The User-Centric Development of a Home Energy Management System: Results from a Field Trial

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ABSTRACT

Home energy management systems are a sound way of bringing feedback on energy use in real time to the household members. Our research involves the user-centric development and testing of a home energy management system, in which both tablet and smartphone are used as the communication device to the test users. The focus of our research lies on discovering the needs of the consumer regarding insights in their energy use. This research led to the development of a home energy management system that was tested in 21 households. During this field trial, regular moments were foreseen for the measurement of the user experience with the home energy management system, using both quantitative and qualitative research methods. This research gave insights on the use of the system and the behavior of the participants in reaction to the system The results indicate that while enthusiasm for using is high the application is high in the beginning, this somewhat decreases over time for a reasonable part of the test families. The testers especially liked the ability to monitor the energy use of their appliances and compare the energy use of weeks and months. A minority persisted in using their appliances in accordance to the dynamic prices that were provided.

Introduction

Information on energy use is often lacking for many families. Mostly, the only feedback that is available for the energy end-user is the annual or monthly energy bill. Often, this comes as quite a surprise to this end-user, and because it comes after the actual energy use, it comes far too late and the damage is already done. Smart meters, which will replace the current mechanical energy meters in the context of smart grids, will offer possibilities to the end-user. Regular feedback, in the form of monthly billing, for example, of the actual usage or a monthly overview of the usage, allows the end-user the possibility to track his energy use more carefully, and can prevent surprisingly high energy bills. Furthermore, research has indicated that feedback is in fact an effective means to help end-users reduce their energy use (Darby 2006, Fischer 2008, Faruqui *et al.* 2009).

Home energy management systems are another way of bringing this feedback to the end-user. These systems exist in many forms and can deliver broad, overall data on general energy use in buildings to very detailed information on appliance level and even guidance on how to save energy. Automation is another possibility of these systems that can allow operation of appliances in accordance to dynamic energy prices, for example.

This article describes the development process of a home energy management system from a user perspective. A multi-method approach, combining quantitative, qualitative and living lab methodologies is presented. A user-centric approach has its starting point in the needs and wants of the user and relies greatly on the constant interaction with this user during the development process (Abras *et al.* 2004). A living lab setting was used to develop and test the

system in a natural household environment. The input of the user was of vital importance to the development of the system. Ståhlbröst (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.

Home Energy Management Systems

In preparation for the user research, a market analysis was performed. The goal of this analysis was to find out what systems are currently on the market, what possibilities these systems offer and what is currently lacking (Brown 2007). This overview will be particularly useful in later phases of the research, when product propositions will be composed for scenario analysis. Eighty products and product websites have been included in the analysis. These products served as an overview of the current energy monitoring market. They were structured according to their functionalities and features and brought together into four product categories. First, we grouped websites that give information and tips, for example questionnaires, a virtual house in which the user can navigate and obtain information on several parts of the house, or mere instructional text on a website, together in the category named "instructive websites." Second, domotics systems whose primary functionality consists of automating window blinds, controlling music and TV screens, burglar alarms, etc., were brought together under the category of "eco-friendly domotics." These systems are often described as eco-friendly because they can also adjust lighting and climate using timers, or dedicated buttons that switch off all appliances at night, or when there is no one in the house. "Reinterpreted everyday objects" are familiar objects that have been redesigned, promoting energy conservation during use. The designs thus have other primary uses. Examples of these are 'augmented' power strips (e.g., WattStopper power strip), or home decoration products (e.g., DIY Kyoto Wattson – see also, for instance (Pierce and Roedl 2008)).

Finally, "home energy management systems" combine usage data collection with the provision of feedback through in-home displays. Moreover, these systems can provide automated control of certain functions with an energy saving goal, such as temperature regulation and lighting control, but also automated use of appliances based on dynamic pricing.

These categories present a continuum ranging from giving basic information intended to create awareness, to fully automated home energy management systems.

A User-Centric Approach

The user is a key factor in the development of a new product. Their needs should ultimately be taken into account from the starting point of the development process to the final testing phase. In our research, we used a user-centric approach. This approach, which can also be labeled as a living lab setting, included a constant interaction with our research panel and a final real life testing phase. Living labs are aimed at facilitating the inclusion of the user. (Eriksson *et al.* 2005, Ståhlbröst 2008).

