

Why Energy Consumption Feedback Is not (Only) a Display Issue

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Abstract. This paper presents the results of a longitudinal study of the appropriation of a consumption display. Our results show that feedback on household energy consumption is contextually interpreted according to personal energy history, other available resources for managing energy issues, including resources for actions and human resources, and in relation with the occurring activity. We show that feedback use is an evolving process co-determined by the actors' preoccupations and their activity context. Consumption feedback should be considered as part of a system of assistance designed to enhance user engagement with energy control. To be appropriate, it must have at least three main characteristics: scalability, complementarity, and operability.

Keywords: Sustainability · Energy consumption · Field study · Consumption feedback · User-centered design

1 Introduction

Sustainability has become an important issue in HCI research. Displaying consumption information is a way to make energy visible and engage people in self-reflective processes that prompt changes in domestic practices and thereby lower consumption. However, this “ideal path” to sustainability does not seem to correspond to observations in smart grid experiments and user research.

The earliest work in this field sought to modify behavior and convince consumers to change their habits. Yet the experiments designed to quantify the impact of displays on consumption often showed contradictory results [4]. The most frequent results were then retained in the literature to define an average range of lower consumption, thus obscuring the wide diversity in the results [3]. The focus on cost savings was linked, especially in the persuasive approach, to a view of the actor as a rational consumer, sensitive to influences and willing to change behaviors in order to control energy use [26].

The limitations of this approach were first noted by researchers in the human “behavior” sciences: social sciences [18, 23], psychology [21] and cognitive ergonomics [8].

The domination of the persuasive approach [17] has nevertheless resulted in many studies to evaluate consumption display types (functionalities, usages) [10], and the impact of functionalities on behaviors has guided the design of displays [1]. Yet both the designs and the evaluation methods remain questionable.

Feedback system design necessarily focuses on functionalities linked to energy use and cost, including consumption at various time scales, normal use compared with that of other households, desirable behaviors (eco-gestures), or the most likely energy bill [16]. Much of this information is too often disconnected from the contexts in which behaviors occur and energy is consumed [27]. Many of the questions about how to monitor and control energy depend on personal and familial contexts (domestic practices and activities, family organization), as well as technical (material, means of action, etc.) and social (skills, preoccupations, expectations, financial means, etc.) contexts. Moreover, the feedback display system is often considered apart from other solutions, like other information sources and ways of remoting appliances.

Another limitation of the experiments has been the focus on before-after behaviors. Perhaps because of experimental or methodological constraints (before/after questions) [25], the actual evolution in behavior has rarely been examined [15]. Yet an interpretation at the end of the experiment can be questioned if nothing is known about the course of the behavior over time and how it was affected by factors that obstructed or facilitated the appropriation of feedback. Increasingly, studies now describe the actual use (or non-use) of feedback displays over time [2, 5, 17, 20]. These studies, which evaluate the long-term impact of energy monitoring, have shown results that differ from those of short-term studies. Notably, they indicate that user engagement with monitoring gradually lessens or disappears [13, 22, 24].

[13], for example, noted a drop in engagement over a 12-month study, despite an initial phase of interest. This drop was attributed to a lack of new information that might have held consumers' interest. Other authors have tested feedback displays with richer functionalities and observed no drop in engagement, but rather a shift from regular use to more occasional use [11, 17]. This has been interpreted as reflecting the shift from novelty to utility rather than a lack of interest, or from a discovery phase to a maintenance phase [14]. The growing competence of users who are quite aware of their energy use ("energy literacy" [17]) suggests that the information supply should be regularly enriched and renewed to respond to increasingly sophisticated user questions [9]. However, these user needs and their evolution have rarely been described in the literature, especially in relation to their socio-technical context, in addition to the feedback function. The impact of feedback displays is also a particularly complex issue because a better understanding of energy consumption does not necessarily result in energy-conserving actions [5] and may even limit action, with household members assuming that their energy use falls within the norms and should therefore merely be maintained [20].

