Studying Always-On Electricity Feedback in the Home

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ABSTRACT

The recent emphasis on sustainability has made consumers more aware of their responsibility for saving resources, in particular, electricity. Consumers can better understand how to save electricity by gaining awareness of their consumption beyond the typical monthly bill. We conducted a study to understand consumers' awareness of energy consumption in the home and to determine their requirements for an interactive, always-on interface for exploring data to gain awareness of home energy consumption. In this paper, we describe a three-stage approach to supporting electricity conservation routines: raise awareness, inform complex changes, and maintain sustainable routines. We then present the findings from our study to support design implications for energy consumption feedback interfaces.

Author Keywords

Electricity Feedback, Home, Behavior Change, Participatory Design

ACM Classification Keywords

H.5.2 Information Interfaces and Presentation: Miscellaneous

General Terms

Design, Measurement

INTRODUCTION

In the past decade, our society has become increasingly concerned about the environment. Emphasis has been put on citizens' responsibility to save resources. However, people are largely unaware of when and where electricity consumption occurs in their homes [16, 18], which can impede efforts to reduce electricity consumption in the home [3, 4]. Most people rely solely on their monthly bill, which typically reports limited or irrelevant consumption information [4, 7].

Fortunately, detailed data about electricity consumption is becoming more readily available. Old meters are being replaced by smart meter units capable of providing household consumption figures wirelessly and regularly. Appliance-specific data is also available through various sensors [11]. Nevertheless, while the amount of available data is increasing, ways to use this data to help consumers become more sustainable are still largely unexplored [5, 6].

Several research projects have studied the use of feedback technologies for electricity consumption [3, 4, 12, 19]. Many are restricted to the study of enhanced bills or meter reading, while few address computerized feedback, and even fewer explore always-on displays (e.g. [15]). Conversely, Fisher's review of feedback studies suggests that successful systems should be frequently updated, interactive, and appliance specific, involving historical or normative comparisons and longitudinal feedback [4]. Some feedback designs provide information in the periphery of users' attention using light intensity or color [15, 12]. However, these do not provide interaction and either fail to scale to an entire house or fail to provide either appliance-specific breakdown or data history. Systems are being developed for exploring smart meter information in desktop or web applications[1]. However they are targeted at consumers *actively* involved in changing their electricity consumption behavior as a focused task. Moreover, they lack the potential benefit of always-on feedback to provide continuous feedback [4], and can serve to motivate all members of the household, as suggested in [1, 12].

In this paper, we first introduce a three-stage approach to supporting electricity conservation routines. We then present a study in which we emphasize the role of home-centered feedback by exploring the design of a feedback system with users in their home. We present design implications for interactive, always-on systems that provide users with personalized feedback of their home electricity consumption and that facilitate the three stages of conservation.

SUPPORTING STEP-BY-STEP BEHAVIOR CHANGE

Based on our experience designing ambient displays [14], on the literature reviewed [3, 4, 5], and on Prochaska's Transtheoretical Model of Change [13], we suggest three consumption behavior-change steps which we believe always-on feedback systems should support: **Raise awareness**, **Inform complex changes**, and **Maintain sustainable routines**. While these steps are encountered in sequential order for any one person, we argue that feedback systems for the home must support all three steps in parallel. Our reason for this is that household members may be at different steps

[1] e.g. Google PowerMeter, http://www.google.org/powermeter

in consumption behavior change and may be motivated by different things [12].

Raise Awareness (S1): People can be responsible for a large portion of home electricity consumption [18], yet they are largely unaware of when and where electricity is consumed [16]. To be able to change behaviors for more sustainable habits, they first need to gain awareness of the impact of their behavior on electricity consumption [5]. Raising awareness should be supported in electricity consumption interface designs by providing detailed information of consumption patterns. When users acquire a good awareness of their electricity consumption, potentially having already adjusted their behavior and experienced a reduction in consumption, a feedback system could then provide interactive features for extracting detailed information to guide the definition of behavior changes.

Inform Complex Changes (S2): Informing complex changes relies on users being familiar with their current electricity consumption (S1), and being willing to further change their consumption behavior. A popular approach in supporting behavior change is to use goal setting [8]. Studies show that integrating goal setting with feedback can positively affect reduction in consumption [19], achieving a 20% reduction in some cases [9]. While feedback systems could provide information about performances relative to a goal, little is known about how to set those consumption goals, or how to adequately provide feedback on them.

In contrast to the previous step, this step encompasses a consolidation of the information gained, and more precise explorations of the data to inform goal changes. Hence, we suggest that electricity feedback systems should provide users with interactions giving them additional information regarding their electricity consumption, the changes they have made, and the opportunities for further reductions, particularly emphasizing the deviation from goal rather than absolute consumption figures.

