

Energy Feedback for Smart Grid Consumers: Lessons Learned from the Kukui Cup

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Abstract—To achieve the full benefits of the Smart Grid, end users must become active participants in the energy ecosystem. This paper presents the Kukui Cup challenge, a serious game designed around the topic of energy conservation which incorporates a variety of energy feedback visualizations, a multifaceted serious game with online educational activities, and real-world activities such as workshops and excursions. We describe our experiences in developing energy feedback visualizations in the Kukui Cup based on in-lab evaluations and field studies in college residence halls. We learned that energy feedback systems should address these factors: they should be actionable, that domain knowledge must go hand in hand with energy feedback systems, and that this feedback must be “sticky” to lead to changes in behaviors and attitudes.

Keywords—Serious games; energy feedback; energy; energy literacy

I. INTRODUCTION

The development of the Smart Grid and the two-way communication that it provides has enabled a variety of new customer-facing possibilities including real-time feedback on electricity usage, real-time pricing, and demand response. However, to make full use of this potential, end-users of the Smart Grid will need to be engaged about their electricity use, and become more energy literate. We believe that in addition to a Smart Grid, we need Smart Consumers.

In this context, we have developed the Kukui Cup Challenge, a serious game [1] (a game with additional goals beyond just entertainment) designed around the topic of energy. One part of the Kukui Cup is a variety of energy feedback visualizations [2] designed to inform and engage the players about their energy use. The Kukui Cup also includes a multifaceted online game with educational activities, and real-world activities such as workshops and excursions [3].

The Kukui Cup is designed to provide players with insight into how their behaviors affect energy consumption and production. Such behaviors occur on a spectrum, from the short-term, immediate impact behaviors such as turning off lights, to the longer-term, collective impact of behaviors such as considering the energy policies of political candidates when deciding how to vote. Creating a challenge that helps players understand energy from this wide scope sets the Kukui Cup apart from other similar “energy game” initiatives. It also

impacts on our understanding of effective feedback for smart grid customer-facing applications.

In this paper we describe the Kukui Cup system, our results from developing and deploying the Kukui Cup in the field over two years, and the lessons learned that apply to energy feedback systems for smart grid consumers. Specifically, we believe that energy feedback systems should address these factors: they should be actionable, that domain knowledge must go hand in hand with feedback systems, and that this feedback must be “sticky” to lead to changes in behaviors and attitudes.

II. THE KUKUI CUP

College residence hall energy competitions have become a widespread mechanism for engaging students in energy issues, with more than 160 taking place or being planned for the 2010–2011 academic year in North America [4]. Residence hall energy competitions are events where residence halls or floors within a residence hall compete to see which building will use the least energy over a period of time. The competitions tap into both the residents’ competitive urges, and their interest in environmental issues. However, unlike home residents, the dormitory residents typically 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. Residents, therefore, are completely unaware of their energy usage, since they lack even a monthly bill as feedback.

Residence hall energy competition technologies range in complexity from simple web pages updated weekly with electricity data to complicated web applications ([5], pp. 6–11). An early adopter of the residence hall energy competition, Oberlin College developed a real-time electricity consumption feedback system as described by Petersen et al. [6]

To build on this area of active energy work, we decided to target our serious game to college students living in residence halls. The Kukui Cup extends the typical college energy competition into a broader energy *challenge* where electricity consumption feedback is only one part of a larger game experience for players. The challenge is named after the kukui nut (also known as candlenut), which was burned



Figure 1. The Smart Grid Game widget, displaying level 2 actions.

by Native Hawaiians to provide light, making it an early form of stored energy in Hawai‘i.

In a Kukui Cup challenge, residents are grouped into teams based on where they live. Different floors of a building or entire buildings can be formed into teams. The electricity usage of teams is measured either through manual meter readings or through automated meter data collection. In addition to the energy competition, the Kukui Cup has a point competition where players can earn points by engaging in educational and social activities on the challenge website. The point system provides a way to motivate players to explore and use the system, as the Kukui Cup is currently deployed as an extracurricular activity.

