ENVIRONMENTAL IMPLICATIONS OF WATER CONSERVATION BY REDUCING SHOWER DURATION AT THE UNIVERSITY OF MASSACHUSETTS AMHERST

An Honors Thesis Presented

By

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ABSTRACT

Our research aims to understand the extent to which reducing shower duration and increasing water conservation efforts can reduce the overall carbon footprint at the University of Massachusetts Amherst (UMass Amherst). The residential halls at UMass Amherst consume almost 80 million gallons of water a year contributing almost 12,000 $MTCO_2$ eq. to the atmosphere. Despite UMass' efforts to increase water conservation on campus beginning in 2007, yearly water consumption in residence has remained constant, which may suggest current conservation efforts are not particularly effective. In a 2018 pilot study, we developed an interactive timer that displays shower duration and cumulative water consumption in order to reduce water waste at UMass. This "active" intervention was placed in multiple residential hall showers for a period of 8 days. Shower durations during that span were compared to a control group where durations were collected during a previous interval and no intervention was present. Through that comparison, we found an astonishing 41% reduction in shower duration. Our current study expands upon this previous work by using various intervention methods, including a similar "active" intervention, as well as a "passive" intervention by means of a poster to determine how much people's behavior changes with increased awareness. We hypothesize that as awareness increases, shower duration will decrease. Any percent decrease could be used as a multiplier for the amount of water consumption reduced yearly, which can then be extrapolated to the impact of campus carbon emissions through the conversion factors identified. The results will inform UMass Amherst about potential water-saving actions that could best decrease overall water consumption in residential halls to help meet UMass' goal of carbon neutrality by 2030. *Keywords:* water conservation, behavior, carbon footprint, UMass Amherst, iCONS

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Introduction

This research seeks to determine the extent to which water conservation efforts may contribute to reducing the carbon footprint at the University of Massachusetts Amherst (UMass Amherst). By examining the relationships between behavioral choices, resource usage, and shower duration, our research will provide a set of evidence-based guidelines that should inform future efforts at UMass Amherst and beyond on how to reduce energy consumption through water conservation.

We seek to answer the questions: (1) how effective are various interventions at reducing shower duration to limit carbon footprint, and (2) what are the environmental benefits of this over time on a larger scale? We hypothesize that as information about water cost and usage becomes more available, detailed, and targeted, students will decrease the time they spend showering, leading to a reduction in water consumption and carbon footprint at UMass Amherst.

We aim to inform the UMass Amherst community about the potential of water-saving activities as a means of mitigating our impact on the environment. Specifically, we can achieve this by reducing greenhouse gas emissions and lowering overall energy costs. By 2030, the stated goal of Carbon Mitigation Initiative is to "achieve carbon neutrality from 100% renewable energy for all heating, cooling, and electricity systems of the main campus" (UMass Amherst, 2019). These results will inform potential policy changes at UMass Amherst to achieve carbon neutrality.

Reducing water consumption has an impact on the downstream side as well by reducing wastewater. This can reduce other environmental impacts beyond the campus carbon footprint associated with water intake and heating by reducing wastewater, thus mitigating the environmental impact via lowered energy inputs and chemical processing of wastewater. This thesis will seek to quantify the potential mitigation of UMass Amherst's carbon footprint, rather than the behavioral implications of conservation awareness.

"Water conservation," defined as the beneficial reduction in water loss, waste, or use (Vickers, 2001), is of extreme importance during the 21st Century. Although water covers over 70% of the Earth's surface, making it seem widely abundant, only 0.5% accounts for potable drinking water. Safe drinking water should be seen as a limited resource as almost 30% of the world does not have regular access to potable water. Since limited access to clean drinking water is not evenly distributed, certain groups are more adversely affected than other. Its scarcity makes it even more important for those with access to clean water to be aware of their water consumption to improve conservation efforts globally.

Water is typically considered a local resource, but its abundance is influenced by patterns of water use and climate, both of which are global mechanisms (Vörösmarty et al., 2015). Patterns of water use like misuse of a water source may impact other countries, as many water sources are not constrained to political boundaries. Even if water consumption locally does not directly impact the consumption in another region of the world, the indirect impacts of energy consumption within water treatment methods contribute to the global carbon footprint, and in turn, affect regional climate changes. Fostering individual and local conservation behaviors will in turn, positively impact global water supplies.

Beyond subtracting from the limited supply of existing potable water, water consumption directly affects energy consumption and greenhouse gas (GHG) emissions. In the United States, water cycles through a multistep industrial process before it can be used for public consumption and returned to the environment; however, to do so requires a significant input of energy in each step. For the Town of Amherst, the average residential per capita per day water consumption is

55 gal/person/day, and for the 38,000 permanent residents, this adds up to 804 million gallons of water for the town per year (MassDEP, 2016). The energy cost of supplying and treating water to the Town of Amherst (excluding UMass) is equivalent of powering 446 homes for a whole year. This energy can be classified as indirect, direct, and embedded (Figure 1).

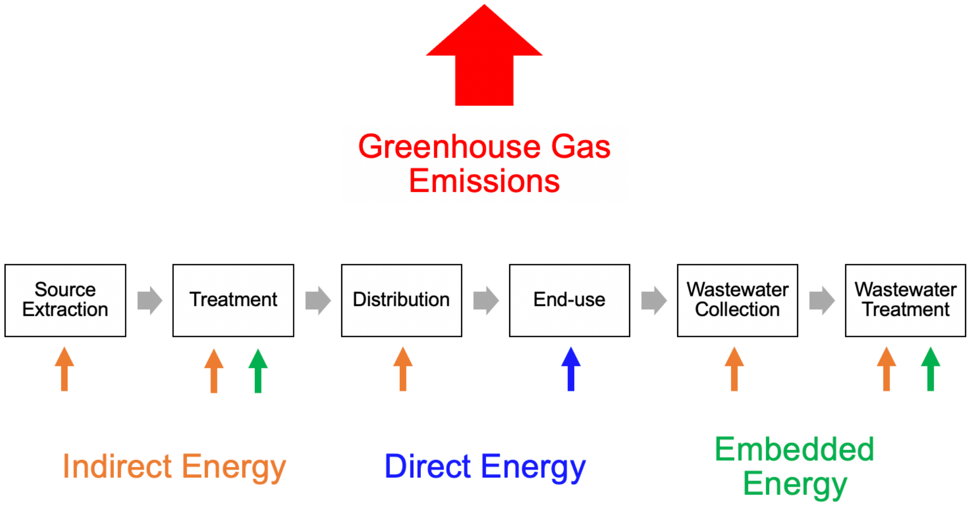

Fig 1. Urban water cycle and energy input by stage in regard to climate change. Energy input at each stage in the urban water cycle is represented by an arrow. Orange = indirect energy; blue = direct energy; green = embedded energy; red = emissions from greenhouse gases. Figure adapted from Cohen et al. (2004).

Indirect energy is the energy required to run motors, pumps, manufacture pipes, and treat extracted water and wastewater. Direct energy is the energy that is required to reach the state that the consumer desires (i.e., heating, softening, purifying, etc.) and embedded energy is the energy that is required for infrastructure and to manufacture and process the chemicals used for treatment (Cohen et al., 2004; Maas, 2009). Unless the energy supplying indirect, direct, and embedded energy costs are from renewable resources, the byproducts of each of these are GHG, including CO_2, CH_4, and N_2O. Simply reducing water consumption directly reduces energy costs and GHG emissions into the atmosphere and mitigates the impact on the environment.

As the world's population continues to increase at an alarming rate, policymakers must think proactively about the resources available for public consumption to ensure their longevity and avoid overexploitation. The history of overexploitation, rapid population growth, and predicted climate changes converge to produce a critical need for regulation. Over pumping of groundwater before sources can recharge is a major source of depletion that has impacted almost all areas of the United States. Between 1900 and 2008, inland California, southern Arizona, the Midwest, and areas around the lower Mississippi River experienced severe groundwater depletion (cumulative 50-400 km3 groundwater) (USGS, n.d.).

Surface flow reduction, an outcome of groundwater depletion, is being seen even in Massachusetts as a result of the over-pumping of the Ipswich River Basin (USGS, n.d.). Between 1998 and 2008, the Upper Ipswich River Basin ran dry 6 times, threatening the stability of a major groundwater source for a third of a million people. With a 5% population increase in the next 20 years, climate change pressures are likely to stress the Basin further (Ryan & Westphal, 2018). In Massachusetts, water consumption is highest between May and September, which coincides with the period of lowest rainfall (IRWA, 2019). Globally, the predicted population to reach between 9.6 and 13.2 billion people according to the U. N.'s World Population Prospects (2017) and current climate predictions indicating a 1.3˚C increase in average temperatures by 2100, it is crucial that we understand how these changes will influence the world's potable water supply and immediately address resource conservation as a whole. My research will focus on these aspects of water conservation, while my partner, Radha Dave, will focus on behavioral outcomes.

To put into context, the average American family uses over 300 gallons of water a day, 70% of which is used indoors (i.e., toilet, clothes washer, faucet, showers) (U.S. EPA, 2020).

Indoor water usage is relatively constant throughout the year, whereas outdoor water consumption typically varies by season (i.e., higher in the summer for irrigation) (U.S. EPA, 2018). One of the highest proportions of indoor water consumption that we have discretionary use over is shower duration, which makes up around 20% of indoor water usage. In this project, we aim to target this "controlled consumption" (consumption in which our behaviors directly influence the amount of water used) as a means to most effectively reduce water usage at a large scale through individual behavior, as these daily changes would be evident throughout the entire year.

Our research started as a pilot study performed in Spring 2018 to address the issue of resource conservation in people's everyday lives. Shower times were measured over three weeks with a stopwatch by a distant observer listening for the water to turn on and off to determine a baseline distribution of shower duration. We found that the mean shower duration before any efforts to raise awareness of water consumption was just over 12 minutes (12.11 ± 6.05 min) and uses around 16.5 gallons (Figure 2).

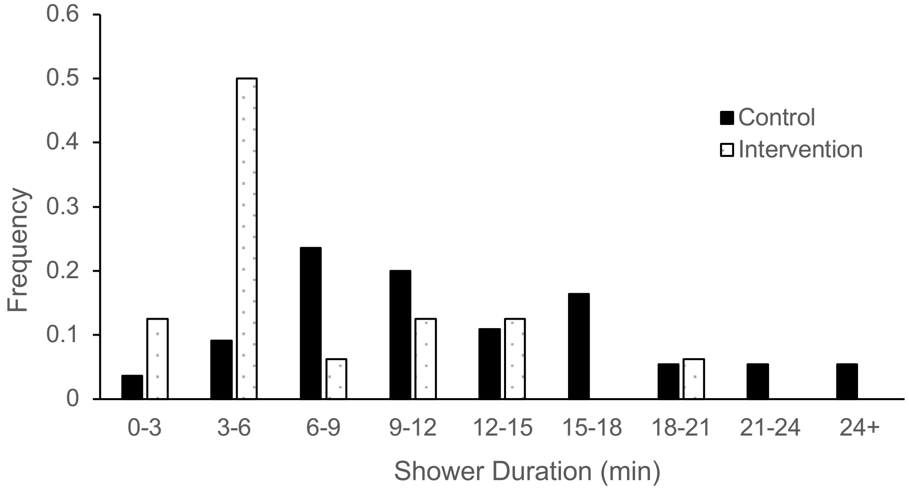

Fig 2. Normalized frequency of showers before and after intervention methods. Data from the preliminary 2018 study on shower duration before (C18 n = 55) and after intervention (Active Intervention n = 17) were collected. Showers before intervention are skewed right with a median of 11.52 min. Showers after intervention are more closely distributed with a median of 5.49 min. Buckets represent upper limits of included frequencies.

In this preliminary study, an intervention was designed to increase awareness of water consumption. We use the term “active invention” to describe an invention that participants are physically interacting with (i.e., actively involved in their own monitoring of water consumption). Later, we will introduce “passive intervention” methods, which are ones that participants do not interact with directly (i.e., reading about conservation methods). The first model for the active intervention was an interactive timer made with a microcontroller and LCD screen that we placed in various dormitory showers (Figure 3).

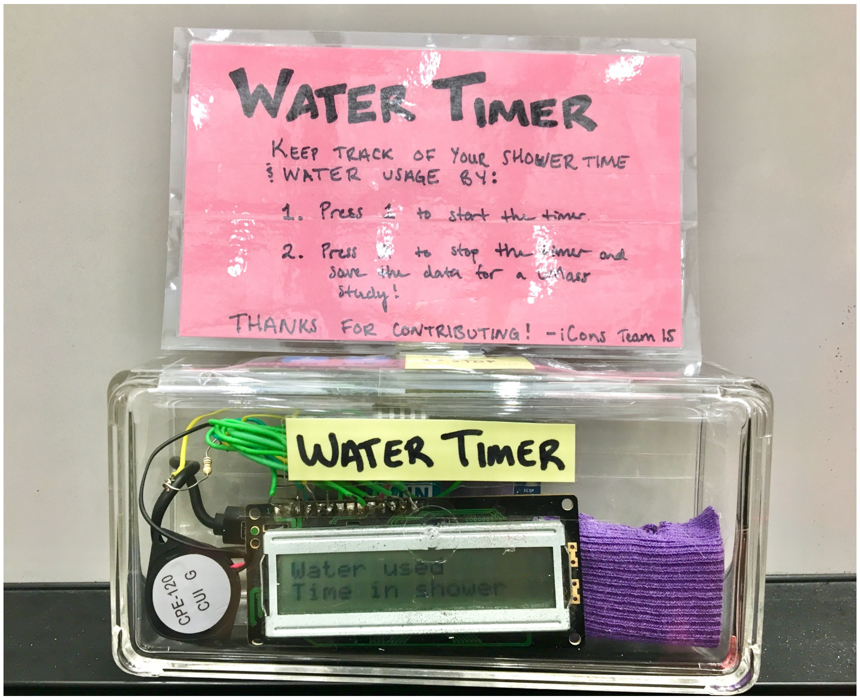

Fig 3. Interactive timer for preliminary study performed in March 2018. The active intervention timer placed in showers displayed real time duration (“Time in shower”) and water consumption (“water used”) of a user’s shower. The prototype consisted of a portable battery, LCD screen, Arduino Uno, waterproof press buttons (not shown), and a speaker. Instructions were included on the top of the device.

