The Design of Eco-Feedback Technology

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ABSTRACT
Eco-feedback technology provides feedback on individual or group behaviors with a goal of reducing environmental impact. The history of eco-feedback extends back more than 40 years to the origins of environmental psychology. Despite its stated purpose, few HCI eco-feedback studies have attempted to measure behavior change. This leads to two overarching questions: (1) what can HCI learn from environmental psychology and (2) what role should HCI have in designing and evaluating eco-feedback technology? To help answer these questions, this paper conducts a comparative survey of eco-feedback technology, including 89 papers from environmental psychology and 44 papers from the HCI and UbiComp literature. We also provide an overview of predominant models of proenvironmental behaviors and a summary of key motivation techniques to promote this behavior.

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Eco-feedback, Environmental HCI, Reflective HCI, Survey

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

General Terms
Design, Human Factors

INTRODUCTION

As environmental issues such as climate change, air pollution, and water scarcity become more salient in the global consciousness, so too have they become more active targets of research within HCI and Ubiquitous Computing [6, 19, 57]. One particularly popular form of environmental HCI research is the design and study of *eco-feedback technology*, which we define as technology that provides feedback on individual or group behaviors with a goal of reducing environmental impact (adapted from [39] and [28], see Figure 1 for examples). Despite this goal, few HCI eco-feedback studies have even attempted to measure behavior change. Although eco-feedback may be seen as an extension of research in *persuasive technology* [17], it actually extends back much further to over 40 years of research in environmental psychology. This leads to two interrelated questions: (1) What can HCI learn from environmental psychology and (2) what should be the role of the HCI community in contributing to eco-feedback research? To explore these questions in detail, we present a review of the related environmental psychology literature as well as a comparative survey of eco-feedback studies in both HCI and environmental psychology.

Figure 1. Examples of eco-feedback technology. (left-to-right) The Infotropism display uses sensors and living plants to provide feedback about recycling and waste disposal [29]. WaterBot provides ambient feedback information about water usage [3]. The UbiGreen Transportation Display semi-automatically senses and feeds back information about transportation to encourage green transit [19].

Eco-feedback technology is based on the working hypothesis that most people lack awareness and understanding about how their everyday behaviors such as driving to work or showering affect the environment; technology may bridge this "environmental literacy gap" by automatically sensing these activities and feeding related information back through computerized means (e.g., mobile phones, ambient displays, or online visualizations). HCI and UbiComp researchers have built eco-feedback technologies for a variety of domains including energy consumption [28], water usage [3], transportation [19], and waste disposal practices [29].

Contributing to this growing interest in eco-feedback technology is the parallel advancement and availability of sensing systems for environmentally related activities (e.g., human activity inference [35]) *and* interactive displays to feedback this data (e.g., iPods and mobile phones). Such advances provide a rich space of opportunities for new types of eco-feedback that could not be considered in the past. Moreover, the next generation of resource measurement systems (often referred to as "smart meters") will soon provide real-time (or near real-time) data on electricity, gas, and water usage in homes and businesses. This will produce tremendous amounts of data that can be

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analyzed and fed back to the user, creating even more opportunities for eco-feedback technology research.

In light of this technological momentum, it is critical for the HCI community to step back and define an approach and theoretical foundation for the design and evaluation of eco-feedback technology. Although some researchers in HCI and UbiComp have applied findings from environmental psychology (e.g., [43, 57]), all too often these findings have been ignored. As far back as the 1970s, studies have shown that eco-feedback technology can affect consumption behaviors. For example, in 1974 Kohlenberg et al. found that a light bulb, which illuminated when households were within 90% of their peak energy levels, changed energy usage behaviors [33]. At that time, environmental psychology was an emerging discipline that had grown out of the realization that environmental conservation was a twofold problem: partly technical and partly human.

The gap between eco-feedback research in HCI and in environmental psychology is unfortunate because it can lead to redundant efforts and, at worst, ineffective designs. This oversight not only affects researchers of eco-feedback technology but also practitioners as commercial eco-feedback systems like Microsoft Hohm and Google PowerMeter begin to be widely deployed.

In this paper, we bridge the gap between findings from environmental psychology and the design and evaluation of eco-feedback systems. We first review work from environmental psychology on why humans exhibit proenvironmental behavior and what motivates us to do so. Of particular relevance is work on the role of feedback (e.g., electricity bills) on these behaviors. We then reflect on the current state of eco-feedback technology through a comparative survey of 44 papers studying eco-feedback technology in the HCI/Ubicomp literature and 12 papers within the environmental psychology literature. We use this survey to contrast the design and evaluation approaches taken in these disciplines and to identify areas in which HCI can make the strongest contribution. Finally, we close with a discussion of issues that warrant further attention in the HCI community including approaches to evaluation, behavior change theories, and the lifecycle of usefulness.

