Feedback Design Heuristics for Energy Conservation

Opportunities abound for HF/E professionals to use their design feedback and evaluation skills to show consumers the impacts of energy use.

By Kevin Trinh & Greg A. Jamieson

FEATURE AT A GLANCE: This article reviews a selection of the literature on strategies for and challenges to eliciting energy conservation behaviors from residential and commercial building inhabitants. We highlight visceral influences as one challenge in particular that has been neglected. We argue that feedback design opportunities are underexploited by designers of energy-consuming devices. To help address this problem, we identify and demonstrate feedback design heuristics that human factors/ergonomics practitioners can employ.

KEYWORDS: behavioral interventions, energy conservation, feedback, heuristic evaluation, visceral influences

Research in energy conservation behaviors for building inhabitants burgeoned during the 1970s energy crisis to reduce dependence on foreign oil. With global warming and climate change, energy conservation is regaining traction as perhaps the most cost-effective way of reducing greenhouse gas emissions (International Energy Agency, 2010). Human factors/ergonomics (HF/E) can be brought to bear on energy and sustainability challenges (Vicente, 1998). However, despite earlier calls to action (see Moray, 1995; Nickerson, 1992), HF/E practitioners have been slow in responding to this, the most important scientific issue of the 21st century (Flemming, Hilliard, & Jamieson, 2008; Phillips, Sellers, & Fiore, 2010).

The goal of this article is to raise awareness of, and provide guidance to, the contributions that HF/E practitioners can make toward effective energy-use feedback design. We begin by identifying some key barriers to energy curtailment behaviors, which are repetitive efforts to curb resource consumption. This section is followed by a discussion on how providing feedback can overcome these barriers. From the literature, we summarize feedback design heuristics that have been demonstrated to support conservation. We also introduce a new heuristic to specifically address visceral influences. Finally, we demonstrate the application of these heuristics through design and evaluation examples.

BEHAVIORAL CHALLENGES

Energy is inexpensive. In Toronto, Canada, the current flat-rate, post-tax, marginal price for delivered electricity is about $0.14 CAD/kWh for residential customers (http://bit.ly/1nobLyx).This price puts the cost of watching an hour of television on a modern 42-in. LCD high-definition TV at about $0.03. It can be argued that unless prices rise substantially, it will be difficult to motivate people to conserve. However, the environmental risks for energy production and consumption are growing, and, inevitably, energy will become more expensive. In addition, many feel a responsibility to conserve. Even with such motivation, there are challenges to eliciting energy conservation behaviors.

Invisibility of energy. Energy use is embedded in buildings, food, and transportation systems, yet it is largely invisible. Most people do not think or talk about the energy they use, which makes it difficult to consciously save energy. It does not help that feedback on energy use happens infrequently, is typically delayed from the time of consumption, and reaches only those who pay the energy bills.

The invisibility of energy use can lead to poor energy use habits (Verplanken & Wood, 2006), and most residential energy is consumed through routine and habitual behavior (Lutzenhiser, 1993; Sauer, Wiese, & Ruettinger, 2003).

Poor mental models of energy use. Ordinarily, people can develop faulty mental models of how energy is consumed, relying instead on folk theories that often lead to suboptimal energy use (Karjalainen & Vastamaeki, 2007; Kempton, 1986; Kempton, Feuermann, & McGarity, 1992; Kempton & Montgomery, 1982). Kempton (1986) found that between 25% and 50% of Americans believe that a thermostat works like a valve, in that a higher temperature setting will deliver heat at a faster rate than a lower setting. The fact is that heating and air-conditioning systems produce or remove heat at a constant rate and can be turned only on or off by the thermostat.

Visceral influences. Even if residents can be made conscious of their energy consumption, visceral influences can compete with conservation behaviors at the point of consumption. Visceral influences (Loewenstein, 1996), such as inconvenience, fatigue, or physical discomfort, focus attention on the immediate and direct hedonic impact of behaviors rather than on long-term objectives. At sufficient intensity, visceral influences can cause people to act contrary to their pro-environment attitudes in favor of impulsive behaviors. This effect is compounded in light of the fact that many energy-consuming technologies are intentionally designed to be viscerally attractive to use (Norman, 2004).