Recent HCI findings have underlined the importance of enlarging the issue of energy savings to include consumer commitment [12], evolving competence [17], the development of reflective processes [7] and the contextual factors of domestic [8, 23] and familial [2, 19] activities. The above-cited studies confirm the need for in-depth analysis of the appropriation phase of feedback to determine how it can be made a part of daily

preoccupations and domestic activities. This analysis can be accomplished by considering feedback use at the familial scale as an evolving process co-determined by the preoccupations of household members and their contexts of activity [9].

In this paper, we describe the first results from a study of the appropriation of an electrical energy consumption display that takes into account its context for use and questions anew its role in the evolution of household preoccupations and engagement with energy control.

2 The Study

We assumed that a longitudinal study would provide a better picture of consumer histories with feedback and energy control and help situate the use (or non-use) of feedback within its context of emergence. Individual users are studied in terms of their growing competence, understanding of energy issues, and changes in personal energy practices.

Description of the feedback. The study is being conducted in France, where a smart grid meter is currently being deployed. We are testing an application that can be downloaded onto iOS and Android smartphones or tablets (Fig. 1). The application receives energy-use data via Bluetooth 4 (low energy) from the smart meter, transmitted by a flash drive in the meter’s USB slot. The application shows household customers the fluctuations in their energy use: current power usage and consumption in euros per month updated every 2 s; average, peak and purchased power; and standby consumption. They can see the peak and off-peak periods, with a summary table presenting their aggregate consumption over several time periods, as well as graphical presentations (in Wh or euros). They can measure consumption over a set period and even measure the consumption of certain appliances (estimating consumption per second, per hour or per euro).



Fig. 1. (from left to right) Start screen showing instantaneous power and consumption, graphical history (daily consumption), consumption information per appliance (measurement underway), consumption results per appliance.

The application was previously tested with users to verify and improve its usability.

Participants. The study has recruited individuals who are not currently participating in other smart grid studies by phone or in the energy supplier boutique. At the beginning of the study, the obstacles to technical eligibility were substantial (specific type of electricity meter, limited number of smartphone models) and these were the main filter for recruitment. We assumed that the willingness to participate in the experiment was the only complementary criterion, the idea being that we would complete the sample later with any missing profiles (type of lodging, family composition, etc.). Of the ten households, eight include children (two adolescents), one couple has no children, and one is a divorced man. All live in detached houses (six had them built) with electric heating (alone or with wood burning) and areas ranging from 80 to 200 m². Nine are homeowners and one is renting. All have time-of-use pricing plans for peak/off-peak hours. The ten houses were equipped between the autumn 2013 and summer 2014. As of December 2015, all were still participating in the study. They have all been compensated on the basis of the length of their participation (70 euros for two visits and phone follow-up, 100 euros for three visits, etc.).

Method. On the first visit to the households, the system is installed, application use is explained, and an interview is conducted. An autobiographical interview provides a history of the participants in their homes as it relates to energy use. The longitudinal study alternates between home visits to gather in-depth information from the customers and document past usage, and remote follow-up to determine ongoing usage. The participants use the application for several months, as and when they choose. They are invited to inform us whenever they use the application (their choice of phone, email or text message). If they do not do so (most often), we send a reminder by phone or email, based on the remote tracking system. Display usage is reconstructed with the users to help us to understand the context that motivated the usage, and according to the sequencing of actions that they report. More home visits are planned for every three to six months. Whenever possible, in situ interviews are conducted with the couples.

Modeling. The interviews are fully transcribed, as are any filmed uses. The collected data are used to build the history of customers as they appropriate the system and to model the course of their reflections about energy use before, during and after we introduce the system.

Any person using the application is assumed to be an actor. As thus far this has often been only one person in the home, we initially analyzed data from his/her point of view, but we distinguished between energy questions or decisions that were personal and those shared with other family members. We intend to separate the evolution of each individual, but analysis will necessarily be partial because of differences in engagement level. This limitation will be addressed in future studies.