Maintain Sustainable Routines (S3): To be effective, behavior changes need to be sustained, however, studies observing long-term effects of feedback often report a relapse to previous behaviors unless the changes have been adopted for three months or more [4, 3]. In this project, we emphasize the long-term role of feedback technology to encourage users to adopt lasting changes and sustainable electricity consumption behaviors. In order to provide long term feedback, the system needs to evolve to fit the home environment and its users, especially their evolving information needs. Furthermore, always-on feedback technology should allow users to customize its representation to envision its long-term integration into the home with respect to aesthetics and privacy.

STUDY

Despite the potential benefit of providing appliance-specific feedback [4], existing systems which do so have been limited to rudimentary approaches, such as meters on appliances or stacked bar graph visualizations [17]. Consequently, we chose to focus on location-based feedback, where appliance feedback is placed according to their location in the home. To further inform the design of feedback technology for energy consumption, especially with respect to the three-step process, we conducted a user study exploring existing strategies for home electricity preservation, motivations for electricity consumption, and the integration of electricity feedback systems in the home. Eight participants between 21 and 38 encompassing four households took part in this study. Two lived in apartments and six in houses. Six participated as couples and two as housemates with both genders being equally represented. Participants included both university students (4) and professionals (4: an engineer, two social workers, and a nurse). Their main reasons for reducing consumption included: economic reasons (3), sustainability concerns (2), social responsibility (1), reduction of waste (1), and none (1).

We conducted contextual and individual semi-structured interviews with each participant, followed by design activities before conducting joint design activities with both participants from each pair. The interview captured background information and inquired about current approaches to electricity consumption and electricity-consuming devices in the home. Individual design activities included a drawing of the home floor-plan and the placement of appliances on it. Group design activities included a discussion of placement, privacy, and aesthetic aspects of an always-on electricity feedback device, as well as a discussion about representations of appliance-centric consumption information.

We outline key results providing inspiration and implications for designing electricity consumption feedback systems, including: disparities in household members' awareness; evidence suggesting location as valid perspective for feedback; self-comparison as a motivator for change; and the interplay between aesthetics, readability, and information availability. Due to the limited sample size, our findings do not generalize directly. Yet, they provide empirical evidence and provoking perspectives for the design of electricity consumption feedback in the home.

Disparities in Household Members' Awareness

To better understand disparities in people's awareness of electricity consumption in their home, we first asked participants to list electrical appliances in their homes to understand the difference in perceptions between inhabitants of the same household. We then asked them to rank these appliances from the most electricity-consuming to the least, considering annual consumption. In fact, while our pairs of participants occupied the same household, they rarely agreed on the number of appliances they possessed or their relative impact on the overall consumption.

Participants in three of our households had strong differences in opinion regarding electricity consumption. For instance, Daniel does not use the microwave and forgot to mention it until pointed out by Christine. Emy is the thriftier person in the household, and tries to convince Francis to adopt more electricity-saving behaviors. While Francis agrees with the need to conserve, he does not make special efforts to reduce, *"I don't go out of my way too much."* Harry tries to avoid wasting resources and would like to do more, whereas Gina thinks their consumption is low enough for them to not have to worry about it.

As in any team or group effort, effective change of a household's behavior requires all household members to be involved in a coherent way. However, while all participants are aware of the *need* to reduce electricity consumption, strategies for doing so are not as easily established considering the differences in awareness of the *amount* of electricity consumption. For instance, Emy tries to switch off appliances when not in use. However, Francis points out that she also sets the thermostat temperature higher than he would have it in winter, potentially offsetting the positive change made earlier. Additionally, participants generally showed interest in knowing how to reduce consumption, but also reported lacking the knowledge which would be necessary to make effective changes. *"I don't really know what appliances really use. . . I'd like to think that I do, but I probably don't." (Daniel).*

Design Implications: Similarly to [1, 5], we suggest that users need a coherent baseline awareness of energy consumption (S1) in the home to develop group efforts toward energy conservation. Hence, the system must help all members reach an agreement on the reality of their habits.

The Map as a Support for Feedback

While describing appliances and their consumption, as well as their conservation efforts, participants largely built upon activities and routines. Considering the importance of activities in information location [2], we investigated how maps could support feedback information in (S1). We first observed that, when listing appliances, many participants adopted a room-by-room approach. Moreover, participants explicitly drew relationships between location and activities, *"I think of organizing the room as far as what happens in each place." (Brie).*

While participants' reactions to the concept of map-related information was largely enthusiastic, some felt a map could quickly become cluttered, *"We have so many appliances, we have like a billion." (Emy).* Nevertheless, when coming together to discuss the two maps, participants had no difficulty reading them, usually commenting on the quality of the drawing or the degree of detail of their respective maps and pointing out omissions in the appliances shown.