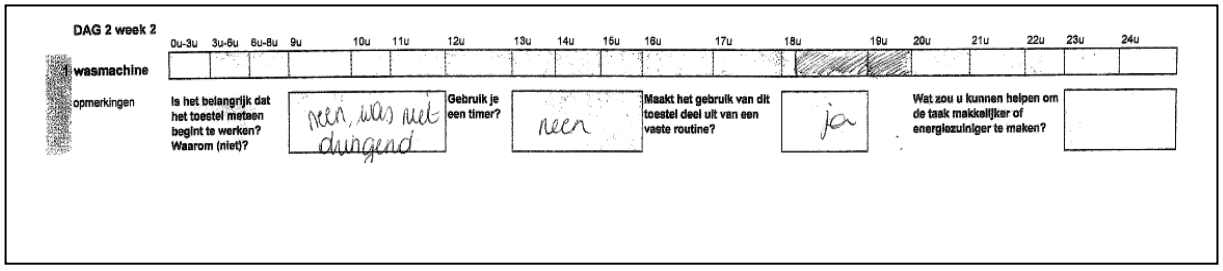
Several stages were completed in the research to come to the final phases of development and testing of the system. As indicated, a user-centric approach was followed, meaning that the development process incorporated needs and wants of the (potential) user of home energy management systems and user input was delivered throughout.

The starting point of the project was a large scale quantitative survey held with a representative sample of the Flemish population. A total number of 1314 respondents filled out the questionnaire. The aim of the survey was threefold: first, we wanted to collect a broad panel of respondents on which we could rely as a research panel for further phases of the development process. Second, we wanted to collect as much information as possible on energy use related habits and behaviour in Flanders. We wanted to know how energy efficient households in Flanders are, by assessing what types of energy saving measures they apply in their homes. To do this we used the energy efficient behaviour scale (Stragier *et al.* 2012), which helps to get insights into this behaviour and adds an important dimension regarding the degree to which households are actively monitoring their energy use. The third goal of the survey was to get a preliminary insight into the adoption potential for home energy management systems in Flanders.

For the next phases of the research process, a panel was built from the respondents of the quantitative survey. All members of this panel had indicated that they wanted to participate further in the research process. A first research activity was a diary study with a subset of 30 families from the research panel. The goal of this diary was get more profound insights into the habits, needs and wants of the energy end-user. The results of the survey formed a "snapshot" of the energy related behavior of the families. To come to this result, a diary had to be kept by the families for a period of two weeks.

Figure 1 provides an example from the diary study for the washing machine. The diary consisted of a list of household appliances for which every moment of use had to be registered on a 24-hour scale. In figure 1, the moment of use of the washing machine is indicated. This family used it from 6 pm to 8 pm on a Tuesday. Under the bar where the usage of the appliance had to be indicated, the respondent was asked to indicate if they find it important that the appliance starts working immediately, if they use a timer for the appliance, if the usage of the appliance is part of a weekly routine and if they have ideas to make the usage of the appliance more energy efficient. The answers to these questions were mainly used as input for the scenario analysis.

Figure 1. Excerpt from the diary study



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 behavior is deeply rooted in their specific home and family situation. A quite obvious observation from the diary study was that the general family and housing situation has a very profound impact on people's energy related behaviour. Differences in this 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.

While the quantitative survey and diary study particularly offered descriptive information on habits, needs and wants, the next phases required the active input and ideas of the research panel.

In the scenario evaluation phase, which followed the diary study, we went back to the participants of the diary study with four scenarios on the possibilities of home energy management systems. The scenarios were developed based on the input from the market overview and the input gathered in the diary study and form a sort of first product proposal on home energy management systems. In the scenarios, a fictitious family was used to illustrate several possibilities of home energy management systems, ranging from very simple to very complex. 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. The participants were quite enthusiastic about the presented scenarios. The third scenario however seemed to be the most interesting one according to the participants. Its focus on detailed feedback per household appliance has the most added value in comparison to the first and the second scenario. The fourth scenario, which involved mostly home automation, was considered to be something of a distant future.

