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Creating an in-home display: Experimental evidence and guidelines for design

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HIGHLIGHTS

- In-home display design approach incorporating customer preferences and experimental evidence.
- A computer-based simulated display to experimentally test feedback information.
- Contrast of customer feedback information preferences with experimental evidence.
- Appliance-specific/dollar feedback is not as effective as aggregated kW h feedback.
- Generalized information feedback may be more effective than a personalized display.

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ABSTRACT

In-home electricity displays (IHDs) are digital devices that can give near-real-time information about electricity usage in the home. These devices have the potential to provide the kind of personalized feedback necessary to effect behavioral change among residential consumers. However, for consumers to be able to act on the information provided on IHDs, they must first be able to understand it. We present an approach to in-home display design that uses research on customer preferences to determine which features to experimentally examine for customer comprehension. Additionally, we compare these preferences against experimental data to determine whether people have insight into what information best works for an increased understanding of energy saving. Using a computer-based simulated IHD, we find that the types of feedback information that consumers prefer (appliance-specific and dollar-feedback) are not as effective for learning about appliance energy use as the less-preferred aggregated kW h feedback. Moreover, it appears that a simpler more generalized format of information provision has the potential to be more effective than a personalized IHD. We discuss how consumer preferences and experimental tests can jointly be used to inform the design of feedback technologies.

1. Introduction

Any information utilities give to residential electricity customers must be adapted to the customer's needs, especially for those who have limited knowledge of electricity-related concepts or a low literacy level. The monthly bill is typically the sole form of information provided to US households, and it is often too complex to be useful. Customers scan it to identify what they owe and then discard it without using the opportunity to learn—either because the information is not interesting or because it is not readily understood [1]. For example, electricity use information is typically presented only in kilowatt–hours (kW h), a unit that is opaque to many customers [2].

In the absence of usable information, customers will create 'folk theories' or mental models of how their appliances use energy [3–6]. If these theories are incorrect and people use them in their energy conservation strategies they may encourage waste, even with the best intentions [7,8]. Take, for example, the "valve" theory of thermostats, which holds that the quantity of cooling or heating in the home is directly proportional to the thermostat setting, rather than whether the setpoint is different from the current temperature. Those who believe this theory may set their thermostat very low (e.g., to 0 °C) hoping for faster cooling, only to waste energy when the air conditioner cools too much. Without information that corrects these folk theories, many customers would not understand how to adopt appropriate electricity-saving measures even if they wanted to.

Researchers and utilities have tried to solve this problem by providing customers with in-home electricity displays (IHDs) that can give near-real-time information about electricity usage. One of the earliest examples of a simple and particularly effective IHD was that used in the Twin Rivers study [9,10]. In this study, participants were given a simple light that flashed blue when one could cool the

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home by opening the windows rather than using the air conditioner. This yielded an almost 20% reduction in monthly electricity use over the short duration of the study. Paired with the digital meters ('smart-meters') of the smart grid, more sophisticated IHDs can provide customers much higher resolution feedback about their electricity consumption. If this feedback is presented in the right way, customers should be able to correct their mental models of how appliances use energy in much greater detail, allowing them to more easily engage in energy efficient behavior.

Since the Twin Rivers study, mounting evidence has shown that IHDs can help customers curtail their electricity use. A variety of displays have been used in these field studies, including retail (e.g., the PowerCost Monitor) and custom devices (e.g., The Residential Energy Cost Speedometer; [11]). Each display provides different types of feedback information (e.g., kW h use, cost of electricity, monthly spending), in different formats (e.g., graphs, tables, numbers, visual-analogs). In a recent review of these field trials, Davis et al. [12] found that four custom displays (Bluelight, [9]; RECS [11], Fitch [13] and Electricity Consumption Display [14]) were the most effective for reducing overall consumption (~20%, ~13%, ~12%, and ~12%, respectively). It appears that custom designed IHDs can provide the right information in an easily understood manner, leading to effective reductions in electricity use.

