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Theory-based Taxonomy of Feedback Application Design for Electricity Conservation: A User-Centric Approach

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ABSTRACT

Electricity consumption feedback applications are considered one of the critical technologies in alleviating the increasing trends of energy consumption and greenhouse gases emissions. Feedback applications are used to motivate electricity users to conserve energy in their households. In this paper, we have relied on an integrative theoretical framework and literature review to propose a comprehensive taxonomy for salient design elements of electricity consumption feedback applications. Using a survey method, we collected data to evaluate the preference and relative importance of the design elements. We found that there is a preferred set of design elements for the feedback applications. Our results could serve as a basis to evaluate the design of existing electricity consumption feedback applications, and help in studying the influence of design elements on beliefs and behaviors related to individuals' electricity conservation.

Keywords

Electricity, energy consumption, taxonomy, feedback application, design element.

INTRODUCTION

Existing trends of energy consumption and carbon dioxide emissions are of growing global concern in several fields of inquiry. Greenhouse gases are expected to double by 2050 (IEA 2011). Based on G8 countries' recommendations, the International Energy Agency has developed smart-grid technology roadmaps to reduce greenhouse gas emissions globally (IEA 2011). Although accounting for only 17% of energy consumption, electricity use contributes 40% of global greenhouse gases (IEA 2010). The residential sector accounted for 37% of total electricity consumption in the US in 2011, exceeding the industrial sector, which consumed 26% (U.S. Energy Information Administration 2012). Effective feedback applications can play a critical role by altering individuals' energy consumption behaviors (IEA 2011). Furthermore, feedback applications for household energy consumptions are considered one of the six trends which will influence the growth of the smart grid (Wheelock et al. 2011). The influence of technologies and feedback mechanisms on consumers' behavior is expected to reduce electricity consumptions by 10 to 30% (Abrahamse et al. 2005).

Industrial and academic researchers have studied electricity-consumption feedback tools and their effects on consumers' electricity consumption. A meta-analysis of 64 pilot projects using existing feedback mechanisms concluded that pilot projects did not achieve the expected rate of electricity conservation (Mattern et al. 2010).

In the IS field, we reviewed the recent Green IS/IT literature (2009-2011) and found 41 papers in the top 6 IS journals and in proceedings from two major IS conferences. Only four papers examine electricity consumption behavior, with focus on the influence of online communities (Baeriswyl et al. 2011b), social competitions (Yim 2011), social norms (Loock et al. 2011), and public games (Baeriswyl et al. 2011a). This clearly shows that the design of IT artifacts for feedback applications in promoting electricity conservation is an area that has not been adequately investigated. This gap has been observed at the international level. "More rigorous and methodical research and evaluation is needed to identify the optimal method to deliver feedback and to understand better the interaction between consumer feedback and pricing or incentives (financial or other) and the effect of enabling technologies (e.g. automation) on results." (IEA 2011, p. 37). Recent Green IT agendas have urged examining the information and levels of detail required by energy consumers to improve their energy efficiency (Watson et al. 2010). Our study addresses this gap by identifying the design elements that motivate electricity consumers' behavior toward energy conservation by asking the following question: What are the design elements of a feedback device application that would motivate electricity consumer's behavior toward energy conservation?

Electricity Conservation and Feedback Applications

Electricity conservation behaviors refer to the actions exerted to reduce energy consumption and are categorized as efficiency behaviors or curtailment behaviors (Abrahamse et al. 2005). Efficiency behaviors refer to one-time actions which reduce electricity consumption such as using energy-efficient light bulbs instead of traditional light bulbs. Curtailment behaviors involve actions over time with the aim of decreasing electricity consumption, such as using laptops instead of desktop computers.

