Evaluating Mobile Phones as Energy Consumption Feedback Devices

Markus Weiss[1], Claire-Michelle Loock[2], Thorsten Staake[2],
Friedemann Mattern[1], and Elgar Fleisch[2]

[1] Institute for Pervasive Computing
[2] Information Management, ETH Zurich

Abstract. With smart electricity meters being widely deployed, data on residential energy usage is increasingly becoming available. To make sensible use of these data, we investigated the suitability of mobile phones as an interface to provide feedback on overall and device-related energy consumption. Based on the results of a user survey, we implemented the most highly valued feedback features on an iPhone that communicates with a smart meter. In a follow-up user study, we evaluated how users perceive the experience of such energy consumption feedback and how they rate the importance of different functionalities. Our work confirms the suitability of energy feedback delivered on a mobile phone. It outlines that a clear and easy to explain use case scenario is key and that knowledge-increasing functionalities as well as those functionalities from which monetary savings can be directly implied are perceived as most important. To address technophobe users, action-guiding feedback that goes beyond displaying aggregated information is required.

Keywords: Advanced metering, energy conservation, feedback systems, behavioral change, energy use.

1   Introduction

Information and communication technology (ICT) can help in many ways to conserve energy. On the one hand it does so by optimizing various industrial processes (and thus increasing their energy efficiency), on the other hand it can increase transparency, create energy awareness, and support individuals to make informed decisions that contribute to a more efficient energy use. Besides the industrial and the transport sector, residential and commercial buildings are a major consumer of resources. Their share is increasing, and they now account for approximately 73% of total electricity use in the U.S. The residential sector alone consumes 37% of electricity end use in the U.S., whereas it accounts for 29% in the EU[1].

It is widely accepted that electricity consumption in residential buildings is highly dependent on the habits of the occupants [16]. However, feedback on energy usage is typically only provided by a monthly (if not yearly) utility bill and thus remains rather vague

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[1] See www.eea.europa.eu/data-and-maps/figures/final-electricity-consumption-by-sector-eu-27-1 and www.eia.doe.gov/aer/

and opaque to most consumers. Most people could reduce their energy consumption (and thus save money and contribute to a reduction of greenhouse gas emissions), but few know how much they consume and even fewer know for what purposes they use how much energy and which of their appliances in the house consume the most energy.

"Smart" ICT now provides opportunity to change that situation. With smart electricity meters being widely deployed and the broad availability of technologies from the ubiquitous computing domain (such as cheap sensors, low-power CPUs, wireless proximity communication, spontaneous networking, touch screen displays, mobile internet connectivity, etc.), it becomes possible to provide real-time energy use feedback on the spot, with almost no additional hardware equipment.

The main contribution of this paper is the goal-driven development of a mobile phone application[2] for residential energy monitoring based on consumption data acquired by a smart meter. It considers general experience on feedback systems described in the psychological literature as well as results obtained from a survey of potential users. The resulting prototype on an iPhone shows how mobile phones can help users to monitor and control their energy consumption and allows evaluating which functionalities are regarded as most important, also with regard to individual differences concerning technological affinity.

The structure of the remainder of this paper is as follows: We first discuss related work before we outline in section 3 different feedback features that are important to get "users in the loop" when it comes to electricity conservation. In section 4, we describe the survey we conducted to gather an indicative basis for our prototypical development. Section 5 describes the experimental setting we used to evaluate the suitability of electricity feedback on mobile phones. In section 6, we describe the user study and report on selected results, before we summarize our main findings and conclude with an outlook in section 7.

2   Information Provisioning on Mobile Phones

With the rise of ubiquitous computing, data about real-world events is being captured at an increasingly detailed level. Together with the rapid growth of the mobile phone market and mobile internet access, this has led to a large number of mobile applications which aim to support users' daily life in a wide range of areas. To name a few, this ranges from insurance claims assistance [3] over shopping assistance [2] to emergency response [13].