Data were formalized to produce a horizontal timeline showing the sequence of decisions, actions (or non-actions) and problems. Associated elements include material contexts (housing type, family composition, work routines, type of heating, insulation, electricity plans and options, electricity bills), resources used (electricity retailer, customer advisors, advertising campaigns, feedback and functionality used), and the underlying concerns expressed from the actor's point of view along with any actions

taken or obstacles encountered. This formalization allows us to track questions and problems and their overlaps and interactions. Also, every problem related to consumption or housing (building a house, cost of electric heating, etc.) is addressed specifically to focus on how the actor dealt with it and to identify his/her needs.

3 Results

Our results show that consumption feedback is part of a global context linked to the life situation that produced the consumption, the family history about energy questions that are a source of particular preoccupations, and the role of other available resources that respond to energy concerns. We present our main results on the basis of our observations.

Energy consumption fits into a past or present “happening situation”. The feedback gives rise to different usages according to the underlying questions and the stage of using the application, and these usages evolve with application use. For example, the participants sought to observe and understand their consumption. This is the first time that users actually see the installation in real time. Although first interested in the cost, they gradually focus on the relationship between the volume (in watts) and the cost, and progress toward increasing attention to volume, which has the advantage of fluctuating with the appliances being used and thus brings more information on the “life” of the household. By gradually integrating the notion of consumption in watts, users define a profile of their home and become able to estimate the cost of an appliance or identify a malfunction: avoiding peaks, not going beyond certain values, or looking for values that are too high or a peak at the start of the hot water system, for example. They then try to figure out what is causing the consumption pattern and think back to recent activities to find the source of the “over”-consumption. The history of consumption, especially the curves, also helps to retrospectively associate consumption with times of activity. The maximum power reached provides information on the adequacy of the power contracted for and the volume of consumption. Some participants have reported conducting tests on appliances by plugging them in or unplugging them to see their impact on consumption. These tests bolster them in their belief that the device in question uses either a lot of energy or very little. They give information on how appliances work (wash cycles, electric heaters, stoves, etc.). To find answers to their questions as they emerge, participants sometimes use different functionalities for similar objectives, seeking answers by employing various means.

The evolution of these uses and user concerns indicate the appropriation of the data and the application. This appropriation in itself results in a change in home behavior. Greater understanding about their consumption leads users to want to change, sometimes to “hunt down waste”: systematically turning off the standby function of certain appliances (coffee machine, printer, etc.) after seeing the difference in the displayed values, identifying an appliance that has been left on (auxiliary heating) because of higher consumption than usual, and so on. For one couple, the possibility of measuring appliance use helped them to focus on only using the washing machine at off-peak hours, systematically turning off lights when leaving a room, and turning off standby functions, verifying with the application that all was off before leaving for work or going to bed.

But finding the cause of elevated use can be more complex when it is not the result of “forgetting” but rather of a malfunction. For example, after checking the display one morning out of curiosity, one participant observed higher consumption than “normal.” Not finding the origin of this consumption, he then consulted the display several times throughout the day and in the following days, until he made the connection between this rise, taking his shower and his hot water heater. Contrary to what he thought, it was not an off-peak heater and used full energy as soon as it was turned on. He solved the problem by connecting the system to a timer, and took advantage to schedule limited-use periods in order to consume as little as possible.

However, this level of appropriation is not systematic and the evolution in behaviors is subject to conditions. Acquiring consumption data does not always mean understanding the data and the causes of fluctuations. Some questions remain unanswered. When they showed us their consumption summaries, some participants admitted that although they could see that they had used more or less energy in a given period, they could not always easily find the cause. These difficulties indicated functional limitations and the need for support to certain users or on the basis of certain data.

In addition, family contingencies (especially when there are children or adolescents) take precedence over energy conservation. This was the case, for example, of a family with teenagers that changed its control practices as the children got older. The adolescents were more demanding and their activities less easy to control, and the parents admitted to sometimes doing the ironing or washing during peak hours to meet a specific need or to triggering the water heater to work outside of off-peak hours to meet a need for more hot water. These were contextual uses that were incompatible with the predefined, anticipated and regular control actions.

