The Dubuque Electricity Portal: Evaluation of a City-Scale Residential Electricity Consumption Feedback System

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ABSTRACT
This paper describes the Dubuque Electricity Portal, a city-scale system aimed at supporting voluntary reductions of electricity consumption. The Portal provided each household with fine-grained feedback on its electricity use, as well as using incentives, comparisons, and goal setting to encourage conservation. Logs, a survey and interviews were used to evaluate the user experience of the Portal during a 20-week pilot with 765 volunteer households. Although the volunteers had already made a wide range of changes to conserve electricity prior to the pilot, those who used the Portal decreased their electricity use by about 3.7%. They also reported increased understanding of their usage, and reported taking an array of actions – both changing their behavior and their electricity infrastructure. The paper discusses the experience of the system's users, and describes challenges for the design of ECF systems, including balancing accessibility and security, a preference for time-based visualizations, and the advisability of multiple modes of feedback, incentives and information presentation.

Author Keywords
Electricity; smart meters; sustainability; behavior change; ECF; consumption feedback systems; social comparison

ACM Classification Keywords
H.5.2 [Information Interfaces And Presentation]: User Interfaces - Graphical user interfaces (GUI);

General Terms
Design, Experimentation, Human Factors.

INTRODUCTION
Energy consumption is a critical global challenge. Demand for energy is increasing both in developed and developing countries. At the same time, side effects of the production and use of energy – such as CO2 emissions and ecosystem damage – have significant environmental consequences.

CHI 2013, April 27–May 2, 2013, Paris, France.

Our concern is with electricity consumption, and in particular with electricity consumption in the home, which in the United States accounts for 37% of all electricity use. This paper examines a residential electricity consumption feedback system designed to be deployed at the scale of a city and whose aim is to encourage households to voluntarily decrease their electricity use.

In its focus on supporting voluntary energy conservation, this paper finds itself in the company of a growing body of work in HCI on sustainability (cf., [2, 7]). Indeed, much research has focused on resource conservation, and especially on energy. The aim of this paper is to address a gap identified by previous researchers: few long term field studies of energy consumption feedback systems examine the uptake and use of the systems' design elements.

We describe a system that provides households with fine-grained feedback on their electricity use, as well as using incentives, social comparisons, and goal-setting to support behavior change. The contribution of the paper is not the design of the system, which combines well-known techniques, but rather its evaluation of the use and impact of the system during a 20-week pilot project involving 765 households. Using logs, a survey, and interviews of 18 participants, the paper examines participants' motivations, usage patterns, and their reports of the impact of the system on their understanding and usage of electricity.

PREVIOUS WORK
Sustainability has garnered increasing attention in the HCI field over the last decade; Blevis et al. [2] and DiSalvo et al. [7] provide good overviews and useful commentary and critique. More particularly, there is a large literature on energy conservation in the fields of environmental psychology (see Abrahamse, et al. [1], Darby [5], and Carroll, et al. [4]) and HCI (see Pierce, et al. [19] and Froelich, et al. [11]). The last ([11]) is particularly useful as it reviews work in both HCI and environmental psychology and notes the differences between work in the two fields.

A major focus of work in both areas has been on what Pierce et al. [19] have termed "electricity consumption feedback research (ECF)." ECF tends to focus on presenting information to individuals in an attempt to change their behavior. For example, a study of electricity

consumption by similar homes – e.g., 10 identically outfitted homes in Florida – showed large variations in electricity use, with one home using 2.6 times as much electricity as another. [14]

ECF systems use a variety of techniques to encourage conservation, including *feedback* (on a household's energy use), *incentives* (points, prizes, differential pricing), *comparisons* (between individuals or groups), *goal-setting* (e.g., explicitly deciding to achieve a conservation goal), and *commitment* (eliciting a public commitment to achieving particular goals). An example that includes all but the last two approaches is Petersen et al's [15] energy conservation contest in which real time electricity consumption feedback provided the backbone for a contest among dorms that resulted in short term reductions of 30 – 55%. More generally, and over longer periods, it is generally agreed that ECF systems can lead to reductions in consumption ranging from 5 to 15% (e.g., Darby [5]; Fischer [10]).

However, work on ECF systems has been the subject of an increasing number of critiques. One is that ECF systems may set a rather low goal by legitimizing current regimes of energy use. Thus, building an energy monitor into a clothes drier to enable load shifting may suggest that using the drier is OK; more generally, ECF systems may legitimize a baseline level of usage: Pierce, et al. [17] observed that individuals using such systems would attempt to avoid greatly exceeding their baseline usage, but never spoke of trying to lower it. A second critique is that ECF assumes rational individuals who are making considered choices about their energy usage, whereas in reality much energy consumption is unconscious and habitual (e.g., [18, 20]). A third critique is that ECF's focus on individual behavior *vis a vis* simple metrics ignores social and political factors (cf. Brynjarsdottir, et al. [3], Dourish [8], DiSalvo et al. [7]).