FOCUS ON FEEDBACK: OPPORTUNITIES FOR THE HF/E COMMUNITY

To address the aforementioned challenges, those designing behavioral interventions typically aim to raise awareness of and motivate conservation habits. Information may come in the form of campaigns (e.g., mass marketing) or technical feedback implementations. Target behaviors may be motivated through the use of goal setting, comparisons, or incentives. For a review of these interventions, refer to Sidebar 1 (next page).

Of the available behavioral interventions, feedback is arguably the most critical in any conservation program. It promotes learning, provides goal-relevant information, and is central to integrating the other interventions; a successful implementation of frequent feedback would be an important component in any conservation program. However, as Fischer (2008) and Flemming et al. (2008) pointed out, the design and evaluation of consumption feedback displays have been sorely lacking.

Advances in feedback infrastructure also have widened the design space for the HF/E community. The movement toward an "Internet of Things" increases access to sensors and wireless communication technologies that enable cost-effective delivery of real-time and disaggregated feedback. Actuators and two-way communications with appliances can allow centralized and remote control for conservation purposes and for home automation. Interactive mobile devices (i.e., smartphones, tablets) are becoming more prevalent and can be used for both display and control. These technologies can provide an incredible amount of data, but how should this information be curated? And how can such controls be designed to be intuitive, effective, and safe?

The HF/E community is well positioned to meet these design challenges. As Flemming et al. (2008) aptly stated,

> [HF/E professionals] can contribute their knowledge of decision making, mental models, and displays and controls, as well as their skills in experimental design and usability assessment, to name just a few. The theoretical frameworks already in use by human factors practitioners may be promising candidates to systematically integrate existing findings, identify research opportunities, and guide design of innovative feedback interventions. (p. 752)

To integrate findings from the feedback literature for the practitioner, we summarize heuristics for feedback design that have been shown to encourage conservation behaviors in building inhabitants. Taken together, they provide a foundation on which feedback designers can rationalize their design choices and critique those of others.

1. Design the message to filter out unimportant information (Gardner & Stern, 2002).
2. Consider the audience; be specific and personalized (Benders, Kok, Moll, Wiersma, & Noorman, 2006; Gardner & Stern, 2002).
3. Benchmark in a fair and meaningful way (Abrahamse, Steg, Vlek, & Rothengatter, 2005; Egan, 1999; Seligman, Becker, & Darley, 1981). Comparisons should be perceived as equitable.
4. Average feedback across meaningful intervals (Seligman et al., 1981) to reduce noise.
5. Make the feedback information task relevant (Sauer, Schmeink, & Wastell, 2007) or related to behavior in an intelligible way (Winett, Neale, & Grier, 1979).
6. Use concrete consequences by framing consumption data using alternative tangible equivalents (Pierce, Odom, & Blevis, 2008).

As reflected in these heuristics, most feedback efforts are designed to improve conservation competency by raising awareness of, improving mental models of, and meaningfully contextualizing energy use. In this vein, feedback designs typically have been informed by fields such as information visualization (Card, Mackinlay, & Shneiderman, 1999; Ware, 2000) or visual analytics (Cook & Thomas, 2005), which focus on visualizations as cognitive aids. This competency approach is prevalent within the HF/E community, with many demonstrated success stories in various design spaces, such as complex industrial control rooms or cockpits.

ADDRESSING VISCERAL INFLUENCES

In addition to the usual challenge of designing for system and task constraints, energy conservation is obstructed by competing visceral influences. However, little attention has been given to understanding how visceral influences can override rational deliberation and undermine conservation goals. Complicating matters is the inconsistency of this effect. For health and environmental reasons, one might make deliberate plans to take the stairs but, at the moment of decision for convenience, succumb to using the elevator.

SIDEBAR 1: A BRIEF REVIEW OF BEHAVIORAL INTERVENTIONS

In this sidebar, we summarize literature on the main behavioral interventions that have been employed to promote energy conservation.