People timed their showers, and the duration was saved on a microSD card. The active intervention method reduced shower time by over 40% (4.89 min; $p < 0.001$), thus saving over 12 gallons per shower. Despite the small sample size (Control $n = 55$; Experimental $n = 17$), we found significant differences between the control and experimental data. This was a significant finding that led to funding from the on-campus SIEF (Sustainability Innovation and Engagement Fund) grant to support a larger study and expand the scope of the pilot study. The funded work proposes to expand the scope of that pilot study in three ways: (1) remove the self-reporting bias inherent in the pilot by using automatic timers that are activated by water flow in shower heads; (2) gather a larger data set to support more robust statistical analysis; (3) publish results available to the public. By understanding how a significant portion of indoor water consumption is affected by behavioral changes, implementation of similar intervention methods at a large scale (i.e., large state universities) may yield a significant positive impact on the environment.

Our research hopes to address the gap in scientific knowledge of how behavioral outcomes give insight into policy recommendations as a means of increasing conservation efforts. Statistics including percent reduction, mean, standard deviation, and skew of the distribution may reveal important trends in energy usage on campus and help explain the environmental impacts on the local water table. By furthering this research, we will be able to analyze the effectiveness of an active and passive intervention on water usage in an effort to better our environmental impact by lowering total energy costs of hot water and reducing GHG emissions.

The Carbon Mitigation Task Force (CMTF) is in the process of finalizing a report with plans to switch from steam-based heating to low-temperature hot water (LTHW) systems beginning in 2024 (CMPTF Plan Appendix K; Unpublished Work). Although LTHW systems are much more energy-efficient, the conversion is projected to cost $97M in 2020, with a return on investment not anticipated for 30 years. Reducing shower water consumption by 33% may save UMass Amherst up to $170,300 per year on water usage alone, and over $415,000 when including the energy used to heat and treat incoming and outgoing water. More importantly, reducing water consumption is an immediate and cost-efficient action that yields effective long-term change. Our results will inform future conservation efforts at UMass Amherst in the residential halls in hopes to reduce the GHG emissions UMass produces indirectly through wastewater treatment. Monetary savings, although seemingly small, are predicted to be $12.5M by the time campus-wide LTHW system installation is complete. Our results may suggest that a 33% reduction in shower duration could shorten the time for ROI of LTHW systems by 10%. Although our research investigates one potential water conservation method, any findings may be generalized to other areas of conservation (i.e., water from laundry, food waste, energy from idle electronic devices) and have the potential to inform work on said areas. A final report to the CMFT will be provided summarizing our results and informing the task force of possible target areas for conservation among the student body (Appendix A).

In addition to the primary utility of our findings, we anticipate several tangential benefits of this work. First, as this research was originally developed as an independent research project in the iCONS program, we hope that our research can be furthered by future iCONS students as inception material for a new case study looking at how conservation efforts can be improved in less-developed areas of the country and costs reduced, as not everyone has equal access to the same technology and resources. Second, our findings will have further implications in future suggestions to Residential Life and general education requirements to emphasize the importance of water conservation campus-wide. Comparison to existing classes focused on conservation at (e.g., NRC100) could verify our results supporting a valid policy change to the course requirements at UMass Amherst and yield a better understanding of the role of education in water conservation.

Literature Review

In this review, we detail previous research on regional climate changes and environmental benefits of water conservation, public awareness and motivations, and other areas for conservation efforts, showing how previous understandings inform our choice of scientific question, methods, and analysis.

Regional Climate Changes

With climate models suggesting that mean global surface temperatures are likely to rise by over 1.1-1.3˚C by 2100 (Hayhoe et al., 2008), impacts on precipitation and severe weather events (i.e., droughts and storms) are important to discuss when proposing water conservation strategies. These predictions are being confirmed by recent shifts in regional climate patterns across the United States.

California is experiencing extreme drought conditions that could last upwards of 200 years, according to National Geographic (Kostigen, 2014 as referenced by Seyranian et al., 2014). The lack of precipitation and increasing temperatures have increased the frequency of fires in northern California and account for over 1.4 million acres of damage since the start of 2020 alone (CALFIRE, 2020). This makes it increasingly relevant for areas that are susceptible to forest fires, like California, to have policymakers, scientists, and educators emphasize how important it is for the public to be aware of their water consumption. Similarly, places that are already extremely arid, such as Arizona and San Antonio, Texas, rely heavily on groundwater for public water consumption; however, with increasing demand and lack of regulation, groundwater supplies have historically been over-drafted, resulting in an urgent need for management (Vaux Jr., 2005). Cape Town, South Africa, is facing severe water shortages due to increasing demands and extreme drought, to the point where individuals are limited to 13 gallons of water a day, which is 7.7 times less than the daily average that Americans use (Leahy, 2018).

Even areas that are considered historically wetter should still be aware of their water usage. With increased temperatures and thus increased evaporation rates, more extreme weather patterns (i.e., droughts and severe rainstorms) are favored (Trenberth et al., 2003). Regional climate model (RCM) methods for predicting climate patterns point to a significant increase in extreme temperature days (i.e., days between 30-35˚C) (Hayhoe et al., 2018). Although Hayhoe et al.'s (2018) results did not find significant differences in daily precipitation rates, extreme precipitation days significantly increased in coastal regions, and in combination with increased extreme temperatures may yield unfavorable conditions for wildlife communities and human health/wellbeing.

Climate change estimates for Massachusetts predict a 3˚ to 5˚C increase in mean ambient temperature and precipitation increases of up to 30% in the winter (Executive Office of Energy and Environmental Affairs, 2011); however, the increase in precipitation is due to the increase in storms, rather than daily precipitation. Droughts and storms stress groundwater systems, making them a less reliable source of water as levels can fluctuate below what the average demand requires. The Charles River in eastern Massachusetts serves as a resource for waste disposal, industrial cooling, and a public water supply, making it an important source of groundwater for a major aquifer (Kirshen, 2002). Under drought stress, it is more than likely that the Charles River will experience decreased flow rates and have reduced water supply potential, thus negatively impacting the surrounding wetlands (Kirshen, 2002). Policymakers around the Charles River should be urged to look into alternative water supply options as aquifers may not be able to sustain a growing population, especially with the increased temperature predictions.

Current Studies on Public Awareness

Kelly and Fong (2015) investigated awareness of water consumption of the user in 124 Scotland residences via participant surveys. The authors grouped individuals based on the participants' self-identification of how water-conscious they are by a binary "Yes/No" question. They found that only 51% of participants identified themselves as water-conscious (Kelly & Fong, 2015). Correlating this self-identification with factors from background questions about the participants' demographics, they found that income and age correlated with an individual's level of awareness most prominently financial accountability: bill payers were 29% more likely to identify as conscious users than non-bill payers (Kelly and Fong, 2015). Despite the lack of awareness in over half of the study group, over 80% of participants had a positive attitude towards conserving water, indicating that the population may be interested in actively reducing their water usage; however, this percentage is relatively low compared to similar studies performed in Australia where upwards of 94% of respondents indicated water conservation as important as described by Kelly & Fong (2014). The motivations of the positive attitude are not stated. Based on these results, it is possible that our study group will have similar attitudes and want to engage in water conservation methods, but we cannot test this with our existing methodology and needs further investigation.

However, attitudes do not directly correspond with behaviors, especially when there is a lack of interaction between the consumer and the resource. For instance, those who use a dishwasher over hand washing dishes may be less aware of the amount of water they use to clean dishes. By increasing the interaction with conservation methods, we can reduce the dissonance between attitudes and behavior. The intervention methods report duration and total water consumption and give understanding through interaction with the user.

Fan et al. (2014) investigated the relationships between perceived and actual water consumption among 776 rural Wei River Basin, China residents. Using daily logs for three days among participants, comparisons between the perceived versus actual water usage yielded a strong underestimation of outdoor and kitchen water usage while overestimating indoor usage (Fan et al., 2014). While overestimates for indoor usage may demonstrate an acute awareness of indoor water conservation, those with higher education levels and incomes underestimated water consumption as a whole. Furthermore, groups that could accurately estimate their water usage had better water conservation awareness (Fan et al., 2014). This suggests that conservation efforts centered around awareness should be targeted towards groups with higher education levels and income, but that efforts aimed to inspire changes in attitude about conservation would be more effective in other groups.

Seyranian et al. (2014) report findings on the efficacy of communication strategies for reducing water consumption among 374 households in Los Angeles County, California. Participants with high baseline water consumption actually increased water usage in a knowledge deficit approach where only factual information is provided (i.e., “Run only full loads in the dishwasher and washing machine. Skip on pre-rinsing for your dishwasher. Saves 300–800 gallons/month.”) implying that an information-only approach may be counterproductive (Seyranian et al., 2014). Although our research uses similar messaging and information as Seyranian et al. (2014), our intervention methods (“passive intervention”) act more like reminders as we want to compare the effectiveness of UMass Amherst’s existing mode of conservation (informational posters) in dormitory bathrooms. Other communication strategies included framing the issue in the context of social identity, personal identity, and social norms and were considered promising in reducing water usage.

Tiefenbeck et al. (2013) analyze the effectiveness of real-time feedback as a means of reducing water consumption. Their 2013 study focuses on 697 Swiss residents with initial research yielding promising results as 80% of participants indicated they would like to keep the read-out device on the showerhead that was provided for further everyday usage. This study lends validity to our hypothesis, suggesting that physical interaction with a similar device may also have similar significant reductions in water consumption. A similar study using the same water metering read-out device performed in 2019 in 265 hotel rooms (N=19,596 observations) found an 11.4% reduction in energy consumption among participants that did not choose to opt-in (Tiefenbeck et al., 2019).

Motivations for Water Conservation

Current public perception of water conservation varies among households. Studies previously mentioned (Fan et al., 2014; Kelly & Fong, 2015) have touched on how public perception of water conservation may be affected by education, age, income level, and whether one was a bill-payer. People's motivations for water conservation vary and can sometimes be unclear even to the individual. In fact, Tijs et al. (2017) found that people viewed monetary incentives as slightly more appealing than environmental ones; however, they demonstrated that environmental appeals were more effective. This disconnect provides some leverage to activists and policymakers seeking to inspire behavioral change, and we should consider using environmental appeals for future conservation efforts. As higher education and income levels generally correlated with lower awareness due to increased usage in water-consuming appliances, further conservation attempts centering on the awareness gap targeting these demographics could be most effective (Fan et al., 2014). Education as a means of encouraging pro-conservation behaviors is found to have beneficial impacts on people's actions via targeting attitudes, habits, and personal capabilities (Venckute et al., 2017). A direct correlation between increased awareness and reduced water consumption is evident (Willis et al., 2011), thus promoting resource conservation through higher education may prove to have significant positive impacts on people's behaviors. As our study focuses on a combination of college students and the surrounding community, it is impossible to determine the extent to which education influences our results but worth investigating further.

Other Areas for Water Conservation

While increasing water conservation awareness in the household is still important, other aspects of water conservation are being investigated as the demand for clean water increases. Studies on the preservation of forests in Beijing prove vital as forests improve the quality of freshwater supplies, absorb rainfall to prevent flooding and maintain stable water bodies, and provide moisture soils for agriculture, reducing the need for supplemental irrigation (Biao et al., 2010). Recycling wastewater is another method of conservation that has multiple encouraging avenues. Used water reduces the need for freshwater where it is used in many applications excessively. Small scale projects all over the world have shown promise to scale up successfully in multiple uses, including agricultural reuse (crop irrigation), urban reuse (supply water for flushing public toilets, fire protection, landscape irrigation), industrial reuse (power station cooling, steel production, oil refining), and supplementation to existing water resources (increase groundwater recharge, river baseflow) (Anderson, 2003). In turn, this has promoted a much higher standard for wastewater treatment, as described in the Clean Water Act and other policies around the world. Other more common practices include rainwater harvesting and water-efficient appliances. Marinoski et al. (2018) suggest that strategies targeting higher potable water savings, the reduction of wastewater, and promote a reduced environmental impact from lower energy costs of wastewater treatment yield the highest water savings.