Other work focuses on providing information about the personal environmental impact of travel, shopping, and residential resource consumption. Ecorio (ecorio.org) and Carbon Diem (carbondiem.com) for example allow for tracking the personalized carbon footprint with the help of the smart phone´s GPS sensor. The greenMeter (http://hunter.pairsite.com) aim at reducing the fuel consumption and resulting cost by using the mobile phone's internal accelerometer to measure forward acceleration and calculate fuel economy as well as carbon footprints. The Carbon Tracker (www.clearstandards.com/carbontracker.html) application serves a similar purpose, but bases the calculation mainly on self-reporting. The authors of [10] developed a mobile application prototype that semi-automatically senses and reveals information about personal transportation behavior and motivates users to choose green transportation.

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[2] Technical details about the infrastructure and its components can be found in [22].

Information provisioning with respect to residential resource consumption has received considerable attention lately. There exist numerous mobile phone applications that allow users to monitor the electricity consumption of individual household devices. These solutions are often based on smart power outlets, like Tendril (tendril.com) or the Energy UFO (visiblenergy.com). Once installed, they measure the attached load and are capable of transmitting the measurement data wirelessly to a remote user interface (UI). However, these products lack the possibility to aggregate the consumption of multiple sensors and to fuse the different data into a comprehensive picture. To surpass this limitation, other work has focused on developing systems that combine multiple sensors. The authors of [23] built a system that enables the integration of commercially available smart power sockets that transmit their measurements via Bluetooth or Zigbee. A gateway is responsible for the discovery of the smart sockets within wireless communication distance. The approach facilitates functions such as remote on/off switching, and offers local aggregates of device-level services (e.g., the accumulated consumption of all sockets). While the concept is interesting and helps to provide important findings for future work, deploying a large number of sensors in a residential environment is often too cumbersome and expensive. In contrast to solutions which provide consumption feedback on device level, Peterson et al. [18] use a circuit breaker box that has to be attached to the fuse box to acquire the electricity data per circuit. Other work has been conducted by Björkskog et al. [4] who developed a mobile prototype targeted to establish a more playful access to energy consumption data to better address non-engineering-related user groups.

Our mobile phone application differs from those applications as it is fully integrated into a backend architecture that is based on smart meter technology which is going to be installed in large numbers in the U.S. and Europe over the next years. This allows us to combine both, feedback on the entire electricity consumption and – with a simple yet powerful functionality – on the consumption on device level. We also emphasize on concepts to present and preprocess information in a way that motivates users to become engaged into their energy consumption.

3   Energy Consumption Feedback

We expect that automation and ambient, autonomous systems will play a major role in increasing energy productivity and energy efficiency. However, in addition to systems which do not require user involvement, approaches that explicitly get users engaged into a sustainable lifestyle can considerably help to achieve today's ambitious saving targets. User-induced saving effects mainly result from two factors: First, the energy demand of many loads (including heating, air conditioning, ventilation, warm water systems, driving habits, etc.) is highly dependent on how we operate them. Virtually identical households (same buildings, same number of habitants, identical age, same location etc.) can vary by a factor of 2.6 in energy usage [17]. Second, the decision to invest in efficient devices and energy saving technologies (including ambient systems, thermal insulation, etc.) is largely up to the consumer. Therefore, awareness and willingness to take action are crucial. Both aspects can be addressed by ICT.

The existence of many unnecessary loads can be attributed to a lack of transparency in energy consumption [5]. This leads, at least partly, to lost saving potentials, because residents lack knowledge about their energy consumption in general as well as about the pool of devices used at home. In fact, they have rather limited possibilities to investigate their household's efficiency with simple measures [20]. However, feedback has been shown to be one of the most effective strategies in reducing electricity usage in the home [12]. With the advent of low-cost sensing technologies and advances in machine learning, we now have the potential to provide personal, relevant feedback in real time for a variety of consumption activities [11].

It is generally expected that with detailed and immediate feedback, 5% to 15% of the residential electricity consumption can be conserved [6]. However, to maximize saving potentials, technology itself is not sufficient, nor is the pure visualization of consumption values in some "obscure" electrical measurement unit. In fact, feedback on energy consumption is often presented in a rather technical and non-interactive way on somber devices that lack the ability to motivate users. We tried to improve on that: By connecting a smart electricity meter with a mobile phone application, our electricity feedback prototype is not only particularly easy to use (and features a nice interface on an iPhone), but it realizes those features that seem to be most promising in terms of energy feedback. Following the literature [9], feedback in the context of energy monitoring has to feature several key characteristics, which we outline below.

