Tracking and learning: Exploring dual functions of residential energy feedback

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ABSTRACT

Residential energy feedback is widely promoted as a promising form of persuasive technology based on its effectiveness in field studies. However, previous research has treated "feedback" as a unified construct, despite a wide variety of device types and categories, and has devoted little energy to understanding how or for whom feedback works. An improved understanding of the psychological mechanisms underlying feedback would be of great benefit at both a theoretical and practical level. The current paper presents results of survey data from 86 individuals who self-reported use of feedback devices. Qualitative analysis of open-ended responses revealed a distinction between the use of feedback for tracking (e.g. monitoring ongoing energy use) and learning (e.g., gaining specific information about energy use). This distinction emerged throughout user responses about adoption (how, where, and why they obtained feedback), usability (likes and dislikes about the use of feedback), and outcomes (changes in knowledge and/or behavior due to use of feedback). These two functions have implications for both the design of energy feedback and its outcomes. Features such as time-series graphs and social comparisons are most likely to facilitate tracking; whereas the provision of discrete information tied to a specific appliance or behavior is most likely to facilitate learning. There may also be individual level differences that moderate who would benefit from a tracking vs. learning approach to feedback provision. It appears that the most beneficial feedback may facilitate both a tracking and learning function.

Categories and Subject Descriptors

H.1.2. [**Information Systems**]: User/Machine Systems – *human factors, human information processing, software psychology*

General Terms

Human Factors.

Keywords

Feedback, Energy, Psychology, Usability, Persuasive technology.

Persuasive 2011, June 2-5, 2011, Columbus, Ohio, USA.

1. INTRODUCTION

National (and international) focus on energy use is at an all-time high. Although physical scientists are hard at work developing alternative energy sources, there is also great potential in demand-side reduction through energy efficiency and conservation. One strategy that has shown significant promise in reducing energy consumption is the provision of feedback [Abrahamse et al. 2005]. Feedback refers to "information about the result of a process or action that can be used in modification or control of a process or system… especially by noting the difference between a desired and an actual result" [Oxford English Dictionary, as cited in Darby 2006, p. 8]. Feedback is considered an important dimension of behavior modification [Bandura 1969] and has been used to promote (or discourage) behavior in a wide variety of fields, including education, public health, and consumer research.

Residential energy feedback has received increasing attention in recent years as a promising form of persuasive technology. Billions of dollars are being spent in countries throughout the world upgrading electricity infrastructure to a "smart grid", which includes the replacement of traditional electricity meters with "smart meters" that allow for wireless communication of electricity usage data in real-time. Leveraging these capabilities, over 200 new products and services have emerged in the past decade that provide energy information to consumers via in-home devices and computer-based programs. Feedback has also been widely studied, with reviews finding it to be effective in field studies, with an average savings of 10% [Darby 2006; Fischer 2008; Ehrhardt-Martinez et al., 2010].

Despite this potential, previous research on energy feedback has been critiqued for its "lack of concern with theory and overemphasis on application" [Katzev and Johnson 1987], leaving large gaps in our understanding of how feedback does (or does not) work. Previous research has treated "feedback" as a unified construct, despite the wide variety in device types and categories, and has devoted little energy to understanding how or for whom feedback works. Recent reviews of research on pro-environmental behavior have called for more attention to the conditions under which behavioral theories are successful in explaining conservation [Steg and Vlek 2009]. An improved understanding of the psychological mechanisms underlying feedback would be of great benefit at both a theoretical and practical level.

The current paper introduces a model of understanding energy feedback in terms of the dual functions of *tracking* and *learning*. These functions are explored through analysis of online survey data and are discussed as functions of both individual motivation as well as the feedback device or system itself.

2. LITERATURE REVIEW

More than 100 studies of energy feedback have been conducted over the past 35 years. Results have shown significant effects of feedback on energy use, with changes ranging from negative (i.e. increase in energy consumption) to up to 20% in energy savings; average savings are approximately 10% across studies [Darby 2006; EPRI 2009; Ehrardt-Martinez et al. 2010; Fischer 2008].