Information Campaigns

Curtailment campaigns provide consumers with information in an attempt to change their attitudes or highlight economic benefits. McKenzie-Mohr (2011) posited that for a message to be effective and influential, it should (among other things)

- capture the reader's attention
- be vivid and captivating
- be tailored to the attitudes and beliefs of the intended audience and its perceived barriers and benefits to taking action
- cite a credible source
- frame the message to highlight a potential loss; provide actionable solutions when highlighting something that may threaten the reader
- keep instructions clear, specific, and easy to remember
- be combined with other approaches.

Although providing information may change attitudes, it does not necessarily change related behaviors (McKenzie-Mohr, 2011; Verplanken & Wood, 2006) or lower energy consumption (Abrahamse, Steg, Vlek, & Rothengatter, 2005). For example, Sauer, Wiese, and Ruettinger (2003) found that knowledge of environmental impacts did not predict environmental performance in the use of consumer appliances. However, if the information is delivered at the point of consumption, it can prompt specific behaviors. The purpose of such prompts is to spur people to do something they are already predisposed to do but may have forgotten (McKenzie-Mohr, 2011). Effective prompts are noticeable, specific, and actionable. Prompts placed around taps and showers displaying the environmental impacts of water use decreased water consumption by 23% (Kurz, Donaghue, & Walker, 2005). Prompts placed over waste bins predicted a 50% reduction in litter (Kort, McCalley, & Midden, 2008).

Feedback

Providing building inhabitants with feedback about their electricity use can reduce consumption by approximately 5% to 15% (Darby, 2006). Feedback facilitates learning by making the invisible visible and providing goal-relevant information. Van Raaij and Verhallen (1983) suggested that energy use feedback works through a three-step process: learning, habit formation, and internalization of behavior. In the learning phase, households observe or become aware of their consumption patterns and learn how their actions affect their consumption. As energy-conserving behavior becomes habit, an individual's attitude will also change to reflect the adjustment in behavior. Ehrhardt-Martinez, Donnelly, and Laitner (2010) found evidence showing the effect of feedback to be persistent.

Darby (2001) distinguished between indirect and direct feedback. *Indirect feedback* is typically processed by the electrical utility and sent out in the form of a bill. *Direct feedback*, by contrast, refers to feedback that is available on demand in the form of a real-time meter or an electronic display. Direct feedback disaggregated at the appliance level has shown to deliver the best results (Ehrhardt-Martinez et al., 2010).

Goal Setting

Commitments to goals can improve the effectiveness of feedback. Setting a performance goal and providing feedback relevant to that goal are basic elements in self-control (Seligman, Becker, & Darley, 1981). However, goals should be achievable and challenging to have an impact on energy conservation (Becker, 1978). Goals are effective when they are clear, agreed upon, and measurable, and when frequent feedback is available (Changing Behaviour, 2009).

Comparisons

Comparisons can also motivate conservation behaviors. There are two types of comparisons: *historic comparisons* (e.g., with one's past consumption) and *normative comparisons* (e.g., with one's neighbor; see Fischer, 2008). Using energy consumption from a previous billing period is an effective historic comparison (Darby, 2006). However, weather and occupancy fluctuations may make this form of comparison less meaningful unless normalizing factors are modeled.

Normative comparisons often happen in the form of competitions, which can be effective, but it is unclear whether their effects persist once they end (Ehrhardt-Martinez et al., 2010). Normative comparisons also suffer from the perception of unfair comparison groups (Darby, 2006). However, using *injunctive* norms, which describe how one should behave, rather than *descriptive* norms, which describe how others have behaved, can prolong the effect of normative comparisons (McKenzie-Mohr, 2011; Schultz, Nolan, Cialdini, Goldstein, & Griskevicius, 2007).

