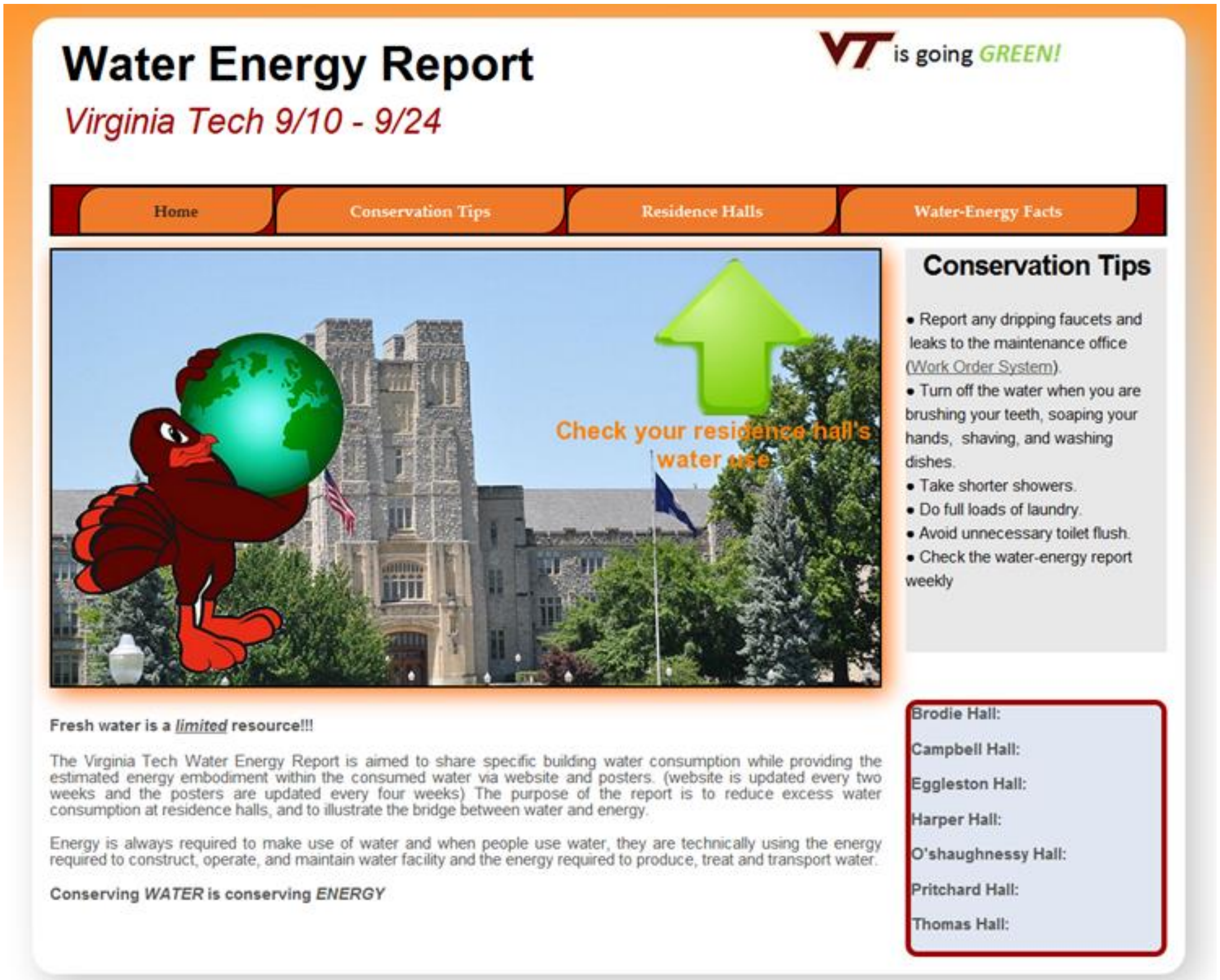


Figure 1 Water-Energy Feedback Group Website. The front page of the website designed for the water-energy study group. The front page provided condensed information of the website. Detailed conservation tips, water-energy facts and residential hall feedback were accessible through the use of one of the tab buttons. The website also provided a link to the Virginia Tech Work Order Systems to encourage the residents to report any leaks to the maintenance office.