Feedback can serve various purposes, such as filling a "knowledge gap", motivating behaviour, and guiding goal attainment [Cook & Berrenberg, 1981]. It is considered a necessary component of goal achievement [Bilodeau & Bilodeau 1961; Erez 1977]. This is especially the case for behaviors, such as home energy use, where the use of electricity is not primary nor is it visible to the user. In these cases, "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)." [Froehlich et al., 2010]

However, feedback alone is not sufficient to promote behavior change [Katzev and Johnson 1987]. In a recent discussion of the psychological aspects of energy feedback, Schultz [2010] notes: "The available data clearly show that feedback is only effective at reducing energy use when the individual is motivated to use less. This motivation can come from existing personal factors such as environmental concern, or it can come from secondary information provided in combination with the feedback." [p. 251] He concludes that, despite its promise, more research is needed to clarify how and why feedback is effective.

2.1 Types of Feedback

Researchers have suggested that the effectiveness of feedback may vary depending on the type provided. Darby [2006] distinguished feedback as either direct or indirect: direct feedback is available on demand with no time delay; indirect feedback is processed by a utility or third party and then provided to the energy consumer. Neenan et al. [2009] further differentiated among the following categories of feedback:

1. *Standard Billing*: Traditional source of feedback that households receive from their utility company, generally in the form of a monthly bill or statement;
2. *Enhanced Billing*: Provision of more detailed information about consumption patterns from the utility, such as historical or social comparison statistics;
3. *Estimated Feedback*: Data supplied by the user is analyzed to produce estimates of resource use;
4. *Daily/Weekly Periodic*: Presents energy information to the user that is time-delayed by a day or more, but is provided more often than the traditional energy bill;
5. *Real-time*: Delivers the home's overall consumption level on a real-time or near-real-time basis; and
6. *Real-time Plus*: Provides disaggregated (e.g. individual appliance) energy feedback and/or allows users to control appliances in the home.

In a meta-review of feedback studies based on these categories Erhardt-Martinez et al. [2010] found "distinct differences in the average and median energy savings associated with different types of feedback". Steg and Vlek [2009] provide the following example: "Meter readings reflect how much electricity, gas, fuel or water has been used by a particular household. Meter readings, however, do not reveal which specific behaviours contributed most to total electricity, gas, fuel or water use. From an educational point of view this is problematic, for people generally do not know which and whose behaviours significantly affect resource use, and people cannot receive specific feedback on the results of their behavioural changes." [p.310]

Erhardt-Martinez et al. [2010] also say, "it is equally important to note the significant variation that exists within each of the feedback categories" [p. 48]. While the authors attribute this "within category" variation to differences in study methodology, it is also possible that there are significant differences between types of feedback within these broad categories as well. Fisher [2008] described the following characteristics of energy feedback that may contribute to its effectiveness based on a psychological model of energy conservation behavior: frequency, duration, content, breakdown, medium and way of presentation, comparisons, and combination with other instruments. However, few studies have investigated these differences and those that have focused primarily on individual variables such as feedback mechanism (e.g. paper vs. computer) or type of comparison (e.g. historical vs. social).

2.2 User Experience

Although the outcome for feedback studies is generally the total amount of energy used (measured in KwH), some studies have also collected data on the experiences of users. Qualitative data from the following three studies highlight participants' motivations to receive feedback, the quality of their experiences with feedback devices, and the impacts and effectiveness of feedback.

Hargreaves & Burgess [2010] recruited 275 households to trial three different smart energy monitors: one *real-time* monitor and two *real-time plus* monitors. In addition to measuring energy use, they interviewed 12 participants about their experiences. They found that interviewees reported four primary motivations for participating: "financial, environmental, information gathering and technological" [p. 6113]. They also also found that these reported motivations were strongly correlated with differences in how they used the devices and their outcomes. Interviewees reported that absolute measures of electricity consumed were not useful but that both the 'fuel tank' symbols which indicated "whether or not the household is on target to meet a self-selected budget" [p. 6114] and information about how much electricity specific appliances were using were both useful. They noted these responses, not only from the real-time plus devices that provided appliance-specific information, but also among the real-time devices that only provided whole-home information. These users "explained how they had used the 'speedometer' dial as a means of calculating the additional load created by, for instance, turning on the kettle or tumbledrier" [p. 6114]. Finally all interviewees reported some behavioral changes, which included going around the home and turning things off when the monitors gave off "high" readings (as compared to a baseline), and identifying 'greedy' appliances and disposing of them or using them differently. However, several reported declines in usage after satisfying their initial curiosity.