Reduce usage barrier. Many available energy monitoring systems require either complex installation around the central fuse box or the use of many electricity sensors. These systems typically induce a high usage barrier because the wiring around the fuse box is – at least across Europe – only accessible to technicians, and because equipping appliances throughout the house with a dedicated sensor is costly and rather burdensome[3]. However, since energy monitoring is a low involvement topic for many people, systems should be designed to allow for easy interaction.

Strong integration into daily life. Integration of feedback into users' daily life is important for long term energy conservation. Trials have shown that when using an additive battery-dependent display for feedback, in 50% of all cases users do not replace the battery once it is depleted [21]. This indicates a loss of interest after the initial curiosity has been satisfied. Thus, since not being integrated into daily life, these additive displays seem not capable motivating for a longer time.

Timeliness of informational support. Feedback should be provided frequently, in real time, and at hand when needed allowing users to relate feedback to a certain behavior or device usage [1]. Continuous feedback has been proven to be most effective. The authors of [20] investigated the effects of continuous versus monthly feedback. The results show that people confronted with continuous feedback save more (12 %) than those who had received monthly feedback (7%). In addition, only feedback that is at hand when needed is able to satisfy spontaneous curiosity.

Breakdown of the entire energy consumption. It is important to provide a possibility to disaggregate the overall consumption. A breakdown (e.g., allocation to specific rooms, appliances, or times of the day) is a powerful way of establishing a direct link between action and result. This considerably improves the intensity of reflection and interpretation of a measure [9].

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[3] A comparison of different energy monitoring solutions can be found in [16].

The above-mentioned characteristics are believed to be important for energy feedback systems to be effective. Hence, we further investigate them in the next sections. We specifically consider how to get "users in the loop", to attract users' attention, and to increase the added value for users.

4   The User Survey

Before designing and developing an energy consumption feedback prototype, we conducted a survey to provide us with an idea what functionalities users would expect. The survey design was developed in three steps. First, we initiated and led a discussion in a focus group[4] in order to identify two applications where the participants were confident that these were easy to explain in a paper-based survey and offered varying degrees of the above-mentioned characteristics. Applications which were found to be suitable were:

1) A mobile phone application that utilizes a smart metering infrastructure that allows users to get feedback on the consumption of individual appliances (timeliness of informational support, suitable for investigation of specific loads, high degree of interaction, and portability).

2) A washing machine with a simple display which provides feedback on energy consumption of specific programs and information on the energy that is saved by choosing eco-programs (low timeliness of information, low degree of interaction, and no portability).

The approach of contrasting two different applications allowed us to draw conclusions based on the "inverse" application, and we also expected the study design to reveal the degree to which user expectations achieved a mature state, i.e. a state where they can be used as a stable basis for a requirements analysis. In a second step, we extended the question catalogue by a set of constructs to evaluate general functionalities of consumption feedback. We used established constructs taken from the Technology Acceptance Model (TAM) [7], constructs on the word of mouth, and questions concerning the willingness to pay. To evaluate the validity of the reported willingness to pay, we used a technique called framing. Framing means that information can be presented in different contexts which affect the perception of the information [14]. In a third step, we evaluated the comprehensibility by reviewing the constructs of the questionnaire with non-experts.

The survey was conducted at lively points throughout the city center of Zurich., Switzerland. 185 persons participated in the survey (50.3% male) with all age groups evenly represented. The sample was slightly biased as respondents with a higher education degree and an above–average income were overrepresented. However, we do not expect this to considerably reduce the validity of the findings. In the following, selected results of the survey are presented. Regarding the general attitude towards conserving energy, roughly 50% of the participants think it is rather cumbersome to save energy and not fun. In doing so, 89% like to be supported by innovative technology.

The left side of Fig. 1 depicts the comparison of the perceived usefulness and the intention to use of the mobile phone application with the washing machine display.

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[4] 3 experts from academia, 4 industry experts, and 4 employees of consumer organizations.

