Dormitory residents reduce electricity consumption when exposed to real-time visual feedback and incentives

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Abstract

Purpose – In residential buildings, personal choices influence electricity and water consumption. Prior studies indicate that information feedback can stimulate resource conservation. College dormitories provide an excellent venue for controlled study of the effects of feedback. The goal of this study is to assess how different resolutions of socio-technical feedback, combined with incentives, encourage students to conserve resources.

Design/methodology/approach – An automated data monitoring system was developed that provided dormitory residents with real-time web-based feedback on energy and water use in two "high resolution" dormitories. In contrast, utility meters were manually read for 20 "low-resolution" dormitories, and data were provided to residents once per week. For both groups, resource use was monitored during a baseline period and during a two week "dorm energy competition" during which feedback, education and conservation incentives were provided.

Findings – Overall, the introduction of feedback, education and incentives resulted in a 32 percent reduction in electricity use (amounting to savings of 68,300 kWh, $5,107 and 148,000 lbs of CO_{-2}) but only a 3 percent reduction in water use. Dormitories that received high resolution feedback were more effective at conservation, reducing their electricity consumption by 55 percent compared to 31 percent for low resolution dormitories. In a post-competition survey, students reported that they would continue conservation practices developed during the competition and that they would view web-based real-time data even in the absence of competition.

Practical implications – The results of this research provide evidence that real-time resource feedback systems, when combined with education and an incentive, interest, motivate and empower college students to reduce resource use in dormitories.

Research was supported by grants from the US Environmental Protection Agency's "P3" program and by the Ohio Foundation of Independent Colleges and the US Department of Energy Rebuild America Energy Efficiency Program. A team of students was responsibility for organizing and advertising the competition, reading utility meters, and collaborated on the design and interpretation of the post-competition survey. This team included: Andrew Barnett, Roman Corfas, Lauren Dennis, Rebecca Derry, Courtney Epstein, Jacob Grossman, Callen Miracle, and Jenna Trostle. Garrett Miller assisted in graphic and web design. Chris Fry assisted with computer technology. Oberlin College facilities personnel, including Art Fruner, Dan Cunningham, Eric McMillion, and Bill Mohler contributed to monitoring system design and installation, trained students and provided historical data on campus resource use. Cindy Murnan, Cal Fry, Art Ripley,John Bucher and others at Oberlin's Center for Information Technology provided critical assistance with system implementation and made it possible to track the locations of web site visitors.

International Journal of Sustainability
in Higher Education
Vol. 8 No. 1, 2007
pp. 16-33

1467-6370
DOI 10.1108/14676370710717562

Originality/value – This is the first study to report on the effects of providing college students with real-time feedback on resource use. The authors of this study are currently engaged in further research to determine: whether reductions in consumption can be sustained over time with and without incentives; the degree to which feedback affect attitude; and the degree to which findings are transferable to apartments and other residential settings.

Keywords Energy consumption, Energy conservation, Feedback, Incentives (psychology), Students, Internet

Paper type Research paper

Background

Resource use and conservation in buildings

The steady expansion in human resource use and its ecological consequences can be partially attributed to activities that take place within the built environment. For example, residents of the United States spend more than 90 percent of their lives in buildings (Evans and McCoy, 1998). Residential and commercial buildings account for two-thirds of the electricity used in the US, 36 percent of US greenhouse gasses, 9 percent of world greenhouse emissions, and 12 percent of US fresh water consumption (Wilson and Yost, 2001). Production of electrical energy contributes to a broad range of environmental and health problems including climate change, acid deposition, lung ailments and mercury poisoning. Freshwater consumption (one source of energy use) leads to groundwater and surface water depletion, pollution and habitat destruction. Bringing about a more sustainable relationship between humans and the rest of the natural world is, in part, predicated on improving the environmental performance of buildings.

On college campuses, the vast majority of energy consumption takes place within buildings, and the environmental consequences of this consumption are considerable. For example, in 2004, the per-student consumption of resources in buildings at Oberlin College included 18,000 gal of water, 3 ton of coal, 23,000 ft^3 of natural gas and 8,000 kW h of electricity (data from Oberlin Office of Facilities Operations). A comprehensive study of greenhouse gas emissions conducted by Rocky Mountain Institute, a prominent environmental consulting firm, found that 92 percent of the 46,500 ton of CO_2 equivalents released by Oberlin College in 2000 could be attributed to heating, cooling, lighting and other energetic services provided to buildings (Heede and Swisher, 2002). A substantial percentage of total campus resource use takes place within dormitories. Previous studies have estimated that occupant activities and choices control up to 50 percent of residential energy use, while the balance depends on physical characteristics of buildings and building equipment over which occupants have no control (Schipper, 1989). Students living in dormitories have a high degree of control over electricity and water use. Personal choices, such as how long they shower, and whether they leave lights, stereos and computers on, have the potential to reduce consumption of electricity and water. Residence halls are, therefore, an obvious target for conservation measures. They also provide an excellent setting for studying the efficacy of strategies that encourage resource conservation.

Three interrelated factors are necessary to stimulate building occupants to exhibit practices that conserve resources: knowledge, motivation, and control (other terms used to describe necessary conditions include “concern, capacity and physical condition” Janda *et al.*, 2002). There are similarities and also important differences in how these factors operate in dormitories versus other residential settings. For example, whereas homeowners and renters typically have a direct financial incentive to reduce water and energy consumption, students living in dormitories pay the same room bill as their neighbors regardless of whether they are relatively frugal or profligate in their resource use. Thus, dormitory residents do not have an immediate economic incentive for conservation. However, college students often express a high level of concern for environmental problems. Research has demonstrated that individuals who report a high degree of connectedness with nature are more likely to make decisions that are beneficial to the environment (Mayer and Frantz, 2004). If dormitory residents can be made aware of the magnitude of their current resource use within dormitories and how this directly contributes to problems such as global climate change, pollution, habitat degradation, and depletion of renewable and non-renewable resources, they may feel motivated for moral or ethical reasons and empowered to conserve resources. Even in the absence of financial incentives, the desire to "do the right thing" for the environment, potentially combined with non-monetary incentives and competition among communities living in different dorms may provide considerable motivation for conservation. The question is, how might a context be created that increases the knowledge, motivation and control of dormitory residents so as to encourage the development of behaviors that conserve resources?

