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Impact of a Motivational Intervention and Interactive Feedback on Electricity and Water Consumption: A Smart Housing Field Experiment

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Abstract

Many interventions designed to curb energy use are ineffective because they fail to inspire individuals to engage in proenvironmental behavior and interact meaningfully with energy information. This field experiment targeted individuals' personal motivations and goals in combination with sensor-recorded energy feedback to decrease electricity and water consumption. Residents from 77 "smart" apartments were randomly assigned to attend a multifaceted motivational program and set action-oriented energy goals. Participants were also randomly assigned to receive interactive energy feedback. Continuous electricity and water data were then collected for 3 months. Those who received the motivational intervention used significantly less hot water than those who did not receive the intervention. Moreover, those exposed to action-focused feedback used significantly less electricity than those who did not receive the feedback—an effect that was

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more pronounced in the motivation condition. Results support the use of interventions directed at personal proenvironmental motivations and action-focused group goals.

Keywords

motivation, feedback, energy use, intervention, proenvironmental behavior

Despite incentive programs, regulations, and advocacy designed to increase energy efficiency, North Americans have the highest energy intensity worldwide (Geller, Harrington, Rosenfeld, Tanishima, & Unander, 2006; International Energy Agency, 2017). Similarly, although technological advancements aspire to curtail energy consumption, their effectiveness tends to recede over time as the user desensitizes to the technology and the technology adapts to the user (Bertoldi, Ricci, & de Almeida, 2001; McCalley, 2006). The unreliability of both policy and technology in the effort to conserve energy may be due to a lack of consideration of the individual-level factors motivating and supporting users (Dahl, 2012; Kollmuss & Agyeman, 2002; Pelletier & Sharp, 2008). Indeed, it is important to empower individuals not just to conserve resources but also to interact meaningfully with technological or information systems. We suggest here that both personal motivation to conserve energy and precise, informative energy feedback technology are crucial for improving sustainable behavior.

Rather than imposing top-down constraints to pressure or lure people to conserve resources, we target individuals' personal, self-determined motivations to conserve. In doing so, we offer the first test of an intervention that aims to energize personal autonomy by directly assisting people in identifying their own individual reasons for engaging in proenvironmental behavior (PEB), and we assess its impact on directly measured electricity and water use over a 3-month period. In addition, we use sensing and monitoring technology to provide continuous and goal-specific energy feedback in a way that informs and supports individuals' energy behavior.

Individuals' Motivation for PEB

Although sustainability is a focal goal of society, harnessing individuals' PEB is not easy because the motivational dilemma underlying pro-ecological action is complex, spanning public, personal, and social domains (Kollmuss & Agyeman, 2002; Larson, Stedman, Cooper, & Decker, 2015). Unlike typical human motivational problems (e.g., health choices, dieting, exercising regularly), engaging in sustainable behavior is not inherently rewarding or egoistic. Instead, it involves trade-offs among personal comfort, economic concerns, and social/global welfare that may not have immediate or personal benefits (Pelletier, Baxter, & Huta, 2011). For example, an individual may face a decision between the higher cost of an energy efficient light bulb and the affordability of an inefficient one. Whereas personal gains are tangible in most behavioral domains, they are fundamentally distal in PEB (Darner, 2009). Thus, the vast majority of social and organizational sustainability initiatives tend to rely on external contingencies to gain compliance with standards or objectives rather than to motivate and inspire people to change their behavior. Most programs use incentives, punishments, financial savings, rewards, control or pressure, rules, social norms, and competitions—all of which rely on external constraints, control, or pressure to influence behavior without changing personal motivation (e.g., Lavergne, Sharp, Pelletier, & Holtby, 2010). As a result, most interventions may successfully stimulate feelings of burden to reduce energy and resource consumption, which may initiate some PEB in the short-term, but sustained behavioral regulation, autonomy, and persistence remain elusive (Bamberg & Möser, 2007). Furthermore, when the external contingency is removed, the behavior often reverts to baseline because the fundamental motivation is externally imposed rather than internally driven and regulated (except see Allcott & Rogers, 2014). In fact, continuous and predictable delivery of external consequences (such as financial rewards, or punishers such as emissions taxes) decreases the likelihood that internalized motivation will ever develop because individuals are never presented with the option to endorse the PEB on their own terms (Ryan & Deci, 2000; Pelletier et al., 2011).

In response to the idea that external consequences generally do a poor job at motivating PEB (e.g., McCalley, 2006; Pelletier et al., 2011), the aim of this research is to *directly assist people in identifying with the importance and value of PEBs* through a motivational program. Given that many non-single family dwellings—such as apartment complexes, retirement centers, community housing, and residences on college campuses—do not directly incur personal utility expenses and so have no external economic pressure to conserve (Bird & Hernández, 2012), it becomes particularly important to help these individuals adopt *personal motivation* for PEB.

Helping People Adopt Personally Important Energy Goals

Our first objective was to encourage the adoption of personally important energy motives and goals to promote energy conservation. Evidence suggests that when people experience a sense of autonomy and personal motivation while engaging in PEB, they are more likely to sustain it (Cooke, Fielding, & Louis, 2016; Osbaldiston & Sheldon, 2003). According to self-determination theory (SDT; Deci & Ryan, 2008), personal (or *self-determined*) motivation is guided principally by personal interests and self-endorsed values, and feels free and noncoercive. In contrast, individuals with a *controlled* (or *non-self-determined*) motivational orientation look to external prompts and controls to determine their behavior and thus experience behavior as restrictive or coercive. Therefore, even if PEBs are not always inherently enjoyable or interesting, they can still be self-determined if they originate from personal needs, goals, or values, and they are believed to be useful and important.

