Working Paper Series
ISSN 1177-777X

Fostering Energy Awareness in Residential Homes Using Mobile Devices

Florian Reinhart, Kevin Schlieper, Michael Kugler, Elisabeth André, Masood Masoodian, Bill Rogers

Working Paper: 03/2013
October 16, 2013

Department of Computer Science
The University of Waikato
Private Bag 3105
Hamilton, New Zealand

Fostering Energy Awareness in Residential Homes Using Mobile Devices

Florian Reinhart, Kevin Schlieper, Michael Kugler, Elisabeth André
Human Centered Multimedia
Augsburg University
Universtitätsstr. 6a
86159 Augsburg, Germany
www.hcm-lab.de
andre@informatik.uni-augsburg.de

Masood Masoodian, Bill Rogers
Department of Computer Science
The University of Waikato
Private Bag 3105
Hamilton 3240, New Zealand
www.cs.waikato.ac.nz
{*masood, coms0108*}*@waikato.ac.nz*

There is considerable global effort being made towards identifying ways of reducing energy consumption to cope with growing demands. Although there is potential for energy saving in many sectors, our focus is on reducing energy consumption in residential homes. We have developed a system which combines home automation and energy usage monitoring technologies. The system offers a range of tools designed for mobile devices to assist users with monitoring their energy usage and provides mechanisms for setting up and controlling home appliances to conserve energy. In this paper we describe our system and a user study we have conducted to evaluate its effectiveness. The findings of the study show the potential benefits of this type of mobile technology.

Mobile technology, energy monitoring, energy awareness, residential homes, information visualization.

1. INTRODUCTION

People require energy every day, for heating their water, for cooking their food, for cooling their houses, etc. Energy is used not only for basic human needs, but also for making people's lives more enjoyable and comfortable. Since we are using more and more energy for maintaining our life styles, the worldwide energy demand is steadily growing. In general, there are two trends that affect the energy supply industry: growing demand and sustainable generation. While worldwide energy consumption has been increasing over the past few decades (U.S. Energy Information Administration 2004), so has our capability and willingness to generate energy in a sustainable manner using renewable sources like solar or wind energy. For instance, in the United States alone the number of homes with photovoltaic installations grew by 40% in 2009 and this trend is likely to continue (Sherwood 2010). Although using renewable energy reduces the output of greenhouse gasses (Casper 2009), these sources of energy are less reliable in terms of generation, and therefore require better management in terms of consumption.

Statistics show that about one-third (29%) of the energy used in the European Union (Commission 2010) is consumed by residential homes (see Figure 1), which is very similar to other developed regions. Although, there are other sectors like industry which consume a lot of energy, private households offer a great potential for saving energy.

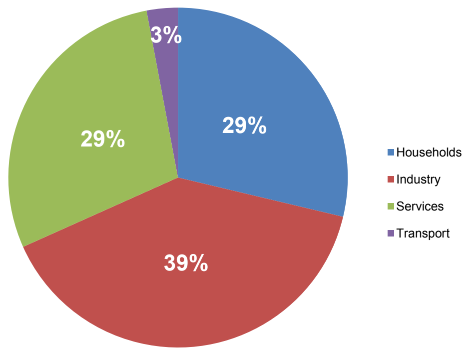

Figure 1: *Electricity usage in the European Union.*

Here we propose two strategies for conserving energy in private households. The first strategy is to use an automated system that controls home appliances, so that energy-wasting behavior by users can be partly mitigated (e.g. automatically turning off the heating when windows are left open). The second strategy is to use mobile technology to assist residents to save energy and encourage them to change their energy consumption behavior. To do this, however, the users must first know how they can improve their usage behavior, and one prerequisite for this is to be are aware of how much energy they are consuming.

In general, the process of a non-automated approach to energy saving in private households can be broken down into two main parts. First, the residents must identify saving potentials in their household, which requires them to be aware of the energy consumption of individual appliances. Second, once they know how and where energy is actually being used, they need to be assisted and persuaded to change their behavior to reduce their energy usage. Unfortunately, however, there are some challenges in achieving both of these two parts. In relation to the first part, usually people know their overall energy consumption, because that is what their energy providers bill them for. Nevertheless, finding out how much energy each device actually uses or how much of the overall consumption each individual person in a house has consumed, is very difficult. As challenging as solving this essentially technical problem may be, overcoming the challenge of changing people's behavior to save energy while still living a comfortable life is even harder.

In this paper we introduce a system, called Ubiquitous Smart Energy Management (USEM), which not only provides an automated solution for reduction of electricity usage, but also caters for the non-automated approach by providing detailed energy consumption information to users, and incorporates mobile tools to assist and encourage users to change their energy consumption behavior. The focus of this paper is mainly on these non-automated components of USEM designed for mobile devices.

We start this paper with a review of related literature on technologies for energy saving at residential homes. We then present the mobile user interface components of USEM, and discuss a laboratory-based study we have conducted to evaluate the usability of these mobile tools. Finally, we briefly provide the results of an analysis of the capabilities of USEM against existing guidelines for the design of persuasive technology.