While these critiques of HCI's approach to sustainability are valuable, the system we discuss in this paper falls squarely in the ECF camp. This is simply a matter of pragmatism: we are studying a real system being deployed in a real city. While the ECF approach has much to criticize, it is nevertheless out in the world and examining how people use and react to it is important. In particular, Froelich, et al. [11] call attention to a gap in the literature. They note that work in HCI has primarily focused on the design of systems for supporting energy conservation, but provides little in the way of field studies (especially for longer periods). In contrast, environmental psychology has carried out numerous field studies, but devotes little attention to the design of the systems, which often use rudimentary forms of display and presentation. Thus, there is a need for field studies that can guide the design of such systems, investigating the types of information and presentation that are most effective in influencing conservation behavior. This paper aims to address this gap.

BACKGROUND: SITE, SYSTEM, PORTAL, PILOT

The Site

The Electricity Portal was deployed in Dubuque Iowa, a city of about sixty thousand in the midwestern U.S. The choice of Dubuque was opportunistic: Dubuque had established a strong sustainability agenda; the City had received grants to deploy smart electricity meters; and the researchers' organization had a good working relationship with the City. Dubuque was also the site for a water consumption feedback system we deployed in 2010 [9] (in the discussion we will compare the use of the two systems).

The System

The system worked as follows: smart meters recorded consumption every 15 minutes and transmitted the data to a gateway. Data was stored and uploaded to a cloud-based repository the next day. There it was analyzed, and the results were fed back to individual households via a web-based Portal. The Portal used well-known techniques – feedback, incentives, comparisons and goal-setting – to encourage conservation. The system was *not* able to track individual device use, although it estimated the proportion of electricity used by high, medium and low load devices.

The Electricity Portal User Interface: A Quick Overview

The user interface (Figure 1) is arranged in six bands. Band 1 identifies the Portal, shows the date, and provides menu access to Alerts, Chat, Password and Profiles. Band 2 shows the user name, usage to date and an estimate of the month's entire usage, and three incentive mechanisms: trend (for self comparison), rank (relative to 30 similar households), and "green points" (awarded for activities such as completing one's profile). Band 3, with the long bar graph, shows daily electricity use for the last year in kWh or dollars. Band 4 has two components: a graph of a single day's electricity use (selected by dragging the green 'thumb' at the right of Band 3), and a changing series of five "consumption insights" that provide textual comparisons (e.g., the users' consumption last month relative to others). Band 5 also has two components. The

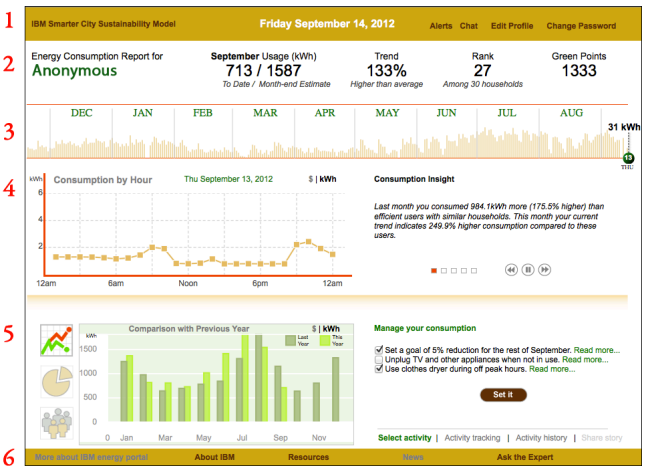

Figure 1. The Electricity Portal user interface.

first provides graphs that allow users to view their usage (i) compared to the previous year (shown), (ii) broken down by load, or (iii) as compared to a set of 30 similar households. The second item in Band 5 allows users to set goals (e.g., reduce use by 5%) and to track their success. Band 6 provides links to more general information.

In summary, the Portal tried four approaches to reducing consumption. It used *incentives* (Band 2): self-competition (trend), contrast with others (rank), and a point system. It provided *feedback* via its consumption graphs (Bands 3 and 4a). It supported *comparisons* via text and graphs (Bands 4b and 5a). And finally, it enabled users to *set and track goals* (Band 5b). More detail is provided in the Results (Figure 2, and the discussion of users' use of the UI components).

The Pilot Project

As part of a pilot project the Portal was deployed to 765 volunteer households located in a few contiguous neighborhoods. The first thing users did when signing on to the Portal was to fill in a profile that included energy-related information ranging from the size of their household (in square feet and occupants) to the devices and HVAC systems used. This information was used to help customize information delivery and advice (e.g., those who stated they were using CFL blubs were not advised to put them in).

The pilot involved more than just turning on a web portal: sustained efforts were made to publicize the project and engage participants. The City used letters, email and phone calls to recruit participants and to encourage them to use the system; support was provided via telephone and a web-based Q&A system. Dubuque 2.0, a local NGO, held training sessions, town hall events, and sustainability meetings to support and encourage participants.

THE STUDY

The pilot project began in July and lasted about 20 weeks, although the Portal continued to be available afterwards. Portal use was logged, and surveys and interviews were used to gather qualitative data about users' experiences. To maintain privacy, users' log, survey and consumption data were anonymous, and could not be combined.