Recent work suggests that self-determined environmental motivation predicts PEB more strongly than other more established predictors such as intentions, subjective norms, perceived control, and even past behavior (Webb, Soutar, Mazzarol, & Saldaris, 2013). In addition to predicting a higher frequency of PEBs, self-determined motivation has also been shown to be necessary when environmental behaviors are difficult to perform and require a great deal of effort (Cooke et al., 2016; Green-Demers, Pelletier, & Menard, 1997). Given the importance of personal motivation, it becomes imperative to determine the usefulness of interventions designed to target PEB.

In this research, we relied on the theoretical framework of SDT to design an intervention that directly encourages individuals to reflect on the personal importance of proenvironmental motivations. According to SDT, environments and contexts support individuals' self-determined (i.e., personal) motivation when they offer informative rationales to identify with the goal or behavior in question (Reeve, 2015). Research has shown, for example, that nonmonetary health-based messages—which are internal rather than external in nature—can motivate energy conservation in multifamily residential households (Asensio & Delmas, 2015, 2016). Our intervention provided informative rationales for resource conservation (e.g., health concerns, climate change, energy security, resource depletion) and then asked participants to identify their own reasons for saving water and electricity. Moreover, because motivation research suggests that personal motivations should be made concrete with active, approach-oriented goals or plans (Koestner, Otis, Powers, Pelletier, & Gagnon, 2008; Pelletier & Sharp, 2008), we also asked participants to set specific action-focused energy goals (e.g., shortening daily shower from 10 min to 5 min) based on their personal motivations.

Our intent was to help students identify their own personal environmental motivation and reasoning in a noncontrolling way. When individuals perceive expectations regarding PEB to support their personal motivation, they are more likely to report higher frequency of PEBs (Lavergne et al., 2010). More recently, Sweeney, Webb, Mazzarol, and Soutar (2014) found that more personal motivation predicted more self-reported energy conservation. In almost all past work, however, the effects of motivation have relied on self-reports of environmental behavior. In this research, we offer the first test of an intervention that directly assists people in identifying with PEBs, and we assess its impact on directly measured electricity and water use.

Goal Progress Requires Feedback and Feedback Requires a Goal

In addition to deficiencies in personal motivation and goal setting, another important reason why people may fail to engage in PEB is that they lack access to the *right kind* of energy use information. Although it has long been believed that allowing energy users to see how much energy they are using encourages conservation, research on the helpfulness of utility feedback has revealed mixed results. For example, Abrahamse, Steg, Vlek, and Rothengatter (2007) found that customized information, feedback, and goal setting elicited minimal impact on energy use. This study did not use objective energy data, however, and was therefore subject to large within-household error in the self-reporting of energy behavior. Other research has underscored that feedback is insufficient to generate conservation behavior (e.g., McCalley, 2006), and indeed, energy feedback must fulfill various requirements to be effective (Fischer, 2008).

In particular, the effectiveness of energy feedback appears to critically depend on whether the user has a *specific energy goal* (e.g., McCalley & Midden, 2002). Goals and feedback are inherently interdependent. Whereas basic models of goal regulation show that goal progress is not feasible without an explicit benchmark from which to compare progress or failure (Fishbach, Eyal, & Finkelstein, 2010; Locke & Latham, 2013), the reverse is also true; that is, feedback services are futile when energy users lack conservation goals that give feedback information context and focus. According to feedback intervention theory (Kluger & DeNisi, 1996), as well as goal-setting theory (Locke & Latham, 2002), feedback is effective when it targets actions and tasks in specific ways, rather than reflecting global or general aspects of motivation, values, or personality. This is because task-specific feedback directs and fixes attention to the task itself and increases knowledge and learning of the behavior (Abrahamse et al., 2007; Ryan & Deci, 2000).

Other aspects of feedback are important for energy conservation. Fischer (2008) reviewed several different types of feedback interventions, from basic and low in granularity to more advanced and high in granularity. These included basic electricity bills, meter readouts, written letters, video feedback, personal advice-based methods, and computerized interactive tools. Fischer also evaluated how feedback was delivered, that is, as economic cost/savings or in basic consumption units (e.g., gallons of water). Like previous work, this study showed that feedback tended to be effective when it was precise and action-oriented (e.g., when it provided information about a specific appliance or type of energy behavior). Fischer's research concluded that best practices involve computerized feedback that is frequent rather than delayed, displays consumption unit comparisons to a standard (e.g., a goal, norm, or expectation), and uses technology the user can interact with (e.g., an interactive display or touch screen). Goal setting in the context of informative feedback tends to enhance performance for individuals as well as groups (Locke & Latham, 2006). Not surprisingly, feedback given to individuals tends to target individual performance, whereas feedback given to teams promotes a focus on team performance (DeShon, Kozlowski, Schmidt, Milner, & Wiechmann, 2004). In the environmental domain, research suggests that group feedback may be more effective than individual feedback—due to the social norms that arise when consumers realize others are using energy reduction strategies (Abrahamse et al., 2007). In this research, although we targeted personal motivations for energy conservation, we asked roommates to set group goals as a team, and we evaluated the effectiveness of goal-related feedback given at the apartment level. This group goal-setting approach is particularly relevant given that it is infeasible to provide accurate individual-level feedback on shared household electricity and water use.

In sum, past work suggests that energy feedback cannot exist in a vacuum, and that it should be connected to individuals' personal, social, and ecological motivations, concerns, context, and goals (Hargreaves, Nye, & Burgess, 2010; Koestner et al., 2008; Locke & Latham, 2002; Lutzenhiser, 2008). Indeed, feedback may be most effective when it is goal-specific, immediate, and interactive. As such, we mapped different categories of electricity and water feedback (e.g., shower duration or living room light usage) to users' energy goals (e.g., "reducing shower length from 10 min to 5 min" or "turning off lights when not in use"). This goal-specific feedback was made feasible: thanks to a sensor array that monitored electricity and water use at each outlet and fixture in each smart apartment. In addition, apartment-level feedback was provided in *near-real time*, so that residents could interpret how much energy was being used by specific behaviors in the moment. Finally, feedback data were displayed on an interactive digital touch screen mounted in the living room wall; users could select to view information based on different types of energy behaviors. Therefore, in addition to targeting individuals' personal motivations for energy conservation and asking them to set specific energy goals as a team, we also installed detailed, action-oriented energy feedback display panels that users could interact with.