The previous research phases provided us with necessary insights into the needs, wants, but also preferences for certain possibilities of home energy management systems. An important aspect which had not been researched up to this point in the project was the interface of the system. This interface will form the communication portal to the user of the data that is being gathered by the system. This next phase of the research was devoted to letting the potential user indicate what data he or she wants to see on the application and in which form. To do this, two focus group discussions (n=10) were held with members of our research panel. Focus groups allow a creative and interactive group dynamic that cannot be obtained through personal interviews. First, the participants were introduced to the concept of home energy management systems and a small discussion was held on current energy saving measures that they already take, followed by a discussion on what information on their energy use they consider to be lacking at the moment. Next, the participants were asked to form groups of two and design the ideal interface for their ideal home energy management system. To do this, participants received pencils, paper and cut-out graphics and icons to design their system from scratch. The information gathered in these two sessions was passed through to the interface designers.

The final design that was going to be developed consisted of a competition-style home page, in which the users can compare their energy use of the present day to that of the day before. Beyond this home screen, the users have access to more detailed information on the energy use of their appliances, the dynamic energy prices of the next day, the ability to compare

the energy use of days/weeks/months of their choosing and they can also impose a (non-binding) limit to their electricity use. This interface was built as an Android application for smartphones or tablets.

Findings from the Field Trial

Forty-three families were invited for participation in the field trial. Twenty-one families agreed to participate, which was more than expected. These families were selected from the project panel. Ten families also participated before in the diary study and the scenario evaluation. As an incentive for their participation, the families could keep the smartphone or tablet which was used as the in-home display. The field trial started November 17, 2011 and ended March 31, 2012.The system that was installed in the houses of the participants 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 user interface of the system connects with the meters through WLAN.

The research methodology we applied during the field trial was a combination of quantitative and qualitative methods. The quantitative research consisted of weekly and monthly questionnaires. At the end of each week and each month, these surveys were sent to the participating families The weekly questionnaire was a short online survey containing questions on basic use of the application 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 allowed us 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 qualitative part consisted of a personal in-home interview with the participants. Three months after the start of the field trial, the participating families were contacted for the scheduling of an interview. This interview would allow us to get more details on their answers to the weekly and monthly questionnaires. The interview was semi-structured, which means the questions were predetermined, but the participants were free to elaborate on each question or topic.

The interview started with a set of questions asking for their general experiences with the application. Then a small user test was conducted to check whether the participants use the application well and have knowledge of all features that can be accessed. Next, a set of more specific question regarding the features they like and the ones that they dislike was asked. Drawing on the results of the weekly and monthly questionnaires, we specifically wanted to know why certain features were used a lot and others far less. Subsequently, we wanted to go into more depth on the usage context of the application. More specifically we wanted to know if the application could be a tool for creating certain “awareness” on energy use within the family: do they talk about the results; do they motivate each other to be conscious about using energy, etc. An important part of the interview was their impression on working with dynamic energy prices: does it fit into their daily lives/schedules, would they subscribe to a tariff plan like this if it were available on the market? Finally, a number of questions were asked regarding their willingness to purchase the system.

Results

In this section we will discuss the most important results of both questionnaires and the interview jointly per topic.

Use of the Application

In the first week after installation of the system, every participant used the system. The number of participants that reported a weekly usage of the application has decreased over the weeks. The majority of the participants still use the system at least once a week however. To those who used the system at least once a week, we asked how many times per week they use the system. From figure 3, it is clear that the proportion of participants who check the application every day gradually dropped over the weeks. Instead most of them changed to consulting the application a couple of times per week.

Figure 2. Have you used the application this week?

