# Low-flow Shower Valve and Environmental Education Effects on Gas and Water Use in University Village

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## ABSTRACT

Because of growing concerns about water scarcity and high carbon emission levels, it is important that consumers modify certain behaviors to reduce natural resource consumption. Showering is a common household activity that accounts for a substantial part of a residence's total energy and water usage. Showering can be targeted through demand side management (DSM), which offers education or technical retrofit strategies to reduce overall demand for natural resources. Combining education with a technical retrofit could lead to higher rates of conservation than using either strategy alone. In this study, I compared residential gas and water use before and after two DSM strategy interventions: a low-flow shower valve and environmental education. I recruited 81 residents from the University Village housing complex in Albany, California to participate in the study. 46 of the residences remained as controls while 35 received the low-flow valve and an informational shower-hanger. 18 of the 35 valve-recipients were given additional email education. I distributed surveys to all participants. I found no statistically significant difference between the cubic feet of gas consumed per day of the valve and control residences, but I did notice trends that suggest the email education contributed to the educated valve sub-group consuming the least amount of gas. I also calculated that when used, the valve would produce 4-13% energy savings, a range that matches the 5% difference in gas use observed between the valve and control groups.

## KEYWORDS

demand side management, resource conservation, human behavior change, technical retrofits, educating environmentalism

## INTRODUCTION

In spite of concerns about limited resource availability and climate change, humans overuse water and energy stocks by depleting aquifers and combusting fossil fuels. Water and energy play important roles in supporting everyday activities, from bathing to cooking, but many consumers use the resources inefficiently or in excess without proper knowledge. Water conservation in California is of particular importance, due to the state's long history with droughts (Benson et al. 2002, MacDonald 2007). In the developed world's domestic sector, water use is intrinsically tied to energy use because activities like showering and dishwashing require an energy input, such as natural gas or electricity, to modify water temperature (Williams et al. 2013, Cheng 2002, Elias-Maxil et al. 2014, Makki et al. 2013). Residents are often unaware of the joint relationship between the water they use and the energy it requires. In fact, much of the energy consumed by residential water users goes towards heating water (Elias-Maxil et al. 2014, Cheng 2002). If occupants adapt to using less heated water, then less gas will be consumed in the process. Encouraging water conservation can thus lead to energy savings as well, which contributes to efforts decrease carbon emissions and alleviate climate change effects (Liu et al. 2010, Cheng 2002).

To influence water and energy conservation, policymakers and resource managers often turn to Demand Side Management (DSM) strategies. DSM strategies refer to methods that reduce overall demand of a resource when supply availability is low (Saini 2004). Research into DSM methods such as implementing resource-efficient retrofits, education campaigns, or resource rationing has shown successful results for water conservation (Renwick and Green 2000, Thogersen and Gronhoj 2010). Simple DSM retrofitting programs such as installing low-flow showerheads and sink aerators increase household resource use efficiency and consistently reduce consumption by 9-12% (Inman and Jeffrey 2006, Renwick and Green 2000). More comprehensive appliance replacement, like installing water-efficient toilets, can even lead to water use reductions of 35-50% (Inman and Jeffrey 2006). More direct DSM policies like resource rationing or restricting usage can also substantially reduce consumption rates by 19% and 29%, respectively (Renwick and Green 2000). Although DSM studies about natural gas are not as prevalent as DSM studies about other resources (e.g., electricity and water), researchers have estimated that gas conservation measures through retrofits could net gas savings between 5 and 10% (De Almeida et al. 2004).

Although a popular strategy for DSM, educational campaigns on their own have had mixed success. Success varies not only because of the unique characteristics of study populations, but also because of differences in conservation approaches. Numerous studies have found that education alone produces minimal resource savings, if any at all (Inman and Jeffrey 2006, Keramitsoglou and Tsagarakis 2011, Black et al. 1985, Renwick and Green 2000). In contrast, DSM strategies that implement educational campaigns in conjunction with retrofits can lead to additional water and gas conservation by influencing consumer habits. Several studies have found through both consumer surveys and data analysis that if supply-side stakeholders (energy and water companies, for example) provide motivational standards and educational interventions to the consumers, they are more likely to observe a long term change in energy and water consumption (Thogerson and Gronhoj 2010, Randolph and Troy 2008, Willis et al. 2011).

According to previous research, showering contributes to one-third of indoor energy consumption and places significant strain on residential energy demand and greenhouse gas emissions (Makki et al. 2013). Low-flow showerhead modifiers are commonly pursued technical DSM retrofits that can offer immediate and long-term decreases in water and gas usage (Renwick and Green 2000, Mayer and DeOreo 1999, Williams et al. 2013), especially considering that showering is one of the activities with the greatest potential to save water indoors (Makki et al. 2013). Homes with low-flow shower retrofits saved 4,500 gallons of water per year (Mayer and DeOreo 1999) and decreased water use by 9-15% (Inman and Jeffrey 2006), so research has clearly proven the efficacy of such retrofits. However, these studies only considered retrofits that yielded immediate resource savings just by the nature of installing them. For retrofits that depend on the user to maximize their conservation potential, no research currently exists. Thus, an exploration of achieving resource savings with consumer-dependent DSM retrofits is needed, and combining informative campaigning with this type of DSM retrofitting strategy could yield further rates of conservation.

In my study, I will analyze two DSM intervention strategies' effects on water and natural gas conservation, as my study site's indoor heating is supplied by natural gas. The technical intervention consists of a low-flow shower valve, and the educational intervention consists of environmental education. Because the shower valves in my study are consumer-dependent DSM retrofits that rely on human behavior to achieve resource conservation, a targeted education campaign may be important in maximizing the valve's use among consumers. I will not only compare the two DSM methods' combined effectiveness towards conservation, but also look closely into the isolated effectiveness of each method. I hypothesized that the families receiving both DSM methods, the valve and the education, would consume the least gas and water out of all the studied families.

## METHODS

### Study system

To study the effects of a low-flow valve and education program on water and gas use, I chose the University Village (UV) as my study site. UV is a housing complex located in Albany, California, a city that borders Berkeley. The University of California converted UV from a military housing complex to married student housing in 1956. Between 1999 and 2006, most of the apartments were rebuilt and more were added. UV currently provides housing for 974 families with 2,718 total residents. Many of the residents of this multicultural community are faculty or graduate students of the UC Berkeley campus or the nearby Lawrence Berkeley Labs. The resident population is diverse and international, with representation from 62 countries. UV residents differ not only in language and culture, but also in habits, principles, perceptions of sustainability, and environmental concern.

Residence in UV is temporary for most occupants and highly sporadic; leases for apartments operate from month-to-month. UV administration charges utility fees for electricity, gas, and water to residents by blocks relating to apartment size, regardless of each resident's actual consumption. However, around one-third of the apartments have natural gas and electricity sub-meters. These sub-metered apartments are located solely in the East Village of UV's East and West Villages, both of which are stratified based on buildings numbers. Buildings 100 to 144 make up the East Village, while buildings 145 to 170 make up the West Village. I chose the residents of UV's East Village as my study population because only East Village apartments provided access to natural gas sub-meters.

### The valve

To study the effects of a technical demand side management method on resource use, I selected a low-flow shower valve from a variety of valve options. I refer to the valve as "low-flow" because it is a small valve that is installed behind the showerhead, with which the user can subtly adjust the flow of water from full flow to nearly no flow by rotating the valve either clockwise or counterclockwise.[1] To estimate the effect of the valve on showerhead flow (in gallons per minute), I fixed the valve at different settings and measured the differences in water output. I found the valve could achieve reductions in flow between 30-90% (see Appendix A2). Thus, I envisioned the user reducing the flow of water from their showerheads when doing less water-intensive activities, such as soaping up, shaving, or lathering, and returning the valve to a higher flow when rinsing off their bodies.