Pilot Project Participants

The term "participant" refers to an entire household, though we will generally refer to them as if they were individuals. Due to logistical constraints, only certain neighborhoods were included in the pilot – these areas were primarily single-family residences. For this reason, and because participants were volunteers, they do not represent the "average" Dubuque inhabitant, and thus generalizing to the entire population must be approached with caution.

About the Survey

To assess the reception and impact of the Electricity Portal, an online survey was developed. It consisted of 32 questions – multiple choice, Likert-scale, and open-ended questions, with valences mixed where appropriate – and took about 10 minutes to complete.

Content. The survey begin by asking respondents about why they participated in the pilot project, and about how often they used the Electricity Portal. Those who reported never using the Portal, or only using it once, were routed to a final open-ended question; those who reported using the Portal more than once were taken to three additional sections of the survey. One section walked them through each part of the Portal user interface, asking about the value and degree of use of each; this included pictures of Portal user interface components to assist respondents' memories. A second section asked about the effects that use of the Portal had on their understanding and use of electricity. A third section asked about physical or behavioral changes they had made in their use of electricity before and during the pilot project, and about changes they intended to make in the future.

Distribution. A link to the online survey was distributed by email when the pilot ended; one reminder was sent the following week. The survey was distributed to the 561 participants who had provided email addresses. 116 participants responded – a response rate of approximately 22%. Because of privacy requirements, survey respondents were anonymous and so it was not possible to link their responses to their other data (usage logs; electricity usage).

Response. While the overall survey response rate was about 22%, those who used the Portal were more likely to respond to the survey. The response rate of those who logged on to the Portal at least once was 34% – i.e., 91 survey respondents indicated using the Portal, and the logs show that 266 households actually logged on. The response rate for those who logged onto the Portal more than once was 53%. Thus, the survey gives us a good picture of those who used the Portal. It does not give us a good picture of those who did not use the Portal – the response rate for those who never used the Portal was about 5% (i.e., 25 survey respondents said they never logged on, out of 490 households in the pilot that never logged on).

About the Interviews

Eighteen participants were interviewed: 1 couple, 4 women and 13 men. They ranged in age from mid-twenties to ninety; most lived in single-family homes, most lived with a spouse, and about a third had children at home. Informants were recruited by the pilot project coordinator, a City employee responsible most of the communication with and support of the pilot participants. What this means is that those interviewed were among the most engaged participants – many were very active users; others had had problems that had required support.

Interviews lasted about 45 minutes; they were conducted in Dubuque at the end of the pilot. Fifteen interviews were conducted in a City office, two in participants' offices, and one in a restaurant. One interview was with a couple; the rest were with individuals. All interviews were audio recorded with the participants' permission; standard procedures were followed.

Interviews followed a semi-structured protocol. After an introduction, the purpose of the interview was explained. It was noted that the interview was not being conducted for public relations purposes but rather to understand what worked well and what did not, and that hearing about things that were difficult, problematic or confusing was especially useful. After that, the interview covered the following areas, generally in the following order:

- The informant's background and household
- Reasons for participating in the pilot study
- The nature and frequency of Portal use
- A walkthrough of the Portal user interface
- How the household's behavior changed; surprises
- Whether they discussed their experience with others
- How the Portal could be improved

RESULTS

Use of the Electricity Portal

Of the 765 households in the pilot project about 35% (266) used the Electricity Portal at least once, according to usage logs. This is the same rate as was seen with a different population of users in the Dubuque Water Portal study [9], in which 106 of the 303 participating households (35%) used the Water Portal at least once. It is difficult to say whether these rates of usage are good or bad, as we do not know of reports of participation rates from similar projects and thus lack a baseline. MacLellan [13] does note that participation rates for "opt-in" energy conservation programs tend to be the single digits, but those programs are quite different from this, so comparison is chancy.

Reasons for Participation in the Pilot Project

Respondents reported multiple reasons for participating. Over 90% said their motivations included

- an interest in reducing electricity costs
- a belief in the importance of sustainability for Dubuque
- a concern about the environment
- a dislike of waste and a preference for being frugal

Majorities also reported

- being curious about the technology 84%
- concern about climate change 72%
- belief that it would be a good educational experience for the family 59%

91% also reported that they had been trying to conserve the amount of electricity they used for a long time. These findings indicate that participants were highly motivated, but also raise the possibility that many had already taken common actions to conserve electricity.

Barriers to Using the Portal

The survey asked whether pilot participants had problems getting to the Portal site. 51% reported that they had no difficulties; the rest reported

- problems with user IDs or passwords 42%
- difficulty finding the site 12%
- not being able to see their data in the Portal 4%

ID's and Passwords

It is clear that users had difficulties with their IDs and passwords. A likely explanation is that, because the system placed a premium on privacy, stringent security standards were used.