Parker et al. [2008] conducted a pilot study in which a convenience sample of 17 households used a *real-time* energy monitor in their homes for a year and 14 completed a one-page survey about their experience. Respondents use of the device varied, from viewing the display several times a day to reported disinterest or dislike for the device and subsequent perceived utility also varied from high interest to apathy. Those who were reported interest in the devices reported behavioral changes,

primarily with regard to the use of equipment or schedules, and quantitative data showed these participants with the highest savings during the two years of the study. They concluded that, "although a very limited sample, this study seems to indicate that interest and motivation were large factors in whether having the feedback device made a difference in energy use" [p. 10].

Liikkanen [2009] conducted interviews with 20 individuals who had borrowed a *real-time plus* power meter from their utility. They found that individuals were motivated primarily by gathering information, technological curiosity, and/or a general sense of curiosity about energy use. Their responses focused on specific appliances and included: (1) determining the "truth" about their home energy use; (2) attributing blame to a group of energy-intensive appliances; and (3) acquiring information on a singular new or suspicious appliance. Many were surprised to find that some appliances used less energy than anticipated and two-thirds reported that they had changed some behavior as a result of using the devices. Finally a few users reported difficulty interpreting results. "Even though they acquired the consumption data, they could not recreate their personal 'electricity equation', that is to discover how their consumption really added up." [p. 8]

Several other field studies surveyed or interviewed participants about their perceived outcomes of the feedback. These studies provided feedback in very different ways, including billing [Brandon & Lewis, 1999; Wilhite & Ling, 1995], daily/weekly [Arvola et al., 1994], real-time monitors in the home [Allen & Janda, 2006; Hutton et al. 1986; Mountain, 2007], and real-time plus feedback with appliance-specific data [Dobson & Griffin, 1992]. Participants across these studies reported gains in both knowledge of energy use and self-reported conservation behavior. Knowledge gains include a general increased awareness of energy use patterns [Allen & Janda, 2006; Haakana et al., 1997; Hutton et al., 1986; van Houwelingen, & Van Raaij, 1989] as well as specific knowledge about *how* to reduce energy use [Kasulis et al., 1981; Vollink & Meertens, 2006]. Many participants reported learning that their energy use was either more [Mountain, 2007] or less [IBM, 2007] than expected. Feedback users also reported specific changes in their behavior, including replacing light bulbs [Mountain 2007; Robinson, 2007], lowering thermostat and hot water settings [Haakana et al., 1997; Mountain, 2007; Winett et al., 1979], closing the refrigerator more quickly [Kurz et al., 2005], shifting use to off-peak hours [Nexus, 2006], and turning off lights when not in use [Haakana et al.,1997; Mountain, 2007]. Many participants express a strong desire to continue using feedback after the study [Arvola et al., 1994; Kurz et al., 2005; Wilhite & Ling, 1995] and report a decrease in energy awareness and conservation behavior when feedback is removed [Allen & Janda, 2006; Dobson & Griffin, 1992].

2.3 Limitations

Despite the abundance of past research, most empirical studies to date share four primary characteristics that limit our ability to understand the underlying psychological processes of feedback:

1. They are not naturalistic. Virtually all studies have employed experimental designs in which participants are recruited to use feedback. Naturalistic users of feedback (i.e., those who independently seek out and use feedback in their daily lives) may have different motivations and experiences with feedback devices.
2. They are not comparative. Most studies test one type of feedback vs. control, rather than compare different types of feedback.
3. Few commercial products have been tested. Although there are over 200 feedback devices, services, and systems available in the marketplace and many study participants have reported device usability issues (see above), less than a dozen different feedback devices have been tested in published studies.
4. They are not testing mediation. Most studies use the amount of energy use (measured in kWh) as the dependent variable for measuring the effectiveness of feedback. Although this is a vital measure, additional information about the subjective experience of using feedback could add to our understanding about not only whether different types of feedback work, but how they work.

As a result of these characteristics, little is known about the qualitative experience of energy feedback and its functions in our current energy market. There is a great demand for this information. Schatsky and Wheelock [2009] suggest that utilities (and device manufacturers) "will want to look for insights about what types of platforms and interfaces click with different segments of their customer base" [p. 3]. Pierce et al. [2010] second this call for more information about naturalistic feedback users, and underscore the need for further research on how feedback affects specific behaviors, attitudes, and understandings of users as well as the quality of individuals' experiences using feedback devices. The current study begins to address this need.