Design Implications: Floor plans are common when representing homes and for situating objects in them. They hold inherent qualities for appliance-specific feedback and can particularly leverage people's implicit knowledge of their home and activities to become aware (S1) of consumption patterns.

Self-Comparison as a Motivator for Change

Our participants welcomed the idea of being able to set personal goals for their electricity consumption, and were especially intrigued by the idea of making it a personal challenge of reducing electricity: *"This would be fun to see how we can keep our bill low." (Anton).* Most felt more motivated by self-comparison than comparison to others: *"There is too much variance" (Emy).* We observed a lack of trust in normative or social comparisons, stating *"Comparison to other people has too many variables." (Emy). "[Social comparison] would be [effective] if we had the same setup. We have different appliances." (Gina).*

The desired method of comparison also varied. Some participants indicated a preference for an absolute measure of consumption, while others preferred a relative measure because, *"Some appliances just by their nature are going to use more power." (Harry).* Most participants agreed that visualizations of consumption relative to past history, whether it be one hour ago, yesterday, or last year, *"Make it easy to compile statistics over an arbitrary period of time." (Harry).* Participants wanted tools to compare in time: *"I want to be able to compare it to other times, times of day or times of year." (Gina).* or were interested in having advanced analysis tools *"I like things as analytic as they can get." (Daniel).*

Design Implications: Considering the breadth of perspectives on electricity consumption that participants reported interesting, such as historical, relative consumption, and social perspectives, we suggest that the feedback system should allow them to explore their consumption from various angles. This further underlines the need for feedback technologies to appeal to users' variety of motivations, including monetary, social, and environmental (as discussed in [12]). This is particularly important when users enter a focused stage of energy reduction (S2), in which the system needs to inform more complex, and possibly more constraining changes.

Aesthetics, Readability and Information Availability

During our design activity, inquiry into potential locations and general concerns for a feedback display prompted participants' discussion about aesthetics, privacy, readability, and access to information. When asked to rank those concerns, all participants ranked privacy last *"I don't even know who cares." (Gina).* However, Anton and Brie shared a home with others who could invite people that they might not know to the home. They therefore demonstrated more concern about who had access to the information if it was visible to visitors of their housemates.

When considering the compromise between readability and aesthetics, we noticed a strong difference between male and female participants in our study. Most females ranked aesthetics first, claiming that a visible object in the home should aesthetically appeal to them: *"I would frame it, laminate it, and it would be color coded." (Christine)*, and *"It's gonna be right where I want my picture." (Emy).* On the other hand, most of the males were primarily interested in the functionality of the device, while also being interested in its aesthetic, ranking readability higher in their priority. *"It sounds like a cool gadget, and I like cool gadgets." (Francis).*

The concern for aesthetics often led to discussions about placement. Gina felt that a feedback device would not fit with her current décor, and hence suggested putting it out of the way to avoid cluttering. Emy proposed a placement out of view, on the breaker box. Anton, on the other hand, was more concerned about having access to the information, while remaining interested in how it would be salient in the home: *"I'd want it in a place where it does not call everyone's attention to it, but it calls my attention to it on a regular basis."* Yet, many participants later suggested using interaction to switch from an aesthetically pleasing but low detailed information display to a more detailed display: *"[You could] hover over [a simple colored dot] to yield the gauge." (Christine).*

While the role of aesthetics has been discussed in the past [10], our participants' comments imply an important interrelationship between aesthetics, feedback location, and information conveyance. Nevertheless, aesthetics is often regarded as a by-product of design, as opposed to being a component of information conveyance and an essential consideration in acceptance of the device as illustrated here.

Design Implication: Aesthetics are a concern for long term acceptance of a feedback system in the home. To support maintenance (S3), the system must be placed in an location permitting regular, long-term viewing and be integrated into the living space while supporting readability and the ability to quickly gather high quality information. Hence, a system could provide a passive, aesthetically acceptable view and an active interaction mode that provides details on demand to allow the user to explore the data, extract insights, form hypotheses, inform change, and set goals.

CONCLUSION

We have described the result of a study exploring the requirements of an always-on feedback system for electricity consumption in the home. We identified a three step approach to electricity consumption behavior change and highlighted several supporting design implications, including the potential of location-based feedback for providing awareness, and the necessary compromise between readability and aesthetics in always-on home feedback. In future work, we intend to perform further participatory design exercise to create a prototype of a home electricity feedback system and conduct longitudinal deployments of the prototype to better understand how users interact with it.

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