Much of the point competition revolves around a section of the challenge website called the Smart Grid Game (SGG). The Smart Grid Game consists of rows of actions arranged into columns based on a particular topic (similar to the popular game show “Jeopardy”), shown in Figure 1. Clicking on a square in the SGG shows details about the action and explains how players can complete the action to earn points. There are several types of actions: short YouTube videos on energy and sustainability topics, activities like measuring the flow rate of a shower, excursions such as visiting a farm that produces all its own electricity, and commitments such as carpooling or not eating meat. There are also creative actions such as writing a poem about energy or a letter to the editor on a sustainability topic. The flexibility of the SGG allows us to provide a wide variety of interesting actions for players to take part in.

The completion of each action (with the exception of commitments) is verified through the challenge website before points are awarded. For activities, players are usually asked a randomly-selected question, and their answer is placed in a queue for challenge administrators to review. The administrator can approve or reject the submission, and can provide feedback on the player’s answer. The game also supports activities that are verified by submission of an uploaded image such as a photo or screenshot.

A. Running a Kukui Cup

A Kukui Cup challenge consists of multiple components working together to provide the entire game experience. For challenges using real-time energy data, the open source WattDepot [7] system is used to collect, store, and analyze the data. The challenge website and associated game mechanics are provided by the open source Makahiki system [8]. The current educational content is tailored to the needs of college students living in residence halls in Hawai‘i, but can be tailored or replaced to suit the needs of other contexts.

B. Field Studies

In addition to in-lab evaluations and beta tests, there have been two sets of field studies of Kukui Cup challenges. The first Kukui Cup challenge took place over 3 weeks starting in October 2011 in four residence halls for first-year students on the University of Hawai‘i at Mānoa campus containing a total of approximately 1070 residents. Pairs of floors, referred to as *lounges*, were the team unit in the 2011 Kukui Cup.

The second set of challenges started in September 2012. The University of Hawai‘i (UH) Kukui Cup is taking place in the same four residence halls with approximately the same number of residents, but over the entire 9 month academic year. The first month of the competition was an intensive period with multiple real-world events taking place each week, while the remaining months will be less intensive. The goal of the much longer time frame is to discourage short-term and unsustainable behaviors (such as forgoing all electronic device use).

In addition to the 2012 UH Kukui Cup, Hawaii Pacific University (approximately 200 residents) and the East-West Center (approximately 130 residents) have run their own challenges using the Kukui Cup system with our support.

III. BASELINES AND GOALS

Goals have been shown to be effective tools in changing energy consumption behavior [9], [10] and are a common component of energy feedback mechanisms. Setting achievable goals is important from a game play perspective, so goals must typically be based on previous energy use. The most common way to generate a goal is to calculate a *baseline* of energy usage based on past energy usage, and then set the goal as some percentage reduction from the baseline.

Two of the most common ways to calculate the electricity baseline are to average recent prior usage (such as the last two weeks), or to average usage from previous years. Both of these methods are problematic because they assume that this previous usage is representative of future usage, even though there are many factors that can significantly alter electricity use over time including: occupancy, weather, activities (e.g., studying for a big midterm exam), and

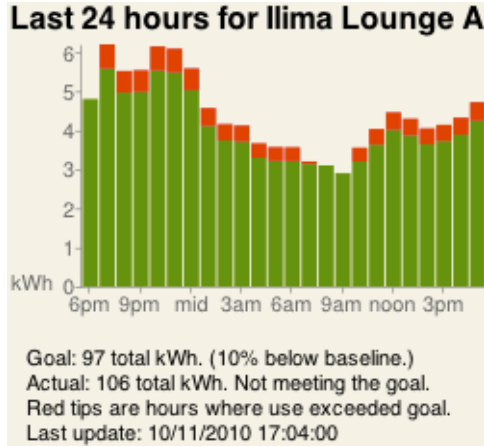


Figure 2. A bar chart visualization of energy use as compared to a goal

changes to the building infrastructure such as efficiency upgrades. Any of these factors can lead to the baseline being an inaccurate predictor of future usage in an energy competition, as described by Johnson et al. [11].

Since baselines can be poor predictors of future electricity use, comparing actual electricity use to the baseline in order to determine how much electricity was “saved” by an intervention is misleading and can tempt designers to make claims about energy saved that cannot be substantiated. However, comparison of actual electricity usage to a goal generated from a baseline can be helpful as a game mechanic to motivate players to conserve energy.