Objectives and Hypotheses

In this field experiment, we sought to determine the effectiveness of the following on electricity and water use: (a) a multifaceted intervention focused on personal motivation and group goal setting, (b) an immediate, goal-related, and interactive energy feedback intervention, and (c) the interaction between the motivation and feedback interventions. Before the school year started, a housing lottery process randomly assigned students to university apartments within each experimental condition. Continuous electricity and water data were collected over a 3-month period using a sensor array to monitor utility use at each outlet and fixture across apartment units (for details, see Powers et al., under review).

We expected that participants in the personal motivational intervention would use less electricity and less water than those who did not receive the intervention. We also expected that those who received continual energy feedback would consume less than those who did not receive feedback. Finally, we were particularly interested in the cumulative effect of the motivational intervention *combined with* feedback; given that the feedback was designed to focus attention on specific goals identified in the motivational intervention, we expected that those who underwent the motivational intervention and also received feedback would show the lowest levels of electricity and water consumption.

Method

Participants and Design

Participants were 353 undergraduate students living in 77 on-campus apartments in Northern New York. Because our campus infrastructure was only able to accommodate a maximum of 26 apartments per year with the necessary sensor technology, our sample consisted of three subsequent years of data collection on independent sets of residents, resulting in a total sample of 77 apartments. The number of participants per apartment ranged from three to seven people. Electricity data were recorded for all 77 apartments. However, due to error in water meters, only 71 apartments were retained for the water analysis. Of the 353 participants, 24 did not complete the demographic questionnaire. Of the 329 respondents, 227 were men, 98 women, and four people indicated a nonbinary gender. Participants' age ranged from 18 to 25 years (M = 20.7 years, SD = .94 years). Most students were junior (n = 153) or senior level (n = 155). The remainder were freshmen (n = 1), sophomore (n = 18), or in graduate school (n = 2). The mean family income was between US$75,000 and US$100,000 per annum.

Before the beginning of each academic year, a standard housing lottery process was leveraged to randomly assign participants to apartments representing four conditions within a 2 x 2 experimental design integrating both motivation (Personal vs. None) and feedback (Granular digital feedback vs. Low feedback). Students were informed during the housing lottery that, if selected to live in the newly renovated buildings, they would be asked to consent to participate in the university's Smart Housing Project.

Procedure

The smart housing testbed. In 2013, the university renovated its Woodstock Village student apartment complex to improve the energy efficiency of the building envelope and mechanical systems. Buildings were transformed from 1970s' era construction with poor insulation and aging energy systems into contemporary, well-insulated structures with low-flow water fixtures and high efficiency heating systems. As part of the renovations, a dense array of electric and water meters were installed in two buildings to better understand patterns of student utility use and enable behavioral interventions. To fulfill the objectives of the current project, apartment-level electricity and water meters were retrofitted in two additional buildings. These four buildings containing 26 apartments provided the testbed for the current research. See Table 1 for a high-level summary of the testbed infrastructure.

Sensor recordings and measurements were obtained over the course of three subsequent spring semesters. For electricity, 16 to 20 separate circuits in each smart apartment measured electric energy in units of kiloWatt hours (kWh) every minute. This information was used to calculate average electricity use per apartment per day. Water consumption was measured with 12 meters per apartment in units of tenths of a gallon every minute. This was used to calculate average daily water use and average daily *hot* water use (calculated as number of gallons per day). Note that, because apartments varied in terms of number of residents, for the final analyses, we calculated average per capita values for both outcomes—electricity and water use. In other words, daily apartment averages for electricity (in kWh) and for water (in gallons) were divided by the number of people living in each apartment.

The motivational and goal-setting intervention. The motivational intervention took place in mid-January of each year—at the outset of the second semester. Residents from two of the four buildings (Buildings 1 and 10; see last line of

Table 1. Summary of Infrastructure in Smart Housing Buildings as Basis for the Experimental Design.

Descriptor	Building 1	Building 8	Building 10	Building 4
Apartment type	4 4-bedroom 2 6-bedroom	4 4-bedroom 2 6-bedroom	3 4-bedroom 2 6-bedroom 1 7-bedroom	6 4-bedroom 2 6-bedroom
Sensor type	Dense array throughout apartment	Dense array throughout apartment	Single sensors—apartment-level only	Single sensors—apartment-level only
Infrastructure for feedback	Touch screen display Shower orb	Touch screen display Shower orb	None	None
Intervention conditions (2 × 2 design)	High feedback & personal motivation	High feedback & no motivation	Low feedback & personal motivation	Low feedback & no motivation

Table 1) were asked to partake in a workshop as a part of their participation in the Smart Housing Project. Thus, apartments were assigned to either a motivational intervention or no intervention condition. The intervention integrated fundamental principles of SDT (Deci & Ryan, 2000) and goal-setting theory (Locke & Latham, 2002, 2013), and was designed to attain three main objectives: (a) to provide participants with a variety of informative and explanatory rationales for engaging in electricity and water conservation, (b) to use these rationales as a basis for participants to identify and reflect upon their own personal motivations to save electricity and water, and (c) to encourage participants to identify and commit to challenging and concrete electricity and water goals as a team. The rate of participation in the intervention workshop was 92%.

In line with SDT, instructional practices can promote the internalization and personalization of motivation by understanding learners' perspectives, nurturing their personal motivations, and by providing informational and explanatory rationales for engaging in the desired behavior (Cheon, Reeve, & Moon, 2012; Reeve, 2015). In the first phase of the workshop, a confederate presented participants with seven categories of rationales for why electricity and water conservation might resonate with different individuals. These included climate change concerns, concerns about resource depletion, environmental destruction, economic concerns, energy security and foreign energy dependency concerns, prosocial concern for future generations, and personal and public health concerns.

