FOSTERING SUSTAINED ENERGY BEHAVIOR CHANGE AND INCREASING ENERGY LITERACY IN A STUDENT HOUSING ENERGY COMPETITION

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Abstract

The world is in the grip of a crisis in the way energy is produced and consumed. Climate change represents a huge threat to the modern way of life, particularly for island communities like Hawaiʻi. Many changes to our energy system will be required to resolve the crisis, and one promising part of the solution is reducing energy usage through changes in behavior. Energy usage in similar homes can differ by a factor of two to four times, demonstrating the potential contribution of behavior change to the crisis.

This research project seeks to find ways to foster sustainable changes in behavior that lead to reduced energy usage. The research will be conducted in the context of a dorm energy competition on the UH Mānoa campus in October 2010. Power meters will be installed on each floor of two freshmen residence halls. Each floor will compete to use the least energy during the 4 week competition.

A competition website will be created, where participants can log in to view near-realtime data about their floor's power usage, and also select from a variety of tasks to perform. Each task is designed to increase the participant's *energy literacy* (knowledge, positive attitudes, and behaviors related to energy), and a certain number of points are assigned for the completion of each task. The points provide a parallel competition to motivate participants to perform the tasks. Prizes will be awarded to floors using the least energy, and participants obtaining the most points.

Several research questions will be investigated using the data collected, including how energy usage changed after the competition is over, whether the website tasks affected energy literacy, and whether floors that had higher energy literacy had more sustained energy conservation after the competition was complete. The research questions will be investigated using energy data from the meters, log files from the website, and an energy literacy survey administered before and after the competition.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

The world is in the grip of an energy crisis. Fossil fuels (oil, natural gas, and coal) form the foundation of the world economy and their use is largely responsible for the industrialization and standard of living increases across the globe in the past century. However, the consumption of fossil fuels has led to a variety of problems that will have severe impacts on our environment and national economies.

There is no 'silver bullet' that will solve this energy crisis, it will require a series of changes in production, transmission, and consumption of energy taking place over decades. While we will need to switch to renewable energy sources, energy conservation is also an important strategy since a reduction in energy demand makes the transition to renewable sources easier. This research examines how to motivate people to conserve electricity by changing their behavior in the context of a university dormitory energy competition.

1.1 Climate Change

The primary motivation for reducing fossil fuel use is climate change. In 2007, the Intergovernmental Panel on Climate Change (IPCC) released its fourth assessment report [6]. The conclusions of this long-running analysis of studies on climate change and its effects are widely accepted as the consensus of the world's scientific community. They found that there is broad agreement that the climate is warming: air and ocean temperatures are higher, snow and ice are melting, and sea levels are rising. Further, natural systems are being affected: plant and animal ranges are moving towards the poles, and there are changes in fish and algae due to rising ocean temperatures.

The IPCC found that the warming of the climate was very likely due to anthropogenic greenhouse gas (GHG) emissions. GHG emissions from humans have increased by 70% between

1970 and 2004. While there are a variety of GHG that impact climate change, CO_2 is the most important of the human-caused GHGs. Sea level rise in the second half of the 20th century was also very likely caused by humans, and rising sea levels have a potentially enormous impact on island communities like Hawai‘i.

The IPCC found that with current climate change policies, GHG emissions are projected to continue to increase this century. Further, there is no single technology that will mitigate the problem of climate change; a range of policies and innovations is required. The report lists both energy efficiency and individual behavior modification as suggested GHG mitigation strategies.

1.2 Energy Conservation

One way fossil fuel use can be decreased is by decreasing the total amount of energy consumed. Socolow and Pacala have proposed a plan for reducing global GHG emissions to acceptable levels through the implementation of a series of ‘wedges’, where each wedge represents a reduction of 25 billion tons of CO_2 emissions over 50 years [43]. One of the 15 wedges they proposed is to cut electricity use in homes, offices, and stores by 25%. On a local level, the state of Hawai‘i has created the Hawai‘i Clean Energy Initiative, which seeks to reduce Hawai‘i’s fossil fuel use by 70% by 2030 through increasing the use local energy sources (for electricity and transportation fuel) to 40% of demand and reducing demand by 30% through efficiency and conservation [31].

Amory Lovins coined the term *negawatt* to refer to power that has been conserved, and therefore, does not need to be generated [24]. Negawatts can be ‘generated’ in two basic ways: by increasing the efficiency of devices that consume energy, and by changing people’s behavior reduce energy use.

1.2.1 Energy Efficiency

Many energy consuming devices have become more efficient over time. For example, incandescent light bulbs are increasingly being replaced with compact fluorescent bulbs that produce an equivalent amount of light but use only 20–30% of the energy. The negawatts generated through use of more energy efficient devices have the primary advantage of not changing the functionality of the device: a more efficient refrigerator keeps food cold just as well as a less efficient one.

While energy efficiency holds significant potential for reducing energy demand, it usually involves replacement of energy-consuming devices. This involves the cost of the new device, and the environmental cost of disposing of the old device, which means that efficiency upgrades often make most economic sense when the old device needed to be replaced for other reasons such as age or wear. There are also many environments, such as offices and rental housing, where the occupants have little control over the energy-consuming devices that are used.

1.2.2 Behavior Change

Changing people's behavior with respect to energy holds significant promise in reducing energy use. Darby's survey of energy consumption research found that identical homes could differ in energy use by a factor of two or more [9]. Data from a military housing community on Oahu show energy usage for similar homes can differ by a factor of 4 [32].

One common way to attempt fostering behavior change is by providing information to the targeted population, often through mass media. While convenient, this approach often turns out to be ineffective [29]. Two strategies that have proven to be effective are providing direct feedback on energy usage [9], and a toolbox of techniques such as making public commitments and establishing social norms [29].

1.3 Research Description

This research project seeks to find ways to foster sustainable changes in behavior that lead to reduced energy usage. As discussed previously, changing behavior related to energy has the potential to be a major contribution towards reducing energy use. However, to be a significant contribution, these behavior changes must be sustainable in the long term.

1.3.1 Setting

This research is based around a dormitory energy competition at the University of Hawaiʻi at Mānoa. These types of competitions have become increasingly common on college and university campuses. Dorms compete to see which one can use the least energy over some period of time, often with prizes for the winning dorm. Unfortunately, there is some evidence that participants engage in unsustainable behaviors (such as keeping hallway lights off at night) in order to win the competition, but return to previous behaviors after the competition is over [37].

1.3.2 System

The dorm energy competition will take place over 4 weeks in October 2010 in two freshman residence halls on the UHM campus. Power meters will be installed on each floor of each building and the power and energy data will be recorded every 10 to 15 seconds. Since each floor has its own meter, each floor will compete to have the lowest energy consumption during the competition.

A website is being built that will provide information about the competition to the participants. Participants will log into the website with their UH username and password, and each participant will see a personalized home page that displays data such as his or her floor's power usage in near-realtime, their floor's cumulative energy usage for the competition, and their floor's ranking in the competition. The website has been designed to take into account the research in environmental psychology about how to foster behavior change.

The other major feature of the competition website is to make a variety of tasks available to the participants. The tasks are designed to either increase the *energy literacy* of the participant, or help reduce the energy consumption of the floor, or both. Energy literacy is composed of knowledge, positive attitudes, and behaviors related to energy. An example of energy knowledge would be the difference between a watt and a watt-hour, an example of a positive attitude would be "Americans should conserve more energy", and a positive behavior would be turning off lights when leaving a room [12]. The tasks are divided into three different types: activities, commitments, and goals.

Associated with each task is a number of points, called Kukui Nut points. When a participant performs a task, such as determining the amount of power each device in their room consumes, they can submit information on the website demonstrating their completion of the task. In the case of the power audit, the information might be the list of devices in their room and the power consumption of each device. Once a website administrator verifies the information, the participant is awarded the points assigned to the completed task. These website tasks create a second parallel competition to see which participants can accumulate the most points.

A variety of prizes will be provided both for the energy conservation side of the competition, and the point competition. This prize structure provides an additional motivation for the residents to participate in the competition.

1.3.3 Research Questions

The research focuses on descriptive and exploratory statistics based around research questions. The research questions that will be investigated are:

- *To what extent was the website adopted by the participants?* Without significant adoption, it is hard to evaluate the other website-related questions.
- *How did energy use change during the competition?* This is the standard measure for an energy competition, with the expected result being energy conservation during the competition.
- *How did energy use change after the competition?* Understanding changes in energy use after the competition is over gives insight into whether changes during the competition were sustainable. Existing research focuses primarily on the competition itself, not examining the reasons why energy usage might rebound after the competition is over.
- *How effective were the tasks available via the website?* The tasks participants undertook can be tracked using website log data and compared to changes in their energy literacy.
- *How appropriate were the Kukui Nut values assigned to tasks?* The Kukui Nut points assigned to tasks are intended to motivate participants to perform the tasks, but the values were assigned without any participant data.
- *What is the relationship between energy literacy and energy usage?* The hypothesis is that more energy literate participants will conserve more energy.
- *How important was floor-level near-realtime feedback?* There are good reasons to believe that floor-level near-realtime feedback will lead to increased energy conservation, but they greatly increase the competition budget and logistical complexity. Is the trade-off worth it?

1.3.4 Evaluation

There are four primary sources of data available to examine the research questions:

- power and energy data from each floor,
- detailed event logs from participant actions on the website,
- participants' performance on an energy literacy survey to be administered before and after the competition,

- and a survey on the competition as a whole to be administered after the competition.

This rich dataset allows the examination of several relationships. The energy data alone provide insight into what effect (if any) the competition had on participants' energy usage, particularly to what degree energy use rebounds after the competition is over.

The combination of the website log data and the pre- and post-competition energy literacy scores sheds light on whether the tasks available on the website led to increased participant energy literacy, and if so, which tasks were most effective.

Finally, the combination of the energy usage data and the energy literacy scores allows look at the hypothesis that those floors that were more energy literate conserved more energy, both during and after the competition.

1.4 Outline

The proposal is organized into the following chapters:

- Chapter 2 looks at related research, including dorm energy competitions, energy feedback, and psychological techniques for fostering behavior change.
- Chapter 3 describes the system we will be evaluating, which includes the dorm energy competition, and the associated website.
- Chapter 4 lists our research questions and explains our plan to evaluate them.
- Chapter 5 concludes the proposal with a list of anticipated contributions and future directions.
- Appendix A covers the definitions of power and energy, and their interrelationship. Understanding these two concepts is critical to understanding the evaluation (and an important part of energy literacy).
- Appendix B lists the set of tasks to be made available to participants through the website to improve their energy literacy.
- Appendix C provides a Hawai‘i-specific survey designed to assess the energy literacy of participants.
- Appendix D contains questionnaire to be administered to participants after the competition has ended.

Chapter 2

Related Work

This chapter examines prior research in this area, and related systems and technology. It starts with a discussion of dorm energy competitions, then energy feedback research and related systems. Then we move into psychological aspects and design research.

2.1 Dormitory Energy Competitions

Energy competitions in residence halls have become a popular event at colleges and universities. The residence halls compete to see which building will use the least energy over a period of time. Some competitions pull in other aspects of environmental sustainability, including reducing water usage, reduced waste production, etc. The competitions tap into both the residents competitive urges, and the interest in environmental issues. However, unlike a home environment, the residents do not financially benefit from any reduction in electricity use resulting from their behavior changes, since residence hall fees are flat-rate and do not change based on energy usage. This leads to residents being completely unaware of their energy usage, since they lack even a monthly bill as feedback.

The most basic type of energy competition website displays energy data which is updated manually on a periodic basis (such as weekly). The Wellesley College Green Cup [40] is an example of this type of competition.

Other schools have more complicated and interactive competition websites, such as the early adopter Oberlin College. Petersen et al. describe their experiences deploying a realtime feedback system in an Oberlin College dorm energy competition in 2005 [37]. 22 dormitories were in competition over a 2 week period, with 2 dorms having feedback updates every 20 seconds, and the other 20 getting updates every week. The realtime dorms also recorded electricity usage for each of the three floors, but only displayed the data from two of the floors, leaving the third as a control.

Web pages were used to provide feedback to students, since they all have computers and Internet access in their rooms. They found a 32% reduction in electricity use across all dormitories, with the 2 realtime feedback dorms reducing usage the most. Freshman dorms were among the highest electricity reducers, while upperclassman dormitories were quite low (average 2% reduction). During a 2 week post-competition period, the average electricity usage was similar to consumption levels during the competition. However, the weather was warmer and there was more sunlight during the post-competition period, so it is unclear if the reduction was competition-related.

In terms of participation, Petersen et al. found 46% of residents looked at the competition website at least once (based on web server logs mapping IP addresses to residence halls). 23% of dormitory residents filled out the online post-competition survey. Survey respondents indicated that some behaviors, such as turning off hallway lights at night and unplugging vending machines were not sustainable outside the competition period.

2.2 Energy Feedback

As Lord Kelvin is famously reputed to have said, “If you can not measure it, you can not improve it.” In the case of electricity usage, for many people the only feedback they receive is a monthly bill detailing the number of kilowatt-hours used over the course of the last month. Ed Lu of Google analogizes this as if there were no prices on anything at the grocery store, and shoppers were just billed at the end of the month [21]. Office workers or dormitory residents might never see any feedback on how much electricity they are using!

To reduce energy use, people must know how much energy they are is using. Feedback systems display the consumption of a resource (such as electricity) to the user, usually in real time. Darby provides a detailed survey of studies on electricity feedback systems from the past 3 decades [9]. The survey of 20 studies finds that, on average, the introduction of a direct (real-time) feedback system leads to reductions of energy usage ranging from 5-15%. Feedback systems providing historical data (such as those provided with billing statements) are not as effective (0-10% reductions), but can be useful for assessing the impact of efficiency measures such as improved insulation or a more energy efficient appliance, since those savings accumulate over time.

Darby found that “consumption in identical homes, even those designed to be low-energy dwellings, can easily differ by a factor of two or more depending on the behaviour of the inhabitants.” This finding demonstrates the significant potential to curb energy usage through changes in individual’s behavior.

Another survey of energy feedback was conducted Faruqui et al., looking at 12 utility pilot programs that installed in-home displays with near-realtime feedback [17]. They found that customers that actively used the display averaged a 7% reduction in energy usage, while those pilot programs that included pre-paid electrical services reduced their energy usage by 14%. The sustainability of the energy reduction is unclear based on the pilot studies since they were of limited length. The authors believe it is unknown whether the residents of homes with displays will acclimate to the display and cease to use it to reduce their energy usage.

Darby also points out that while feedback is critical for energy conservation behaviors, feedback alone is not always enough [8]. Other factors that lead to higher rates of energy conservation include contact with an advisor when needed, and training and social infrastructure.

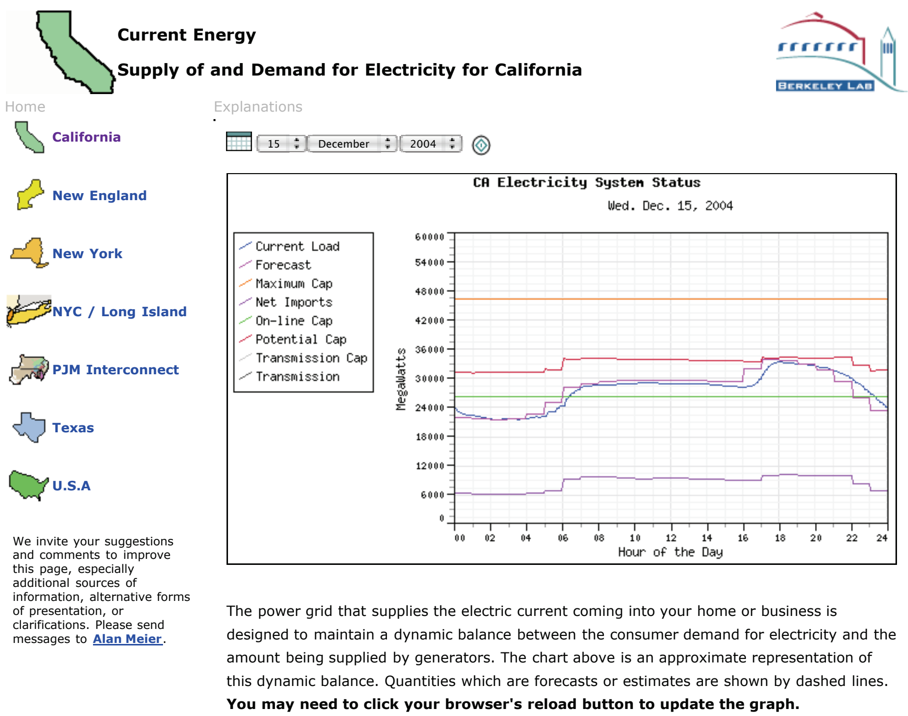
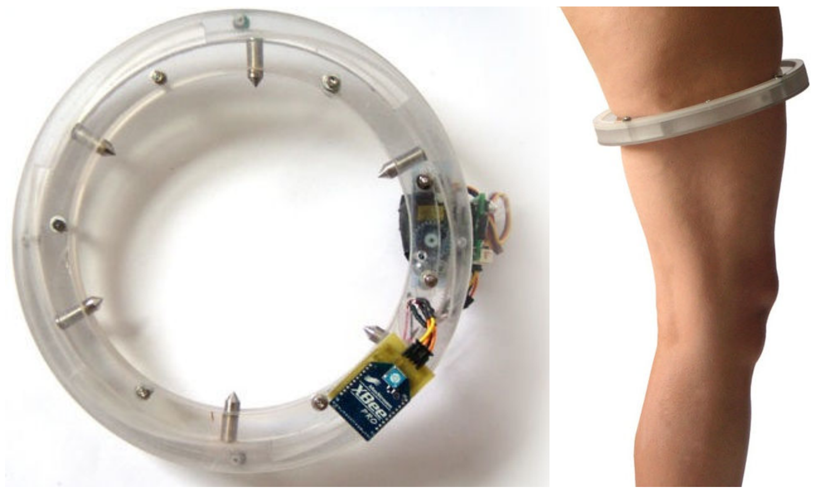


Figure 2.1. View of LBNL's Current Energy Web Site on December 15, 2004

During California's energy crisis in 2000 and 2001, Lawrence Berkeley National Laboratory created a web site that graphed data from utility organizations [2]. The graphs showed consumer demand for electricity (actual and forecast), and the utilities' generation capacity (see Figure 2.1 for an example graph). Darby reports anecdotal evidence that people viewing the graphs changed their electricity usage based on the data [9].

