Some consideration on the (in)effectiveness of residential energy feedback systems

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ABSTRACT
Energy feedback systems, particularly residential energy feedback systems (REFS), have emerged as a key area for HCI and interaction design. However, we argue that HCI researchers, designers and others concerned with the design and evaluation of interactive systems should more strongly consider the *in*effectiveness of such systems, including not only potential limitations of specific types of REFS or REFS in general but also potentially counterproductive or harmful effects of REFS. In this paper we outline research questions and issues for future work based on critical gaps in REFS research identified from (i) a review of REFS literature and (ii) findings from two qualitative studies of commercial home energy monitors.

Keywords
Sustainability, energy, design, home, everyday practice

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Designing interactive systems to promote sustainable consumption behaviors has recently emerged as a key and rapidly growing area of interest within HCI and other areas concerned with interactive systems. In a recently awarded Best Paper at CHI 2010, Jon Froehlich, Leah Findlater, and James Landay argue that "eco-feedback" is an important area of HCI research, but that much can be learned from environmental psychology in terms of how to design and evaluate such systems [5].

Residential energy feedback systems (hereafter referred to as REFS) in particular are receiving a great deal of attention from the HCI and interaction design communities. While substantial progress has been made over the last 40 years within and outside of HCI with respect to the design and evaluation of REFS, significant challenges and questions remain. For example, although energy savings of 7-20% have been attributed to the use of REFS (as well as negative reductions) [3,4], we point out that surprisingly little is known about *what* specific conservation behaviors do or do not result in such reported savings, *how* individuals engage or do not engage with feedback, or *why* conservation does or does not occur in relation to various types of feedback.

The primary contributions of this paper are: (i) to outline several critical gaps identified in a literature review of evaluative work related to REFS, (ii) to outline some specific potential limitations and other issues based on our empirical findings from two ethnographically informed qualitative studies of commercial home energy monitors, and (iii) to argue for the importance of a complementary perspective for empirical and theoretical inquiry related to REFS, "eco feedback", and interactive systems in general: inquiring into the "*in*effectiveness" of such systems.

CRITICAL GAPS IN ENERGY FEEDBACK RESEARCH
Grounded in a basic assumption that home dwellers lack information and general awareness concerning household energy consumption, a number of studies have investigated the "effectiveness" of various forms of feedback in terms of promoting energy conservation behavior. Our literature review focuses primarily but not exclusively on 4 recent literature reviews and meta-reviews of REFS [1,3,4,5], which review over 20 original source papers reporting evaluations of the REFS. We also review a number of HCI and interaction design papers related to REFS, including all such papers cited in [5,6] and those presented at CHI '10.

Our review of evaluative work concerning REFS highlights a number of critical gaps in REFS research. Prior empirical work referenced and discussed in the aforementioned reviews tend to treat the home as a "black box", ignoring aspects ranging from basic interactions within the home (e.g., accounting for reductions in terms of specific appliances and interactions) to more complex issues (e.g., the subjective experiences of using and living with energy feedback systems). Notwithstanding recent work investigating the aesthetics of energy (e.g., [2,7]) and sociological investigations of energy consumption (e.g., [8,9]), formative and evaluative empirical studies related to REFS typically focus on assessing the "effectiveness" of energy feedback—defined in terms of measurable reduction in energy consumption—to the neglect of a myriad other factors. Surprisingly these include determining precisely which behaviors (e.g., adjusting the thermostat) can or

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cannot be attributed to reported reductions or lacks thereof.

In particular, we highlight a lack of REFS research investigating: *(i) the effects of feedback on specific behaviors, attitudes, and understandings of users* (e.g., what specific behaviors account for the measured reductions?), *(ii) the effects of feedback on individual "experience"* (e.g., is the implemented system subjectively experienced as pleasing, engaging, desirable, useful?), *(iii) social and cultural factors related to feedback* (e.g., how does feedback affect social relations within the home?), *(iv) factors related to domestic consumption in terms of everyday practices* (e.g., how is the system symbolically and materially "domesticated" or appropriated over time by users?), and **(v)** *broader critiques of energy feedback research* including the philosophical assumptions underlying REFS research (e.g., what is meant by "effective"?, and what precisely are "sustainable energy systems" attempting to sustain?).