After describing each category of concerns and giving a relatable example for each category (e.g., for health concerns, a link between pollution and asthma was described), participants were asked to reflect on their "own personal reasons for wanting to save electricity and water." They were encouraged to elaborate on the reason that "made the most sense to them personally" and to describe "what reasons they identified with the most." Participants then spent several minutes writing about their personal proenvironmental motivation (please see supplemental online materials for workshop activities).

Although the personal motivation exercise was completed independently, participants then created electricity and water goals as a team (i.e., with their roommates). Group goal setting was integrated with the personal motivational reflection exercise as a means to provide actionable scaffolding to the broad personal valuation process. Participants were presented with possible energy goals likely to generate reliable savings. Then, each group of roommates was asked to choose two specific water goals (e.g., reducing shower time from 10 min to 5 min, using a dishpan for washing dishes rather running water) and two specific electricity goals (e.g., turning off common lights when not in use, using a power strip for appliances). They then pledged to those goals by jointly signing a commitment statement (see supplemental online materials). In line with the most basic tenets of goal-setting theory, these goals were specific, challenging, self-endorsed, and amenable to feedback (Locke & Latham, 2002).

In addition, we sought to reinforce the intervention throughout the 3-month experiment (February-April). To underscore both the personal reflection exercise and the goal-setting exercise, individual residents were sent two emails each week reminding them of their motivations and group goals. To nudge students about their motivations, we performed a content analysis on the reflection exercise data using a grounded theory approach (Strauss & Corbin, 1994). This revealed six categories of motivations for electricity and water conservation.[1] We then created six email message templates recapping each category of motivation, which were bounced back to the target participants twice per week, along with a reminder of one of the group's action-focused goals. These email messages were intended to extend the experimental effect of the motivational workshop. See online materials for example messages.

Energy feedback intervention. Half of the 77 participating apartments received electricity and water use feedback (Buildings 1 & 8) through a touch screen tablet display mounted on the wall of their living room (Figure 1). For the 3 months of the test period, electricity and water use was monitored, assessed, and made immediately available to participants. The displays enabled students to explore and monitor their apartment's water and electricity consumption in different ways. They could view their usage across time (i.e., minute, hour, day, or 2 weeks), as well as in reference to specific energy behaviors. That is,

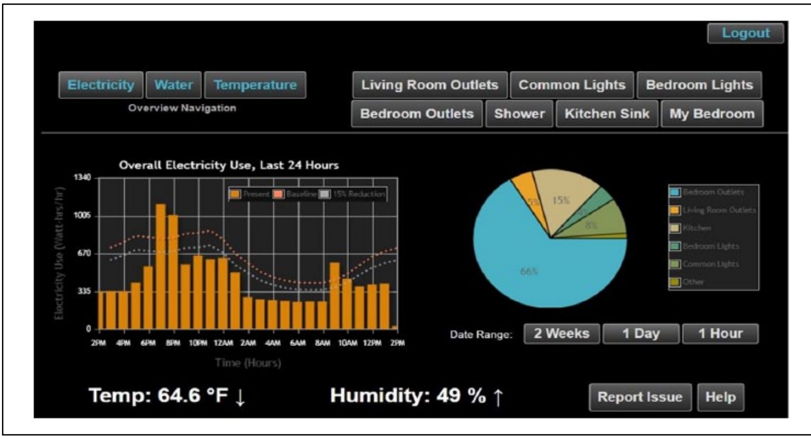

Figure 1. The electricity and water feedback display.
Note. The feedback display was offered as tablet mounted on living room walls, as well as a browser-based website login.

goal tabs at the top of the screen linked to specific types of usage, including shower water usage, kitchen sink water usage, living room lights, and living room appliances/outlets. Also as part of the feedback, each bathroom was equipped with a shower orb that monitored shower duration. Its light stayed green when a shower lasted 5 min or less, then turned yellow until the 8 min mark, and red thereafter. To orient students with their feedback displays and teach them how to interpret the feedback, a brief workshop was held the day before the tablets were turned on (75% participation).

As in the motivational intervention, residents in the feedback condition also received two email prompts each week, reminding them to check their displays for energy use information and also presenting their water and electricity consumption for the previous week (for participants exposed to both motivation and feedback, emails were combined, so that no students received more than two per week). These helped reinforce participants' engagement with feedback information. Finally, students in the low feedback condition received a simple monthly energy use statement that reflected overall electricity and water usage, similar to what would be included on a utility bill.

Analytic Strategy

Sensor network and raw sensor data. At the outset of the project (i.e., early fall 2013), we deployed the physical sensors, meters, data loggers, signal wiring, network equipment, network wiring, computer equipment, and software and computer system configurations necessary to support our sensor network to measure our several thousand variables at a frequency of once per minute. All of the data communication components were completed and reliable data collected from all sensors. We also implemented mechanisms to monitor the continued operation of our sensor network and to identify any gaps in data for our internal operations, and performed preventive maintenance as necessary throughout the implementation periods. Data were collected at the apartment level, stored in university servers, and downloaded off the servers and processed using SPSS. Data files were created for each apartment, with separate files for each utility type (i.e., water vs. electricity).

Final utility data. Utility data from group-level apartments were included in analyses. Utility use data were collected over the course of 3 months, directly following the intervention. Electricity use was calculated in kWh per day per apartment, which was then divided by number of people in the apartment—to account for variation in number of residents. Water consumption was calculated as average daily water use and average daily *hot* water use, in number of gallons per day, per person.