3. METHODS

3.1 Procedures

Data were gathered through an online survey conducted in Spring 2010. A purposive sample of potential energy feedback users was recruited via several online recruitment tools (email, Facebook, Craigslist, and professional/environmental listservs). About half of the survey respondents (53%) found out about the survey through email from a personal contact and the remaining respondents found out via a listserv, website, or newsletter. Survey design was based on Dillman's Tailored Design Method [2007]; progress indicators, multiple screens, and a simple layout were used to maximize survey completion. The survey took approximately 15 minutes to complete and respondents were entered into a raffle for a $50 gift certificate to Amazon.com. All respondents were asked to forward the survey via email to their own contacts after completion and a reminder email was sent 30 days after the initial contact email.

3.2 Participants

838 individuals completed the survey, of which 86 participants indicated they had used a residential feedback device and reported impressions of using such a device. When compared to the 749 non-users in the sample (via independent samples t-tests), feedback users were significantly more likely to be male, older, married, liberal, have a higher income, live in a detached house, and be a homeowner (see table 1).

3.3 Measures

Data were collected as part of a residential energy survey, which was designed to address three major topics: (1) energy conservation behavior and its predictors, (2) perceptions of energy use and feedback, and (3) use of residential energy feedback devices. The current paper presents a subset of results from analyses of the last part of the survey (i.e., use of residential energy feedback devices). A manuscript of complete findings from this dataset is currently in preparation.

In this section of the survey, respondents were asked whether they had used a feedback device. If they said yes, they were asked a series of open-ended questions about the product and their experiences with it. These questions were designed to address three general topics of interest: adoption (how, where, and why they obtained feedback), usability (likes and dislikes about the use of feedback), and outcomes (changes in knowledge and/or behavior due to use of feedback). If the respondent had used more than one feedback product, s/he was asked to answer these questions separately for each product.

Table 1. Sample Characteristics (compared to non- users)

	Feedback users	Non-users
Gender***	46% female 54% male	70% female 30% male
Age**	45.5 years	39.9 years
Race	80% Caucasian 1% Hispanic 8% Asian 1% African-American 10% Other/Decline	82% Caucasian 7% Hispanic 6% Asian 2% African-American 3% Other/Decline
Marital status*	65% married 35% not married	51% married 49% not married
Political affiliation[a]*	3.96	3.67
Education	18.0 years	17.4 years
Income*	$106,000	$88,000
Home type***	76% detached house 24% apartment/other	53% detached house 47% apartment/other
Home ownership***	83% own 17% rent	57% own 43% rent

* $p < .05$. ** $p < .01$. *** $p < .001$.
[a] Scale from 1 (Extremely Conservative) to 5 (Extremely Liberal).

3.4 Data Analysis

Open-ended responses of the feedback users were analyzed using a modified grounded theory approach. A coding sheet was developed to document and analyze findings. Code development was iterative and utilized the constant comparison method and multi-phase coding [Corbin & Strauss, 2007; Creswell, 2009]. Codes were developed through an initial round of open coding of the raw data and then grouped into categories through axial coding. Finally, themes were constructed from analysis of the codes and categories in conjunction with a review of the literature.

4. RESULTS

The use of feedback for tracking and learning emerged as distinct functions throughout the user responses. This was initially noted during open coding through the prevalence terms such as track (8), monitor (15), learn (6), and find (10) throughout user responses. The following operational definitions were created:

- Tracking: monitoring patterns of energy use over time
- Learning: the act, process, or skill of gaining knowledge

These codes were added to the coding sheet for all open-ended questions; responses were found among questions related to adoption (motivation), usability, and outcomes. Subsequent analysis of co-occurrence between and across questions revealed additional patterns and attributes of these two feedback processes.

4.1 Feedback Devices Used

A wide variety of products were reported by survey respondents. A list of these products, grouped by the feedback categories described in the introduction [Neenan et al., 2009], is provided in Table 2. An additional category for heating, ventilation, and air conditioning (HVAC) was added because analyses of user responses resulted in unique findings for this subtype of product. Specific type of feedback used was unidentifiable for two respondents. The 86 respondents reported using a total of 99 feedback products (12 respondents reported using more than one type of feedback device). The table reflects the total number of devices reported.