Last, the most engaged households were those with financial worries (such as the divorced man living alone with diminished financial resources in an outmoded and poorly-insulated house, or families with young children who had just bought their home). The need to limit spending is a key variable in user engagement and contributes as much to the situation as the current activity.

Appropriation is thus encouraged or hindered by conditions not directly related to the “happening situation” of domestic activities, but instead influencing them. Thus, the happening situation is not sufficient to understand feedback use and user needs. It is important to take into account the context, as it is marked by a history of energy questions and problems that are more or less resolved.

Energy feedback is situated within a history of learning about energy issues.

Energy feedback is given in a preexisting situation that comprises the socio-technical environment and personal learning and experience. All households have energy concerns linked to past events. These concerns are more or less present (actualized) because of financial worries and/or the experience of discomfort (rarely for environmental reasons).

For example, all the homeowners who had had their homes built had chosen electric heaters of poor quality, uncomfortable and expensive to run. Some wanted to change the heating system but could not afford to. They had to handle the heating problem by seeking auxiliary solutions and by developing more competence to make decisions about

a supplementary heating mode, changing radiators, or installing an energy manager. They sometimes consulted professionals who proved less than competent, which engendered distrust. One participant had to manage the repeated breakdown of an obsolete and costly fuel-based heating system and an antiquated electrical installation. The most expensive work was deferred (single-phase meter, insulation). Several households were aware that the insulation in their homes needed improvement. Not knowing what work was most relevant or unsure of the prospective costs, they dealt with high consumption for heating, discomfort (low temperature or limited to certain rooms) and high bills. These homes were also pioneers in the installation of smart electricity meters because of their geographical location. Unfortunately, malfunctions occurred: the new meters are more sensitive to power overloads and often caused the circuit breakers to shut off power in one of the homes. Two other households found that the new meters had been installed without notice or consideration. They remain wary and monitor their bills and outages.

These issues affect the users' engagement with energy control, their energy questions, and their personal repertoires of feasible energy management actions. The commitment to dealing with energy issues provides the context for the appropriation of feedback. It encourages the use of feedback and affects the expectations for specific functionalities: knowing what costs can be reduced (standby, appliance use, off-peak hours, consumption while out of the home), alerts for "abnormal" consumption, responses to questions about heating systems by comparing the consumption of different types of systems. However, the application is insufficient for this type of testing. To avoid further unpleasant surprises on the bill, they monitor consumption over a billing period and expect that this consumption history will prepare them for the next bill. Last, they try to avoid tripping the circuit breaker by monitoring the maximum and average power used.

Conversely, if the proposed functionalities do not give users a better understanding of their actions or a new source for savings, use can become less frequent. Users on a tight budget who are already trying to reduce consumption (systematically turning off lights and standby systems, unplugging chargers) feel less room to maneuver with the feedback display. Moreover, when functionalities do not actually allow the expected calculations, users can draw erroneous conclusions. Thus, a household wanting to know the difference in cost of running a washing machine in peak and off-peak periods based their conclusion on a historical measure distorted by the use of other appliances running at the same time (hot water and heating). They concluded that off-peak was more expensive and did not see the interest of doing laundry at off-peak hours. Promoting the appropriation of feedback means providing enough functionalities to address concerns. It also implies articulating the feedback with other modes of assistance that help users throughout their learning and questioning.

Energy feedback is a part of a system of assistance. The design and evaluation of feedback systems are often considered apart from other devices that consumers can use. However, we note that feedback is part of a set of systems, as a complement, substitution or control.

All consumers obviously receive bills, which are often the first (or only) way to monitor consumption. Often, the billing frequency is not considered sufficient to anticipate mistakes or excesses in consumption. Thus, a couple with young children considered enrolling in a plan to follow consumption (with monthly paper reports) to have more detail on their energy use. But the offer was not free (2 euros per month) and they concluded that the solution was expensive for the expected gain. They thus remained without a solution until the application was proposed to them free of charge. Another household on a monthly plan (fixed payment every month based on an annual estimate, with an adjustment made in the last month based on actual consumption) used the application to anticipate the amount of the adjustment bill: they knew they had consume less than the estimate made by the energy company (by adding wood heating) and monitored their monthly consumption to estimate the annual amount and stay within budget. Several households also created their personal space on the site of their energy company. They can find their past bills and the main elements of their contracts (power, peak periods, etc.). In this case, there is additional information to that proposed by the smart-phone display.