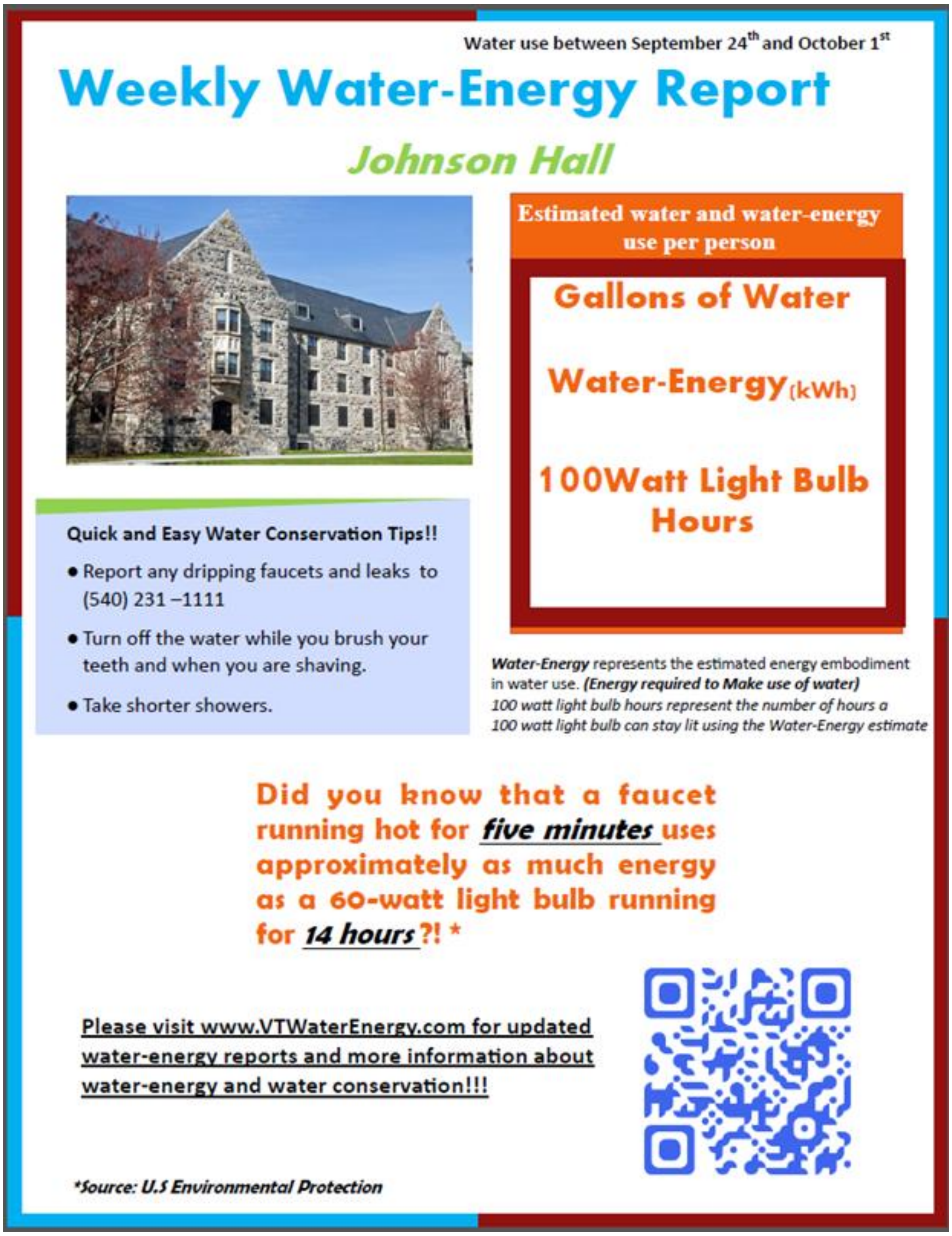


Figure 2 Water-Energy Feedback Group Poster. A poster designed for the water-energy study group. The water-energy poster provided weekly water consumption trends, water consumption in gallons, kWh, 100-watt light bulb hours, general conservation tips and highlighted the relationship between water and energy. The Quick Response Code in water-energy posters led to the water-energy website.