Role of information feedback in stimulating conservation

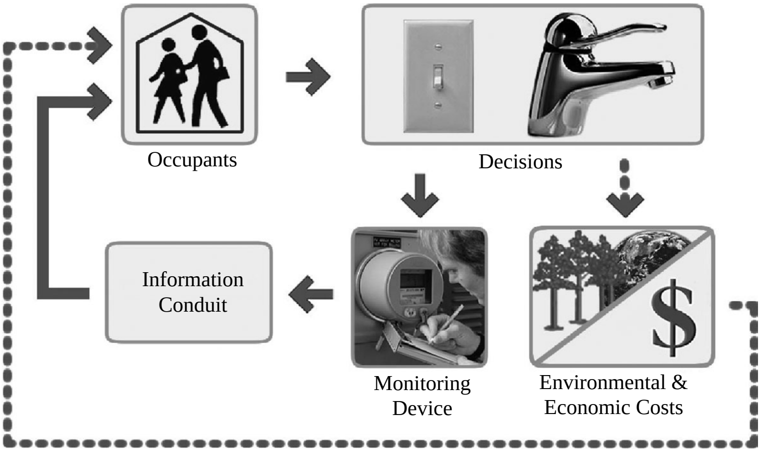
Although general concern about the environment may be a necessary prerequisite, a premise of the study described here is that building occupants will not be motivated to act differently unless they understand the direct and immediate connections between their behavior and the environmental consequences of this behavior. This is where the concept of feedback comes into play. The relevant dictionary definition of feedback is:

> . . . the return of a portion of the output of a process or system to the input, especially when used to maintain performance or to control a system or process (*The American Heritage Dictionary of the English Language*, 2000).

In this case, feedback means making building occupants more directly and immediately aware of their resource use and of the financial and environmental consequences of this use (Figure 1).

A comprehensive review of 38 studies of household energy use conducted over the last 25 years in Europe and the US (Darby, 2000) concluded that information feedback on rates of consumption provided to building occupants can increase awareness and motivate decreased energy use. Others have found that environmental concern and environmental knowledge of the building occupant are important factors that improve the success of feedback (dotted line in Figure 1). For example, a comprehensive study that examined energy conservation in households concluded that residents who identified themselves as environmentally concerned, but who had not previously engaged in conservation practices, were the most likely group to reduce consumption in response to new feedback on energy use (Brandon and Lewis, 1999). Since, college students often identify the environment as a major interest and concern a premise of the research described in this paper is that feedback on water and electricity use presented in the context of the environmental impacts of this resource use can stimulate conservation in this group.

Although concern for the environment has the potential to motivate building occupants to conserve resources, the feedback signal connecting resource use with its environmental impact is often indirect, obscure, weak, or otherwise difficult for the



Notes: Occupants are thereby empowered to make informed decisions that alter the flow of resources. A secondary feedback loop (dotted line) involves knowledge of the relationship between domestic resource consumption and the environmental or economic costs of this consumption. The authors of this study assume that these are mutually reinforcing loops

Figure 1.
A simple feedback loop in which domestic consumption of water and electricity are monitored and delivered to building occupants by means of an unspecified information conduit

average person to perceive, understand and react to (Darby, 2000; Roberts and Baker, 2003). This is particularly true for college dormitory residents who, unlike household consumers, do not receive even the minimal feedback on resource consumption contained in a monthly utility bill. Indeed, it would be very unusual for a college student to receive any information from the institution regarding either the amount of resources she is using in her dormitory or the environmental impact of this resource consumption. Even if the student has a good general understanding of the overall impact of resource use on the environment (dotted line in Figure 1), there is no direct information conduit (solid line in Figure 1) that would allow her to observe the effects of resource use choices. The authors of this study initiated the research described in this paper with the operating hypothesis that, combined with an incentive and information on the environmental implications of resource use, easily accessible feedback on resource use in buildings can be used to empower and motivate students to conserve resources in dormitories.

Computer and internet technology as mechanisms for introducing socio-technical feedback

Modern "smart building" control systems are designed to use technological feedback to regulate building functions with a minimum of occupant input. In contrast, socio-technical feedback systems engage human beings as key decision-making elements in loops that involve technology. A well-designed socio-technical feedback system essentially allows building users to teach themselves how to conserve resources by trial and error (Darby, 2000). The question is, how should such a system be designed and implemented in a residential setting so as to maximize resource conservation? Recent developments in metering and datalogging technology, software, and the internet enable new mechanisms for this sort of feedback. A number of studies conclude that sophisticated utility meters and computers that display and analyze real-time electricity consumption in an easily accessible place within a residence can stimulate energy conservation (Darby, 2000; Brandon and Lewis, 1999; Roberts and Baker, 2003). The fact that most households, including dormitory rooms, now have personal computers and internet access within the domestic space suggests a natural information conduit for delivering real-time data on domestic resource use to those who control the resource use. However, this information venue has not been widely used for this purpose; to the authors' knowledge, this study is a first attempt to translate resource use occurring within multiple college dormitories into contextualized information that is easily accessible from within the residential environment via the web and interpretable to non-experts.