(continued)

SIDEBAR 1: Continued

Rewards and Incentives

Incentives, rewards, and disincentives provide extrinsic motivation to perform existing behaviors or learn new behaviors to which consumers would otherwise be indifferent or resistant (Abrahamse et al., 2005; McKenzie-Mohr, 2011). Implemented correctly, incentives foster sustainable behaviors. For example, introducing bottle deposits in Oregon, Vermont, and Michigan resulted in decreases in litter of 68%, 76%, and 82%, respectively (Syrek & Legislature, 1980). A program in California that charged residents for the amount of waste they put out on the curb resulted in a 46% reduction in landfill-bound waste and a 158% increase in recycling (Federation of Canadian Municipalities, 1996). However, Abrahamse et al. (2005) found that although rewards produce large effects, these effects quickly diminish once the reward is discontinued.

We have adopted *temporal construal theory* (TCT; Liberman & Trope, 1998) to help characterize the effect of visceral influences. TCT describes how temporal distance systematically changes people's mental representations (i.e., construals) and associated valuations of future events. TCT posits that an increased temporal separation from an event or activity shifts preferences to more abstract goals. Conversely, more temporally immediate events are associated with contextualized features that are more concrete. These features are examples of high-level construals (HLCs) and low-level construals (LLCs), respectively (see Table 1). HLCs are relatively simple, decontextualized representations that consist of general, superordinate (i.e., goal-relevant, "why" features), and essential features of events (Trope & Liberman, 2003). By contrast, LLCs are akin to visceral influences in that they are more concrete and include subordinate, contextual, and incidental features of events. For example, composting may bring about HLCs, such as environmental preservation or financial benefits (reasons one would want to compost), but also may evoke LLCs, such as negative thoughts of dirt and odors (contextual factors associated with the act of composting).

Table 1. Distinguishing Low-Level and High-Level Construals

Low-Level Construals	High-Level Construals
Concrete	Abstract
Complex	Simple
Unstructured, incoherent	Structured, coherent
Contextualized	Decontextualized
Secondary, surface	Primary, core
Subordinate ("how")	Superordinate ("why")
Goal irrelevant	Goal relevant

Note. Adapted from Trope and Liberman (2003).

Figure 1 shows a highly simplified time-construal function, depicting the conflicting impacts of HLCs and LLCs on decisions over time. In the near future, LLCs spurred by visceral influences have more impact on decisions than do HLCs. In the distant future, HLCs representing one's attitudes toward conservation have more influence than do LLCs. For stubborn or habitual consumption behaviors, we posit that the default time perspective is typically near-term, as represented in Figure 1 by the dotted line in the near future.

The visual representation of TCT in Figure 1 leads to three distinct insights. First, it suggests an explanation for a related finding in energy conservation research: that attitudes do not necessarily predict behaviors (Gatersleben, Steg, & Vlek, 2002; McKenzie-Mohr, 2011). Second, the representation forms the basis of a conceptual framework to help characterize four strategies for behavioral interventions in energy conservation (see Sidebar 2). Third, it provides insight into how behavioral interventions can be targeted to address visceral influences.

To target visceral influences, feedback designers may try to maximize the impact of HLCs by making them more salient (see Sidebar 2, Strategy 4) – that is, reminding users *why* they should conserve energy may counteract visceral influences. Using this strategy, we derive a new feedback design heuristic, introduced here as Heuristic 7, to address visceral influences.

Heuristic 7. Use projective and comparative elements to support a distant-future retrospective evaluation.

There are two key ideas to take from Heuristic 7. The first is the notion of using a temporally distant retrospect to invoke HLCs. Showing projected savings might encourage a distant-future perspective and HLCs, given that it explicitly displays goal-oriented information. The second idea is the notion of using evaluation to provide a critical link between one's goals and one's behaviors. One way to evaluate behavior is through a baseline comparison. By using projective and comparative

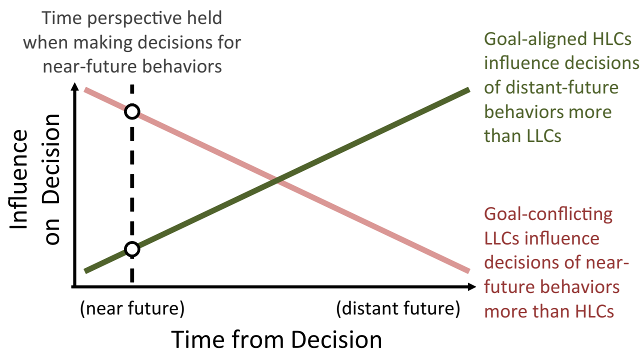


Figure 1. Simplified default construal-time relationship based on temporal construal theory.

elements (i.e., comparing past and projected consumption) in a feedback display, Heuristic 7 attempts to make HLCs more salient and tangible.