2. ENCOURAGING ENERGY SAVING

Although one might assume that people would naturally be inclined to save energy, not only because this is good for the environment, but also because it leads to saving money, this does not always seem to be the case. Therefore, in recent years several technologies have been proposed to encourage energy saving by fostering awareness of energy use. These technologies can be categorised into those that utilize games or social media, and those that rely on ambient devices.

2.1. Games and Social Media

Several systems have been developed to encourage people to conserve energy and increase their energy use awareness through games and social media. The Power Explorer (Gustafsson et al. 2009) game tries to help teenagers save energy. This mobile phone game takes into account the changes in energy consumption at home by the players. There are different game elements: habitat, pile and duels. The habitat shows the user's avatar in a virtual climate environment, in which energy usage causes CO_2 clouds to appear, which is bad for the avatar. In the pile view players can see how they are ranked compared to other players, and in the duels players compete directly against each other. The goal of the duels is to increase the energy awareness about the appliances, since players have to adjust their household energy consumption to win. A study of Power Explorer showed that a group players consumed about 20% less energy than a reference group of non-players.

Other research has focused on integration of home energy feedback into social networks. For instance, Mankoff et al. (2007) demonstrated integration of energy usage feedback to the MySpace social network to motivate people to conserve energy. Similarly, Foster et al. (2010) have developed a Facebook application, and have shown in a study that energy consumption can be reduced through social encouragement and competition. Petkov et al. (2011) expand the idea of social comparison with their social application EnergyWiz in which users can compare their energy usage with their own history and that of others.

Midden and Ham (2008), on the other hand, performed a laboratory-based experiment in which participants could save energy while using a simulated washing machine. This study showed that social feedback provided by an embodied agent was more effective than just factual feedback about the energy savings made.

These types of social network related systems rely on surveillance and self-monitoring techniques. However, they generally only provide feedback at the household level and not at the individual user's level.

2.2. Ambient Devices

Kim et al. (2010) outline design requirements for ambient devices to create effective persuasion. In a study they identify ten stages from raising awareness to behavior change and the maintenance of behavioral changes. Based on their findings, they then propose several persuasion methods including virtual and visually attractive rewards, personalized and tailored feedback, self-monitoring, and use of social media to compare one's own performance with others.

The Energy AWARE Clock (Broms et al. 2010) is an example of an ambient device that visualizes current and past energy usage of a household. The three design principles of complexity, visibility and accessibility are used to reduce the complexity of consumption data, make visible “hidden” or not directly obvious electricity consumers, and have the consumption data easily accessible. A three month user study of nine households showed that the users developed a better awareness of their energy use, and thought about changing their behavior to save energy.

Other ambient devices have been developed to help users save other resources such as water. Examples of these include UpStream (Kuznetsov and Paulos 2010) and Shower Calendar (Laschke et al. 2011). Studies of these systems have shown that these systems lead to reduction in water consumption.

Ham et al. (2009) conducted a study to see if ambient technology has the capability of persuading people subconsciously. In this study the participants were asked to rate the energy usage of three devices. The three groups of participants either received supraliminal feedback (150 ms), subliminal feedback (25 ms) or no feedback at all on their given answers. The feedback was given in the form of smiley faces directly after rating the consumption of a device. The results indicated that both groups with feedback gave more correct answers on average than the group without any feedback. Furthermore, the subliminal feedback group gave comparable answers to the supraliminal feedback group, and they also stated that they had not consciously seen any feedback.

3. ENERGY SAVING AT HOME

Technologies available to residential users to assist them with saving energy at home can be divided into two broad categories: energy use measurement and home automation systems.

Energy use measurement systems are able to record the energy usage for either individual home appliances or the entire household. Energy consumption statistics can then be generated and analyzed by the user to identify where energy savings could be made. Examples of such systems are Current Cost (Current Cost Ltd. 2013), the Energy Detective (Energy Inc. 2013) and Wattson (DIY Kyoto 2013). However, these systems only show users how much energy they have consumed in the past, and at best make some general suggestions about how to reduce energy usage in the future. These types of systems cannot actively control appliances to put energy saving tips into practice.

Home automation systems, on the other hand, can actively control energy consuming devices in a household, usually using a range of sensors that react to their environment (e.g. an air-conditioning system can be automatically switched on/off based on temperature sensor data). Examples of such systems include HomeMatic (eQ-3 AG 2013), Gira (Gira Giersiepen GmbH 2013) and Intellihome (Intellihome Automatisierungstechnik GmbH 2013). These types of system however are not very widely used.

One of the reasons why home automation systems are not used is because there are currently no universally adopted standards for home automation. Although standards such as KNX (KNX Association 2013) exist, the majority of home appliances do not conform to them. Without these standards, controlling off-the-shelf devices is usually limited to switching them on/off. Although this can be sufficient for controlling simple devices (e.g. lights), it is not useful for controlling more complex appliances (e.g. a washing machine).

Another reason why home automation systems are not broadly adopted is due to their complex configuration. Most people do not want to, or simply cannot, deal with a complex system set-up, especially the elderly (Meyer et al. 2003) but also the younger users (Ringbauer and Heidmann 2006).