The figure shows the mean as well as the standard deviation (as black error bars). The ratings for both applications are above average, with the mobile phone application performing worse over all the ratings. It was surprising to us that the washer application performed better than the mobile device with regard to the likelihood to recommend the application to a friend, the likelihood to use the application, and the expectation that the information would lead to energy savings. A potential explanation for this unexpected outcome is that the washer application had an inherent use case (the application domain "washing" and saving by selecting an "eco-program" was clear), while the innovative phone application had a more general and not very obvious use case ("you can follow your energy consumption and measure how much energy your devices consume, which can help you save").

In addition, we investigated the self-reported willingness to pay for a mobile application that allows for measuring the electricity consumption only. Knowing of the difficulty to obtain a reasonable indicator for a sales price with this method, we used the findings to get an indication for the relative price range, and for developing a better understanding on how stable the perceived value is. For that, we used two different, slightly modified versions of the questionnaire and distributed them half-half amongst the participants. The first version asked people for their willingness to pay, but not indicating the possible saving potential of such a technology measure. The second version indicated the monetary amount of potential savings (85$), thereafter asking for the amount people would spend. While the mean values do not vary significantly between both versions, the median increases from 16$ to 30$ when presented the version with frame. Thus, by providing an annual saving value, participants were willing to pay a higher price for the application. In addition, the standard deviation decreases significantly. This effect is referred to as framing effect and highlights that the expectations are only vague. From these results we can conclude that the price regarding such a mobile phone application is not yet set. Participants have a general understanding that mobile phone applications are low-priced. On the other hand, the results also show that it is hard to determine the price for an innovative product that is not yet touchable and the price can be varied according to the context the application is presented.
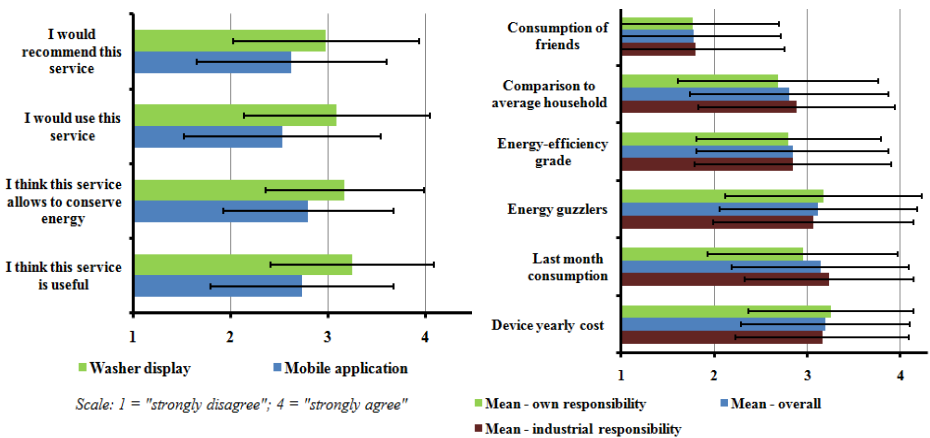

Fig. 1.

In order to conserve energy, it is important to be aware of how much particular appliances consume as well as of effective measures that increase the energy-efficiency. Thus, we asked users with what information they would like to be provided on a mobile phone application. The right part of Fig. 1 shows the participants' assessment of the different functionalities offered. Besides depicting the overall mean of the whole sample and the standard deviation in error bars, the figure provides a more in-depth view on the mean of participants that regard energy conservation as their own responsibility (N=65) and those that believe it is industry's responsibility (N=120). Those who strongly or slightly disagreed on the statement "The industry is primarily responsible for saving energy" (1 or 2 points on the four point Likert scale) belong to the first group. The second group consists of people who slightly or strongly agreed with the statement mentioned above (3 or 4 points). Overall, we find that participants prefer to be provided with the yearly cost of single appliances followed by the last month consumption and the biggest energy guzzlers of the household. However, users do not want to compare their consumption to the one of their friends or family. A closer look on the attitude of the participants reveals that participants who regard saving electricity as their own responsibility rate the identification of the biggest energy guzzlers significantly higher than others. We assume this goes along with their higher involvement and interest for both, their personal energy efficiency and defined measures that allow for conserving energy.