In the 2011 Kukui Cup, we used a baseline that was derived from an average of the two weeks prior to the challenge. In the 2012 Kukui Cups, we have switched to a dynamic baseline [11] that consists of the average electricity usage for the two previous weeks, but the baseline is recomputed every day throughout the challenge. The dynamic baseline means that as the challenge progresses, the baseline will include usage during the challenge. In essence, a goal generated from a dynamic baseline requires a team to reduce their energy usage compared to the recent past. Since the baseline is not a static value picked once before the challenge, anomalous conditions during the period before the challenge will soon be replaced with new, more representative data.

IV. ENERGY FEEDBACK DESIGN EXPERIENCES

Feedback on electricity consumption has been used as a means for facilitating energy conservation by researchers in the human-computer interaction community [2] as well as in the broader energy efficiency [12]–[14] and environmental psychology [9], [10] communities. One reason for this focus on feedback is undoubtedly the hidden nature of electricity, so feedback provides an awareness that is otherwise unavailable.

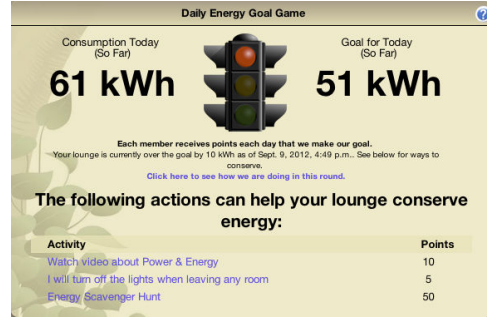


Figure 3. The Daily Energy Goal Game feedback visualization

One of the fundamental principles of energy feedback in the Kukui Cup is that it be *actionable*. While any energy feedback may implicitly encourage energy conservation behaviors simply by making energy use visible, this does not meet our definition of actionable. A feedback display that shows that a home has used 20 kWh so far on a particular day leaves the viewer with natural questions: is that a lot? what should I do if I wanted to reduce my energy use?

A. The Energy Bar Chart Visualization

An early attempt at energy feedback for the Kukui Cup is shown in Figure 2. This “Energy Bar Chart” shows hourly energy use for a team participating in the Kukui Cup over 24 hours as compared to an energy goal. Note that the data shown in this particular figure are simulated. Bars that are entirely green show the actual energy usage for that hour and indicate that the energy use was below the hourly goal. For mixed red and green bars, the main green portion represents the energy goal for that hour of the day, while the red tips of the bars represent the actual usage in excess of the goal.

This form of energy feedback shows the variation in energy use over the course of a day, which is an important energy literacy concept. It also shows in what parts of the day energy use is exceeding the goal, and by how much. By displaying the times during the day when the hourly goals are not being met, residents could focus on understanding what activities are going on during those periods.

As (naive) designers, we felt that this visualization provided a great deal of useful feedback both clearly and concisely. However, results of an in-lab evaluation were unequivocal: the visualization provided too much information, the meaning of its components was not obvious, and the “actionable” aspects were not obvious. This feedback was a failure, and we began a redesign to address its deficiencies.

B. The Daily Energy Goal Game Feedback Visualization

To make our energy feedback easier to understand and also more actionable, we developed the Daily Energy Goal Game (DEGG) visualization shown in Figure 3. The three most prominent components of the DEGG are: the energy consumption so far during the current day, the energy goal

so far for the current day, and a traffic light that shows in the most straightforward way whether the team is meeting their energy goal. The display updates once every 10 minutes with new energy data.

We picked the daily time frame for the game for two reasons. First, having a daily goal makes behavior changes more visible and feedback more immediate than a longer time frame such as weekly or monthly. Second, by concentrating on a daily goal, teams that are performing poorly on a particular day can redouble their efforts to do better the next day. Similarly, a team that does particularly well for one day cannot rest on their laurels, they must make an effort to conserve on every day. This game design reflects our belief that changing energy behaviors is a marathon and not a sprint: radical short-term changes made to win an energy competition are unlikely to be sustainable, and are therefore of very limited utility.