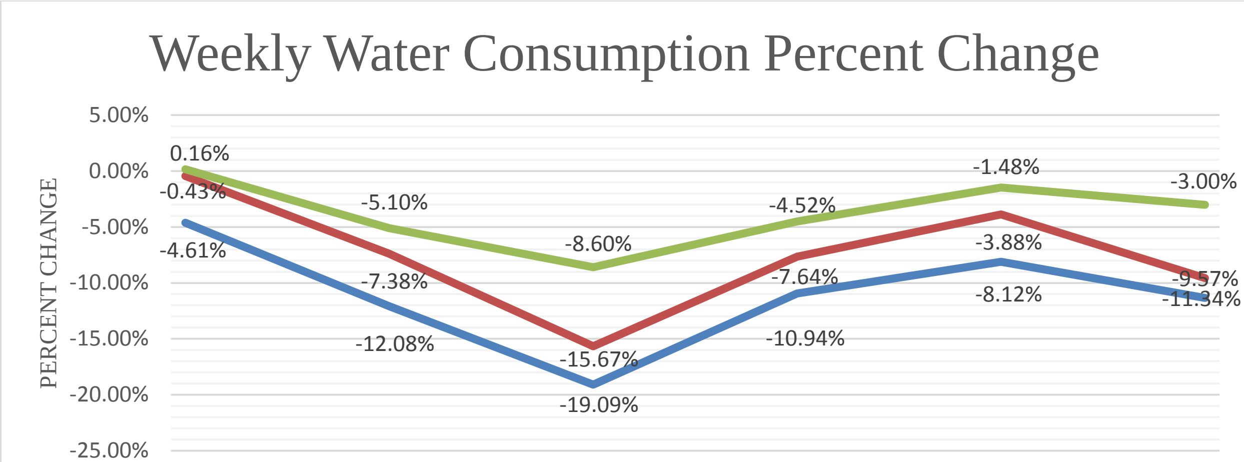
The following equation was used to calculate the weekly water consumption percent change of all residential halls included in this study, the equation was used for all groups.

$$\Delta W = \left(\frac{Ww}{Wb} - 1\right) * 100$$

ΔW represents the weekly water consumption percent change (negative percent change represent reduction in water consumption and positive percent change represent increase in water consumption). **Ww** represents the weekly water consumption per capita, and **Wb** represents baseline weekly water consumption per capita).

Results

The calculated weekly percent changes in water consumption of the control, water-only and water-energy groups are plotted in Figure 3. Even though the residential halls in the control group did not receive any feedback, the control group experienced some reduction in their water consumption during the study period. Reduced water consumption in the control group may be due to externalities, such as weather changes, which were consistent across all groups. The water-energy group consistently reduced their water consumption more than the other groups over the study period, while the water-only group consistently reduced their water consumption more than just the control group.



	10/1/2012	10/8/2012	10/15/2012	10/22/2012	10/29/2012	11/5/2012
Water - Energy	-4.61%	-12.08%	-19.09%	-10.94%	-8.12%	-11.34%
Water	-0.43%	-7.38%	-15.67%	-7.64%	-3.88%	-9.57%
Control	0.16%	-5.10%	-8.60%	-4.52%	-1.48%	-3.00%

Figure 3 Weekly Water Consumption Percent Change. Plot illustrates the weekly percent water consumption change for the control, water-only and water-energy study group. The general trend between the control and the study groups are very similar. Weekly water consumption percent change is lowest on the 3rd week for the control and the study groups.

The calculated weekly water consumption percent change was also used to test for independence between the study groups and the control group to compare the relative effectiveness of feedback. The distribution of building level water consumption raw data collected during the feedback period was checked for normality to identify the possible statistical tests that can be utilized for the study. The data were plotted against a theoretical normal distribution and Figure 4 contains the Quantile-Quantile plot of the data that showed that the original raw data followed the normal distribution assumptions. The plotted points fell approximately on a straight line, which indicated high positive correlation with the theoretical normal distribution. The parameter estimates of the normality test are summarized in Table 2.

Once the distribution was confirmed to be normal, Repeated Measures Analysis of Variance (ANOVA) model was used for statistical testing. Figure 5 contains a summary of fit for the

Repeated Measures ANOVA. The R Squared value was 0.78, which indicated that the data fit the Repeated Measures ANOVA model. The Repeated Measures ANOVA Fixed Effect (FE) tests identified that feedback and time had a statistically significant influence on the weekly percent of water conservation. The result of the Repeated Measures ANOVA is summarized in Table 3. The ANOVA fixed effect test indicates that the weekly conservation percent of water consumption varied significantly over time and between the study groups and the control group.

A Tukey Honestly Significant Difference (HSD) pairwise comparison test was used to determine if the differences in the water consumption changes between the study groups and the control group were statistically significant and to test the null hypotheses of the study. LS Means Tukey HSD controls for possible type I error rate increase, similar to Bonferroni Correction, as multiple statistical comparisons are performed between the study and the control groups.