Research Questions

Previous research and other data sources on climate change add merit to our study, as they provide reason for why water conservation should be investigated further. Various studies suggest that our methods of increasing awareness to modify and environmental motivations for conservation have been effective in other contexts and are worth exploring as a component of campus conservation efforts. As stated previously, we seek to answer the questions:

(1) how effective are various interventions at reducing shower duration to limit carbon footprint?

and,

(2) what are the environmental benefits of this overtime on a larger scale?

We hypothesize that people will decrease their shower duration as they increase their awareness of their water consumption. If true, this will lead to the reduction in overall water conservation and GHG emissions from waste treatment plants, thus lessen one’s carbon footprint. We will test this by monitoring shower duration of 9 households with various levels of intervention and use the percent difference between interventions and the control as a multiplier for projected water savings of a larger population over 15 years. Monetary and GHG emissions savings will be extrapolated from the results and presented with their associated environmental impacts.

Materials and Methods

Recruitment

To recruit participants for our study, we sent out a screening form via different online UMass Amherst community groups (i.e., UMass Epic, Class of 2021 Facebook Page, Makerspace Discord) to ensure participants have access to a private shower head (i.e., not a shared dormitory bathroom) (Appendix B). Ideally, participants were to be UMass students living on campus in residence halls, as they would be the target group for future conservation efforts; however, recruitment for remote research has included all community members, as their water usage contributes to the community water consumption. Communication protocols were developed to keep participants' identities confidential. IRB approval was obtained (IRB Protocol #2329) and approved consent forms were sent out to participants on a rolling basis with data collection in waves to eliminate the possibility of identifying information based on collection dates. A total of 15 participants enrolled in our study and they were randomly assigned to either the Control, Passive Intervention, or Active Intervention Group with 5 participants in each group.

Experimental Setup

With COVID-19, changes to our original experimental design (placing sensors in residence halls at UMass Amherst to ensure complete anonymity) were made to account for the imposed constraint of going fully remote. Fifteen participants opted in and received sensors, but only 9 people reported data. Members of the Control Group received a remote sensing device to monitor shower duration. Members of the Passive Intervention Group received a remote sensing device and non-interactive poster with instructions on placement. Members of the Active Intervention Group received a remote sensing device as well as an interactive stopwatch-style timer, displaying real-time shower duration and water consumption, to be placed in the shower and operated by the user. All participants were provided with an instruction manual for protocols on device installation, management, and data collection (Appendix C). Communication protocols were developed to ensure that data could not be connected to individual identities. Data collection occurred for ten weeks before devices were sent back to Meg Davis.

Participants were self-selected as they are the ones to opt-in to the study, and results are likely be affected due to the self-selection bias. Those who opted-in may already have an increased awareness of their water consumption or environmental impact and chose to participate as a way to further their conservation efforts. This self-selection bias may be mitigated if more than one person in the household shares the same shower, as they are not the ones interacting with the sensor for data collection. Data were sent via email by participants as raw text files, and participant identities were removed before analysis to ensure confidentiality. Although only 9 sensors were in use, an estimated 30 people participated as one shower could be used by multiple individuals.

Device Specifications

The remote sensing devices detected sound via vibrations from the water flow as a proxy to trigger a timer indicating shower length. These sensors consisted of a SparkFun sound detector, Adafruit Feather M0 datalogger, and a 3.7 V 350 mAh lithium-ion polymer battery housed within a 3D printed casing (Appendix D). Passive intervention devices were half-page laminated posters with a device to measure water usage (Appendix E). Active intervention devices consisted of a Teensy LC KL2X evaluation board, Adafruit lithium-ion battery backpack, LCD screen, pushbuttons, and a 3.7 V 1.1 Ah lithium-ion polymer battery housed within a 3D case with recycled plastic as waterproofing (Appendix F).

Data Analysis

In the Results section that follows, data were analyzed for significant differences between control and the two experimental groups (Passive and Active). Data from the Control Group in 2018 was used for comparison to the results found in the Control Group from the 2021 study as an indicator of behavioral change in showering from knowing participants showers were being recorded. Data points < 120 s were filtered out as they were most likely the result of device malfunctions or inaccurate water flow detection. Significant decreases ($\alpha = 0.05$) indicated a significant reduction in shower duration. The calculated percentage of water reduction among intervention methods served as a multiplier for existing water usage and cost as a predictor of future water consumption savings. GHG emission predictions were provided, and estimated savings included. If deemed as an effective water metering device, results will inform future water conservation efforts at UMass Amherst among residential halls and potentially other areas of conservation.

Results

Distribution of Shower Durations

The average shower duration of the control group from 2018 (“C18”) was 12.11 min (median = 11.52 min) and for the Control Group from the 2021 (“C21”) was 11.05 min (median = 9.11). Both distributions are slightly skewed right as the data is centered slightly left of the mean (Figure 4). A pairwise t-test between C18 and C21 indicated no significant difference between the two groups.

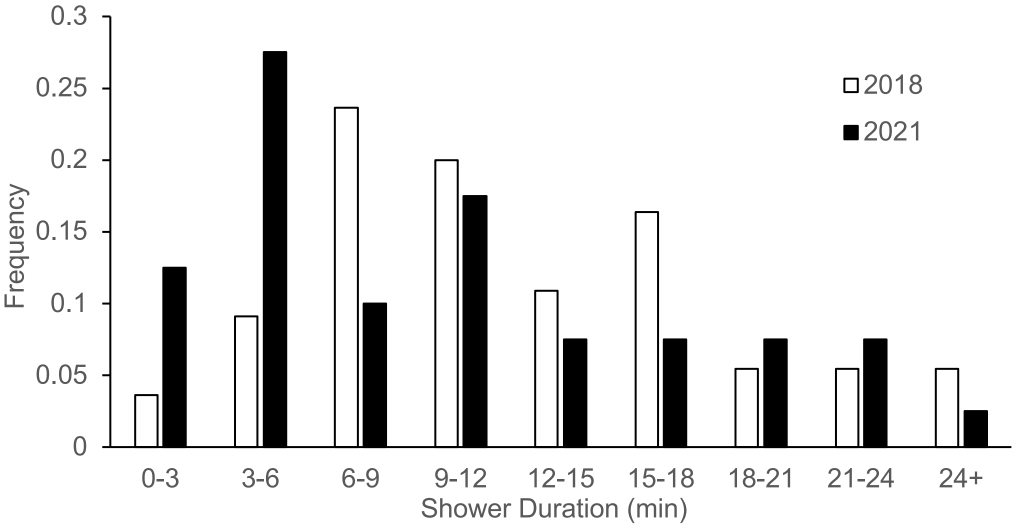

Fig 4. Normalized frequency of showers between control groups. Data from the preliminary 2018 study on shower duration (C18 n = 55) and from our current research (C21 n = 40) are normalized and binned. The mean and median for C18 was 12.11 min and 11.52 min respectively, while the mean and median for C21 was 11.05 min and 9.41 min respectively. Both distributions are skewed right as the data does not center around the mean, but rather lower than it. No significant difference between C18 and C21 was found.

Looking at the data from the C21, Passive Intervention and Active Intervention Groups, only 9 of the 15 participants that opted in sent data. Three participants contributed to the 40 data points in C21, four participants contributed to the 70 data points in the Passive Intervention Group, and two participants contributed to the 96 data points in the Active Intervention group. Average shower duration for the C21 was 11.05 min (median = 9.11 min) while mean shower durations for the Passive and Active Interventions were 7.40 min (median = 5.92 min) and 10.64 min (median = 9.62 min) respectively. The normalized distributions for all 3 groups are unimodal skewed right as the median for all 3 groups were lower than the mean. The C21 and Passive Intervention Group had large outliers (Figure 5), which contributed to the skew of the distributions.

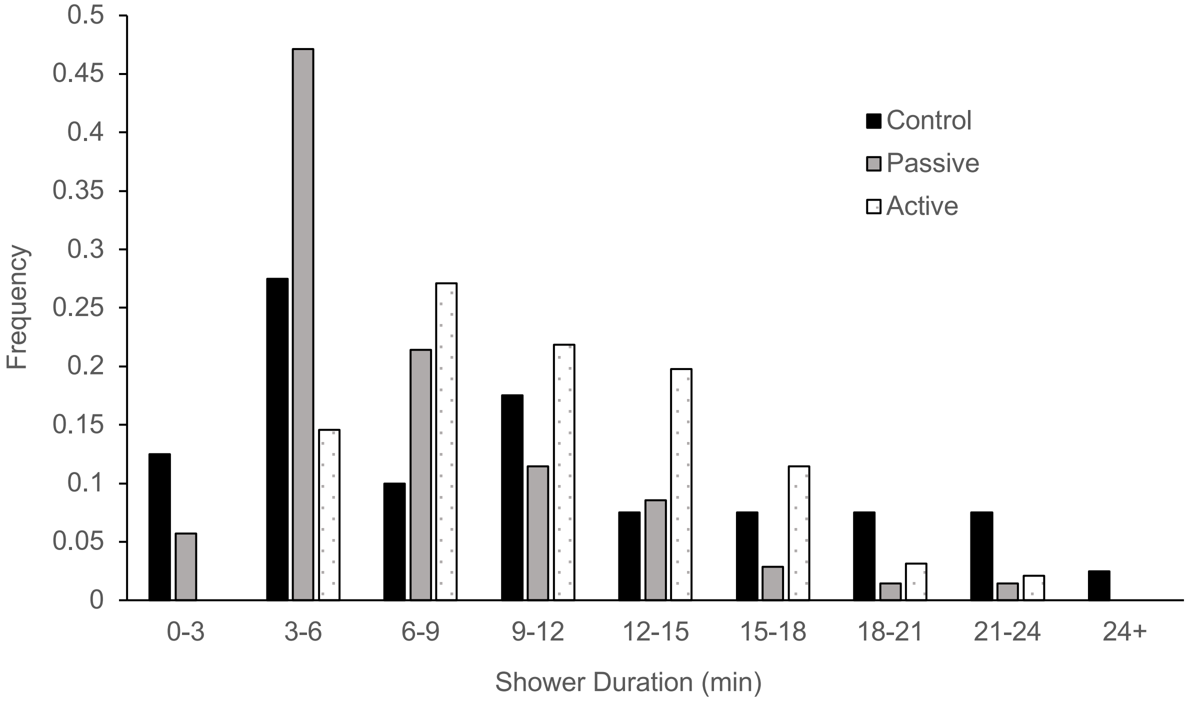

Fig 5. Normalized frequency of showers between Control, Passive, and Active interventions. Data from C21 (40 DP), passive (70 DP), and active intervention groups (96 DP) are normalized and binned. The mean (and median) for C21 was 11.05 min (9.11 min), while the mean (and median) for passive and active interventions were 7.40 min (5.92 min) and 10.64 min (9.62 min) respectively. All three distributions are skewed right as the data does not center around the mean, but rather lower than it. Significant differences between C21 and Passive intervention, and between Passive and Active interventions were found ($p < 0.0167$; Bonferroni corrected) with a 33.0% reduction in duration between C21 and passive intervention.

A single-factor ANOVA between the C21, Passive Intervention, and Active Intervention groups yielded a significant p-value ($p = 0.00371$) and pairwise t-tests were performed to determine if there was a significant difference among interventions (Table 1). Significant differences between the C21 and Passive Intervention, as well as the Passive and Active Intervention were found ($p < 0.0167$; Bonferroni corrected). There was a 33.0% reduction in mean shower duration (35.0% reduction in median duration) with the addition of a Passive Intervention when compared to C21. No significant difference was found between the C21 and Active Intervention.

Table 1. Pairwise t-test matrix between experimental groups. Results from pairwise t-tests performed between the control groups from 2018 and 2021, the passive intervention, and active intervention are displayed as a matrix. P-values obtained from the tests are listed only if a significant difference was found ($p < 0.05$). Mean shower durations as follows: C18 = 12.11 min; C21 = 11.05 min; P = 7.40 min; A = 10.64 min.

	C18	C21	P	A
C18	-	NS	$p = 2.0x10^{-6}$	NS
C21	-	-	$p = 0.012$	NS
P	-	-	-	$p = 1.9x10^{-6}$
A	-	-	-	-

NS = Not significant, C18 = Control Group 2018; C21 = Control Group 2021; P = Passive Intervention Group; A = Active Intervention Group.

Discussion

The significant reduction in shower duration between the Passive Intervention and C21 suggest that simple reminders may be effective methods at causing behavioral changes to conserve water. The observed 33% reduction in duration with the addition of intervention validates our hypothesis that increasing aware through interventions will reduce shower duration. The significant difference between Passive and Active Interventions leads us to believe that a targeted message towards participants may be more effective than using an interactive timer.

In addition, the observed decrease in water usage from showers can be extrapolated to an overall reduced carbon footprint from decreased wastewater and GHG emissions via treatment plants. Students at UMass Amherst area estimated to use 47 million gallons of water a year on showers, which makes up 58% of the total water consumption by residential halls. The estimated 20% of indoor water use from showers by the EPA is not representative of residential hall use likely due to the presence of bathrooms elsewhere on campus, pointing to even larger monetary and emission savings.

Implications

Our results have multiple real-world implications addressing water conservation as a whole. A significant reduction in shower duration has both short- and long-term monetary savings, as well as emission savings. Lower water and energy demands yields lower GHG emissions into the atmosphere. In addition, reduction in overall wastewater has significant environmental benefits for many species and ecosystems.