In addition to selecting an information conduit – in this case data from sensors processed by a computer and delivered to a web site – choices need to be made regarding the level of detail to be presented. That is, feedback on resource use can be provided with different degrees of resolution (i.e. aggregated over different time intervals and over different numbers of end uses). For instance, at the low-resolution end of the spectrum, occupants might be provided with monthly feedback on the aggregate resource use of an entire dormitory or apartment complex. At the high-resolution end of the spectrum, occupants could be provided with real-time (i.e. instantaneous) feedback on resources used in individual rooms or even by individual appliances within rooms. It seems intuitively obvious that it is difficult to make short-term, small-scale decisions about how best to conserve energy or water based on the information delivered in the form of the low-resolution (i.e. highly aggregated) feedback provided by monthly utility bills. With that said, little is known about how the degree of resolution in feedback affects the strength of response, and one of the objectives of this study was to assess this.

Researchers involved in this study developed a prototype system for metering, processing and displaying data on resource use in dormitories. Specifically, electricity and water use were compared among groups of students that represented three levels of resolution: once per week feedback on the aggregate electricity and water consumption of an entire dormitory, real-time feedback on the aggregate electricity use of an entire dormitory, and real-time feedback on the electricity use by students on individual floors within a dormitory. This paper reports on the effectiveness of a package of measures that were simultaneously undertaken to influence resource consumption behaviors. This package included: web-based feedback; educational materials posted in all dormitories describing the environmental impacts of electricity and water consumption; and a competition among dormitories to see which dormitories could reduce resource use by the largest percentage with a prize for residents of the winning dormitories. Feedback was socially comparative in the sense that each dormitory could see how other dormitories were doing during the competition. The goal of this paper is to quantify and assess the environmental and economic impacts of different resolutions of feedback combined with education and the incentive of a competition and also to quantify and assess student utilization of and reaction to the feedback provided.

Methods

Consumption of electricity and water in dormitories

This study examines electricity and water that are directly consumed within Oberlin College dormitories. Energy used for heating is excluded from this study for two reasons. First, the metering technologies used in the study only monitor electricity and domestic water. Heat is provided to individual buildings either by a central steam plant or by gas boilers within the buildings. Monitoring these flows of thermal energy would have necessitated the installation of different kinds of meters at additional cost. Second, dormitory residents are provided with very little control over the set-point temperature of their rooms; thermostats are controlled by the College's Office of Facilities. Accordingly, providing feedback on these resources would be less likely to result in any conservation behaviors. Some electricity related to heating is used to operate exhaust fans and compressors in the mechanical rooms of dormitories. One would expect use of these components of the heating system to change with outdoor temperature. The authors of this study believe that these are likely to be small loads relative to electricity used for lighting and plug loads. However, electricity related to heating was controlled in this study by considering outdoor temperature in the analysis of the data. Temperature data monitored at a nearby local airport were obtained through the National Oceanic and Atmospheric Administration.

Electrical lighting is responsible for a large fraction of dormitory electricity use and students have substantial control over light in their rooms and public spaces such as bathrooms, hallways and lounges. Lighting needs are dependent on outside conditions and can be expected to change with both short-term weather conditions and with seasonal changes in day length. The study considers light intensity as a factor that could influence electricity consumption in dormitories. Outside light conditions were monitored throughout the study with an on-campus weather station.

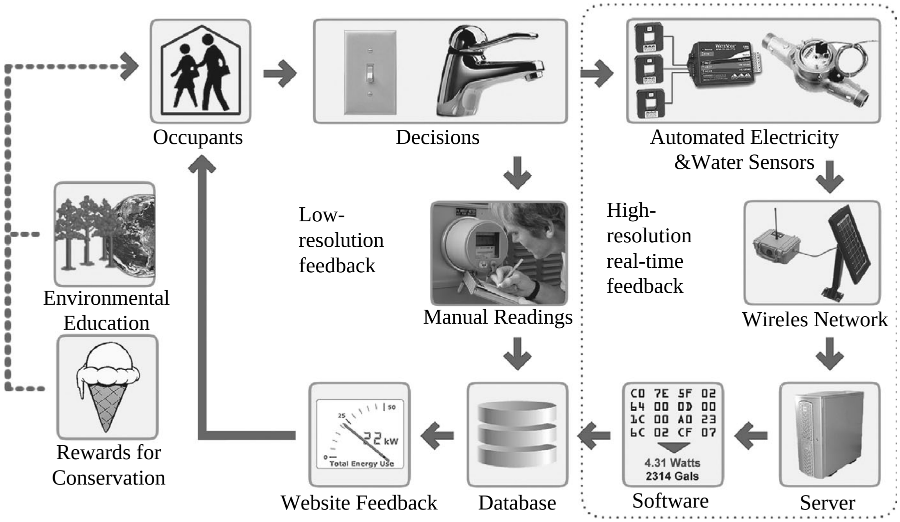
In Oberlin dormitories, water is restricted to use in bathrooms, laundry rooms, small residential kitchens, and in some cases large dining halls. Water is not used for landscaping. Owing to the relatively short duration of the study, the authors assume that there were no seasonal or weather related effects on water use in the dormitories.

Hardware and software technology for data acquisition, processing and real-time display

This study required the capacity to collect, process and display real-time data on electricity and water consumption in a subset of Oberlin dormitories (Figure 2). A review of existing technology indicated that there was no integrated off-the-shelf, cost-effective product or even combination of products available in the market that could accomplish the objectives of collecting, processing and displaying resource use in multiple existing buildings that lack centralized building automation systems. This research therefore required that hardware and software be developed and adapted to serve this purpose. With funds obtained through a people, prosperity and the planet ("P3") grant from the US Environmental Protection Agency, a prototype wireless data monitoring and display system was developed that enabled easy observation and interpretation of real-time resource use in two dormitories on the Oberlin College campus. Specifically, the authors of this study combined:

- off-the-shelf water and electricity flow sensors;
- newly available and relatively inexpensive wireless datalogging and networking hardware (www.xbow.com); and
- networking, database management and display software custom developed by the research team.