Electricity consumption feedback applications are designed to provide feedback on household electricity consumption to promote electricity conservation (Midden et al. 2007). Feedback device applications can be categorized into in-home display monitors, website applications, and mobile phone applications. A survey conducted on 1,041 electricity consumers in the US showed that 66% were willing to pay for feedback applications, 52% had very strong interest in such devices, and 45% were interested in becoming active users in order to decrease their electricity consumptions (Wheelock 2009). These results show that the general public has significant interest in feedback applications. The design of effective feedback applications requires an in-depth understanding of salient design elements, which is the focus of this work. To this end, we developed a comprehensive taxonomy of design elements for electricity consumption feedback applications based on a theoretical framework and extensive literature review. This taxonomy is used to develop a survey instrument for collecting data about the relative importance of design elements. The analysis of data resulted in the identification of critical design elements for feedback applications.

THEORETICAL FRAMEWORK

In identifying salient design elements for electricity conversion feedback applications, we examine salient theories and prior research that explored the relationship between feedback interventions and the attitudinal and behavioral processes of electricity consumers. Two theories fall within this framework—the Feedback Intervention Theory (FIT) (Kluger and DeNisi 1996) and the Learning Theory (Kolb 1984).

Feedback Intervention Theory (FIT) (Kluger and DeNisi 1996) examined the influence of feedback interventions on performance. FIT defines feedback interventions as any action performed by an "external agent" to deliver feedback on the performance of the task (Kluger and DeNisi 1996). Integrating several theories such as control theory (Carver and Scheier 1981), goal setting theory (Locke and Latham 1990), and action theory (Frese and Zapf 1994), FIT suggests that individual's performance is positively influenced if feedback is well-timed, directs attention to the details of the task with guiding information, and is coupled with an appropriate goal setting intervention. For example, in our context, a goal is defined as a newly assigned level of electricity consumption relative to an initial (or prior) consumption level. The pertinence of having a goal coupled with feedback was supported by a meta-analysis of 23,663 observations (Kluger and DeNisi 1996). Moreover, FIT argues that goals or levels of control are organized hierarchically—with the lowest level being task-specific, going up to task-motivated, and then to meta-tasks (self-related). Feedback interventions could change behaviors depending on the goal level in the hierarchy. In our context, the task is energy conservation. In this context, if users have a self-related goal such as being pro-environment, they will be less affected by feedback interventions focusing on task-specific goals, such as saving energy when using appliances (McCalley et al. 2011).

Learning Theory (Kolb 1984) posits that feedback information modifies individuals' perceptions and behaviors. Based on learning theory, feedback impacts users' perceptions and abilities related to electricity conservation. The learning process involves electricity usage and receiving feedback. This process helps users better manage their consumption, eventually leading to more sustainable practices (Darby 2010). Therefore, users with different levels of motivation and skill need feedback to guide them in enhancing their electricity conservation behaviors in terms of saving or more efficient usage (Darby 2010).

Our theoretical framework is an integration of FIT and the learning theory. Based on this framework, we propose that residential households will go through a learning process when presented with feedback information (Figure 1).

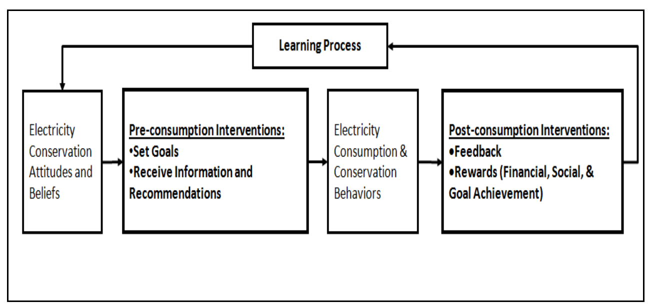


Figure 1. Feedback Intervention Process

We posit that users initially have attitudes and beliefs related to electricity conservation. When introduced to a device on which a feedback application resides, users go through the pre-consumption intervention stage (or antecedent interventions) whereby they use the feedback application to set their goals and receive information, tips and recommendations from the feedback application (Figure 1). After consuming electricity, users are exposed to the post-consumption intervention stage when the feedback application provides users with feedback and rewards in terms of their performance. According to the learning theory (Kolb 1984), the feedback application constitutes a reverse process flow, in which the flow reverses back through learning to dynamically impact users' salient beliefs and attitudes. Our study focuses on developing the taxonomy of design elements feedback applications' pre- and post consumption interventions.