*Preliminary data collection*

To establish a method of quantifying shower water use out of gas meter readings, I collected preliminary data in two ways. First, I took two readings from the gas sub-meters of 15 random East Village residences to obtain an estimate of the average gas use of a typical apartment per month. I recorded gas use from the sub-meter dials located in the water heater closet of each residence. These dials record the flows of natural gas in units of cubic feet. Second, I tested how various gas and water appliances in typical UV apartments affect the readings on the gas sub-meter. To approximate the percentage each appliance or activity contributes to an average monthly gas use, I watched the gas sub-meter for changes in cubic feet of gas consumed per minute for each of the following energy uses: heating the oven, stovetop burners, thermostat, water heater pilot light, and heating the water from the sinks, tubs, and showerheads.

*Participant recruitment and initial meter readings*

[1]After trying out three other models, I chose the low-flow type of retrofit based on its high quality, its relatively low price per unit ($15), and its potential to be used by residents in UV. Rather than restricting the user to two settings (*e.g.*, either full-flow or no-flow), the low-flow valve allows the user the greatest amount of flexibility in adjusting the flow of water from their showerhead.

To recruit families to participate in the study, I knocked on the doors of 200 occupied residences. I selected only two bedroom and one bathroom residences for three reasons: 1) any residents selected for the valve study could only have the valve installed in one bathroom; 2) I wanted to keep the square footage among participating apartments relatively even; and 3) the use of both hot water and natural gas was restricted to two bedrooms and one bathroom. I then stratified the UV residences into two different floor plans (63 townhouses and 37 flats) and used the random number generator function in Microsoft Excel to attach a random number to each residence.

I visited residences in the order displayed on my randomly generated list until I obtained consent from at least 100 families. I displayed my university ID card, provided the resident with background information on the study and a consent form, asked for permission to take a gas meter reading, and then asked the resident to fill out a brief survey, either in-person or online. The preliminary survey asked residents for information on how many occupants live in the apartment and how frequently they use various water and gas appliances in their homes. If residents wished to fill out the survey online, I emailed them a link to the Google Forms version of the survey. To encourage completion of the survey, I offered a raffle prize of four $25 Target gift cards to participants. From the period of 5 September 2013 to 22 October 2013, I recruited and took the first meter reading for 100 residences (37 flats and 63 townhouses).

Over the course of the study, I collected three sub-meter readings per residence. I defined the *baseline period* as the period of gas meter measurement before I administered any interventions (Meter Readings 1 – 2) and the *intervention period* as the period of gas meter measurement after I administered the valve and education interventions (Meter Readings 2 – 3). To estimate cubic feet of gas consumed per day per apartment, I used the difference between Meter Reading 2 and 1 for the baseline period and Meter Reading 3 and 2 for the post-intervention period and divided by the days between the readings.

*Second meter readings and valve intervention randomization*

To decide which residences received the low-flow valve intervention, I randomized the group of 100 residences into two halves: control and intervention residences. I again used Microsoft Excel to randomize the samples; 50 residences (18 flats and 32 townhouses) were designated as valve recipients, while 50 residences (19 flats and 31 townhouses) remained as controls.[2] 15 out of the 50 valve residences declined to accept the valve so I withdrew them from the study to avoid self-selection bias, which would have been an issue if they remained as control samples. An additional four control residences withdrew their participation from the study. UV maintenance staff installed low-flow valves in the intervention residences, and I distributed a waterproof shower-hanger with educational information to each valve-recipient. The 46 control residences did not receive a valve or shower-hanger. We obtained the second sub-meter readings for the remaining 81 residences between 12 November and 20 November 2013.

*Education intervention randomization and outreach*

To decide which part of the valve intervention group would receive environmental education in addition to the shower-hanger, I performed another randomization on the original intervention group. Half of the 35-residence intervention group (6 flats and 12 townhouses) received the education intervention. The education component consisted of a modified shower-hanger with environmental benefits information and follow-up emails with reminders to use the valve and elaborate on water and gas conservation's importance.[3]

*Third meter readings and final survey*

To close out the study, I returned to the 81 participating residences after a one-month period of time and took the final gas meter readings from 12 December to 14 December 2013. I chose a one-month period to match the average time frame between the first and second meter readings and because of my time constraints with an approaching winter break. To gather residents' opinions on the low-flow valve, I administered a final survey to those in the intervention group to

[2]Because 37 and 63 are odd numbers, I flipped a coin to determine which apartment group would receive an extra representative in the intervention group.
[3]These methods are similar to those used by UV to educate residents on typical household issues.

ask about their experience with the valve, including why they may or may not have used it. The survey I gave to the education intervention group had additional questions about their experience with the outreach program.

**Data analysis**

*Effect of the valve on gas used*

Using the “Rcmdr” package in R statistical analysis software (Fox 2005), I performed a Welch two-sample t-test on the mean cubic feet of gas consumed per day (=$ft^3$/day) between the Control and Valve apartment groups for both the baseline and intervention time periods.

To see if education affected the $ft^3$/day, I performed a one-way analysis of variance (ANOVA) and with a pairwise comparison of means using Tukey Contrasts. I drew comparisons between the Control apartment group and the two subgroups of the Valve apartment group: the Education (Edu) and the No Education (NoEdu) Valve sub-groups.

To assist in identifying this relationship and stratifying analyses by different apartment characteristics (number of persons per apartment, numbers of showers taken per apartment), I used estimates from my preliminary data collection and measurements.

*Final survey analysis*

To understand the Valve group residents’ opinions of using the valve and the impact of my outreach efforts, I used summary statistics and two-sample t-tests to analyze my final survey results. For each question of the survey that asked the respondent to rank their agreement with a statement on a 1-5 Likert scale, I averaged the values by Edu and NoEdu group as well as attaining a combined average. I used the responses to create a new binomial variable called “Used Valve Y/N,” which allowed me to categorize each respondent as a valve user or not for the study. Using this variable I performed two-sample t-tests between each survey question in attempts to find relationships between different factors that could explain valve use or disuse.

## RESULTS

## Gas use data analysis

The 81 participating families consumed an average of 80 $ft^3$/day (= cubic feet of natural gas consumed per day) during the baseline period and an average of 114 $ft^3$/day during the intervention period. These rates correspond to a monthly use of ~2500 $ft^3$ for the baseline period and then a monthly use of ~3400 $ft^3$ for the intervention period.

### *Effect of the valve on gas used*

**Table 1:** Gas use across the different treatment groups. Edu and NoEdu combined make up the Valve group. The Edu group consumed the least amount of gas on average of all groups.

| **Treatment Group** | **Baseline $ft^3$/day (mean)** | **Baseline $ft^3$/day (std dev)** | **Intervention $ft^3$/day (mean)** | **Intervention $ft^3$/day (std dev)** | **% Δ b/w Base. & Int. $ft^3$/day** |
|---|---|---|---|---|---|
| Ctrl | 79.7 | 28.0 | 114.1 | 43.9 | +43% |
| Valve | 82.3 | 35.0 | 113.9 | 36.0 | +38% |
| Edu | 82.5 | 32.1 | 109.5 | 35.3 | +33% |
| NoEdu | 82.1 | 39.5 | 119.2 | 37.3 | +45% |

I found that the means for baseline gas use between the Control and Valve groups were not significantly different (Two-sample t-test: $t=-0.34$, $df=55.6$, $p=0.74$). The Control apartments ($n=43$) consumed an average of 79.7 $ft^3$/day while the Valve apartments ($n=31$) consumed 82.3 $ft^3$/day. The mean length of the baseline period was 54 days.

I found the means for intervention gas use between the groups was not significantly different (Two-sample t-test: $t=0.02$, $df=70.8$, $p=0.98$) during the intervention period. The Control apartments consumed an average of 114.1 $ft^3$/day while the Valve apartments consumed 113.9 $ft^3$/day. However, the Valve group did experience a 5% less change in its gas consumption compared to the Control group. The mean length of the intervention period was 33 days.