MODELS OF PROENVIRONMENTAL BEHAVIOR

Understanding why people engage in environmentally responsible behavior is a complex topic spanning many disciplines including education, economics, sociology, psychology, and philosophy. Although numerous theoretical models of proenvironmental behaviors have been developed and studied, no definitive explanation has yet been found [34]. Still, these models offer insights into why people do act environmentally and thus they have direct implications for the design of eco-feedback technology. Even if it is not explicitly recognized, designers approach a problem with some model of human behavior.

We highlight a few of the most commonly used models, which extend from two views of proenvironmental behavior. The first, *rational choice models* (e.g., [2]), are often employed by psychologists who view environmental behavior primarily as driven by self-interest; the second, *norm-activation models* [47], tend to be used by researchers who view pro-social motives as most important.

Rational Choice Models

Rational choice models assume that human behavior is regulated by a systematic process of evaluating expected utility. Of these, the oldest and simplest models of proenvironmental behavior are called *attitude models*, which assume that favorable attitudes translate into favorable behaviors (e.g., [2]). Attitude models are based on a three part linear progression leading from knowledge to concern to proenvironmental behavior. A key issue with these models, however, is that any number of other factors may also influence behavior, so there is not always a strong relationship between attitudes and subsequent actions [11]. For example, researchers have found that people who cite conservation as the single most important strategy for averting an energy crisis are no more likely than others to engage in energy-conserving behaviors [11].

A more recent model, called the *model of responsible environmental behavior*, attempts to account for additional factors [27]. Through a meta-analysis of 128 proenvironmental research studies, Hines and colleagues proposed this model to emphasize the intention to act as well as situational factors that are conducive to such action (e.g., economic constraints or social pressures). This model brought attention to the fact that both knowledge of issues *and* of appropriate action were important factors in whether attitudes actually predicted behavior [18].

Finally, the *rational-economic model* assumes that people act to maximize rewards and minimize costs. With respect to the environment, this model is often simplified to suggest that people will adopt environmentally responsible behaviors that are economically advantageous (though cost need not always be financial). Indeed, there is strong evidence that price plays an important role in stimulating conservation behavior. For example, the US government has found that an increase in gasoline prices corresponds to a drop in total freeway trips and a rise in demand for fuel efficient cars [10]. However, the rational-economic model assumes that people understand whether a behavior or a device is cost effective, which is not always the case. It also discounts the effect of non-economic factors such as personal comfort, convenience, habit, and social norms [58]. Finally, in some cases, price simply cannot be significantly manipulated to change behavior. For example, dramatically increasing the cost of water quickly becomes an ethical issue.

Norm-Activation Models

Unlike the models above that assume behavior is regulated by reasoning about costs and benefits, *norm-activation models* are based on the premise that moral or personal norms are direct determinants of pro-social behavior [47]. Environmental actions often involve collective or community goods and the recognition that personal behaviors can affect others as well as future generations. A potential contradiction, then, in a rational choice model is that an optimal choice for the self-interested "rational actor" may not be optimal for the collective. Schwartz's model [47] suggests that proenvironmental behavior can be stimulated if a person is aware of the negative consequences for others and ascribes some amount of responsibility for taking ameliorative action. Thus, norm-activation models differ from rational-choice models in two important ways: (1) they recognize that behavior may be rooted in altruistic values and (2) that personal norm activation (e.g., moral obligations) may trump subjective perceptions of utility [50].

Stern et al. [52] extend this model with the *value-belief-norm theory* of environmentalism, which applies a similar value-based logic to a range of values such as curiosity, personal achievement, and feelings for wildlife. In this way, behaviors are activated not just in regard to other persons (who would suffer from environmental damage) but also in regard to the self and non-human species.

Relating Models to Eco-Feedback Technology

The discussion above highlights two of the predominant theories of proenvironmental behavior in environmental psychology. It is not meant to be a step-by-step guide on which to base eco-feedback designs but rather an attempt to highlight the complexities and nuances underlying environmental behavior. Eco-feedback designers, whether conscious of it or not, imbue their designs with some theory of human behavior. For example, an implicit assumption often underlying the design of eco-feedback technology is that the presentation of information, particularly at a time of local decision making, is enough to provoke environmentally responsible behaviors. However, *how* the technology presents this information is fundamentally based on how the designer believes humans behave and react. It is important, then, to begin questioning and exposing the theories used in eco-feedback designs and, when possible, to relate them back to work in environmental psychology.

Subscribing to one model versus another could result in strikingly different choices about the type and presentation of information. A design based on the norm-activation model should be value-centric: for example, feedback combining water usage data with updates about wildlife in a local watershed may invoke an altruistic response. In contrast, a design based on the rational economic model may stress the cost savings of a low-flow showerhead. The models are also useful in uncovering behavioral variables for eco-feedback technology to explore. That is, environmental psychologists have spent much effort examining different predictors of environmental behavior and building models around such predictors. These factors are worth attending to in eco-feedback designs.