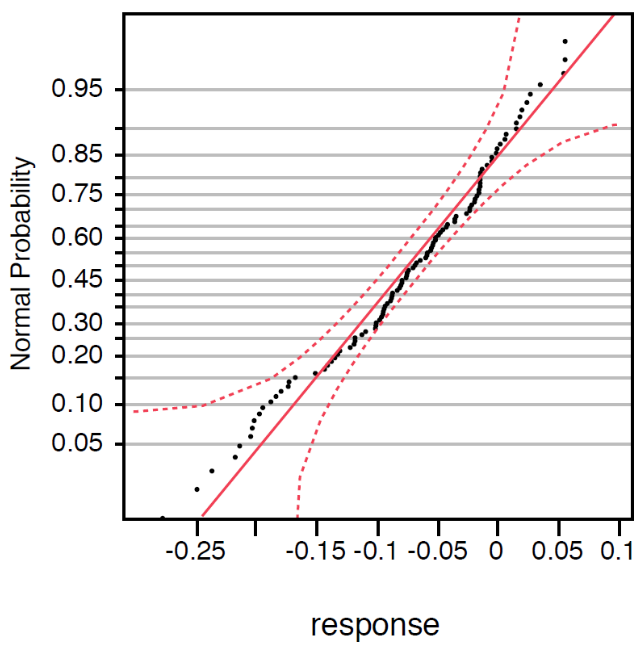


Figure 4 Q-Q Plot. The plotted points fall approximately on a straight line, indicating high positive correlation with the theoretical normal distribution.

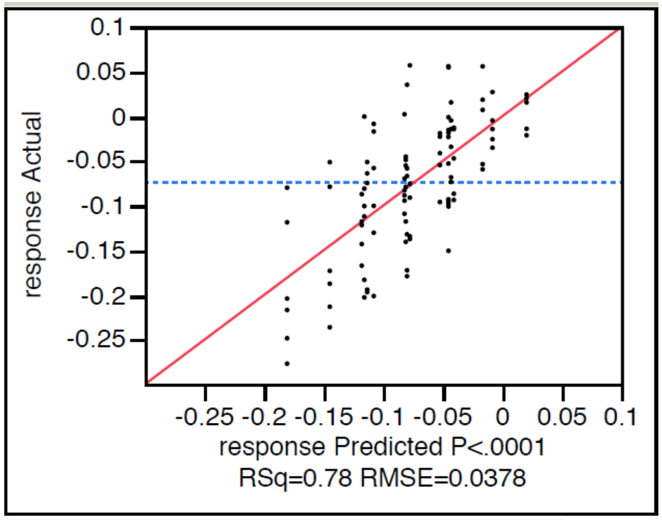


Figure 5 Summary of Fit. The R Squared value is 0.78 and the predicted P value is less than 0.001, which indicates that the data fit the Repeated Measures ANOVA model.

Table 2. Distribution Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	-0.0740	-0.0880	-0.0601
Dispersion	σ	0.0729	0.0642	0.0842
-2log(Likelihood) = -257.738				

Quantile-Quantile analysis for the normal distribution assumption are summarized in this table.

Table 3. ANOVA Fixed Effects Tests

Source	Nparm	DF	DFDen	F Ration	Prob > F
Treatment	2	2	15.04	3.926	0.0425
Time	5	5	84.08	23.37	<.0001

The results of the ANOVA Fixed Effects Tests are summarized in this table.

The results of the Tukey HSD pairwise comparison test and the average water consumption change are summarized in Table 4. When compared to baseline readings, the control group had an average of -3.75% water consumption change compared to -7.44% and -11.03% for the water-only and the water-energy groups, respectively. These findings are summarized in Table 5. The p-value between water-only and water-energy was 0.3759, indicating no statistically significant difference in conservation rates between these two groups. However, the p-value between the control and the water-energy group was 0.0338, which shows a statistically significant difference between the control and the water-energy group at the $p \leq 0.05$ level.

Table 4. Tukey HSD Pairwise Comparison

Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
C-WE	0.0727	0.0260	0.00531	0.140	0.0338
C-W	0.0369	0.0260	-0.0305	0.104	0.356
W-WE	0.0358	0.0260	-0.0316	0.103	0.376

The results of the Tukey HSD Pairwise Comparison are summarized in this table. **C** represents the control group, **W** represents the water-only group and **WE** represents the water-energy group.

Table 5. Conservation Summary

Groups	Daily Average Water Consumption Change (%)	Daily Average Water Consumption Change Per Capita (Gallons)
Control	-3.76	-1.0
Water-Only	-7.43	-2.1
Water-Energy	-11.03	-3.0

The daily average water consumption change is summarized in this table.

Discussion

The results of the Tukey HSD pairwise comparison indicate that water-only feedback did not result in statistically significant conservation. The null hypothesis 01, that there will not be a statistically significant difference of water conservation between the control and the water-only study group, cannot be rejected. However, there was a statistically significant difference between the control and the water-energy group allowing us to reject the null hypothesis 02, that there will not be a statistical significant difference in water conservation between the control and the water-energy study group. Therefore the results support the hypothesis that statistical significant water conservation can be achieved through the use of water-energy feedback in an environment where the building residents do not have direct incentives to conserve water.