While these findings are encouraging, the small sample sizes of these studies ($N = 20$, 99, 101, and 8, respectively) alone should raise doubts about their real-world effectiveness. Casting further doubt, field studies of IHDs report methodologies and measurements that vary so much it is difficult to quantitatively aggregate them, or even compare them to one another [15–19]. While studies that demonstrated large versus small effects differed in many ways, an important difference was the type of IHD they used, suggesting that specific features of the displays may play a unique role in spurring energy reducing behavior.

1.1. Beyond preferences

To determine whether features of the display matter, one can just ask customers what they want, as they have strong preferences about the kinds of information they want to see. Relying on preferences alone to infer how customers will behave, however, is an incomplete approach, as "what people think they want and what they actually want are not always the same" [20]. Basic psychological research has shown that people are not always good at predicting what they will like, concentrating too much on changes [21] or showing bias toward their present feelings [22]. People also have been known to reject policies in prospect, but like them once implemented [23]. Thus, examining preferences alone may give a certain, but potentially incorrect, perspective of how an in-home display should be designed to be most effective.

Beyond their preferences, a variety of social factors will certainly affect consumers' ability to translate the information they view on the display into actual behavioral change. The novelty of the experience [24], willingness to conserve [25], household disposable income [26], cultural norms of energy savings [27] and physical limitations, such as lacking the ability to repair or replace inefficient appliances (e.g. low income public housing residents, see [28]) are just some of the factors that can affect whether feedback information is effective.

In this paper, we take a step back from real-world use of IHDs to examine the more basic question of whether consumers can actually understand and learn from the individual types of feedback information they might see on an IHD,[1] using a simple computer-based in-home display simulation. By identifying those features that best allow for learning, we can begin to make recommendations about which features to include on an IHD to potentially prompt behavior change.

Our approach complements this research by using consumer preferences to determine which features to experimentally test. We then compare preferences against experimental data to determine whether people can use the kind of feedback information that they believe would allow them to change their behavior. To date, little experimental work (with the exception of enhanced bills, [29,30]) has been conducted. The various field studies, interviews, and surveys have neither separated specific elements of IHDs according to their effectiveness, nor measured important intermediaries of effectiveness, such as learning and motivation [31–35].

1.2. Existing research on consumer preferences

Past research on customer preferences for IHD features has used interviews, surveys, and other similar approaches (e.g., focus groups). The options participants generated or could choose from have generally fallen into five categories outlined below [32,36].

1.2.1. Units

Information about electricity can be displayed on an IHD in different units, such as current cost ($), cost/day, power (W or kW), energy (kW h), or carbon dioxide emissions (CO_2 tons). In general, people prefer the cost of electricity above all other possible ways to display electricity use [36,20]. This is consistent with customers wanting simple information in units that they already understand. A number of studies have found that people prefer seeing their costs either as current rate of expenditures (in $/day) or cumulative cost in $ per billing period [36].

1.2.2. Time aggregation

Information can be displayed in increments ranging from years to real-time updates. Unlike preferences for units, there appears to be no consensus regarding preferences for time aggregation. Some, for example, prefer to see their electricity consumption on an hourly basis [20], while others prefer to see it on a quarterly basis, compared to some reference point like the previous quarter [31]. Still others prefer to see their electricity use displayed as daily load curves [37] rather than 10-day curves [38]. However, while there is no unanimous preference for time-period, people generally want to be able to switch time periods with the press of a single button [2,20]. Although monthly billing information is common, more frequent information may be helpful [24].

1.2.3. Physical aggregation

While we know of no research on whether people prefer electricity use information by room, by specific household member, or for the whole house, two recent studies found that people strongly prefer appliance-specific information [36] in monetary units [20].

1.2.4. Comparators

Comparisons typically examined have been to oneself (historic), to other customers (social), or to targets (goal). The most frequent finding is that people want to compare their current use to their own use at some point in the past [31,36]. Moreover, people want to compare their personal electricity use to a self-set goal or target [2,20]. In contrast, nearly all people express a strong rejection of social comparisons [31,20,39], wherein they see their electricity use compared to some other group of customers, such as their neighbors. Indeed, there is little evidence suggesting social comparisons motivate people to reduce their household electricity use [33].

[1] See Wilhite and Ling's 'information-deficit' model for a lengthier discussion of why knowledge is a crucial precursor to behavior change [24].