Table 2. Feedback Categories/Devices (Number of Users)

Standard and enhanced billing (9)
- *utility company bills* (3)
- *websites* (6)
Estimated feedback (2)
- *online carbon footprint calculator* (1)
- *Wattbott* (1)
Daily/weekly feedback (4)
- *Self-monitor* (3)
- *Google Power Meter* (1)
Real-time (15)
- *TED* (9)
- *BlueLine PowerCost Monitor* (2)
- *Wattson* (1)
- *Square D Meters* (1)
- *Home Energy Cost Monitor* (1)
- *Computer display of wind turbine* (1).
Real-time plus (54)
- *Kill-A-Watt* (42)
- *Plug-in energy monitor* (5)
- *Watts up? (*4)
- Plugwise (1)
- *Ampere Meter* (1)
- *Green Switch* (1)
Other – HVAC (13)[a]
- *Automated thermostat* (5)
- *Thermal sensors* (4)
- *Hobo Data Loggers* (3)
- *Home thermometers (1)*
Other – cannot categorize (2)
- *not sure*
- *prototype*

[a] Devices do not meet the technical definition of energy feedback but were reported as such by survey respondents.

Although both tracking and learning responses were reported across all feedback types and specific devices, general patterns across open-ended responses indicated that users of real-time plus devices as well as estimated feedback and HVAC devices were more likely to include responses related to *learning* motivations, functions, and outcomes of feedback than users of billing, estimated, daily/weekly, or real-time feedback. Those with whole-home data and data about usage across time (e.g., standard and enhanced billing, daily/weekly, and real-time) were among the most likely to discuss motivations and outcomes related to *tracking*.

4.2 Motivation

When asked about motivation for using a feedback device, analyses revealed a distinction between *tracking* ongoing energy use and *learning* about the energy load of specific appliances (See Table 3). Those motivated by *tracking* reported an interest in ongoing information about home energy use: "*interested in tracking instantaneous home energy use overall", "to track energy use and compare over time more easily"*. Those related to an interest in *learning* discrete pieces of information about energy use throughout the home: "*trouble shoot inefficient devices*", "*measure power draw on suspect appliances*", "*see what energy use was on a plug load.*" Specific energy sources in the home mentioned included home heating and cooling, computers, pumps, a deep freezer, and an entertainment center.

Table 3. What is your reason for getting this product?

Tracking	Learning
Wanted to track information I couldn't track easily with watt meters	To understand the electricity being used by various appliances in my house.
Interest in tracking instantaneous home energy use overall	Wanted to know how much power my pond pump uses
To track energy use and compare over time more easily.	Find leaky spots around windows, doors, outlets
Compare my present usage to last year at same time	Troubleshoot inefficient appliances
Identify our electric usage for appliances and over time	To see what appliances were energy hogs.
To monitor electric usage	Curious of heat losses in our home
To monitor the energy use of the components and totality of my entertainment system	To eliminate/reduce phantom loads and trouble shoot inefficient devices.
I got this product in order to monitor my energy usage.	Measure power draw on suspect appliances

4.3 Usability

Analysis of usability revealed positive experiences across a related to both tracking and learning functions (see Table 4). Positive responses related to tracking included features such as comparative information and graphs of data: *"fun to see graphical info without having to enter in each data point", "quick comparison information*". Positive responses related to learning included receiving instantaneous information and the ability to receive information that related directly back to appliances or behavior: "*the instant feedback; having a hard measure of what the appliance or behavior is costing*".

Table 4. What do you like about using this product?

Tracking	Learning
See if I'm using more/less and how it effects my bill (i.e.I use less, bill goes up)	Helps id the most wasteful stuff
It shows in real time how much energy is being used and the info can be downloaded to the computer.	Verify purported energy use of device
Graphing the data and seeing what options are out there to eek out a lower use.	the instant feedback; having a hard measure of what the appliance or behavior is costing.
It was fun to see graphical info without having to enter in each data point.	I like how easy it is to use--all you have to do is plug the appliance into it and it will give you a reading of electricity consumption.
nice that you can monitor instantaneous use or use over time	Immediacy - it told you how your energy use at that moment cost per hour.
The immediate feedback I can get and even long term feedback if left in place for a few days.	Immediate data, easy to move around to check lots of appliances
ease of use and quick comparison information	Being able to determine how much it costs to operate different appliances.
comparison to market, neighborhood average, etc.	kind of fun to see how much energy various things use

When asked what they didn't like about using feedback, many users mentioned that they received an "incomplete picture" of energy use and their desire to be able to see both comprehensive as well as specific energy information (See Table 5). Users of aggregate (whole-home) feedback reported a desire for isolating appliances: *"would be more effective if it could tell you specifically which appliance was causing the most usage", "it didn't isolate particular appliances.*" Users of appliance-specific feedback products expressed a desire for whole-home energy information: "*turning appliances on individually to measure their energy consumption [is OK] for researching and learning, but not for modifying behavior on an ongoing basis", "hard to implement for long term or whole house."* Some users expressed frustration about lack of data storage, reflecting an interest in tracking ongoing energy use, rather than receiving one-time immediate feedback: *"information is not recorded, indexed, or tabulated",* "*no on board memory (e.g. needs to be plugged into computer in order to log data)."*

Table 5. What do you dislike about using this product?