There are several energy related prototype systems for residential homes that aim to deal with these problems. These system provide either or both of home automation and energy usage monitoring capabilities. Table 1 gives a summary of the capabilities and limitations of these systems against a number of important criteria. As can be seen, none of the systems satisfies all the identified requirements.

4. USEM PROTOTYPE SYSTEM

We have developed USEM (Kugler et al. 2011) to overcome some of the limitations of the existing systems, as summarized in the previous section. Like some of these systems, USEM supports residential users in conserving energy by combining

	Energy usage monitoring	Controlling appliances	Manual task scheduling	Automatic task scheduling	Support for off-grid renewable energy	Support for off-the-shelf devices	Ease of installation	Extensibility
Solar Home, (Banerjee et al. 2011)	yes	yes	no	no	yes	yes	difficult	no
AIM, (Capone et al. 2009)	yes	yes	yes	no	no	no	difficult	no
Energy Aware Smart Home, (Jahn et al. 2010)	yes	no	no	no	no	no	moderate	no
Intel Home Energy Management, (Intel Corporation 2013)	yes	yes	yes	no	no	yes	easy	yes
HESS, (Choi et al. 2009)	yes	yes	no	no	no	yes	difficult	no

Table 1: *Comparison of existing energy usage monitoring and home automation systems.*

the functionalities of home automation and energy usage monitoring systems.

To make people aware of their energy usage, USEM provides detailed statistics about the household's past energy consumption. For example, the overall consumption can be displayed for individual rooms, devices, or occupants of the house. These statistics allow the users to analyse their consumption history and, thus, identify saving potentials. In some cases USEM might also be able to suggest actions that would lead to a decrease of energy consumption. Furthermore, USEM supports the user to put theoretical energy saving ideas into practice. For instance, the user can schedule appliances to run when varying energy rates are the cheapest, or USEM can switch off devices when they are not needed (e.g. turning off the printer whenever the PC is switched off). By providing an intelligent scheduling for energy consuming tasks USEM is also able to use energy when it is available in off-grid cases (e.g. when the solar panels are generating electricity). Using a combination of these techniques USEM attempts to ensure that energy usage peaks are avoided, maximum renewable energy is used when available, and overall power usage reduced in an intelligent manner without necessarily reducing comfort levels.

To interact with USEM we have developed three different user interfaces (1) a web interface for performing more complex tasks such as managing manual and automatic task scheduling, (2) a tablet interface acting as a control unit that could be used from around the house, and (3) a mobile phone interface that can be used to interact with USEM while on the go.

The web interface has not specifically been tailored towards mobile technology. As mentioned, it provides higher-level access to the functionality of the system, and allows configuration, scheduling, and visualization of relevant information. The web interface, along with the more intelligent components of USEM required for task scheduling, etc. have been discussed elsewhere (Kugler et al. 2013). The focus of this paper, on the other hand, is on the tablet and mobile phone components of USEM.

4.1. Tablet Interface

The tablet interface acts as a control and access unit for USEM. Although the current application has been developed for an Apple iPad, it is envisaged that it could also in the future be installed in flat-panel displays incorporated into furniture, picture frames or walls to act as an ambient device interface.

Figure 2 shows the home screen of the tablet interface which is visible when the device is not being controlled by the user. This allows the users to have a constant view of the most important information about their household, which encourages them to monitor their energy use. The home screen is customizable with several widgets to display information such as a list of currently running devices, up-to-date energy prices when available, etc. This screen also shows the energy usage target set by the user, the current usage level, to motivate the user to keep their usage below their set target. If the target is being threatened, for instance when the user turns on a device, they get a warning from the system giving them the option of turning off a device which is not being used (if any) or not going ahead with their scheduled activity.

Figure 2: *Home screen of the tablet interface of USEM.*

This interface also allows users to view their energy consumption information over the past year, month, or day. Figure 3 illustrates one of the energy usage visualization. This information can be viewed in several different chart formats, and in various categories such as for the entire house, different rooms, all users, different users, all devices, different category of devices, etc. This is another important element of the user interface in terms of encouraging energy usage awareness.

Furthermore, the tablet interface gives energy saving recommendations, based on the past and current energy consumption data, to help users reduce their energy use. Figure 4 presents an example energy saving tips screen. On this screen the system suggests actions that would decrease the household's energy consumption, as well as calculating the savings that could be made if the advice is followed.