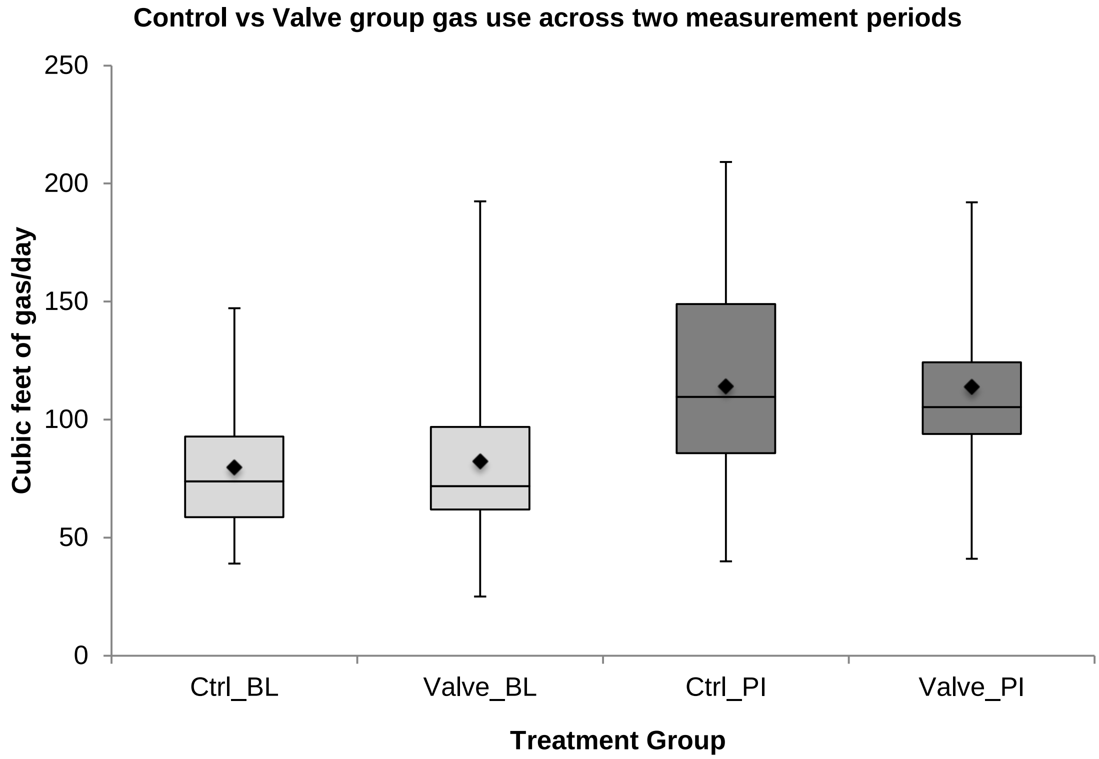


**Figure 1:** A boxplot displaying the ft$^3$/day the Control (Ctrl) and Valve (Valve) apartment groups consumed during the baseline (BL) period and the intervention (PI) period. The medians are denoted as lines in the boxes while the means are symbolized by black diamonds.

*Effect of the valve and education on gas used*

While I found that the Education (Edu) Valve group had the lowest mean ft$^3$/day for the intervention period (Table 1), the differences were not statistically significant (One-way ANOVA: $F(2,71)=0.22$, $p=0.81$; Figure 1). The Edu group consumed slightly less gas (109.5 ft$^3$/day) than the Ctrl (114.1 ft$^3$/day) and NoEdu (119.2 ft$^3$/day) groups. More importantly, the Edu group experienced only a 33% increase in gas use during the study while NoEdu group experienced a 45% increase, indicating a 12% less rate of change for the Edu group.

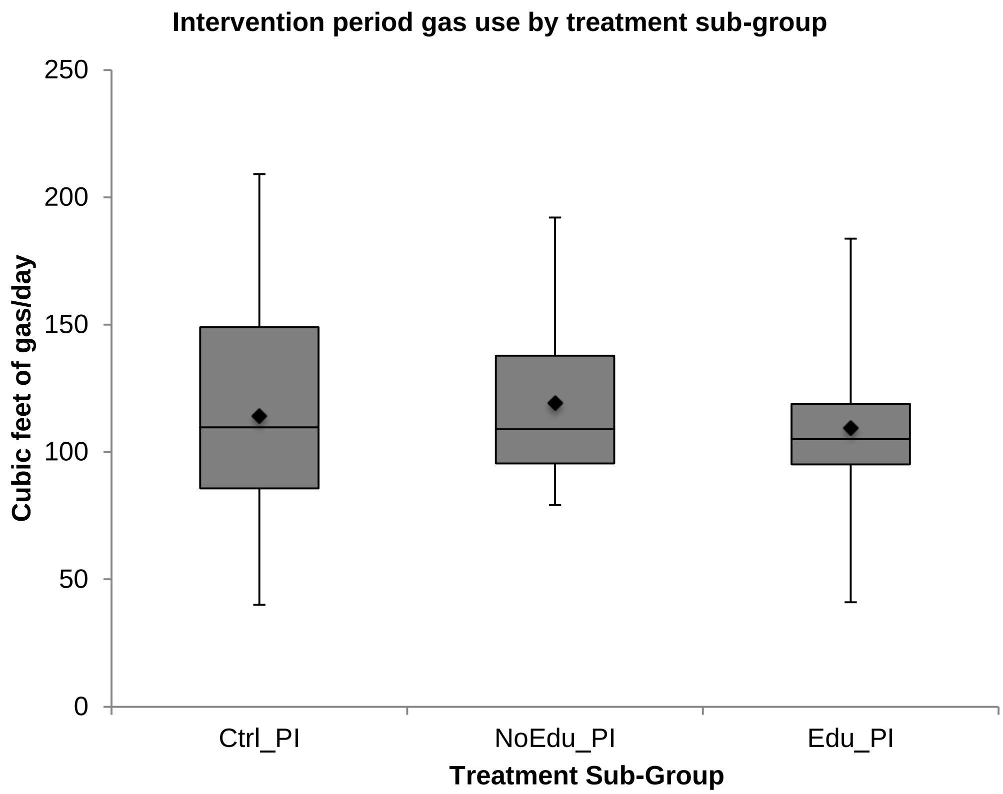


**Figure 2:** Boxplot showing the $ft^3$/day of gas consumed for each treatment group in the intervention period. While the Edu group consumed slightly less gas (109.5 $ft^3$/day) than the Ctrl (114.1 $ft^3$/day) and NoEdu (119.2 $ft^3$/day) group, there is no significant difference between them.

*Effects of other factors on gas used*

The number of occupants living in the apartments was significantly correlated with higher gas use for the intervention period (Pearson's correlation, $p=0.05$), but not with the baseline measurement period (Pearson's correlation, $p=0.19$). Apartment occupancy ranged from 2 to 5 persons.