Cost and Emission Savings

Total energy costs of a single shower may not seem high, but when put into perspective over multiple years or among a large population are extremely high. A single shower costs $0.67, and in a four-person household, this translates to $18.76/week or $975.52/year (Appendix G). Energy consumption for supplying, distributing, and treating water typically ranges between 1,250 kWh/MG and 6,500 kWh/MG (Griffiths-Sattenspiel & Wilson, 2009; Carlson & Walburg, 2007). The average inlet water temperature (water entering the pipes to the home) in Massachusetts is 47˚F (Rinnai America Corporation, 2019). Combining the total energy to obtain, heat, and treat water yields an average energy consumption of 3.51 to 3.60 kWh/shower or 0.003 MTCO$_2$ Eq. (Appendix G). For the 13,000 students living on campus at UMass Amherst, this adds up to 6,975 MTCO$_2$ Eq. over the calendar year (assuming 7 showers/week for 30 weeks). Results from our study could reduce carbon emissions by 2,524 MTCO$_2$ Eq. yearly assuming a 33% reduction in shower duration as observed in our study (Figure 6).

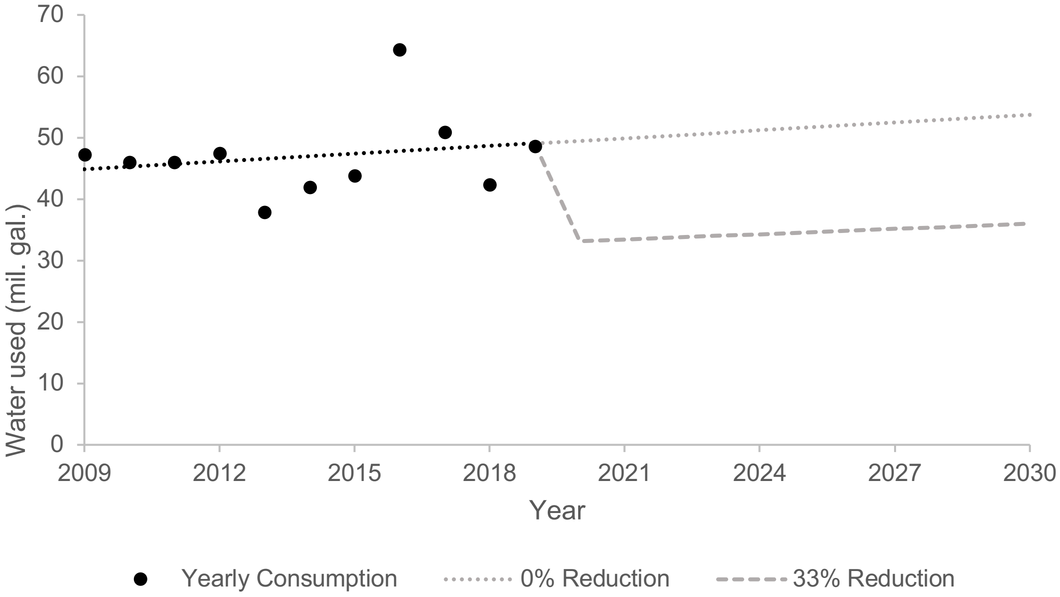

Fig 6. Projected yearly water consumption for showers in UMass Amherst dormitories in 2030 from 2009-2019 data. Data for shower water consumption is estimated at 58% of total dormitory water usage. Projections are made from the linear regression and adjusted by decreases in y values by 33% as found in our 2021 study. Water consumption data from 2009-2019 was obtained from the UMass Amherst Utilities Campus Data on Sustainability (Small, 2019).

Environmental Benefits of Conservation

Significant environmental benefits of reducing water consumption include reduced wastewater production and pollution to the surrounding ecosystems, lower construction impacts on wildlife habitats, and water retention in naturally occurring systems (i.e., rivers, reservoirs, groundwater basins, wetlands) (Maddaus, 1999). All wastewater created inside the home (i.e., water from the toilet, sink, dishwasher) either ends up in a septic tank or public sewer system and is sent to wastewater treatment plants for processing. Within wastewater treatment plants, GHG released via different treatment steps contribute to the 290 million $MTCO_2$ emissions annually (Griffiths-Sattenspiel & Wilson, 2009). Although wastewater treatment plants filter many contaminants, microplastics and endocrine-disrupting chemicals (EDCs), like pharmaceuticals, are not effectively removed and discharged into many aquatic and marine habitats. These micropollutants disrupt the development of many aquatic species (Mason et al., 2016; Nikolaou et al., 2007). Such impacts can be acute or chronic even at low concentrations and have negative impacts on crucial aspects of population demographics including fertility, fecundity, development, and survival rates (Antakayali et al., 2015).

The retention of groundwater is especially important, as water that flows back into naturally occurring sources should, in principle, replenish the amount pumped out for public use while also providing wetland habitats for many species (Ryan & Westphal, 2018). Ecological communities depend on groundwater recharge to maintain healthy and stable habitats; however, areas of overexploitation can lead to decreased diversity of ecosystems due to repeated drying-up, like in the Ipswich River Basin (Ryan & Westphal, 2018). In 2009, the relative abundance of stream dwellers in the Ipswich River Basin was expected to make up the majority of the community while only 28% were expected to be habitat generalists, but researchers observed that habitat generalists made up 96% of the community (Kashiwagi & Richards, 2009). The shift from specialists to generalists supports the hypothesis that climate change stressors are negatively impacting stream communities, making our results a component of potential solutions for water conservation in these areas through informing policymakers.

Study Limitations

Although results may indicate a significant reduction among intervention methods, significant limitations to our study exist, thus results should be analyzed with such in mind. The shift from in-person to remote data collection dramatically increased our limitations, forcing our sample population to change.

One limitation is how our participants were recruited. Participants were recruited via various social media platforms and email servers, and they opted into our study via a Google Form. This raises multiple issues including self-selection bias and reduced sample size as many people did not want to engage with our research, which suggests our study group is not representative of the true population. Those that did want to participate may already be conscious of their water usage and saw our research as an opportunity to further engage in an issue they already care about. Despite this limitation, a similar study with analogous interventions found an 11.4% reduction in shower duration among participants that did not opt in, and therefore had no self-selection bias present (Tiefenbeck et al., 2019). This suggests that our results may still have significant reductions in shower duration, but not to the degree we observed.

A second limitation is the reliability of the devices themselves, which were designed to be installed and monitored by the researchers rather than the study participants. Many remote sensing devices malfunctioned and did not record showers accurately and extremely involving for participants as they were the ones to try troubleshooting remotely. Data was either missing as participants knew a shower was taken in the timeframe that the device was installed or was not recorded as a single shower, but rather broken up into multiple durations. Data points were filtered out if shower durations were shorter than 120 seconds. These data points could not be included as recorded durations were in strings of multiple <120 s showers that could be added up to a single shower duration. Without timestamps, it was impossible to distinguish which set of <120 s data points belonged to a single shower and thus were removed completely to avoid analyzing missense data. Programming remote sensors to only record data to a microSD card if water flow is sustained past 2:00 min would address these errors in our data collection.

Control group participants were still aware that their showers were being recorded and although interaction with the remote sensing device were minimal, they were still present; however, no significant difference was found between our 2018 and 2021 control groups, making it possible that knowledge of recording had no effect on shower behavior. Despite seeing no significant difference between control groups, future research experiments should ensure no interaction with any device occurs as to best represent shower behavior without prescribed intervention methods.

Data collection was to last 10 weeks but ended up only being a few weeks as some participants only sent data once after receiving their device. Participants had the option to opt in between December and February making the data collection period irregular and variable from participant to participant. A longer and more regular data collection period would have yielded less biased results that are more indicative of the population's true behavior.

Participants were to upload data on a regular basis, but only some participants sent data, and even fewer sent data regularly. Of the 15 participants that opted in and received a device, only 9 sent data. The infrequent submission by participants made it hard to analyze overall behaviors as their contribution to the dataset was extremely limited and distributions are extremely skewed towards one or two participant households within a group.

Lastly, data analysis may be more accurate if analyzed by individual participant. Data by participants were aggregated together by experimental group for analysis; however, this may not be effective as participant households may have different baseline shower durations making comparisons that combine households inaccurate.

Future Directions

Study Improvement

As this research was a self-driven student-led project within the UMass iCONS program, our hope is that this research can be furthered by future students at UMass Amherst. There are multiple aspects of our research that we would like to improve upon to yield more substantial results and a more holistic understanding of water conservation behavior as a means of limiting environmental impacts, the first of which focuses on methodology improvements, and the second focuses on other areas of conservation.

Our most pressing need for device development is improving battery life and its data taking capabilities. A few ways to accomplish this include modifying the code to incorporate a sleep function, replacing the batteries with ones that have longer Ah outputs, and including a Bluetooth data function. These changes would eliminate the need to uninstall and reinstall the devices for data collection and frequent need for charging. Bluetooth capabilities would also enable the creation of a smartphone application similar to the Fitbit® App. Developing an application that would allow users to track their showers day by day and monitor their duration over time would provide greater engagement with water conservation. Fitbit® technologies are designed to increase physical activity among users. One of the reasons why this self-monitoring technology is so effective is its utilization of the behavior change technique of providing feedback to the user via a mobile app and website (Hartman et al., 2018). Rather than tracking physical health, our technology tracks water usage and by providing an interactive platform where individuals can actively monitor their consumption over time and be reminded to reduce their shower duration, we would hope to see the same positive effect.

Regarding the methodology of our experiment, future studies should focus on limiting the interaction between devices and the users for the control group and performing our original experiment in the residence halls at UMass Amherst. Limiting interaction for those in the control group would reduce the effect of knowing the user is being studied. Not only would this increase sample size, possibly resulting in sufficiently robust statistics for UMass Administration to act on, but it would also minimize the risk of human error between the devices and participants, as only one or two people would be involved in the relatively demanding set methodology.

Other areas for possible improvement or expansion of our current study design include researching various communication strategies optimizing behavioral change, as well as increasing the relevance of our study in diverse communities. Our devices, although designed for this experiment, are still prototypes and are not accessible to most people. Either making these designs open source or finding a way to reduce costs would enable more people to engage with this research. Ideally, this effort could become a community research endeavor, involving high school students in data collection and analysis. Lastly, compiling existing data on effective intervention methods and improving our interventions based on a meta-analysis may yield greater reduction in shower duration than what we observed. Further discussion is elaborated on by Dave (2021).

Recommendations for UMass Amherst

With the significant reduction in shower duration found in the passive intervention and low investment costs of such efforts, we recommend that Sustainable UMass should investigate various messages targeted towards students and placement of conservation posters to optimize shower reduction. It is likely that the placement of posters in shower stalls themselves was frequent reminder to participants making them more likely to remember to shorten their showers. Placing similar posters in the residence hall shower stalls may yield results similar to those found in this study.

In addition, possible suggestions for UMass Amherst include providing simple kitchen timers or mechanical timers that provide real-time and accurate feedback to the user on duration spent in the shower. Although no significant difference was found in our study between the control and active intervention, the small sample size and frequent device malfunctions may have prevented data collection from recording all shower durations and misrepresented the true population. Further research should be performed on similar active intervention methods to make a better-informed recommendation.

Campus-wide engagement in water conservation and participating in water-saving behaviors is not only a good way to save water, but to encourage UMass students to make a lifestyle change and foster community attitudes. Significant reductions in water consumption among residence halls can help UMass achieve its goal of reaching carbon neutrality by 2030. A small section of the CMTF Report (2021) focuses on behavioral change as a means to mitigate carbon emissions, and although it suggests changes in behavior may only account for 2% of energy demands, developing attitudes yields a more permanent, long-term mindset that can be translated into other aspects of one’s lifestyle. Further analysis of community-based attitudes and conservation awareness can be read in Radha Dave’s thesis (Dave, 2021).

Insight

Other results that were not directly significant to our dataset, but worth mentioning include the difficulty of communicating with participants remotely and the durability of the devices. Participants were extremely slow to communicate via email and were not reliable to actively participate in our study. It was extremely hard to get participants in the area to pick up devices, use the remote sensing device as outlined in the instruction manual, and to send data. Many emails were sent as a reminder to send data weekly. Four participants were reassigned as they were not responsive to emails after 3 weeks and had not come to pick up their devices.

The battery life of the devices and amount of interaction participants had to send data made this experiment harder. Battery life is estimated at 26 hours for the remote sensing device and 50 hours for the active intervention timer. A schedule is suggested in the instruction manual to optimize battery life, but the level of attention participants had to maintain to ensure accurate data collection was much higher than anticipated. It is likely that by minimizing participant interaction with data collection, there will be more representative data of the population; however, with COVID-19, this was the safest method of data collection possible.

With the shift in methodology from in-person to remote data collection, complete IRB approval was required to perform our research. Initial IRB determination was relatively quick and the original experiment to be performed in the residence halls was determined to not need IRB approval (March 2020), but with the changes to our experiment, IRB approval added 9 months to our timeline before we could start data collection (Appendix H) .

The development of the remote sensing device was a 2.5-year process that began in August 2018 and completed in January 2020. Multiple areas of expertise were needed for the completion of the two devices developed. Professors and students with backgrounds in engineering, computer science, psychology, environmental science, chemistry, physics, biology, and public policy were involved through various settings at including Makerspace, iCONS, M5 (ECE multi-purpose student space), and other personal connections. Without the collaboration between disciplines, our research could not have succeeded to the degree it did.