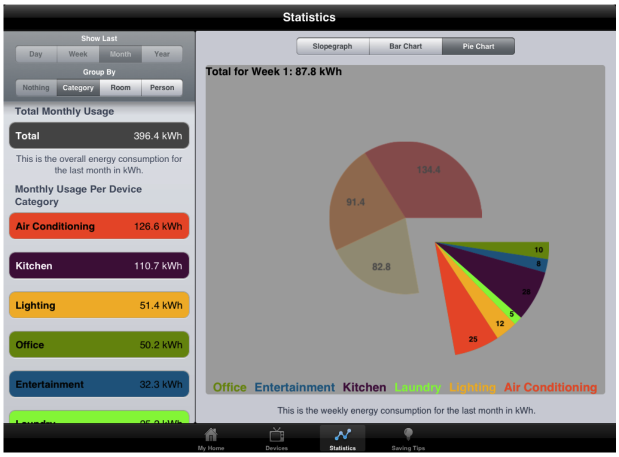

Figure 3: *Usage information screen of the tablet interface showing a pie chart.*

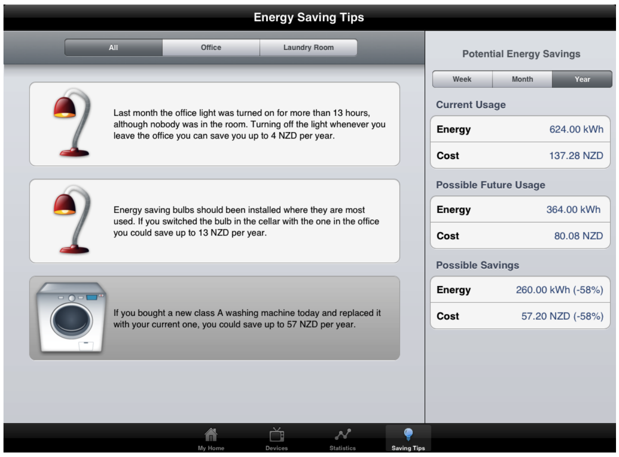

Figure 4: *Energy saving recommendations and their consequences if applied.*

4.2. Mobile Phone Interface

The mobile phone interface, developed for Apple iPhone, can be used to retrieve the status of home appliances or to interact with them remotely. It also notifies the user about energy usage events that occur while the user is away (e.g. a scheduled task cannot be undertaken because there is not enough renewable energy available). In such cases the mobile phone interface provides suggestions (Figure 5) about how the problem could be resolved and gives the user the opportunity to decide what to do (e.g. cancel a scheduled task, or turn off another device).

Of course the mobile phone interface can also be useful while the user is at home. For instance, it can be used to remotely access any of the devices connected to USEM (Figure 6, left). Users can also directly interact with home appliances by scanning the unique barcode that is attached to each device when they are added to USEM. For example,

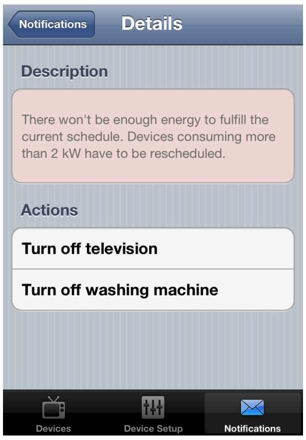

Figure 5: *Event notification screen of the mobile phone interface.*

this allows creating a new task for the washing machine right after the user has put the laundry into the machine. The mobile phone application also simplifies the initial set-up procedure for new devices, by mapping the barcode tags attached to power sockets with those of devices connected to them through a simple scanning process (Figure 6, right).

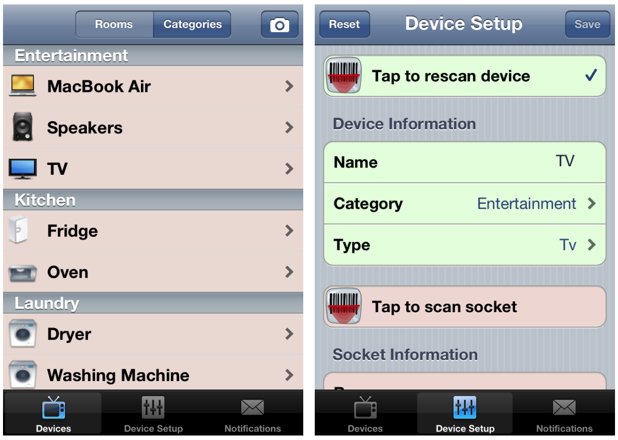

Figure 6: *USEM devices (left) and new device set-up (right) screens of the mobile phone interface.*

5. USER STUDY OF USEM

We conducted a user study to evaluate the usefulness of USEM and gauge if people would actually use a system like USEM to save energy if they had access to it. In the following sections we describe this study and discuss some of its main findings.

5.1. Methodology

The study was conducted at a usability lab, where the participants performed a series of tasks using the web, tablet, and mobile phone interfaces. To do the tasks the participants were provided with a laptop, an iPhone, an iPad, and model of a dryer and a computer as two home appliances (each with a barcode attached), as shown in Figure 7. We also attached a barcode to a power socket to make it recognizable by the mobile phone interface of USEM.

Figure 7: *The set-up used for the user evaluation.*

Each session started with a tutorial, which included some sample tasks similar to the actual tasks that the participants performed after the tutorial. The study session took about an hour in total, and was divided into three parts covering the use of the three interfaces of USEM. The sessions started with the web interface, as this was the most general part of the system and gave the user a comprehensive overview of USEM (this part of the study is not relevant to this paper and is not discussed here). This was followed by tasks that users performed using the mobile phone and tablet interfaces.

At the end of each task the participants answered several questions related to the task and the tool they had just used. Further, at the end of the session the participants completed a final questionnaire covering some questions about the users' overall impression of USEM.