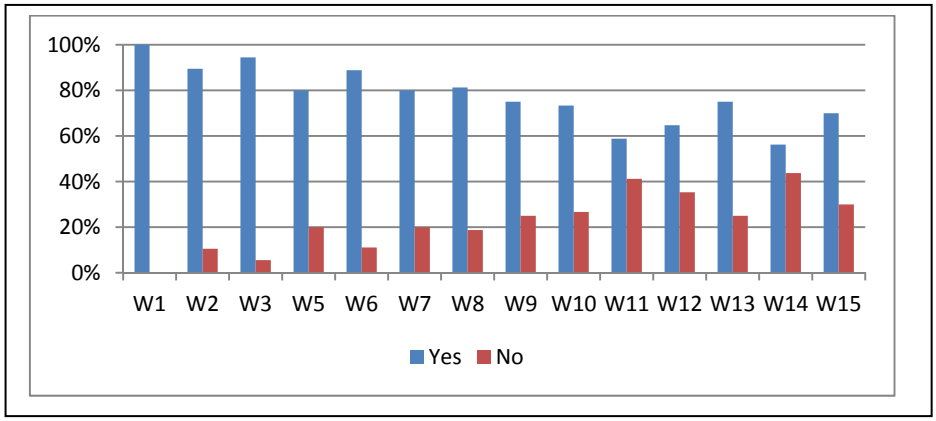
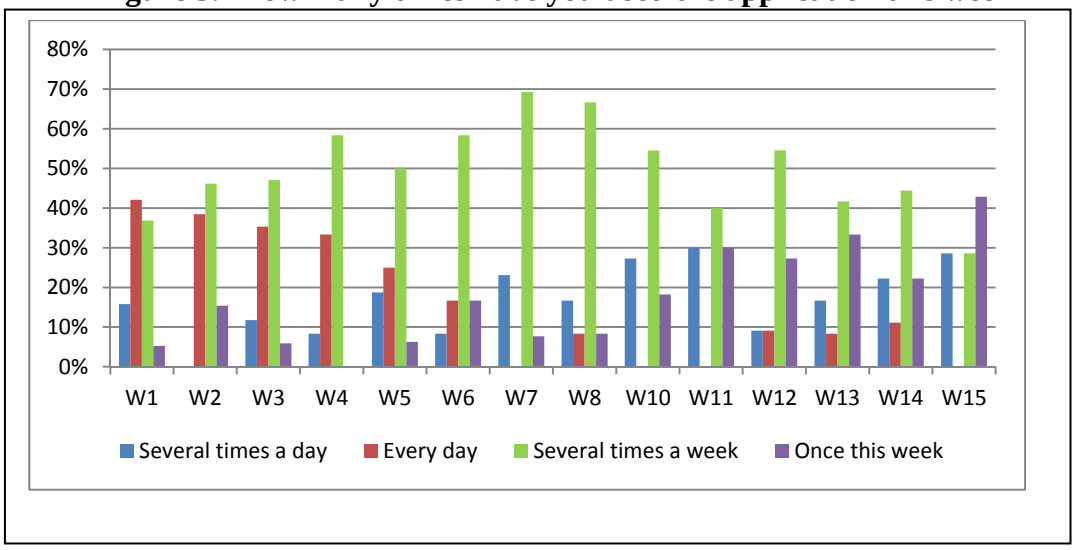


Figure 3. How many times have you used the application this week



From the personal interviews, we obtained more detail on the moments of use of the system. It seems that the actual use of the application is quite variable within the participants. Some of them have a fixed routine: checking the application every morning, after breakfast or dinner, or every Monday (to make weekly graphs). Others do not really have a routine and use the application "when I think about it", "when I suspect an excess consumption", "mostly at night but not every day", "about twice a week", "when it suits me"...

"After you have used the system for a while, it is no longer useful to check it daily or frequently. I only check for example this month's data compared to last month – was there any outstanding consumption data? But it doesn't add anything to check it daily."

An important question is to understand what participants are doing with the application. We asked this as an open ended question in the weekly questionnaire. In the first weeks after installation we saw that the participants were checking out every possible feature of the system. After a few weeks, this enthusiasm settled for a more routine based use of the app. Checking the current energy use, following the energy use of their appliances and checking the historical energy use are the most frequently used features of the application. Especially comparing a week's or month's energy use to that of a previous week/month seems to attract more interest from the participants during the study.

In the interview, we asked the participants if they had actually learned something about their energy use since they started using the system. Most of them stated that they definitely did. Some examples of what they reported were:

- Getting information on: our stand-by electricity use, the heat pump, the relatively large share of the heating in the total energy use, internet modem, devices that need replacement.
- Seeing the variation of the energy use of the dishwasher, several devices, different circuits, different periods (for example being at home or not).
- Learning to lower the energy use by doing small things: switching off laptop, LED TV versus plasma TV, turning the lights off, closing the doors, monitoring the heating.

Usage of Specific Features

Without going into detail on all of the features in the application, we will briefly discuss the findings of two specific features. One of these features is the competition based home page of the system (Figure 4).

Figure 4. Home screen of the application

A green or red smiley appears on the home screen if the participant is doing better or worse, respectively, with regard to his energy use comparing to the day before. While the participants believe this is a valuable feature, they don't think the basis of comparison (comparing to the day before) is the right one. As one participant puts it:

"Two successive days are hardly ever the same. Take a Sunday and a Monday for example. On Sundays, everybody's home during the day. On Mondays, we're all out to work."