The survey results served as an indicative basis for our prototypical development. It encouraged us to offer a simple use case that makes the value of an innovative energy consumption feedback application clear even to individuals who are not familiar with the system. As an easy to explain use case, we identified a measurement function that can be explained as "learn how much a device consumes by just switching it on or off". On that basis yearly costs can be calculated and the biggest energy guzzlers can be identified.

However, the results on willingness to pay, perceived usefulness, and the intention to use the system also showed us that innovative services seem to go beyond the imagination of users. Thus, it is necessary to investigate possibilities of electricity consumption feedback on mobile phones in a controlled environment, ideally in a user study where users can get in touch with the application and where the understanding of the application`s functionalities can be guaranteed.

5   Experimental Setting

In this section, we present the setting we used to evaluate the suitability of electricity consumption feedback on mobile phones. Our prototype [16, 22] consists of a back-end architecture and an UI on the iPhone, and implements the above mentioned key feedback features. Being based on smart meters, which are currently rolled out in large numbers in Europe and in the U.S., the system requires no further modifications by the user. Thus, the necessary effort is limited to downloading an application, which leads to a low usage barrier.

By providing feedback through a mobile phone application, the prototype features both: feedback on a device that is already integrated in users' daily life, as well as the opportunity to provide immediate feedback that is at hand when needed. Through an interactive measurement functionality, the application not only allows users to

monitor, measure, and compare the energy consumption of the entire household, but also the electricity consumption of individual devices. It thus allows for users to link specific actions to their effects and helps them to identify the biggest energy guzzlers, which is key to take effective energy conservation measures [19].

The System Architecture of our prototype consists of three independent, loosely coupled components: The *mobile phone application* is linked through *a gateway* to *a smart meter* which measures the total electricity consumption of all household devices. The gateway's function is to manage and provide access to the data acquired by the smart electricity meter, while the mobile phone application allows users to interactively monitor, measure, and compare their energy consumption in real time. The system is based on the REST (Representational State Transfer) paradigm [8]. It enables easy and seamless integration of physical resources to the Web and makes them available through URLs. Through providing a web-based interface to the smart meter, we allow for easy interoperability with other applications, such as the mobile phone application.

Compared to traditional electricity meters used today, a smart meter contains a communication interface that is intended to enable remote meter readings for billing purposes. In order to achieve real-time feedback, we extended the meter's capabilities to send out all available consumption data every second to a gateway, which parses and stores the received data in a SQL data base. A small Web server provides access to the gateway's functionalities and the meter readings through URLs. It further handles the incoming requests from the UI. A more detailed view on the system and the benefits gained by using embedded Web technologies can be found in [22].

The User Interface. The mobile phone application, realized on an iPhone 3GS, is used to provide electricity feedback. The UI consists of four main views (Fig. 2) – current power consumption, history, device inventory, and measurement – on which we elaborate in the following.

Fig. 2. The UI (left to right): Consumption view, history view, measurement view, and device inventory view

The *consumption view* is used to determine the real-time electricity usage of the entire electricity demand of the household. Once the view is active, the scale is auto-updated every second to provide instantaneous feedback. The color-coded intervals help users distinguish how high their current consumption is compared to their historic values. Red indicates a high, yellow a normal, and green a low consumption. Since an equidistant partition of the color ranges leads users to believe their consumption is

seldom high, we tried experimenting with different interval sizes and ended up with a partition where the intervals correspond to the quantiles. The blue part of the scale depicts the level of the household standby electricity consumption (i.e., base load). It is determined by a weighted moving average of the consumption values measured between two and four o'clock in the morning. The weight for each new value taken into account corresponds inversely proportional to the difference between this value and the previous average consumption value.

The *history view* combines historical consumption feedback with budgeting and projections. The view's upper half depicts the historical consumption of the household in form of a line graph. Users can choose between different predefined time periods ranging from one hour to one year. The lower part of the screen can be changed to either display aggregated consumption or budgeting and projections. For both the scale can be swapped between kWh and cost. Per default it shows the aggregated consumption of the last five selected periods (Fig. 2) and provides users with an easy way to identify at what times their accumulated consumption peaked. The bar scale is color-coded, providing users with feedback on how their consumption compares to a typical household with same characteristics (e.g., size, location). When changed to budgeting and projections, users can see their remaining budget on a bar that drains as budget runs out together with a projection of where their consumption is going to cease in case it remains at the current level. All calculations are done based on values users enter on the application's first startup.

