A USER CENTRIC APPROACH TO THE DEVELOPMENT AND TESTING OF A HOME ENERGY MANAGEMENT SYSTEM

Jeroen Stragier[1] and Jan Derboven[2]

1 Interdisciplinary Institute for Broadband Technology – Research Group for Media and ICT (IBBT-MICT), Department of Communication Sciences, Ghent University, Korte Meer 7-9-11, 9000 Ghent, Belgium

[2] Interdisciplinary Institute for Broadband Technology – Centre for User Experience Research (IBBT-CUO), Faculty of Social Sciences, Katholieke Universiteit Leuven, Parkstraat 45 bus 3605, B-3000 Leuven, Belgium

Jeroen.Stragier@UGent.Be, Jan.Derboven@Soc.KULeuven.be

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Abstract: The development and small scale field trial in Flanders of a home energy management system is presented. During the development, a user-centric approach was used to create interaction between developers and possible end-users in a living lab setting. This allowed actively addressing people's needs and wants in the development process and testing the system in their homes. The preliminary results of the field trial indicate a high usage during the starting week, which gradually slows down over the weeks that follow. Usage of the different elements in the system varies over the weeks but a consistent "top 3" of elements remains. Dynamic pricing is used by a small but consistent part of the participants. They actively adapt their appliance usage to these prices.

1. INTRODUCTION

Smart grids are high on the agenda. While the focus of the benefits of these improved electricity infrastructures are mainly on the technical and structural side, end-users and more specifically households can also benefit from the new possibilities of smart grids and especially smart meters that are to be installed in their houses. These new meters can provide the end-user with detailed information on their energy use, something that many households find lacking today. Moreover, many studies have indicated that information or "feedback" is indeed an effective means to create awareness and possibly reduce energy use. Not only information on energy use can be improved, new energy pricing strategies can be developed, such as dynamic pricing, in which varying electricity prices can be used over the course of the day, with e.g. high prices at peak moments and low prices at off-peak moments. The delivery of detailed information to the end-user can be done in many ways starting with e.g. more detailed billing over online monitoring portals to full scale home energy management systems. This paper presents a user-centric approach to the development of a home energy management system. The research involved the constant interaction between system developers and the panel of users, whose input was of vital importance to the development of the system, in a living lab setting. Stahlbrost (2008) defines a living lab as a "human-centric research and development approach in which IT-systems are co-created, tested, and evaluated in the users' own private context". This has been the main approach from the start of the development to the final testing. Currently, a small scale field trial is in progress in the homes 21 families in Flanders, Belgium. Preliminary results on usage of the developed system are presented.

2. EFFECT OF FEEDBACK ON ENERGY USE

Feedback can have a positive effect on a households energy use, as research has indicated many times (Darby 2006; Dobson and Griffin 1992; Fischer 2008; Froehlich 2009; Ueno et al. 2006; Wood and Newborough 2003). It provides users with information on the results of the energy efficiency measures taken. Home energy management systems can be an effective means to provide tailor-made feedback to households. Evidence for this has been found in several experiments in which feedback was provided to household by means of computer systems or in-home displays (e.g. Brandon and Lewis 1999; Ueno et al. 2006)). However, although the effect of feedback of energy use on behaviour has been indicated by many studies, similar studies also argue that its effect on behaviour and awareness is likely to fade away when no further feedback is provided (for instance, when proof-of-concept technology is removed from the house). This implies that giving feedback on energy use does not necessarily lead to long-term changes in the users' behaviour. Darby (2006) argues that continued feedback is necessary to create persistence in the change of behaviour. Home energy management systems offer an excellent means to provide end-users with persistent feedback on their energy use.

3. USER CENTRIC DEVELOPMENT OF THE SYSTEM

In this section, the methodology and the results of the user research are presented. The research part first presents the actual user research consisting of a description of the field research, and the further (both qualitative and quantitative) analysis of the field data. Preliminary results of a currently ongoing field trial are subsequently presented

3.1 User research

3.1.1 Large scale survey

As a first step in the actual user research, an online survey was held with a representative sample in Flanders. The sample collected through this survey would form the base of recruitment for the next phases of the research. In the survey, structural, behavioural and attitudinal data regarding energy use in a domestic situation was collected. This resulted in a database (N=1314) containing information of the panel members on e.g. their type of house, level of insulation of the dwelling, how consciously they're using energy, their environmental attitude and so on. A number of questions addressed the degree to which they already monitor their energy use by keeping e.g. excel files containing meter readings or by using existing tools. We also asked how likely they would be to buy devices helping them to monitor e.g. their electricity use. From the database of the quantitative survey, a list of interesting respondents was compiled to be contacted for further participation in the development.