In practice, Heuristic 7 is synergistic with Heuristics 5 and 6 (see page 2). The combination of Heuristics 5 and 7 suggests linking specific short-term indulgences with long-term consequences. For example, projected energy costs of running an air-conditioning unit can be directly linked to the thermal comfort it provides. Similarly, feedback can be used to express the cost for the conveniences of using a dryer (in contrast to hang-drying clothes). The combination of Heuristics 6 and 7 suggests using concrete frames aligned with pro-environment attitudes (e.g., equivalent trees or greenhouse gases).

HEURISTICS IN APPLICATION

In this section, we show how the heuristics may be applied in the design and evaluation of feedback displays.

Design example. To illustrate the seven heuristics in application, Figure 2 depicts a feedback display prototype (to be shown on a shared display on site or on a mobile device) intended to promote hang-drying of clothes in a university dormitory. This feedback display is tailored to this specific conservation behavior (Heuristics 1 and 5) and the target user group of dorm residents (Heuristic 2). It is historically benchmarked (Heuristic 3) across a meaningful interval (Heuristic 4) of 1 week (within which we anticipate there being a laundry day). Finally, it employs tangible consequence frames (Heuristic 6) that, when aggregated among the whole community of target users, demonstrate significant projected savings from hang-drying clothes (Heuristic 7).

In a usability study, Trinh (2010) presented participants with four feedback display conditions paired in counterbalanced fashion with four hypothetical conservation behavior requests. The four feedback conditions included a no-feedback condition and three feedback displays with cumulative levels of information: Starting with a basic feedback display of past consumption with equivalent units (applying Heuristics 1, 2, 4, 5, and 6), a projected savings comparison was added (applying Heuristics 1 through 7), with the third condition reinforcing Heuristics 6 and 7 by adding CO_2 and forest equivalents (applying Heuristics 1, 2, 3, 4, 5, 6+, and 7+), as depicted in Figure 2. Participants reported that the latter two feedback displays were the most motivational and preferable, suggesting that those displays might also be most readily adopted in practice. However, authors of future work should examine the efficacy of such displays that are implemented in the field.

Heuristic evaluation. Tools for visualizing commercial building energy information have been a popular application area for research on energy feedback. These tools leverage existing building automation infrastructure and increasingly available data from utilities. In a recent survey of seven such tools, Lehrer and Vasudev (2011) found that the industry is converging on several of the design heuristics described earlier. Here, we offer a heuristic evaluation of a representative tool (see Figure 3) produced by Lucid Design Group, an early entrant into the field. Although we critique only a sample display, it should be noted that these tools are often customizable and interactive to address functional requirements drawn from diverse user groups, user tasks, and display formats.

The Building Dashboard tool is intended to be viewed by building inhabitants in a kiosk. It provides real-time feedback by resource type: electricity (as shown in Figure 3), gas, and water use. The Building Dashboard tool appears to address Heuristics 3, 4, and 6. Data are presented in numerical and visual form (color-coded orbs). The dashboard also shows historical (bar chart over the past week) and normative (against another building) comparison data (Heuristics 3 and 4). Unit equivalents (e.g., laptop use, vehicle driving range) are also available (Heuristic 6).