There is also evidence that just the knowledge that one is being monitored can cause one to consume fewer resources. A group of researchers simulating a mission to Mars or the Moon in the Canadian Arctic for four months tracked the crew members' water usage [1]. Water usage was monitored via automated meters during the entire mission, but during certain multi-day study periods, crew members were also required to manually log their water usage at the point of use. The authors found that water usage was 10% less during these study periods. The reduced water usage could be due to the knowledge that the usage was being examined more closely, or perhaps the extra effort required to manually record their water usage led to crew members reducing non-essential water use (see subsection 2.3.3 for another possible benefit to manual data collection).



(a) Device itself (b) As worn on leg

Figure 2.2. Thighmaster energy feedback mortification device

Rüst has implemented an extreme energy feedback system called the Thighmaster [39]. Inspired by the cilice (a small metal garter with inward facing spikes) worn by some members of the Catholic Opus Dei organization as part of a practice of mortification, the Thighmaster is a "techno-garter" that pokes the wearer with spikes when their actions are not environmentally responsible (as defined by Rüst), see Figure 2.2 for a depiction of the device. Specifically, the Thighmaster communicates wirelessly with electricity usage sensors and a human speech sensor that monitors whether the user speaks with their plants. While more of a demonstration, the Thighmaster shows the complex emotions involved in people's reactions to climate change. It goes without saying that being pierced by spikes is unlikely to be a viable energy feedback mechanism for most users.

2.3 Related Systems

In this section we examine other systems that have been designed to help users become more aware of their environmental impact, or make environmentally-positive behavior changes.

In a position paper, Sutaria and Deshmukh describe using networks of ad hoc sensors to monitor both electricity usage and miles driven by automobile, while providing real-time feedback to the user [47]. The system described would compare the household's energy usage with others in similar situations. They envision smart energy meters that can also provide suggestions on how users can reduce their energy usage. They also mention the possibility of integrating personal carbon trading (a sort of carbon cap-and-trade system for individuals) into the system. The system described by Sutaria and Deshmukh appears to be hypothetical at this point.

2.3.1 StepGreen

StepGreen is a web application designed to encourage people to undertake environmentally responsible actions [45]. Mankoff et al. have written about the rationale for the system and description of the design, presumably written before the site was active [28] . The paper introduces the fact that, in the U.S., half of a person's energy consumption is their control. Therefore, by modifying their behaviors, Americans can affect up to half their CO_2 emissions. StepGreen (also known as Footsteps, possibly an earlier name for the system) is designed to leverage online social networks to motivate personal change, by providing suggestions for improvement.

The StepGreen system is currently open to the public. Figure 2.3 shows an example of the default page shown when a user logs in. Users create an account on StepGreen, and then are presented with a list of actions with positive environmental consequences (mostly reduced GHG emissions). Example actions are "Turn off the lights when you exit the house in the morning for the day", "Take the stairs at work", and "Set your home computer to automatically hibernate/sleep after a short period of inactivity". Each action is associated with its cost savings and reduction in CO_2 emissions. Users can get more information about the action and how the savings were calculated. For each action, users can indicate whether they are already performing that action, whether they commit to undertaking that action, or whether the action is not applicable to them. Users can create new actions to be added to the list, but since the new actions have not been analyzed by the site maintainers, the financial and CO_2 savings are listed as unknown.

Once users have selected actions that they are either already performing or commit to performing, they can track them on the Reporting page. For one time actions, such as replacing

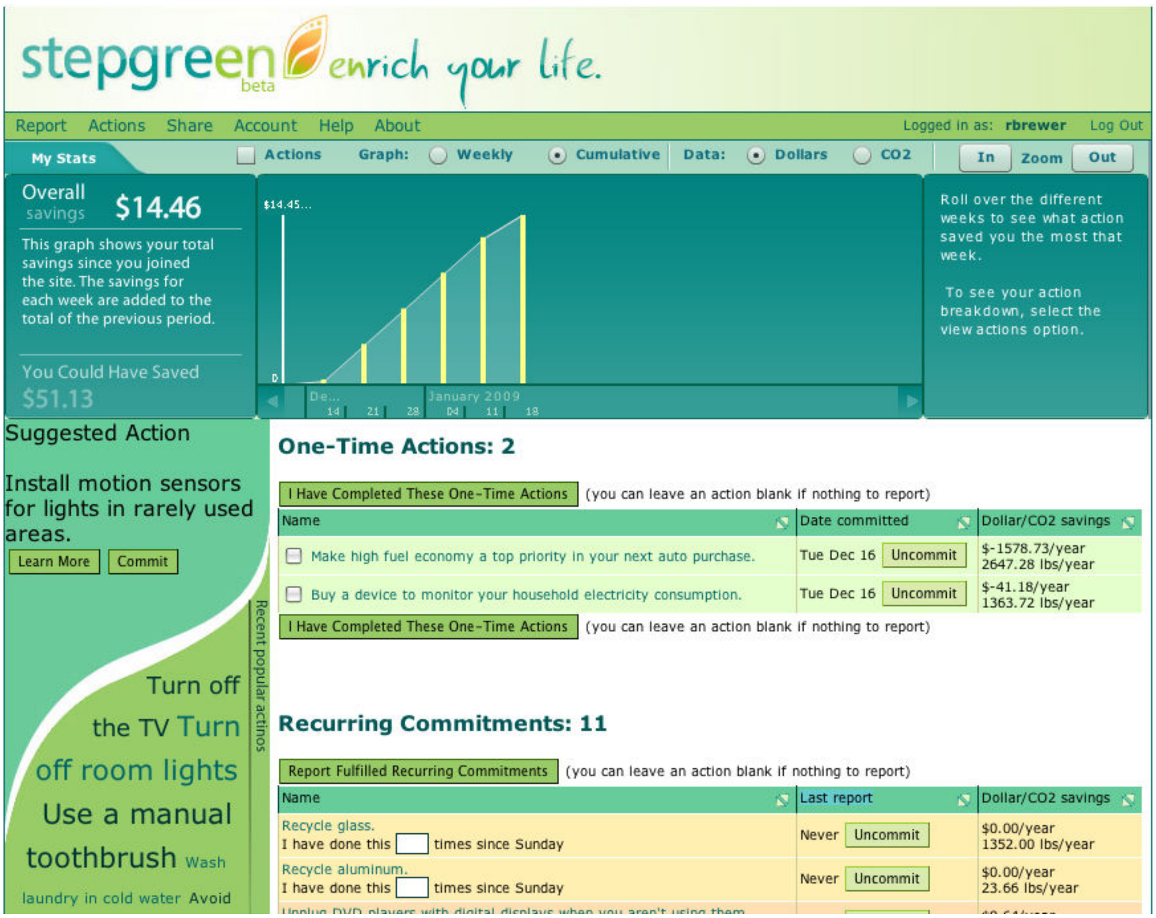


Figure 2.3. Example page from StepGreen website

an incandescent light bulb with a compact florescent bulb, users simply check off when they are completed. For recurring actions, users must indicate how many times they have performed the action since their last report in order for the system to track the activities. Based on the user's self-reporting, StepGreen calculates the amount of money saved, pounds of CO_2 saved (i.e., reduced), and missed pounds of CO_2 saved, and provides a historical graph of these values.

StepGreen also provides links to social networking sites. They provide a linked Facebook application, a MySpace profile widget, and a connection to Twitter. Each of these links provides a way to inform the user's social network about what actions the user is undertaking. This feature can serve to recruit other people to use StepGreen, provide comparisons on financial and environmental savings among peers, and encourage users to keep to their StepGreen commitments.

StepGreen provides a useful platform for research on convincing users to change their behavior to reduce their carbon footprint. For example, a virtual polar bear was implemented to motivate users to reduce their carbon footprint (see subsection 2.3.5). Notes on the StepGreen research website [44] indicate that there are plans to support the input of sensor data from the UbiGreen transportation sensing project that they are a part of [22].

In its current state, StepGreen would be challenging to keep up to date due to the reliance on manual data input. Due to the limitations of manual reporting, StepGreen may report missed savings that are not accurate, annoying users. For example, recycling glass is an action that is listed as having substantial carbon savings. However, if one chooses to drink water from a mug instead of purchasing a beverage and later recycling the glass container, clearly the carbon savings are greater from using the mug, but StepGreen will count the lack of recycling as missed savings.

2.3.2 Personal Kyoto

Personal Kyoto is a web service that tracks the electricity usage of users in the New York area, and compares it to a "Personal Kyoto Goal" for the user [16]. The Personal Kyoto Goal represents the limit of electricity usage that would apply to the user if the Kyoto Protocol (which the USA is not a party to) were administered on an individual basis rather than on a national basis.

The user's electricity usage is retrieved from the local utility's web site (Con Edison) using the user's account number. In addition to the monthly usage (which can vary substantially due to circumstances and the seasons), a 12 month rolling average is computed to remove the seasonal effects. The Personal Kyoto Goal is defined as 75% of the first point of the monthly rolling average when the user signed up with the web site. Figure 2.4 shows an example graph with monthly averages and a personal Kyoto goal.

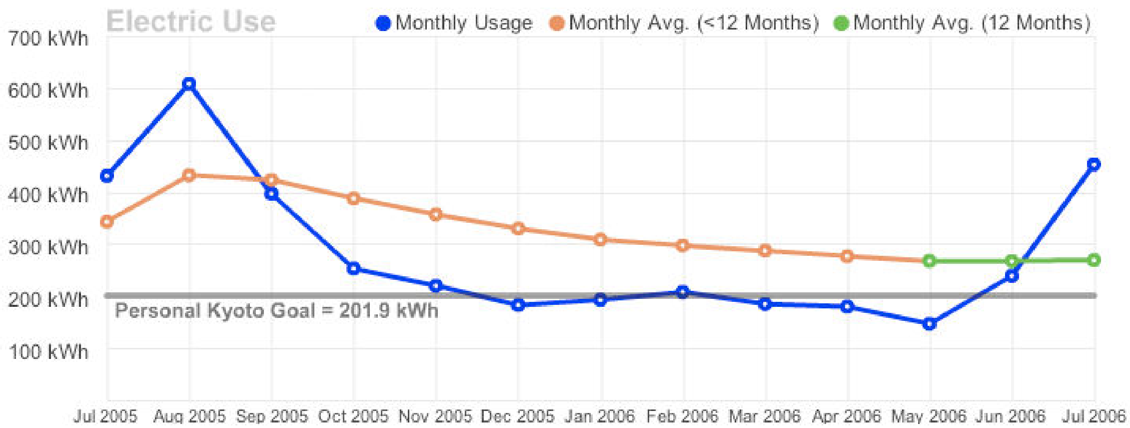


Figure 2.4. Example graph of electricity usage from Personal Kyoto

Personal Kyoto is a cleverly designed system in that it uses the user's real data, but avoids manual data entry by scraping the data from the utility web site. It also gives the user a specific goal for reducing electricity use that has a real justification and ties into the environmental "gravitas" of the Kyoto Protocol.

2.3.3 EcoIsland

Takayama and Lehdonvirta have constructed a system they call EcoIsland, which attempts to "motivate behaviour changes that reduce CO2 emissions" using a background game-like activity, with a centrally installed display in the home [48]. Figure 2.5 shows an example of the user interface. Each family member has an avatar on the virtual island, and they set a family CO_2 emissions target. The family's emissions are tracked via sensors and self-reporting. If the emissions exceed the chosen target level, the water level on the island rises, and if the water level continues to rise it will eventually end the game.

Participants mobile phones have a list of suggested actions to reduce emissions, and they can self-report their actions using the phone. Participants can see the islands of other participants and they receive a periodic allowance in a virtual currency. The participants can use the virtual currency to buy decorations for their island, or to purchase carbon credits from other users. Participants with low emissions, therefore, can decorate their island, while those with high emissions have to spend their money on carbon credits. EcoIsland provides a metaphor for the users' emissions and makes them aware of the consequences of their actions.

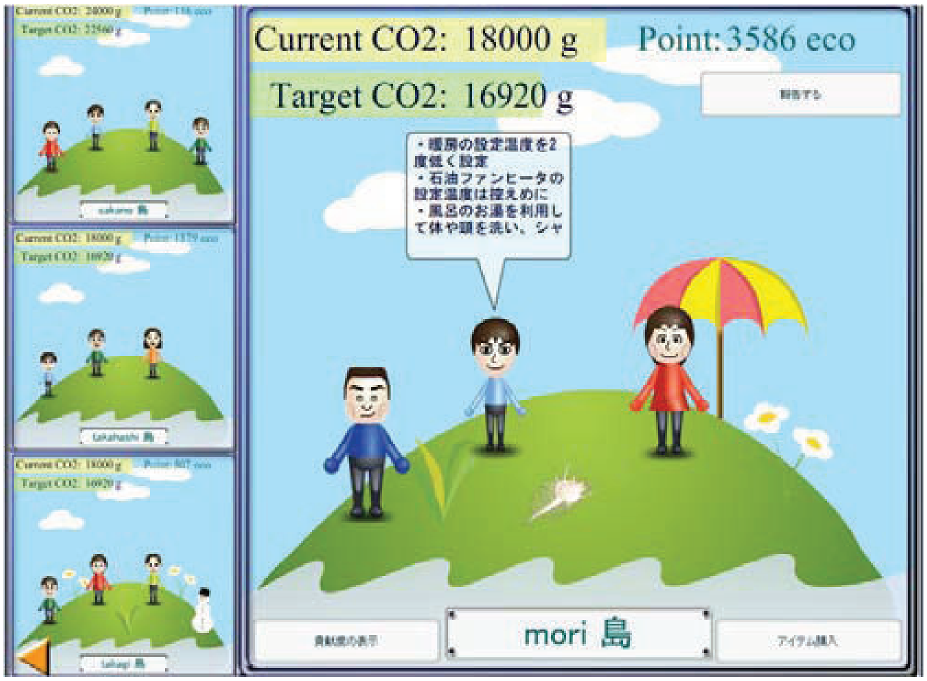


Figure 2.5. Example EcoIsland display, with family avatars

The sensor portion of the system was not yet implemented at the time the authors conducted their study. The authors performed a four week pilot study of EcoIsland with 20 people in six families. During the first week, the baseline electricity usage of each participant's air conditioning system was monitored using a plug load meter (for more information on this type of meter, see subsection 2.8.1). During the second week, one participant from each household was asked to use the system, while in the third week all members were asked to use it. In the fourth week, the carbon trading system was introduced to participants. At the conclusion of the study, the participants were surveyed and 17 of 20 participants said "they were more conscious of environmental issues after the experiment than before." However, users indicated that they were motivated by game issues (such as saving the sinking island and buying in-game decorations) rather than saving the environment. Few of the participants used the carbon trading system because their targets were easy enough to achieve without trading. Air conditioner usage in participant homes showed no correlation with game outcome, but the authors believe that the short study may have affected that outcome. The study was conducted in winter, which might seem like an inappropriate time to measure air conditioner use. However, in Japan, many air conditioning units also function as heaters, so it may be this type of air conditioner usage that the authors are referring to. One interesting result is that participants noted that manual reporting contributed to their motivation, so replacing the reporting with sensors could reduce user's motivation to change.

2.3.4 Google PowerMeter

Utilities are starting to install 'smart meters' (also called AMI for Advanced Metering Infrastructure) on homes as part of an overall push towards the 'smart grid'. However, these smart meters are often thought about from the utility's perspective: eliminating manual meter reading, enabling time-of-day electricity pricing, and monitoring power reliability. While there are many benefits for the utility, frequently updated power data from the meter could be very useful if provided directly to the people being metered, as discussed in Section 2.2.

Google PowerMeter is a web application developed to make smart meter data available to the end users living in smart metered homes [20]. Google partners with utilities that have rolled out smart meters, and collects the power data from the utility. PowerMeter also works with the TED 5000 home energy meter that can be installed by end-users without interaction with the utility (see subsection 2.8.2). The data is recorded at 15 minute intervals, and presented in a variety of graphs that show daily usage and home base load levels. Figure 2.6 shows an example display for a home in Hawaiʻi. The primary interface for PowerMeter is a web gadget that is installed on the user's iGoogle home page. PowerMeter allows users to share their data with others, and has added an API to allow users to get access to their raw data.

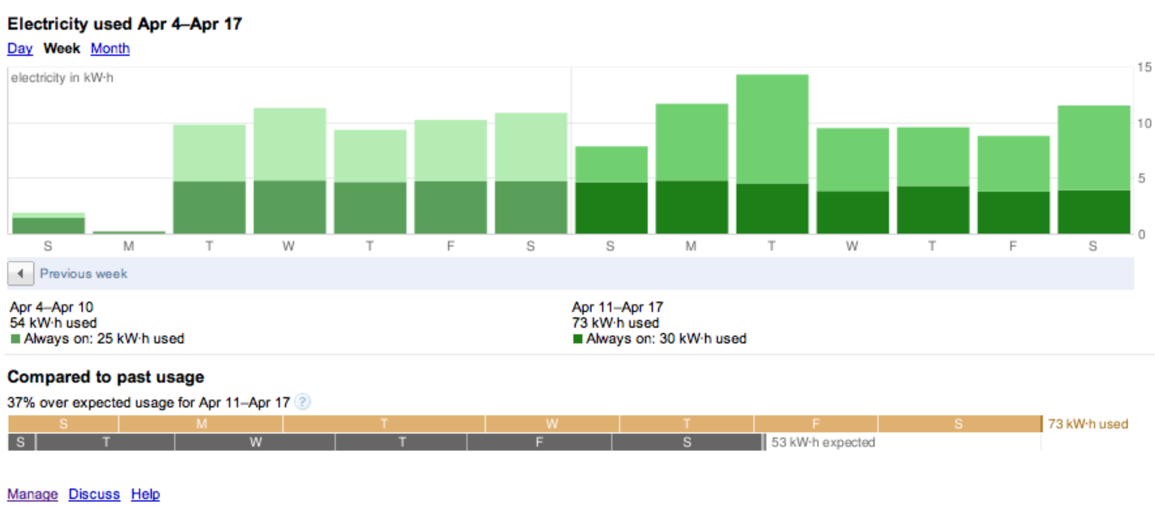


Figure 2.6. Google PowerMeter data for a home in Hawaiʻi

2.3.5 Virtual Polar Bear

Dillahunt et al. (who are involved with the StepGreen project) have built a system providing a virtual polar bear that is affected by the user's environmental choices as a means to motivate users to reduce their carbon footprint [13]. They note that there are strong emotional bonds between humans and animals, which may help to encourage environmentally-responsible behavior. The authors performed a one week study, with subjects divided into two groups: an attachment group and a control group. The attachment group read a story about climate change impacting polar bear habitats, and were asked to name their virtual polar bear. As participants make or decline commitments to environmentally responsible actions, the ice under polar bear either grows or shrinks (see Figure 2.7 for images of the polar bear). The study had 20 subjects (10 for each group), all of whom were surveyed before and after to test for levels of empathy and environmental concern. The subjects in the attachment group had more fulfilled environmental commitments, which was a statistically significant difference. The attachment subjects also had a greater level of environmental concern after interacting with the polar bear. The authors were unsure whether effects would be sustained in a longer study. They are now working on bringing the system to a mobile platform and creating a polar bear application for Facebook and MySpace.