MOTIVATING PROENVIRONMENTAL BEHAVIOR

While models of proenvironmental behavior provide us with a philosophical approach on which to base our designs, they do not offer specific strategies for changing behavior. The search for what motivates environmentally responsible behavior has far-reaching consequences: in 2002 alone, US energy utilities invested over $2 billion in promoting energy conservation [36]. We cover some of the most popular motivation techniques used in behavioral psychology (e.g., [21]) and offer examples that show how they have been applied to environmental behaviors. We review feedback as a strategy, as well as other popular techniques that may be used in conjunction with feedback, such as providing information or incentives.

Information

The most widely used means to promote proenvironmental behavior change is information [50] (e.g., via media campaigns, pamphlets, or websites). The assumption is that with better information people will act in more environmentally beneficial ways. However, various studies of informational programs have shown that simply presenting people with information on the benefits of proenvironmental behaviors typically results in only a marginal effect [8]. To maximize information's transformative potential it must be easy to understand, trusted, presented in a way that attracts attention and is remembered, and delivered as close as possible—in time and place—to the relevant choice [7].

Many conservation programs use high-level written or verbal messages, called prompts, to promote conservation (e.g., "Use Energy Wisely"). Investigations into general prompting strategies have shown that prompting has limited influence on behavior but can be made more effective by improving specificity, timing, and placement [22]. For example, Winett et al. [56] showed that placing signs next to doorways with specific information about when and who should turn out the lights (e.g., the last person leaving the room) resulted in a 60% reduction in the number of days when the lights were left on compared to signs that were placed above light switches and contained only general messages about saving energy. This is a particularly rich opportunity for eco-feedback technology, which could provide feedback proximal in location and time to the target behavior. That said, deciding on *how* and *where* to present eco-feedback is a research question within itself and will likely need to balance attentiveness, cognitive load, user motivation, information relevancy, and cost. Highly localized displays may perform best with respect to behavior change (e.g., placed directly on water fixtures or electric appliances), yet the cost of deployment and aesthetically fitting into homes are major barriers.

Goal-setting

Another well-studied source of motivation is goal-setting, which operates through a comparison of the present and a desirable future situation [54]. Individuals, groups, and external agents (e.g. a coach) can all set goals. Latham and Locke [37] summarized 35 years of empirical research on goal-setting and found that goals affect behavior primarily through four mechanisms: first, goals serve a directive function—they direct attention and effort toward goal-relevant activities; second, goals have an energizing function and, in particular, high goals often lead to greater effort than low goals; third, goals affect persistence; and finally, goals affect behavior indirectly as individuals use, apply, and/or learn strategies or knowledge to best accomplish the goal at hand.

Goal-setting has been successfully applied in some technology aimed at behavior change (e.g., UbiFit [9]) but it has not been significantly explored in environmental HCI. There is evidence, however, that goal-setting is a valuable technique to stimulate environmentally responsible behavior, particularly when combined with feedback. For example, in a study of electricity use, Becker [5] found that households that received a difficult goal and feedback about their performance conserved the most (15.1%) compared to a control group. Similarly, in a more recent study, van Houwelingen and van Raaij found that goal-setting in conjunction with daily feedback about consumption reduced natural gas usage by 12.3% [54].

Comparison

A comparison between individuals or groups can be useful in motivating action, particularly when combined with feedback about performance. Even feedback that provides information comparing one's current behavior to past behavior has been shown to be effective (i.e., self-comparison). The effectiveness of *social* comparisons in environmental psychology, however, has been mixed. Siero et al. [49] conducted a study of energy consumption behavior at two units in a metallurgical company and found that the unit exposed to comparative feedback saved more energy than the unit who received feedback only about their own performance. However, studies by Haakana et al. [26] and Egan [14] show that while people are often interested in comparisons, they do not necessarily have an impact on their behavior. One complexity is that eventually a performance plateau is reached, beyond which point emphasizing improvement over historical performance or the performance of others may not be effective.

Social media, such as Facebook or Twitter, has only recently made massive real-time social sharing and comparison possible. It is a relatively new topic of research (e.g., [38]) and is also perhaps one of the most underexplored aspects of motivating behavior change. Social networking sites have the potential to provide accountability and pressure to engage in proenvironmental behavior (e.g., [23]), including the incorporation of competitions, social comparisons, and public commitments.

Commitment

A commitment is a pledge or promise to behave in a specific way or attain a certain goal. A person that expresses commitment increases the probability that s/he will pursue that behavior [24]. For example, Wang et al. [55] found that a signed pledge to recycle led to a 47% increase in recycling compared to baseline data. Similarly, Pallak and Cummings [41] used public commitment to promote gas and electricity conservation among households—the group committed to publicizing their results used 15% less natural gas and 20% less electricity than other conditions. The type of commitment a person makes, the person or group to whom the commitment is made, and whether the commitment is public or private are three factors that impact behavior.