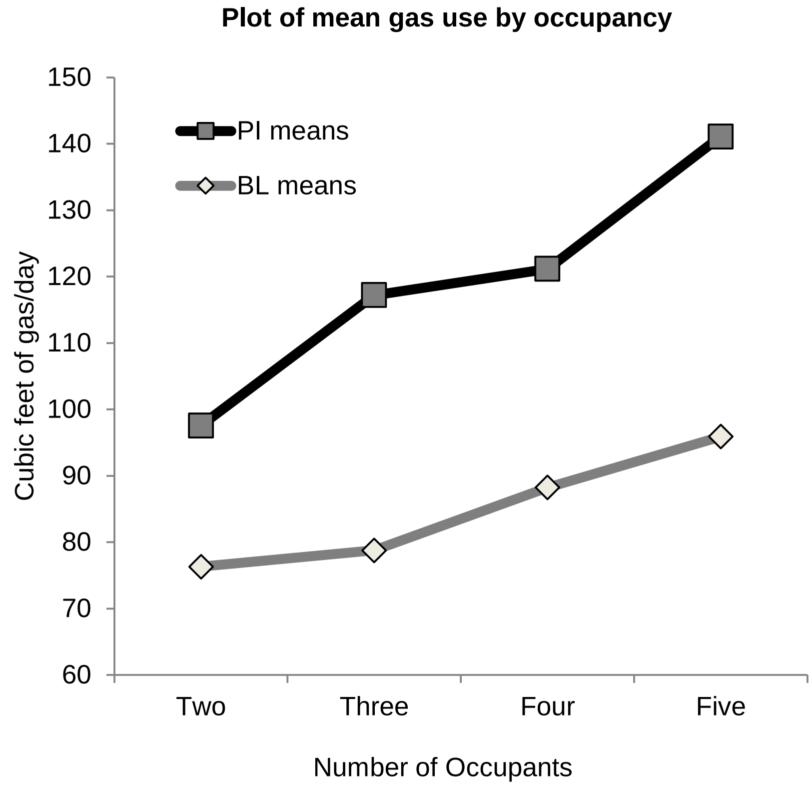


**Figure 3:** Mean gas use across different occupancy apartments shows linearly increasing consumption with increased occupants in both the baseline (BL means) and intervention (PI means) periods.

The floor type of the apartments associated with neither the baseline $ft^3$/day (Two-sample t-test: t=0.07, df=56.8, p=0.95) nor the intervention $ft^3$/day (Two-sample t-test: t=0.14, df=45.0, p=0.89).

The residents' tendency to cook meals at home correlated insignificantly with gas consumed during both the baseline (Pearson's correlation; t = 0.02, df = 46, p-value = 0.98) and intervention periods (t = -0.48, df = 46, p-value = 0.64).

Each apartments' total showertime (= showers/day x minutes/shower) correlated insignificantly with basline gas use (Pearson's correlation; t = -0.10, df = 47, p-value = 0.92) but correlated significantly with intervention period gas use (Pearson's correlation, t=1.95, df = 47, p-value = 0.057).

*Final survey analysis*

The survey I administered to the 35 apartments in the Valve group yielded 30 responses and some positive feedback. I found that 60% of the group reported they used the valve either weekly or daily, while another 30% said they rarely used the valve (Figure 4). Thus, 90% of the Valve group used the valve at least once.

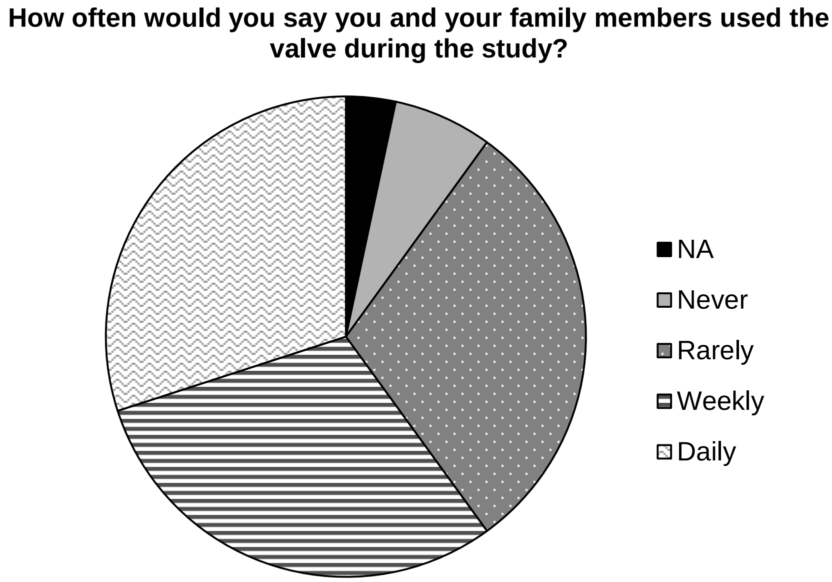


**Figure 4:** Pie chart of the Valve group's frequency of use of the valve. 90% of the surveyed sample (n=30) used the valve either Rarely, Weekly, or Daily; 60% used the valve Weekly or Daily.

However, the "Used Valve Y/N" variable that I created revealed that 15/30 respondents significantly used the valve during the intervention period while the other 15/30 did not. Table 2 shows a comparison of values between the respondents that used the valve and those that did not. Most statistics were equal between the groups, but the Y group consumed more $ft^3$/day than the N group and also cooked 28% more often than the N group.

**Table 2:** Descriptive statistics for the Valve group's users (Y) and none users (N).

| Used Valve? | Avg. Occupants | Intervention $ft^3$/day | % Δ b/w Base. & Int. $ft^3$/day | Avg. apt temp. (°F) | % Meals Home-Cooked | Showertime (showers/day x minutes/shower) | Leave water running in shower? (% Yes) |
|---|---|---|---|---|---|---|---|
| Y | 3.1 | 121.5 | +62% | 73 | 83% | 13.5 | 80% |
| N | 3.2 | 111.5 | +58% | 74 | 55% | 14.2 | 75% |

Table 3 shows the averaged answers for the final survey questions presented by treatment group in addition to the results of a two-sample t-test. Valve users indicated that the valve's noticeability in their showers and its ease of use played a significant role in influencing whether they used the valve during the intervention period (Table 2, p=0.05 and p=0.02). The Edu subgroup acknowledged that the email outreach was significantly associated with their decision to use the valve (Table 2, p=0.004). The valve's use or disuse was not associated with a decrease or increase in showertime, nor was it significantly related to the valve possibly changing the water temperature. The informational shower-hanger's noticeability and visual presentation did not significantly factor into the valve users' decisions, but the shower-hanger's information clarity and capacity to encourage valve use was slightly related to valve use (Table 2, p=0.09 and p=0.09).

**Table 3:** Summary of Final Survey answers. Numbers listed are mean values of Likert scale responses (1=Strongly disagrees, 5=Strongly agrees). The *Significance* column refers to the results of two-sample t-test performed between each survey variable and a binomial "used/didn't use valve" variable.

| Survey Question | Means (Edu) | Means (NoEdu) | Total Means | Significance (y/n/p-value) |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Used valve | 3 | 3 | 3 | Y; p<<0.001 |
| Valve noticeable | 3.7 | 4.6 | 4.2 | Y; p=0.05 |
| Valve easy to use | 3.7 | 4.6 | 4.1 | Y; p=0.02 |
| Believe valve saves W&G* | 4.3 | 4.2 | 4.2 | N |
| Valve changes flow | 4.4 | 4.1 | 4.3 | N |
| Valve changes water temp. | 2.5 | 2.1 | 2.3 | N |
| Valve incr. showertime | 3.1 | 2.5 | 2.8 | N |
| Valve decr. showertime | 2.5 | 2.2 | 2.4 | N |
| Shower-hanger noticeable | 3.9 | 3.1 | 3.5 | N |
| Shower-hanger nice visual | 3.4 | 3.4 | 3.4 | N |
| Shower-hanger understandable | 4.4 | 4.5 | 4.4 | N; p=0.09 |
| Shower-hanger encouraged valve use | 3.6 | 3.1 | 3.3 | N; p=0.09 |
| Email info interesting | 3.7 | - | 3.7 | N |
| Email info applicable | 3.8 | - | 3.8 | N |
| Email info encouraged valve use | 3.5 | - | 3.5 | Y; p=0.004 |
| Email info encouraged W&G* conservation | 3.3 | - | 3.3 | N |

*W&G = Water and Gas

## DISCUSSION

Although my statistical results suggest that the distribution of low-flow valves did not significantly affect University Village residents' gas use, even when accounting for other independent factors such as occupancy and residence floor type, my data and calculations hint that the valve may have played some role in leading to 5% less gas consumption amongst its users in the Valve group. Additionally, education appears to have played a part in reducing overall gas use and increasing the adoption of the valve within the Valve group's education-receiving sub-group. This result implies that in cases where valve effectiveness depends on human involvement, the valve distribution must be combined with education. While the literature indicates that education alone is not sufficient to prompt behavior change in most cases, this study suggests that the pairing of education with a retrofit to achieve conservation can have an important impact on resource use.