Conclusions

Significant reduction in shower durations increased with passive intervention methods. We found that passive intervention methods are enough to foster an increased awareness of water usage and created a behavioral change. Through increased conservation efforts, shower duration at UMass Amherst could see upwards of a 33% reduction. These results have implications on various aspects of water conservation at UMass Amherst from informing future policy recommendations to saving UMass around $400,000 a year. Not only do such changes campus-wide have the potential for significant monetary savings, but they also have indirect environmental benefits. By reducing water consumption, there are lower water demands on the local water table and less wastewater created that needs to be treated, and thus lower energy demands and greenhouse gas production. Although our study had a few limitations including a small sample size and possible self-selection bias, further research should be performed to better estimate percent reduction in shower duration at UMass.

Acknowledgements

I would like to thank my research partner, Radha Dave, who has been working in tandem with me through the iCONS program at UMass Amherst since 2018. Without her, this research could not have succeeded to the degree it has. I would also like to Dr. Justin Fermann and Dr. Charlie Schweik who have supported our research over the past 3 years, and lastly a long-time friend, Blake Hatch (Northeastern Univeristy '21) who helped prototype and code the remote sensing device and active intervention timer. Funding for this research was provided by the UMass Sustainability, Innovation & Engagement Fund.

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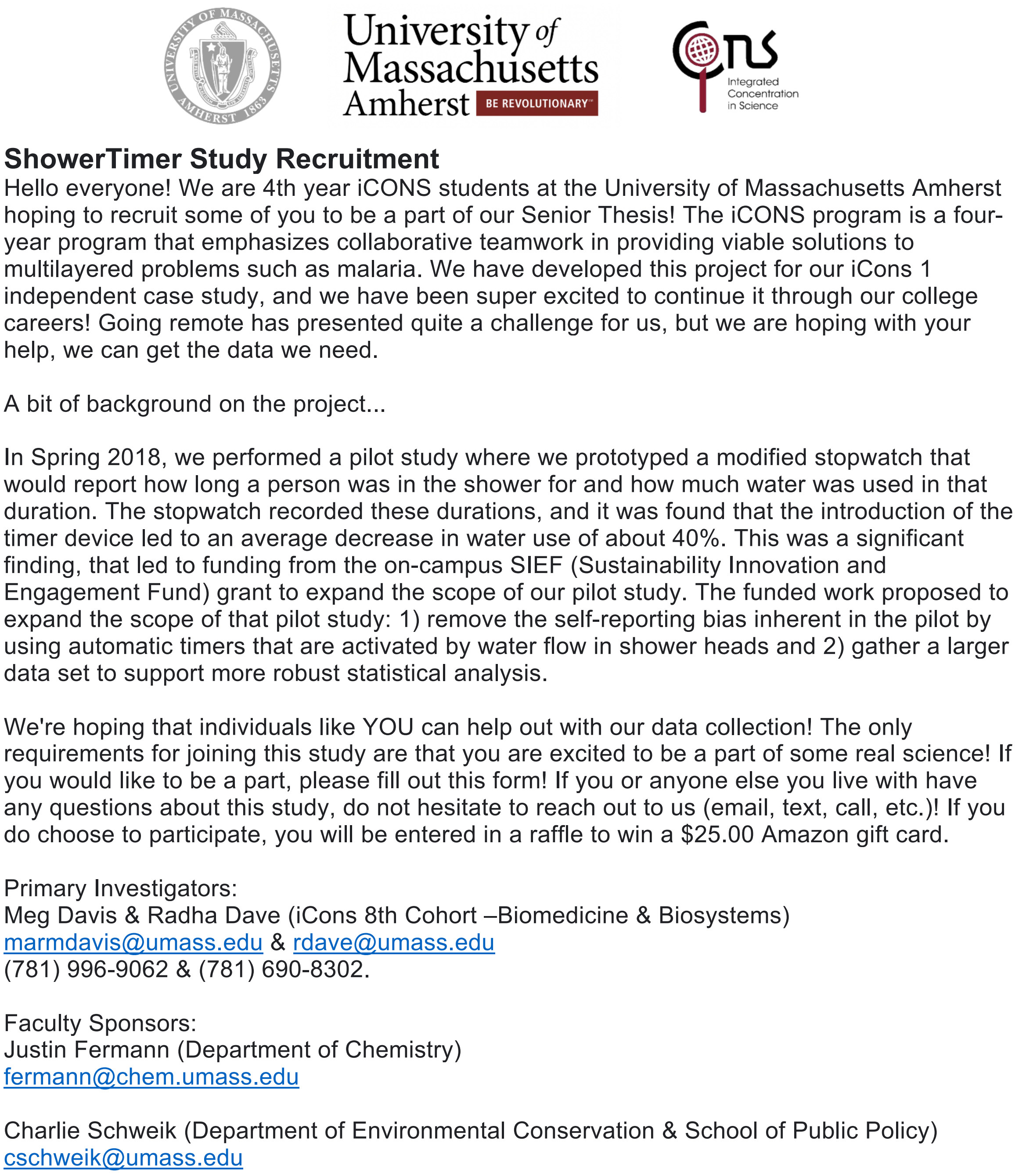
Appendix A. Joint Report on Findings for UMass Amherst Organizations

A joint report discussing Radha Dave and my findings will be sent to various organizations at UMass Amherst. This report will be sent to the Carbon Mitigation Task Force as our work can help inform their plans to reach carbon neutral by 2030, the Sustainability, Innovation & Engagement Fund to report what their funding has helped us achieve, and Residential Life as they will be the target for future conservation efforts based on our research.

We will discuss background information on conservation behaviors and environmental impacts of water consumption, as well as our findings, limitations, and possible suggestions for future conservation efforts on campus.

Appendix B. Google Screening Survey

A copy of the Screening Survey used for inviting participants via Google Forms is provided below. Answering “No” on questions 4, 8 and 10 will automatically disqualify households from participating, as everyone in the household is required to sign the Consent Form, provide an email or residential address for communications, and willing to follow the protocol set forth.



ShowerTimer Study Recruitment

Hello everyone! We are 4th year iCONS students at the University of Massachusetts Amherst hoping to recruit some of you to be a part of our Senior Thesis! The iCONS program is a four-year program that emphasizes collaborative teamwork in providing viable solutions to multilayered problems such as malaria. We have developed this project for our iCons 1 independent case study, and we have been super excited to continue it through our college careers! Going remote has presented quite a challenge for us, but we are hoping with your help, we can get the data we need.

A bit of background on the project...

In Spring 2018, we performed a pilot study where we prototyped a modified stopwatch that would report how long a person was in the shower for and how much water was used in that duration. The stopwatch recorded these durations, and it was found that the introduction of the timer device led to an average decrease in water use of about 40%. This was a significant finding, that led to funding from the on-campus SIEF (Sustainability Innovation and Engagement Fund) grant to expand the scope of our pilot study. The funded work proposed to expand the scope of that pilot study: 1) remove the self-reporting bias inherent in the pilot by using automatic timers that are activated by water flow in shower heads and 2) gather a larger data set to support more robust statistical analysis.

We're hoping that individuals like YOU can help out with our data collection! The only requirements for joining this study are that you are excited to be a part of some real science! If you would like to be a part, please fill out this form! If you or anyone else you live with have any questions about this study, do not hesitate to reach out to us (email, text, call, etc.)! If you do choose to participate, you will be entered in a raffle to win a $25.00 Amazon gift card.

Primary Investigators:
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Charlie Schweik (Department of Environmental Conservation & School of Public Policy)
cschweik@umass.edu

*** PLEASE NOTE: People with private bathrooms are encouraged to participate in this study. If more than one person is using the bathroom, then all people must consent to be a part of the study. Consent Forms will be sent to participants through the ShowerTimer@protonmail.com email, so please look for it! ***

* Required

1. Email address *

   ____

2. What is your name?

   ____

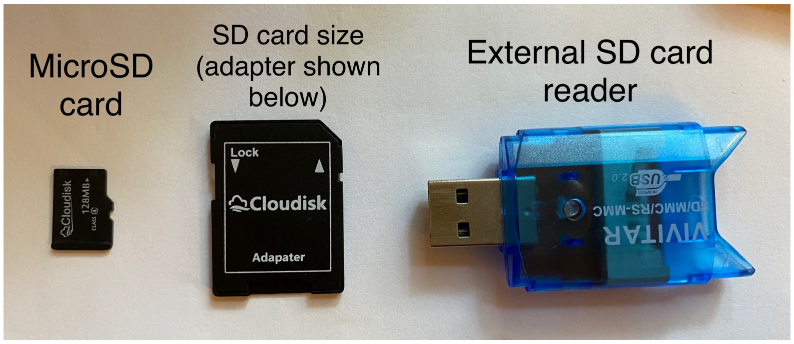
3. How many OTHER people do you live with that use the same shower? *
   - ○ No one, I live alone or have a private bathroom
   - ○ 1
   - ○ 2
   - ○ 3
   - ○ 4
   - ○ 5+

4. Research will capture household members which may include minors, but formal parental permission and assent will not be sought as there is no way to differentiate the usage of the device between minors and adults. If you live with other people and share a shower, does EVERYONE you live with that will use this bathroom AGREE to signing the provided Consent Form and participating in this study? *
   - ○ Yes, everyone has agreed to sign the Consent Form and it will be submitted via email once I have been selected.
   - ○ No, not everyone agrees to sign the Consent Form and I cannot participate in this study.

5. Do you have access to a microUSB (i.e. Android) charging cable and wall connector?*
   - ○ Yes, I have a charging cable.
   - ○ No, please provide me with one.

6. Do you have a *micro SD card (not SD card) reader that can be connected to a laptop? Please see the reference image below this question. *
   - ○ Yes, I have a micro SD card reader that can connect to my computer
   - ○ I have a standard SD card reader (external or built into my computer), but not a micro SD card adapter. Please provide me with a microSD card adapter.
   - ○ No, I have neither, please provide me with one.

A micro SD card will be where the information is recorded (LEFT). A standard SD card is much bigger, but an SD card adapter (MIDDLE) can bridge the gap between microSD cards and your computer if you have a standard SD card reader. If you have neither a standard SD card reader or a microSD card reader, an external card reader will be provided to you (RIGHT). *Model provided will not be identical to this image



7. Can you pick up the device in the Amherst area (in a socially distant manner) or will you need it shipped to your residence? *
   - ○ Yes, I can come pick it up
   - ○ No, I will need to have it shipped.

8. We are asking you to provide your email and residential address so if any devices break, we can send you a new one. We have taken precautions to ensure your personal information cannot be connected to any data. Are you willing to provide your email and residential address? *
   - ○ Yes
   - ○ No

9. What is your mailing address?

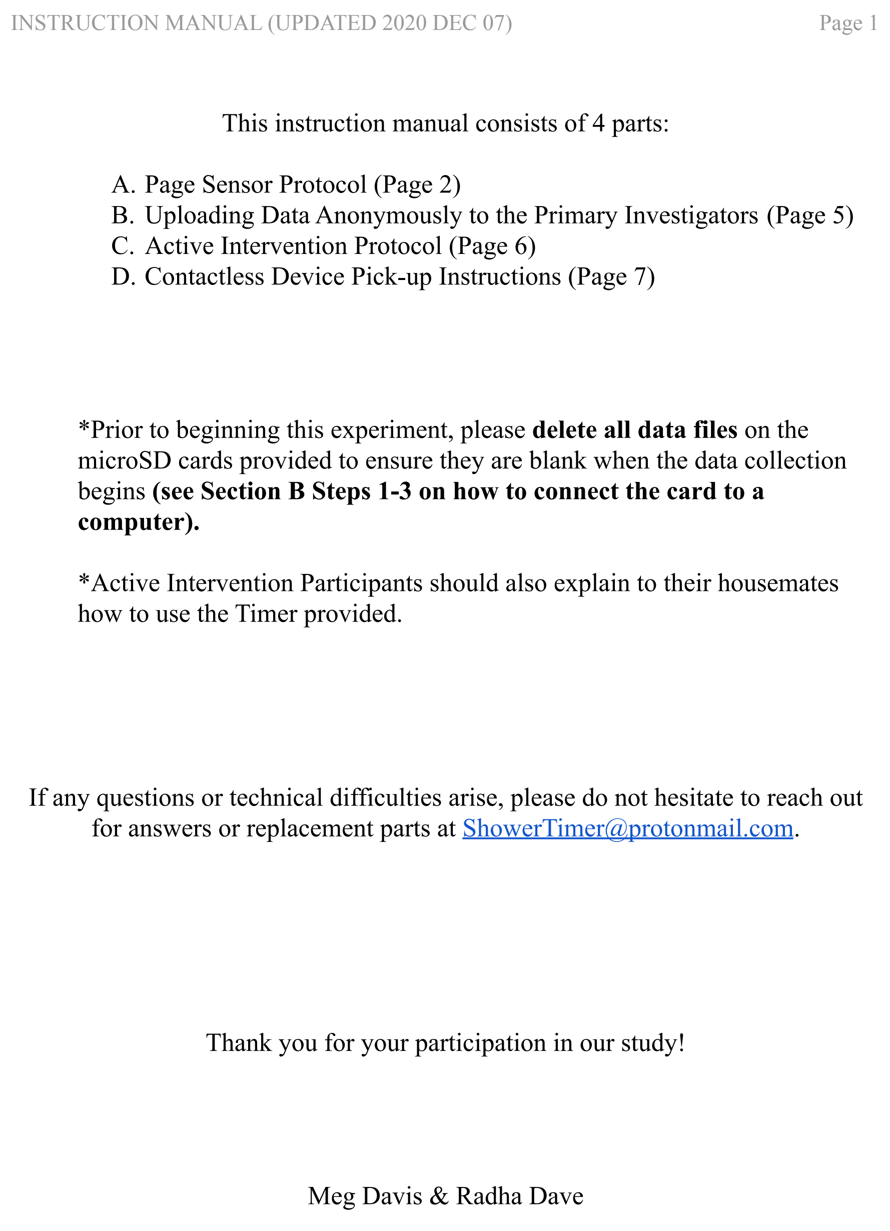
   ____

10. We will be providing you all the necessary instructions for how to set up each device, obtain the data, and upload it confidentially. Even if others use the bathroom, YOU will be the one in charge of collecting the data, charging the device, etc (not your roommates/family/friends) and must follow the protocol we will provide if you are selected. Are you still interested in participating in this study? *
    - ○ Yes! I can't wait to be a part of some real science!
    - ○ No, sorry, I don't think I am interested anymore.