5.2. Study Participants

Twenty participants took part in this study. They were between 20 and 62 years old, with an average age of 35. Five of them were female and 15 male; 11 were students, two researchers, two managers, two office administrators and one housewife. Thirteen of the participants (65%) had previous experience using a multi-touch screen; 11 (55%) owned a smartphone and 4 (20%) owned a tablet device. All of the participants used a computer daily, none had any previous knowledge of USEM. Table 2 shows a summary of the participants' demographic data.

	No. of Participants	Percentage
Gender		
Male	15	75.00 %
Female	5	25.00 %
Occupation		
Student	11	55.00 %
Researcher	2	10.00 %
Other	7	35.00 %
Experience		
Multi-touch screen	13	65.00 %
Daily PC usage	20	100.00 %
Own device		
Smartphone	11	55.00 %
Tablet	4	20.00 %

Table 2: *Demographic of the study participants.*

5.3. Study Tasks

As mentioned earlier, the study participants had to perform specific tasks using each of the different USEM mobile device interfaces. We asked the user to perform the following tasks on the mobile phone:

1. Adding a new home appliance to USEM.
2. Controlling a home appliance remotely.
3. Creating a new scheduled task to let USEM execute it at a later time.
4. Sending users a demo notification and asking them to react accordingly.

The participants then performed the following tasks using the tablet interface:

1. Controlling a home appliance remotely.
2. Exploring energy consumption statistics using a bar chart visualization.
3. Exploring energy consumption statistics using a pie chart visualization.
4. Exploring energy consumption statistics using a slopegraph visualization.

Figure 8 shows an example of type of slopegraph (Tufte 2013; Park 2013) used in this study.

5.4. Task Questionnaires

As mentioned earlier, after the completion of each task the participants were asked to answer a questionnaire. Two questions were common to all the task questionnaires. These are:

1. How easy was it to perform this task?
2. How useful would it be to have this functionality?

Figure 8: *Usage information screen of the tablet interface showing a slopegraph.*

The participants answered these questions using a Likert scale of 1-7, with 1 being the least positive and 7 the most positive.

5.5. Final Questionnaire

To evaluate the participants' overall impression of USEM we asked them the following questions as part of a final questionnaire:

1. How likely do you think it would be that you would decrease your energy consumption with the help of the visualizations on the iPad?
2. Would you want visualizations like on the iPad to be a permanent part of your home?
3. How often would you use your mobile phone to control your appliances remotely while you are away from home?
4. How often would you like to be notified on your mobile phone about what is going on in your household in terms of energy consumption?

5. Would you adapt your daily routine in order to use more renewable energy? (e.g. start cooking dinner an hour later?)
6. How useful do you find the overall system with regard to efficient energy usage?

5.6. Study Results

5.6.1. Results for the mobile phone interface

Figure 9 provides a summary of the average ratings given by the study participants for each of the two questionnaire questions for each of the 4 tasks performed using the mobile phone interface. As the results show, the participants generally found the tasks easy to perform, and the functionality provided by the interface useful.

Task 3 was the only task that was considered as being slightly more challenging than the other tasks. However, the functionality needed to perform this task was still rated as being useful. It is also important to note that this task was the most abstract task, which relied on the intelligent scheduling components of USEM.

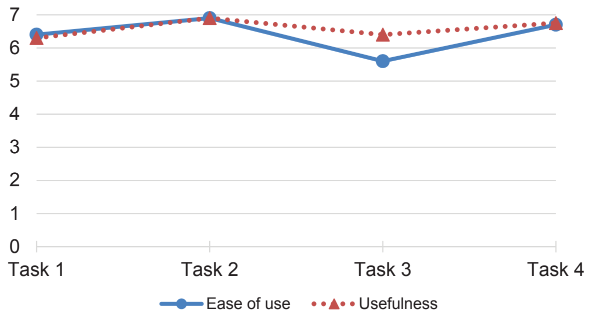

Figure 9: *The average ratings given by the participants for the tasks performed using the mobile phone interface.*

5.6.2. Results for the tablet interface

Figure 10 shows a summary of the average ratings given by the study participants for each of the two questionnaire questions for each of the 4 tasks performed using the tablet interface. Since the difficulty of the tasks steadily increased, the ease-of-use rating for the tasks decreased slightly from Task 1 to Task 4.

However, in general all task have been rated as easy to perform with average ratings ranging from 6.30 to 6.75. The ratings given to the usefulness of the functionality provided by the tablet interface for performing each of the tasks has a similar trend to the difficulty of the tasks. Once again, overall the participants found the functionality provided very useful.