Incentive / Disincentives and Rewards / Penalties

Although sometimes used interchangeably, incentives and disincentives are distinct from rewards and penalties. Incentives and disincentives are antecedent motivation techniques—they come *before* a behavior [21]. Rewards and penalties are consequence motivation techniques—they come *after* a behavior. Incentives have been used effectively to motivate a range of proenvironmental consumer behaviors from investments in home insulation to rebates for new energy-efficient home appliances. Incentives need not always be monetary; those incentives associated with status or convenience may also have important effects on proenvironmental behavior. For example, specially reserved parking spots for rideshare have been shown to increase carpooling, and curbside pickup of recyclable materials has significantly increased recycling efforts [51].

Research into the effects of rewards have found that people respond to rewards even if they are nominal in nature (e.g., an acknowledgement of positive behavior) and that the reward should be linked as closely with the target behavior as possible [53]. Previous research in persuasive health technology has shown that even providing an asterisk after the completion of a behavior is enough to elicit a positive response [9]. Eco-feedback designs may not be able to offer financial incentives, but most certainly can rely on game-like reward elements (e.g., points, levels, etc.) to promote behaviors (e.g., see [4] or elements of [19]).

Feedback

Many of the above motivation techniques require some sort of *feedback* to be effective (e.g., goal-setting requires feedback about performance towards a goal). One of the best-established findings in psychology is the positive effect that feedback can have on performance [5]. Feedback comes in two forms: *low-level feedback* can provide explicit detail about how to change or improve specific behavior (e.g., the particular problems marked wrong on a math test); *high-level feedback* is summative and can help improve performance towards a goal or in comparison to others (e.g., obtaining an 'A' in math class).

A majority of research into the effect of feedback on proenvironmental behaviors has focused on home resource consumption. Fischer [15] reviewed approximately twenty studies and five compilation publications from 1987 onward exploring the effects of feedback on electricity consumption and on consumer reactions, attitudes, and wishes concerning such feedback. She found that feedback resulted in typical energy savings of between 5 and 12% (though the absolute range was 0 to 20%). In cases where no savings were found: the feedback occurred too infrequently (e.g., in the form of a semi-annual bill update), was too disconnected from the consumption behavior, or the homes themselves were already low consumers.

Although only 3 of the 20 studies reviewed by Fischer used computerized feedback (in contrast, for example, to redesigned bills), those studies resulted in the greatest change in energy consumption. In particular, she found that the most effective feedback interfaces contained multiple feedback options (e.g., consumption over various time periods, comparisons, additional information like energy saving tips), were updated frequently, were interactive (e.g., the user could "drill-down" into data), and/or were capable of providing detailed, appliance specific breakdown of energy usage. More work is needed to determine if these results translate to other forms of consumption or environmentally impactful behavior; however, these findings highlight the potential of eco-feedback technology.

Relating Motivation Techniques to Eco-Feedback

The above section summarizes key motivation techniques that environmental psychology and the behavioral sciences at large have used to change behavior. As is apparent from our summary, these techniques have a varying degree of effectiveness. When designing eco-feedback technology it is important to consider not just which motivation techniques to employ but what behaviors, in particular, a design is hoping to motivate.

Each behavior has its own set of contexts and constraints which impact behavior change. An individual considering bicycle commuting, for example, must have access to a bicycle, helmet, and lock; live within a reasonable distance of his/her workplace; plan an appropriate bicycle route; have access to a change room and shower; and so on. One must also think about *why* the individual is considering bicycle commuting—is it for the exercise, for the reduction in CO_2 emissions, for the image it presents to co-workers, or is bicycling just an opportunity to be outside?

Thus, eco-feedback designers must think deeply about and study the particular behaviors they hope to change and/or motivate before building their prototypes. Ethnography is certainly one valuable approach here, surveying is another; both have been effectively applied in environmental HCI (e.g., formative studies in [19] and ethnographic studies in [57]). It is also critical to turn to environmental psychology to see which types of behaviors have been explored and what motivation techniques have been used.

SURVEY OF ECO-FEEDBACK TECHNOLOGY

We now focus more explicitly on studies of eco-feedback technology in the environmental psychology and HCI/UbiComp literature to uncover differences in their approaches, treatments, and evaluations. The goals are to: (1) tease out what environmental psychology can offer to HCI; (2) better understand the theories and methodologies employed in studies of eco-feedback technology in both disciplines; and (3) uncover open areas of investigation that HCI and environmental psychology may be able to collaboratively pursue.

From HCI/UbiComp, we draw upon papers primarily from the CHI, UbiComp, and Persuasive conferences and related workshops. We found 139 papers related to both HCI and the "environment" or "sustainability." Our corpus includes 58 workshop papers, 36 full papers, 32 papers found in extended abstracts (e.g., demos, works-in-progress, alt.chi), and 13 short papers, journal or magazine articles. Roughly 44% of these papers were published in 2009 and 92% were published in the last three years. Of the 139 papers, 56 were related to eco-feedback technology—44 of these provide a unique eco-feedback artifact, while the rest are essays. If an artifact was published more than once, we removed redundancies in favor of full papers.