The survey's finding was mirrored in comments of the informants. Although most managed to make use of the Portal, many said they had password problems, although often their descriptions were vague: the password didn't work, or stopped working. The clearest complaint had to do with the complexity of the initial passwords and user IDs (mixed numbers and upper and lowercase letters). One user commented that it was ironic that the requirements for accessing his electricity bill were stricter than those for getting to his online bank account.

Other Barriers

Asked about other problems that "kept you from using the Portal more than you did," the most frequent responses as the ID/Password issues were "I kept forgetting" (27%), and "I didn't have time" (26%). These responses suggest that participants had difficulty integrating this kind of activity into their ordinary life and routines. The least frequently cited barriers to use were the Portal was "too difficult" (5%) or "too complicated" (4%). Given the amount of information presented, and the range of approaches used, this is an encouraging result.

Degree of Use

The survey asked respondents to estimate the frequency with which they used the Portal. Responses were as follows:

- five or more times a week 12%
- about once a week 18%
- occasional use 31%
- rare use 25%
- not applicable / don't recall 14%

Roughly speaking, 30% of the respondents reported using the Portal once a week or more, 30% reported occasional use, and 40% reported rare (or non-) use. These proportions are similar to those observed in the Water Portal study. [9]

In the Water Portal study [9], one pattern reported in interviews was that some participants used the Portal to understand their baseline consumption and then decreased or ceased using the Portal. We were curious to see whether this pattern occurred for the Electricity Portal, and if so how widespread it was. In response to a survey question, 30% reported that they used the Portal more frequently at first and then less as time went on; 20% reported that regular use; the rest reported sporadic use.

Manner of Use

How did participants use the Portal? Which components were looked at most frequently? Which helped users understand their usage? Which encouraged them to change their behavior? Which were easiest to understand? These questions are difficult to address in a real deployment.

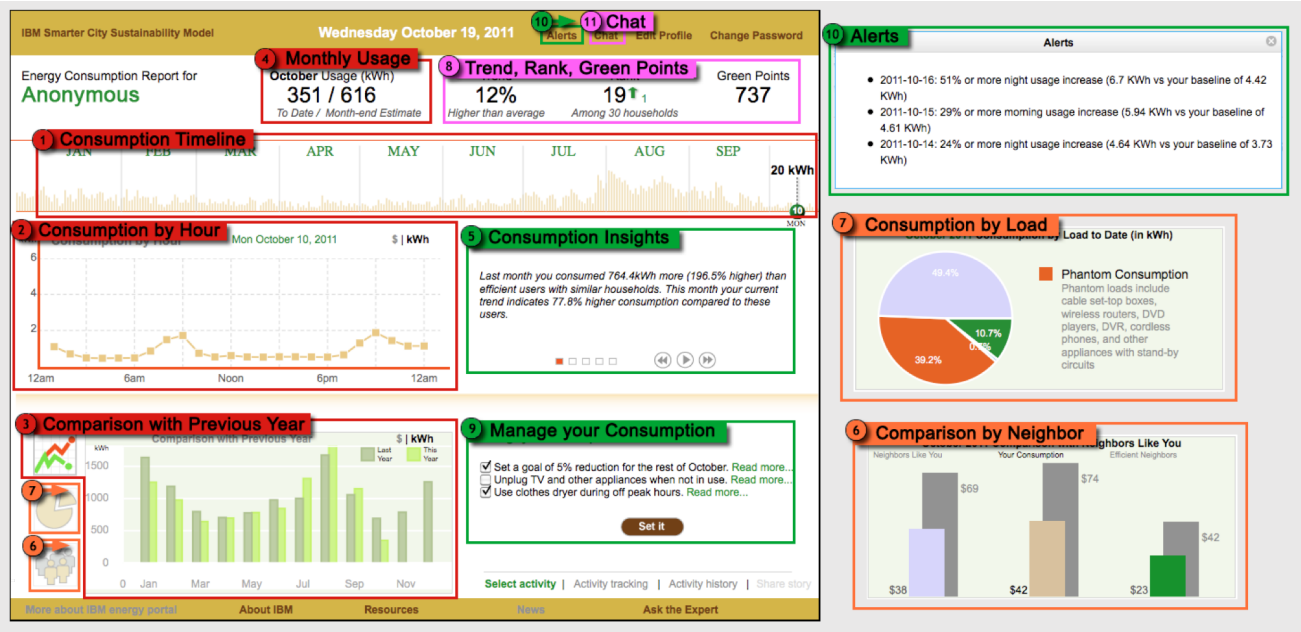

Figure 2. The Electricity Portal user interface with the components asked about in the survey and interviews highlighted

Survey Findings

In this study we used the survey and interviews to address these questions. Figure 2 shows the Portal user interface, and Figure 3 summarizes the responses to the second part of the survey which, for each UI component, asked

- if they usually looked at it
- if they needed more explanation of what it meant (abbreviated as "It was entirely clear" in Figure 3)
- if it helped users better understand their electricity use
- if it encouraged them to take action

The first four components – the Timeline, Consumption by Hour, Comparison with Last Year, and Monthly Usage – were reported to be both most looked at and clearest. Note that the first 3 are time-based graphics, and the 4th is a time-based metric. The least looked at components were the Alerts and the Facebook Chat, both of which required going through a menu to access. In the next section we will look a bit more deeply at this using interview results.