Tracking	Learning
can only use on one device at a time. information isn't recorded, indexed, tabulated	it didn't isolate particular appliances and so we had to go around and switch individual appliances on in turn and record the energy consumption
Can't check everything at once, moving data off of it can be tricky	I don't always know all the info I need about my home appliances
great at measuring individual appliances or plug loads, but doesn't give whole house info. hard to implement for long term or whole house.	It did not react fast enough for me to distinguish between loads: I would turn on a modest power hog but the meter would not respond; only major loads could be detected.
there's no memory/battery back up so if power goes out or it is unplugged before reading the data you lose it. (especially the cumulative data).	I live in a compound with two houses and the device is only able to measure the energy use of both houses at once. I am not able to isolate my house's energy consumption.
This product could be improved significantly if it had a backup battery to hold the data. Once the device is unplugged, any data recorded on it is lost.	I cannot isolate loads to one item unless I know nothing else has changed. If the refrig or A/C start up while I'm measuring something else, I need to know that.

4.4 Outcomes

The distinction between *tracking* and *learning* also emerged in the data related to outcomes of feedback (See Table 6). Some users referred to gaining general information about energy use patterns: "*I know what my energy usage is and how much it costs*); others mentioned specific knowledge gains and/or behavior change: "*got rid of one always-on server due to power draw"*.

Table 6. What was your most surprising experience?

Tracking	Learning
That I use less than the average home in my neighborhood	Really seeing vampire energy at work.
Only used 7 kWh daily in summer [thanks to solar water heater]	Our new printer used 25w in "sleep" mode while the 10 year old laserjet used 1w.
lots of data to crunch.	how much microwave used
The energy wasting behavior that became evident	The large amount of standby power that my computer and television consume even when they are turned off
How I use so much more energy than most of the country.	how many of my appliances showed 0 W when plugged in but turned off

There was strong consistency between the type of feedback provided and the specificity of reported knowledge gain in respondents. The majority of appliance-specific responses were reported by users of *learning* (e.g., real-time plus) products (24): *"I checked refrigerators, entertainment center, and devices I thought would be our largest contributors to energy usage"* (*Kill A Watt*); *"I seem to have a constant 150-200 Watt baseline…that can represent 1/3 of our energy use"* (*WattsUp*). A third of real-time users also reported being surprised by individual appliances and phantom loads, but also mentioned their increased awareness and knowledge of energy use more generally as well as in terms of appliances. Users of *tracking* feedback (e.g., billing, daily/weekly, and real-time) generally reported an increased ability to track change and reduce usage, but without reference to appliance-level information: *"I know what my energy usage is and how much it costs", "I use less than the average home in my neighborhood"* (*utility website*).

Over half of respondents mentioned at least one behavior that they changed as a result of using a feedback product; no changes were reported in 24 instances. Most commonly reported behavior changes were unplugging and switching off power (20), decreased use of appliances (15), and increased use of power strips (7). As mentioned with regard to knowledge gain, specificity of reported behaviors generally matched the specificity of feedback. Billing users reported very general changes in energy use: *"cut back"*; *"used less energy by lowering electrical usage."* Real-time feedback users reported both general behavior changes (e.g. "*generally more aware and conscious*") as well as appliance-specific behavior changes: "*stopped using a second refrigerator", "changing water heater set point."* Real-time plus users primarily changed their appliance-specific behaviors, as well as reducing phantom loads and increasing use of power strips: *"got rid of one always-on server due to power draw, line dry when possible", "incorporated the use of Power Strips with "on and off" switches" (Kill A Watt).*

4.5 Continued Use

Comparison between user responses found that individuals who reported tracking feedback use were more likely to continue using the device: "*I like to check myself and make sure I'm on track*"; those who utilize feedback primarily for learning were more likely to report that they no longer use the product: *"it's served its purpose"* (See Table 7).