*Effects of the valve on gas used*

Because I found that the difference in means of cubic feet of gas used per day between the Control and Valve groups was not significant, any effect the valve may have had on overall gas use was minimal. However, the $ft^3$/day (= cubic feet of natural gas consumed per day) metric I used accounted for *all* gas use within the residence. Thus, it is possible that while the valve decreased gas use for showering, its savings were eclipsed by residents' increased or continued use of other gas-intensive appliances and activities.

Between the baseline and intervention periods of the study, the overall increase in gas consumption in both groups reflects the seasonal change from fall to winter during the study, where average gas use jumped from 80 $ft^3$/day to 114 $ft^3$/day, or a monthly use increase from 2500 $ft^3$ to 3400 $ft^3$. This notable 900 $ft^3$ surge between the baseline and intervention periods could mainly be attributed to residents increasing the use of space heaters, which makes sense when noting that heating can account for 17-61% of a residence's gas consumption (Table A1). Additionally, the months of November and December also contained the family holidays of Thanksgiving and Christmas, so temporary increased occupancy in each residence could have also factored into increased gas use for the intervention period, as greater occupancy equals more hot water use for showers and possibly increased frequency of home cooking with the stovetops and oven. It is also likely that occupants stayed home more frequently during the winter months when campus was closed. Finally, the addition of potential visitors suggests the possibility of increased resource consumption without conservation, as the study subjects may not have informed guests to use the valve. However, my survey evidence and calculations imply a greater reason for the lack of a notable effect: a lack of using the low-flow valve.

Only half of the Valve families that responded to my final survey (15/30) indicated they used the valve substantially, suggesting that the valve will not yield considerable decreases in resource consumption without extensive use. This result agrees with other studies that have found the effects of similar "non-price" water conservation methods to not "strongly influence" water use frequencies of residents (Dupont and Renzetti 2013). Increased occupancy also seems to only be minimally influential, as only 9/30 responding families said they hosted visitors for Thanksgiving during the intervention period. Additionally, valve users may have offset their savings due to the valve because of their tendency to cook more meals at home, as they cooked 28% more of their meals at home compared to the valve non-users (Table 2). This suggestion is not unreasonable to consider because my estimates show that stove and oven use can contribute ~15% to a residence's total gas use (Table A1).

The gas consumption increase within the Valve group was 5% less than the increase within the Control group (Table 1), which suggests that the use of the valve could have played a role in reduced gas consumption. Previous studies support this range of impact, such as an expected 5-10% range for water and energy savings from low-flow showerheads in one study (De Almeida et al. 2004) and 9-12% in savings in other studies (Inman and Jeffrey 2006, Renwick and Green 2000). These results also fall within my own estimates, in which I calculated an expected range of 4-13% gas savings for households that use the valve (Table 4). The observed 5% gas savings match those of my calculated savings, so the valve could have a pronounced impact on gas and water consumption within University Village at a larger scale.

**Table 4:** Calculated resource savings due to the low-flow valve. "Min. Savings" refer to using the valve in its 30% flow-reduction state for 4/10 minutes of a 10-minute shower, while "Max. Savings" refer to using the valve in its 90% flow-reduction state. By averaging gas consumption rates for the baseline (80 $ft^3$/day) and intervention (114 $ft^3$/day) periods together, I got an average daily consumption rate of 100 $ft^3$/day for the year. Over a year, a family using the valve will save 4-13 $ft^3$/day, which translates to 4-13% energy savings. All calculations are based on the following variables: 3.5 10-minute showers/family/day, 25 gallons of water/shower, 10 $ft^3$ gas/shower, 0.1171 lbs. $CO_2/ft^3$ gas*, \$0.004/gallon water**, and \$0.005/$ft^3$ gas**.

*From http://www.eia.gov/environment/emissions/co2_vol_mass.cfm
**Rates based on total utility bills for University Village

| **Min. Savings** |
|---|

| | # of Families Using Valve | Gallons $H_2O$/Year Saved | $ft^3$ Gas/Day Saved | $ft^3$ Gas/Year Saved | lbs. $CO_2$/Year Avoided | $ $H_2O$/Year Saved | $ $ft^3$ Gas/Year Saved | Total $/Year Saved |
|---|---|---|---|---|---|---|---|---|
| | 1 | 3833 | 4 | 1562 | 183 | 15.33 | 7.81 | 23.14 |
| | 10 | 38325 | 43 | 15621 | 1829 | 153.30 | 78.11 | 231.41 |
| | 35 | 134138 | 150 | 54674 | 6402 | 536.55 | 273.37 | 809.92 |
| | 100 | 383250 | 428 | 156213 | 18293 | 1533.00 | 781.06 | 2314.06 |
| | 974 | 3732855 | 4169 | 1521512 | 178169 | 14931.42 | 7607.56 | 22538.98 |
| | 1000 | 3832500 | 4280 | 1562127 | 182925 | 15330.00 | 7810.64 | 23140.64 |
| **Max. Savings** | | | | | | | | |
| | 1 | 11498 | 13 | 4686 | 549 | 45.99 | 23.43 | 69.42 |
| | 10 | 114975 | 128 | 46864 | 5488 | 459.90 | 234.32 | 694.22 |
| | 35 | 402413 | 449 | 164023 | 19207 | 1609.65 | 820.12 | 2429.77 |
| | 100 | 1149750 | 1284 | 468638 | 54878 | 4599.00 | 2343.19 | 6942.19 |
| | 974 | 11198565 | 12506 | 4564535 | 534507 | 44794.26 | 22822.68 | 67616.94 |
| | 1000 | 11497500 | 12839 | 4686381 | 548775 | 45990.00 | 23431.91 | 69421.91 |

*Effects of education on valve use*

While I saw no significant differences in $ft^3$/day between the treatment groups (i.e., Edu and NoEdu) within the Valve group, my final survey data imply that the education program contributed to greater gas conservation and valve use. The Edu (education) group not only had a lower mean $ft^3$/day than the NoEdu (no education) group (109.5 $ft^3$/day vs. 119.2 $ft^3$/day, Table 1), but its increase in gas consumption was 12% below that of the NoEdu group. This 12% difference between the Edu and NoEdu groups falls within the calculated range of savings due to the valve mentioned in Table 4.

Because valve use was significantly associated with the email education's capacity to encourage conservation (Table 2), this factor further reinforces the importance of supplying education in addition to other demand-side management strategies such as the low-flow valve. Past research on environmental education has been variable, with some studies finding that education campaigns reduced utility demand by 5-8% (Inman and Jeffrey 2006) while others concluded that education alone yields negligible resource savings (Keramitsoglou and Tsagarakis 2011, Black et al. 1985, Renwick and Green 2000). My study supports the conclusions from Inman and Jeffrey (2006) while also offering a promising combined-approach method for improving the long-term effectiveness of the education solutions proposed in the Black et al. and Keramitsoglou and Tsagarakis studies.

*Effects of other factors on gas used*

I found evidence that relates greater gas use with greater occupancy, despite my mixed statistical results for the baseline ($p=0.19$) and intervention ($p=0.05$) periods. The mean $ft^3$/day linearly increased with occupancy in both the baseline and intervention periods (Figure 3), an expected association because additional per capita resource use will contribute to a home's overall resource use. Previous research has positively associated greater occupancy with greater shower water use (Makki et al. 2013) and used occupancy as a forecasting parameter for resource use (Willis et al. 2010, Mayer and DeOreo 1999). While my results do not directly support Makki et al.'s conclusion, they do lend indirect support to the well-studied intrinsic connection between shower water and energy use, both of which are dependent on number of occupants (Cheng 2002, Elias-Maxil et al. 2014, Willis et al. 2013, Williams et al. 2013).