The right side of Figure 2 shows, for each user interface component, the percentages of respondents who agreed that

- it helped them understand how they used electricity
- it encouraged them to take action

In general, there is a clear correlation between the user interface components people usually looked at and the components that helped them understand how their use of electricity. This seems reasonable: users looked most frequently at components that helped them understand what was going on. These components were also most likely to encourage them to take action (though to a lesser degree). Comparison by Neighbor, Alerts, and Facebook chat were reported to be the least successful in promoting understanding of electricity use and encouraging change, with Chat being by far the worst.

Interview Findings

Just as the survey walked respondents through the main components of the Portal user interface, so did the interview. The responses of the informants were consistent with the findings of the survey; in addition, informants provided additional information about their experiences.

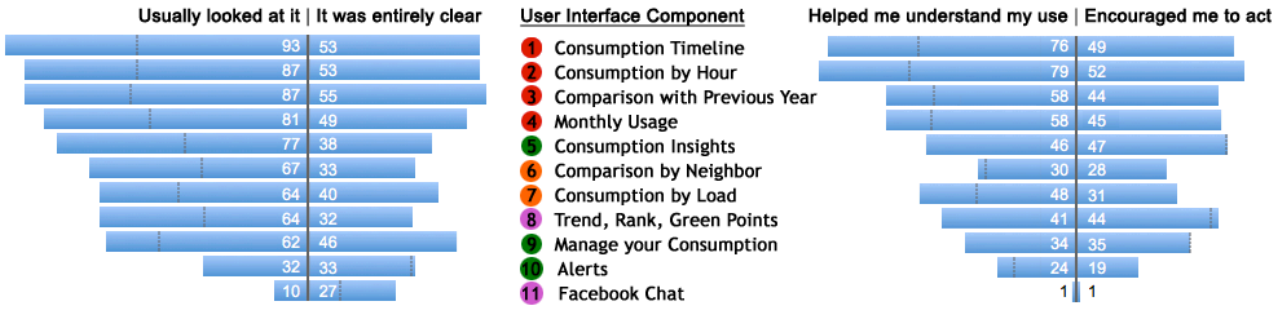

Figure 3. The user interface components, ordered by popularity, with percentages agreeing with each statement.

Incentives. In the survey, about a third of survey respondents reported doing things to try to earn green points and raise their rankings, whereas the rest were non-committal or explicitly reported that they didn't do things for these reasons. In the interviews we found that informants spanned this spectrum. Many said they were uninterested in how they compared to others, but were interested only in how their household was using energy, and how it compared to their previous use. Others were interested in how they compared to others, and paid attention to their rankings and how they did with respect to "similar neighbors." Several of these users commented that no matter what they seemed to do, their rank didn't change much. This was true of informants whose ranks were relatively high ('even when I didn't think we did very well, our rank stayed high'), and whose ranks were low – the latter were quite frustrated because nothing they did seemed to make a difference. This problem might 'fix itself,' as with a larger scale deployment groups of 30 households would be more similar, and thus moving around in the rankings would be more likely. Finally, some users *were* interested in earning points. Some of these reported being frustrated because they had already done some of the activities suggested in goal setting that would have enabled them to earn points; they felt as thought they were being penalized for good behavior before the pilot began.

Context for Interpreting Feedback and Comparisons. Many informants wanted more context to help them understand their energy use or take action. For instance, many of those who liked to compare their current energy use with that of a year ago wanted information such as the average temperature, or degree-heating/cooling days. They wondered, for example, if summertime electricity savings were due to increased efficiency or because it was cooler. Similarly, informants noted that vacations and other trips reduced their electricity use, and that that made comparisons more difficult. In both instances, it is possible to envision ways in which the Portal could provide this information from databases (e.g., for degree-heating/cooling days) or analytics (e.g., detecting when a household is temporarily vacant).

Goal Setting – More Actionable Information

Another request was for more goal-setting activities. Some informants reported that they had done most of the activities before they began the pilot; others said that they had quickly completed the available and relevant activities. In both cases informants were disappointed that new activities did not appear as often as they would like.

Chat. According to the survey, the least used user interface component was the Chat function, which took users to a Facebook page for the Dubuque 2.0 NGO. The interview findings were consistent with this. While a few informants did not notice the link to Chat, most seemed aware of it and said that they had looked at it once or twice but not used it. A closer look at the chat posts on the Facebook page confirm that it received almost no use. No pilot participants shared tips, stories or chatted with one another (i.e. responded to another participant's post). Only four posts were made by participants: two questions, one suggestion, and one post praising the portal. This is disappointing, because the ability of users to communicate with one another, and share tips, experiences and stories would seem to have great potential for promoting sustainability. This is clearly an area that merits further work.

Impacts of Portal Use

Having discussed the manner in which the Portal was used, we now turn to the question of what impact it had on users' understanding and behavior. Here we have three sources of data: energy consumption data; survey data; interviews.