Collectively we argue these research gaps point toward a subtle yet critical bias that apparently underlies much prior REFS research: a bias toward the effectiveness to the neglect of the *in*effectiveness of REFS. Largely absent from our review of REFS research are investigations of questions such as: What behaviors are unlikely to be affected positively by REFS interventions? What are the potential negative effects of REFS? What are possible alternative and more effective interventions? In order to begin to explore such under-addressed aspects of REFS research, including the lack of qualitative formative or evaluative work, we conducted two studies of commercially available energy monitors.

INVESTIGATING THE (IN)EFFECTIVENESS OF *REFS*

Studies and methods

We present and compare findings from two qualitative home studies. The first is an ongoing study of a commercially available energy monitor, the PowerCost Monitor (PCM) from Blueline (Figure 1). We present initial findings from this study including 9 participants from 5 households in Pittsburgh, Pennsylvania, USA. For each household we (i) conducted an initial home visit and interview (roughly 1 hour), (ii) left participants with the PCM for 6-12 days, along with several simple activities designed to engage them with the device (e.g., try to maximize and minimize consumption momentarily), and (iii) conducted a follow-up home visit and interview (roughly 1-2 hours). Additionally, we present findings from a study recently published by the authors at CHI '10 [6]. Data are presented from a subset of this study including 8 participants from 8 households in the San Francisco Bay Area of California, USA. During this study participants were given a paper chart we designed with estimated energy and monetary costs of using various appliances for given amounts of time, and similar information was also posted directly nearby some major appliances in participants' homes. We also gave participants a Kill-a-Watt (KaW) device by P3 International for monitoring individual appliances (Figure 1), which was presented to participants as a "bonus" for their participation and not a required part of the study. For each household we (i) conducted an initial home visit and interview (roughly 1 hour), (ii) left each household with the price charts and KaW device for 3-10 days, and (iii) conducted a follow-up home visit and interview (roughly 1-3 hours). Throughout the remainder of this paper it is assumed that all findings reported are associated with the study involving the PCM unless indicated otherwise.

Figure 1. The PowerCost Monitor (left); the Kill A Watt (right).

Findings

Baseline consumption. All participants frequently described their interactions with the PCM in terms of a "baseline" during the interviews (several participants explicitly introduced the term "baseline" unprompted; others referred to, e.g., the "normal amount" displayed). All participants determined (without being asked to by the researchers) their baseline or "normal" consumption level, i.e., a rough approximation of their average level of power consumption when they were home. In all homes the baseline (when someone was home) was roughly in the range of 1-3 kilowatts (kW). Interestingly no participant mentioned trying to reduce their baseline (average or "typical" consumption level), but rather only discussed trying to keep consumption at or near their baseline.

Awareness and engagement. Participants described one of the major effects of the PCM in terms of an increase in their "awareness". (The researchers did not explicitly ask participants if the device raised awareness; rather, we asked questions such as "Did the device affect your daily routines in any ways or not?") One participant, a psychology student, described this explicitly in terms of a "Hawthorne affect". Another participant described the significance of the "realness" of the device as a reminder:

> P2: It's still in my mind even when it's not there. I'm still gonna be thinking about it. It's like a reminder.
>
> I: How is this different than, say, a sign?
>
> P2: Well… this is, like, *real*. Maybe they can put a sign up there and remind me but this can *track* what I do. *It's really on the meter*!

This example clearly points to differences between static, paper-based signs and real-time feedback displays, in terms of engagement and perceived significance. However, importantly this participant was only willing to attribute very minor behavioral changes to this increased awareness: "I tried to turn off lights more often…and my Christmas tree…and I unplugged my digital photo frame"; "I'm going to try to turn my computer off more."