A priori power analyses indicated a required sample size of 67 apartments to detect a moderately strong effect with $1 - \beta = .80$ and a required sample size of 90 apartments to detect a slightly weaker effect ($f = .30$) with $1 - \beta = .80$. We collected data from 77 apartments for electricity and 71 apartments for water. These sample sizes represent the maximum total apartments equipped with sensor arrays, and although power is minimally acceptable, data are highly reliable recordings of objective energy behavior averaged across time.

Although this field experiment was designed with a control condition to measure between-group differences, we also attempted to gather baseline (i.e., pre-intervention) electricity and water data from all apartments. Initially, we sought to determine whether it might be feasible to calculate within-group energy changes in addition to between-group differences by including pre-intervention baseline scores as a covariate in our analysis. Unfortunately, this was impossible due to substantial changes (~50%) in occupancy in our apartments between the fall and spring semesters (half the residents either left the buildings after the baseline period or new students moved in for the test period only). Because of the magnitude of apartments affected by turnover, we did not have grounds to measure behavioral effects within-apartments. Moreover, simple exclusion of the affected apartments in the final analysis would have left us underpowered with only 10 to 11 apartments per cell. As such, we concluded that a post-intervention between-group analysis, rather than a pre-post within-group analysis, was the most appropriate strategy.

Despite our inability to include pre-intervention energy use as a covariate in our analysis, we nonetheless verified whether the four test groups were statistically different in the week before the intervention took place (see next section).

Thus, the focal analysis of the present project was to assess the effects of (a) the motivational intervention, (b) the feedback, and (c) the Motivation x Feedback interaction on actual electricity and water use. All variables were evaluated at the apartment level of analysis. A 2 (Motivation: Personal vs. None) x 2 (Feedback: Granular digital energy feedback vs. Low feedback) between-subject analysis of variance (ANOVA) was performed. Because we expressed the a priori hypothesis that the Motivation + Feedback group would demonstrate the lowest use of electricity and water, we also performed a series of planned comparisons. That is, we tested for differences between the control group (no motivation and low feedback) and the three test groups.

Results

Verifying Between Group Similarity Pre-Intervention

Utility use data collected for 1 week before the intervention verified whether our four conditions were similar to one another before the intervention. For each case (i.e., apartment), we calculated the average amount of electric energy used per day, per person (to account for different numbers of occupants per apartment). We also calculated the total volume of water and hot water consumed by each apartment—in gallons per day, per person. These overall electricity and water usage variables were submitted to a one-way between-group ANOVA. Results showed no differences among the four groups/buildings in terms of electricity, $F(3, 74) = 1.59, p = .20$, total water, $F(3, 68) = .62, p = .60$, or hot water consumed, $F(3, 68) = 1.90, p = .14$. Although this short time period (1 week) is not an adequate and representative baseline covariate per se, it does provide evidence of the uniformity of the four test conditions immediately prior to the intervention.

Also, because our data were collected in three waves spanning three academic semesters, we verified that there were no differences across waves of data collection for electricity, $F(2, 74) = .72, p = .49$, hot water, $F(2, 68) = .91, p = .41$, or overall water, $F(2, 68) = .24, p = .79$.

Descriptive Statistics and Correlations

Three utility outcome variables were calculated: (a) average daily electricity consumption (kWh) per person, (b) average daily water use per person (in

Table 2. Descriptive Statistics and Correlations Among Utility Variables in the Current Study.

	Electricity (kWh/ day/person)	Overall water (gal/ day/person)	Hot water (gal/ day/person)
M	2.24	31.14	15.30
Standard Deviation	0.75	11.00	5.90
Skewness	0.97	1.36	0.93
Kurtosis	0.73	1.05	1.05
Correlations			
Overall water	.21		
Hot water	.27*	.89***	

*$p < .05$. ***$p < .0001$.

gallons), and (c) average daily hot water use per person (in gallons). Descriptive statistics and correlations among these variables can be found in Table 2. Energy data were normally distributed. Electricity consumption and hot water use were moderately and positively correlated.

To provide some context for these descriptive statistics, observed electricity use was consistent with what might be expected. That is, average electricity use for our four-person apartments (9.5 kWh/day) was close to a typical apartment in the northeastern region of the United States (9.0 kWh/day) with no electricity used for heating or cooling (U.S. Department of Energy & U.S. Energy Information Administration, 2017). For water, residential U.S. households without laundry or a dishwasher typically consume 42.6 gallons per day per person (DeOreo, Mayer, Dziegielewski, & Kiefer, 2016), which is 37% higher than the mean of our college students.

Main Analyses: Effects of Interventions on Resource Use

Electricity consumption. Results for electricity consumption are presented in Figure 2. Average daily electricity use per capita was calculated in kWh and submitted to a 2 (Motivation: Personal vs. None) x 2 (Feedback: Granular digital feedback vs. Low feedback) between-subject ANOVA. The main effect of motivational intervention on electricity consumption was not significant, $F < 1$. That is, those who underwent the motivational intervention showed similar electricity usage (M = 2.18 kWh/day/person, SD = .76) compared with those who did not receive the intervention (M = 2.29 kWh/day/person, SD = .75). However, the feedback intervention elicited an impact on electricity consumption, with those in the high feedback condition using

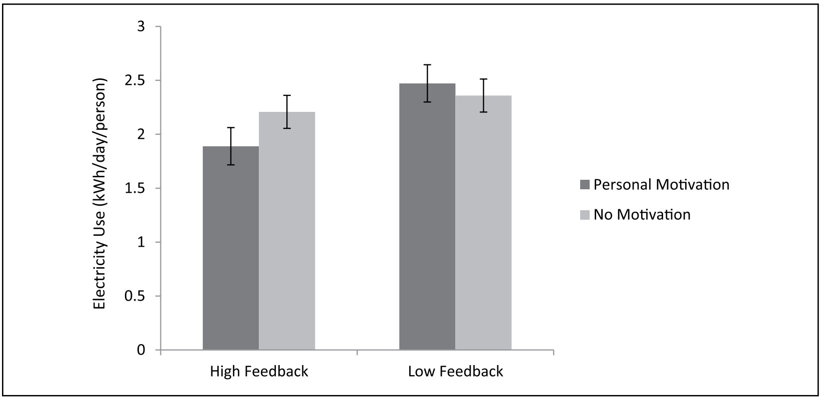

Figure 2. Effects of motivation and feedback on daily electricity consumption.
Note. Error bars represent standard errors.

significantly less electricity (M = 2.05 kWh/day/person, SD = .63) than those in the low feedback condition (M = 2.41 kWh/day/person, SD = .81), $F(1, 73) = 4.73, p = .03, \eta_p^2 = .06$.