About the Portal Users

Before examining the impact of the Electricity Portal, it is important to say a bit more about the participants. Recall that the users were all volunteers, and therefore may have been exceptional. And indeed, the survey indicates that the users who responded to the survey were already tuned in to energy conservation: 90% agreed that they had been trying to conserve electricity for a long time – since before the pilot started. More specifically:

- 96% reported that before the study began they had made at least one change to their energy infrastructure, e.g., changing to CFL's (82%), adding insulation (71%) or purchasing energy star appliances (60%).
- 86% reported that before the study began they had made at least one change to their behavior to conserve electricity, e.g., reducing their use of lights (66%), air conditioning or heating (76%), or hot water (59%).

So, for the pilot study participants, it is evident that much of the low hanging fruit had been picked before the pilot began. That makes the finding of a reduction in consumption quite impressive.

Energy Consumption Reduction

The 266 participants who used the Portal showed a reduction in their energy consumption. Compared to a baseline from the previous year, they conserved about 31,817 kWh (or $3,818) over a 20-week period – a monthly reduction of 3.7%. More particularly, the 97 Portal users who took part in goal-setting activities (i.e., "Manage your consumption") achieved over half of the savings, reducing their usage by 17,595 kWh (or $2,111) – a monthly reduction of about 7%. These reductions are in line with those reported for other ECF systems (e.g. [5, 10]).

Greatly Increased Understanding…

The survey asked a number of questions about the impact using the Electricity Portal had on users shown in Table 1 below. Large majorities of the Electricity Portal users agreed that it increased their understanding of how they use electricity (69%) and enabled them to see the effects of changes they made (69%).

…but only Moderate Electricity Conservation

Yet, in the third and fourth questions, smaller proportions of the Portal users (46% and 49%) said that the Electricity Portal actually helped them conserve energy in general, or had helped them find specific measures to take. Why is this? It is clear that many users had already taken various measures to conserve electricity, and 72% of respondents agreed with the statement "Using the Energy Portal reinforced what we already do to save energy." This finding also aligns with concerns that ECF systems tend to support only small changes, rather than leading users to radically change their usage practices (e.g., Strengers, et al. [20]).

Talking with Others

Another question is the extent to which using the Electricity Portal caused people to have conversations about their experiences with others. Given that the attempt to use Facebook's chat received almost no use, it was good to see that people did talk with one another, both within and beyond the households.

A large majority (69%) of survey respondents discussed their electricity use with others in their household (note that some participants lived alone). Fewer discussed their results outside the household, but still a majority (54%) did so at least once. Such discussion can be an important way of getting others to use the system early in the deployment, and, as Strengers et al. [20] note, provide one way in which users can be encouraged to alter their habitual routines.

Table 1. The impact of the Portal

Question	% Agree-Neutral-Disagree (na) or multiple choice
Using the Energy Portal increased my understanding of how I use energy	**69**-21- 9 (2)
The Energy Portal allowed me to see that changes I've made do affect my energy usage	**69**-22- 7 (2)
The Energy Portal helped our household conserve energy	**46**-25-28 (2)
The Energy Portal helped me find specific ways to reduce my energy consumption	**49**-35-15 (2)
Using the Energy Portal reinforced what we already do to save energy	**72**-22- 4 (2)
I discussed energy usage information from the Portal with other members of my household	18 (Never) 15 (Once) **30** (A few times) 25 (More than a few times) 13 (NA: 1-person household)
I discussed energy usage information from the Portal with people who do NOT live in my household	**47** (Never) 9 (Once) 29 (A few times) 14 (More than a few times) 2 (NA)

Conservation: Changes to Appliances and Behaviors

The survey asked Electricity Portal users about changes *they had made during* the study, or *planned to make in the future*. Although as noted above, many Electricity Portal users had made such changes before the study began, many also reported that they had made other changes during the study, or planned to in the future.

- 61% of Portal users reported making at least one change to their energy infrastructure, with the most frequent alteration being to reduce the use of standby (phantom) power by unplugging devices (40%). 42% reported plans to make such changes, with the most frequent planned alteration being to purchase an energy star appliance (28%).
- 69% of Portal users reported making at least one change in the ways they used electricity during the study. The most popular of these behavioral changes was to shift electricity use to non-peak periods (51%) – *this is the only example of a change that was done by more people during the study than before it*. Other changes included reducing the use of lights (33%), and reducing the use of hot water by taking shorter showers or using shorter washer or dishwasher cycles (32%). 28% reported plans to make a behavioral change in the future, the most common being electricity use shifting (21%).

Overall, 90% of Electricity Portal users reported doing or planning to do something. 79% reported at least one change to either an appliance or in the ways in which they used electricity during the study. 54% reported plans to make such changes in the future, the most popular being to purchase an energy star appliance (28%). These reports are consistent with the observed reductions in electricity use.

DISCUSSION

Limitations

This paper has used logs, a survey and interviews to examine the user experience around a large, relatively long term deployment of a residential energy consumption feedback system. While the opportunity to evaluate this system in a realistic urban context is valuable, it is also important to recognize that this work has a number of limitations that spring both from the nature of the deployment and the methodology.