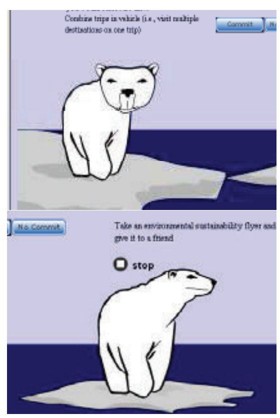


Figure 2.7. Example images of virtual polar bear with lots of ice and with little ice

2.3.6 iamgreen

iamgreen is an application for the Facebook social networking platform that provides an online gathering place for environmentally conscious users [23]. iamgreen provides all of the standard components of Facebook: a newsfeed of events from members, status updates, news articles, etc. The application provides a list of environmentally responsible statements called “leaves”, such as “Most of my lightbulbs are compact fluorescents”, “I recycle, even when it is not convenient”, and “When I drive, it’s over 40mpg baby” (see Figure 2.8 for an example of the leaf selection page). For each statement, users can indicate if they engage in that behavior, they aspire to that behavior, they wish to hide the statement (removing it from the list of choices), or they want to recommend it to a friend. Users can then display the number of leaves they have committed to in their Facebook profiles. Users can also contribute new leaves, which will be displayed as options to other iamgreen users.

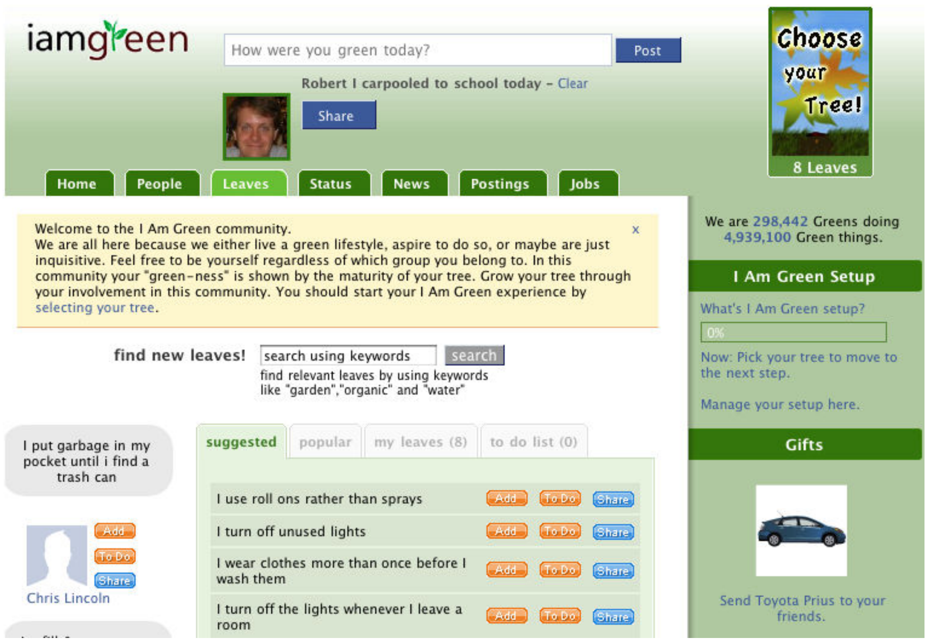


Figure 2.8. Leaf selection page of iamgreen Facebook application

While the leaves concept is a simple way to encourage users to make more environmentally positive choices, it suffers from some obvious deficiencies. First, leaves, for the most part, have the same value (though apparently some actions, such as not owning a car, are worth more than one leaf). The leaf system also lacks any quantitative feedback other than the number of leaves, so the user is not provided with real insight into their environmental footprint. Like any system based on manual reporting, users have to spend time reporting any changes to their action list. Without quantitative feedback, it seems likely that many users will make some selection of leaves and then revisit them infrequently or never again.

2.4 Motivation

De Young investigated the motives behind individual's environmentally responsible behaviors (ERBs) through a series of surveys [52]. Traditionally, the motives invoked by researchers attempting to promote ERB were constrained to material incentives or disincentives and altruistic reasons. The problem with incentives is that they "needed constant reintroduction to remain effective and they proved to be less reliable than we had hoped". Incentives can initiate ERB, but people's behavior changes back when the incentives end, and even continuing incentives can have low reliability.

De Young also describes some of the pitfalls that can be encountered in motivating ERB, such as psychological reactance, where people do the opposite of the ERB they are being asked to undertake. Even those initiating the behavior changes can be negatively impacted. De Young describes some initiators experiencing feelings of contempt for those whose behavior they are trying to change, and also contempt for themselves.

Self-interest is generally considered the cause of environmental problems: "focusing solely on short-term individual or familial gain to the exclusion of long-term societal or environmental benefits". De Young, however, suggests that self-interest can be a solution to environmental problems. He distinguishes self-interest from selfishness: self-interest meaning each individual is responsible for getting their own needs met. De Young believes that intrinsic satisfaction is a better way to motivate ERB, as people find that "certain patterns of behavior are worth engaging in because of the personal, internal contentment that engaging in these behaviors provides."

Based on 9 different studies of ERB across different populations and environmental focuses, the author found 3 intrinsic satisfactions:

1. "satisfaction derived from striving for behavioral competence"
2. "frugal, thoughtful consumption"
3. "participation in maintaining a community"

Competence involves the enjoyment in completing tasks and solving problems. Frugality is enjoyment from the "careful stewardship of finite resources". Participation is the enjoyment from participating in community activities such as sharing news and collaborating with others toward a shared goal.

While attitudes and norms can lead to behavior change, people also need tools and guidance to realize this change. As De Young puts it, "without considering these variables, we make the error of assuming that once people know what they should do and why they should do it, they will automatically know how to proceed." In the particular case of competence as a motivator, it is important to provide people with the opportunity to utilize their competence or they will grow frustrated. He suggests that motivating through competence be accomplished by providing an environment where information on procedures is available and new behaviors can be tried out in a supportive environment.

Darby's survey of electricity feedback programs found similar results on motivations [9]. She found that energy conservation efforts stopped when incentives were removed. When trying to get people to change their behavior, she found that behavior changes formed over a 3 month period is more likely to persist than changes made over shorter periods. She also found that internal motivation is most important for continued conservation efforts.

2.5 Fostering Sustainable Behavior

A variety of methods have been employed in an attempt to get people to change their behavior to be environmentally sustainable; McKenzie-Mohr provides a good summary of the area in his online book [29]. One of the most common techniques is the information-based campaign, which relies on providing information to the public through advertisements and documents like pamphlets and brochures. One type of information campaign attempts to shape peoples' attitudes towards an environmental, in the hope that those new attitudes will lead to more sustainable behavior. Unfortunately, these campaigns are usually unsuccessful. For example, Geller performed an investigation of the impact of three hour workshops on energy conservation that included a survey before and after the workshop [19]. The results of the survey indicated that the workshop had increased the energy literacy of the attendees and they indicated a willingness to implement energy conservation in their homes. However, followup visits with a selected group of 40 of the attendees found that very few had actually taken action (insulating their water heater or installing low-flow showerheads that had been given out during the workshops).

The other type of information-based campaign is based on financial incentives. In energy, this would include a utility advertising the rapid return on investment from a solar hot water heater, or promotion of rebates for more efficient appliances. This approach is also problematic, since it assumes that people are purely rational when making financial decisions, which they are not. For example, in 1983 California utilities were spending "200 million dollars annually to promote energy conservation" but with very limited success [7].

To avoid the problems with information-based campaigns, McKenzie-Mohr has developed a process he calls Community-Based Social Marketing (CBSM) [29]. The process consists of several steps:

1. identifying barriers to the desired behavior, and the benefits of the desired behavior to the individual
2. developing a strategy to overcome the barriers using behavior change tools
3. piloting the campaign on a small portion of the intended community, and making changes as needed
4. evaluating the effectiveness of the campaign on fostering the desired behavior

We focus here on the behavior change tools, which are critical to actually getting people to change their behavior: commitments, goals, and norms.

2.5.1 Commitments

Asking an individual to make a commitment has been shown to be an effective tool in changing behavior. In particular, an initial small, innocuous commitment can lead later to a larger commitment. For example, Freedman and Fraser conducted experiments in which subjects were asked to perform a small task (such as signing a petition to keep California beautiful) and then later asked to perform a more onerous task (such as placing a large billboard on their lawn that said "Keep California Beautiful") [18]. They found that subjects that committed to the small task were much more likely to agree to the second task. The authors call this the "foot-in-the-door" technique. One of the reasons this technique is believed to work is the desire by individuals for self-consistency.

Making commitments public can increase their effectiveness. Pallak et al. studied residents that were asked to make a commitment to conserve electricity and natural gas [34]. Some homes were asked to make a private commitment, while others were asked if their commitment could be publicized, though they were never actually published. Those that made commitments that they thought were public conserved more energy than the private committers, even one year later and after they were told that their names were not actually going to be publicized.

2.5.2 Goals

Goals can be thought of as commitments that can be objectively measured, which makes for a good pairing with feedback (see Section 2.2). Becker investigated goal setting along with feedback of home electricity use [3]. Half of the subjects were given a goal of reducing electricity use by 20% during the summer, the other half were given a goal of 2%. The subjects given the higher goal conserved between 13%–15%, while the group with the smaller goal did no better than a control group. Houwelingen and van Raaij investigated use of natural gas in homes and compared daily feedback with monthly feedback and self reporting, with all groups having a conservation goal of 10% [49]. The group with daily feedback reduced their energy use by 12.3%, and some reduction continued in the year after the feedback device was removed from their home.

2.5.3 Norms

Social norms are one way in which people's behavior is influenced by the behavior of others. Cialdini et al. make the distinction between descriptive norms (the way things are) and injunctive norms (the way things ought to be) [5]. In a series of experiments on littering, they found that subjects that the behavior of confederates of the researchers significantly changed the subjects' behavior. For example, subjects that viewed a confederate littering were more likely to litter a handbill that had been placed on their car. Also, subjects that viewed a confederate littering into a clean environment were less likely to litter than those that observed littering into an environment that already contained a lot of litter.

One problem with descriptive norms is that they can lead to 'boomerang effects' where the norm has the effect of decreasing the desired behavior. Schultz et al. investigated this issue in the context of home energy conservation [41]. 290 homes were divided into two groups: one that would receive a written descriptive norm regarding their energy usage, and one that would receive the descriptive norm plus an injunctive norm. The descriptive norm showed subjects whether they were above or below the average energy usage in their neighborhood. The injunctive norm was simply a frowning or smiling emoticon based on whether the subject home was using more or less than the average consumption respectively. They found that homes that only received the descriptive norm led to energy conservation in homes above the average, but led to increased energy usage in homes below the average (the boomerang effect). However, those homes that also received the injunctive emoticon did not have a boomerang effect. Clearly injunctive norms are an important addition to any attempt to use comparative data to foster energy conservation.

Cultural norms can strongly influence what behaviors are non-negotiable. Strengers performed an ethnographic study of 10 households participating in a smart metering trial to examine how their comfort and cleanliness norms affected their energy savings [46]. Participants were provided with metering devices that displayed electricity and water usage, and greenhouse gas emissions in real time. The author was attempting to use feedback to change the participants societal norms for comfort and cleanliness. For example, until relatively recently, bathing weekly was the norm, but now bathing daily is considered normal behavior. Like many people, the participants did not understand the connection between the consumption data and their practices. Participants tended to increase conservation by changing technology (such as using compact florescent lamps (CFLs) instead of incandescent light bulbs), or by minor behavioral changes like "taking shorter showers, doing full loads of laundry".

Strengers states that people act the way they do (in matters of cleanliness and comfort) because "they believe society expects them to" and because many companies and organizations have a vested interest in keeping it that way. Therefore, just providing people information about their consumption is not enough, because individuals are constrained by infrastructures and social norms. She suggests increasing social interaction regarding the feedback system by making placement more prominent and encouraging discussion with household visitors, because people tend to conform to the expectations of their peers. However, it would seem that changing cultural norms is one of the hardest possible means for reducing consumption. It also feeds into many of the negative stereotypes of environmentalism: smelly people living in dark, cold homes. Despite the irrationality of some of these norms, effort may be better spent focusing on areas where the effort will meet less resistance.

2.6 Design of Environmentally Persuasive Systems

There is considerable research on the subject of designing environmentally persuasive systems. Woodruff et al. performed a qualitative study of individuals who are making a significant effort to be green, in an effort to inform future designs by documenting existing green practices and beliefs [51]. The participants were all involved in making their home more sustainable and energy efficient. The authors found that these environmentally inspired people have diverse affiliations. Traditional environmental activism, for example, isn't always central to their interests. Thirty-five homes participated in the study, with 56 people in total. The participants were mostly "bright green environmentalists", that is environmentalists that believe that technology can make the world more sustainable, rather than believing that technology is the root of unsustainable behavior and should be abandoned. The authors divided the participants into three groups based on their motivations: "counterculture bio-centric activism; American frontier self-reliance and rugged independence; and trend-focused utopian optimism." The first group focused on stewardship of the earth, the second group on frugality, do-it-yourself activities, and patriotism from getting off foreign oil. The third group was focused on trend-setting, and being “eco-chic”.

The authors found that the participants were reflective about the positive environmental choices they made, often trying to improve their sustainability through playful analysis of the options, such as buying a product online versus buying it from a store. They found that participants eagerly assessed the performance of their homes, so that they could tune their houses for better energy savings. This assessment included extensive data collection, both manual and automatic. In making their homes more efficient, the participants would work on improving one area at a time, then move on to the next area. However, after living in a house for 1.5 years, their interest in data collection had waned, in part because their routines had been internalized. Participants also wanted to live by example and inspire others, such as by driving a hybrid car.

Based on the interviews, the authors found several implications for design. The participants tended to learn about sustainability in a depth-based manner (focusing on one area at a time) rather than in a breath-based manner. Many popular attempts to encourage environmentally responsible behavior involve short lists of relatively easy actions, which is contrary to how the participants sought information. The authors suggest that advice systems focus on the user’s primary motivations in an in-depth manner rather than providing a list of easy actions. The participants found mentorship to be an important part of the learning process, so the authors suggest that systems match mentees with mentors that have already mastered the area of expertise being sought. The authors suggest that users be provided with ways to express their identity and share their green activities to others via social networks. The authors observed that many participants enjoyed the process of determining the most sustainable option among many choices. Woodruff et al., therefore, suggest providing users with modest mental puzzles that help users explore the outcomes of different actions rather than telling them the answer outright.

Darby’s review of energy feedback studies yielded some suggestions for design of environmentally persuasive systems [9]. She observed that historical feedback of the user’s energy consumption is more effective than feedback that compared usage to others, or feedback that compared usage to normative values. However, users did report finding pie charts of typical breakdowns of home energy use helpful, even though they were averages of all users rather than the user’s own data. Although users reported that they liked to see comparative information, it didn’t necessarily lead to energy conservation. In addition, if a user is shown comparative data that indicates that their usage is lower than their peers, it could lead to the user feeling less concerned about energy conservation.

Chetty et al. performed a qualitative study of the resource management processes of 15 households in an effort to help ubiquitous computing researchers design better resource feedback systems [4]. They found that participants were unaware of real-time resource consumption for both the entire home and individual appliances. The study examined the participants' usage of natural gas, electricity, and water. Thermostats were a problem for participants. They argued about how the thermostats should be set, and half of the homes with programmable thermostats hadn't actually programmed them. Some participants were in living situations where they paid a flat rate for their utilities, which led to a lack of motivation to conserve resources. Participants wanted real-time information on their resource usage, utility pricing (if there is peak load pricing), and also alerts if there is anomalous usage (such as a broken toilet using an excessive amount of water). The authors report that participants were also aware of potential privacy issues, such as being able to infer other's habits from their resource usage, and being able to detect the wasteful use of resources.

Based on their study, Chetty et al. provide some suggestions for future system designs. In the modern world, infrastructure is invisible: you don't have to know how much energy an appliance uses when you plug it in. Therefore, the authors suggest visualizations "that equate our resource usage with units of production, for example, buckets of water, bags of coal, stacks of wood, as well as a monetary amount." They point out that households are often made up of multiple people with different levels of interest in being green and different responsibilities (some may not have to pay the bills!), so system design will have to reflect these differences. The authors also worry about the "green divide" in that lower income households might not be able to afford expensive equipment. They suggest the need to make sure devices supporting resource conservation are affordable to all.

One of the issues raised by Oberlin dormitory energy competitions is how to help residents sustain their interest in conservation principles and transfer their energy-saving behaviors once they leave the dormitory context [36]. The dormitory energy competition is clearly able to reduce energy consumption when students are living in the dorms, but without engagement in larger issues (at the institution, community, or global level) then their long-term behavior may not be environmentally positive.

2.7 Energy Literacy

Energy literacy is the understanding of energy concepts as they relate both on the individual level and on the national/global level. Solving the world energy crisis will require everyone to understand how energy is generated and consumed, so that they can make more informed choices in their lives and as informed citizens involved in their communities.

Defining and assessing energy literacy are therefore key to any attempt to improve energy literacy. DeWaters and Powers of Clarkson University have been working on an energy literacy survey instrument for middle and high school students [12, 11]. They define energy literacy as consisting of three components: knowledge, attitudes, and behaviors. An example of energy knowledge would be understanding that the kilowatt-hour is the basic measure of electrical energy. Energy attitudes refers to concepts like needing to make more use of renewable energy in our power grid. Energy behaviors refer to specific things that can be done to reduce energy use, such as turning off lights when leaving a room.

Their survey consists of one section for each of the components, the knowledge questions using a multiple choice format, and the attitude and behavior questions using a 5-point Likert-style scale from strongly agree to strongly disagree. The pilot studies among 955 students showed students fared better on attitude (mean 73%) and behavior (mean 66%) scores, while mean knowledge scores were 42%. DeWaters and Powers conclude from this that students may have the desired attitudes, but lack the knowledge to act on those attitudes.

Earlier work on assessing energy literacy includes a survey of attitude, knowledge, and intentions by Geller [19] given to participants at energy conservation workshops in the wake of the 1970s energy crisis.

2.8 Electricity Metering

Electricity metering systems can be broken down into two types: plug load meters that measure the electrical load directly plugged into them, and whole home energy meters that measure the electrical usage of an entire home. Both typically provide a real-time display of electricity usage, and some sort of historical total (usually in kilowatt hours, kWh).