Taxonomy of Design Elements

Based on FIT, effective feedback is the one which relates to the goals and enables the elimination of the discrepancy between current and future desired state (Kluger and DeNisi 1996). We posit that feedback applications design elements should enhance the learning process. This requires an investigation of feedback information contents that includes goals, recommendations, assessment of consumption and feedback information. Furthermore, influencing users' behaviors requires an effective delivery of feedback information through a suitable interface and an appropriate device or medium on which the application works. Hence, design elements could be categorized into feedback information, interface, and media elements. Guided by this theoretical framework, we carried out extensive literature review to identify the taxonomy of details within each category. Figures 2, 3, and 4 show the proposed taxonomy. The table summarizing the the definitions and sources for concepts used in the taxonomy and the discussion of each category were removed due to the space limitation.

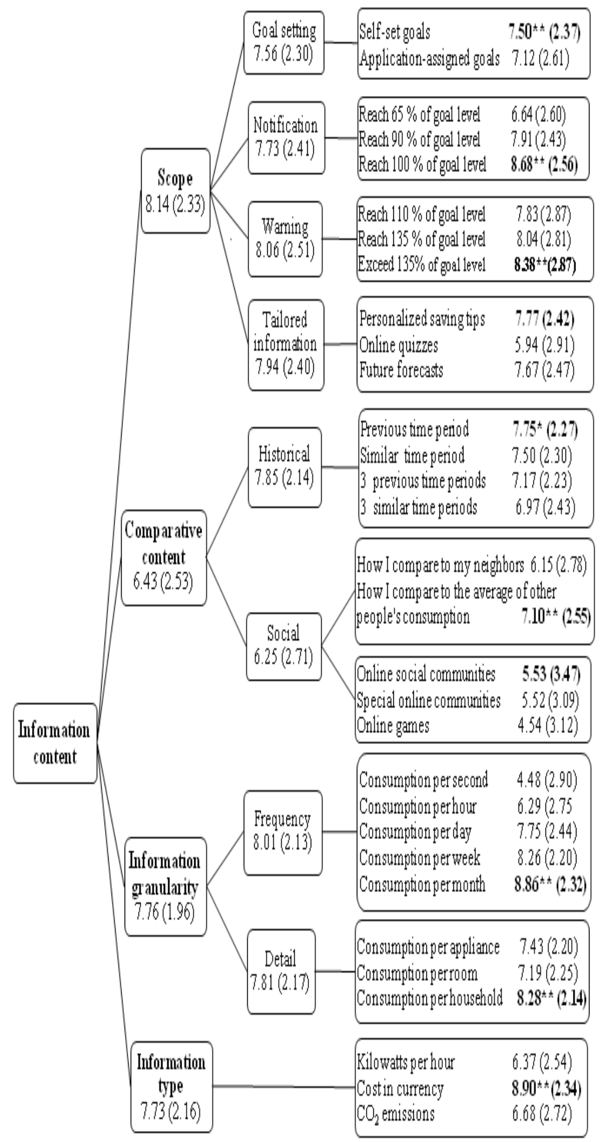
Information Content Category. The taxonomy for this category is reported in Figure 2. This category involves the information contents of feedback applications and has scope, comparative content, information granularity and information type as subcategories.

Visual Display Mode. Different display options are available to communicate information in feedback applications. Users can see their consumption information not only in numbers—kWh, money or carbon emission—but also in various graphical displays, dashboards or even pictograms.

Media Category. The taxonomy for this category is reported in Figure 4. This category refers to the elements related to devices or media on which the feedback application runs, as well as their privacy and security features.