On average, individual residents of the water-only group conserved approximately 2.1 gallons of water on a daily basis and individual residents of the water-energy group conserved approximately 3 gallons of water on a daily basis, with only the water-energy group's result being statistically significant. Even though the absolute amount may not seem substantial, the gallons of extra water saved each day by the water-energy group was accomplished simply by illustrating the connection between water and energy. The water-energy group as a whole also conserved approximately 2000 more gallons of water than the control group on a daily basis.

The water-only group, like the water-energy group, was provided with education for the residents to identify and relate their current water consumption behaviors with the current and foreseeable issues surrounding potable water. However, the water-energy group had more opportunities for subjective and social norms to influence and promote water conservation behaviors. Water consumption was linked with energy consumption for the water-energy study group, and it may be possible that the additional societal social norm of energy conservation could have been a contributing factor in the difference between the statistically significant and nonsignificant water conservation results. Energy and water conservation studies that have utilized feedback to promote pro-environmental behaviors have concluded that feedback of residential end-users' consumption information can induce pro-environmental behaviors. If an end-user's feedback indicates that they are excessively consuming water and/or energy, the end-user may be inclined to adopt pro-environmental behaviors to match the current social norms related to water and energy conservation. The sense of control over an end-user's behaviors is also magnified by the feedback, which has been shown to be a significant factor in inducing behavior change, e.g., if an end-user adopt water conservation behaviors, the result of adopting such behaviors can be easily observed by feedback[27]. adopting water conservation behaviors will result in lower water consumption Providing frequent feedback also introduces the consequences of no action, which may also assist in inducing behavior change[33]. Furthermore, energy conservation is also more emphasized than water conservation at Virginia Tech, which has established multiple energy conservation initiatives but no water conservation initiatives[34]. Therefore, it may be possible that the residents of Virginia Tech were more mindful about energy conservation than water conservation, possibly translating into the residents of the water-energy group conserving more water than the residents of the water-only group in efforts to conserve energy.

Limitations

The energy embodied in water varies depending on the geographical location, the water treatment method and the condition of the water utilities. Energy required to pump water will be higher in geographical locations where water can only be transported through pumping, e.g., water sources in low elevations, whereas the energy required to transport water will be lower in geographical locations where gravity can be used to transport water, e.g., water sources in high elevations[35]. The energy required to make use of either groundwater or surface water will also differ due to different pumping and treatment practices. Even the condition of water utilities will impact accurate calculation of the embodied energy in water, as inefficient and deteriorating water utilities tend to use more energy than efficient water utilities. Accurate calculation of embodied energy is very complex and to simplify such a calculation, the embodied energy in water was roughly estimated; the estimate did not account for all the possible energy involved in the lifecycle of water consumption. However, this study focuses on the impact of the relationship between water and energy through the use of feedback, and it was assumed that such rough estimates of embodied energy would suffice for the purposes of this research.

It is difficult to determine whether water-energy feedback will yield the same results in a non-university residential environment. Furthermore, it may be difficult to generalize the results of this study because the accessibility and scarcity of potable water can vary depending on the region.

Future Research

This study can be expanded in several ways to explore water-energy feedback in further detail. The duration of the study can be extended to study the long term impact of water-energy feedback. This will determine whether water-energy feedback has diminishing returns over time. The effects of providing real time water-energy feedback can also be investigated, as frequency of feedback has been shown to have a significant influence on behavior change. Real time water-energy feedback may yield more significant water conservation than weekly water-energy feedback. The water consumption data collected for this study was on a building level; however a future study can be designed to collect the water consumption data on an individual level, thus making the water-energy feedback more relevant to the residential end-users.

The setting of the study can be expanded towards non-university residential settings, such as multi-family residential buildings, townhouses and single family homes. At multi-family residential buildings, in particular, many residents do not have direct incentives to conserve water which is similar to the residents in the residential halls we studied. Future research should examine whether water-energy feedback provided in this non-university but similar setting will yield similar water conservation results as identified in this study.

Conclusions

In this study we explored the use of water-only and water-energy feedback to induce water conservation at residential halls. The purpose of this study was to determine if water conservation can be achieved in an environment where there are no direct incentives to conserve water, such as university residential halls. Potable water conservation will play an increasingly significant role in ensuring water security and it is hoped that the results of this study will assist in developing an effective water feedback system in any environment.

This study builds on previous studies that have utilized feedback to promote water and/or energy conservation. The overall results of this study further demonstrate the impact of a properly tailored feedback on adopting of pro-environmental behaviors, as only the water-only feedback was able to achieve statistically significant water conservation. This study also fills a research gap, because the relationship between water and energy has yet been explored as a feedback representation. The results of this study have shown that the relationship between water and energy can be utilized to promote water conservation and it further adds knowledge to the growing interest of non-financial interventions on consumer behaviors.