A copy of your responses will be emailed to the address you provided

Appendix C. Participant Instruction Manual

Instruction manual provided to all participants is attached below. The same manual was sent to all groups and to be followed for 10 weeks. Instructions include information on how to install the remote sensing devices, collect, and upload data. Additional information on how to use and maintain the Active Intervention timer and contactless pick-up and drop off of materials was included.



INSTRUCTION MANUAL (UPDATED 2020 DEC 07) Page 1

This instruction manual consists of 4 parts:

A. Page Sensor Protocol (Page 2)
B. Uploading Data Anonymously to the Primary Investigators (Page 5)
C. Active Intervention Protocol (Page 6)
D. Contactless Device Pick-up Instructions (Page 7)

*Prior to beginning this experiment, please **delete all data files** on the microSD cards provided to ensure they are blank when the data collection begins **(see Section B Steps 1-3 on how to connect the card to a computer).**

*Active Intervention Participants should also explain to their housemates how to use the Timer provided.

If any questions or technical difficulties arise, please do not hesitate to reach out for answers or replacement parts at ShowerTimer@protonmail.com.

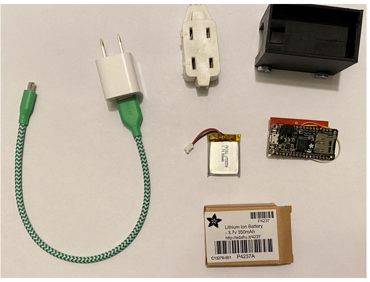
Thank you for your participation in our study!

Meg Davis & Radha Dave

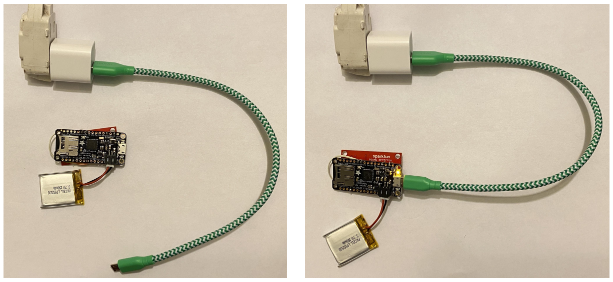
A. Sensor Protocol

1. **Charge the sensor overnight.**

PARTS:
- Charger
- battery & box
- Sensor
- 3D printed case
- Outlet (extension cord)

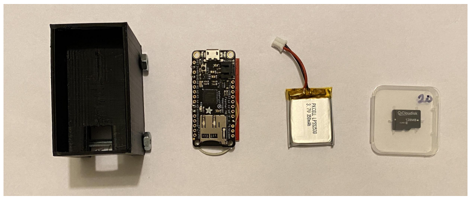


a. Plug the battery into the sensor and plug the charger into an outlet. Then plug the charger into the sensor. The light on the sensor near the charger should turn on.

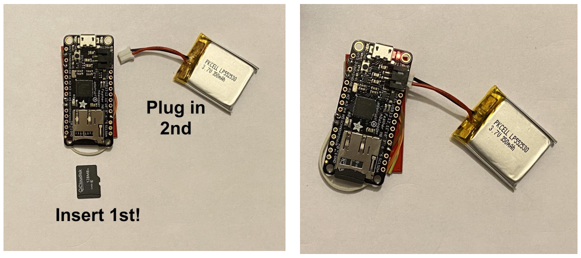


2. **Install on shower following the steps below:**

PARTS:
- 3D printed case
- Sensor
- Battery
- microSD card & case

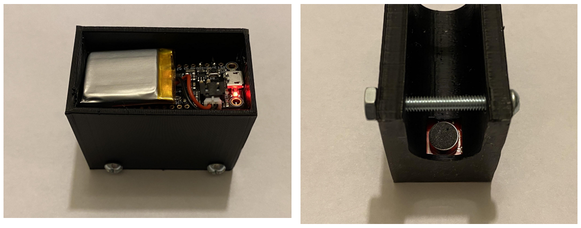


a. Identify the microSD card and battery. Insert the micro SD card in **FIRST**, then plug in the battery. Be sure to do this in the correct order!



INSTRUCTION MANUAL (UPDATED 2020 DEC 07) Page 3

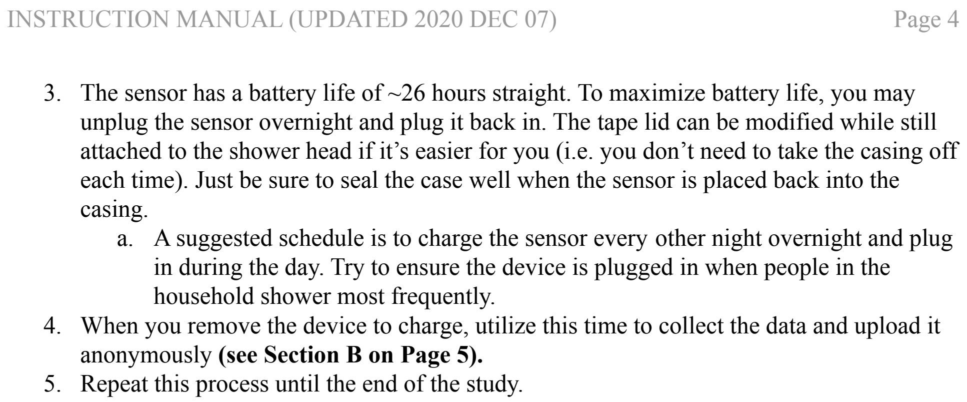
b. Place the sensor and battery inside the 3D printed case with the sound detector inside the hole (*see image on right*).



c. Take a short piece of duct tape long enough to cover the length of the casing. Press on the top rim of the casing to seal the device (*see image in middle*). Fold the edges of the tape over and press to seal (*see image on right*).

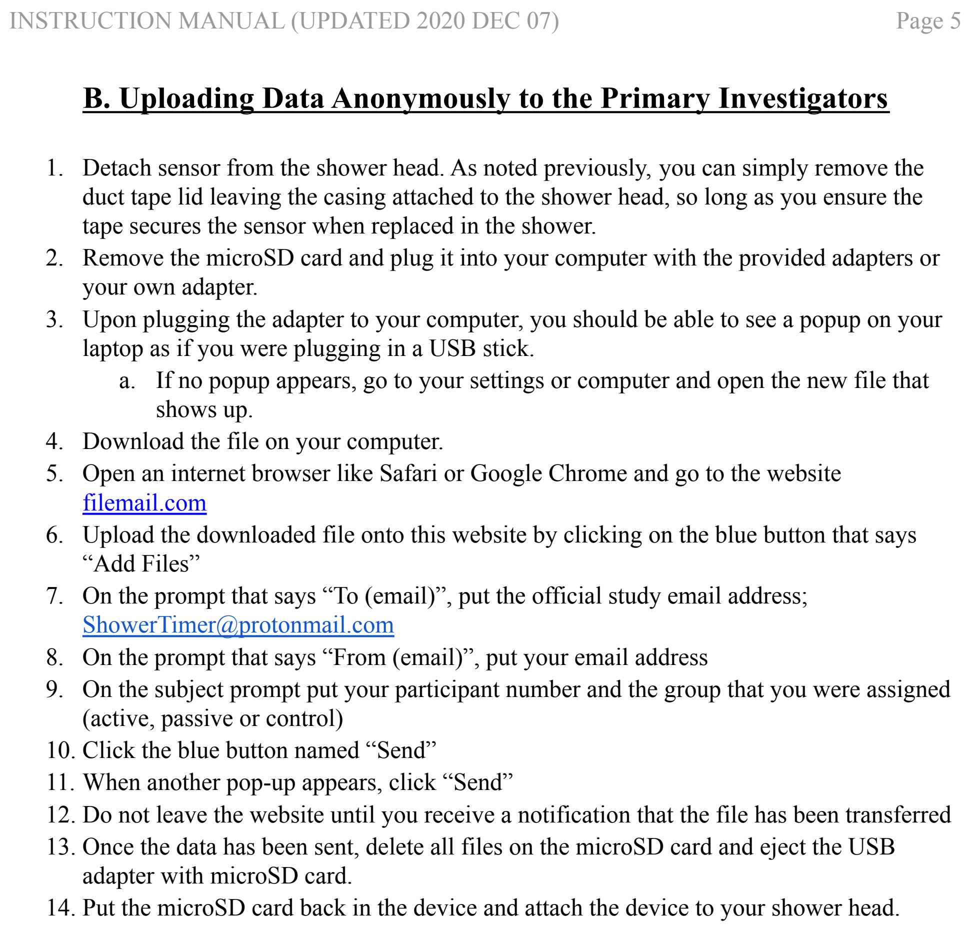
d. Identify the pipe of your shower head as well as 2 nuts and bolts on the sensor’s casing. Unscrew the nuts and remove from the case.

e. Place the sensor on the shower head and screw the nuts and bolts back onto the casing.



INSTRUCTION MANUAL (UPDATED 2020 DEC 07) Page 4

3. The sensor has a battery life of ~26 hours straight. To maximize battery life, you may unplug the sensor overnight and plug it back in. The tape lid can be modified while still attached to the shower head if it's easier for you (i.e. you don't need to take the casing off each time). Just be sure to seal the case well when the sensor is placed back into the casing.
    a. A suggested schedule is to charge the sensor every other night overnight and plug in during the day. Try to ensure the device is plugged in when people in the household shower most frequently.
4. When you remove the device to charge, utilize this time to collect the data and upload it anonymously **(see Section B on Page 5).**
5. Repeat this process until the end of the study.



INSTRUCTION MANUAL (UPDATED 2020 DEC 07) Page 5

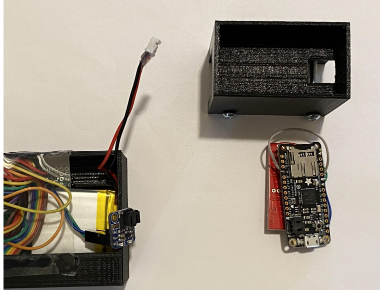
B. Uploading Data Anonymously to the Primary Investigators

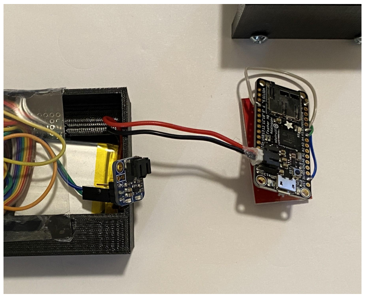
1. Detach sensor from the shower head. As noted previously, you can simply remove the duct tape lid leaving the casing attached to the shower head, so long as you ensure the tape secures the sensor when replaced in the shower.
2. Remove the microSD card and plug it into your computer with the provided adapters or your own adapter.
3. Upon plugging the adapter to your computer, you should be able to see a popup on your laptop as if you were plugging in a USB stick.
    a. If no popup appears, go to your settings or computer and open the new file that shows up.
4. Download the file on your computer.
5. Open an internet browser like Safari or Google Chrome and go to the website filemail.com
6. Upload the downloaded file onto this website by clicking on the blue button that says "Add Files"
7. On the prompt that says "To (email)", put the official study email address; ShowerTimer@protonmail.com
8. On the prompt that says "From (email)", put your email address
9. On the subject prompt put your participant number and the group that you were assigned (active, passive or control)
10. Click the blue button named "Send"
11. When another pop-up appears, click "Send"
12. Do not leave the website until you receive a notification that the file has been transferred
13. Once the data has been sent, delete all files on the microSD card and eject the USB adapter with microSD card.
14. Put the microSD card back in the device and attach the device to your shower head.