The *measurement view* allows for users to interactively breakdown the entire electricity usage and to detect how much power switchable appliances consume in operation (and by unplugging the device also in standby). To perform a measurement, users simply activate the process by pressing the start button and thereafter switching the device under measurement on or off. The corresponding result is shown in two to ten seconds. Besides considering the increase or drop in real power, the measurement algorithm [24] also takes the different electric circuits and other physical variables, such as apparent power and power factor, into account. This allows determining on which circuit the switching event has occurred, and can be used for failure detection.

The *device inventory view* provides users with an overview of the previously measured devices as illustrated in Fig. 2. After measuring a device, users can personalize the measurement. The UI offers the possibility to take a picture of the appliance, adjust utilization on which incurred cost calculation is based, enter a location, and assign a device category. In case a category is selected, further category-specific information and guidance on how to save energy can be obtained.

6 The User Study and Selected Study Results

In the following, we first focus on the user study we conducted to evaluate the suitability of mobile phones as energy feedback devices, before we report on selected study results with respect to the application and the perceived value of different feedback functionalities.

The User Study. To evaluate which of our implemented functions are perceived as most valuable on a mobile phone, we conducted a user study with 25 participants of different background from students over marketing and sales persons to industry

experts. Twelve of them were male (48%). We covered all age groups: 32% were between 18 and 25 years old, 28% between 26 and 35 years, 36% between 36 and 49 years, and 4% between 50 and 70 years.

The user study was divided into two parts: The first part aimed at familiarizing participants with the functionalities of the application. First, the consumption as well as standby consumption of five appliances (a light bulb, an energy saving lamp, a kettle, a game console, and a flat screen monitor) had to be measured by each participant (Fig. 3) to provide an idea of how easy it might become in the future to determine the consumption of different devices – compared to the rather cumbersome solutions that exist today. This also allowed us to validate the measurement functionality of the iPhone application. After that, we used a guided interview to explore and discover the different functionalities and their meanings. For that, each user had to accomplish different tasks which involved various implemented features (e.g., determine highest historical consumption or current consumption, how current consumption compares to historical, standby consumption, etc.) and aimed at gaining a solid understanding of the application.

The second part of the study consisted of a questionnaire that aimed at a general evaluation of the application and at assessing the functionalities that are perceived most valuable from a user perspective. The questionnaire was anonymously completed in an unobserved environment. We asked the participants to rate the importance of implemented as well as possible future functionalities. Moreover, users had to rate the complexity, usefulness, ease of use, ease of learning, and satisfaction of the mobile phone application. The latter four factors are taken from the USE, an established questionnaire for measuring the usefulness, satisfaction, and ease of learning of a UI by Lund [15]. Additionally, we asked the participants to indicate their intention to use (once a week, once a month, or never), and the willingness to tell their friends (word of mouth). All items were rated on a five-point Likert scale.

Selected Study Results. The general evaluation of the mobile applications shows that participants had understood the UI and the underlying functionalities. On a scale from one (lowest) to five (highest), participants rated the ease of use (4.04), ease of learning (4.04), and satisfaction with the application (4.16) all significantly above average (means in brackets). Taking into account that we covered a wide age range (18 to 51 years) and only five participants were iPhone users, we regard this as a very positive response for a prototypical application. General results also indicate that the feedback latency was perceived as more than satisfactory, the measurement functionality as easy to handle, and the individual views as easy to understand (Fig 3 right). Determining the consumption of individual devices, over all conducted measurements participants achieved an accuracy of ±5% compared to the real consumption we had previously verified.