The advantage of wireless datalogging technology over more traditional wired technology is that it avoided wiring costs. The authors of this study designed and



Notes: Two dormitories were equipped with automated monitoring systems that provided high-resolution, real-time feedback (pathway within dotted box on right). For the 16 dormitories receiving low-resolution feedback, utility meters were read by hand and consumption data were posted on the www.oberlin.edu/dormenergy website once per week. Both high- and low- resolution dormitories received identical educational materials and an incentive was provided in the form of an ice cream party for dormitories that reduced electricity and water use by the largest percentage

Figure 2.
Pathways of data flow and information feedback in Oberlin dormitory study

implemented server management software and custom developed all of the software used for the web site display using PHP and Macromedia Flash.

All components of the monitoring and display system were developed between June 2004 and January 2005. Between February 1, 2005 and January 2006 (the date that this paper was submitted for publication), the monitoring system for the two "high-resolution," intensively monitored dormitories was in continuous operation. Every 20 s, the following sequence of events occurred in this system:

- sensing stations located in the mechanical rooms of the two monitored dormitories collected data from electricity and water flow sensors;
- data were processed by the receiving datalogger into several discrete packets and transmitted by radio signal from the sensor station through intermediate relay stations to a base station;
- data received by the base station were inserted into a database that resided on a PC server;
- raw data delivered to the database were processed by the server to create derived variables;
- derived variables were made available to the internet; and
- when the web site was called, graphics software created and "played" time-series graphs on the web site of the visitor's computer.

The objective in designing the web site interface for the resource-use feedback system was to place data on resource use in an environmental context and to make it as easy as possible for a non-technical audience to interpret. Electricity data on the web site were expressed in units of average power consumption (kW) during defined time intervals. Web gauges dynamically updated with current data every 20 s. The web interface was designed so that the web visitor could select the scale over which time-series data are graphed (last day or last week). Cumulative consumption was converted to units of air pollution averted as a result of electricity savings (i.e. lbs of CO_2, SO_2 and NO_x). Mini-movies adjacent to graphs and gauges explained the meaning of energy units in layman terms. Since, all Oberlin dormitory rooms have internet access and most rooms have at least one computer, the data were easily and immediately accessible to the target audience. In addition, as part of the study, computer kiosks were temporarily installed in the lobbies of the two high-resolution dormitories that had real-time feedback systems. A kiosk was also installed in the lobby of the College's Science Center to run continuous presentations of dormitory resource use data. The www.oberlin.edu/dormenergy web site, where feedback data are displayed, was made publicly available on March 10, 2005 to coincide with the beginning of the "Dormitory energy competition."

Research methods for determining impacts of feedback on behavior and interest

A two week long campus-wide "Dormitory energy competition" was employed to provide an incentive for conservation and a context for advertising, educating and delivering feedback on resource use within college dormitories. Publicity and education included posters announcing the competition and fliers and posted materials describing the environmental impact of water and electricity use. Because the authors were interested in the extent to which students could "self teach" themselves to conserve, these materials intentionally excluded specific suggestions on how students might conserve water and electricity. To reduce bias, informational materials and advertising were distributed at similar densities in all participating dormitories.

Two dormitories received the high-resolution feedback on consumption provided by the wireless data monitoring system described above. Specifically, total real-time electricity use was displayed for both dormitories and for two of the three floors within each of these dormitories. Electricity data for the third floor were collected, but not displayed so that this floor could be used as a control with which to assess the effect of supplying information at the level of individual floors. Efforts to monitor and display real-time water use in these two dormitories were not successful. Furthermore, the city water meter in one of these high-resolution dormitories failed during the competition so that neither high nor low resolution data on water use in this dormitory were generated.

In addition to the high-resolution feedback described above, an attempt was made to deliver low-resolution data for 20 of the 25 dormitory buildings that are present on the Oberlin College campus. Utility meters in these dormitories were read on a weekly basis throughout the study. Because of faulty meters and errors in meter reading, four of the dormitories monitored for electricity use were disqualified, leaving a total of 16 low-resolution dormitories (combined total occupancy $= 1,612$ students) that were included in the final energy analysis. As a result of similar problems, five of the dormitories were dropped from the study of water use, leaving a total of

15 low-resolution dormitories for this component of the analysis (different dormitories were dropped from energy and water components of the study, total occupancy for successful water metering = 1,623 students). Several additional water meters were not read during the post-competition period and as a result, comparison of this period was dropped from analysis of water data. Low-resolution data consisted of whole-dormitory electricity and water use integrated over the weekly meter readings. For the purpose of the competition, dormitories were grouped into two categories, each with its own winners, those that contained campus dining facilities and those that did not. In both categories, the dormitory that reduced electricity use by the largest percentage and the dormitory that reduced water use by the largest percentage were invited to an ice cream party as their prize.

The average rates of water and electricity consumption were assessed over three distinct time periods. First, consumption was monitored for a three-week "baseline period" from February 20 to March 10, 2005. During the baseline period, no educational materials were provided and no data were made publicly available on the Dormitory Energy web site. The start of the competition marked the beginning of the two-week "competition period," which extended from March 10 to 24, 2005. During the competition period, students competed to reduce their resource use in dormitories. Consumption feedback was made continuously available on the web site for the two high-resolution dormitories, and data were posted on the web site once in the middle of the competition and once at the end of the competition for the 16 low-resolution dormitories. During the competition period, kiosks with a continuously looping real-time display of dormitory resource use (similar in content to the Dormitory Energy web site) were installed in the lobbies of the high-resolution dormitories and in a display case in the lobby of Oberlin College's Science Center. Finally, in addition to the baseline and competition periods, data were gathered during a two-week "post-competition" period that extended from April 6 to April 20. This post-competition period was discontinuous from the other study periods because of an intervening spring recess during which very few students were on campus. Winning dormitories were announced prior to the post-competition period. The Dormitory Energy web site continued to display real-time data for the two high-resolution dormitories during the post-competition period, but the lobby displays were removed; during this period no publicity or educational materials were provided and the prize incentive was eliminated.