The interaction of Motivation x Feedback did not reach significance, $F(1, 73) = 1.65, p = .20$. However, because we hypothesized a priori that the combination of motivation and feedback would produce the lowest level of electricity use, we conducted planned comparisons between each condition and the control group. In line with our expectations, only the Motivation + Feedback group used less electricity (M = 1.89 kWh/day/person, SD = .50) than the control group (M = 2.36 kWh/day/person, SD = .78): $F(1, 39) = 4.88, p = .033, \eta_p^2 = .11$. All other comparisons to the control group were not significant.

In sum, results for electricity use show that feedback is more effective than no feedback overall. However, planned comparisons suggest that this effect may be contingent upon the motivation condition. Although we should use caution here because the Motivation x Feedback interaction was not significant, we can conclude that only the Motivation + Feedback group was significantly different from the control group—yielding a 20% savings in electricity relative to the control group.

Total water consumption. There were no reliable group differences in overall water use. Those in the personal motivation condition (M = 29.66, SD = 10.99) used a similar amount of water compared with those in the no motivation condition (M = 32.67, SD = 10.96), $F(1, 67) = 1.30, p = .26, \eta_p^2 = .02$.

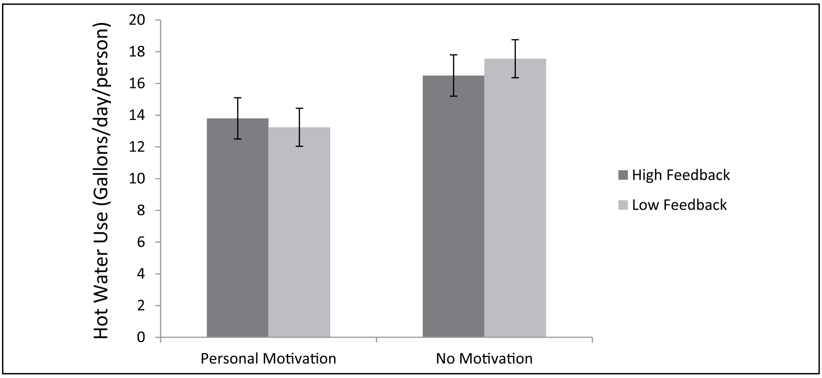

Figure 3. Effects of motivation and feedback on daily hot water use.
Note. Error bars represent standard errors.

Similarly, those in the high feedback condition used a similar amount of water ($M = 32.22$, $SD = 11.81$) compared with those in the low feedback condition ($M = 30.26$, $SD = 10.00$), $F < 1$. There was no evidence of a Motivation x Feedback interaction, $F < 1$.

Hot water consumption[2]. We specifically targeted hot water behaviors in our motivational intervention and feedback system. That is, we asked participants to set goals for shower duration and dish washing behavior—both of which presumably use hot water. Therefore, the effects of motivation and feedback should be more readily revealed in hot water behaviors than in overall water use, particularly because cold water use is conflated by toilet usage, which is less amenable to behavioral intervention. Average daily hot water use per capita was entered into a 2 (Motivation: Personal vs. None) x 2 (Feedback: Granular digital feedback vs. Low feedback) between-subject ANOVA. Results revealed a main effect of the motivational intervention on average daily hot water use per person, suggesting that those who received the motivational intervention used significantly less hot water on a daily basis ($M = 13.52$ gallons/day, $SD = 6.15$) compared with those who did not receive the motivational intervention ($M = 17.13$ gallons/day, $SD = 5.05$), $F(1, 67) = 6.52$, $p < .013$, $\eta_p^2 = .09$. Results for hot water are presented in Figure 3.

The main effect of the feedback intervention on daily hot water use was not significant, $F < 1$. That is, those in the high feedback ($M = 15.22$ gallons/day, $SD = 5.55$) and low feedback ($M = 15.56$ gallons/day, $SD = 6.05$) groups used statistically comparable levels of hot water. The Motivation x Feedback interaction was not significant ($F < 1$).

Planned contrasts revealed significant differences between the control condition and both motivation conditions (i.e., Buildings 1 and 10), such that the control buildings used significantly more hot water (M = 17.56, SD = 5.21) than the High Motivation/High feedback buildings (M = 13.80, SD = 6.19), $F(1, 37) = 4.25$, $p = .046$, $\eta_p^2 = .10$, and the High Motivation/Low Feedback buildings (M = 13.24, SD = 6.28), $F(1, 37) = 5.53$, $p = .024$, $\eta_p^2 = .13$. There was no difference between the control and the Low Motivation/ High Feedback building, $F < 1$. Results support an overall effect of motivation on reducing hot water consumption, regardless of feedback.

Discussion

This field experiment uses objective behavioral data (i.e., meter-recorded) to illustrate the effects of motivation and energy feedback interventions on real life energy consumption. Energy use was continuously and systematically recorded for 3 months after receiving a motivational intervention and/or up-to-the-minute energy feedback. This work is the first of its kind to use personalized, self-generated motivational reasoning to promote tangible PEB. Although several researchers have previously demonstrated the effects of goal setting on resource conservation (e.g., Becker, 1978; Delmas, Fischlein, & Asensio, 2013; Harding & Hsiaw, 2014), we use goal setting and feedback to complement our focus on personalized motivational support. Several hypotheses were supported.