Comparing engagement with the PCM with the static paper-based cost information we provided participants during our previously published study [6], we find that

participants appeared to engage to a much greater extent with the PCM. However, participants did not engage with the PCM to the extent that we initially suspected they might. For example, only one participant appeared eager to want to test or "set off" the device by seeing if it responded accurately to the turning on and off of various appliances. This finding offers support for findings that indicate that REFS employing interactive and real-time feedback displays are typically more effective in terms of reducing overall electricity consumption [4].

However, it should also be noted that participants did not always engage with the interactive energy monitors. In the study reported in [6], we left participants with KaW power monitors and *absolutely none of the participants in that study used the KaW device*—not even once to simply to try the device out. The KaW (Figure 1), which measures the energy/power consumed by a particular appliance but must be manually plugged into the appliance and outlet in order to display the consumption data, was presented to participants as "bonus" and not a required part of the study. Typical explanations for not using it included: "well, I wanted to but I didn't get around to it" and "I was just too busy…" Thus, the relationships among engagement, awareness, and action are still quite unclear. What is clear is that increased engagement and awareness with and through REFS does not necessarily lead to conservation.

Actual and anticipated behavioral change. Actual or anticipated behavioral changes described by participants as associated with the PCM were surprisingly absent, even when prompted to describe any such behaviors. *Conservation behaviors that were attributed by participants to the PCM and persisted beyond the structured activities* (e.g., to minimize consumption momentarily) *were limited to the following*: turning off lights more frequently (mentioned, often with some uncertainty, by all participants); and turning off computer, turning off Christmas tree lights more often, and unplugging a digital photo frame (P2). All participants expressed unwillingness or perceived inability to adopt various conservation practices, despite learning that certain practices consumed large amounts of energy. For example, participants were very unwilling to reduce the temperature settings on their washer or dryer, or air-dry their clothes instead of using the automatic clothes dryer:

> P5: I knew the dryer used a lot but I didn't know it used 5kW. I didn't know it used *that* much.
>
> P6: (P5's wife): I guess I feel a little bad now when I turn on the dryer, but, I mean, I'm not gonna *not* wash my clothes!

Participants of one household were very conservation-minded for self-described environmental reasons and tried to air dry clothes whenever possible. However, they described how difficult this was especially with their newborn child during winter months. They used their automatic clothes dryer more in the winter as a consequence, knowing it consumed large amounts of energy. These findings are very similar with those we reported in [6], which presents many examples of participants being resistant to changing their routines, in order to save energy, money, or otherwise.

Difficulty fine-tuning consumption for conservation. In instances in which participants already took significant steps to conserve (e.g., strategic use of space heating; use of CFL lighting), these participants also had difficulty "fine-tuning" their energy consumption in order to reduce it. For example, one participant (a mechanical engineer) describes the difficulty in further reducing his household's energy consumption:

> I: Studies have shown that people sometimes reduce consumption by 10-20% from using energy monitors like this one…
>
> P4: [Interrupts] Well, let's see. If I replaced all these [bulbs in kitchen fixture] with CFLs [compact fluorescent light bulbs]….that'd be about 10%. I'm not sure where I'd look next to cut 400 watts. I'd have a hard time figuring out where I could save another 400 watts on average.

In the study reported in [6] we found similar difficulties with fine-tuning conservation. In that study, 2 of the 7 participants from the San Francisco Bay Area were self-described as "conservers" and took significant steps to reduce their consumption, primarily for financial reasons. However, surprisingly neither of the "conservation" participants significantly engaged with our price charts or used the KaW device. Both of these participants seemed to feel as though they already did all they could to conserve energy and were not concerned with "fine-tuning" their consumption any further, even though we provided them with tools we thought might help them to do so.

IMPLICATIONS FOR HCI AND *REFS* RESEARCH

In this section we outline some considerations for future work related to REFS for HCI and interaction design based on the critical research gaps identified and specific areas of concern suggested by interpretations of our field data.