The Dormitory Energy web site was also designed to provide a quantitative tool for assessing student utilization of feedback data. To accomplish this, algorithms were built into the site to record the unique computer IP address of each internet visitor. Data obtained from the Oberlin College Center for Information Technology, were used to determine and record the physical location of each visiting computer down to the level of the floor of the dormitory to which the IP was registered. Thus, the authors were able to determine how often students on each floor of each dorm viewed the web site and which pages they viewed.

Four mechanisms were used to quantify the impact of feedback combined with education and incentives on student resource use and student interest in resource use:

- the environmental and economic value of resource use reductions that occurred between baseline and competition periods were determined;
- resource use reductions were compared between the dormitories given low- and high-resolution feedback;

- the origin, target page and number of unique and repeat visitors to the Dormitory Energy web site were analyzed; and
- dormitory occupants were surveyed regarding conservation strategies, their interest in the feedback data and their intentions for future conservation.

An online post-competition survey was developed and students were enticed to participate with entry in a raffle for gift certificates to local restaurants. Several different format questions were used. For example, students were asked to use check boxes to select all water and electricity conservation practices that they employed from a list of possible options. Text boxes were used for comments and to allow students to identify conservation strategies not included in the lists. Another type of question asked students to rank their degree of agreement with various statements about the competition. For the agree/disagree type questions, percentage agreement is reported as the sum of survey respondents selecting 1 or 2 (1 = strongly agree, 5 = strongly disagree), divided by the total number of survey respondents for that question. Disagreement is reported as the percentage of students marking 4 or 5.

Metrics and calculations

Because each dormitory on campus has a distinct and unique combination of building attributes, differences in resource-use behavior among dormitories were assessed by comparing percent changes in resource use rather than by comparing absolute or per capita change. Using percent change allowed us to compare changes across buildings of different vintages, different construction types, different solar exposures, and with different installed appliances (e.g. incandescent vs fluorescent desk lighting). Reductions in water and electricity use for each dormitory during the Dormitory Energy Competition were calculated as: percent reduction = 100 × [(average baseline period rate) − (average competition period rate)]/(average baseline period rate). Total resource savings for each dormitory during the two-week competition period were determined by multiplying the difference in average consumption rates between the two periods by the time elapsed. For example: electricity saved in kW h = (baseline kW − feedback kW) × (24 h × 7 days/week × 2 weeks). Economic and ecological values of these savings were calculated using the conversion factors in Table I.

Results

Light and temperature during the study periods

Outside temperature differences between baseline and competition periods were small (average of 28 vs 30°F, respectively). Although day-length was increasing over the duration of the study, variability in cloud cover resulted in only small differences in

Currency	Cost	Source
\$ for electricity	0.0747 \$/kW h	Oberlin College Office of Facilities Management
CO_2 emissions	2.163 lbs/kW h	Murray and Petersen (2004)
SO_4 emissions	0.0199 lbs/kW h	USDOE for Ohio electricity
NO_x emissions	0.00762 lbs/kW h	USDOE for Ohio electricity
\$ for water + waste water	0.0128 \$/gal	Oberlin College Office of Facilities Management

Note: Costs are expressed per kW h of electricity and per gallon purchased

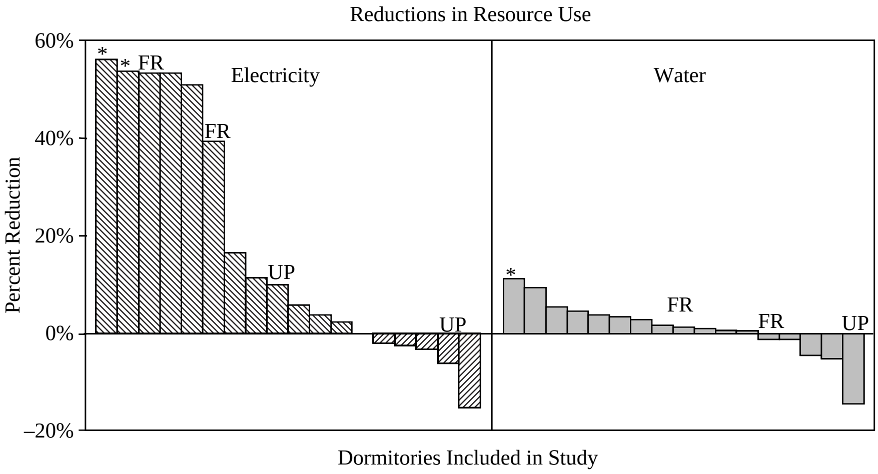
Table I.
Economic and ecological costs of resource use in Oberlin, Ohio

average light intensity between baseline and competition periods (129 vs 134 W/m^2, respectively). Since, outdoor light and temperature conditions were so similar, the discussion and conclusions of this study assume that differences in dormitory resource use between baseline and competition periods are attributable to changes in student behavior in response to the combination of the competition, educational materials and feedback technology. Temperature and outside light intensity had changed considerably by the post-competition period. During the post-competition period temperature had risen to an average of 52°F and light intensity had risen to an average of 224 W/m^2 (a 73 percent increase in light intensity from the baseline period). The analysis therefore assumes that changes (or lack of changes) in electricity use between the competition period and the post-competition period are some unknowable combination of seasonally driven differences in demand and continued conservation on the part of the students.