First, we found evidence of a main effect of feedback on electricity consumption. That is, those who received the feedback intervention used less electricity overall compared with those who only received a crude monthly statement of utility use. This finding supports past work on the importance of specific, behavior-focused digital feedback that is interactive (e.g., Grønhøj & Thøgersen, 2011; McCalley, 2006)—particularly regarding the self-monitoring of electricity-related behaviors (Petersen, Shunturov, Janda, Platt, & Weinberger, 2007).

Contrary to our expectations, however, we did not observe a main effect of the motivational intervention on electricity use, nor was the Motivation x Feedback interaction significant. At first glance, these results suggest that motivation did not contribute to electricity conservation overall. However, when evaluating our planned comparisons, it was revealed that the group who received feedback in combination with the motivational intervention used the least amount of electricity—significantly less than the control group. None of the other conditions differed from the control group (or each other). Although these results should be interpreted cautiously because of the non-significant interaction, it indeed appears that the *combination* of motivation (including group goal setting) and detailed feedback produced the greatest savings in electricity. This finding echoes current theory and research on motivation and feedback, suggesting that feedback requires motivational context and a goal object to be effective (e.g., Fishbach et al., 2010; Kluger & DeNisi, 1996; Locke & Latham, 2002).

There were no group differences in overall (i.e., total = hot + cold) water use. In hindsight, this is not surprising—for two main reasons. First, there was no effect on cold water use ($F < 1$) because a large percentage of cold water (32%) was attributable to toilet flushing. Toilet flushing is not something easily influenced through behavioral control; it is unlikely that a motivational intervention would impact toilet flushing behavior. Second, our intervention strategies targeted hot water use rather than cold water use—which would also reduce the likelihood of observing effects on total/cold water. That is, we encouraged students to think about hot water conservation—particularly in terms of reducing shower duration and using a dishpan in the sink to wash dishes rather than letting water run. When participants set their water goals, they were exclusively hot water goals. For this reason, it is unsurprising that only hot water was impacted, rather than overall water.

Indeed, we observed several important effects on hot water use. First, there was a main effect of the motivational intervention on hot water use, suggesting that those who reflected on personal reasons to save energy and set energy goals used significantly less (i.e., 21% less) hot water than those who did not. Planned contrasts shed further light on this effect, revealing that both motivation groups—regardless of level of feedback—used less hot water than the control group. In other words, there was no effect of feedback on hot water use. Given that these results support a rather strong overall effect of motivation on reducing hot water consumption, regardless of feedback, it appears that the targeting of personal energy motivation and goals is quite relevant for hot water conservation behavior. This finding extends theory and research on self-determination and sustainability (e.g., Cooke et al., 2016; Green-Demers et al., 1997; Osbaldiston & Sheldon, 2003; Pelletier, Tuson, Green-Demers, Noels, & Beaton, 1998; Webb et al., 2013) by showing that interventions designed to promote personal motivation and goals for PEB can have a real-world impact. This finding is particularly noteworthy given that there has been little to no research on how to motivate water conservation specifically (except see Dickerson, Thibodeau, Aronson, & Miller, 1992).

An unexpected finding in the present study is that electricity and hot water conservation may be supported through different mechanisms. Whereas motivational reflection, goal setting, and motivational messaging were effective in reducing hot water use, the addition of feedback was critical for electricity conservation. In contrast, feedback did not elicit an impact on water conservation. Perhaps motivation and goal setting were more sufficient and pertinent for the initiation and maintenance of concrete water-saving behaviors such as reducing shower duration. Or, alternately, perhaps we were simply ineffective in providing useful water feedback. It may be that the 75% participation rate in the instructional workshop negatively affected level of engagement with the display, which negated water conservation.

Although feedback was not useful for reducing water use, it was effective in electricity conservation. Interestingly, this particular finding corresponds to previous research showing that dynamic visual feedback in dormitory apartments produces a decrease in electricity consumption but not water use (Petersen et al., 2007), and that energy saving competitions and incentives are effective for saving electricity but not water (Petersen et al., 2015). A possible explanation may be that shared electricity consumption in common areas of the apartment are made more visible and tangible through feedback information. Accordingly, Petersen and colleagues (2015) note that electricity behaviors are relatively more public than water behaviors. For example, they found that participants in an energy competition reported turning off lights in public spaces to conserve electricity, but that there was no clear equivalent for this with respect to water use—which is more personal and private (Petersen et al., 2015). Our results coincide with this idea by revealing that *personalized* motivational messages (but not general feedback) were effective in targeting water use. An important implication here may be that different interventions should be used for different types of resource use; what is effective for electricity reduction may be different than what is effective for hot water conservation. Further research is needed to understand why hot water use and electricity consumption appear to be malleable through somewhat different mechanisms or interventions.

Limitations and Future Considerations

This research has various limitations. As with most field studies and intervention research, our intervention is multifaceted and therefore lacks some experimental control and internal validity. In other words, it is likely that both the motivation workshop and the feedback service influenced multiple social and psychological processes, and we therefore cannot attribute our effects to any singular explanation. Although this work provides evidence of objective behavioral effects in the real world, the tradeoff is that we do not understand the mechanisms through which these effects occurred. For example, because the motivational intervention contained several elements (i.e., personal motivational reflection, goal-setting exercise, motivational reminder emails), we do not know which element—or combination thereof—was responsible for the hot water savings. Despite this drawback in precision, multidimensional interventions like those described here are often more effective in targeting desired outcomes in real world settings, relative to cleaner, more singular interventions (Su & Reeve, 2011).

On a related note, although our interventions were based on contemporary motivation and feedback theories, we were unable to measure and ascertain the psychological constructs related to our observed effects. Future work should try to understand the social psychological variables that might help explain these behavioral findings.