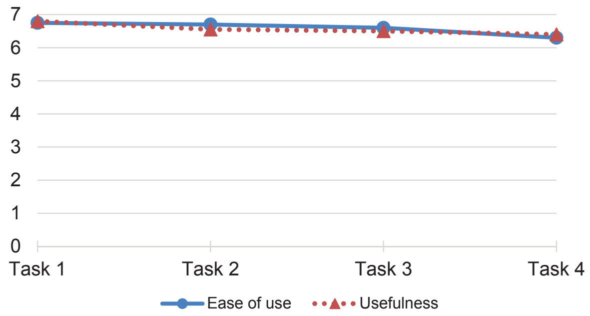

Figure 10: *The average ratings given by the participants for the tasks performed using the tablet interface.*

5.6.3. Results of the final questionnaire

The results of the final questionnaire are summarized in Figure 11. Perhaps the most important finding we can conclude from the final questionnaire is that the participants believe that USEM would be useful in helping them use energy more efficiently (Question 6). It is also important to note that the participants believe they would change their daily routines in order to use more renewable energy (Question 5).

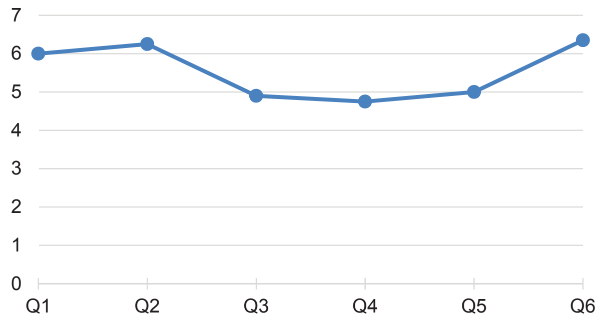

Figure 11: *The average ratings given by the participants for the questions of the final questionnaire.*

The following is a summary of some of the main points made by the study participants in their comments to questions of the final questionnaire.

- Many of the participants stated that they would like to be able to determine what events they should be notified about. They feared that they would get annoyed or distracted by notifications if they did not have some control over the notifications sent to their mobile phone.
- Most of the participants especially liked the possibility of controlling all the appliances using a single interface, rather than using a variety of different user interfaces for controlling different home appliances.
- The participants confirmed that they do not know how much energy each of their

appliances uses. They rate their energy usage awareness as relatively low. They liked the energy usage visualizations provided by USEM, and thought that these would assist them to better understand the power usage of their appliances.

- Several participants stated that they do not have a good understanding of the kWh measurement unit. Instead they would prefer some kind of visualization, which is easier to understand and does not require any technical knowledge. They also suggested to display dollar amounts, and setting the saving goal in dollars as well.
- One participant commented that he would like recommendations for a saving goal. In this participant's opinion it is difficult to set a saving goal, since it might be hard to determine a realistic energy consumption limit. So the system could provide a recommendation for a feasible saving goal based on previous usage data.

6. PERSUASIVE ASPECTS OF USEM

It is important to note that tools and technologies, such as USEM, which aim to assist people with changing their behavior need to be "persuasive" in their approach. The idea of *computers as persuasive technology* was introduced by (Fogg 1997) to deal with the question of how interactive computer technology could be used to persuade people to change their behavior or attitude. The functional triad, as defined by (Fogg 2003), is a framework that illustrates three roles computers can play in a persuasive context (Figure 12). These roles are categorized as tool, medium and social actor.

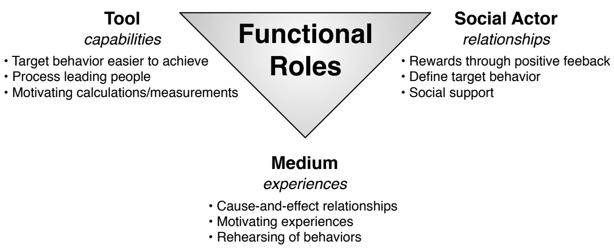

Figure 12: *The roles computer technology can play in persuasive context, as defined by Fogg (2003).*

In the context of the work presented in this paper we are mainly concerned with computers as persuasive tools. Tools increase capabilities by making the desired behavior easier to achieve, by guiding people through processes, or by calculations and measurements that motivate people to reach their goals. There are seven different categories of persuasive technology tools (Fogg 2003), which can be combined together in a single system or application.

1. **Reduction:** People can be persuaded by reducing complexity. A good example of a reduction is the *one-click buy* functionality provided by Amazon (Hartman et al. 1999), which reduces the ordering process to a simple button click.
2. **Tunneling:** This is the process of leading a user step-by-step through a specific procedure. An example of tunneling is the ordering process of online shopping sites. Such a guided process can provide opportunities for persuasion along the way. For instance, an online shopping site can suggest other items of interest to the buyer during the ordering process.
3. **Tailoring:** This approach persuades through customization, by providing only the type of information which is relevant and interesting to the user. An example of this is customized newsletters sent to users offering them products that match their buying profiles.
4. **Suggestion:** This means providing suggestions at the right moment. An example of this is advertisements along a highway, that for instance place an advert for a restaurant near its physical location and not miles away.
5. **Self-Monitoring:** People like to control themselves and check whether they have reached a predetermined goal. An example of this is a heart rate monitor that can be used to monitor the heart rate during exercise.
6. **Surveillance:** People tend to change their behavior when they know that they are being observed. An example of this is messages like "How am I driving?" at the back of some delivery trucks, to ensure that the drivers know people can complain about their bad driving, so they drive more carefully.
7. **Conditioning:** Giving positive, or negative, reinforcement can have a persuasive effect. An example of positive reinforcement is being on the high scorers list in a computer game, which can persuade people to play the game longer to improve their placement on the list.