First, in spite of the realistic nature of the setting, note that the households studied are not a random sample of the city's population. Due to logistical constraints, the deployment of smart electricity meters was constrained to a compact, contiguous area of Dubuque. This means that the households have particular social and economic characteristics that are correlated with this geographic area. In this case, the residences were primarily single family, and participants were employed in blue or white collar jobs, or retired. In addition, the participants were internet literate. All of these factors argue against generalizing from the participants to the population as a whole.

Second, the fact that the study is composed of volunteers can have varied effects. On the one hand, it can be argued that this population is highly motivated and will therefore be more inclined to use the Portal and take various energy conservation measures than the general populace. On the other hand, it can be argued that the same attitudes may mean that this population has already taken actions to conserve electricity – and as shown by survey responses and interview comments, this is indeed the case. As we don't know to what degree these two opposite tendencies balance one another, we have a second reason to be cautious about generalizing to the population as a whole.

Third, the use of surveys and interviews come with well understood limitations. Because participation is voluntary, the picture provided by these methods tends to over-represent participants who are most active and motivated. Those who were not as engaged by the system are less likely to respond than those who were, as could be seen in the survey responses: 53% of those who used the Portal more than once responded to the survey, whereas only 5% of those who did not use the Portal responded. In sum, these findings should be taken as most representative of the most active and motivated participants. This is not an entirely bad thing. As von Hippel has argued [21, 22], users often drive innovation, and studying the practices of those "lead users" who are unusually motivated can be a valuable way of uncovering innovation (and identifying barriers to adoption). The bottom line is that while we should be cautious of generalizing to the entire population, we should pay particular attention to the problems and challenges encountered by this set of users. If they have difficulties, it is likely that those who follow them will as well.

Challenges for Moving Forward

Accessibility

About 35% of those who volunteered actually used the Portal. Without other deployments of similar systems is difficult to say whether this is a reasonable rate.

It was clear that the biggest barrier to access was difficulty with IDs and passwords. As readers will recognize, the password and ID complexity is driven by a concern for privacy. Obviously, fine-grained details of a household's energy consumption can reveal a lot about the life of the household: when inhabitants get up, when they go to bed, when they are on vacation, when they have visitors. It also shows how their usage compares to similar households, creating the possibility of unfavorable comparisons. Given that the deployment of the Electricity Portal was championed by the City government, the last thing that anyone wanted was a 'privacy disaster,' and so strict security measures were taken. At the same time, there is no denying that ID and password complexity frustrated users. It seems clear that a challenge for the future is how to provide easier yet secure access to private data. Potential solutions range from biometrics to development of a single sign-on identity at the municipal, state or national level.

Engagement

The second most cited barriers to use were that survey respondents said they "kept forgetting" or "didn't have time." These responses suggest that participants had difficulty making Portal use part of their ordinary life and routines. And that's not surprising – as pressing as our environmental problems are, it seems implausible to imagine a world where most get up and check their energy consumption every day. This issue also arose in our earlier work, on the Dubuque Water Portal, and our response is much the same. We need to re-think the ways in which we envision our systems engaging people.

A direction we are exploring has to do with the notion of creating engagement campaigns. Rather than assuming that a population will pay continuous if low level of attention to an issue, instead assume that particular events – natural or artificial – can focus collective attention an the issue. In the case of electricity consumption, a campaign might be timed for the beginning of summer, focusing on making people aware of the electricity demands of air conditioning, and encouraging thought and discussion about how to change practices – from the level of a 'normal' thermostat setting to alternate strategies for coping with heat. Or a potential crisis – perhaps a shortage of energy leading to rolling brown outs – might serve to focus public attention.

Manner of Use

The Electricity Portal user interface components that participants reported looking at the most, and found to be the clearest, were time-based visualizations electricity use. This is consistent with findings by Darby [5], who notes that "historic feedback (comparing with previous recorded periods of consumption) appears to be more effective than comparative or normative information."

However, perhaps the most interesting finding is that participants reported using quite a lot of the Portal user interface components. While time-based representations were slightly favored, majorities of survey respondents paid attention to all the user interface components with the exception of chat and alerts. This is consistent with a report by Fischer [10], who notes that most effective ECF systems contained multiple feedback options. Similarly, different participants – both in the survey and the interviews – reported responding to different incentives. We suspect this is even more true when children are included: as noted in the Water Portal study [9], kids were quite engaged by the water saving competition. The bottom line here is that multiple ways of presenting information are preferable; there is no silver bullet.

Chat received little uptake either here, or in the earlier deployment of the Water Portal. The fact that participants were willing to have face to face conversations with others outside their households suggests that the problem is not privacy *per se*. Perhaps the lack of uptake is due to this particular set of users, or to a lack of critical mass – if this is so, the problem may self-correct in larger deployments.