Furthermore, the study demonstrates that emails, posters and websites, which can be implemented quickly and cheaply, can induce significant water conservation among residents of residential halls when the feedback is tailored properly. Feedback systems such as, emails, posters and websites, are an inexpensive alternative to promote water conservation than retrofitting. The initial investment of emails, websites and posters are very low unlike household retrofits, and implementing feedback systems may be a worthwhile investment to promote water conservation.

It is hoped that the outcome of this study will assist Virginia Tech and other universities in the United States to adopt proper water conservation initiatives and feedback systems. Assuming continuous population and economic growth, it will only get harder to meet the global demand for potable water and the energy required to make use of water will only increase. Water conservation should be promoted whenever possible and it is hoped that the result of this study will assist in promoting water conservation.

Appendix

Feedback Loop

Feedback loop indicates that providing people with information about their actions and giving them a chance to change those actions may result in better behaviors due to consequences of no action[33]. The water-energy group introduces more relevance and higher consequences of no action than the water-only group, and it is possible that the increased relevance and higher consequences of no action influenced the result of the study. Figure 7 summarizes the concept of water-only and water-energy feedback illustrating the difference between the two in terms of relevance and consequences of no action.

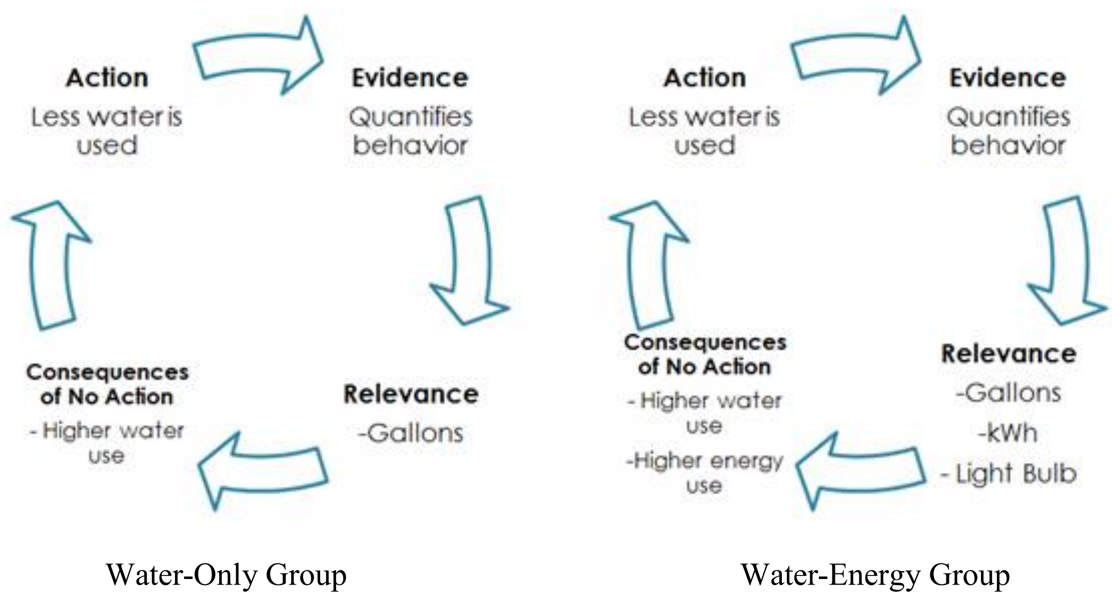


Figure 6 Feedback Loop. Feedback loop modeled for Water-Only and Water-Energy Group (After Goetz 2011)

Estimated Energy in Water

The embodied energy in water consumption was estimated based on water consumption parameters presented in a report by River Network. The report broke down different types of residential water consumption and it estimated the energy embodied in those types, e.g., 148,017 kWh is utilized for 1MG of water consumption. The report also accounted for energy used in heating of water, as it estimated the percent of hot water utilized in different type of residential water consumption, e.g., 72.70% of faucet usage are heated[13]. The parameters are summarized in table 6.