It can be further argued that unimportant information is filtered (Heuristic 1). The feedback partly addresses Heuristic 2 in that the display is specific to the buildings in question and for its mode of presentation on a kiosk. However, typical for Building Dashboard implementations, it does not appear to be behavior specific (Heuristic 5), nor does it link specific behaviors to their specific energy consequences (Heuristic 7). Without clear ties to end uses, it is not obvious how the user should interpret the feedback to change his or her behavior. Furthermore, it can be difficult to comprehend the larger potential impacts to justify such behavior changes.

Perhaps Heuristics 5 and 7 are omitted because of the cost of the infrastructure required to provide such granular feedback. Addressing visceral influences directly with Heuristic 7 also reflects an underexplored application of feedback. However, breaking down consumption by end use (e.g., lighting vs. plug loads vs. central air conditioning) and/or by location (e.g., floors or zones) can incrementally help address Heuristics 5 and 7 without fully disaggregating end uses. Implementing some projections for larger savings is a matter

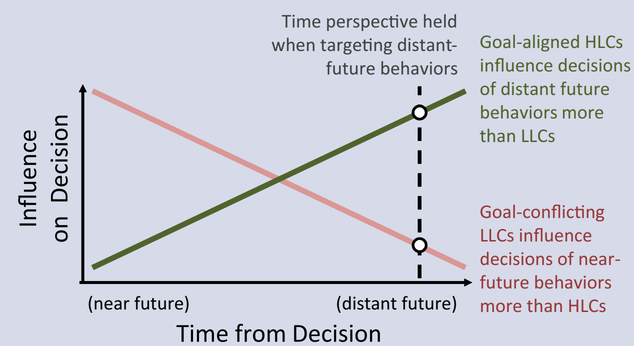
SIDEBAR 2: A CONCEPTUAL FRAMEWORK FOR BEHAVIORAL INTERVENTIONS

The visual representation of temporal construal theory (shown in Figure 1) suggests a conceptual framework for behavioral interventions. The framework (see Table S2-1) consists of four strategies, each represented by a unique departure from the default, nominal time-construal relationship. We offer behavioral interventions that would fall within each strategy.

Table S2-1. A Conceptual Framework for Behavioral Interventions Based on the Default, Nominal Time-Construal Relationship

<table>
<tr><td>Strategy 1:

Circumvent the effect of LLCs by targeting distant-future behaviors.

(e.g., encourage pledging or social commitments)</td><td>
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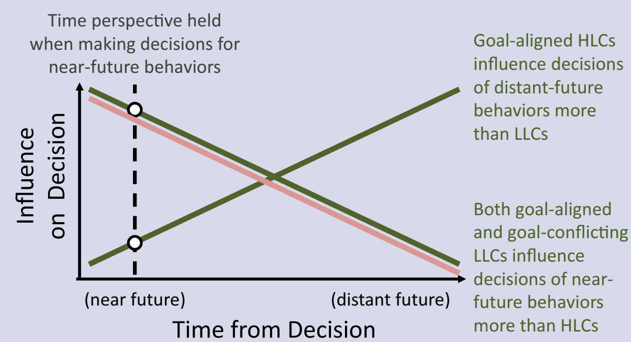
<tr><td>Strategy 2:

Compete against conflicting LLCs by fostering goal-aligned LLCs.

(e.g., offer rewards or make the activity enjoyable)</td><td>
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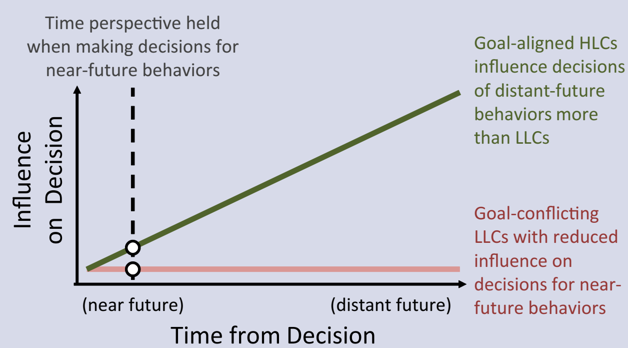
<tr><td>Strategy 3:

Minimize the influence of conflicting LLCs by removing external barriers.