Our environmental psychology survey draws primarily from journals in psychology and sociology, such as the *Journal of Environmental Psychology*, *Journal of Consumer Research*, *Journal of Social Issues* and *Journal of Applied Social Psychology*. We also looked at the papers mentioned in three well-known surveys of energy feedback studies [1, 12, 15]. We found 82 papers related to the effects of feedback on environmental behaviors including recycling, transportation and home resource consumption (e.g., gas, water, and electricity). Given the long history in environmental psychology of exploring eco-feedback [1, 15], many of these studies were conducted before technology was seen as a practical feedback tool. Thus, most of these studies did not use eco-feedback *technology* in particular but rather other forms of feedback such as bill designs, media campaigns, pamphlets, and home audits. This was the source for much of the work referenced in the models and motivation techniques sections above. Here, though, we focus solely on the 12 studies in environmental psychology that did use eco-feedback *technology* (often referred to as "computerized feedback" in this literature).

Treatment of the Eco-Feedback Technology

The most striking contrast between the HCI and the environmental psychology literature is the emphasis (or lack of emphasis) on the visual design of the eco-feedback interface itself. Although both disciplines are ostensibly interested in understanding the role of feedback technology in changing behavior, environmental psychology has largely focused on the effect of the feedback intervention itself while HCI has concentrated on the production of the eco-feedback artifact and rarely on conducting field studies to actually study behavior change. This discrepancy largely reflects core orientations of the two fields.

Indeed, *only half* of the environmental psychology papers even provide a graphic of their eco-feedback interface. In several cases, the descriptions of the interfaces were only a few sentences long and no visuals were provided in the papers (e.g., [48, 54]). Figure 2 shows the two most commonly reported designs: (1) a simple LCD display, and (2) a bar or line chart showing a breakdown of usage on a

PC, with some amount of historical data available for self-comparison. Almost all (10/12) of the devices used were semi-interactive, but interactions were often limited, for example, to pressing a button that would cycle through statistics like the current day's electricity rate or the amount of the last month's bill (e.g., [48]).

In contrast, the eco-feedback designs in the HCI papers were much more diverse and fully explained. Of the 27 HCI papers that provide some sort of study of their eco-feedback technology, only four papers do not disclose a screenshot of the interface. In addition, the studies employed a range of presentation mediums for their feedback including: ambient displays (e.g., [3, 25, 42, 44]), mobile phone applications (e.g., [19, 45]), desktop games (e.g., [4]), and social websites [38]—see Figure 3.

Unfortunately, many of the eco-feedback designs in HCI do not link back to work in environmental or behavioral psychology. In our survey, less than half of the HCI eco-feedback papers referenced behavioral psychology literature and 58% referenced environmental psychology literature. Even more dramatically, no study in environmental psychology referred back to HCI. This represents a profound gap between disciplines. Interestingly, one author McCalley (e.g., [40]) has published in both fields—having published in both the Persuasive conference and journals in psychology and energy. Perhaps a future goal for HCI should be to initiate collaborations with environmental psychologists.

Discussion of Treatment

The primary motivation of eco-feedback technologies in both disciplines is to promote proenvironmental behaviors. Despite the relatively simple interfaces and lack of focus on design, the environmental psychology studies have achieved impressive results, a finding which should be cause for reflection by eco-feedback researchers in HCI. HCI researchers/practioners should ground their designs in the basic principles uncovered by environmental psychology. They can then apply the unique methodologies and approaches found in HCI (e.g., user centered design) to further the design of eco-feedback technology.

Although the environmental psychology studies show that eco-feedback can reduce consumption, they do not clarify the extent to which this impact is based on specific design elements. Considering only the designs that appeared in the environmental psychology studies, we can see questions that HCI researchers are well-suited to study: How

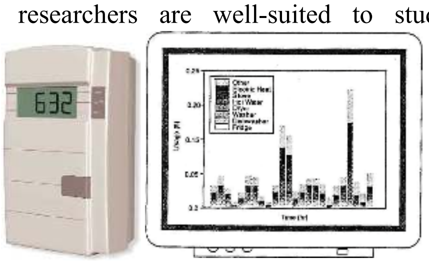

Figure 2. Two of the most commonly reported eco-feedback designs in environmental psychology: (left) a simple LCD display [32]; (right) a bar chart showing current and historical consumption data [13].