2.8.1 Plug Load Meters

The Kill-A-Watt is an example of an inexpensive plug load meter [33]. It is designed to be plugged into a wall outlet, and the load is then plugged into the Kill-A-Watt. An LCD display shows the current voltage, current, power, frequency, power factor, and cumulative energy used since the unit was plugged in. The Kill-A-Watt provides an easy way to determine how much electricity a particular appliance (or set of appliances if connected via a power strip) uses. The manufacturer claims the Kill-A-Watt has 0.2% accuracy. There are several drawbacks to the Kill-A-Watt. Because of its shape, it generally obscures both of the outlets commonly found on a wall outlet in the US, preventing the second outlet from being use while measurement is taking place. The load must be plugged in via the Kill-A-Watt, so that means that the user must disconnect the load from power at least momentarily, which can be inconvenient for some loads (computers, refrigerators, etc.). The Kill-A-Watt also has no facility for exporting the data it collects, and if power is lost for any reason, the data collected will be lost as well.

LeBlanc attempted to address the issue of data collection with his work on recording device-level power consumption [25]. He developed a sensor that sits between the load and the wall outlet, like the Kill-A-Watt. The sensor records electricity usage, and transmits the data wirelessly using the ZigBee protocol to a base station. Details on how to construct the wireless power monitor can be found at the author's personal website [26]. This system solves the problem of automated data collection, but still requires the load to be unplugged before monitoring. It also faces the problem of all plug-load meters, which is that it can only monitor what it is connected to, therefore it is unsuitable for providing a comprehensive picture of electricity usage in a home.

2.8.2 Whole Home Meters

The Energy Detective TED Model 5000 is a whole home electricity meter from Energy, Inc [15]. TED consists of three components:

- a Measuring Transmitting Unit (MTU), which is connected directly to the incoming power lines at the circuit breaker box
- a Gateway that receives data from the MTU through the electrical wiring of the home, stores it, and makes the data available via HTTP using an Ethernet connection
- a handheld, wireless display unit that provides a continuously updated display of power usage sent via the Zigbee protocol from the Gateway.

The MTU uses current transformers, which clamp over the incoming power cables, and measure the amount of current being transmitted over them. Because the transformers clamp over the existing cables, there is no need to alter the existing wiring. The instantaneous power consumption can be computed using the current data combined with the utility voltage. These data are transmitted to the display unit through the home's electrical wiring.

The display unit receives the instant power consumption data from the Gateway unit every few seconds. The power consumption data can be displayed in real time in kW or dollars (after the user enters pricing data). It can also track historical consumption, peak usage, and project usage for the rest of the month based on historical usage. The Gateway unit provides a detailed web interface to the power data for computers inside the home, and can be configured to upload data to Google PowerMeter (subsection 2.3.4) every 15 minutes. Energy Inc makes an XML API available for developers who wish to use the data directly. TED appears to be the lowest cost option for whole home electricity monitoring with data recording and Internet accessibility.

While whole home energy meters provide only household-wide usage data, users can use the real-time display to figure out the impact of particular uses as air conditioning through trial and error experimentation. Parker et al. describe a protocol for using a household-wide meter and a circuit breaker panel to localize the energy usage in a home [35]. All the breakers are turned off, and then turned on one at a time while recording data from the electrical meter. In 2–4 hours, users were able to generate a spreadsheet mapping the electricity usage in their homes.

2.8.3 Building Energy Displays

Another type of electricity usage monitoring is building energy displays, which monitor electricity usage for an entire building (usually non-residential, such as a school or office building) and display the usage information in some public area such as a lobby. Green TouchScreen [38] and Building Dashboard [27] are examples of this type of product. These devices aim to make building occupants aware of the overall environmental impact of the building, which is something usually invisible to the occupants. Some systems make the displays available via the web so that users can view the information from their desk as well as the lobby. The displays often provide information beyond just electricity usage, such as water or natural gas usage, and may display the usage in units other than kWh, such as number of incandescent light bulbs lit or hours of TV watching. Beyond their potential utility in helping building occupants to reduce their energy usage, informative displays can be used to get points toward Leadership in Energy and Environmental Design (LEED) certification for a building.

Chapter 3

System Description

The system to be evaluated is a combination of an energy competition between residents of two freshman residence halls, and an associated competition website to be used by the residents participating in the event. The system has three goals:

- Enable research into fostering sustainable environmental behavior change
- Improve the energy literacy of the participants
- Reduce the energy consumption of the residence halls

The participants compete both to reduce energy consumption in the participating residence halls, and to accumulate points by performing tasks related to energy literacy and conservation through the competition website.

This chapter describes the components of the system, and ends with a discussion of the factors that pose a risk to the successful implementation and evaluation of the system.

3.1 Competition design

We will examine the behavior of freshmen residents in student housing at the University of Hawai‘i at Mānoa in the context of a energy competition. An student housing energy competition typically involves residence halls attempting to reduce their energy consumption during the competition period by the greatest amount. The competition planned here is more complicated than standard competitions so that we can obtain data on a wider variety of behavior. The working name for the competition is the Kukui Cup. The kukui nut was burned by Native Hawaiians to provide light, making it an early form of energy in Hawai‘i.

3.1.1 Location

The two residence halls being targeted for the competition are Lehua and Mokihana from the Hale Aloha towers [42]. Each tower contains 13 floors with the following composition:

- Floor 1: Lobby
- Floor 2: Non-student resident(s)?
- Floor 3–12: Student residents
- Floor 13: Laundry, kitchen

3.1.2 Participants

The participants of the competition will be freshmen residents of two on-campus residence halls. The freshman residence halls are specifically targeted for two reasons. First, based on conversations with UHM undergraduates, residents in the freshman buildings are more likely to attend floor meetings and events, while upper class residence halls are more like apartments where residents might not know their neighbors well or be motivated to attend floor meetings. Second, as the goal is to improve energy literacy and foster behavior changes in the participants, we wish to make an impact as early as possible for maximum benefit to themselves and the University.

Each floor of the targeted residence halls has a resident advisor (RA) and 13 double occupancy rooms, and there are 10 floors of student residents. Therefore, assuming full occupancy, there are 260 potential participants per hall and 520 potential participants in total. While all residents are indirectly participating since all electricity usage in the building will be monitored, we define participants as those residents that actually log into the competition website at least once.

3.1.3 Timing

The competition is organized into 4 rounds, each lasting a week, starting in early October 2010. While some student housing energy competitions have taken place over shorter periods, such as 2 weeks [37], 4 weeks provides participants a longer period to change their behavior. Structuring the competition into rounds ensures that residents that did not participate initially can start participating in a later round without undue disadvantage.

The precise starting date will be determined based on factors such as equipment installation and coordination with Student Housing Services (see subsection 3.5.3 and subsection 3.5.4).

3.1.4 Infrastructure

The core infrastructure required to enable an energy competition is electricity metering. In Hawaiʻi, the vast majority of energy used in buildings is electricity, so measuring direct energy use reduces to measuring electricity use. While building-level metering is common for energy competitions, for this competition we plan to have floor-level metering of electricity. Metering at the floor level has several advantages:

- Finer-grained data about electricity usage
- Individual behavior changes more likely to be visible in data
- Makes the residents of a floor a natural 'unit' of competition

We also require that the meters provide sub-minute sampling times, preferably 10 to 15 seconds. This is an unusual requirement for meters used outside the home. We term this requirement *near-realtime* monitoring. As discussed in Section 2.2, providing near-realtime feedback on energy use is associated with greater reductions in energy consumption. Near-realtime feedback also enables participants to empirically determine how much electricity different devices consume, and become more aware of their energy use.

The other meter requirements are provision of an open API to allow retrieval of the data, and affordable pricing.

We have evaluated several building energy meters based on these criteria, and found 4 meters that meet all the criteria. All 4 meters support the Modbus/TCP protocol [30], which allows the meters to be queried over the Internet using a standardized protocol. Final selection of the meter will be done based on feedback from UHM facilities and the results of development of software to read data from the meters.

Installation of the meters involves placing current transformers over the incoming power lines in the electrical room on each floor. The current transformers convert current flowing over lines providing each phase into a small voltage which is then measured by the electrical meter. The electrical meters under consideration all have Ethernet ports, allowing them to be connected directly into the residence hall LAN. Once connected to the UHM network, they can be queried from any location.

The other infrastructure required is to place large TV display connected to an Internet-connected computer in the lobby of each building. This display will be used as a 'billboard' that cycles through information about the competition, such as the floor standings and upcoming events (see subsection 3.2.3). The Hale Aloha towers already have flat panel displays present in the lobby, which might be suitable for billboard display. Otherwise, two displays will need to be purchased. Some manufacturers make large format displays that embed a Windows PC in the display and are designed for this type of usage (such as the Samsung 460UXN-2, which costs approximately $2,000).

3.1.5 Metrics

There are two metrics for the competition: energy consumption (EC) score and Kukui Nut (KN) score. Energy consumption is the total amount of electrical energy consumed by a floor in kWh during a round as measured by the power meters. The energy consumption is normalized by subtracting the minimum floor power multiplied by the time interval in question (see subsubsection 4.2.1.1). Therefore, floors are ranked in increasing order of energy consumption, with the floor with the lowest energy consumption being the winner. The floor-level energy consumption score can be aggregated spatially to obtain a score for an entire building, and also temporally to obtain a score for the entire competition across all rounds.

The parallel metric for the competition is Kukui Nut points. Kukui Nut points are assigned to individual participants for performing certain tasks via the competition website. The verification of task completion and recording of the Kukui Nut points are done entirely through the website, see Section 3.2 for more details. Kukui Nut points can be aggregated spatially to obtain a point total for an entire floor or for an entire building, and also temporally to obtain a score for the entire competition across all rounds.

3.1.6 Awards and prizes

Using the competition metrics, we can define various awards that can be won in the competition. In the event of ties, the winner will be resolved by random selection. Since the competition consists of 4 rounds, a common pattern is to have an award for each of rounds 1 through 3, and then an award for the entire competition (all 4 rounds). To incentivize participation, each award has an associated prize. We define the following awards for individuals. Note that all individual awards relate to KN since energy data only goes down to the floor level, not individual:

- Highest KN score on each floor for rounds 1–3 (60 winners per competition, prize value $5 [e.g. Jamba Juice coupon])

- Highest KN score for each round 1–3 (3 winners per competition, prize value $25 [e.g. iTunes gift card])
- Highest total KN score for competition (1 winner per competition, prize value $200 [e.g. iPod Touch])

Awards for floors:

- Highest total KN score for competition (1 winner per competition, prize value $300 [e.g. energy efficient HDTV for lounge])
- Lowest EC score for each round 1–3 (3 winners per competition, prize value $50 [e.g. ice cream party for floor])
- Lowest total EC score for competition (1 winner per competition, prize value $300 [e.g. movie ticket voucher for everyone on floor])

Awards for residence halls:

- Lowest total EC score for competition (1 winner per competition, prize value $500 [pizza party for hall])

Approximate prize budget: $1,825.00

3.2 Website Design

The competition website serves as the focal point for information about the competition, including information on individual and floor competition standings. The website also provides the only way for participants to accumulate Kukui Nut points, the competition that parallels the energy consumption aspect.

The design of the website itself has been conducted in collaboration with the students taking ICS 414 in the Spring 2010 semester, as well as with Professor Philip Johnson. Fellow ICS graduate student George Lee is the primary implementor of the website, which he is performing as a part of his Masters thesis research.

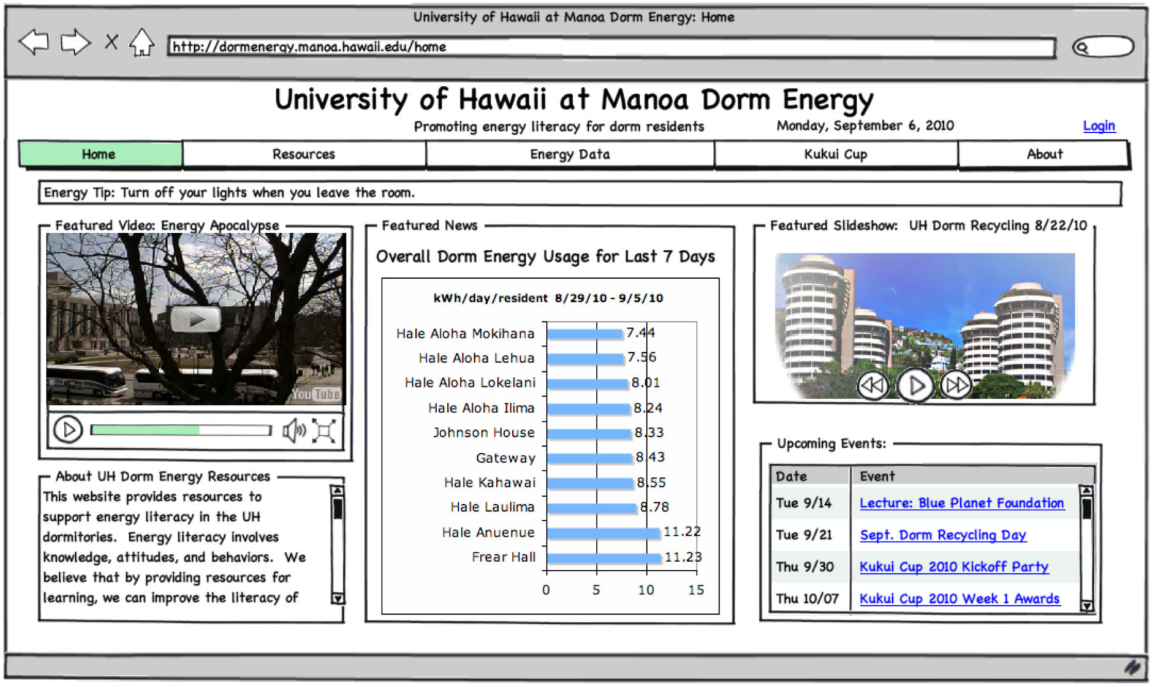


Figure 3.1. Mockup of website home page (created by Philip Johnson)

3.2.1 Public portal

While the impetus for the website is to support the competition, it is also intended to be provide information about the competition and residence hall energy consumption to the public (non-participants). Therefore, the website is conceived as a general portal into residence hall energy usage that will be available before and after the competition. During the competition period, the competition-specific portions of the website will be made available to participants. Figure 3.1 shows a mockup of the front page of the website, where we can see overall residence hall energy consumption.

3.2.2 Personalized participant page

Competition participants will be able to log into the website using their UH username and password, which will lead them to a personalized home page. The website will provide the following information to participants:

- Competition rules
- Competition news (awards, reminders, etc.)

- Floor-level power and energy consumption data
- Individual Kukui Nut scores
- Rankings of individuals, floors, and residence halls based on EC and KN score totals
- Lists of upcoming competition events
- Tasks that can be performed for Kukui Nut points
- Resources on energy literacy and conservation

Figure 3.2 shows a mockup of the personalized home page for a participant named Maile. On the left hand side we see Maile's profile, showing her name, room number, and how many Kukui Nut points she has accumulated during the competition. The center column of the page relates to the tasks that Maile can perform to gain Kukui Nut points (Section 3.3 describes the task system in detail). The right hand side displays both power data and competition standings. The upper number is the near-realtime power usage for Maile's floor, which is colored in red as an indicator that this value is above the pre-competition baseline. The lower number is the total electrical consumption for Maile's floor in this round, which is colored in green since it is below the baseline and on target to meet the floor's goal of a 10% reduction in energy usage for this round. The box in the lower right hand corner displays the competition standings that are most relevant to Maile.

3.2.3 Billboard

The billboard is a non-interactive mode for the website designed to convey competition information to participants in the lobby of the residence halls in an ambient fashion. It is also expected that the billboards will remind the residents about the competition, making them more likely to participate. The billboard consists of a series of pages, which are cycled through after an appropriate delay (approximately 20 seconds). Billboard pages will display competition standings (individual, floor, and building), upcoming events, tasks recently performed by participants (in the style of the Facebook newsfeed), prize descriptions, and energy conservation tips. Figure 3.3 shows a mockup of the billboard display.

3.2.4 Administration

As the website is intended to be the hub for competition activity, it provides an contest administration interface where participants can be added, tasks created (see Section 3.3, and tasks

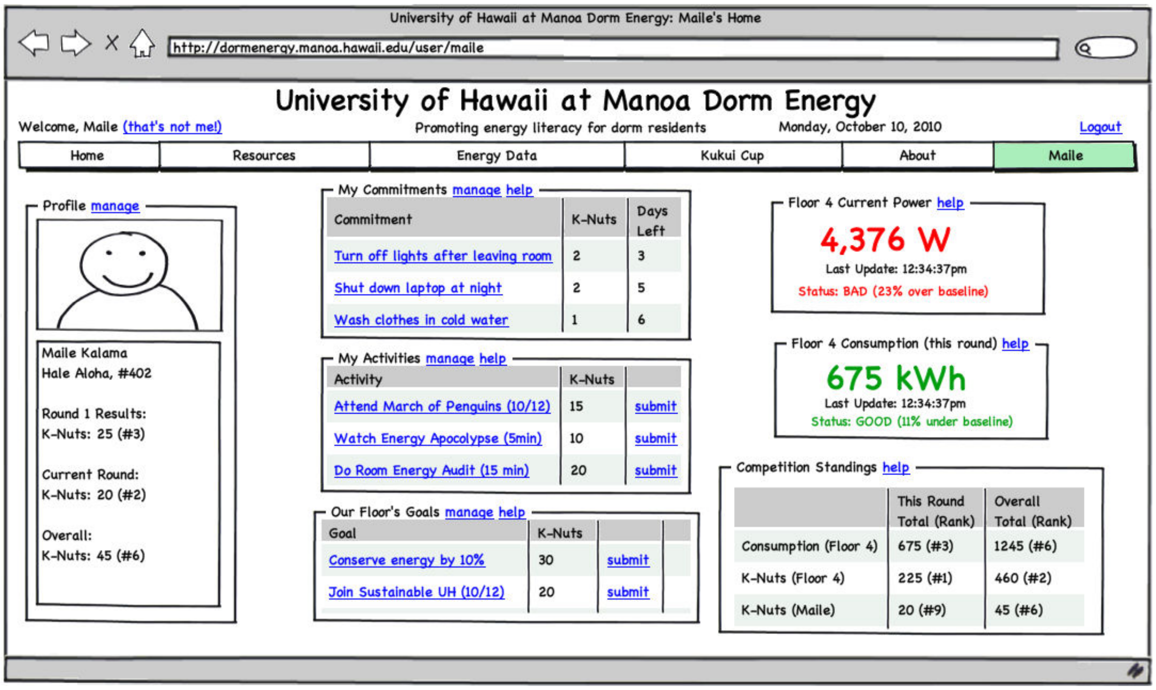


Figure 3.2. Mockup of personalized participant home page (created by Philip Johnson)

verified (see subsection 3.3.1). The contest administration interface is separate from lower-level administrative tasks such as the layout of the website, database table maintenance, etc. The contest administration will be performed by the researchers, and potentially trained volunteers 'deputized' to verify task completion, depending on the actual workload.