(e.g., instead of having city residents compost their own organics, offer regular organics collection)</td><td>
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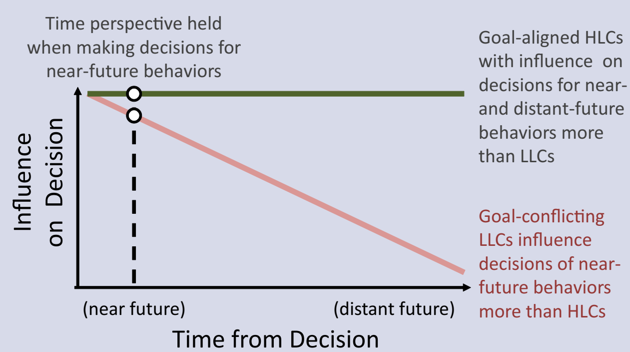
<tr><td>Strategy 4:

Maximize the influence of HLCs by making them more salient.

(e.g., prompting, real-time feedback)</td><td>
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SIDEBAR 2: Continued

Taken together, the four strategies emerging from the time-construal relationship model represent a conceptual framework that may be used to gain insight into how behavioral interventions can be selected to work in concert. For example, a conservation program that focuses on commitment strategies (Strategy 1) and an information campaign (Strategy 4) overlooks possible external barriers (Strategy 3) and potential benefits from supporting complementary low-level construals (Strategy 2).

Alternatively, by reviewing the strategies presented, the framework can help developers think from the energy consumer's standpoint in terms of their high-level construals and low-level construals. A developer might ask, "What interventions most effectively target the external barriers and visceral influences at play?" Here, interventions from Strategy 2 and Strategy 3 might work best.

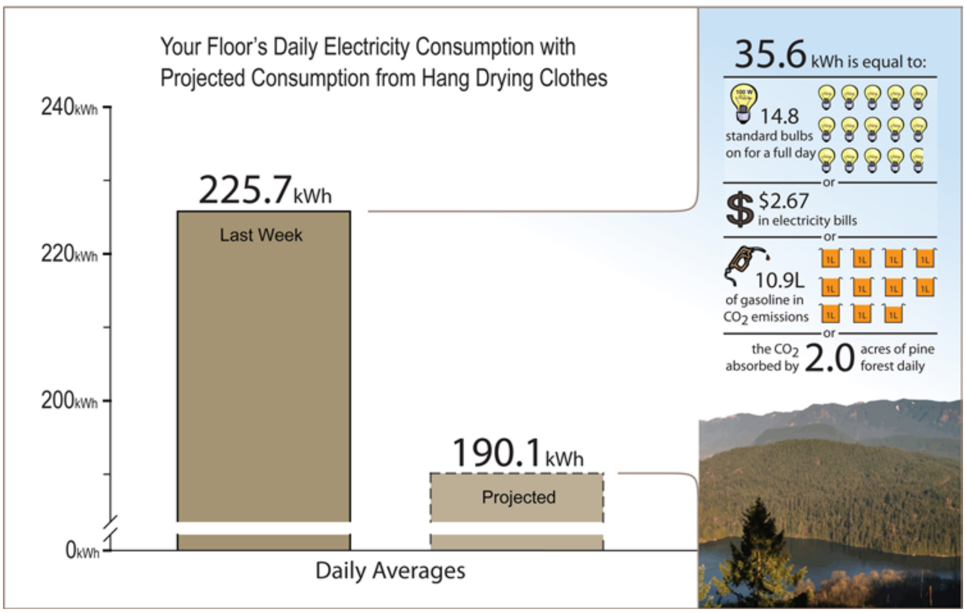

Figure 2. Feedback display employing all seven design heuristics.