3.1.2 Diary study

In total, 30 households agreed to participate in the diary study. This study was conceived as a small snapshot of the participants' daily energy use habits. To get this snapshot, the interviewees were asked to keep a diary during two weeks. Use of electrical appliances, heating settings, bathing frequency, specific actions taken to lower energy use, general behaviour, such as talking about energy use, searching for information, etc. were registered in the diary. In order to make this as easy as possible to fill in, a diary template was distributed to the participants. In the templates, they were asked to fill in a general section (especially heating settings that are rarely altered), a daily section with a 24 hour time window to specify when an appliance was used, and a weekly section which primarily contained questions asking about the participant's general behaviour during the past week (e.g. searching for information about energy use, registering of meter readings etc.). The daily section was the core part of the diary. A 24-hour time window was provided in the template to the participants. Per appliance used during the day, start and end time of the use was recorded down in the diary.

The diary offered insights in the participant's routines and in the reasons participants have for their specific behaviour. Often it was observed that people's behaviour roots deeply in their specific home and family situation. A quite obvious observation from the diaries was that the general family and housing situation has a very profound impact on people's energy related behaviour. Apart from obvious differences based on specific family and housing situations, differences in energy-related behaviour often come down to quite small details in behaviour. A lot of energy saving methods are that common that almost everyone has the same energy saving behaviour, for instance drying laundry outside instead of using the tumble dryer when the weather is good, or only turning on the dishwasher when it's full. Participants that went one step further often focused on small improvements, such as unplugging specific devices to reduce phantom power. Only few participants took more drastic measures to reduce their energy use, such as consciously not owning/using energy devouring appliances such as dishwashers or microwave ovens. Often, luxury considerations prevent people from going further in energy efficiency.

3.1.3 Scenario evaluation

All participants from the diary study agreed to participate in a subsequent interview. The main topic of the interview was the discussion of four scenarios containing different functionalities of a home energy management system. These scenarios were developed based on the results of a market overview and the input gathered in the diary study. They can be seen as sort of a first product proposal. In these scenarios several possibilities such as user feedback and automated control were illustrated by means of a fictitious family. The first scenario illustrated basic applications of a smart meter such as detailed billing. The second scenario elaborated more on creating awareness of energy use (on a global level for the household) by means of visualization through mood lights, PC or smart phones. The third scenario went more into detail and discussed feedback on appliance level. Feedback in this scenario was visualized through an in-home display. The fourth and most advanced scenario illustrated the possibilities of home automation in relation to energy use.

Although it has to be noted that the participants were quite positive about most of the applications in the scenarios, they generally preferred scenario 3. Scenario 1 was a scenario on which they agreed that it presented basic information that "should be standard" - of course with today's mechanical meters, this is quite impossible. This scenario offered the least added value to their present situation. The advantage of scenario 3 over scenario 2 was the level of detail. Whereas scenario 2 was limited to a visualization of overall meter readings on the computer screen, scenario 3 added the in-home display as a means of easy access to the data and, more importantly, added more detail as it showed the energy use per appliance. This last feature was something that was clearly appreciated by the participants as indicated by the following quote:

> *"The increased level of detail really gives a lot of added value. As long as the data is on an overall level, it's all interesting and you might start thinking about it somewhat, but I don't think you will act on it, as you don't know where the problem is."*

3.1.4 Interface design

The design process of the application consisted of several stages. Besides the ethnographic data, respondent interviews and qualitative data gathering presented above, participatory design techniques were used to involve end users in the actual design of an energy management system (Schuler and Namioka 1993). A total of 2 focus group discussions (N=8) were held with members from our research panel.

Focus group sessions allowed for a creative approach. After an introduction and discussion of the concept of home energy management, participants were asked to design an energy management system that would meet their needs. To do this, participants received pencils, paper and cut-out graphics and icons to design their system from scratch.

In a final stage, the user research data, together with the participatory design results were used to create the design of the final smart application for smart phones and tablets. The final application design includes a competition-style home page, in which users can compare their energy use of the present day to that of the day before.

This allows users to see whether they are doing better or worse, and can trigger them to try to do better. In this way, the competition-style home page can be seen as a quick, one-glance self-monitoring screen that can persuade its users to try to do better than the day before (Fogg 2003). Besides navigation buttons, the home screen also offers a direct link to relevant system messages about the users' current energy use, such as changing energy tariffs, information about appliances that remain switched on upon leaving the house, etc.