Table 6. Estimated Energy Embodied Parameters

Water-Energy Parameters	Estimated Embodied Energy (kWh/MG)	Percent of Hot Water Consumption	Average Water Consumption %
Municipal Water System	6,500	-	N/A
Laundry	56,600	27.80	21.7%
Faucet	148,017	72.70	15.7%
Leaks	54,565	26.80	13.7%
Shower	148,832	73.10	16.8%
Toilet	0	0	26.7

This table summarizes the parameters utilized to estimate the energy embodied in water consumption

The following equation was used to estimate the energy embodied in water consumption:

$$\text{ECF}= \frac{(LE)(LP)+(FE)(FP)+(EE)(EP)+(SE)(SP)+MWS}{1{,}000{,}000}$$

ECF (Energy Conversion Factor): Energy (kWh) to produce 1 gallons of water
LE: Laundry Estimated Embodied Energy (56,600 kWh/MG)
LP: Laundry Average water Consumption % (21.7 %)
FE: Faucet Estimated Embodied Energy (148,017 kWh/MG)
LP: Faucet Average water Consumption % (15.7 %)
EE: Leaks Estimated Embodied Energy (54,565 kWh/MG)
EP: Leaks Average water Consumption % (13.7 %)
SE: Shower Estimated Embodied Energy (148,832 kWh/MG)
SP: Shower Average water Consumption % (16.8 %)
MWS: Municipal Water System Estimated Embodied Energy (6,500 kWh/MG)

Raw Data

W-E	10/1/2012	10/8/2012	10/15/2012	10/22/2012	10/29/2012	11/5/2012
HARPER HALL	9257	8647	8349	8987	9044	9469
JOHNSON HALL	6932	6057	5534	6537	6509	6495
LEE HALL	11733	11450	9754	10461	11450	10602
MONTEITH HALL	4207	3854	4038	4109	4147	3897
SLUSHER HALL	20929	19939	17393	20222	20787	19656
VAWTER HALL	4518	3980	3456	3838	4107	3810
BARRINGER HALL	2890	2640	2168	2448	2551	2330
EGGLESTON HALL	17233	16489	14797	15760	15467	15070
MILES HALL	3435	3112	2686	3156	3361	3185
NEWMAN HALL	7808	7396	7646	23012	8147	7204
PAYNE HALL	13592	12902	12213	13607	13578	13328
PRITCHARD HALL	18055	16440	14825	16293	17908	16880
RASCHE HALL	7086	6300	6543	6343	6700	6471
NEW HALL WEST	7429	7137	6555	7429	7429	7429
O'SHAUGHNESSY HALL	13282	12193	10760	12207	12995	12480
THOMAS HALL	3257	3514	3271	3286	3243	3214
BRODIE HALL	7571	6671	7329	7043	7357	7357
AMBLER JOHNSTON HALL	27249	26213	24141	26420	27560	27249

References

1. Mo, W.; Nasiri, F.; Eckelman, M. J.; Zhang, Q.; Zimmerman, J. B., Measuring the Embodied Energy in Drinking Water Supply Systems: A Case Study in the Great Lakes Region. *Environmental Science & Technology* **2010,** *44* (24), 9516-9521.
2. Boccaletti, G.; Grobbel, M.; Stuchtey, M. R., The Business Opportunity in Water Conservation.(Special Report: The Water Imperative). In McKinsey & Company, Inc: 2010; Vol. 2010, p 67.
3. Campbell, H. E.; Johnson, R. M.; Larson, E. H., Prices, Devices, People, or Rules: The Relative Effectiveness of Policy Instruments in Water Conservation1. *Review of Policy Research* **2004,** *21* (5), 637-662.
4. Graymore, M.; Wallis, A.; O'Toole, K., Rural and Regional Urban Water Use Behaviour Change: A Matter of Personal Contact and Diaries? In *11th Biennial Conference of the International Society for Ecological Economics*, , Oldenburg and Bremen, Germany, 2010; pp 1-21.
5. U.S.EPA Water Supply in the United States. http://www.epa.gov/WaterSense/pubs/supply.html (Acessed August),
6. Roy, S. B.; Chen, L.; Girvetz, E. H.; Maurer, E. P.; Mills, W. B.; Grieb, T. M., Projecting Water Withdrawal and Supply for Future Decades in the U.S. Under Climate Change Scenarios. *Environmental Science & Technology* **2012,** *46* (5), 2545-2556.
7. Corral-Verdugo, V.; Frías-Armenta, M., Personal Normative Beliefs, Antisocial Behavior, and Residential Water Conservation. *Environment and Behavior* **2006,** *38* (3), 406-421.
8. Lofman, D.; Petersen, M.; Bower, A., Water, Energy and Environment Nexus: The California Experience. *International Journal of Water Resources Development* **2002,** *18* (1), 73-85.
9. Osbaldiston, R.; Schott Paul, J., Environmental Sustainability and Behavioral Science: Meta-Analysis of Proenvironmental Behavior Experiments. *Environment and Behavior* **2012,** *44* (2), 257-299.
10. U.S.EPA Indoor Water Use in the United States. http://www.epa.gov/watersense/pubs/indoor.html (Acessed August),
11. U.S.EPA State Water Facts. http://epa.gov/watersense/our_water/state_facts.html (Acessed June),
12. Zeman, C.; Depken, D.; Rich, M., Research on How the Composting Process Impacts Greenhouse Gas Emissions and Global Warming. *Compost Science & Utilization* **2002,** *10* (1), 72-86.
13. Griffiths-Sattenspiel, B.; Wilson, W. *The Carbon Footprint of Water*; River Network: 2009.
14. Strutt, J.; Wilson, S.; Shorney-Darby, H.; Shaw, A.; Byers, A., Assessing the Carbon Footprint of Water Production. *Journal American Water Works Association* **2008,** *100* (6), 80-80.
15. Shrestha, E.; Ahmad, S.; Johnson, W.; Batista, J. R., The Carbon Footprint of Water Management Policy Options. *Energy Policy* **2012,** *42* (1), 201-212.
16. Zhou, Y.; Zhang, B.; Wang, H.; Bi, J., Drops of Energy: Conserving Urban Water to Reduce Greenhouse Gas Emissions. *Environmental Science & Technology* **2013**.
17. Petersen, J. E.; Shunturov, V.; Janda, K.; Platt, G.; Weinberger, K., Dormitory Residents Reduce Electricity Consumption When Exposed to Real-Time Visual Feedback and Incentives. *International Journal of Sustainability in Higher Education* **2007,** *8* (1), 16-33.