METHODOLOGY

The proposed taxonomy presents a guideline for designing feedback applications. We developed a survey instrument to collect data for the different importance ratings of design elements and the preferences for the different design options. The survey results allowed us to investigate whether there are certain design elements which were significantly preferred and whether there are major differences in the preferences signifying the need for personalization of feedback applications based on users' profiles. A web-based survey was used for data collection. Students in a Midwestern state in the US were invited to participate in the survey, and a small extra credit was offered as an incentive. Invitations were sent either by email to targeted students or in face-to-face invitations in the classroom. 546 participants were invited to participate and 372 took the survey, resulting in a response rate of 68%. The data was cleansed to remove those who had taken less than 7 minutes and 30 seconds to complete the survey—the minimum time deemed needed to take the survey with care—to ensure that responses were the result of careful reading.



Means are inserted outside parentheses, and standard deviations in parentheses, **=p<0.01, *=p<0.05

Figure 2. User Preferences for Information Content Elements in Feedback Applications

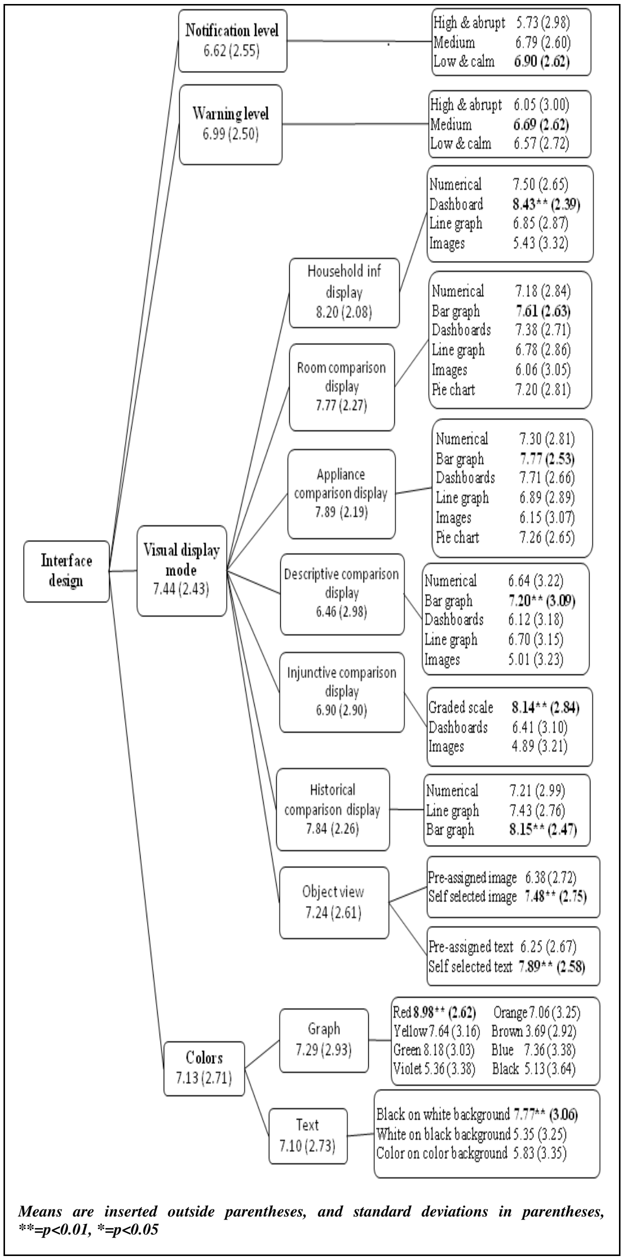


Figure 3. User Preferences for Interface Design Elements in Feedback Applications