The floor type of the residences associated with neither the baseline $ft^3$/day nor the intervention $ft^3$/day, suggesting that the minor differences in residence square footage were not enough to contribute to noticeable increases or decreases in gas use. This conclusion is reasonable because all residences in the study had two bedrooms and one bathroom and a range of occupants distributed within each floor type, so resource use was probably tied more strongly to other factors.

Similarly, the percentage of meals cooked at home correlated with neither baseline nor intervention gas use, indicating its muted effect across a host of other variables. This result could be explained by cooking rates that were variably spread among all residences and treatment groups. Additionally, cooking appliances only consume around 15% of a residence's total gas intake, so this factor alone may not have substantially affected statistical differences in gas use.

*Perceptions of the valve related to valve use*

The final survey responses' relationship to actual valve use suggested that while there was nothing inherently wrong with the low-flow valve, there were still barriers to its extensive use that my methodology did not successfully address. The users' perceptions of the valve's convenience and comfort appeared to have an effect on encouraging some use of the valve, as seen from the significant associations between valve use and the valve's "ease of use" and "noticeability" (Table 3). Had the informational shower-hanger been used to its full potential, it should have been positively associated with valve use. Because the shower-hanger's "noticeability" was not associated with valve use, it is likely that the users did not place the shower-hanger in their showers with the valve like they were told to. This result could also explain the shower-hanger's weak capacity to "encourage valve use" (Table 3).

The valve's low adoption rate (15/30 users, according to the final survey) could also be attributed to convenience and comfort factors. Some valve users complained that the water pressure in their shower was already too low, so they were not keen to use the valve to reduce it further. Others stated they were "too short" to even reach the valve while showering. A few residents used the valve alone while other family members did not at all.

Thus, some of the blame for the valve's underuse can be linked to inadequate communication and education throughout the study. Had the valve's properties and function been more clearly defined during the recruitment phase or installation period, a greater amount of residents may have been compelled to use the valve. The email education may have also been overlooked for several reasons: the emails may not have been shared between spouses, or they may not have been read or noticed at all.

**Limitations and future directions**

My greatest limitation for this study was the metric I used to estimate savings due to the valve. Because of restrictions on how University Village collects its total utility data, the only option I had available to me to feasibly measure any per residence gas or water consumption was the gas sub-meters of residences in the East Village. The dials that measure flow on these meters are only readable to the nearest 100 cubic feet consumed, and gathering readings from them is arguably more subjective than objective. Thus, there was a high chance for error due to meter reading inconsistencies, which I attempted to minimize by doing the vast majority of the readings with my own eyes and/or by taking pictures. Regardless, several data points had to be dropped from the study due to meter reading errors.

Because of miscommunications in the recruitment and baseline measurement phases, 15/50 families randomly selected to receive a valve rejected the valve's installation in their home. Consequently, my sample sizes among the Control and Valve groups were unequal and my statistical power was reduced due to a sample size smaller than what I initially recruited. Additionally, the valve users that complained about their low shower water pressure or their inability to reach the valve illustrate two unforeseen circumstances that are worth noting for any future projects hoping to achieve resource conservation through shower retrofits.

In a similar vein, 69% of the 81 participating families responded to the preliminary survey and 85% of the 35 valve users responded to the final survey. While these response rates are relatively high, I was still left with missing data points that could have given me a more complete picture for my statistical analysis.

I offer several suggestions for future studies to circumvent these shortcomings. First, I would emphasize maximizing communication during the recruitment and valve-installation periods so families understand exactly what the valve will do and what to expect from its use. If relying on subjective sub-meter measurements to gather data, one should take pictures and carefully record each meter for each reading so as to minimize measurement errors. If possible, install electronic data loggers for ultimate accuracy when tracking gas usage over long periods of time. In order to minimize variation between the study groups, I would recommend restricting the study to one seasonal period or collect data for a longer time period, such as an entire year. For example, reducing the study to only the summer months would minimize large variations in gas usage due to central home heating use, thus allowing for easier extrapolation of the effects on gas due to the valve. To increase statistical power and overcome participant attrition, recruiting a much larger sample population would greatly benefit the study results. Finally, I propose developing a more robust education program for all recipients of the valve retrofit. While email outreach proved relatively effective in encouraging valve use, studies have shown that greater personalization and face-to-face contact will help cultivate social norms (Carlson 2001). Grouping the targeted Valve population in a meaningful way so that valve users may interact and encourage each other to use the valve will help strengthen their impetus to use the retrofit, appeal to their personal obligation to do so, and inspire "social conformity" for environmental action (Fielding et al. 2008, Harland et al. 1999, Carlson 2001, Gilg and Barr 2006).

**Broader implications and conclusion**

While the low-flow valve has the potential to be a vital water-saving tool, especially in the face of ongoing drought, it is less likely to be effectively used without proper education and guidance. Implementing personable and group-oriented education programs along with the valve retrofit may prove to have the greatest success in reducing overall gas and water consumption within a residential residence setting. However, it is still important to recognize the limitations and characteristics of a study population, such as their tolerance to discomfort or inconvenience. Even if University Village residents are interested in saving water and gas while showering, they might not see the valve as an ideal method doing so if other external factors overcome their environmental beliefs (e.g. “the water pressure is already too low,” “not tall enough to reach valve”). One could also argue that a demand side management (DSM) method that requires consumer habituation is an inferior alternative to retrofits that offer immediate savings, such as a low-flow showerhead or sink aerators. While studies have indeed proven the efficacy of these DSM strategies (Inman and Jeffrey 2006, Renwick and Green 2000, Makki et al. 2013, Mayer and DeOreo 1999, Mayer et al. 2004), retrofits like the low-flow valve used in this study offer another step to achieving more resource savings once the low-hanging fruit of other technical DSMs have already been removed. Still, the human element of this type of DSM cannot be overlooked, so implementing proper programs to develop behavior change and strengthen social norms with the retrofit will help maximize potential resource conservation.

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## APPENDIX A1: University Village Residence Gas Use Estimates

**Table A1:** Calculated consumption rates and contributions to a University Village residence obtained by tracking the turns of the gas sub-meter dials per units of time. The Oven and Thermostat appliances are listed in ranges because of variable temperature and programming settings a resident may make. The assumptions I made to present these estimates: *Pilot light*: is on 24 hours per day everyday; *Oven*: the resident cooks a meal in the oven 3.5 days per week at 350 °F for 20-40 minutes (includes preheating time); *Stovetop*: the resident cooks on the medium-high setting for 90 minutes per day for 5/7 days per week; *Thermostat*: the resident uses a pre-programmed setting, a 70 °F constant temperature setting, or a setting that balances between 60 and 70 °F; *Shower*: 3 showers per day taken for 10 minutes each; *% Monthly Use*: the monthly use ($ft^3$) per appliance as a percent of average monthly total gas use 2500 $ft^3$.

| Gas Appliance | Consumption Rate ($ft^3$/min) | Monthly Use ($ft^3$) | % Monthly Use |
|---|---|---|---|
| Pilot light | 0.01 | 512 | 20 |
| Oven | 0.16−0.21 | 56−81 | 2−3 |
| Stovetop | 0.15 | 294 | 12 |
| Thermostat | 0.01−0.03 | 435−1523 | 17−61 |
| Shower | 1.02 | 931 | 37 |
| **Total** | − | 2228−3341 | 88−133 |