To measure the success of a system as a persuasive technology clearly requires a long-term study of the use of the system in real-life settings to see if it indeed assists its users with changing their behavior. Although we are yet to conduct such a study of USEM, we have attempted to analyze the ways in which USEM might be able to play the role of persuasive technology listed above. Below we provide a summary of this analysis.

1. **Reduction:** USEM reduces the complexity of the large volume of energy usage data, collected for many devices over an extended period, by categorizing it, and allowing the user to view it in a variety of forms.

2. **Tunneling:** USEM provides step-by-step guidance for dealing with the process of adding new appliances to the system, dealing with notifications, managing energy saving targets when they are breached, etc.

3. **Tailoring:** Energy usage information provided is tailored to individual users (i.e. their personal data), energy saving recommendations provided are tailored to each specific USEM installation and are always relevant to the context.

4. **Suggestion:** When USEM warns users about missing their targeted saving goals, it suggests what actions could be taken, for instance by giving a list of devices that could be turned off. Also when USEM sends notifications to the mobile phone interface when scheduled tasks cannot be undertaken, it provides a list of suggestions that the user can select from.

5. **Self-Monitoring:** By measuring energy usage of each individual (when possible), USEM allows them to monitor their own current performance against targeted saving goals, as well as allowing them to monitor their past usage history in various statistical visualization forms.

6. **Surveillance:** Due to the fine granularity of energy usage data that USEM collects, the user knows (even when living in a house with others) that their consumption behavior is recorded and can be tracked by others when allowed.

7. **Conditioning:** By allowing users to compare their own energy usage behavior to others, as well as their set targets, USEM provides users with positive or negative reinforcements depending on their performance.

7. CONCLUSION

This paper has presented the mobile interface components of the USEM system, which aim to support the inhabitants of residential homes with the process of monitoring their energy usage, and making energy savings possible without necessarily reducing their comfort levels. USEM allows its users to connect and control their home appliances, as well as analyze and understand energy consumption information by those appliances using a range of scheduling, notification, and visualization tools specifically developed for mobile devices.

Our laboratory-based user evaluation of USEM has shown the potential benefits of its interface components for mobile devices in providing the necessary means of assisting people with saving energy, as well as encouraging them to monitor and change their energy use behavior.

We have also briefly analyzed the capabilities of USEM as a persuasive technology, by examining some the features of its mobile interface components against existing guidelines for the design of persuasive technology. Although this analysis shows that USEM satisfies these guidelines, it is important to conduct a more formal real-life user evaluation of the persuasive capabilities of USEM.

We are therefore planning to deploy USEM in residential homes to carry out a long-term study to evaluate the effectiveness of USEM in changing users' behavior in terms of making energy conservation.

ACKNOWLEDGEMENTS

We would like to thank the participants of our user study. This research is related to the IT4SE, funded by BMBF. For information regarding IT4SE visit `http://www.it4se.net`.

REFERENCES

Nilanjan Banerjee, Sami Rollins, and Kevin Moran. Automating energy management in green homes. In *Proceedings of the 2nd ACM SIGCOMM workshop on Home networks*, HomeNets '11, pages 19–24, 2011.

Loove Broms, Cecilia Katzeff, Magnus Bång, Åsa Nyblom, Sara Ilstedt Hjelm, and Karin Ehrnberger. Coffee maker patterns and the design of energy feedback artefacts. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems*, DIS '10, pages 93–102, August 2010.

A Capone, M Barros, H Hrasnica, and S Tompros. A new architecture for reduction of energy consumption of home appliances. In *Proceedings of the European conference TOWARDS eENVIRONMENT*, March 2009.

J. K. Casper. *Greenhouse Gases: Worldwide Impacts*. Global Warming. Infobase Publishing, December 2009.

Kwang-Soon Choi, Yang-Keun Ahn, Young-Choong Park, Woo-Chool Park, Hae-Moon Seo, Kwang-Mo Jung, and Kyeung-Hak Seo. Architectural design of home energy saving system based on realtime energy-awareness. In *Proceedings of the 4th International Conference on Ubiquitous Information Technologies & Applications*, ICUT '09, pages 1–5, December 2009.

European Commission. *Energy: Yearly statistics 2008*. Publications Office of the European Union, June 2010.

Current Cost Ltd. Current Cost. http://www.currentcost.com, August 2013.

DIY Kyoto. Wattson. http://www.diykyoto.com, August 2013.

Energy Inc. The Energy Detective (TED). http://www.theenergydetective.com, August 2013.

eQ-3 AG. HomeMatic. http://www.homematic.com, August 2013.

B. J. Fogg. Captology: The study of computers as persuasive technologies. In *CHI '97 Extended Abstracts on Human Factors in Computing Systems: Looking to the Future*, CHI EA '97, page 129, March 1997.