18. Abrahamse, W.; Steg, L.; Vlek, C.; Rothengatter, T., A Review of Intervention Studies Aimed at Household Energy Conservation. *Journal of Environmental Psychology* **2005,** *25* (3), 273-291.
19. Bonanni, L.; Arroyo, E.; Lee, C.-H.; Selker, T., Exploring Feedback and Persuasive Techniques at the Sink. *Interactions* **2005,** *12* (4), 25-28.
20. Grønhøj, A.; Thøgersen, J., Feedback on Household Electricity Consumption: Learning and Social Influence Processes. *International Journal of Consumer Studies* **2011,** *35* (2), 138-145.
21. Lee, M.; Tansel, B.; Balbin, M., Influence of Residential Water Use Efficiency Measures on Household Water Demand: A Four Year Longitudinal Study. *Resources, Conservation and Recycling* **2011,** *56* (1), 1-6.
22. Geller, E. S.; Erickson, J. B.; Buttram, B. A., Attempts to Promote Residential Water Conservation with Educational, Behavioral and Engineering Strategies. *Population and Environment* **1983,** *6* (2), 96-112.
23. Lee, M.; Tansel, B.; Balbin, M., Influence of Residential Water Use Efficiency Measures on Household Water Demand: A Four Year Longitudinal Study. *Resources, Conservation & Recycling* **2011,** *56* (1), 1.
24. Che, D.; Liu, Y.; Gao, C., Evaluation of Retrofitting a Conventional Natural Gas Fired Boiler into a Condensing Boiler. *Energy Conversion and Management* **2004,** *45* (20), 3251-3266.
25. Martinaitis, V.; Kazakevičius, E.; Vitkauskas, A., A Two-Factor Method for Appraising Building Renovation and Energy Efficiency Improvement Projects. *Energy Policy* **2007,** *35* (1), 192-201.
26. Al-Ragom, F., Retrofitting Residential Buildings in Hot and Arid Climates. *Energy Conversion and Management* **2003,** *44* (14), 2309-2319.
27. Ajzen, I., The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes* **1991,** *50* (2), 179-211.
28. Wilson, C.; Dowlatabadi, H., Models of Decision Making and Residential Energy Use. *Annual Review of Environment and Resources* **2007,** *32* (1), 169-203.
29. Parece, T.; Grossman, L.; Geller, E. S., Reducing Carbon Footprint of Water Consumption: A Case Study of Water Conservation at a University Campus. In Springer Berlin Heidelberg: 2013; pp 1-20.
30. U.S.SBA State and Local Energy Efficency Programs. http://www.sba.gov/content/state-and-local-energy-efficiency-programs (Acessed August),
31. Christen, K., Managing Western Water Shortages. *Environmental Science & Technology* **2003,** *37* (17), 317A-318A.
32. Begley, A. L. The Effect of Gender on Residential Water Usage Behaviors in the United States. ProQuest, UMI Dissertations Publishing, 2013.
33. Goetz, T., The Feedback Loop. *Wired* **2011,** *19* (7).
34. Tech, V. Monthly Electricity Reports. http://www.facilities.vt.edu/sustainability/monthElecRpts.asp (Acessed August),
35. Perrone, D.; Murphy, J.; Hornberger, G. M., Gaining Perspective on the Water−Energy Nexus at the Community Scale. *Environmental Science & Technology* **2011,** *45* (10), 4228-4234.