## APPENDIX A2: Shower-hangers for NoEdu and Edu Sub-groups

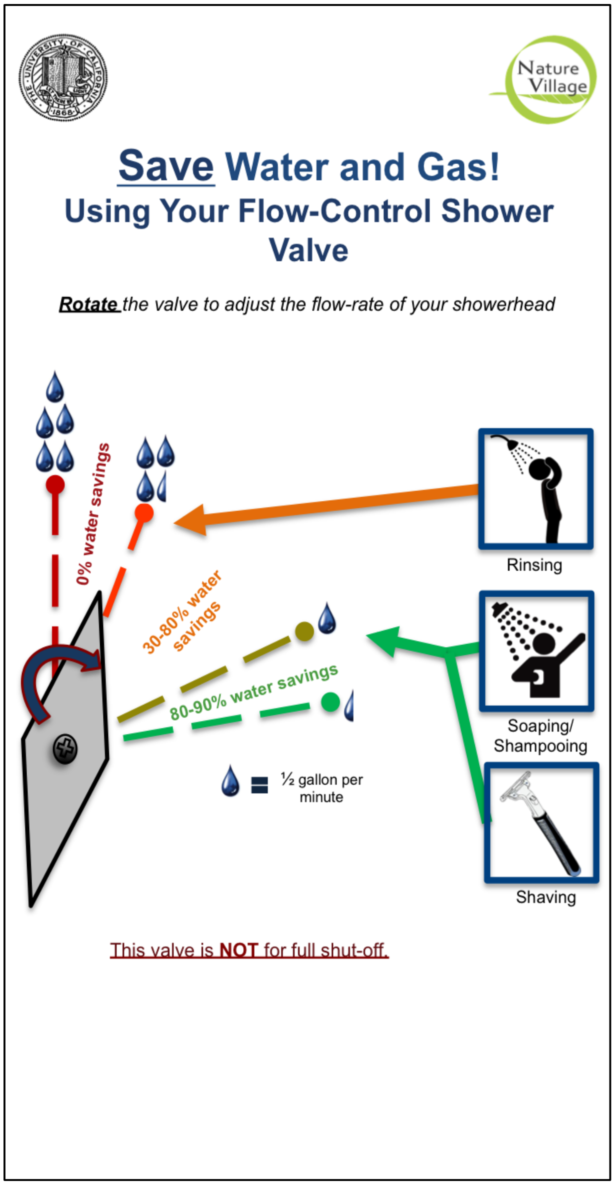


**Figure 1:** The shower-hanger for the NoEdu Valve sub-group. Includes information on how to use the low-valve only.

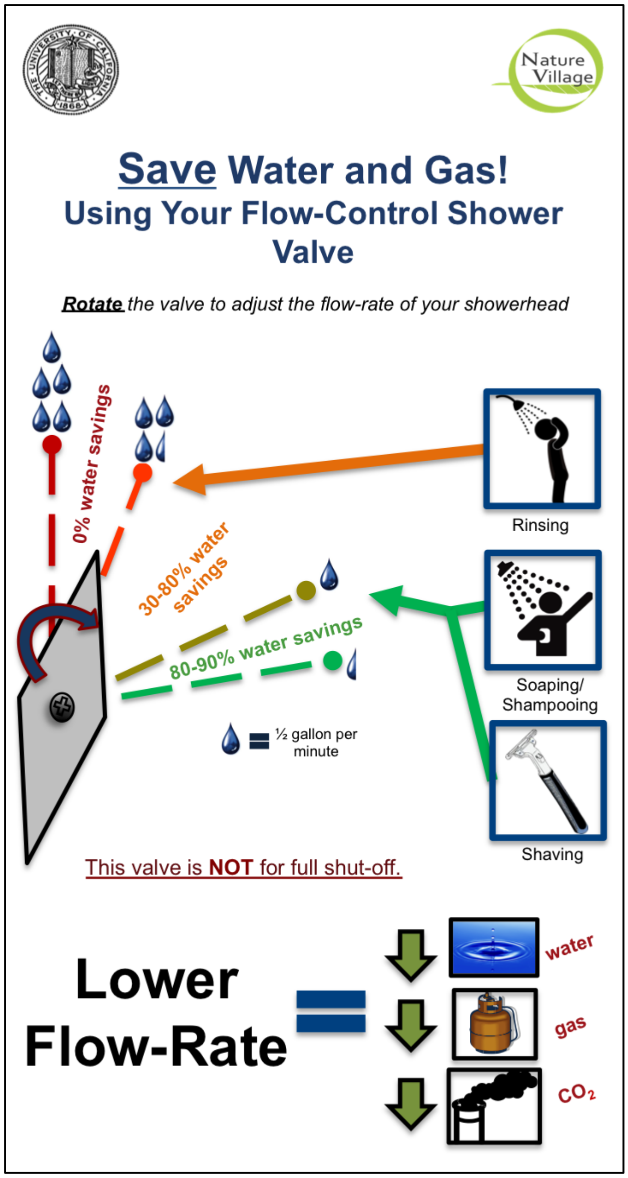


**Figure 2:** The shower-hanger for the Edu Valve sub-group. Includes information on *how* to use in addition to visual connections to the environmental benefits of using the low-flow valve: water and natural gas conservation and reduced carbon dioxide emissions.

## APPENDIX A3: Email Education 1 for the Edu Sub-group (sent 20 Nov, 2013)

Good Evening!

I am emailing you because you are a recipient of a flow control shower valve, which is currently installed behind your showerhead. You should also have a laminated hanger with information on how I recommend you use the valve. If you have not done so already, please hang it behind your showerhead so it is visible to whomever is using the shower! In this way, you can help encourage its maximum usage in your apartment. (As a reminder, I've attached pictures of both the valve and the hanger in this email!)

Why should you use this valve, you may wonder? Well, here are some basic reasons, reasons which I encourage you to **share with all members** of your household:

1. It is easy to use and modify to your tastes
2. You can save water without compromising the warmth of your shower water
3. You can save water without having to completely turn off your shower head
4. You are not only saving water, but also natural gas.

To emphasize that last point: every time you heat the water in your shower, you are using the natural gas in your water heater to do so.
**In fact, a 10 minute shower at full water flow requires ~50 cubic feet of natural gas and 25 gallons of water, and releases 6 pounds of CO2** (assuming you have a 2.5 gallon/minute showerhead). To rephrase, 50 cubic feet is the equivalent of 375 gallons! Imagine 375 milk gallons full of gas being burned to power your shower. Like coal and oil, natural gas is a fossil fuel that emits carbon dioxide (CO2), and as you probably know, CO2 is a greenhouse gas that traps heat and reinforces global climate change. It is possible to reduce your impact on this global phenomenon by minimizing your gas use in your shower, and the flow control valve can help!

Dont forget that freshwater is a limited resource that takes energy to bring to you as well! According to the EPA, **a family of four uses 400 gallons of water per day**. While I honestly think this is an overestimate for UVillage residents, saving water is still important! Even though we've become very efficient in cleaning and reusing the water we have, it's important to remember that the human population continues to grow, meaning we will have more people wanting the same amount of available water.

All in all, I hope the take away message is this: **using the flow control valve not only conserves freshwater, but also reduces natural gas emissions!**

Every minute counts!

Thank you for reading, and I'd like to remind you that I am available to answer questions or concerns at all times through email.
Have a great week! :)

Regards,

Kareem Hammoud

## APPENDIX A4: Email Education 2 for the Edu Sub-group (sent: 1 Dec, 2013)

Hello again!

I hope you enjoyed a lovely Thanksgiving with your families and loved ones. I hope you are also continuing to use your **flow control shower valve** to its full potential in your day to day life! I do not only refer to the life of the you, the reader of this email: I also hope you pass this knowledge down to your companion, spouse, and/or children. Although we may not feel the effects in the present, the way we use resources today will ultimately impact the lives of our children and our children's children. It is our responsibility to do our best in using only what we need and not more than that. The flow control valve installed in your shower can help you do just that, saving not only **water** but also **natural gas**!

Your actions to conserve can go beyond the way you take showers. Adopting an attitude of general water and gas conservation may seem difficult, but it is merely an exercise of habit formation and practice once you have the right knowledge. I intend to supply you with some of this knowledge today, and I leave the rest to you!