The left of Fig. 4 illustrates the results for the mobile application assessment in terms of usefulness, intention to use, and word of mouth. Besides depicting the overall mean of the whole sample and the standard deviation in error bars, the figure provides a more in-depth breakdown in terms of technological affinity. It was assessed based on four items: 1) my friends and colleagues often ask me what I think about new telecommunication technologies, 2) my friends and colleagues are better informed about new technologies than me (inversed), 3) I am always up on the latest technologies in my area, and 4) I think it is fun to test new technologies. We calculated the average response for the four items after inverting question two. People
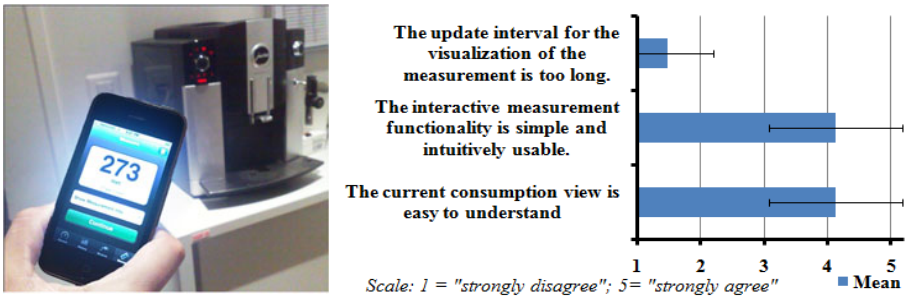
Fig. 3. User measuring the power consumption of a device (left) and evaluation of the iPhone application (right)

with a scale mean of 3.64 or less were grouped to "not technological affine" (N=10), whereas people with a higher mean were assigned to the group "technological affine" (N=15). The evaluation on perceived usefulness, intention to use, and word of mouth was only marginally affected by the technology affinity (except frequency of use where the technophile users received higher scores). The application reached high scores especially for positive expectations towards saving effects and knowledge gains. Not surprisingly, technophile people indicate they would use the application more often than others. The word of mouth effect is significantly high. It thus offers potential for utilities or smart meter manufactures to positively influence their image providing such an application. A large part of the participants agrees that the application is useful. The prime use of the application – especially with technophobe participants – is seen in increasing the knowledge about the electricity consumption of individual devices. In consistence with the survey results, the claimed external social motivation ("demonstrate good behavior to others") to use such a mobile application remains low. Users in general do not feel the need to express their proenvironmental behavior to others (or are not willing to admit it), but technophile people would rather do it than non-affine.

In order to evaluate which functions with respect to energy feedback are perceived as most valuable on a mobile phone, we asked the participants to indicate their impressions on the following functionalities: Real-time visualization of the total consumption; visualization of the household's standby consumption; comparison of the current consumption with the historic consumption; costs of recent months; consumption of individual devices; consumption of recent months; projections of yearly cost on device level; efficiency grade of appliances; overview of biggest energy guzzlers; comparison of the consumption with the one of friends; possibility to show others my appliance pool; possibility to set a saving target.

Fig. 4 right provides an overview of the assessment of mobile electricity consumption feedback features. It depicts an in-depth view on the rating per functionality sorted in an ascending order according to the overall mean value (shown on the right). Overall, we find that participants value at-a-glance-feedback on their most prominent energy guzzlers most (mean of 4.72), followed by those functionalities that increase the knowledge about consumption or cost. The real-time view of the entire consumption achieves similar ratings with a mean of 4.6. For both, 96% of the participants
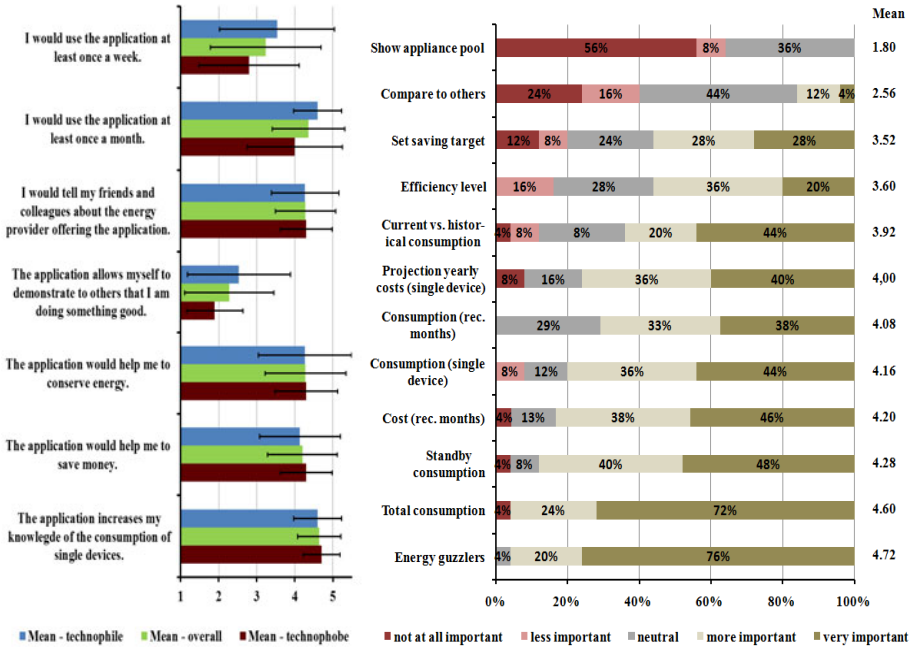
Fig. 4. Mobile application assessment: Usefulness, intention to use, and word of mouth (left). Mobile electricity feedback: Functionalities (right).