3.3 Competition Tasks

One of the goals of the competition is to improve the energy literacy of the participants. As discussed in Section 2.7, we have defined energy literacy as consisting of knowledge, skills, attitudes, and behaviors. While the knowledge component can be conveyed through a website, the other parts require the participants to engage in activities outside the website. Further, research in environmental psychology described in Section 2.5 indicates that the incorporation of techniques like public commitments and goal setting can increase the likelihood of sustainable behavior change.

To increase the energy literacy of the participants and to motivate their participation, the website provides a variety of tasks that can be performed to earn Kukui Nut points (KN). These tasks are divided into three categories:

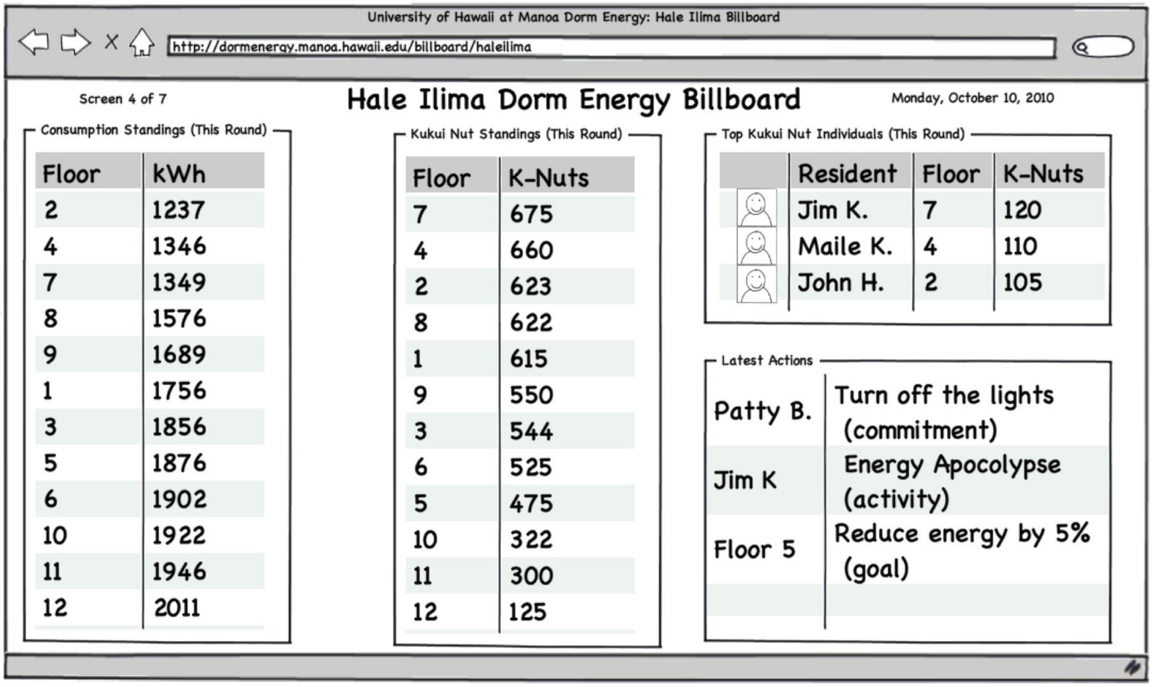


Figure 3.3. Mockup of competition billboard (created by Philip Johnson)

- *Activities:* one-time, verifiable tasks that are performed by an individual
- *Commitments:* ongoing, non-verifiable behaviors that are performed by an individual
- *Goals:* one-time, verifiable tasks that are performed by a group of participants from a floor

The complete list of tasks defined for the competition can be found in Appendix B. Participants can view the list of available tasks on their personalized home page (Figure 3.2). Tasks can be specified as only being visible during a range of dates (such as a few days before and after an event takes place).

3.3.1 Verification

After a participant completes a task, they select the task on the website and submit the required verification information that proves that they completed the task. The completed task is then added to the administration queue, where a competition administrator reviews the verification information and either awards the specified Kukui Nut points to the participant, or bounces the task back to the participant for further verification (if the information is missing or suspect).

Verification information can take one of three forms:

- A free-form text field (such an answer to a question)
- An uploaded image (such as a photo from a digital camera)
- A non-forgeable, single-use attendance codes

Some tasks are verified by asking the participant a question, which they then answer in a free-form text field. To make it more difficult for participants to cheat by sharing answers, each question-verified task has multiple associated questions and the question posed to each participant is selected randomly.

Other tasks are difficult to verify with text only (such as changing out a incandescent bulb with a CFL). For these tasks, participants can take a picture that provides some proof that they have completed the task (such as holding both the incandescent bulb and the CFL).

Another type of task involves attendance of an event. To verify attendance, at competition events a responsible party (contest administrator or resident advisor) will hand out small slips of paper that contain an *attendance code*. An attendance code for an orientation event could be "orientation-158-B7QRX13". Each attendance code is unique to the event, and contains a random string of characters generated by the website in advance. After the event, participants that attended can log onto the website and enter the attendance code they received. Since each attendance code was pre-generated, the website can verify that the code is valid, has not already been used, and corresponds to the event in question.

3.3.2 Activities

Activities are one-time tasks that can be verified using the website. Example activities are:

- Attend the Energy Pong tournament
- Perform an energy audit of your room
- Watch a short YouTube video about energy

After performing the activity, the participant can request KN via the website. Since activities can be verified, they are the baseline for KN points and are worth around 5 KN. Activities cannot be repeated once they have been successfully completed.

3.3.3 Commitments

Commitments are ongoing behavior changes that are believed to either improve participants energy literacy or reduce energy consumption, but for practical reasons cannot be externally verified. Example commitments are:

- Turning off the lights when leaving a room
- Turning off/shutting down all appliances before going to sleep
- Washing laundry in cold water

Each commitment lasts 5 days and then expires, and each participant can have no more than 5 commitments at one time. All commitments made by participants are made public to the other participants. After the commitment has expired, the participant can self-verify their completion of the commitment by clicking on a button to affirm that they did live up to the commitment. While this self-verification still allows a participant to receive points without actually performing the commitment, it requires the participant to make a conscious decision to do so. The public nature of commitments also allows for participants to police their peers, and call them out if they are violating their commitments. Since there is the potential for cheating, commitments are mostly worth 2 KN, less than activities and goals. Participants can repeat commitments after they expire, if they wish.

3.3.4 Goals

Goals are one-time, verifiable tasks that involve a group of participants from a floor. Example goals are:

- Reduce floor energy consumption by 10%
- Determine minimum floor power
- All floor residents attend Energy Pong tournament

Goals are selected by participants on a floor using the website. Each floor can have up to 6 goals active at one time, and each participant can select no more than 2 goals for their floor on a first-come-first-served basis. Each goal is active for 5 days. If the floor achieves the one of the active goals, then the participant that selected the goal must log onto the website and verify the completion of the goal. Once verified by a contest administrator, KN points are awarded to all participants on the floor (whether they actively participated or not). Participation goals (such as attending an event) require at least half of the floor to participate to receive any KN. If a floor achieves 100% participation, they receive double the KN. Goals that are achieved cannot be repeated, but goals that are not achieved before they expire can be repeated.

3.4 Energy Data Infrastructure

To provide a way to collect, display, and analyze energy data, we have developed an Open Source system called WattDepot [50]. WattDepot provides an ecosystem for energy data, from the collection of data from meters, to storing it in a repository, to displaying it in a variety of formats. The WattDepot system has been in use in a classroom setting since October 2009, and has been the focus of several ICS 414 student projects in Spring 2010. Since WattDepot handles all the energy data collection and storage, the competition website need only use high-level graphical widgets to display graphs and realtime meter data to participants.

3.5 Risk Factors

The system described in this chapter has many "moving parts" including hardware installations, cooperation with other organizations, and several hundred residents whose participation is not a foregone conclusion.

3.5.1 Meter installation cost

In order to provide floor-level near-realtime electricity usage data in two residence halls, a physical meter needs to be installed on each floor to be monitored. The meters under consideration cost between $1,000 and $1,500 and must be installed by a qualified electrician. The Hale Aloha residence hall towers where the competition is planned to take place have 10 floors each of freshman residents, so the cost for the meters alone will be more than $20,000, not including installation costs. While we are exploring several options for funding the hard costs related to the competition (rolling the costs into planned renovations of the residence halls, funding from the Renewable Energy and Island Sustainability group, or possibly external funding) there is some risk that sufficient funds will not be available to purchase and install all the meters required.

If we are unable to secure funding for the installation of meters on all 20 floors, the easiest fallback position would be to switch to a competition in a single residence hall, which would roughly halve the meter expense. The impact to the research would roughly halve the number of potential participants, and eliminate building to building competition, which is a relatively minor aspect of the competition and evaluation.

If we are unable to install meters for all floors in one entire building (due to funding, or some other logistical reason) then the next fallback position would be to only install meters on some of the floors, with a minimum of two floors. This reduction would be much worse than using a single building, as it would further reduce the set of potential participants. It would also create difficulties in communication, since any competition information would only be relevant to the floors participating. There could also be tensions between participating floors, which would be eligible to win prizes, and the non-participating floors. Overall, running the competition on a size smaller than an entire building would be a last resort.

3.5.2 Meter install timing

The other major consideration regarding the meters is the timing of their installation. Our goal is to install the meters during the summer, so that we can work through any technical issues before students move into the residence halls. The other reason to have the meters installed before students arrive is to be able to measure the minimum floor power (see subsubsection 4.2.1.1).

If the meters cannot be installed before students move in, they must at least be installed and working two weeks (at a minimum) before the competition begins in October 2010 so that pre-competition energy consumption can be measured.

Should we be unable to install the meters in time for an October 2010 competition, then the competition start date could be moved forward to February 2011. October 2010 is preferable to February 2011 for several reasons: increased possibility of funding complications (budget situation worsening), freshmen will be less “fresh” (perhaps less open to behavior changes and less likely to be spending their time inside the residence hall), and this author’s graduation schedule may be impacted.

3.5.3 External cooperation

Unlike some ICS research, this project requires extensive cooperation with entities outside of the ICS department. Running the competition in student housing requires the enthusiastic cooperation of Student Housing Services, since the participants live in student housing and the meters need to be installed in the residence halls. We have met with Michael Kaptik, the director of Student Housing Services, and he appears eager to facilitate the competition (and of course Student Housing Services would benefit from any reductions in electricity use by residents). Installation of the meters themselves needs to be coordinated with Facilities, which handles electrical work on campus. We have met with David Hafner, Assistant Vice Chancellor for Campus Services who heads Facilities, and he is also very supportive of the competition plan and has indicated his willingness to facilitate the installation of the floor meters.

While the initial discussions with Student Housing and Facilities have all been positive, situations and personnel can change over time. There remains the risk that one of these entities might be unable or unwilling to cooperate, preventing the competition from taking place as planned.

If Student Housing were not supportive of holding the competition in the residence halls, it might be possible to switch to a competition between floors of some multi-story building on campus. However, this would significantly change the character of the research, and would require extensive redesign of both the competition and the website.

If Facilities was unwilling or unable to allow the installation of the floor meters in the residence halls, the research as planned could not take place. It might be possible to design an experiment that revolved solely around evaluating the effectiveness of increasing energy literacy using a redesigned website, but it would lack the critical component of evaluating the relationship between energy literacy and energy usage.

3.5.4 Participant engagement

The installation of the meters to record floor-level electricity usage is the enabling component for the energy competition between floors and residence halls. However, energy literacy and near-realtime energy feedback rely on the competition website, and particularly on participant use of the website. The vast majority of entering freshmen own computers (Michael Kaptik stated that based on past surveys student housing resident computer ownership was something like 98%) and have used the Internet extensively. Thus there is little risk that the potential participants will not be able to use the website, but there is considerable risk that they will not bother to use the website due to lack of interest or conflicting demands on their time and attention.

We will attempt to limit this risk in several ways. First, participants can only compete in the Kukui Nut portion of the competition through the website. There will be prizes for both individuals and floors with the most Kukui Nut points, which we expect to be a substantial motivator for participation. Second, we plan to have large computer displays in the lobby of each residence hall that loop through interesting competition information, including current competition standings, upcoming events, and recent tasks performed by participants. We expect the billboard displays to provide a continuous reminder to residents about the competition and how they might participate. Third, we plan to have posters on each floor of the residence hall to remind residents about the competition and the website. Fourth, participants will be notified about competition events via email and Facebook, with embedded links back to the website. Finally, the website makes it as easy as possible for participants to use the website by utilizing the University of Hawaiʻi single-sign-on system, allowing participants to log on with their UH username and password, rather than a username and password specific to the website.

Chapter 4

Evaluation

This chapter describes the design of the experiment using the competition and associated website described in Chapter 3. First we cover the different sources of data available for the experiment, followed by analyses performed on the data. The research questions we propose to investigate are:

- *To what extent was the website adopted by the participants?* Without significant adoption, it is hard to evaluate the other website-related questions.

- *How did energy use change during the competition?* This is the standard measure for an energy competition, with the expected result being energy conservation during the competition.

- *How did energy use change after the competition?* Understanding changes in energy use after the competition is over gives insight into whether changes during the competition were sustainable. Existing research focuses primarily on the competition itself, not examining the reasons why energy usage might rebound after the competition is over.

- *How effective were the tasks available via the website?* By using website log data, we can track what tasks participants undertook, and compare that to changes in their energy literacy.

- *How appropriate were the Kukui Nut values assigned to tasks?* The Kukui Nut points assigned to tasks are intended to motivate participants to perform the tasks, but the values were assigned without any participant data.

- *What is the relationship between energy literacy and energy usage?* We hypothesize that more energy literate participants will conserve more energy, so we examine the relationship both during the competition and afterwards.

- *How important was floor-level near-realtime feedback?* There are good reasons to believe that floor-level near-realtime feedback will lead to increased energy conservation, but they greatly increase the competition budget and logistical complexity. Is the trade-off worth it?

4.1 Data Sources

4.1.1 Power Usage Data

We will record both instantaneous power and cumulative energy consumed on a floor by floor basis for each residence hall, beginning at least one month before the competition starts and continuing for at least 6 months after the competition ends (see Appendix A for an in-depth description of power, energy and their interrelationship). The sampling rate will be a minimum of 1 minute outside the competition period, and a maximum of 1 minute during the competition period (with a target of 10 seconds), with both rates kept constant during the study to the degree possible.

4.1.2 Pre and Post-Competition Energy Literacy Questionnaires

The energy literacy of participants will be assessed at the start and end of the competition. The assessment will be through a questionnaire that is presented to participants via the contest website as an activity that can be performed for Kukui Nut points. The pre-competition questionnaire will be made available only in the first week of the competition, while the post-competition questionnaire will be made available only in the final week of the competition. Appendix C lists the questions that will make up the pre and post-contest questionnaires.

Since the website-administered questionnaire is simply a task that can selected by participants, there is the potential that only those participants that feel that they are energy literate will participate in the survey, leading to bias. For this reason, in addition to administration through the website, the questionnaire will be administered in person on paper to two randomly-selected floors. While the assignment of residents to a floor is not random, it is at least not self-selected. The questionnaire will be administered to the floors before the competition starts, and in the final week of the competition. The questionnaire will be removed from the activity lists shown to participants on the floors that were selected for in-person administration. However, those participants that fill out the survey on paper will receive Kukui Nut points just as if they had filled it out online.

4.1.3 Website Log Data

The contest website will log data about participants' actions on the site. All participant actions and events will be logged with a timestamp. A few examples of the type of events to be logged:

- Participant logs onto website
- Participant selects goal for floor participation
- Participant submits text to verify completion of an activity
- Participant makes a selection to display energy consumption for a floor different from his/her own
- Participant logs off of website

These events are used to create a profile of the participant, as described in subsection 4.2.2.

4.1.4 Post-Competition Feedback Questionnaire

After the competition has ended, participants that used the website will be emailed a link to a qualitative questionnaire, as part of the energy literacy post-test described in subsection 4.1.2. This questionnaire will ask for participants' assessment of the competition, the website, and energy literacy in general. Appendix D lists the questions to be placed in the questionnaire.

4.1.5 Post-Post-Competition Sustainable Conservation Questionnaire

In early in the following semester (February 2011), the power data for floors will be re-examined to see whether conservation begun as part of the competition has been sustained months later. Floors with particularly high sustained conservation (compared to pre-competition average floor power), and those with low or non-conservation will be selected for an additional questionnaire, and possible face-to-face interviews to determine residents' self-assessment about why they were or were not sustaining the conservation gains made during the competition.

4.2 Data Analysis

Based on the raw data collected, we can perform analyses that allow the data to be understood at a higher level of abstraction.

4.2.1 Power analyses

4.2.1.1 Minimum floor power

Minimum floor power is the power consumed by each floor before residents move in and with all switchable devices (such as lights) turned off. This reveals the power used by the hidden infrastructure of a floor, and may be differ between floors. The value is measured by recording the kWh consumed by each floor over a period of time (preferably days to average out any periodic consumption spikes) and divided by the length of the time interval.

4.2.1.2 Pre-competition average floor power

Pre-competition average floor power is the power consumed by each floor after residents move in, but before the competition has begun. This reveals the power use profile of the floor's residents, and will almost certainly differ between floors. The value is measured by recording the kWh consumed by each floor over a long period of time (preferably weeks to average out any periodic consumption spikes) and divided by the length of the time interval.

4.2.1.3 Pre-competition total monthly floor energy

Pre-competition total monthly floor energy is the energy consumed by each floor after residents move in, but before the competition has begun. This reveals the power use profile of the floor's residents, and will almost certainly differ between floors. The value is measured by recording the kWh consumed by each floor over a long period of time (preferably weeks to average out any periodic consumption spikes) and extrapolated to a monthly value. Thus if 15 days of data are recorded, then the pre-competition total monthly floor energy would be twice the kWh value recorded for the 15 day period.

4.2.2 Participant profile

Since the website associates activity with a particular user, we can build a profile of each user that incorporates multiple sources of data. The fields in the participant profile are described in Table 4.1.

We can categorize participants based on their profile. For example, participant website activity could be classified in as shown in Table 4.2. Visiting the website is one level of activity, but completing tasks is a better measure of engagement with the website, as categorized in Table 4.3.

Field	Description	Possible values
Visits	number of times the participant visited the personalized website	0–?
Pre-test	participant's score on the pre-competition energy literacy survey	0–15
Post-test	participant's score on the post-competition energy literacy survey	0–15
Test-diff	difference between Post-test minus Pre-test	-15 – 15
Total-energy	total energy consumption during the competition for participant's floor	unknown
Total-KN	total Kukui Nuts participant accumulated during the competition	0–?
Tasks	total number of tasks completed during competition	0–?