First of all: **Do you know which actions or appliances in your apartment use most gas?** I've done the measurements myself, so I'll give you a small list of my findings in terms of *% of one apartment's monthly gas usage*:

1. 20 - 60%: Gas required to use your thermostat (home heater), depending on the settings you choose.
2. 25%: Gas required for a household that takes 4 showers per day at an average of 8 minutes/shower.
3. 12%: Gas required to use your kitchen stove for 90 minutes/day for 5/7 days per week.

Whether these stats directly apply to your home situation or not, I implore you to consider minimizing excessive use of any of your gas-operated appliances. Bundle up in warmer clothes before increasing the heat on your thermostat; take shorter showers and use your flow control valve to reduce water flow when it is not needed (like when you are soaping your hair and body); turn off the sink in between tasks when you are brushing your teeth, shaving, or washing the dishes. There are additional conservation tips like these in the following links, which I encourage you to explore in your free time.
http://www.epa.gov/WaterSense/our_water/why_water_efficiency.html
http://www.epa.gov/epahome/home.htm#water

As always, if you have any problems or questions, please email me and I will do my best to help. Remember: every minute in the shower counts!

Thank you for your attention!

Sincerely,

Kareem Hammoud

**APPENDIX A5: Preliminary Survey Given to Residents During Recruitment**

# Preliminary Survey *Water and Gas Conservation Study*

Date: ________________________ Interviewer:______________________
Building-Apartment #:____________ Email:___________________________
Phone #:________________________

## Background

1) **How long have you lived in University Village?**_____months OR _____years
2) **Within the next 3 months, are you planning to leave your apartment unoccupied for more than 4 days? (vacation, subletting, going to do research somewhere, etc.)**
   a) Yes. How many days?___________
   b) No
3) **How many people live in your apartment?**____________

## Heater

**Heater Type**_______________

4) **Do you set your central home heater manually, or do you use a timed program?**
   a) Timed (go to Q5) b) Manually (go to Q6)

### Timed

5) **Before you moved in, UC Village maintenance programmed the heater's timer to a default schedule. Have you ever adapted this program yourself?**
   a) No
   b) Yes
   **What temperature and/or schedule changes did you make to this program?**_______________________________________________

**OR**

### Manually

6) **What average temperature do you heat your home to?**______________
7) **Which months of the year do you regularly use the heater?**
   From _________________ until ___________________
8) **Which hours of the day/night do you use the heater?**
   **Day:** From _________________ until ___________________
   **Night**: From _________________ until ___________________

## Stove/Oven *If either the stove or oven is not used, write '0'*

9) **On average, how many hours is the stove used each day?**_______________
10) **On average, how many stove burners are used when cooking?**__________
11) **On average, how many hours is the oven used each week?**_____________

12) **What percentage of your meals are cooked at home each week?___________**

## Bath/Shower/Sink

13) **On average, how many total showers does your family take each day?______**
14) **On average, how long is each shower?____________**minutes
15) **If there are major differences in shower times between members of the family, please explain briefly:**

    ____________________________________________________________

    ____________________________________________________________

    ____________________________________________________________

16) **How many baths does your family take in a day *or* week?_____**per**_________**
17) **On average, how many minutes per day *or* week does your family wash the dishes?______** per________
18) **Do you boil or heat your water with your sink, on the stove, or in an electric kettle (**circle one**)? On average, how many times per day do you boil water?__**

*The following questions apply to activities done by all members of your family. If you cannot easily say "Yes" or "No," please answer "Other" and explain.*

19) **While showering, is the water running the whole time you are in the shower (even when you're soaping or lathering)?**
    a) Yes
    b) No
    c) Other__________________________
20) **While washing dishes, is hot or warm water used? If yes, is the water running the whole time?**
    a) Yes
    b) No
    c) Other__________________________
21) **While brushing teeth, is hot or warm water used? If yes, is the water running the whole time?**
    a) Yes
    b) No
    c) Other__________________________
22) **While shaving, is the water running the whole time?**
    a) Yes
    b) No
    c) Other__________________________

Final Notes/Extra Comments:

*(verbal Q) If you are not a native English speaker, was it hard for you to fill out this survey?*

*(verbal Q) Do you have any recommendations to improve this survey?*

**APPENDIX A6: Final Survey Given to Valve Group After Third Meter Reading**

# Final Survey *Water and Gas Conservation Study*

| Building-Apartment #:____________ Email:___________________________ |
|---|

*The following questions will ask you about your experience with various portions of the project during the duration of the study. While we appreciate you answering all questions, feel free to decline answering any questions that make you uncomfortable. Thank you!*

## Thanksgiving: Questions about gas consumption

1. Did you use your oven to cook dinner for the Thanksgiving Holiday?
   a. Yes. For approximately how many hours? ______________
   b. No
2. Did your household accommodate any additional guests during the Thanksgiving Holiday?
   a. Yes. How many persons? ___________ For how many days? ______________
   b. No

*Some of the following questions will ask you to rank your opinion on a scale of 1-5. Please circle the number closest your relative opinion. Choose "3" if you have a "neutral" opinion.*

## Valve Use: Questions about your experience to inform us about the valve's cost-benefits

3. **I, the survey respondent**, used the valve when showering
   Strongly Disagree 1 2 3 4 5 Strongly Agree

4. **My family** used the valve when showering
   Strongly Disagree 1 2 3 4 5 Strongly Agree

5. How often would you say you and your family members used the valve during the study?
   Daily Weekly Rarely Never

6. The valve was a noticeable and easy-to-find fixture in my shower
   Strongly Disagree 1 2 3 4 5 Strongly Agree

7. The valve was easy to use
   Strongly Disagree 1 2 3 4 5 Strongly Agree

8. I believe the valve is a good way to save water and gas
   Strongly Disagree 1 2 3 4 5 Strongly Agree

9. The valve made a noticeable change on the flow of water from my showerhead
   Strongly Disagree 1 2 3 4 5 Strongly Agree

10. The valve made a noticeable change on the temperature of water from my showerhead
    Strongly Disagree 1 2 3 4 5 Strongly Agree

11. Using the valve increased the time I spent in the shower
    Strongly Disagree 1 2 3 4 5 Strongly Agree

12. Using the valve decreased the time I spent in the shower
    Strongly Disagree 1 2 3 4 5 Strongly Agree

## <u>Informational Shower Hanger: Questions to help us evaluate our design skills</u>

13. The shower hanger was a noticeable feature in my shower
    Strongly Disagree 1 2 3 4 5 Strongly Agree

14. The shower hanger was visually appealing
    Strongly Disagree 1 2 3 4 5 Strongly Agree

15. The shower hanger was easy to understand
    Strongly Disagree 1 2 3 4 5 Strongly Agree

16. The shower hanger encouraged my family to use the shower valve
    Strongly Disagree 1 2 3 4 5 Strongly Agree

## <u>Education & Outreach: Questions to evaluate the effectiveness of outreach on conservation</u>*

17. The information provided through emails was educational and interesting
    Strongly Disagree 1 2 3 4 5 Strongly Agree

18. The information provided through emails was applicable to my life
    Strongly Disagree 1 2 3 4 5 Strongly Agree

19. The information provided through emails had a noticeable influence on encouraging **MY** use of the shower valve
    Strongly Disagree 1 2 3 4 5 Strongly Agree

20. The information provided through emails had a noticeable influence on encouraging **MY FAMILY** to use the shower valve
    Strongly Disagree 1 2 3 4 5 Strongly Agree

21. The information provided through emails had a noticeable influence on encouraging overall conservation of gas and water in my apartment beyond using the valve
    Strongly Disagree 1 2 3 4 5 Strongly Agree

22. Would you like stay in touch with us in the future (beyond December 2013)?
    a. Yes. I plan to be moving out________________________________
    b. No

<u>Final Notes/Extra Comments for the research team:</u>

***Note**: Only the 18 Edu families received a survey with questions 17 – 22