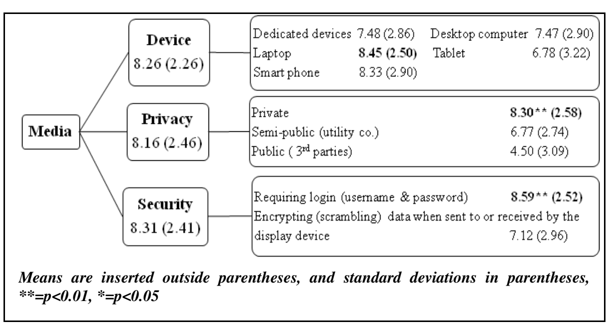


Figure 4. User Preferences for Medium Elements in Feedback Applications

ANALYSIS AND RESULTS

In order to study the preferences of the design elements by our respondents, we calculated the mean and standard deviation for each element in our taxonomy and performed t-tests to study the elements that were significantly preferred over others within each category. A statistically significant result implies that at least one element in the last level was preferred over all other options in the taxonomy. Figures 2, 3, and 4 show the preferences of the design elements in the taxonomy.

Information content (Figure 2). For the scope, goal setting in the scope subcategory is often described as a crucial method of inducing electricity conservation. Results indicated respondents preferred to set their own goals. Users mostly prefer to get notified when their consumption reaches 100% of their pre-set goal and to be warned when they exceed their goal by 135%. Although these findings do not provide a high range of detail to the user, they reinforce literature findings suggesting that some users find notification disruptive (Isaacson et al. 2006). Supporting this finding was the fact that participants preferred notification and warning levels should respectively be low and medium. Energy saving tips was the most preferred tailored information. These indicated the need for personalized guidelines in helping users conserve electricity based on their habits and lifestyle.

Regarding information comparisons, historical comparison to the previous period and comparison to social injunctive norm (comparison with other people's consumption) were preferred. Surveyed participants were interested in having social interaction with online communities, affirming today's social trends of online socialization.

For information granularity, there was a clear preference for consumption information at the household level over room and appliance details. Furthermore, there was a preference for information delivered monthly, which was an unexpected result. It seems that respondents preferred getting feedback in the style of monthly electricity bills to which they were accustomed. This could also be due to the lack of strong motivations such as achieving a pre-set goal.

For information type, our results showed that the currency unit seemed to be the most important information type unit, indicating preference for financial reward by reducing cost. This is in line with existing literature (Bartram et al. 2010) which suggests that kWh and carbon emissions are abstract for individuals who are not electrical engineers.

Visual display modes (Figure 3). The results indicated preference for dashboards to display household consumption. For comparisons' display bar graphs seemed to be the favorite mode. The only exception lies in the injunctive social comparison where there is a preference for a grading scale that shows how well they are doing compared to others. When required to choose display colors, there was a clear preference for the use of red. Interestingly, the second most popular choice was green. There could be two interpretations that support this preference. First the use of symbolic and familiar colors like red and green that have well known meanings (as on traffic lights) facilitates user's interpretation of information. Second, studies in neurobiology of human vision show that the color red is perceived at a faster rate than other colors, attracting one's attention (Chen et al. 2011).

Media (Figure 4). Most participants preferred laptops as the device. This choice confirms the importance of mobile devices (Bartram et al. 2010). We note that the majority of our participants had access to the Internet and laptops. Privacy and security issues received high ratings since most users preferred to preserve private access to their consumption information and requiring logging in.

LIMITATION AND FUTURE WORK

This paper developed a taxonomy of design elements for electricity consumption feedback applications based on an integrative theoretical framework and extensive review of the existing literature. In order to study the preferences of the design elements, data was collected using a survey method. The results indicated that there were distinct preferences for some design element options, indicating the need for personalization of feedback applications. This work contributes to the effective design of feedback applications and the evaluation of existing feedback applications for changing energy users' consumption behaviors. Our data was collected from a young segment of the population. This work should be extended by collecting data from other populations and cultures. This work could also be extended to evaluate the impact of various salient design elements in promoting energy conservation.

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