Four mentioned that they no longer used feedback because they had all the information they needed: *"it's served its purpose."* It appeared that individuals who used feedback for *tracking* purposes were more likely to continue using it than those who used feedback primarily for *learning*. One user even distinguished between the two, saying: "*I checked almost every device I have, so continued usage isn't very informative unless I start tracking usage in a spreadsheet - way too much work.*"

Table 7. Do you still use this product? Why or why not?

Tracking	Learning
I like to check myself and make sure I'm on track	It's served its purpose.
Still useful, especially for measuring long-term usage	I use it less frequently… when I want to check out draw of a new appliance
on occasion to compare present/past usage	Only once in a while if I'm chasing down a draft.
season changed - have to base usage on season to season, as heating and cooling makes a big difference	Got most of the information it can provide.

5. DISCUSSION

The emergent distinction between the use of feedback for *tracking* and *learning* introduces a new way of thinking about and understanding feedback. There has been little research on the psychological mediators of feedback and this finding suggests a promising avenue for future study. The present data suggest that these two feedback functions are related to users' motivations to adopt feedback technologies, the way users interact with those technologies, and the outcomes of feedback use.

Reviewing themes across responses reveals a set of key characteristics of tracking and learning feedback (See Table 8). Tracking takes place over time and requires collecting many "bits" of information to present patterns and comparisons (to past use, to others, or a set goal). Therefore, it is generally associated with feedback systems that collect, store, and present temporal use data, such as the feedback provided by utilities and real-time devices. Learning, as the acquisition of knowledge, can take place instantly and with as little as one piece of information. This type of feedback is therefore easier to translate to specific behaviors or actions and is generally associated with device-specific (e.g., real-time plus) feedback.

Table 8. Key Characteristics

Attribute	Tracking	Learning
Temporality	Happens over time	Happens in a moment (instantaneous)
Data	Many "bits" of information	One "bit" of information
Behavior	Not necessarily correlated to specific action(s)	Enables specific action / behavior change
Comparisons	Enables comparisons (e.g., historical, social, goal)	Does not provide comparable information
Motivation	Provides additional motivation for conservation behavior (e.g., competition, goal-setting)	Potential for rebound and/or decreased attention to smaller conservation behaviors
Type	Generally associated with aggregate (whole-home) feedback	Generally associated with disaggregated (appliance-specific) feedback

Although there is a strong correlation between the type of feedback received and these categories (e.g., recipients of billing, daily/weekly and real-time feedback are more likely to use feedback for tracking, whereas users of real-time plus devices are more likely to use feedback for learning), both tracking and learning functions were mentioned among users of all feedback types and it is possible to receive feedback that serves both a tracking and learning function, though such systems currently are uncommon.

Learning feedback provides a clear benefit in its direct link to specific behaviors, appliances, or actions. However, simple information provision has been found to be largely ineffective in leading to actual energy conservation behavior. Feedback enables provision of both specific information about energy-related actions as well as information related to the outcomes of actual behavior, which differentiates it from general information provision. The addition of *tracking* enables a motivational element, as temporal or social comparisons can provide a context for individual energy use. Often called a referent, this element provides additional information that can make the feedback more meaningful and motivating [Schultz, 2010; Kluger & DeNisi 1996]. Feedback can include historic comparisons to past behavior (Van Houwelingen & Van Raaij, 1989), comparisons to other users (Midden et al., 1983), and comparison to specific goals (Abrahamse et al., 2007).

As these findings emerged from an exploratory study of the user experience of residential energy feedback, further research is needed to validate and extend them. A clear understanding of the functions of tracking and learning clearly have implications for the design of residential energy feedback as well as its outcomes. It appears that the most beneficial feedback may facilitate both a tracking and learning function but much is still unknown. Questions to ask moving forward include:

- Do tracking and learning appeal to all consumers equally?
- Can a single device/system serve both functions?
- Could giving both tracking and learning feedback lead to information overload?
- What is the optimal combination of information that leverages both a tracking and learning function?

Further investigation into this distinction may lead to advances in both the design and marketing of feedback technologies.

6. ACKNOWLEDGMENTS

Many thanks go out to the following members of uci@home research team who collaborated on the energy conservation survey: Professor Dan Stokols, Professor David Kirkby, Angela Sanguinetti, Nora Davis, Kristen Gamble, Jessie Baker, and Kristen Figueira.

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