Residential energy use varies in intensity over the course of a day: typically low when people are sleeping and much higher during evening hours. For the students in the residence halls in our studies, the energy usage peak occurs at approximately midnight, and the lowest value is between 8 and 9 AM, which is considerably different than an average single-family home. There is also daily variation between days of the week, as the activities taking place on a Monday night are different than those on a Saturday night. To account for the hourly and daily variation in energy use, our we compute hourly and daily baselines for energy use, and the goal value is a percentage reduction from the baseline. The energy consumption and goal values displayed in the DEGG are computed over the time period from midnight to the current time. This choice of time frame is particularly important for the goal value, because if a daily goal value was simply spread linearly over the course of a day, players would see their energy use as always under the goal during low-usage periods, but then going above the goal during the high-usage periods, possibly to a degree that makes it impossible to meet the goal for that day.

Below the traffic light display of the DEGG is a list of actions from the Smart Grid Game that players can take to either learn more about energy, or directly help reduce their energy use. The actions displayed depend on what actions the player has already completed in the rest of the system. The direct links to actions that players can take to reduce their energy usage, tailored to the opportunities available in their residence hall make the DEGG highly actionable.

Evaluation of the DEGG visualization during actual game play indicates that players do not have a problem understanding the visualization. The stoplight image provides a clear, unambiguous signal, and the actual/goal numbers provide further context. In addition, the visualization is explicitly paired with links to descriptions of appropriate actions for that player in the context of the game and the team's current energy use. Log data indicates that players do click on these

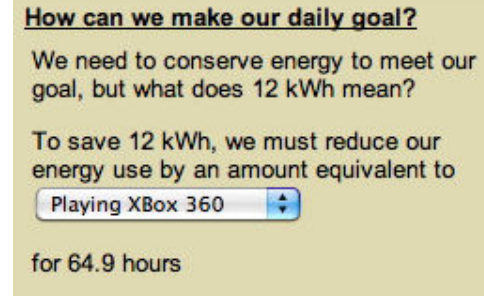


Figure 4. The “How can we make our daily goal?” widget

links in order to understand how to take action based on the energy feedback. This energy feedback was a success and is included in the current version of the Kukui Cup.

C. The “Wii Hours” Energy Feedback Visualization

In another energy feedback design effort, we created a small widget below the DEGG titled “How can we make our daily goal?”. This widget, shown in Figure 4, showed how much the player’s team energy usage was above the goal, and provided a drop-down menu of electrical devices commonly present in student rooms: laptops, Xbox 360, Wii, etc. When a device was selected from the menu, the system would display the approximate number of hours of device use that would equal the amount of team energy use over the goal value. The time value was intended to show players how much device use they would need to *forego* in order to get back on track to their energy goal, and develop their intuition about the relative power use of different devices (i.e., plasma TVs use much more power than Wii game consoles). Therefore a short time value could point out an easy way to make the goal, and a long time value would indicate less significant energy conservation.

However, during in-lab evaluations of the system, we found that multiple subjects misinterpreted the time value, thinking that high time values were bad rather than good. Since the Wii was the device on the list with the smallest power use (20 W) compared to an Xbox 360 or Playstation 3, it led to the highest time values. Some subjects drew the conclusion that using a Wii was worse than using an Xbox 360 or Playstation 3, which was precisely the opposite goal of this widget. One subject even took the time to use our in-game team discussion forum to post the message “don’t play wii” after using the widget! Because of this example, we dubbed this confusion the “Wii problem”.

Clearly, energy feedback that can lead at least some players to the opposite conclusion than intended is a failure. The “Wii Hours” visualization never made it into production, and we are still searching for a design variant that can convey this information in an unambiguous fashion to players with minimal energy literacy.

V. DOMAIN KNOWLEDGE AND ENERGY FEEDBACK

Energy feedback systems provide data on some aspect of behavior with the goal of reducing negative environmental impact [2]. However, they often assume users possess some level of domain knowledge about the environmental topic they hope to address. In the area of energy, the term *energy literacy* has been used to describe the understanding of energy concepts as they relate both on the individual level and on the national/global level.

Some examples of energy literacy are: understanding the difference between power and energy; knowing that a microwave uses much more power than a refrigerator, but that the refrigerator will use much more energy over time; and knowing how electricity is generated in one's community.