Starting a discussion group from scratch may also be setting a high bar; it might be better to direct participants to existing local discussions, and perhaps provide ways to make it easy to share their data and experiences with the Portal. This seems like an important area for further research, as the ability of users to share information and experiences is an important way of furthering sustainability in general and behavior change in particular.

Credibility

One of the more interesting issues that arose in the interviews is that some informants expressed uncertainty or skepticism about information contained in the Portal. In one case, an informant reported that one day she had looked at the Portal and noticed a big spike in electricity use at a time when no one was home. She could not imagine what could have caused this – they had no central air conditioning, nor had she left appliances running – and thus suggested that the system was broken or in error. (Of course, other things – like a refrigerator going on a defrost cycle, an electric hot water heater or dehumidifier going on – could well explain this, but many ways in which electricity is consumed are invisible to users, and the Portal, at present, provides little assistance.) For the future, it might be worth exploring proactive explanations: for instance, if the system detects a spike in usage, perhaps it could offer a list of possible explanations, or it could direct users to a forum where they could chat with others who have experienced spikes.

Other users reported similar reactions due to what they saw as "stupid" comments by the system. For example, one user was alerted that his electricity use was far above normal – but it was during a hot spell when he was using the air conditioning constantly. While technically the alert was correct, it was so obvious that it was annoying rather than informative, and that led him to question the "competence" of the system. While one can imagine a workaround for this particular issue, the more general challenge is how to maintain the credibility of a system that provides alerts and recommendations that are intended to be taken seriously, while at the same time not raising unrealistic and soon-to-be-dashed expectations of competence.

CONCLUSION

Over the last decade HCI has become increasingly concerned with sustainability, and in particular has explored systems intended to support voluntary reductions in resource consumption. Work in HCI has primarily focused on the design of such systems, exploring a range of innovative and occasionally beautiful designs. Less has been done, however, in terms of carrying out field studies of the use of such systems.

This study used logs, a survey and interviews to evaluate the use the Dubuque Electricity Portal, a system aimed at supporting voluntary reductions of electricity consumption. It examined the results of a pilot project that involved the deployment of the Portal to 765 households in small U.S. city for about 20 weeks. The Portal provided each household with fine-grained feedback on its electricity use, as well as using incentives, comparisons, and goal setting to encourage conservation.

Even though the volunteers who participated in the pilot project had previously undertaken a wide range of energy conservation actions, those who used the Portal did decrease their energy use. They also reported increased understanding of their usage, and reported taking an array of actions – both changing their behavior and making alterations to their electricity infrastructure. They also reported that, based on their experiences, they intended to make changes in the future (e.g., like purchasing energy star appliances when it became time to replace something).

The study discusses the experience of the systems users, from adoption through use through impact. It notes issues having to do with accessibility, a preference for time-based visualizations, and the advisability of multiple modes of feedback and information presentation. It also comments on two problems: the failure of chat, and the issue of how to maintain system credibility in the face of non-obvious consumption patterns and ill-founded advice.

Finally, let's revisit the HCI community's critiques of ECF systems discussed earlier. That is, a number of researchers (e.g., [17, 18, 20]) have argued that ECF systems reify existing norms, leading participants to action primarily when they see themselves exceeding their usual usage; this enables incremental improvements but not the radical changes in usage that may be necessary to address our energy challenges. We have two responses to these claims. First, our experience is consistent with this view. Both in this study, and the Water Portal study [9], we found that participants oriented to their own baselines, focusing primarily on cases or periods where they markedly exceeded them. In the interviews, participants expressed reluctance to make radical changes in routines or expectations. They might take shorter showers, but they were not willing to give up daily showers; they might raise the thermostat in the summer, but no one was willing to dispense with the air conditioner altogether.

But second, barring a few short term examples that we do not believe would persist – generally competitions on college campuses to reduce resource usage for a week or so (e.g., [15]) – we have not seen approaches that offer viable methods of achieving larger reductions. In our view, the most likely instigator for radical changes in consumption will be either crises or prices, most likely both. In this case some form of ECF will be a necessary part of the solution. That is, individuals will still need to understand their consumption, and be able to view it in the context of achieving societal goals (e.g., avoiding rolling brownouts) or avoiding individual penalties (e.g., triggering higher prices in a tiered energy pricing regime). For instance, during the California energy crisis of 2000 – 2001, a simple visualization that contrasted available supply with predicted demand put up by a group at the Lawrence Livermore

National Lab received over 2 millions hits a day; comments from users suggested that some were modulating their energy use in response to the visualization (Darby, 2006, p24).

It does not require a great leap of imagination to envision a future version of the Electricity Portal that embeds electricity availability or tiered pricing in the visualizations of individual energy consumption, and offers alerts and goal setting tailored to achieving those ends. As our energy-related challenges become more pressing, the increasingly evident environmental consequences of our energy consumption – particularly when reflected in pricing – may serve as a more effective driver of radical change than points or ranks or comparisons.

ACKNOWLEDGMENTS

This project would not have been possible with the support of the City of Dubuque, the Dubuque 2.0 NGO, and the 756 households who participated in the pilot study. Finally, thanks to our CHI reviewers for helpful and constructive comments.

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