B. J. Fogg. *Persuasive Technology: Using Computers to Change What We Think and Do*. Morgan Kaufmann, 2003.

Derek Foster, Shaun Lawson, Mark Blythe, and Paul Cairns. Wattsup?: Motivating reductions in domestic energy consumption using social networks. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, NordiCHI '10, pages 178–187, October 2010.

Gira Giersiepen GmbH. Gira. http://www.gira.de, August 2013.

Anton Gustafsson, Magnus Bång, and Mattias Svahn. Power explorer: A casual game style for encouraging long term behavior change among teenagers. In *Proceedings of the International Conference on Advances in Computer Enterntainment Technology*, ACE '09, pages 182–189, October 2009.

Jaap Ham, Cees Midden, and Femke Beute. Can ambient persuasive technology persuade unconsciously? Using subliminal feedback to influence energy consumption ratings of household appliances. In *Proceedings of the 4th International Conference on Persuasive Technology*, Persuasive '09, pages 29:1–29:6, April 2009.

Peri Hartman, Jeffrey P. Bezos, Shel Kaphan, and Joel Spiegel. *U.S. Patent 5960411: Method and system for placing a purchase order via a communications network*. Amazon.com, Inc., September 1999.

Intel Corporation. Intelligent home energy management proof of concept. http://www.intel.com/embedded/energy/homeenergy/323157.pdf, August 2013.

Intellihome Automatisierungstechnik GmbH. Intellihome. http://www.intellihome.com, August 2013.

M. Jahn, M. Jentsch, C. R. Prause, F. Pramudianto, A. Al-Akkad, and R. Reiners. The energy aware smart home. In *Proceedings of the 5th International Conference on Future Information Technology*, FutureTech '10, pages 1–8, May 2010.

Tanyoung Kim, Hwajung Hong, and Brian Magerko. Design requirements for ambient display that supports sustainable lifestyle. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems*, DIS '10, pages 103–112, August 2010.

KNX Association. KNX Standard. http://www.knx.org/knx-standard/standardisation, August 2013.

Michael Kugler, Florian Reinhart, Kevin Schlieper, Masood Masoodian, Bill Rogers, Elisabeth André, and Thomas Rist. Architecture of a ubiquitous smart energy management system for residential homes. In *Proceedings of the 12th Annual Conference of the New Zealand Chapter of the ACM Special Interest Group on Computer-Human Interaction*, pages 101–104, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0676-8. doi: 10.1145/2000756.2000770. URL http://doi.acm.org/10.1145/2000756.2000770.

Michael Kugler, Elisabeth André, Masood Masoodian, Florian Reinhart, Bill Rogers, and Kevin Schlieper. Assisting inhabitants of residential homes with management of their energy consumption. In *Proceedings of the The 4th International Conference on Sustainability in Energy and Buildings*, volume 22 of *KES series in Smart Innovation, Systems and Technologies*, pages 147–156. Springer Verlag, 2013.

Stacey Kuznetsov and Eric Paulos. UpStream: Motivating water conservation with low-cost water flow sensing and persuasive displays. In *Proceedings of the 28th international conference on Human factors in computing systems*, CHI '10, pages 1851–1860, April 2010.

Matthias Laschke, Marc Hassenzahl, Sarah Diefenbach, and Marius Tippkämper. With a little help from a friend: A shower calendar to save water. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '11, pages 633–646, May 2011.

Jennifer Mankoff, Deanna Matthews, Susan R Fussell, and Michael Johnson. Leveraging social networks to motivate individuals to reduce their ecological footprints. In *Proceedings of the 40th Hawaii International Conference on System Sciences*, HICSS 2007, pages 87–96, January 2007.

S Meyer, U Böhm, and A Röhrig. Smart Home - Smart Aging. Akzeptanz und Anforderungen der Generation 50+. *Vierter Smart Home Survey des Berliner Institut für Sozialforschung*, 2003.

Cees Midden and Jaap Ham. The persuasive effects of positive and negative social feedback from an embodied agent on energy conservation behavior. In *Proceedings of the AISB 2008 Symposium on Persuasive Technology*, volume 3 of *AISB 2008*, pages 9–13, April 2008.

Charlie Park. Edward Tufte's "Slopegraphs". `http://charliepark.org/slopegraphs`, August 2013.

Petromil Petkov, Felix Köbler, Marcus Foth, and Helmut Krcmar. Motivating domestic energy conservation through comparative, community-based feedback in mobile and social media. In *Proceedings of the 5th International Conference on Communities and Technologies*, C&T '11, pages 21–30, June 2011.

Brigitte Ringbauer and Frank Heidmann. Usability von smart home user interfaces - Herausforderungen und Lösungsansätze. *i-com Zeitschrift für interaktive und kooperative Medien*, 5(1):24–33, January 2006.

L. Sherwood. U.S. solar market trends. In *Proceedings of the Solar Conference 2010*, 2010.

Edward Tufte. Slopegraphs for comparing gradients: Slopegraph theory and practice. `http://www.edwardtufte.com/bboard/q-and-a-fetch-msg?msg_id=0003nk&topic_id=1`, August 2013.

U.S. Energy Information Administration. *World Energy Use and Carbon Dioxide Emissions, 1980-2001*. April 2004.