Unfortunately, all indications are that energy literacy is low in the United States. DeWaters and Powers have developed an energy literacy survey instrument for middle and high school students. They found that the student mean attitude scores were 73%, but that knowledge scores lagged far behind (42% correct) [15]. Based on their findings, they make some recommendations, such as energy curricula be "hands on, inquiry based, experiential, engaging, and real-world problem solving...", and using the campus as a "learning laboratory". Similarly a nationwide survey of adults on energy by Southwell et al. found that the average respondent answered fewer than 60% of the energy knowledge questions correctly [16].

One energy literacy topic that we emphasize in the Kukui Cup is the difference between power and energy, power being the rate at which energy is being consumed or produced (measured in watts) and energy is the quantity of work that can be performed by a system (measured somewhat confusingly for electricity in kilowatt-hours). In the Kukui Cup we explain this relationship as being analogous to speedometer and odometer in a car.

Through answers submitted to the online activities in the Kukui Cup, we can see that many players have trouble understanding the concepts of power, energy and their interrelationship. Players often confuse the two concepts and often fail to grasp the time sensitivity of power, and thereby considering devices that consume a lot of power as "bad" irrespective of how long they are actually used. When the users of visualizations do not understand the concepts that are being visualized, understanding of the visualizations becomes much more difficult. It is for this reason that we claim that energy feedback systems should incorporate educational components, or risk being unintelligible to users. However, we reject the notion that power and energy, watts and kilowatt-hours are too complicated and that users should be provided instead with analogies to cars driven or hamburgers eaten. These energy concepts are important for effective customer participation in the smart grid, and should

not be reduced to analogies alone.

VI. ENERGY FEEDBACK, STICKINESS, AND SERIOUS GAMES

A meta issue for all energy feedback systems is how to ensure that they continue to be "sticky" for users, as a feedback system that users do not look at will be unable to accomplish anything. There are indications that the long-term impact of energy feedback may be diminished due to habituation. Froehlich suggests that the average user will spend less than one minute per day exploring their energy consumption behaviors [17]. A study by Houde et al. of households using Google PowerMeter found an "immediate decrease in electricity consumption, but in the long term these electricity savings decrease and disappear." [18] This finding suggests that a primary concern for any energy feedback system is ensuring that users continue to interact with it over the long term. Put another way, energy feedback alone is not enough to accomplish the goal of long-range customer engagement with their energy consumption.

One solution to the lack of stickiness of energy feedback systems is the incorporation of game play. Serious games like the Kukui Cup provide an alternative route to promote both learning and engagement with energy feedback. It is for this reason that we designed the Kukui Cup as a serious game that incorporates electricity consumption feedback as one aspect of the game experience, rather than an energy feedback system that has been "gamified".

While games are not the only way to promote long-term engagement with energy issues, we submit that any normal energy feedback system will quickly be abandoned by users once the novelty wears off. There must be a continuing reason for users to revisit the system that even the most novel and interesting energy feedback systems lack.

VII. FUTURE WORK

The Kukui Cup is an ongoing project and we continue to build upon our initial work. The first area of future work is the 2012 UH Kukui Cup. The 2012 UH Kukui Cup will last nine months and should shed light on several issues: can we maintain player interest over longer periods despite fewer prompts from intensive marketing and events, can the new player-provided educational content fill the gap of the longer challenge duration, and the results of the DEGG with dynamic baselines over a long time frame.

The 2012 Kukui Cups happening at Hawaii Pacific University and the East-West Center will also offer new insights into how challenge administrators outside our research group design Kukui Cup challenges tailored to their organization, and how different student populations perform in the Kukui Cup.

A longer range goal is to integrate the Kukui Cup with Hawai'i's smart grid efforts. The Kukui Cup is currently a effort-intensive program, so scaling to hundreds of thousands

of players will require scaling the management of the challenge, finding a means of funding, and a way for players to incorporate household energy data fairly in a completely heterogeneous environment.

One final area of research is longitudinal studies of players after the game is over and they have moved out of the residence halls. We want to find out whether the Kukui Cup experience actually had lasting impacts on players, and whether they were able to continue any new behaviors after leaving the context of the residence hall.

VIII. CONCLUSION

We have described the Kukui Cup serious game, and our results from field trials of the system. We have discussed some of the energy feedback visualizations we developed, including both those that succeeded and those that failed. Based on our experiences, we provide three areas that energy feedback systems for the smart grid should address: they should be actionable, they must address users lack of domain knowledge, and they must find ways to be sticky.

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