1. Design details. Prior REFS literature acknowledges that the modes of interaction and the information presentation of REFS can significantly affect their effectiveness. However, stronger consideration should be given to the often subtle ways in which design details shape and give structure to people's perception and action with regard to energy, consumption, and more. For example, in our study of the PCM all participants learned and described their "baseline" consumption without being instructed to do so, yet no participant challenged their baseline by aiming to reduce it. Instead, participants described "using too much" and "going over" their baseline, apparently assuming the baseline to be the norm. It may be the case that the way the PCM presents information encourages maintenance of a baseline: small reductions are perhaps encouraged but more dramatic reductions are not. Another example of design details significantly affecting engagement is the precision of the PCM, which does not allow the lower consumption devices such as certain lights and electronic devices to register. By not easily displaying the consumption of these devices the PCM may be said to imply such devices are unimportant (and indeed were rarely mentioned by our participants). Such design details not only contribute to the

success or failure of intended effects of REFS, but also and importantly can structure behavior and understandings significantly in *unintended* ways.

2. Non-negotiable interactions & practices. Another crucial finding of both of our studies has to do with the "non-negotiability" of many domestic interactions and practices—a term which owes to Elizabeth Shove's sociological investigations of everyday "inconspicuous consumption" [8]. For example, we described how one participant was surprised at how much energy the dryer consumed yet was unwilling to alter this practice: "I'm not gonna *not* wash my clothes!" Examples of this non-negotiability abound in both of our studies. Such examples point unambiguously to the fact that awareness does not imply conservation action. This is not to suggest that certain practices are in fact incapable of being altered; indeed REFS can and should aim to re-configure "non-negotiable" practices. Rather, REFS must seriously take into account the non-negotiability of everyday practices and the power of habit. In [6] we proposed a vocabulary of energy-conserving interactions, specific types of ways of conserving energy for which to design. REFS may be more effectively designed if such energy-conserving actions were explicitly taken into account during design and evaluation.

3. Identifying limitations and considering alternatives. Taking into account the non-negotiability of practices points to the broader issues of considering and identifying potential limitations and alternative modes of intervention. For example, we have throughout noted the surprising absence of REFS research that articulates specific types of interactions that account for reductions in consumption or lacks thereof following a REFS implementation. Two general categories of potential limitations to consider would include: (i) categorizing domestic interactions and practices in terms of the degree to which they are re-negotiable and re-configurable (e.g., REFS are, in a certain context, likely to encourage turning off lights when not in use but *unlikely* to encourage air drying clothes), and (ii) identifying potential conservation thresholds or upperbounds related to such categorizations (e.g., reductions of greater than 10% are unlikely to occur for a given REFS in a certain context).

As a concrete example of a potential limitation and implication in terms of alternative intervention, consider the response of one participant who calculated that the estimated 10% reduction resulting from devices like the PCM could be accounted for by replacing all of his incandescent light bulbs in one fixture with CFLs, which he had been meaning to do but had not yet done. The participant then commented: "I'd have a hard time figuring out where I could save another 400 watts on average." This begs the question: What is the role of a particular REFS over time? Are there simpler ways to achieve a 10% reduction in consumption than an interactive REFS system?

4. Unintended effects: Sustaining the unsustainable? Thinking more broadly about limitations of REFS, designers and researchers should consider the potential for REFS to actually work *against* intended goals such as reducing consumption, as well as against other goals of sustainability. For example, installing a feedback device on the automatic clothes dryer may help negate its being displaced by the clothesline. Implicit in the act of monitoring the appliance is the assumption that people *will use* it rather than, for example, *switching* [6] usage by drying clothes on a clothesline. Similarly, presenting dwellers with their "baseline" may actually encourage the sustainment of the baseline rather than more drastically challenging the amount of energy demanded by dwellers.

5. Alternative aims. Finally, we note that the focus on effectiveness in terms of measurable reductions in household consumption is to the neglect of a myriad other ways of evaluating or judging the effectiveness or value of REFS. For example, REFS also serve symbolic functions, perhaps communicating to homeowners and visitors that conservation is an important and valued practice. Backlund et al. [2] have explored the "aesthetics of energy" through various unconventional REFS. Alternative types of value that may be created by REFS are enumerated in [7].

CONCLUSION

While REFS has emerged as a key area, we have argued that designers and researchers should equally consider the *in*effectiveness of such systems. We have outlined several critical gaps in REFS research and suggested specific areas that may serve as a basis for future work related to REFS.

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