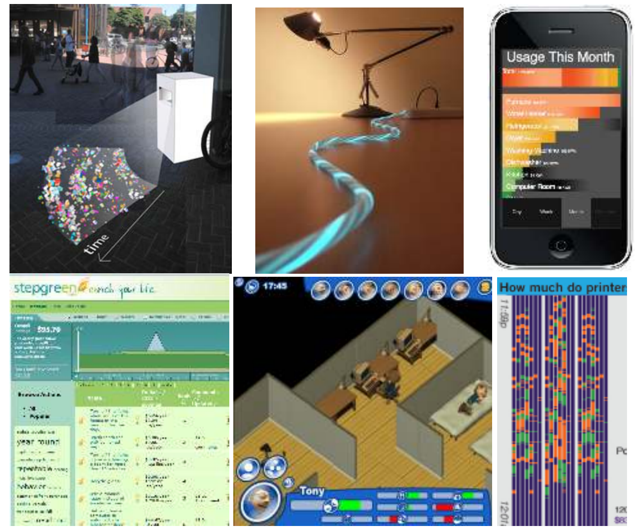

Figure 3. (clockwise): JetSam: ambient display for trash [42]; Power-Aware-Cord: ambient energy usage display [25]; WattBot: mobile phone home energy feedback [45]; Stepgreen: proenvironmental behavior tracking social website [38]; ThePowerHouse: resource eco-feedback in a virtual game environment [4]; Imprint: environmental impact of printing ambient public display [44].

important is it that eco-feedback be even minimally interactive? What types of information and presentation mediums are most effective (e.g., graphs vs. abstract ambient representations)? To what degree does the physical placement and access to the device impact its overall effectiveness? Answering these questions should allow us to identify how environmental psychologists may improve on the advances they have already made.

Consumption Targets of Eco-Feedback Technology

Eco-feedback technologies have been developed to target many types of consumption. The most common target is residential electricity usage: 41% of the papers in HCI and 92% of the papers in environmental psychology. This emphasis is both a reflection of the impact that electricity usage behaviors have on the environment as well as the ease with which energy usage can be automatically sensed.

As a field partially composed of computer scientists and designers, HCI researchers often have the resources to construct both their own novel sensing systems as well as their own feedback interfaces. HCI has also developed techniques to test and iterate on prototypes for exploring interactions and interfaces independent of the current state of technology (e.g., Wizard-of-Oz evaluations). As such, HCI has explored eco-feedback technologies for a larger set of behaviors than have been studied in environmental psychology. We found 20 HCI papers on eco-feedback for electricity, 4 on water, 4 on transportation, 4 on carbon tracking, 3 on garbage and recycling behaviors, 3 on the environmental impact of product purchases, 2 on paper usage and 1 on eco-feedback for a virtual game world.

Discussion of Consumption Targets

The HCI studies have shown that people are open to new types of eco-feedback for behaviors outside of energy usage. One role for HCI is then to challenge the limitations of current eco-feedback technologies by envisioning and exploring novel consumption targets for environmental behavior change.

Study Methodology

Another important distinction between the two disciplines is in study methodology (Table 1). HCI researchers have largely focused on laboratory studies or qualitative field studies of eco-feedback technology. Although behavior change is often reported as the primary motivation for these projects, the emphasis tends to be on the artifact itself rather than its effect on behavior. This is not to say that the designs are not evaluated. Of the 44 eco-feedback technology papers from HCI, only 17 of them do not provide some sort of user evaluation of their designs (and 9 of these were workshop papers).

The HCI laboratory studies tend to be informal in nature, seeking feedback about understandability, aesthetic, and perceived usefulness (e.g., [3, 25]). For example, a Wizard-of-Oz lab study comparing three visualizations of the Power-Aware cord (Figure 3) found that 13/15 participants understood the feedback without explanation, but that there was a tension between two different designs (pleasing vs. informative) [25]. As the authors state in the paper, "*At this stage, the Power-Aware Cord is meant to be a conceptual design statement, mostly used to test people's reactions and provoke thoughts around the area of energy consumption.*" This is a common approach taken in emerging areas of HCI. It is also consistent with the principled HCI tradition of iterative design, since the laboratory offers a rather low-cost means of receiving feedback about a design idea or preliminary prototype.

With respect to field studies, we found 8 papers in the HCI literature that conducted field studies of their eco-feedback technology, lasting between 1 to 4 weeks with an average of 11 participants. Of these studies, 4 reported behavior change data [29, 30, 31, 59]. However, none of the studies included a control group that was not exposed to a feedback intervention, and only one study [29] collected any baseline data (of 1 week). In this respect, the study designs were better suited for collecting preliminary user feedback and conducting iterative design of the prototypes. The study in [29] was the most similar of the 8 to those found in our review of environmental psychology, although it was much shorter and without a non-exposed control. The study evaluated the effect of an ambient plant display (Figure 1) on garbage and recycling behaviors over a 2-week deployment in a university cafeteria. The researchers found no change in the amount of trash and a marginal increase in the amount of recycling; they also conducted interviews to uncover reactions to the design. Again, however, the focus was much less about quantitative experimentation but rather about subjective reactions to the feedback artifact.