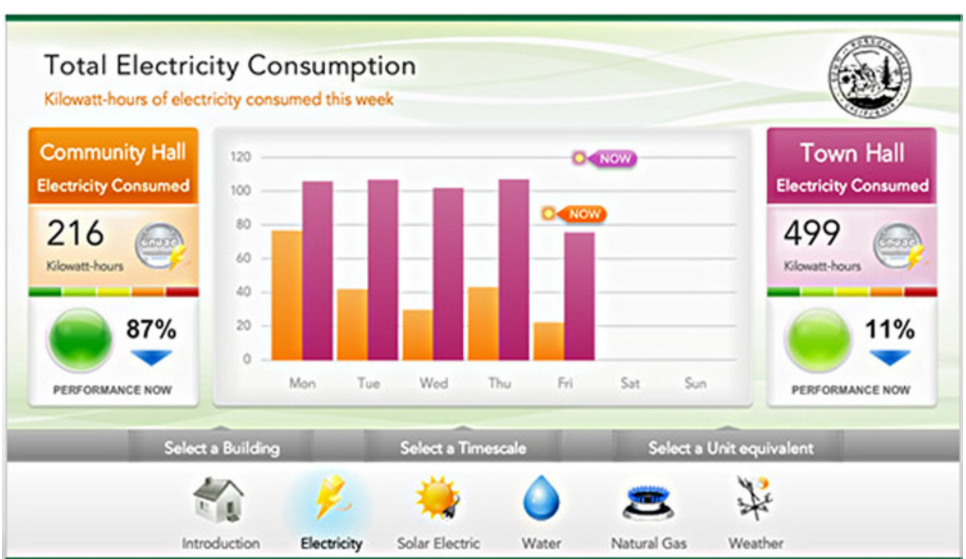

Figure 3. Building Dashboard tool by Lucid Design Group (www.luciddesigngroup.com).

of analytics that perhaps can be paired with specific behavior recommendations tailored to building occupants.

Finally, we would be remiss not to acknowledge that feedback should be used in conjunction with other behavioral interventions. Combined with an information campaign or prompting strategies to target relevant behaviors, such detailed feedback can be a powerful motivator. Additionally, if feedback is provided in real time and delivered at the point of consumption (e.g., on a smartphone or through a display directly on an electrical appliance), it may "intercept" visceral influences by prompting self-control behaviors (see Sidebar 1, prompts in "Information Campaigns").

SUMMARY AND DISCUSSION

With recent advancements in technology, the infrastructure for providing real-time and disaggregated feedback is increasingly accessible. These technological capabilities lead to two distinct opportunities for HF/E practitioners. First, it widens the design space for feedback design. The design heuristics summarized in this article, although not exhaustive, provide a foundation on which feedback designers may rationalize their design choices and critique those of others. It is encouraging to see industry already adopting many of the feedback design heuristics described in this article. We hope to have raised awareness of the benefits of pursuing others.

Second, it provides an opportunity to apply theory, analysis, and design frameworks to advance feedback interventions. Using TCT, we developed a conceptual framework to characterize the effect of visceral influences and to show how they may be addressed. In general, we find that visceral influences are an underexplored factor when designing behavioral interventions, possibly because of how the HF/E community believes users behave and react to feedback displays. Human factors/ergonomics designers work predominantly in domains in which behavior is best characterized by a rational-economic model (e.g., control rooms, cockpits).

We challenge the HF/E community to consider other models. For instance, the norm-activation model (Schwartz, 1977) predicts that behaviors are determined by personal or moral norms, in this context about pro-environment behaviors. Lehrer and Vasudev (2011) found that the main motivation of typical office occupants to conserve stemmed from environmental and ethical concerns. Drawing a distinction between the underlying behavioral models to which the designer subscribes is important because it may directly influence the design of an information display (Froehlich et al., 2009).

In this context, the adoption of either model can lead to feedback information represented in vastly different frames. For example, whereas a designer adopting the rational-choice model might present consumption costs in dollar value equivalents, a designer adopting the norm-activation model might present those costs in terms of the size of a forest required to offset CO_2 emissions or the shrinking size of an iceberg on which a polar bear rests. This latter approach is in line with the strategy to make HLCs of conservation more salient in the present (see Sidebar 2, Strategy 4) and can be an effective way to address visceral influences.

Much more research is needed to validate such effects, but we hold that the HF/E community is ready and able to tackle the challenge.

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