Table 4.1. Fields of participant data profile

Visitation level	Visits
None	0
Rare	1–5
Moderate	6–19
Frequent	$>= 20$

Table 4.2. Participant visitation levels

Activity level	Tasks
Inactive	0
Low	1–5
Medium	6–19
High	$>= 20$

Table 4.3. Participant activity levels

Using these two categorizations, we could classify a participant as a 'voyeur' if they were a frequent visitor but had low activity, or a 'poster child' if they were frequent and active visitor. A participant who rarely visited the website but was highly active might have been initially very interested, but their interest quickly waned.

We might similarly break the difference between pre-test and post-test energy literacy scores into 5 categories as shown in Table 4.4. To assess the website's effect on energy literacy we can examine the literacy difference categories. Obviously participants with terrible literacy differences would be an area to follow up with interviews to see whether this was an artifact of the survey or actually indicative of dramatically reduced energy literacy.

Literacy change	Test-diff
Terrible	-15 – -10
Bad	-9 – -4
Minor	-3 – +3
Good	4 – 9
Excellent	10 – 15

Table 4.4. Energy literacy score difference categories

4.2.3 Floor profile

We can also aggregate data from all the participants on a floor to generate a floor profile. The fields in the floor profile are described in Table 4.5. We define high floor participation as being a floor-participation value above 13, the minimum amount required to successfully complete an attendance goal (50% floor participation threshold, see subsection 3.3.4).

The floor-post-test scores can be categorized into thirds as in Table 4.6. Using these categories we can talk about whether floors with high floor-post-test scores also ranked among the lowest floor-energy-during values.

4.3 Research Questions

Rather than use a traditional treatment-based design, we have opted to provide all participants with equal access to all the tools and information we hypothesize may be helpful via the

Field	Description	Possible values
Floor-participation	number of residents who logged into website at least once	0–26
Floor-KN	number of Kukui Nut points accumulated by participants on the floor	0–?
Floor-post-test	mean of the floor's participants' post-competition energy literacy questionnaire scores	0–15
Floor-energy-before	pre-competition average daily floor energy	unknown
Floor-energy-during	average daily floor energy during competition	unknown
Floor-energy-after	post-competition average daily floor energy	unknown

Table 4.5. Fields of floor data profile

Literacy level	Floor-post-test
Low	0–5
Medium	6–10
High	11–15

Table 4.6. Energy literacy score categories

competition website. Thus, instead of positing hypotheses to be assessed using significance testing, we focus on descriptive and exploratory statistics based around research questions.

4.3.1 To what extent was the website adopted by the participants?

While great effort has gone into creating the competition website that will be used by the participants, failure of participants to use the website is a significant risk (see subsection 3.5.4). Therefore, it is important to assess whether participants actually adopted the website.

We plan to measure adoption in multiple ways. The first hurdle is getting participants to actually log into the website. Based on the website logs, we can measure what percentage of residents actually logged into the website at least once. Petersen et al. found in an Oberlin dorm energy competition that 46% of participants viewed the competition website, though it did not require logging in [37]. Because of our website requires login, which might deter some users, we believe if 30% of the potential participants actually log in, this would be indicative of website adoption. Another measure is the average number of visits per participant, as a single visit by a participant during the first few days of the competition would indicate that the participant did not find the website relevant or useful. We set the threshold for average number of visits per participant indicating adoption to 4, one for each round of the competition.

Once logged in, the primary interactive feature of the website is the competition task system. The number of tasks completed per participant will provide an indication of how engaged participants are in the energy literacy aspect of the competition. Following the definition in Table 4.3, we set the threshold for adoption at the medium activity level of 6 or more tasks completed on average per participant.

Finally, we can get direct data about participants' opinion of whether the website was useful through the post-competition questionnaire.

4.3.2 How did floor and dorm energy usage during the competition differ from the energy usage before the competition?

This question goes to the basic premise of any energy competition: that an organized competition that includes a quantitative measure of energy usage will lead to a reduction in energy usage. There are a variety of ways to quantify changes in energy use. One way is to compare the average daily energy used for each floor before the competition with the average daily energy used during the competition, giving an overall difference in energy use. Since weekend energy use may differ significantly from weekday usage, it is important to ensure that the days used for the average include the correct portion of weekdays to weekend days (5 to 2). Based on other student housing energy competitions (see Section 2.1) we expect that the trend for average daily energy use to be lower for each residence hall compared to the usage before the competition.

We will also examine the daily energy used per floor and averaged across all floors of each building to look for trends in daily usage over the competition and pre-competition period. As the competition progresses through the 4 rounds, we would expect daily energy usage to trend downward as floors vie for the grand prize. Alternatively, an initially downward trend that reversed itself during the competition could indicate waning interest in the competition or frustration with behavior changes.

Hour-to-hour patterns of energy use can show what time of day participants are using energy, and how that might change during the competition. As an example of this type of analysis, Figure 4.1 shows a heatmap visualization of 4 floors of Saunders Hall, the social sciences building on the UHM campus, generated using a WattDepot visualization gadget [14]. The visualization shows the heaviest energy use between 12 and 6 PM, as expected for a building with classrooms and faculty offices.

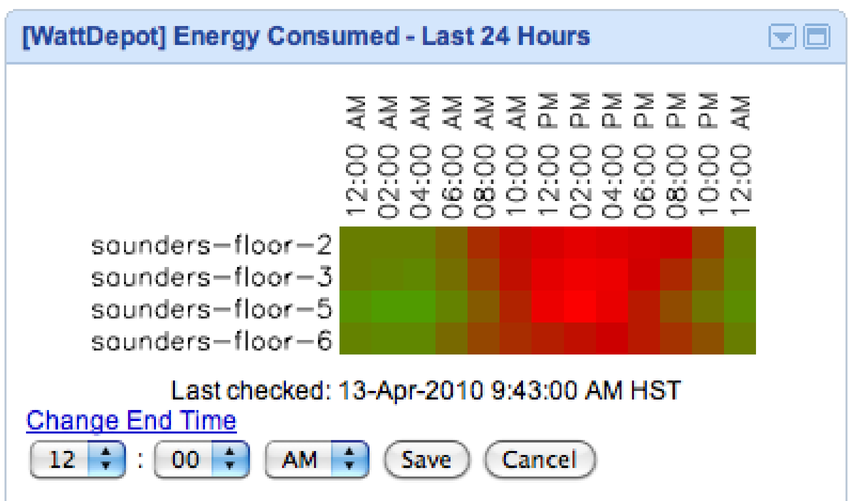


Figure 4.1. Heatmap visualization of 4 floors of Saunders Hall

The addition of energy feedback has been shown over several studies to lead to conservation values from 5% to 15% (see Section 2.2). We expect the average energy use for each building during the competition to be reduced by at least 10%. However, energy usage on an individual floor may or may not be reduced compared to the pre-competition period, as some floors may not actively participate in the competition. We expect average energy use during the competition to be greater than 10% for the floors that are actively participating (see subsection 4.2.3).

4.3.3 How did energy usage during the competition differ from the energy usage after the competition?

While the question in subsection 4.3.2 is the usual one asked about energy competitions, this question addresses the issue of sustainability: what do participants do after the incentives have been removed? Since student housing energy competitions typically last only a fraction of a semester, if the behavior is not sustained after the competition then the positive impact both to the environment and the institution's utility bill is limited. We will quantify the changes in energy use in the same way as described in subsection 4.3.2.

We hypothesize that the energy usage will be higher after the competition is over, as the incentives will have been removed and overall focus on energy by the participants will be greatly reduced. However, some habits started during the competition may persist, and the website will still provide residents with energy usage feedback, which has been shown to reduce consumption.

4.3.4 How effective are the tasks available via the website at improving energy literacy and reducing energy usage?

The design of the website (described in Section 3.2) and the tasks it makes available to participants are specifically intended to increase the energy literacy of those that participate in them. The effectiveness of the set of tasks is critical to determine whether the added complexity of the tasks and Kukui Nut point system is worth the effort.

We will investigate this question in the following ways. First, we examine the correlation between Kukui Nuts earned by participants and their post-competition energy literacy score. We rank order all participants by the number of KN they earned, and then rank order all participants by the change in energy literacy score from pre-competition to post-competition. We can then compute the non-parametric Spearman's rank correlation coefficient ρ which ranges from -1 to +1, with -1 indicating perfect negative correlation, 0 indicating no correlation, and +1 indicating perfect positive correlation. A strong positive correlation would provide evidence that those that actively used the website increased their energy literacy. The same comparison can be done between ranked KN scores and ranked post-competition energy literacy score, which would show correlation for participants who we active on the website but already had high energy literacy and thus little change in their energy literacy score post-competition.

Second, we will examine the correlation between total KN per floor and the difference between average daily energy usage before and during the competition. We use Spearman's rank correlation coefficient ρ, though this time we are ranking floors rather than participants. A strong positive correlation would suggest that tasks completed via the website may help participants to reduce their energy usage in the context of the competition.

Third, we look at the correlation between total KN per floor and the difference between average daily energy usage before and after the competition. Again, we compute ρ using the floor KN ranking and a ranking of the difference in energy usage before and after the competition. A strong positive correlation here would indicate that website tasks help to sustain energy conservation after the competition.

Finally, we can get information about the participants' opinion of the effectiveness of the website using the questionnaire described in subsection 4.1.4.

4.3.5 How appropriate were the Kukui Nut values assigned to tasks?

Beyond just making tasks available to participants, the website assigns Kukui Nut point values to each task. The point values have been assigned by hand based on several factors:

- the expected difficulty of the task
- the expected time required for the task
- a guess as to how useful the task is to increasing energy literacy and/or reducing energy consumption
- the degree to which verification is possible (i.e. commitments, which are self-verified, are worth less than activities and goals)

Evaluating the appropriateness of KN scores for individual tasks can be done by examining the correlation between a participant's completion of a particular task and the difference between that participant's pre and post-competition energy literacy scores. Tasks that are strongly correlated with improved energy literacy would be candidates for increased KN values for future competitions.

It also makes sense to examine the popularity of tasks. If a task was correlated with improved energy literacy scores but was not popular, then it makes sense to further increase the number of Kukui Nut points assigned to it in future competitions. Tasks that required multiple verification attempts by participants before being accepted by administrators could also be candidates for increased Kukui Nut values, since this represents additional effort on the part of participants.

4.3.6 What is the relationship between energy literacy and energy usage?

We hypothesize that more energy literate participants will conserve more energy. This is one of the goals of energy literacy: to make students understand the reasons for being concerned about energy use, and the techniques they can use to reduce their energy usage. This question can be broken down into three sub-questions:

1. do floors with higher average pre-competition energy literacy scores have lower average daily energy use during the pre-competition period?
2. do floors with higher average pre-competition energy literacy scores have a greater reduction in average daily energy use during the competition?
3. do floors with higher average post-competition energy literacy scores have a lower sustained energy usage in the post-competition period?

The first sub-question investigates whether participants who were already more energy literate were already using less energy before the competition started. This neglects the possibility of participants improving their energy literacy through means outside the competition during the pre-competition period (classes, involvement in campus organizations, etc.), but this seems a reasonable assumption.

The second sub-question examines whether those participants who started the competition with higher energy literacy scores used less energy during the competition, independently of any change of literacy during the competition.

The third sub-question looks at the critical question of the sustainability of behavior changes in the wake of the competition. Sustainability is the ultimate goal of any attempt at behavior change.

We will evaluate this question using the methods described in subsection 4.3.4. While that question looked at the relationship between KN and energy, here we rank floors by their combined energy literacy score. A high post-competition energy literacy score accounts for both those participants that already had a high degree of energy literacy, and those that gained energy literacy during the competition.

4.3.7 How important was floor-level near-realtime electricity usage feedback to achieving electricity conservation?

Provision of floor-level near-realtime electricity usage feedback is one of the key features of this research. Providing feedback at the floor level enables competition between floors (instead of just between buildings as is commonly done), allows individual participants to see their behavior changes reflected in electricity usage (which would be swamped by the activity if measured at the building level), and provides a reason for participants to communicate and collaborate with their floormates. Near-realtime feedback allows participants to perform their own 'experiments' and see how their behavior changes electricity usage.

Unfortunately, the logistics of floor-level near-realtime electricity metering provide some of the most significant challenges to the research: the cost of purchasing the meters, the time and effort required to have them installed by electricians, and the lead time required to have the meters in place before the competition can begin.

Thus it is reasonable to ask whether deploying floor-level near-realtime electricity metering is worth the effort. Since we are not undertaking a 'treatment'-style experiment where some floors or buildings receive the metering and others do not, we look at indirect indications of the utility of the metering. One source of data is the popularity of tasks (based on website logs) that make use of the floor-level near-realtime metering, such as the floor goal of determining the floor's minimum power or the floor goal of reducing energy use by 10% (see Section B.4). The other source of data is participant responses to questions about the usefulness of the floor-level near-realtime metering in the post-competition feedback questionnaire.

We believe the importance of floor-level near-realtime monitoring would be demonstrated if:

- The website is adopted by the participants (using the threshold discussed in subsection 4.3.1.
- Of those participants that completed at least one task, 25% completed a task that required either floor-level monitoring or near-realtime monitoring.
- Respondents to the post-competition questionnaire agree on average that having floor-level near-realtime monitoring was helpful in the competition.

Ultimately, the decision to use floor-level near-realtime metering in future energy competitions will be a based on a cost/benefit analysis, and the answer for one institution or situation might not be appropriate for all.

Chapter 5

Conclusion

This proposal laid out a research plan to investigate the sustainability of energy conservation in a dorm energy competition using a competition website that integrates techniques from environmental psychology in an attempt to improve participants' energy literacy. The competition will employ floor-level near-realtime power meters to allow competition between floors, and make participants more aware of their energy usage. The competition website creates a parallel competition for Kukui Nut points through completion and verification of tasks intended to increase energy literacy. To examine the relationship between energy literacy and the website, and the relationship between energy literacy and energy conservation, an energy literacy survey has been developed and will be administered to the participants.

5.1 Anticipated Contributions

The anticipated contributions of this research are:

- An increased understanding of the energy use of residence halls after an energy competition ends.
- Insight into the effect of energy literacy on energy conservation in a University residence hall context.
- Experience in designing a website intended to foster behavior changes related to energy use, and detailed data about participants' use of the website.
- An increase in energy literacy among the participants of the competition.
- A permanent metering infrastructure in two residence halls that will permit future competitions and research on those competitions.

- Institutional knowledge and logistical infrastructure for performing future competitions.
- A reduction in energy use (and therefore cost savings to Student Housing) for the two residence halls in the competition.

5.2 Future Directions

There are a variety of directions that can be pursued once this research is complete, such as:

- Repeating the energy competition in future years (possibly in more buildings if funding is available), using insights gained from this research. Freshmen are a renewable resource, so the competition can be run once a year with new participants. Professor Johnson already plans to run future competitions, and has submitted an NSF grant proposal to that end. If the data indicates some subset of the website tasks are particularly useful, future competitions could switch to a treatment-based design to investigate those effects more robustly.
- Moving beyond residence halls to other buildings on the UHM campus. Does a competition make sense for buildings where faculty and staff are the primary occupants? Outside the dorm, long-term financial incentives generated by returning a portion of financial savings to the departments that conserve energy might make more sense than prizes.
- Fostering energy conservation in homes through behavior change. With the growth of the smart grid, near-realtime power usage data will be available to more and more homes. While the direct feedback coupled with the incentive of lower utility bills is likely to lead to some energy conservation, web-based tools have the potential to help motivate behavior change on a large scale.

5.3 Timeline

The planned timeline for the research is given below. Note that if the competition should be delayed due to one of the factors in Section 3.5, the competition might take place in February 2011 rather than October 2010. Even in this scenario, we believe it is possible to complete the dissertation by the end of the Spring semester in May 2011.

- Spring 2010: competition design, website design, buy-in from stakeholders

- Summer 2010: install meters in dorms
- September 2010: competition website complete
- October 2010: competition takes place
- November 2010: data analysis and dissertation writing begin in earnest
- February 2011: followup study takes place
- May 2011: dissertation defense

Appendix A

Physical Concepts: Power and Energy

When discussing energy, and in particular electricity, it is important to understand what power and energy are, and how they interrelate.

A.1 Energy

Energy is defined as the amount of work that can be done by a force. Most of us have an intuitive notion of energy: is makes things move, it heats things up, etc. There are many units used to measure energy: joules (a very small amount of energy), BTUs, calories. When talking about electricity, the most common unit is the watt hour, abbreviated as ”Wh”, which is equal to 3600 joules. A watt hour is the amount of energy required to to provide 1 watt of power for one hour. Note that from a certain perspective it is somewhat peculiar to measure energy in units that include power (watt), since power is defined in terms of energy in the first place. This underlines how central the concept of power is in most of our dealings with electricity.

A.2 Power

Power is defined as the rate of change for energy. As with any rate, it is expressed as a quantity of energy over a unit of time. The most common unit for power is the watt, abbreviated as ”W”. One watt is defined as one joule (a measure of energy) per second. You might be familiar with a 60 watt incandescent light bulb, which expresses how much power it uses when turned on.

A.3 Analogy To Cars

Power and energy are closely related, but frequently confused concepts. As an analogy, think about a car. We can talk about the speed of a car (in miles per hour, or kilometers per hour) and we can also talk about a distance driven in a car (miles or kilometers). The speedometer in the car measures the speed (distance over time), while the odometer measures the distance traveled. Speed is a rate, like power, while distance is like energy.

When we talk about speeds, we usually talk about instantaneous measurements of speed. A speed limit is the maximum instantaneous speed at which you are allowed to drive, i.e. the car's speedometer should never register a speed greater than the limit. However, when we talk about distance driven, it only makes sense to talk about a distance driven between two locations, or the distance driven over a particular time interval. There is no such thing as an instantaneous distance driven, because in at a precise instant in time, the car is not moving.

A.4 Power vs. Energy

Since power is the rate of change of energy, if you know how power changes over time, you can determine how much energy was consumed or produced (the area under the power curve). Similarly, if you know how much energy was used over an interval of time, you can compute the average power over that period of time (but not the instantaneous power).

In our interactions with appliances, we usually talk about their power consumption and not their energy consumption. For example, we have 60 watt light bulbs, but we wouldn't generally talk about a 60 watt hour lightbulb (unless it consumed 60 watts for an hour and then burned out!). This is because power consumption is an intrinsic characteristic of things that use electricity, while the amount of energy used by an electrical device is determined by how long you keep it plugged in or turned on. On the other hand, energy is very important to the utility that provides your electricity, since you are billed by how much energy you have used (typically in kilowatt hours).

The two key points to remember are: power is a rate, and we always talk about energy over an interval of time.