In addition, the current work does not provide insight into behavioral changes within individuals as a function of the motivational intervention and feedback delivery. Although this limitation is mitigated somewhat by the use of a control group in a between-group design, future research would be prudent to administer eco-interventions at a point in time where resident turnover is minimal, to reduce the mass attrition and participant fluctuation we experienced between semesters, before the intervention was administered.

Because such "real world" field experiments sometimes sacrifice internal control for external validity, another shortcoming entails the possibility of cross contamination across experimental groups. Participants from the four buildings lived in close quarters for the duration of the semester-long experiment, and it is theoretically possible they communicated with one another about the study. We took several measures to address this potential problem—including a face-to-face request not to talk about the study with non-roommates, and an informal post-experiment probe that revealed that students spent little to none of their spare time discussing the experiment. Although cross contamination is a potential threat in any field experiment that spans more than a single experimental session, one might argue that choosing residents in different locales to avoid the possibility of cross contamination would introduce additional confounding differences between groups.

Another noteworthy caveat pertains to the generalizability of our findings and the scalability of our methodology. We use advanced technology, time-intensive feedback and communication methods, and instructor-led motivational intervention workshops to support participant engagement. These resources are not likely to be available to most energy users. Caution should be made when generalizing the current findings to other populations and settings. At the same time, the current work holds promise for future research, development, and programming. Our motivational workshop materials, for example, may be easily transferred and adapted across campuses world-wide, and even to other residential spheres—such as apartment complexes and retirement residences—where personal motivation becomes important as residents do not pay utility bills directly and so have no financial motivation to conserve. Moreover, as advancements in digital feedback continue to be made, our work offers important insight into the manner in which these might capitalize on motivation and goal setting.

From a statistical standpoint, sample size and power are only minimally adequate. It should be noted, however, that because we use objective sensor data, measurement error is effectively zero, which helps lend validity to the findings. Another statistical issue pertains to the way our data were analyzed; although our data spanned continuously across most of the spring semester, we did not investigate any fluctuations over time but rather looked only at overall daily averages across the semester. In the future, it would be interesting to inspect time- and weather-related variations in utility use.

Finally, from a design perspective, future work should also consider improving our feedback display interface and specific content of the motivational messages. User experience research is needed to capitalize on the strengths of our feedback screens and to redesign or remove ineffective features or modes of communication.

Moderators of the Effectiveness of Motivation and Feedback Interventions

There remains a need to consider the broader psychological, social, and cultural factors that influence people's energy use. It seems likely that various moderators exist at various levels, which may influence how different individuals respond to both motivation and feedback interventions. Indeed, this is likely to explain many of the mixed findings regarding the effectiveness of feedback in general (Hargreaves et al., 2010; Lutzenhiser, 2008). For example, researchers have noted that, rather than administering one-size-fits-all interventions, communication should be targeted to the individual's level and type of motivation (Pelletier & Sharp, 2008). Other work has noted that democrats and republicans perceive environmental communications differently, suggesting that messaging should take into consideration social and economic ideology (e.g., Costa & Kahn, 2013). And, new evidence suggests that wealth influences responsiveness to message content—where affluent people respond more readily to appeals to agency and power, whereas the less affluent are more receptive to messages related to community values (Whillans, Caruso, & Dunn, 2017). Future research should evaluate the role of these moderators in modulating responsivity to individual-level motivational interventions.

Conclusion

The moderate effects presented here (i.e., 15%-21% differences) are considerably better than typical incentive programs and other interventions designed to curb resource consumption, which characteristically report savings in the range of 7% to 15% (e.g., Abrahamse, Steg, Vlek, & Rothengatter, 2005; Staats, Harland, & Wilke, 2004). This work therefore offers encouraging evidence of the potential for personal motivational interventions and messages to reliably decrease resource consumption without the use of external incentives or controls. This finding is particularly valuable and cost-effective in light of mounting evidence that financial incentives or punishments are poor motivators for sustainable energy behavior.

Authors' Note

Author order denotes an order of merit approach.

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Supplemental Material

Supplemental material for this article is available online.

Notes

1. These categories mapped closely onto the seven categories of reasons for saving energy presented in the workshop. No differences in conservation were observed as a function of motivation category—suggesting that personalizing motivation to the user/learner may be more important than the objective content of the motivation.
2. A multivariate analysis of variance (MANOVA) was performed as a supplementary analysis to (a) address possible corrections for Type 1 error and (b) explore the potential covariate of income in explaining the observed effects. Income was

calculated as the average household income of all residents in a given apartment. Results of the multivariate test, which included electricity and hot water as dependent variables, did not show any effect of mean-level apartment income on utility use, Pillai's Trace = .007, $F(2, 65) = .238$, $p = .789$. There was a multivariate effect of motivational intervention, Pillai's Trace = .091, $F(2, 65) = 3.24$, $p = .045$, $\eta_p^2 = .091$, and a marginal multivariate effect of feedback, Pillai's Trace = .082, $F(2, 65) = 2.90$, $p = .062$, $\eta_p^2 = .082$. The multivariate interaction was not significant, Pillai's Trace = .024, $F(2, 65) = .799$, $p = .454$, $\eta_p^2 = .024$. When examining between-subject effects, there was no observed influence of income on either electricity or hot water (both Fs < 1). Mirroring results reported in the main findings, feedback reduced electricity consumption, $F(1, 66) = 5.71$, $p = .020$, $\eta_p^2 = .080$, and motivation reduced hot water use, $F(1, 66) = 6.53$, $p = .013$, $\eta_p^2 = .090$. There was no main effect of feedback on hot water nor of motivation on electricity (both Fs < 1). The interaction effects on electricity and water were not significant, $F(1, 66) = .950$, $p = .333$, $\eta_p^2 = .014$ (for electricity) and $F < 1$ (for water).

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