	Env. Psych. (12 total studies, 10 field studies)	**HCI (27 total studies, 8 field studies)**
avg # of participants in field studies	210	11
avg # of field study conditions	3.6	1.8
avg field study length (including baseline)	15.5 mos	2.5 wks
avg field study length (excluding baseline)	7.15 mos	2.5 wks
# of field studies that collected baseline data	9 (90%)	0 (0%)
avg % difference in consumption after feedback introduced in field studies	-18%	-10 liters in [31], "marginal increase" in recycling in [29]
# of field studies that reported qualitative data	6 (60%)	6 (75%)
# of total studies that included eco-feedback interface screenshot	6 (50%)	23 (85%)

Table 1. Comparing studies of eco-feedback technology between the environmental psychology literature and the HCI literature.

In comparison to the HCI research, the studies in the environmental psychology literature were almost exclusively field studies (10/12), with one survey and one lab study. All of the studies looked at the effect of feedback on home resource consumption (either water, gas, or electricity). The field studies here included a much larger number of participants than did the HCI studies, ranging from 3 to 784 households (*avg*=210). The study with 3 households is the first known study of eco-feedback technology: the Kohlenberg light bulb study [33] referenced in the introduction. The largest studies (*avg*=414 households) were conducted in partnership with utility companies, which allowed researchers access to a large pool of data. Every study included a control group that did not receive an intervention, and all but one of the field studies collected baseline data. Few papers discussed the actual design process of their eco-feedback interface.

Only one of the environmental psychology studies was a controlled lab study [40], but it offers a contrast to the HCI literature because it included a much larger sample size (N=100) and tested several different feedback conditions on behavior. A more typical study design from the environmental psychology literature was conducted by Van Houwelingen [54] and examined the impact of multiple intervention conditions on natural gas consumption. Interventions included electronic feedback, less frequent external feedback, self-monitoring, and information only. The study lasted three years, with one year each of baseline data collection, intervention, and post-intervention data collection. Results showed that all intervention conditions reduced consumption, with the electronic feedback condition being the most effective (a 12.5% reduction). Perhaps most interesting was that this reduction in natural gas usage did not last for the one year post-intervention period—in fact, there was no significant difference between the experimental and control groups after the interventions were removed. Thus, the feedback seemed to only have an effect during the period it was given. No long term habit formations were found.

Discussion of Methodological Findings

Researchers in HCI and environmental psychology have approached the design and evaluation of eco-feedback technology differently. The environmental psychology papers establish rough guidelines about how much baseline and intervention data studies need to collect in order to measure behavior change. In contrast, HCI offers techniques for iterating on feedback designs, particularly with respect to understandability, usability, and aesthetic. The styles of evaluation used in HCI are particularly important to employ before time and money are invested in extended behavioral change evaluations.

Both evaluation approaches are valuable, but the disciplines can also learn from each other. For HCI researchers, if our goal is to study behavior change, the environmental psychology literature demonstrates the importance of rigorous comparative controls, whether this is through improved collection of baseline data or the inclusion of control groups who are not exposed to an intervention. HCI does not, as yet, have a culture of longitudinal behavior studies—at least for eco-feedback technology.

This prompts the question: what incentives do HCI researchers have to conduct these sorts of studies and *should* it even be a goal? If not, then what is our goal in evaluating eco-feedback technology? Is it enough to demonstrate that a technology is usable and engaging, at which point we hand it off to psychologists to conduct larger and more formal behavioral studies? Based on our survey, eco-feedback researchers in HCI have yet to reach a definitive consensus on these issues.

Summary

This comparative survey has exposed differences in HCI and environmental psychology in terms of both goals and methodologies. Despite the long history of research in environmental psychology, we have identified areas that HCI is particularly well-suited to explore, and we expand on this opportunity in the next section.

DISCUSSION

We have helped uncover findings in environmental psychology that may be relevant to HCI and, at the same time, suggest where HCI offers the strongest contributions to the area of eco-feedback technology. Perhaps most importantly, we have started a conversation that may help bridge researchers in both fields. The most prevalent behavioral models and motivation techniques used in environmental psychology present a rich design space that can ground HCI research. Here we discuss some implications for future eco-feedback research and design.

Design implications. Our analysis has highlighted some of the more salient design factors that need more exploration. These include the frequency with which a feedback system updates, the measurement units or other representation of consumption that are most appropriate to present, the level of granularity of the data (e.g., do users see data from each appliance or the whole house), the accessibility and medium of the information (e.g., push vs. pull, or an ambient display vs. a webpage), and the ability to make comparisons (either with one's past behaviors or the behaviors of others). These various design attributes have yet to be fully investigated in either HCI or environmental psychology, although [14] and [16] offer a good start.