Beyond the home screen, users can access more detailed information, such as detailed graphs with their energy use and energy prices, estimates of the yearly energy bill, etc. Apart from visualising and comparing usage information, the system gives users advice on their energy use behaviour in the system messages, and warns them when an energy use threshold has been reached.

4. FIELD TRIAL

The developed system was installed in 21 homes spread out over Flanders, the Dutch speaking part of Belgium. The households were selected from the project panel. They were contacted asking for their participation in the project. A total number of 43 households were contacted of which 21 agreed to participate. An initial visit was scheduled in

September with the participants to explain the purpose of the field trial, assess the applicability of the dwelling (not every house was suitable for the installation of the system) and consequently concretize what measures would have to be taken in order to get the system installed. From October 17th until November 17th 2011, a second appointment was made with the participants for the actual installation of the system in their homes. The installation supports the measurement of the total electricity use in the house, a number of sub measurements of specific appliances or circuits and in some cases a measurement of the gas use. The total electricity measurement is possible through the installation of a modern smart meter. The submeterings take place in the fuse box of the participant. Metering modules measure the current and voltage of the circuits that the participant wants to be able to monitor (up to 6 submeterings). The impact on the existing electricity installation of the house is limited because of the use of current clamps that can be clicked around the conductor. If the existing gas meter has a so called pulse output, the gas use in the house can be monitored through a module that counts these pulses. The smart meter and the metering modules send their measurements to the database in the home energy controller (HEC). This HEC is incorporated into the home network and has an internet connection. The user interface of the system connects with the HEC through WLAN. Since the actual technical installation of the system is not the aim of this paper, we will not elaborate any further on this. As a user interface to interact with the system, the participating households were given either an Android based tablet or smartphone.

The field trial started November 17th 2011 and is scheduled to end March 31st 2012 (although continuation is possible). The purpose of the field trial was to get insights into the interaction of the participating households with the system. To do this, the following research design was set up:

1. A weekly questionnaire
2. A monthly questionnaire
3. A three monthly in-home interview with the participants

Currently, 8 weekly questionnaires and one monthly questionnaire have been sent out to the participants. The scheduling of the first interview is in progress at the moment of writing. The weekly questionnaires are sent out at the last working day of each week.

The weekly questionnaire is a short online survey containing questions on basic use of the applications such as whether or not they used it, how many times per week, at which moment they mostly use it, and of course, which of the features they use the most.

The monthly questionnaire is a longer version of the weekly survey. It allows to go more into depth on issues identified in the weekly questionnaire and their actual usage and liking of the different elements included in the application. The following section of the paper will summarize the results of both questionnaire types. We will not go into detail on the results of every question asked, but try to summarize the general trends seen in the use of a home energy management system. Since the field trial runs for approximately six months only, our focus is not on the actual potential of the system to lower the energy use of the participating families, but more on the way they interact with the system.

4.1 Preliminary results

4.1.1 Application features

Most of the participants consult the system at least once a week. The frequency of consulting

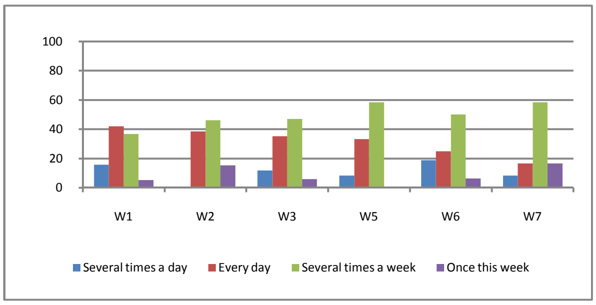

Figure 1: Degree to which the application is consulted (week 1 to week 7, in %)

less frequent however over the weeks (the percentages in the figures have to be interpreted with caution given the small scale of the field trial). Figure 1 indicates that the proportion of respondents that consult the app every day gradually reduces over the course of the weeks (In week 4, the monthly questionnaire was sent out. No data about weekly use was collected in this week). The novelty aspect of the system seems to fade out somewhat. The share of participants consulting the app several times a week instead, increases over the weeks.

The participants don’t quite have a fixed moment at which they consult their energy usage data. Most of them consulted the application quite randomly at the start of the field trial. Over the course of the weeks however, this is clearly showing a downward trend. More participants seem to find somewhat fixed moments to consult their data. However, we need to be careful with interpreting these trends. Results from weekly surveys in the next weeks will provide more insights. During weekdays the app is mostly consulted in the evening, whereas during the weekend, day-time consultations are seen far more frequently.