Resource use reductions in response to manipulation

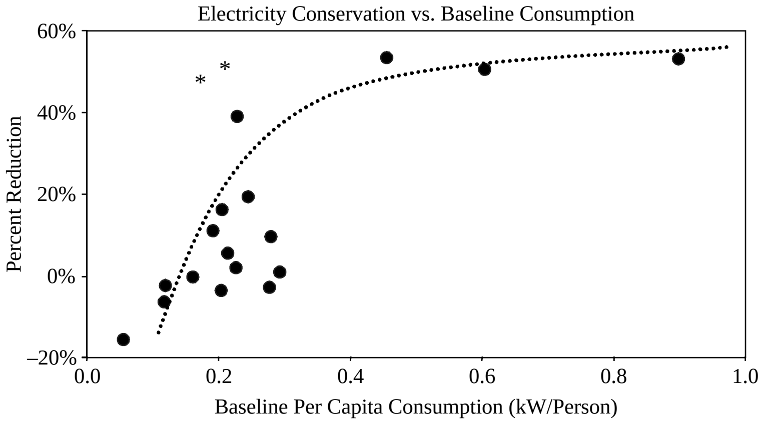
Electricity use decreased substantially between baseline and competition periods (Figure 3). The rate of per capita dormitory resident electricity consumption averaged over all 18 dormitories included in the study was 367 W during the baseline period and 250 W during the competition period, representing a 32 percent overall reduction in electricity use in these dormitories. In general, dormitories that had the highest per capita baseline electricity consumption tended to exhibit the highest percent reductions during the competition (Figure 4). A total of 68,300 kW h of electricity were saved by these 18 dormitories during the two-week competition period. The winning dormitory reduced electricity consumption by 56 percent.

The highest electricity reductions were observed in the two dormitories in which the high resolution data monitoring systems were installed. Average electricity reduction in these high-resolution feedback dormitories was 55 percent, compared to an average of



Notes: In each category, dormitories are sorted from highest to lowest percent reductions. Dormitories with a negative value for reduction increased their use. Symbols are used to identify dormitories receiving high-resolution feedback (*) and those that exclusively house freshman (FR) and upperclassmen (UP)

Figure 3.
Percent reductions in electricity and water use between baseline and competition periods for all dormitories included in the study



Notes: The two dormitories marked by * symbols are those that received high-resolution feedback. As indicated by the best fit line, electricity reductions achieved a maximum value a little above 50%. One dormitory that extended beyond the scale is excluded from this graph

Figure 4.
Percentage reduction in electricity use between baseline and competition periods for each dormitory in the study as a function of per capita electricity use during baseline period

31 percent for low-resolution dormitories. Within the two high-resolution feedback dormitories, there was no clear difference in electricity reductions among students who had the electricity use of their individual floor displayed on the web site and those who did not have their individual floor's electricity displayed. It is also worth noting that the two exclusively freshman dormitories on campus exhibited relatively high electricity reductions (average = 46 percent), while the two exclusively upperclassman dormitories exhibited anomalously low electricity reductions (average = 2 percent). Despite significantly warmer and brighter days, the average rate of dormitory electricity consumption during the post-competition period was similar to consumption levels during the competition period (241 vs 250 W/person, respectively).

Reductions in water use were considerably less than reductions in electricity (Figure 3). Between baseline and competition periods, the overall per capita rate of water consumption fell from 37 to 35 gal/student/day. This 3 percent reduction amounted to a two-week savings of 20,500 gal in the 17 dormitories included in the water component of this study. The winning dormitory reduced its water consumption by 11 percent.

Total financial and environmental savings and financial payback

The 68,300 kW h of electricity saved by all dormitories during the two-week period when feedback was provided translates to cost savings of $5,107 (see Table I for conversion factors). The 20,500 gal of water conserved during the competition period represents savings of $261 in freshwater and wastewater fees. Combined, electricity and water savings totaled $5,368 for the two-week competition period. This represents a $3.08 per student savings in utility bills for the two-week competition period. Pollution equivalents can be calculated based on the mix of electrical generation facilities in the local electrical grid (Table I). Since, Oberlin is in a region of the country dominated by coal-fired power plants, pollution intensity savings from electricity conservation are particularly large. Based on savings of 68,300 kW h of electricity, the two-week competition period resulted in averted emissions of 148,000 lbs of CO_2, 1,360 lbs of SO_2 and 520 lbs of NO_x.

Ten thousand US dollars were spent in equipment costs to instrument the two high-resolution feedback dormitories in this study. Assuming a more conservative installation cost of \$10,000 per dormitory, it would cost \$250,000 to install high-resolution, real-time feedback systems for all 25 dormitories on campus. In 2004, annual combined electricity and water bills for Oberlin dormitories were \$657,400. If the 20 percent savings in the monetary costs of combined utilities experienced by dormitories during the competition period of this study could be sustained over all dormitories, the technology would pay for itself in less than two years. However, since the savings took place in the context of a competition among dormitories it seems reasonable to assume that sustained resource use reductions would be considerably lower than 20 percent. With sustained utility savings of 5 percent in response to feedback, the system would pay for itself in less than eight years. In terms of pollution, at current pollution intensities (Table I), a 5 percent electricity savings in dormitories sustained over all Oberlin dormitories for a ten-year period would prevent 4,300,000 lbs of CO_2, 40,000 lbs of SO_2, and 15,000 lbs of NO_x from entering the atmosphere.

We directly measured the electrical power necessary to run the datalogging devices, the server computer and the three monitors used to display electricity in the lobbies of the two high-resolution dormitories. Consumption of these devices was less than 600 W. The authors assume that students who viewed the Dormitory Energy web site would probably have been using their computers anyway, so this electricity consumption is ignored. The monitoring/feedback system itself consumed energy at a negligible rate equivalent to 0.3 percent of the rate of electricity savings during the competition period (in terms of electricity consumption, the monitoring/feedback system paid for itself in electricity savings during the first hour of the competition).