Appendix B

Participant Kukui Nut Tasks

This appendix lists tasks intended to be undertaken by the competition participants. Each task should increase the energy literacy of the participants performing it, help them modify their behavior to reduce electricity usage, or both. The following lists all the possible tasks, and indicate how they would be performed, validated, and what the potential benefit would be to the person performing it. The tasks are grouped into four categories: events, activities, commitments, and goals. For more information, see Section 3.3.

We expect that additional tasks will be developed between the time of this proposal and the actual competition start date.

B.1 Events

One common type of task is attendance of an event. In our model, there are two ways to get credit for attending an event: activities (individual attendance), and goals (floor attendance). Since the parameters are often identical between the activity version and the goal version of an event, they are grouped together here.

For both event activities and goals, attendance is verified using non-forgeable, single-use attendance codes such as ”orientation-158-B7QRX13”. The codes are printed on small slips of paper that are handed out by some responsible person who is not a participant (such as the event speaker or an RA).

In the case of activities, to get credit for attending, the individual participant logs into the web site and enters in the attendance code. The website automatically awards KN points if the attendance code is valid, and it has not already been entered.

For goals, the participant that initiated the goal must log into the website after the event and indicate that the goal was met (perhaps prodding any floormates to enter their attendance codes if they haven't already done so). The website will then award the appropriate KNs to all members of the floor (including those who did not attend). Goals must have the participation of at least half of the floor participants to be successful. If a floor achieves 100% participation, they receive double the KN.

Relatively passive events like movies or lectures should be worth around 5 KN, while more interactive events like workshops should be worth more (perhaps 10-15 KN).

B.1.1 Attend Kukui Cup orientation

Description: Participant attends a large orientation meeting about the Kukui Cup competition.

Potential benefits: Understanding of the competition mechanics, collaboration with other floor participants on competition strategy.

Psychological justifications: ?

Activity reward: 4 KN

Goal reward: 5 KN (unlikely to be obtained, since this happens at very beginning of competition)

B.1.2 Attend EnergyPong tournament

Description: Participant attends the EnergyPong tournament for their building.

Potential benefits: Improved energy literacy through hearing energy questions answered, floor bonding.

Psychological justifications: competition

Activity reward: 2 KN

Goal reward: 4 KN

B.1.3 Attend a special Kukui Cup SustainableUH meeting

Description: Participant attends a special presentation by SustainableUH team members on what SustainableUH is doing on campus.

Potential benefits: Getting involved with peers on campus, learning what challenges exist and how students are working to overcome them.

Psychological justifications: ?

Activity reward: 2 KN

Goal reward: 5 KN

B.1.4 Watch the movie ”Who Killed the Electric Car”

Description: Participant watches the movie.

Potential benefits: Understanding of the possibility of de-carbonizing transportation, difficulty of changing status quo.

Activity reward: 2 KN

Goal reward: 5 KN

B.1.5 Watch the movie ”Enron: The Smartest Guys in the Room”

Description: Participant watches the movie.

Potential benefits: Understanding risks and problems from utility deregulation, ethical issues.

Activity reward: 2 KN

Goal reward: 5 KN

B.1.6 Watch the movie “The End of Suburbia”

Description: Participant watches the movie.

Potential benefits: Understanding peak oil, design of communities around automotive transportation and plentiful cheap energy.

Activity reward: 2 KN

Goal reward: 5 KN

B.1.7 Watch the movie ”A Crude Awakening: Oil Crash”

Description: Participant watches the movie.

Potential benefits: Understanding peak oil, consequences for society.

Activity reward: 2 KN

Goal reward: 5 KN

B.1.8 Watch the movie ”The Great Warming”

Description: Participant watches the movie.

Potential benefits: Understanding climate change, consequences for society.

Activity reward: 2 KN

Goal reward: 5 KN

B.1.9 Watch the movie ”An Inconvenient Truth”

Description: Participant watches the movie.

Potential benefits: Understanding climate change, consequences for society.

Activity reward: 2 KN

Goal reward: 5 KN

B.1.10 Participate in a 10/10/10 work party

Description: [http://www.350.org/ 350.org], a climate change advocacy organization is organizing a series of ”work parties” to take place on October 10, 2010 (10/10/10). Participant participates in a work party in Honolulu (check website for options). Since this is off campus, might need to support alternate verification (photo and text) instead of attendance codes.

Potential benefits: Understanding climate change, consequences for society.

Activity reward: 5 KN

Goal reward: 7 KN

B.2 Activities

B.2.1 Perform room energy audit

Description: Resident borrows a Kill-A-Watt plug load meter from their RA, then checks all plug-in appliances in their room to see what their energy consumption is when on and off.

Verification: Participant fills out form on website that contains a list of rows for each device with columns: device name, power (watts) when off, power (watts) when on, notes. Admin reviews data, checking mainly for completeness (more than 1 device?) and sanity (XBox 360s don’t use 1000 W).

Reward: 10 KN

Potential benefits: Increased intuitive understanding of the watt, familiarity with vampire power, understanding of how device usage would impact energy consumption, reduced electricity usage due to turning off devices when not in use.

Psychological justifications: feedback, activity-based learning (?)

B.2.2 Replace incandescent bulb with compact fluorescent (CFL)

Description: Participant finds an incandescent bulb (perhaps from a desk lamp) and replaces it with a CFL, throwing away the incandescent bulb.

Verification: Participant takes a picture showing both the incandescent bulb and the CFL replacement and uploads it via a verification form on the website, along with a text field indicating where the replaced bulb is located. Admin briefly reviews the picture to ensure that in fact both bulbs are present.

Reward: 3 KN

Potential benefits: Reduced energy usage via CFL, awareness of energy impact of incandescent bulbs.

Psychological justifications: activity-based learning (?)

B.2.3 Configure computer & monitor to sleep after inactivity

Description: Participant configures their computer and any external display to sleep after 20 minutes of inactivity.

Verification: Participant takes a screenshot from their computer showing sleep settings ¡= 20 minutes and uploads it via a verification form on the website. Admin briefly reviews the picture to ensure that the settings look correct.

Reward: 3 KN

Potential benefits: Reduced computer & monitor energy usage, knowledge of how to set it up on other computers (friends, work, future purchases, etc).

Psychological justifications: none

B.2.4 Play in EnergyPong tournament

Description: Participant is on their floor's team in the EnergyPong tournament for their building.

Verification: Some responsible person who is not a participant (such as the speaker or an RA) records attendance and performance, which is reported to the website admins either on paper or via email.

Reward: 4 KN + 1 KN per bracket completed + 5 KN for the winning team

Potential benefits: Improved energy literacy through answering energy questions answered, floor bonding.

Psychological justifications: competition, incentives (if prizes are awarded to winning team)

B.2.5 Connect to Kukui Cup on Facebook

Description: Participant becomes a fan of the Kukui Cup Competition group on Facebook.

Verification: Participant takes a screenshot from their computer showing Facebook fan status. Admin briefly reviews the picture to ensure that the participant is a fan.

Reward: 3 KN

Potential benefits: Another avenue for communicating with students, promotion of the contest and energy literacy.

Psychological justifications: community involvement?

B.2.6 Tweet about Kukui Cup

Description: Participant sends a tweet promoting the Kukui Cup Competition with a link to the website.

Verification: Participant takes a screenshot from their computer showing the tweet in their newsfeed. Admin briefly reviews the picture to ensure that the participant tweeted.

Reward: 2 KN

Potential benefits: Promotion of the contest and energy literacy.

Psychological justifications: social networking?

B.2.7 Facebook Status update about Kukui Cup

Description: Participant updates their Facebook status promoting the Kukui Cup Competition with a link to the website.

Verification: Participant takes a screenshot from their computer showing the status in their newsfeed. Admin briefly reviews the picture to ensure that the participant updated their status.

Reward: 2 KN

Potential benefits: Promotion of the contest and energy literacy.

Psychological justifications: social networking?

B.2.8 Label all plug loads in room

Description: Followup to room energy audit. Based on the audit results, make a label for each device with the number of watts consumed when on and off, located close to the power switch for those devices that have them.

Verification: Participant takes a picture of the devices with their labels. Admin briefly reviews the picture to ensure that labels are present.

Reward: 3 KN

Potential benefits: understanding of how device usage would impact energy consumption, reduced electricity usage due to turning off devices when not in use.

Psychological justifications: prompts

B.2.9 Determine carbon footprint using calculator

Description: Participant uses a web-based carbon footprint calculator to determine their carbon footprint.

Verification: Participant enters in their computed carbon footprint into a text field. Admin briefly reviews the footprint to make sure it is sane (units include CO2 and it isn't huge or tiny).

Reward: 3 KN

Potential benefits: learning about carbon emissions, learning how carbon emissions impact the environment.

Psychological justifications: personalized data

B.3 Commitments

Note that per the requirements, commitments are participant-verified without outside intervention, so that field is not used for this category.

B.3.1 Turn off lights when I leave the room

Description: The participant commits to turning off all lights whenever they are the last person to leave a room.

Reward: 2 KN

Potential benefits: Reduced electricity usage due to less unneeded lighting, highly obvious reminder of need to conserve energy.

Psychological justifications: public commitments

B.3.2 Use task lighting instead of overhead lights

Description: The participant commits to using task lighting (i.e. a desk lamp) instead of overhead room lights. Might only be appropriate if housing rooms have overhead lights.

Reward: 2 KN

Potential benefits: Reduced electricity usage due to less excess lighting.

Psychological justifications: public commitments

B.3.3 Always disconnect vampire loads using a power strip

Description: The participant commits to turning off any vampire loads (cell phone charger, iPod charger, game consoles, TVs) using a power strip when they are not using them.

Reward: 2 KN

Potential benefits: Reduced electricity usage due to vampire loads, awareness of vampire loads.

Psychological justifications: public commitments

B.3.4 Turn off water when brushing teeth, shaving, etc

Description: The participant commits to turning off any vampire loads (cell phone charger, iPod charger, game consoles, TVs) using a power strip when they are not using them.

Reward: 2 KN

Potential benefits: Reduced electricity usage due to vampire loads, awareness of vampire loads.

Psychological justifications: public commitments

B.3.5 Turn off water when sudsing and scrubbing in shower

Description: The participant commits to turning off water when showering except when actively rinsing off.

Reward: 2 KN

Potential benefits: Reduced electricity usage due to less water heating and pumping.

Psychological justifications: public commitments

B.3.6 Use natural light instead of electric lighting whenever possible

Description: The participant commits to using natural light from windows or outdoors instead of turning on electric lighting. This can mean opening shades instead of turning on the lights, and/or planning their day so that tasks that require light (like reading books, doing written homework) are done during the day.

Reward: 2 KN

Potential benefits: Reduced electricity usage due to less use of electric lights.

Psychological justifications: public commitments

B.3.7 Turn off printer when not printing

Description: The participant commits to turning off their printer when they are not actively printing out documents.

Reward: 2 KN

Potential benefits: Reduced electricity usage due to less standby electricity for printer.

Psychological justifications: public commitments

B.3.8 Use stairs instead of elevator

Description: The participant commits to using the stairs instead of elevators whenever feasible.

Reward: 2 KN

Potential benefits: Reduced electricity usage due to less elevator traffic. Increased exercise for participant.

Psychological justifications: public commitments

B.3.9 Recycle all beverage containers

Description: The participant commits recycling all (recyclable) beverage containers at an appropriate location.

Reward: 2 KN

Potential benefits: Reduced carbon emissions due to recovery and eventual reuse of recyclable material, reduction in waste stream.

Psychological justifications: public commitments

B.3.10 Don't drive off-campus using a single-occupant car

Description: The participant commits to not traveling off-campus in single-occupant car, using bus, bike, walking, or vehicle with 3+ occupants instead.

Reward: 2 KN

Potential benefits: Reduced carbon emissions due to less single occupant car travel, reduction in traffic and parking.

Psychological justifications: public commitments

B.3.11 Turn off/shut down all appliances before going to sleep

Description: The participant commits to turning off or shutting down appliances like computers, TVs, DVD players, and game consoles before going to sleep each night.

Reward: 2 KN

Potential benefits: Less electricity wasted on appliances that aren't being used.

Psychological justifications: public commitments

B.3.12 Limit TV watching to 1 hour a day or less

Description: The participant commits to watching not more than 1 hour of TV per day.

Reward: 2 KN

Potential benefits: Less electricity used by television.

Psychological justifications: public commitments

B.3.13 Do only full loads of laundry

Description: The participant commits to always doing full loads of laundry.

Reward: 2 KN

Potential benefits: Less electricity & hot water used per piece of laundry washed.

Psychological justifications: public commitments

B.3.14 Wear Kukui Cup button every day

Description: The participant commits to wearing their Kukui Cup button every day during the commitment period.

Reward: 2 KN

Potential benefits: promotion of the contest.

Psychological justifications: public commitments

B.3.15 Walk to destinations less than one mile away

Description: The participant commits to walking to any destination less than one mile away from their residence hall.

Reward: 2 KN

Potential benefits: Reduced gasoline usage due to car usage. Increased exercise for participant.

Psychological justifications: public commitments

B.3.16 Wash laundry in cold water

Description: The participant commits to washing laundry in cold water instead of warm or hot water.

Reward: 2 KN

Potential benefits: Reduced electricity usage by reduction in water heating and pumping.

Psychological justifications: public commitments

B.3.17 Reduce the shower time by 1 minute

Description: The participant commits to measuring the length of their shower with a watch, and reducing the time by 1 minute.

Reward: 2 KN

Potential benefits: Reduced electricity usage by reduction in water heating and pumping.

Psychological justifications: public commitments

B.3.18 Turn off music when leaving room

Description: The participant commits to turning off their music (from computer, stereo, etc) when they leave the room.

Reward: 2 KN

Potential benefits: Reduced electricity usage.

Psychological justifications: public commitments

B.3.19 Do something "unplugged" every day

Description: The participant commits to doing something that doesn't require electricity instead of watching TV, using their computer, or playing a console game.

Reward: 2 KN

Potential benefits: Reduced electricity usage, increased exercise?

Psychological justifications: public commitments

B.3.20 Bring reusable bags when shopping

Description: The participant commits to bringing and using reusable bags when shopping instead of the paper or plastic ones offered by the store.

Reward: 2 KN

Potential benefits: Reduced waste, reduced carbon footprint.

Psychological justifications: public commitments

B.3.21 Don't eat meat

Description: The participant commits to not eating any meat (beef, pork, chicken, fish, shellfish, etc) for the commitment period.

Reward: 2 KN

Potential benefits: Reduced carbon footprint, potentially improved health.

Psychological justifications: public commitments

B.4 Goals

B.4.1 Reduce our floor's energy consumption by target

Description: A floor participant picks a target goal (hopefully in consultation with rest of floor) for reduction for the current period from a list of choices from 5% to 50% in 5% increments. When the goal is specified, the system uses the Average Floor Power as the value being reduced from. The system can provide a graphic that is updated in near-real time to show whether (a) the current usage is above or below the target, and (b) whether the cumulative usage so far is above or below the target. The graphic can also provide a count-down timer showing the time remaining to achieve this goal in days:hours:minutes.

Note that the percentage reduction is always relative to the baseline, not the prior week. So, a floor might start out with a conservative goal of 5%, then find that they actually achieved 16% during the period. So, they could restart the goal for the next period, this time choosing 15%.

Verification: Participant that picked the goal must use the web interface indicate that the goal has been met or not met, and an admin assigns points accordingly.

Reward: If the floor achieves the target reduction, then each member of the floor is awarded 1 KN per target percentage reduction. For example, if the target reduction was 5% and the floor achieved 7%, then each member gets 5 KNs for achieving this goal.

Potential benefits: Reduced electricity usage, group planning for how to achieve target through behavior changes.

Psychological justifications: goal setting with feedback, social norms

B.4.2 Finding the minimum floor power

Description: A floor participant picks a day and time for the floor to try to determine the minimum amount of power the floor can consume. Everyone on the floor must disconnect and unplug all loads, all lights must be turned off, etc. Then, using a laptop or mobile device, the floor's instantaneous power value is recorded from the monitors on the contest website.

Note that this goal requires near 100% participation to be successful.

Verification: Participant that picked the goal must use the web interface indicate what power value the floor was able to record. The admin can then compare this to the Minimum Floor Power determined before residents moved in. If the participants got within 10% of the MFP, then the KN are awarded.

Reward: Each member gets 10 KNs for achieving this goal.

Potential benefits: Awareness of building infrastructure power draws, group collaboration to turn everything off, awareness of vampire loads.

Psychological justifications: ?

Appendix C

Energy Literacy Questions

This appendix lists the questions that assess participants' energy literacy. The questions are separated into sections based on the topic they are addressing. We provide an even number of questions for each concept being tested, so that they can be used to assess energy literacy both before and after the competition. To determine if the phrasing of the question impacts the results, half of the participants will be given the first question in pre-test, while the other half will get the second question in pre-test, and vice versa in the post test. Keywords have been attached to each question to indicate which subjects they attempt to assess. This is useful to ensure that there exists energy literacy content that addresses the concept represented by each keyword.

The questions are intended to be displayed one at a time without the ability for the participant to go back to previous questions, as later questions may imply the answer to previous questions. When administered via a web site, this is straightforward to accomplish. When administered on paper, each question could be printed on a separate sheet of paper, and participants could be directed to not turn back to previous pages.