System development and evaluation. In HCI it is rare to see field deployments on the scale of those conducted in the environmental psychology community. Although behavior change may be the ultimate goal of eco-feedback technology, it is clearly one that requires large amounts of time and resources to properly investigate. While this may be seen as a limitation of the HCI evaluation methodologies, we offer that this is not a detriment, but simply a difference. HCI has developed tools that allow us to explore aspects of eco-feedback technology that are not yet feasible for long-term deployments. Rapid prototyping, low-to-medium fidelity prototyping, and Wizard-of-Oz can be used to envision and study novel eco-feedback designs that circumvent technological limitations. Indeed, we see a role for HCI in providing eco-feedback designs that have been evaluated on merits such as evocativeness, engagement, understandability and usability. Even three-to-four week pilot studies are important in demonstrating potential. Those designs that seem particularly effective may then be handed off or evaluated collaboratively with environmental psychologists.

For testing ideas, the laboratory offers a context to evaluate understandability, aesthetics, and feelings towards the design. For higher fidelity prototypes, field deployments are more appropriate. Although the information presented in eco-feedback technology is intrinsically tied to the data provided by the underlying sensing system, in some cases these limitations can be thwarted by careful study design (e.g., manual meter reading to update interfaces). This allows the HCI researcher to focus on the eco-feedback artifact itself rather than implementing a durable sensing system.

Targeting feedback behaviors. What specific behaviors should eco-feedback technology be attempting to impact? Gardner and Stern [20] draw a useful distinction between two types of consumption behaviors: (1) *efficiency behaviors*, which are one-time actions that provide a lasting impact, such as buying a fuel-efficient vehicle, and (2) *curtailment behaviors*, which involve forming new routines to reduce environmental impact, such as taking the bus to work. A large majority of the eco-feedback technologies we reviewed in both HCI and environmental psychology have focused on the latter, yet it may be worth focusing on both. Gardner and Stern contend that that the energy saving potential of efficiency behaviors *far outweighs* the potential of invoking curtailment behaviors. For example, the installation of compact fluorescent lighting (CFL) could be much more effective than remembering to turn off the lights. It is thus critically important that designers understand the environmental behaviors that they are trying to motivate and to design around those behaviors. An eco-feedback technology for water need not simply visualize daily water usage but could also make specific recommendations about efficiency behaviors—for example, quantifying the amount of money that could be saved by installing a low-flow showerhead.

Learning and feedback. Eco-feedback technology may have a lifecycle of usefulness. Van Houwelingen [54] emphasizes the role of learning in feedback: subjects learn the connection between the amount of resources they use and the consuming behavior. Darby [12] argues that the effects of feedback are largely rooted in educational theory: feedback is an essential component in learning. Often, feedback provides information that individuals did not have before. If *learning* is one of the key benefits of eco-feedback, then how long does it sustain relevancy in a person's life? If a proenvironmental behavior is achieved, does the eco-feedback begin to lose its importance?

Models of behavior change. This paper discussed models of proenvironmental behavior and techniques to induce behavior change. Due to space limitations, however, we did not explicitly cover *behavior change* theories (i.e., theories about how people change their behaviors over time). Many of the most prominent behavior change theories have emerged from health psychology (e.g., addiction studies) rather than environmental psychology. Thus, it is not yet clear if they can be wholly applied to proenvironmental behaviors. For example, does a person move through the same stages of behavior change in the Transtheoretical Model [46] when trying to quit smoking—a behavior that is clearly in their best self-interest to stop—compared to an environmental behavior, such as trying to eliminate wasteful energy usage? Regardless of these contextual differences, the behavior change literature offers a rich corpus of both behavior change techniques and behavior change theories, which should be investigated further.

Large-scale commercial deployments. With the introduction of Google PowerMeter and Microsoft Hohm, eco-feedback technology may well become part of a common technological landscape. Millions of households will be able to view their home resource consumption data on their mobile phones and web browsers. This will provide great opportunities for the behavioral analysis of eco-feedback technology through massive AB testing. This uptake in the commercial sector also raises issues of privacy and trust, since eco-feedback technologies can collect vast amounts of information on personal habits.

CONCLUSION

We have investigated the ways in which HCI and environmental psychology approach eco-feedback technology research. Our goal was to explore: (1) what HCI can learn from environmental psychology and (2) what the role of the HCI community should be in contributing to eco-feedback research. We believe that eco-feedback technology is a particularly ripe area for HCI and UbiComp research because it often requires sensor building, information visualization, and novel interfaces and interactions. These are key areas of our expertise. HCI also offers a set of methodologies founded on rapid prototyping, user involvement, and iterative design that allows for design feedback early and often. As a community, however, HCI has yet to define how these methodologies should be used to evaluate the potential strengths of an eco-feedback design with respect to its ability to change behavior. Regardless of this outcome, it is crucial that HCI and UbiComp researchers look to the environmental psychology literature on proenvironmental behaviors and behavior change strategies for techniques and inspiration. We believe eco-feedback technology will soon play a major role in the ways in which we think about and act in the world. The HCI community should ensure that it is integral in helping shape the role of eco-feedback in the future.

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