Utilization of feedback by dormitory occupants

The number and identity of visitors to the Dormitory Energy web site provide a measure of the degree of interest and utilization of feedback. This web site received a total of 4,082 hits during the two-week competition period (a "hit" is defined as each single visitation to a web address). These visits were made by 1,036 unique computers and 835 of these computers were registered to dormitory residents. This means that 46 percent of dormitory residents viewed the web site on computers they own and likely use in their rooms. The authors assume that many of the hits to the web site were also from dormitory residents who did not own a computer or for other reasons chose to view data in computer laboratories on campus. Residents of the high-resolution feedback dormitories showed greater interest in feedback, visiting the Dormitory Energy web site an average of 4.8 visits/resident compared to 2.5 visits for the low-resolution group. Although the existence of the Dormitory Energy web site was not publicly advertised to audiences outside of the college, during the two-week competition the site received 181 visits (4 percent of the total visits) from computers that were not registered on the campus network as belonging to Oberlin students or faculty. When the competition period ended, all advertising ceased and the lobby monitors were removed. However, real-time electricity consumption data continued to be updated on the Dormitory Energy web site during the post-competition period and interest in the real-time data on the web remained high. During this two-week period the web site received a total of 1,187 hits (29 percent as much interest as during the competition).

Survey results

About 418 students (23 percent of students in participating dormitories) completed the online post-competition survey. Unfortunately, mid-way through the survey period an error was discovered in the wording of two key survey questions related to strategies for electricity and water conservation. As a result, the authors of this study excluded 200 responses to the affected questions from analysis. Survey results indicate that students used a variety of strategies to conserve electricity. The most popular strategies included (percentage utilizing each strategy included in parentheses): turning bathroom lights off when unoccupied (71 percent), keeping lights off when dormitory rooms were unoccupied (70 percent), using natural lighting during the day (59 percent), shutting off computer monitors while not in use (50 percent), using less hot water in showers and clothes washing (45 percent), turning off hall lights (42 percent), and turning computers off when not in use (39 percent). Students reported feeling that some of the practices employed during the competition (e.g. being conscientious about turning off lights and computers) could be sustained beyond the competition, while others (e.g. unplugging vending machines and turning off hallway lights at night) were not. A majority of students agreed with the statement that they were likely to continue to employ new strategies for electricity conservation that they adopted during the competition both within Oberlin dormitories (52 percent agree, 22 percent disagree) and outside of Oberlin dormitories (51 percent agree, 25 percent disagree). 35 percent of the text comments on electricity conservation were statements to the effect that the student was already employing the listed conservation practices before the competition began.

The most popular strategies used to conserve water included (percentage reported included in parentheses): ensuring that faucets were not dripping (55 percent), taking shorter showers (48 percent), turning off water while brushing teeth (48 percent), washing clothes less often (35 percent), taking fewer showers (27 percent), and flushing toilets less frequently (26 percent). There was considerable division over the issue of toilet flushing; 17 percent of the text comments on water conservation were complaints that not flushing was an unacceptable method of water conservation. More students agreed than disagreed with the statement that they were likely to continue to employ new water saving strategies adopted during the competition while at Oberlin (42 percent agreed, 25 percent disagreed). 44 percent reported an intention to continue these water conservation strategies outside of Oberlin dormitories.

Student respondents to the survey generally stated that feedback on the web site was interesting and motivating. Students were particularly interested in real-time (i.e. high-resolution) feedback; 55 percent of survey respondents agreed with the statement that they would choose to view graphs and gauges depicting real-time consumption data on a web site even if no competition were in progress. 45 percent of students agreed with the statement that the availability of real-time data on resource use within their dormitories would motivate them to conserve resources (31 percent disagreed).

Discussion

Results of this study provide strong evidence that, when supplied with information on the environmental consequences of resource use, an incentive and easily accessible web-based feedback, students can substantially decrease electricity use in dormitories. The survey results, together with the dramatic reductions in electricity use, suggest that students were engaged by the accessibility of data and were inspired to think about their personal and collective resource use in ways that may have lasting consequences and extend beyond the campus. Individually and collectively, dormitory residents engaged in the act of teaching themselves how to conserve resources. Indeed, a number of students reported that, in response to the competition and feedback, their entire dormitories held planning sessions to brainstorm on ways that they could lower resource use. Others reported ongoing e-mail-based discussions of resource reducing strategies among dormitory residents. In the end, a relatively small number of students from the winning dormitories actually attended the ice cream party that served as the advertised reward for winning dorms (a rough head-count indicated less than 10 percent attendance). This lack of attendance suggests that factors other than the incentive of a reward were responsible for the changes in behavior. Further study is necessary to determine the degree to which behavioral change resulted from feedback, education, competition and the reward, or the combination of these factors.

Students in both high- and low-resolution feedback groups substantially reduced electricity use. However, the data indicate that students who received high-resolution feedback in the form of real-time depictions of their electricity consumption demonstrated greater interest in receiving feedback and were more effective at conserving resources then dormitory residents who received only weekly updates on electricity consumption in their dormitories. The fact that students in the high-resolution feedback group with access to real-time data on their own floor's electricity use did no better at conservation than fellow dormitory residents who were not provided with electricity use by floor suggests that real-time feedback at the scale of whole dormitories may be sufficient to stimulate resource conservation. On the other hand, had the competition been constructed between floors, then perhaps real-time feedback at the scale of individual floors would have influenced the outcome. In a general sense, the findings suggest that the resolution of feedback should be carefully linked to the particular structure of the feedback and reward mechanisms. For example, if housing residents were billed for electricity consumption within individual apartments or rooms, then the level of feedback best suited to eliciting resource conservation would likely be short-term electricity use within individual apartments and rooms.