An important question is of course what the participants are doing with the application? What elements do they use the most? According to the answers of the participants, in the first week after installation in their homes, most of the elements in the system were tested. A top 3 of elements that remained quite consistent over the weeks that followed were “Checking my current energy use”, “Following the energy use of my appliances” and “Checking my historical energy use” (at that moment only the previous days were consultable however). Although these three elements remain the most consulted ones in the field trial, the share of “Following the energy use of my appliances” gradually dropped over the weeks. Apparently, once people know what an appliance uses, their attention to this element seems to fade out. Two other elements that were highly consulted were “Checking my stand-by electricity use” and “Real-time following of the electricity use of an appliance”. The attention to this element also faded out over the weeks. A growing attention was paid to “comparing my current energy use to the past days/weeks” over the course of the weeks.

In the first monthly online survey, more specific questions were asked on the usage of some elements in the application that are less frequently used: the estimation of the yearly electricity bill, the possibility to impose usage limits and the making of comparisons between days, weeks or months.

The app provides the user with a comparison of his energy use with that of the day before. Depending on the difference between two days, a green or a red smiley is shown in the application, indicating a better or worse situation than the day before. When asked if they believe that the comparison with the previous day is correct, most of the participants state that they do so. The question that is often raised however is whether the comparison is a relevant one. A comparison of a Sunday with a Monday for example, is a comparison of two worlds to some participants (a day where everybody is at home all day versus a working day). When asked what type of comparison they would prefer, comparing a week with the previous one seems to be more to the liking of the participants. Given the fact that daily consultation of the application doesn’t seem to be common with our participants, this might indeed be a better way of comparing.

The application also provides the possibility to get an estimation of the annual electricity bill. 13 of the participants state that this is a feature they use. Only half of them however, believe that the estimation is in fact an accurate one. The main reason for this is that most of the participants are aware that the prices used in the field trial are fictitious. Others have questions on whether the system uses relevant parameters such as seasons in its calculation of the bill. One respondent however gives the interesting remark that when dynamic prices would in fact be used in the future, the estimation would come in very useful as it would be very difficult to make that estimation on your own.

Finally, imposing a (non-binding) limit to their energy usage per day was considered not to be used by the participants. Only two of the participating households indicated to use the usage limit.

4.1.2 Dynamic prices

Every day, the respondents are provided with new electricity prices for the next day. When asked if these prices have an influence on the moment of use of their electrical appliances, 8 out of 21 participants state that they do. Indeed, a small, but consistent part of them actively adapt the use of certain appliances to these dynamic electricity prices, as is seen in both the weekly as well as the monthly questionnaire. The appliances that are often shifted in accordance to the dynamic prices are typically those with a large flexibility such as dishwasher, washing machine and tumble dryer.

The participants were asked to give a specific example of a situation in which they shifted their electricity use in accordance with the electricity prices and a situation in which they didn’t. The responses to these questions are quite straightforward. While the answers to the first question (a situation in which they did) are not surprising and mostly related to shifting of the appliances indicated above, the reasons why someone wouldn’t are more related to the relative inflexibility of cooking and watching TV or using the personal computer. Other reasons not to use the dynamic prices are forgetting to set timers or just being in a situation where an appliance has to work at that moment and can’t be shifted.

5. CONCLUSIONS

This paper presents a user-centric development of a home energy management system and the preliminary results of the ongoing field trial. The user-centric approach has proven to be very useful in the development stage. Constant feedback from user research was incorporated into the development. The preliminary results indicate that while the first weeks of the field trial were marked by a high application consulting rate of the participants, this decreased somewhat in the weeks that followed. It was clear that the amount of daily consulting gradually decreases in favor of weekly consulting. Day to day comparisons of energy use doesn't seem to be the most interesting base of comparison. Week to week comparing is indicated as a more interesting base. Estimations of yearly bills are found interesting, despite the fact that the prices provided in our setting are not delivered by the energy supplier and therefore not accurate. Because some of the participants were clients with another energy supplier than the one that is a partner in the project, fictitious prices had to be used. It is indicated that these calculation modules will be of great interest when dynamic prices are in fact on the market. These pricing strategies will make it very difficult for the end user make decent estimation of their yearly bill. Approximately one third of our participants are currently to some degree adapting their electricity usage in accordance to the dynamic prices that are being provided the day before. Shifting of usage mostly implies appliances with a certain degree of flexibility such as washing machines and dishwashers. Those who don't adapt their electricity use to these tariffs indicate that this is mainly because of not being at home at the time of low prices. Automation will be an important function of home energy management in the future, especially when using dynamic prices. The small scale of the field trial makes overall conclusion somewhat difficult, but still, general trends are detectable. The personal interviews are currently in the process of being scheduled, and will certainly attribute to insights on the use of the system within the households and its influence on household dynamics and routines with regard to energy use.

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