C. Active Intervention Protocol*

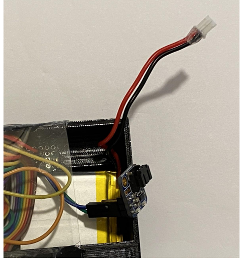
**This protocol is only applicable if you were assigned to the Active Intervention group. Passive Intervention and Control groups do NOT need to follow the protocol below.*

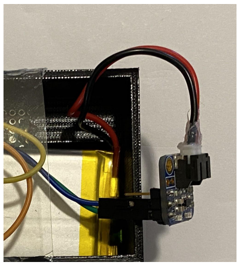
1. Charge overnight via the sensor. Plug the Active Intervention Timer into the sensor as if it were the battery to the sensor itself. *See picture.* Then plug the sensor into the wall charger (if confused, see Section A Step 1).





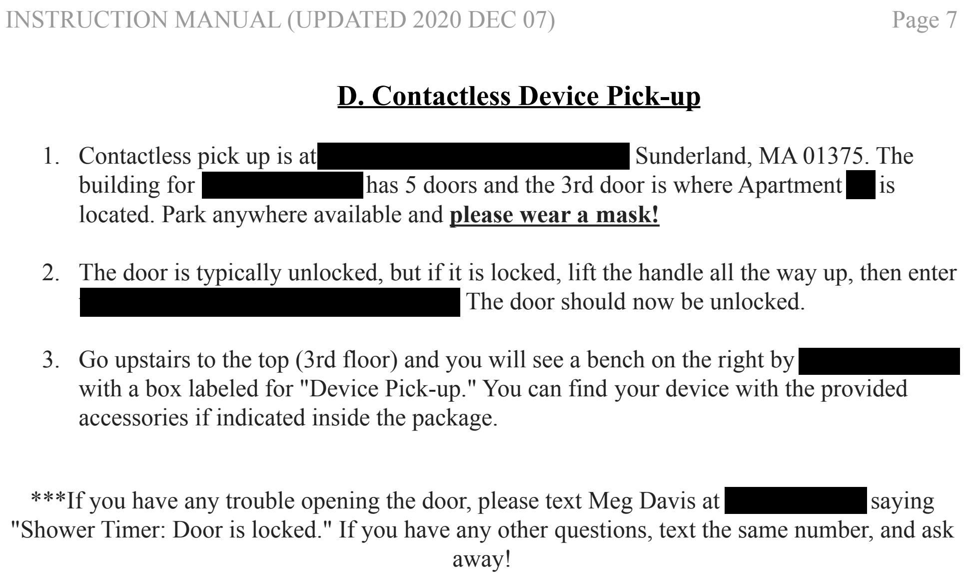
2. Identify the battery and battery port in the back of the Timer. Plug the battery into the port to power the Timer.





3. Place in the shower <u>inside a plastic bag</u> (provided or with one of your own) in a spot where people can see it. Press the button when you start your shower. Once your shower is complete, press the same button. The screen will flash indicating that your shower is complete. After 5 seconds, the home screen will return for the next shower user. <u>**Be sure to explain to your housemates how to use this device!**</u>

4. Charge as needed. The battery life is ~48 hours. A suggested schedule is to charge the battery using the sensor every other day if the timer is continuously on. If you decide to unplug the battery for the timer overnight, then the battery will need to be charged every 3-4 days instead.



INSTRUCTION MANUAL (UPDATED 2020 DEC 07) Page 7

D. Contactless Device Pick-up

1. Contactless pick up is at [redacted] Sunderland, MA 01375. The building for [redacted] has 5 doors and the 3rd door is where Apartment [redacted] is located. Park anywhere available and **please wear a mask!**

2. The door is typically unlocked, but if it is locked, lift the handle all the way up, then enter [redacted] The door should now be unlocked.

3. Go upstairs to the top (3rd floor) and you will see a bench on the right by [redacted] with a box labeled for "Device Pick-up." You can find your device with the provided accessories if indicated inside the package.

***If you have any trouble opening the door, please text Meg Davis at [redacted] saying "Shower Timer: Door is locked." If you have any other questions, text the same number, and ask away!

Appendix D. Remote Sensing Device Design

Pinout diagram and 3D printed housing for the remote sensing device are provided below.

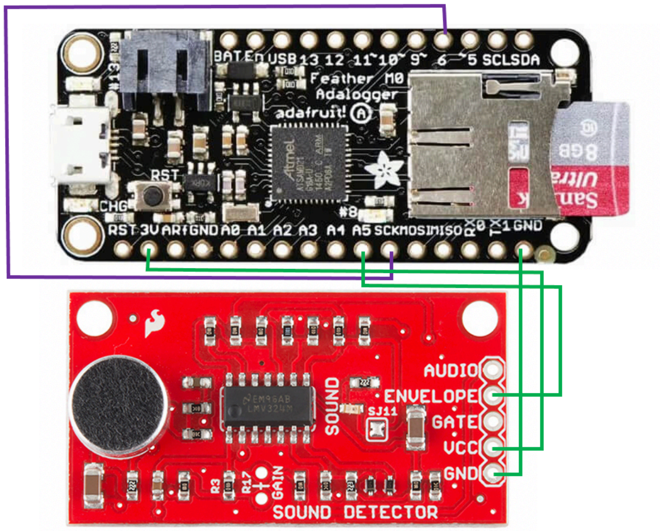


Figure D1. Remote sensing device pinout diagram. An Adafruit Feather M0 Adalogger microcontroller and Sparkfun sound detector are used, and data is stored on a microSD card. A 350mAh 3.7V rechargeable lithium-ion battery is used as a power source. Cost of parts totaled $43.15.

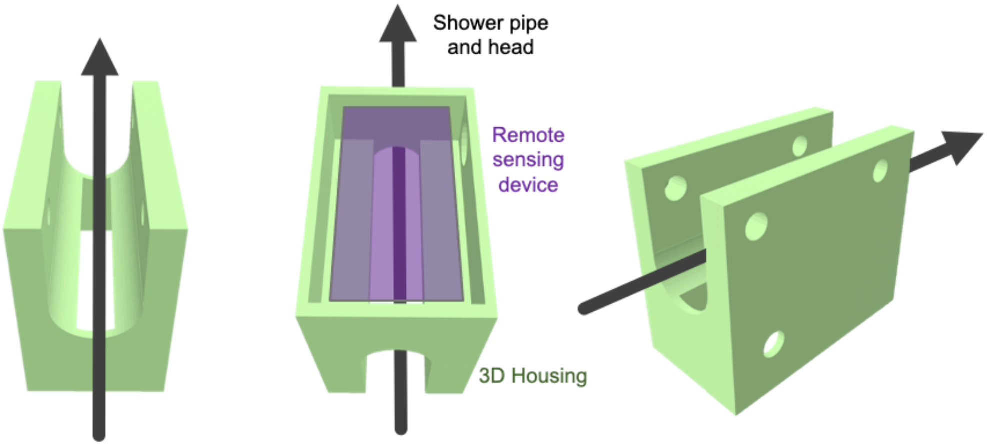


Figure D2. 3D printed housing for remote sensing devices. 3D printed cases were designed with the help of Dennis Spencer from the UMass Libraries Digital Media Lab. The remote sensing case (top) holds the remote sensing device with the sound detector contacting the shower head. No lid is provided and is closed with duct tape as easy access is required to obtain data from the microSD card.

Appendix E. Passive Intervention Poster

The passive intervention poster was developed to mimic the existing #UMassSavesH2O Sustainability posters in residence halls. This intervention is a non-interactive method targeted for individuals to read as they step into shower stalls.

Appendix F. Active Intervention Design

Pinout diagram and 3D printed housing design for the active intervention timer are provided below.

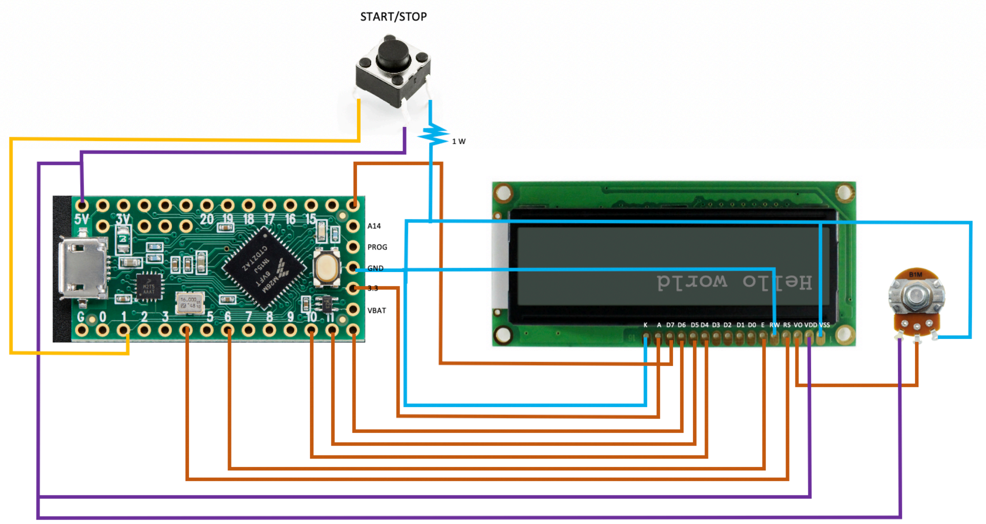


Figure F1. Active intervention device pinout diagram. A Teensy LC microcontroller, LCD screen, push button, and Adafruit lithium-ion battery backpack are used to display real-time feedback to the user about shower duration and water consumption. A 1.1Ah 3.7V rechargeable lithium-ion battery is used as a power source. Cost of parts totaled $41.77.

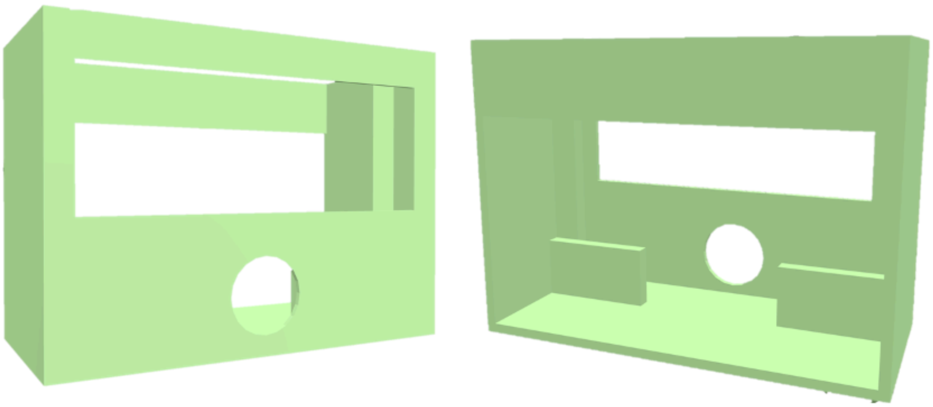


Figure F2. 3D printed housing for Active Intervention. 3D printed cases were designed with the help of Dennis Spencer from the UMass Libraries Digital Media Lab. The active intervention case houses the LCD screen and microcontroller with access to a button in the front. Flexible plastic from recycled plastic bags covers the button to ensure no water enters the device. The back is also covered with a stiffer recycled plastic and the active intervention is kept inside a plastic bag to prevent water damage.

Appendix G. Estimated Energy and Emissions Calculations

Calculations to estimate energy consumption of a single shower are provided below. Municipal energy consumption estimates are used as upper and lower bounds. Energy estimates were entered into the EPA emissions calculator for estimated GHG emissions of a single shower.

$E_{segment} + E_{household} = E_{total}$

Where: $E_{segment}$ represents total energy for water use cycle segments (supply & conveyance, initial treatment, distribution, collection & final treatment, and discharge;

$E_{household}$ represents the energy consumed to heat total gallons of 1 shower from 47˚F to 130˚F with an electric water heater

Low: $1{,}250\,\frac{kWh}{MG} \rightarrow 0.00125\frac{kWh}{gal} + \ 0.203\frac{kWh}{gal} = 0.2042\frac{kWh}{gal} \times \ 17.2\ gal = 3.51\ kWh\ per\ shower$

High: $6{,}500\,\frac{kWh}{MG} \rightarrow 0.0065\frac{kWh}{gal} + 0.203\,\frac{kWh}{gal} = 0.2095\frac{kWh}{gal} \times \ 17.2\ gal = 3.60\ kWh\ per\ shower$