The purpose in monitoring resource use during a post-competition period was to assess the lasting effects of feedback. One plausible hypothesis that the authors of this study considered at the outset was that resource use would increase during this period since both the competitive incentive and the low-resolution feedback were removed. Another possibility that was considered was that resource use would remain low because students would continue to exhibit the conservation practices that they developed during the competition. In fact, electricity use slightly decreased between the competition and post-competition periods. Although substantial increases in outdoor light and temperature confound clear interpretation of this trend, the sustained low electricity consumption during the post-competition period is at least consistent with continued conservation on the part of students.

An obvious question emerging from the results of this study is, why were dormitory residents so much less successful at conserving water than electricity (Figure 3)? There are ranges of possible answers to this question. One simple possibility is that the advertising for the competition placed greater emphasis on electricity; the event was titled and advertised as the “Dormitory Energy Competition,” and the web site was titled the “Dormitory Energy” web site. A second possibility is that the lack of any high-resolution, real-time feedback on water for any of the dormitories decreased interest and made it difficult for students to effectively strategize on saving water. A third possibility is that it is more difficult for students to modify their water use behavior than it is for them to modify electricity use. Further research, in which real-time data are made available for water consumption, is necessary to determine the validity of each of these possible explanations.

Achieving maximum reductions for an investment in feedback technology

The results of this study suggest that, at least at Oberlin College, there is a good potential financial return on investment in data monitoring and display technology. Even for those who choose not to employ feedback technology, a number of findings from this study should be of interest. Specifically, the results of this study suggest that efforts to reduce resource use in dormitories should focus on inefficient dormitories, on large dormitories and on freshman dormitories.

Community engagement was clearly essential to the success of efforts to reduce resource use in dormitories. A very intriguing finding was that dormitories dominated by first-year students tended to be more successful at conserving electricity than those dominated by upperclassmen (Figure 3). One possible explanation that was suggested by student members of the research team is that freshman dormitories tend to develop a stronger sense of community than dormitories dominated by upperclassmen. Consistent with this explanation, in the post-competition surveys, first-year students were more likely to report participation in collaborative efforts with their fellow dormitory residents to conserve resources. The fact that freshmen are more responsive to feedback is an excellent reason to focus special attention on this group. An equally important reason is that it is possible (though as yet unproven) that once these students have taught themselves conservation techniques they will continue to exhibit these techniques throughout their academic stay and beyond.

Transferability of technology and approach

Oberlin College has a national reputation for having a strong environmental studies program and may therefore attract a student body that is somewhat predisposed towards a positive response to the type of feedback provided in this study. Nevertheless, the authors of this study believe that computer-based real-time socially comparative feedback that includes education on the environmental impacts of resource use, similar to that employed in this Oberlin study, could be used to stimulate resource use reductions at other colleges and in other multi-family residential settings. Based on the interest expressed by those outside of Oberlin College, others appear to agree. Since, work on this project began, students and facilities personnel at educational institutions ranging from grammar schools to small colleges to large universities have contacted the authors of this study to inquire about employing similar technology on their campuses. Within the private sector, several developers/managers of apartment complexes have also contacted the authors to explore how feedback technology might be employed in this context. For example, a "green" developer in downtown Oberlin would like to incorporate data monitoring and display systems into a new building project, so that individual apartment residents can view their resource use in real-time, track how it changes, and compare their use over time and with that of other apartment owners. The authors of this study assisted an environmental organization in New York City that is working on a grant that would use this type of technology to monitor and display resource use in an entire city block of apartments. These groups see socio-technical feedback technology as a tool that can be harnessed to achieve the combined goals of educating members of the community, motivating and empowering building occupants to save money on utility bills, and advancing the goal of environmental sustainability.

Conclusions

The results of this research provide evidence that it is possible to create resource feedback systems that, when combined with education and incentives interest, motivate and empower college students to reduce resource use in dormitories. However, the authors of this study fully acknowledge that the limited number of dormitories receiving high-resolution feedback, the short duration of the study, and the combination of causal factors make it difficult to draw firm conclusions about the impact of such a system on the long-term knowledge, interests, attitudes, values and behaviors of dormitory residents. A broader scale, longer-term study is necessary to accomplish this. Towards this end, a real-time monitoring and display system is currently being completed at Oberlin College that will include a total of 28 dormitories and student houses. A broader team of researchers has also been engaged that includes members with expertise in environmental psychology and in the sociology of resource conservation so that future research can better quantify long-term relationships between feedback, attitude and behavior.

Technologies aimed at increasing resource use efficiency are not likely to solve environmental problems by themselves. Ultimately, changes in attitude and lifestyle are essential to reducing resource use and bringing about a more sustainable relationship between humans and the rest of the natural environment. Unsustainable relationships between people and the environment are at least partially attributable to ignorance and alienation between humans and the resource flows on which our cultures depend. The feedback technology described in this paper is distinct from many other “green” building technologies in that it is specifically designed to break down this alienation by making people more aware of the resource flows that support their daily activities.

The emerging green building industry has placed a great deal of emphasis on developing and deploying so-called “smart building” control technology. This technology is designed to maximize resource conservation by shifting control decisions from sometimes unpredictable building occupants to sophisticated building automation systems. On one hand, resource savings from this strictly technological approach have been demonstrable. On the other hand, smart buildings remove management decisions and the thinking that goes with these decisions such that building occupants are at best only passively engaged and uninformed about the importance of resource conservation. For this reason, it could be argued that “smarter” buildings may lead to environmentally dumber people. Furthermore, the vast majority of building stock in the US is comprised of older structures which are not easily upgraded with smart building control technology. In marked contrast to smart building technology, the type of socio-technical information feedback system described in this paper is specifically designed to encourage building occupants to teach themselves how to conserve resources by engaging them in resource conservation decision making. Indeed, the technology incorporates humans as a critical component of an overall feedback system that is designed to minimize resource use. In contrast to the smart building philosophy, here the objective is to construct environmentally smarter people in what are often environmentally and technologically dumb buildings.

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