C.1 Power and Energy Concepts

C.1.1 Watt definition

1. The watt is a unit of:

a) energy

b) power

c) distance

d) force

Correct answer: power

Keywords: power, units

2. Power is commonly measured in units of:

a) BTU

b) joule

c) kilowatt-hour

d) watt

Correct answer: watt

Keywords: power, units

C.1.2 Watt abbreviation

3. The watt is abbreviated as:

a) wt

b) Wh

c) W

d) tt

Correct answer: W

Keywords: power, units

4. The abbreviation ”W” refers to what unit:

a) watt-hour

b) wind power

c) wave power

d) watt

Correct answer: watt

Keywords: power, units

C.1.3 Watt-hour definition

5. The watt-hour is a unit of:

a) energy

b) power

c) distance

d) force

Correct answer: energy

Keywords: energy, units

6. Electrical energy is commonly measured in units of:

a) BTU

b) erg

c) watt-hour

d) watt

Correct answer: watt-hour

Keywords: energy, units

C.1.4 Watt-hour abbreviation

7. The watt-hour is abbreviated as:

a) Wh

b) wth

c) W

d) erg

Correct answer: Wh

Keywords: energy, units

8. The abbreviation ”Wh” refers to what unit:

a) watt

b) wind-hour

c) watt-hour

d) power

Correct answer: Wh

Keywords: energy, units

C.1.5 Power/energy calculations

9. A compact fluorescent lightbulb uses 13 W. If it is run for 2 hours, how much energy does it use?

a) 7.5 Wh

b) 13 Wh

c) 26 Wh

d) 52 Wh

Correct answer: 26 Wh

Keywords: power, energy, unit-intuition, calculation

10. A compact fluorescent lightbulb (CFL) used 26 Wh after running for 2 hours. How much power did the bulb consume?

a) 7.5 W

b) 13 W

c) 26 W

d) 52 W

Correct answer: 13 W

Keywords: power, energy, unit-intuition, calculation

11. If your game console uses 200 W when turned on, how much energy would it waste if you left it on all weekend while you were away?

a) 15000 Wh

b) 100 Wh

c) 960 kWh

d) 9.6 kWh

Correct answer: 9.6 kWh
Keywords: power, energy, unit-intuition, calculation

12. While reading your electric bill you notice that you used 72 kWh more than the previous month. You search your apartment for anything out of the ordinary and find you left a fan running in a closet all month long! Approximately how much power does the fan use?

a) 100 W

b) 10 W

c) 300 kWh

d) 1 kWh

Correct answer: 100 W
Keywords: power, energy, unit-intuition, calculation

C.2 Energy Intuition

C.2.1 Consumption intuition

13. Roughly how much power does a normal compact fluorescent lightbulb (CFL) use when running?

a) 20 mW

b) 3 W

c) 60 W

d) 13 W

Correct answer: 13 W

Keywords: power, unit-intuition

14. Roughly how much power does an electric oven use when turned to its highest setting?

a) 100 W

b) 500 W

c) 1 kW

d) 2.5 kW

Correct answer: 2.5 kW

Keywords: power, unit-intuition

15. On average, how much electrical energy does a home in Hawai‘i use per day?

a) 13 kWh

b) 4 kWh

c) 57 kWh

d) 328 kWh

Correct answer: 13 kWh

Keywords: energy, unit-intuition, Hawai‘i

16. On average, how much electrical energy does a home in Hawai‘i use per month?

a) 37 kWh

b) 104 kWh

c) 390 kWh

d) 2000 kWh

Correct answer: 390 kWh

Keywords: energy, unit-intuition, Hawai‘i

C.2.2 Solar intuition

17. What is the approximate maximum power generated from a single standard rooftop solar panel?

a) 25 W

b) 50 W

c) 200 W

d) 800 W

Correct answer: 200 W
Keywords: power, unit-intuition, generation, PV

18. Approximately how much energy does single standard rooftop solar panel in Hawaiʻi generate each day?

a) 100 Wh

b) 1000 Wh

c) 10 kWh

d) 100 W

Correct answer: 1000 Wh
Keywords: energy, unit-intuition, generation, PV

C.3 Grid knowledge

C.3.1 Generation

19. What is the source of approximately 80% of Hawaiʻi's electricity?

a) coal

b) wind

c) solar

d) oil

Correct answer: oil

Keywords: generation, utility, Hawai‘i

20. Burning oil is used to generate approximately what percentage of Hawai‘i’s electricity?

a) 100%

b) 50%

c) 78%

d) 17.5%

Correct answer: 78%

Keywords: generation, utility, Hawai‘i

C.3.2 Demand

21. What is the approximate maximum electrical power demand for the entire island of Oahu?

a) 560 kW

b) 3800 kW

c) 11.8 GW

d) 1.2 GW

Correct answer: 1.2 GW

Keywords: power, unit-intuition, generation, utility, Hawai‘i

22. What is the approximate total electrical energy demand for the state of Hawai‘i?

a) 10,500 million kWh

b) 100 million kWh

c) 2 million kWh

d) 4,500 million kW

Correct answer: 10,500 million kWh

Keywords: energy, unit-intuition, generation, utility, Hawai‘i

23. What is the electrical grid demand curve?

a) A graph of the amount of power used on the grid over time

b) The number of efficient appliances demanded by consumers

c) A graph of the amount of energy used on the grid over time

d) The amount overhead power lines can bend before breaking

Correct answer: A graph of the amount of power used on the grid over time

Keywords: power, generation, utility

24. Why is the shape of the electrical grid demand curve important?

a) Less efficient power plants must be used if there are peaks in the curve

b) A flat curve means nobody is using any electricity

c) The shape shows how many power plants are running

d) The curve is lower at night if there is a lot of solar power in the grid

Correct answer: Less efficient power plants must be used if there are peaks in the curve

Keywords: power, generation, utility, Hawai‘i

C.3.3 Hawai‘i Clean Energy Initiative

25. What is the goal of the Hawai‘i Clean Energy Initiative?

a) Maintain Hawai‘i’s energy use at current levels forever

b) Decrease Hawai‘i’s oil use by 20% by 2020

c) Get 70% of Hawai‘i’s energy from clean sources by 2030

d) Get 50% of Hawai‘i’s energy from wind by 2050

Correct answer: Get 70% of Hawai‘i’s energy from clean sources by 2030
Keywords: energy, generation, utility, Hawai‘i

26. What is the breakdown of the clean energy mandated by the Hawai‘i Clean Energy Initiative by 2030?

a) 50% from renewable sources, 10% from conservation

b) 30% from solar, 30% from wind, 10% from waves

c) 30% from renewable sources, 20% from conservation, 10% from natural gas

d) 30% from energy conservation, 40% from renewable sources

Correct answer: 30% from energy conservation, 40% from renewable sources
Keywords: energy, generation, conservation, utility, Hawai‘i

C.4 Climate change

27. What are the effects of climate change?

a) Global temperatures increasing by a few degrees on average

b) Changes in seasonal rainfall patterns (droughts, floods)

c) A significant rise in the sea level

d) All of the above

Correct answer: All of the above
Keywords: climate change

28. What is the primary cause of climate change?

a) Melting glaciers in Greenland

b) Carbon dioxide released from burning fossil fuels

c) Natural solar cycles

d) Radioactive waste from nuclear power plants

Correct answer: Carbon dioxide released from burning fossil fuels

Keywords: climate change

29. Approximately how much rise in sea level is predicted by the end of the century due to climate change?

a) 2 inches

b) 6 inches

c) 1 foot

d) 3 feet

Correct answer: 3 feet

Keywords: climate change

30. Approximately how much carbon dioxide is in the atmosphere now, and what level is considered safe/acceptable?

a) 450 ppm, 500 ppm

b) 387 ppm, 350 ppm

c) 331 ppm, 350 ppm

d) 600 ppm, 450 ppm

Correct answer: 387 ppm, 350 ppm

Keywords: climate change

Appendix D

Post-Competition Qualitative Feedback Questions

This appendix lists the questions that assess participants' experiences with the competition and website. The questions are separated into sections based on the topic they are addressing. Some questions draw from the energy literacy survey developed by Jan DeWaters [10].

D.1 Adoption of website

1. How often did you visit the competition website?

a) never

b) once

c) a few times

d) a few times per week

e) daily

2. Did you find the website useful during the competition?

a) strongly agree

b) agree moderately

c) neither agree nor disagree

d) disagree moderately

e) strongly disagree

3. What did you like **most** about the website?

Text field for answer.

4. What did you like **least** about the website?

Text field for answer.

5. If you could change something about the website, what would it be?

Text field for answer.

D.2 Tasks effectiveness at improving energy literacy

6. How much do you feel you know about energy?

a) A lot — expert

b) Quite a bit — informed

c) A “medium” amount — somewhat informed

d) Not much — novice

e) Nothing — not in the running

7. When it comes to energy use, how would you describe yourself?

a) High energy user

b) Moderately high energy user

c) Medium energy user

d) I try to save energy sometimes

e) I almost always try to save energy

8. Did you find the activities on the website interesting?

a) strongly agree

b) agree moderately

c) neither agree nor disagree

d) disagree moderately

e) strongly disagree

9. Do you feel you learned more about energy from the website activities?

a) strongly agree

b) agree moderately

c) neither agree nor disagree

d) disagree moderately

e) strongly disagree

10. What was the favorite activity you completed on the website?

Text field for answer.

11. What was the favorite activity you attempted or completed on the website?

Text field for answer.

12. Do you have any ideas for activities to add to the website?

Text field for answer.

D.3 Opinion of floor-level near-realtime meter data

13. Did you enjoy competing with other floors in your dorm?

a) strongly agree

b) agree moderately

c) neither agree nor disagree

d) disagree moderately

e) strongly disagree

14. Was the power display on the website helpful during the competition?

a) strongly agree

b) agree moderately

c) neither agree nor disagree

d) disagree moderately

e) strongly disagree

f) never used the website

15. Did you ever try turning something on or off and use the website to see how much power it used?

a) yes

b) no

D.4 General competition questions

16. Overall, did you enjoy the energy competition?

a) strongly agree

b) agree moderately

c) neither agree nor disagree

d) disagree moderately

e) strongly disagree

f) never used the website

17. Anything else you would like to share about the experience?

Text field for answer.

Bibliography

[1] M. Bamsey, A. Berinstain, S. Auclair, M. Battler, K. Binsted, K. Bywaters, J. Harris, R. Kobrick, and C. McKay. Four-month Moon and Mars crew water utilization study conducted at the Flashline Mars Arctic Research Station, Devon Island, Nunavut. *Advances in Space Research*, 43(8):1256–1274, 2009. Space Life Sciences.

[2] Emily Bartholomew, Chris Bolduc, Katie Coughlin, Brian Hill, Alan Meier, and Robert Van Buskirk. Current energy website. `http://currentenergy.lbl.gov/` Archived by WebCite at `http://www.webcitation.org/5d0BWK9id`, December 11 2008.

[3] Lawrence J. Becker. Joint effect of feedback and goal setting on performance: A field study of residential energy conservation. *Journal of Applied Psychology*, 63(4), 1978.

[4] Marshini Chetty, David Tran, and Rebecca E. Grinter. Getting to green: understanding resource consumption in the home. In *UbiComp '08: Proceedings of the 10th international conference on Ubiquitous computing*, pages 242–251, New York, NY, USA, 2008. ACM.

[5] Robert B. Cialdini, Raymond R. Reno, and Carl A. Kallgren. A focus theory of normative conduct: Recycling the concept of norms to reduce littering in public places. *Journal of Personality and Social Psychology*, 58(6):1015–1026, June 1990.

[6] Core Writing Team, Rajendra K. Pachauri, and Andy Reisinger, editors. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC, Geneva, Switzerland, 2007.

[7] Mark Costanzo, Dane Archer, Elliot Aronson, and Thomas Pettigrew. Energy conservation behavior: The difficult path from information to action. *American Psychologist*, 41(5):521–528, 1986.

[8] Sarah Darby. Making it obvious: designing feedback into energy consumption. In *Proceedings, 2nd International Conference on Energy Efficiency in Household Appliances and Lighting*. Italian Association of Energy Economists/ EC-SAVE programme, 2000.

[9] Sarah Darby. The effectiveness of feedback on energy consumption. Technical report, Environmental Change Institute, University of Oxford, 2006.

[10] Jan E. DeWaters. Energy literacy survey – high school issue. Pre-publication, 2009.

[11] Jan E. DeWaters and Susan E. Powers. Development and use of an energy literacy survey. In *Proceedings of the 38th ASES National Solar Conference*, Buffalo, NY, May 2009. http://www.clarkson.edu/cses/pdf/Development_and_Use_of_an_Energy_Literacy_Survey_ASES09.pdf.

[12] Jan E. DeWaters and Susan E. Powers. The energy literacy assessment project. Presentation at the third annual Behavior, Energy and Climate Change (BECC) Conference, November 2009.

[13] Tawanna Dillahunt, Geof Becker, Jennifer Mankoff, and Robert Kraut. Motivating environmentally sustainable behavior changes with a virtual polar bear. In *Proceedings of Pervasive 2008 Workshop on Pervasive Persuasive Technology and Environmental Sustainability*, pages 58–62, May 2008.

[14] Kendyll Doi and Edward Meyer. WattDepot Gadgets home page. http://wattdepot-ui-googlegadgets.googlecode.com/.

[15] Energy, Inc. The Energy Detective. http://www.theenergydetective.com/.

[16] Ben Engebreth. Personal Kyoto website. http://personal-kyoto.org/, December 17 2008.

[17] Ahmad Faruqui, Sanem Sergici, and Ahmed Sharif. The impact of informational feedback on energy consumption–a survey of the experimental evidence. *Energy*, 35(4):1598–1608, 2010. Demand Response Resources: the US and International Experience, Demand Response Resources: the US and International Experience.

[18] Jonathan L. Freedman and Scott C. Fraser. Compliance without pressure: The foot-in-the-door technique. *Journal of Personality and Social Psychology*, 4(2):195–202, August 1966.

[19] E. Scott Geller. Evaluating energy conservation programs: Is verbal report enough? *Journal of Consumer Research*, 8(3), December 1981. http://www.jstor.org/stable/2488892.

[20] google.org. Google PowerMeter. http://www.google.org/powermeter/, February 2009.

[21] Miguel Helft. Google's energy ideas might emerge under open source licenses — or not. http://greeninc.blogs.nytimes.com/2008/10/28/googles-energy-ideas-might-emerge-under-open-source-licenses-or-not/, October 28 2008.

[22] Human-Computer Interaction and Design at the University of Washington. Ubigreen website. http://dub.washington.edu/projects/ubigreen, December 18 2008.

[23] i2we Inc. iamgreen facebook application. http://www.facebook.com/apps/application.php?id=2422301007, December 16 2008.

[24] Elizabeth Kolbert. Mr. green: Environmentalism's most optimistic guru. *The New Yorker*, January 22 2007.

[25] Jeffrey LeBlanc. Device-level power consumption monitoring. In *Proceedings of the UbiComp 2007 Workshop on Ubiquitous Sustainability: Technologies for Green Values*, Innsbruck, Austria, September 2007.

[26] Jeffrey LeBlanc. Wireless power monitoring construction instructions. http://www.jeffreyleblanc.org/powermonitoring/ Archived by WebCite at http://www.webcitation.org/5d9ZPIJko, December 17 2008.

[27] Lucid Design Group, LLC. Building Dashboard. http://www.luciddesigngroup.com/, Oct 2008.

[28] Jennifer Mankoff, Deanna Matthews, Susan R. Fussell, and Michael Johnson. Leveraging social networks to motivate individuals to reduce their ecological footprints. In *Proceedings of the 40th Annual Hawaii International Conference on System Sciences (CD-ROM)*. Computer Society Press, January 2007.

[29] Doug McKenzie-Mohr. *Fostering Sustainable Behavior: Community-Based Social Marketing*. McKenzie-Mohr & Associates, Inc., 2009.

[30] The Modbus Organization. Modbus website. http://www.modbus.org/.

[31] National Renewable Energy Laboratory. Hawai'i Clean Energy Initiative home page. http://www.hawaiicleanenergyinitiative.org/.

[32] Paul Norton. The path to zero energy homes. http://hawaii.gov/dbedt/info/energy/efficiency/RebuildHawaiiConsortium/Events/PastEvents/2010-03-10/2010-03-10%20Norton%20Rebuild%20Hawaii%20ZEB%20.pdf, March 10 2010.

[33] P3 International. Kill-A-Watt. http://www.p3international.com/products/special/P4400/P4400-CE.html.

[34] Michael S. Pallak, David A. Cook, and John J. Sullivan. *Commitment and Energy Conservation*, volume 4 of *Policy Studies Review Annual*, chapter 22, pages 352–370. Sage Publications, 1980.

[35] Danny Parker, David Hoak, Alan Meier, and Richard Brown. How much energy are we using? Potential of residential energy demand feedback devices. Technical Report FSEC-CR-1665-06, Florida Solar Energy Center/University of Central Florida, 1679 Clearlake Road, Cocoa, Florida 32922, USA, 2006.

[36] John Petersen. Employing multiple modes and scales of real-time feedback to engage, educate, motivate, and empower electricity and water conservation. Presentation at the 2009 Behavior, Energy, and Climate Change conference, Washington, D.C., November 2009.

[37] John E. Petersen, Vladislav Shunturov, Kathryn Janda, Gavin Platt, and Kate Weinberger. Dormitory residents reduce electricity consumption when exposed to real-time visual feedback and incentives. *International Journal of Sustainability in Higher Education*, 8(1):16–33, 2007.

[38] Quality Attributes Software. GreenTouchscreen. http://www.qualityattributes.com/greentouchscreen/, Oct 2008.

[39] Annina Rüst. Thighmaster website. http://web.media.mit.edu/~rusti/thighmaster/about.html Archived by WebCite at http://www.webcitation.org/5d6APewvw, December 15 2008.

[40] Catherine Salop. Wellesley college green cup website. http://www.wellesley.edu/AdminandPlanning/Sustainability/greencupcompetitions.html (Archived by WebCite at http://www.webcitation.org/5p37hBzP7), April 16 2010.

[41] P. Wesley Schultz, Jessica M. Nolan, Robert B. Cialdini, Noah J. Goldstein, and Vladas Griskevicius. The constructive, destructive, and reconstructive power of social norms. *Psychological Science*, 18(5):429 – 434, 2007.

[42] Student Housing Services. Hale aloha website. http://www.housing.hawaii.edu/halls/ha.cfm.

[43] Robert H. Socolow and Stephen W. Pacala. A plan to keep carbon in check. *Scientific American*, 295(3):50–57, September 2006.

[44] StepGreen.org. Stepgreen research website. http://research.stepgreen.org/site/Footprints/Projects, December 16 2008.

[45] StepGreen.org. Stepgreen website. http://stepgreen.org/, December 16 2008.

[46] Yolande Strengers. Challenging comfort & cleanliness norms through interactive in-home feedback systems. In *Proceedings of Pervasive 2008 Workshop on Pervasive Persuasive Technology and Environmental Sustainability*, pages 104–108, May 2008.

[47] Ronak Sutaria and Aalok Deshmukh. Taking the guesswork out of environmentally sustainable lifestyles. In *Proceedings of Pervasive 2008 Workshop on Pervasive Persuasive Technology and Environmental Sustainability*, pages 109–112, May 2008.

[48] Chihiro Takayama and Vili Lehdonvirta. Ecoisland: A system for persuading users to reduce CO_2 emissions. In *Proceedings of Pervasive 2008 Workshop on Pervasive Persuasive Technology and Environmental Sustainability*, pages 113–116, May 2008.

[49] Jeannet H. van Houwelingen and W. Fred van Raaij. The effect of goal-setting and daily electronic feedback on in-home energy use. *The Journal of Consumer Research*, 16(1), June 1989. http://www.jstor.org/stable/2489305.

[50] WattDepot home page. http://wattdepot.googlecode.com/.

[51] Allison Woodruff, Jay Hasbrouck, and Sally Augustin. A bright green perspective on sustainable choices. In *CHI '08: Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems*, pages 313–322, New York, NY, USA, 2008. ACM.

[52] Raymond De Young. Expanding and evaluating motives for environmentally responsible behavior. *Journal of Social Issues*, 56(3):509–526, 2000.