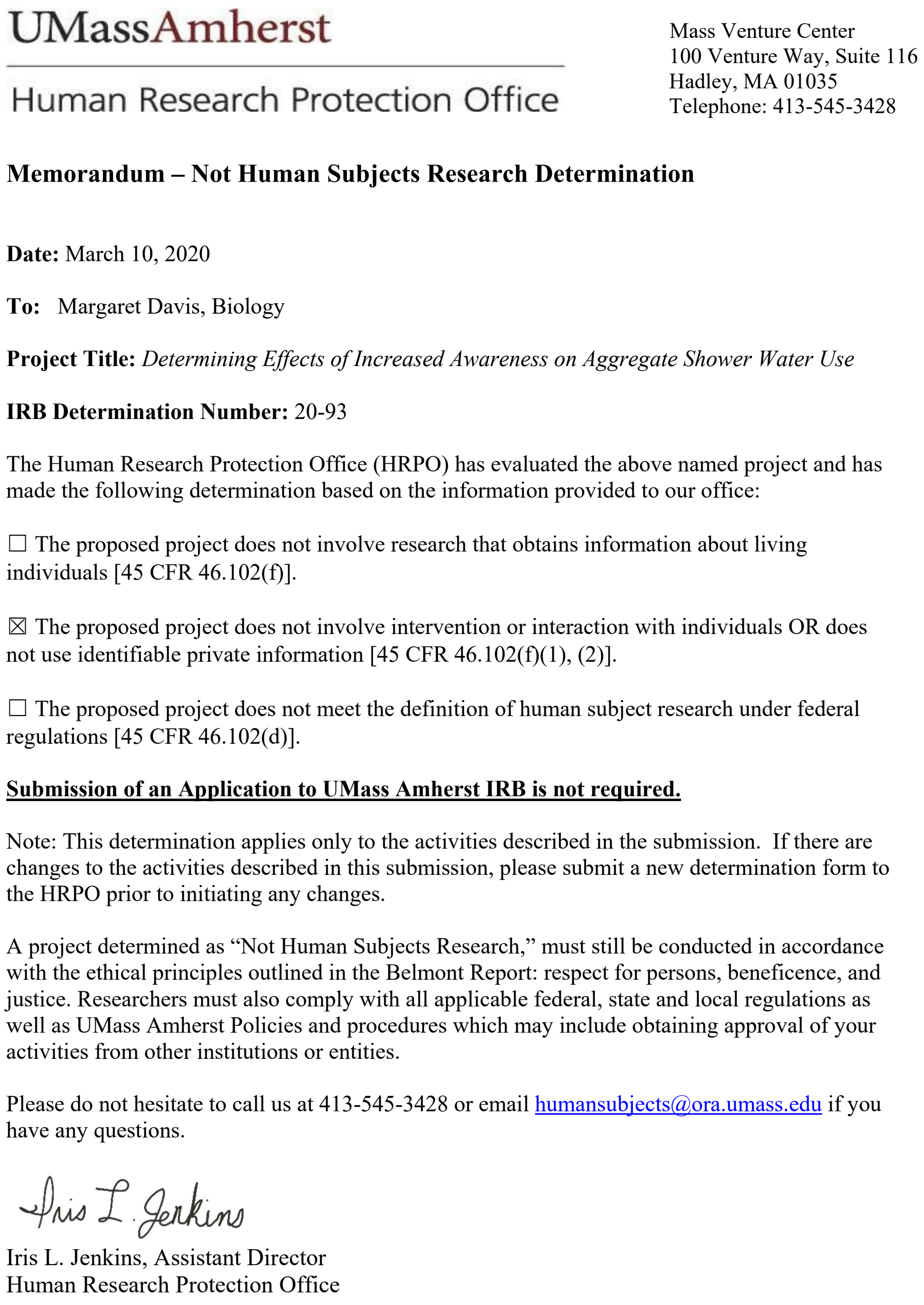
Assumes: Total water consumption for 1 shower is 17.2 gallons (GreenGEEKblog.com); low and high estimates of municipal water from Griffiths-Sattenspiel & Wilson (2009) and Carlson & Walburg (2007); average inlet water temperature for Massachusetts = 47˚F; and water temperature of electric water heaters = 130˚F

Calculator from GreenGEEKblog.com (How Much It Costs You To Shower And How Much You Can Save On Each One) using parameters listed above.

The EPA Greenhouse Gas Equivalencies Calculator was used to convert kWh to metric tons of carbon dioxide equivalents (MTCO$_2$ eqs.) (https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator)

Appendix H. IRB Determination

Initial IRB determination from the UMass HR Protection Office is provided. Determination was received on March 10, 2020 and concluded that our original study design did not need full IRB approval.



UMassAmherst
Human Research Protection Office

Mass Venture Center
100 Venture Way, Suite 116
Hadley, MA 01035
Telephone: 413-545-3428

Memorandum – Not Human Subjects Research Determination

Date: March 10, 2020

To: Margaret Davis, Biology

Project Title: *Determining Effects of Increased Awareness on Aggregate Shower Water Use*

IRB Determination Number: 20-93

The Human Research Protection Office (HRPO) has evaluated the above named project and has made the following determination based on the information provided to our office:

☐ The proposed project does not involve research that obtains information about living individuals [45 CFR 46.102(f)].

☒ The proposed project does not involve intervention or interaction with individuals OR does not use identifiable private information [45 CFR 46.102(f)(1), (2)].

☐ The proposed project does not meet the definition of human subject research under federal regulations [45 CFR 46.102(d)].

Submission of an Application to UMass Amherst IRB is not required.

Note: This determination applies only to the activities described in the submission. If there are changes to the activities described in this submission, please submit a new determination form to the HRPO prior to initiating any changes.

A project determined as "Not Human Subjects Research," must still be conducted in accordance with the ethical principles outlined in the Belmont Report: respect for persons, beneficence, and justice. Researchers must also comply with all applicable federal, state and local regulations as well as UMass Amherst Policies and procedures which may include obtaining approval of your activities from other institutions or entities.

Please do not hesitate to call us at 413-545-3428 or email humansubjects@ora.umass.edu if you have any questions.

Iris L. Jenkins

Iris L. Jenkins, Assistant Director
Human Research Protection Office

Appendix I. Remote Sensing Device Code

Coding for the remote sensing device was created on ArduinoCreateAgent written in C++. Code was developed by Blake Hatch where sound vibrations via water flow over a certain threshold started a timer and absence of sound stopped the timer. Data was saved on a microSD card.

```
#include <SPI.h>
#include <SD.h>
#include <ArduinoLowPower.h>

// Set the pins used
#define cardSelect 4

File logfile;

// blink out an error code
void error(uint8_t errno) {
  while (1) {
    uint8_t i;
    for (i = 0; i < errno
        ; i++) {
      digitalWrite(13, HIGH);
      delay(100);
      digitalWrite(13, LOW);
      delay(100);

    }
    for (i = errno; i < 10; i++) {
      delay(200);
    }

  }
}

void wakeUp() {
  //logfile.println("Waking up");
  //logfile.flush();
  Serial.println("Wakey wakey!");
}
// This line is not needed if you have Adafruit SAMD board package 1.6.2+
// #define Serial SerialUSB

void setup() {
  //connect at 115200 so we can read the GPS fast enough and echo
  // also spit it out
  Serial.begin(115200);
  Serial.println("\r\nAnalog logger test");
  pinMode(13, OUTPUT);

  // see if the card is present and can be initialized:
  if (!SD.begin(cardSelect)) {
    Serial.println("Card init. failed!");
    error(2);

  }
  char filename[15];
  strcpy(filename, "ANALOG00.TXT");
  for (uint8_t i = 0; i < 100; i++) {
```

```
    filename[6] = '0' + i / 10;
    filename[7] = '0' + i % 10;
    // create if does not exist, do not open existing, write, sync after write
    if (! SD.exists(filename)) {
      break;
    }
  }

  LowPower.attachInterruptWakeup(A5, wakeUp, HIGH);

  logfile = SD.open(filename, FILE_WRITE);
  if ( ! logfile ) {
    Serial.print("Couldnt create ");
    Serial.println(filename);
    error(3);

  }
  Serial.print("Writing to ");
  Serial.println(filename);

  pinMode(13, OUTPUT);
  pinMode(8, OUTPUT);
  Serial.println("Ready!");

}

uint8_t i = 0;
long soundStart = 0;
long soundDuration = 0;
boolean waterRunning = false;
//soundCutoff was originally 20
long soundCutoff = 15;
long mindurationforlog = 10;

void loop() {
  unsigned long time = millis();
  digitalWrite(8, HIGH);
  delay(500);

  if (analogRead(5) >= soundCutoff && waterRunning == false) {
    waterRunning = true;
    soundStart = time;
    Serial.println("Water Now Running");

  }

  else if (analogRead(5) < soundCutoff && waterRunning == true) {
    // calculates the duration of the sound by subtracting the starting time from the
    // current time, then divides by 1000 to convert the ms to seconds.
    soundDuration = ((time - soundStart) / 1000);

    Serial.print("water ran for ");
    Serial.println (soundDuration);
    //logfile.println(soundDuration + "test");
    if (soundDuration >= mindurationforlog) {
      Serial.println("Logging to file");
      logfile.println(soundDuration);
      logfile.flush();
    }

    waterRunning = false;
    //LowPower.sleep();
  }

  else if (analogRead(5) < soundCutoff && waterRunning == false) {
```

```
    Serial.println("Nighty night");
    //logfile.println("sleeping");
    //logfile.flush();
    LowPower.idle();
  }
  //Serial.flush();
  digitalWrite(8, LOW);
}
```

Appendix J. Active Intervention Code

Coding for the remote sensing device was created on ArduinoCreateAgent written in C++. Code was developed by Blake Hatch where real-time feedback was provided on an LCD screen displaying duration and water consumption in that duration via a flow rate conversion factor (based on the average showerhead at UMass Amherst).

```
#include <LiquidCrystal.h>
#include <Snooze.h>

char lcdPrintArray[] = "Time your shower";
char lcdPrintArray1[] = "Press start!";
String timerDisplay = "Time: ";
String gallonDisplay = "Water: ";
LiquidCrystal lcd(4, 6, 10, 11, 12, 13);
int buttonPin = 2;
int col = 16;
int row = 2;
int cursorPos = 0;
int t = 100;
int timerButtonState = 0;
boolean showInitialScreen = true;
boolean timerRecording = false;
boolean canChange = true;

double secToGalConvFactor = 0.04167;
double totalGallons = 0.0;

unsigned long startMill;
unsigned long currentMill;
unsigned long elapsedMill;
unsigned long elapsedMin;
unsigned long elapsedSec;

SnoozeTimer timer;
SnoozeBlock config(timer);

void setup() {
  lcd.begin(col, row);

  pinMode(buttonPin, INPUT);
}

void loop() {
  // read the state of the timer button
  timerButtonState = digitalRead(buttonPin);

  if (timerButtonState == LOW) {
    canChange = true;
    if(!showInitialScreen) {
      currentMill = millis();
      if(timerRecording == true) {
        displayTime();

        displayGallons();
      }
```

```
      else {
        int flashDelayTime = 500;
        for(int i = 0; i < 5; i++) {
          displayWithoutRecording();
          delay(flashDelayTime);
          lcd.clear();
          delay(flashDelayTime);
        }
        showInitialScreen = true;
      }
    }
    else {
      //Set Cursor to first row to print
      lcd.setCursor(cursorPos, 0);

      //Print to first row
      lcd.print(lcdPrintArray);

      //Set Cursor to second row to print
      lcd.setCursor(cursorPos, 1);

      //Print to second row
      lcd.print(lcdPrintArray1);

      elapsedMill = (currentMill - startMill);
      elapsedMin = ((elapsedMill / 1000) / 60);
    }
  }
  else {
    showInitialScreen = false;

    if(!timerRecording && canChange) {
      timerRecording = true;
      startMill = millis();
    }
    else if(timerRecording && canChange) {
      timerRecording = false;
    }
    canChange = false;

    lcd.setCursor(cursorPos, 0);
    lcd.print(timerDisplay);
  }
    delay(t);
    //Clear the lcd before next loop.
    lcd.clear();
}

void setTimerDisplay(long em, long es) {
  String elapsedMinStr = String(em);
  String elapsedSecStr = String(es);
  if(elapsedMin < 10 && elapsedSec < 10) {
    timerDisplay.concat("0").concat(elapsedMinStr)
    .concat(":").concat("0")
    .concat(elapsedSecStr);
  }
  else if (elapsedMin < 10) {
    timerDisplay.concat("0").concat(elapsedMinStr)
    .concat(":").concat(elapsedSecStr);
  }
  else if (elapsedSec < 10) {
    timerDisplay.concat(elapsedMinStr).concat(":").concat("0")
    .concat(elapsedSecStr);
  }
  else {
```

```
    timerDisplay.concat(elapsedMinStr).concat(":").concat(elapsedSec);
  }
}

void displayTime() {
  elapsedMill = (currentMill - startMill);
  elapsedSec = ((elapsedMill / 1000) % 60);
  elapsedMin = ((elapsedMill / 1000) / 60);
  lcd.setCursor(cursorPos, 0);
  setTimerDisplay(elapsedMin, elapsedSec);
  lcd.print(timerDisplay);
  timerDisplay = "Time: ";
}

void displayGallons() {
  elapsedSec = ((elapsedMill / 1000));
  lcd.setCursor(cursorPos, 1);
  totalGallons = (elapsedSec * secToGalConvFactor);
  if(totalGallons > 100) {
    gallonDisplay.append(totalGallons);
    gallonDisplay[gallonDisplay.length() - 1] = ' ';
    gallonDisplay.append("gal");
  }
  else {
    gallonDisplay.append(totalGallons).append(" gal");
  }
  lcd.print(gallonDisplay);
  gallonDisplay = "Water: ";
}

void displayWithoutRecording() {
  lcd.setCursor(cursorPos, 0);
  setTimerDisplay(elapsedMin, elapsedSec);
  lcd.print(timerDisplay);
  timerDisplay = "Time: ";

  lcd.setCursor(cursorPos, 1);
  if(totalGallons > 100) {
    gallonDisplay.append(totalGallons);
    gallonDisplay[gallonDisplay.length() - 1] = ' ';
    gallonDisplay.append("gal");
  }
  else {
    gallonDisplay.append(totalGallons).append(" gal");
  }
  lcd.print(gallonDisplay);
  gallonDisplay = "Water: ";
}
```