indicated the importance of these functionalities. Down to a mean value of 4.16, still 80% of the participants perceive functionalities such as standby consumption and consumption of an individual device important. All these functionalities have in common that they provide an action-guiding feedback from which users can directly draw effective measures to lower their electricity usage. Surprisingly, cost of the recent months receives a high importance ranking of 84%, although the feature itself is not action-guiding. Below a mean value of 4.16 the picture changes. Those functionalities that present aggregated information from which people cannot imply a direct action (e.g., consumption of recent months, comparison of the current vs. historical consumption) receive significantly lower ratings and reside in the bottom half. Functions aiding users through motivational support (e.g., set a saving target) are not perceived as important, nor are those that deal with social aspects (e.g., compare to others). They reside in the bottom third and especially the latter two receive a low importance rating of 16% and 0% respectively. A closer look on the technological affinity reveals that in general technophiles rate the functionalities higher. However, technophobes value features that present action-guiding (e.g., energy guzzlers) and device-level information (e.g., consumption of an individual device) over aggregated information.

7 Discussion and Future Work

Our contributions are threefold: First, we could confirm that the existence of a clear and simple to explain use case behind energy consumption feedback systems is a key success factor, whereas when left to the imagination of the potential users, energy consumption feedback applications receive only medium ratings. Second, we developed a system that implements several promising feedback features, and which succeeded to receive positive ratings from users. The findings can serve as a starting point for further application development in this field. And third, we tested the benefits and capabilities and confirmed the suitability of such a mobile phone application to serve as an energy feedback system in a user study. We also identified the functionalities that are perceived most valuable by users, in general and with regard to individual differences concerning technological affinity.

We consider the applied methodology to develop a prototype application based on preliminary interviews and a survey with diametric application scenarios to be well suited for application development at an early stage. It helped us to critically assess the user requirements and to extend the application's functionalities. Exposing people to a functioning prototype was crucial for us to gather experience with the application, while at the same time participants better understood the usefulness of the application. In order to get users in the loop, we implemented the most promising feedback features and evaluated the different functionalities with our application. We found that the knowledge-increasing functionalities as well as those from which monetary savings can be directly implied are perceived as most useful. In contrast, functionalities that present aggregated information receive lower scores. In addition, the survey results as well as the user study indicate that social motivation is so far not an important factor in terms of energy consumption feedback. In order to address different target groups, we focused on the individual difference between technologically and non-technologically oriented people. To target the latter ones, a closer look revealed that it is important to implement simple, easy to understand, and action-guiding feedback that goes beyond aggregated information, such as a list of energy guzzlers.

Another important aspect is the interactivity of energy consumption feedback that is introduced through the mobile phone application. We believe that this is key to get users involved into energy conservation. The measurement functionality, which allows users to determine the consumption of individual devices, is a good example how interactivity can be used in this context. It easily enables users to familiarize with their energy consumption. However, providing feedback to get users in the loop is just the first step. As our results show, participants are more likely to use the application once a month rather than once a week without additional measures. Thus, it will be crucial to develop concepts that aim at keeping users in the loop. Besides further analyzing which functions users expect, our future work will investigate engagement strategies (e.g., competitions, alerts, and bonus points) to further involve users after their initial curiosity has been satisfied. Overall, we believe that the user-in-the-loop-paradigm together with automated energy saving systems can contribute considerably to mitigate energy consumption.

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