Digital systems are nevertheless not sufficient to respond to users' energy issues. User support should be thought of as a system of support for their engagement, with the offer of multiple resources, including human resources. In the histories of all our participants, we found that they have called on intermediaries for help in the past: friends, people knowledgeable about electricity, electricians and heating specialists. Yet they might have called their energy distributor or stopped by one of its boutiques. The man living alone in his energy-obsolete house was well supported by a customer advisor, first by telephone and then with a home visit, as he sought to understand the reasons for his high bills despite behavioral changes. The need for monitoring and personalized advice for deciding on concrete actions means that feedback displays should be seen as part of a much broader network of assistance, wherein other components may be deficient and thus compensated by the feedback display (in detecting that the water heater is not set for off-peak because the electrician forgot to set it, for example).

To bring about actions to control energy use, the display must be supplemented by other technologies. Although it detects problems, solving them often requires concrete actions such as equipment changes (heating manager, remote control outlets, power strips, controllers, etc.). However aware users become (publicity and information campaigns that help to improve competence and engagement), the willingness to act still requires the means for acting and technical assistance in adapting practices. Thus, our most active participants learned about, acquired and managed programmable outlets and standby power controllers.

Last, we have seen that financial constraints are an obstacle to action: consumers have to determine what they can do themselves, but they also should be able to obtain low-cost assistance or even financial aid.

Energy feedback is a resource among others for making decisions, learning and acting: human resources (family, personal relationships, customer advisers), information and advertising, financial resources and the concrete means for acting (control systems). The households request these resources according to their evolving preoccupations, competences and experience.

4 Conclusion

Our study shows that a focus on the appropriation of feedback provides insight into the determinants of the shift to active control of energy use.

This study has limitations, one of which we identified as the need to consider all household members in order to investigate collective appropriation. It will also be important to study the households that themselves opted for the feedback systems, in addition to those that were specifically recruited. We also plan to study a population that is energy-insecure. A new version of the application that includes missing functionalities and a complementary application for budget monitoring are also under development.

Analysis of the appropriation process shows that feedback use is determined by specific questions that vary over time and according to evolving user competence. This explains why the device was used differently over time. A consumption display cannot be the only way for consumers to engage with energy control because engagement depends on many factors that feedback alone cannot address. Changing behavior cannot be reduced to influence or persuasion; it must be seen as depending on a response to concerns through technical and cognitive resources, of which feedback is clearly one.

Consumption feedback is contextually interpreted and must be designed to fit into the user's context. The context must be defined from the user's point of view and considered as distributed over time: in connection with ongoing activities and questionings already experienced, resolved or persisting, all of which have needed diverse resources in the past. It therefore must take into account user development and the acquisition of new competences.

This means that consumption feedback must have at least three main characteristics to be appropriable: scalability, complementarity and operability. Thus, it must be functionally rich (to respond to evolving needs and capacities): the link to activity makes information essential – in real time, historically and per appliance. Effective feedback should contain multiple feedback options, not limited to a value unit (e.g., money), a timescale or a type of measure. The structure of feedback should allow for more in-depth uses as new questions and needs emerge. It must also be complementary with other forms of assistance: feedback cannot meet all consumer needs. It is important to differentiate the needs for assistance that can be met by a display from those needs best met by other resources, with the ultimate objective being the design of global support for user engagement. Last, it should allow for action: information alone is not sufficient. Feedback must allow the prediction of the impact of an action. Comparisons between situations and simulations of “what if” scenarios are needed. These should be extendable with the means for acting.

These contextual and operational constraints broaden the issue beyond the display. It will be important to design aids for a process in construction using diverse resources from the perspective of complementarity as users evolve and grow in commitment.

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