In the opinion of the participants, comparing weeks or months would be a better option, or at least comparing on day to the same day the week before.

Another feature was the submetering of their household appliances. While with a full system it would be possible to submeter every energy user in the house, in our test setting this was limited to six appliances, including photovoltaic solar panels if present. The participants greatly valued this feature as it provides them with more detail about their energy use and allows them to detect their largest energy users. The results of the monthly questionnaires showed that more than 90% of the participants greatly value this feature. This result remains the same in every monthly questionnaire. The feature was more frequently used in the beginning of the field trial however. One participant reported:

"Once you know how much an appliance uses, there's not really a need to check it again, unless you want to be sure that it doesn't suddenly start to use more electricity."

Still, the feature remains one of the most popular ones in the application.

Dynamic Prices

The other important feature in the application is that of dynamic prices. Every day, the participants were provided with new electricity prices for the next day. These prices were different for every hour of the day and were announced at 6 pm the day before. It has to be mentioned that the participants are not billed in accordance to the dynamic prices, so the tariffs

are to be considered as a "game."A small, but consistent part of the participants actively adapted the use of certain appliances to these dynamic electricity prices, as could be 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 dishwashers, washing machines and tumble dryers. They do state that it is not always easy to shift their behaviour according to dynamic prices:

"I just try to avoid the peaks."

"We try not to cook around 18-19h, but sometimes that is really difficult. Also, when the children have exams, it is really not comfortable for them to eat so late."

"Those tariffs are high every time the energy use in our household is high... So I don't think those dynamic prices would be more profitable for me than my regular day and night tariff. It would take a pretty large increase of the energy price to make me break my routine and diminish our comfort level."

The participants that don't follow the dynamic prices give a variety of reasons not to do so. One of them is of course the fact that the prices are fictional. Other reasons are not being able to comply with these prices, for example, because they are not at home during the day or because of safety issues.

"It's too hard with a baby in the house: when the laundry has to be done, it has to be done …"

"I would never use timers to follow the dynamic pricing information. We never leave our devices switched on when we go to bed or when we are not at home, for safety reasons."

Usage Context

The majority of the respondents are the sole users of the application within their families. Some others mention that their partner or their children also use the application. Some of those who are the sole users of the application however, told us that they sometimes share the results with their household members. They also have discussions with their partner about changing certain behaviors or about the energy use of their household appliances.

"It's good that my children also try to use the application sometimes. That way it is easier for us to make them aware of some things, for example having them turn off the lights and close the doors and so on. Everything becomes much more visible."

Conclusion

In this paper we outlined some of the results of the user-centric development process of a home energy management system. Involving the (potential) user in the development proved to be a valuable approach in this context. Using a combination of both qualitative and quantitative methods allowed us to gather different kinds of insights on household energy use. This resulted in a solid base of knowledge on the needs and wants of energy users with regard to feedback.

Involving them in the development process resulted in a user interface and a system which provides features that the user wants and which are displayed in a manner that is comprehensible. However, a field trial remains a necessary part of the development process. A field trial allows one to see how a potential user handles an innovative interface. In our case, it confirmed that the features they really wanted to be included in the system, were also the ones that were used the most (submetering and comparing). However, the field trial also gave some interesting insights which we didn't expect. Comparing energy usage to other households, was of no interest to the respondents in the development process. In the field trial however, many of the participants put forward that they would like the possibility to do so. Another example is the readability of the graphs. Testers during the development process considered these graphs to be clear, but some of the participants in the field trial had difficulties interpreting them. These are just a few examples of the value of a field trial. Another example of this value are the results from the dynamic prices experiment. This experiment used fictional dynamic prices in an attempt to shift household appliance use to off-peak moments of the day. The fact that these prices were fictional resulted in only a small part of the sample actually complying. However, some of the other participants indicated that if the prices would have been real, and if they would prove to be more profitable than their current energy tariffs, dynamic prices would be considered. They also put the issue of automation forward in this matter.

To conclude, we believe our research provides an interesting view and approach on development of home energy management systems. This approach would possibly prove valuable in the development of other innovations also. The small scale of the field trial however, limits its representativeness. Nonetheless, it proves to be a method that yielded relevant results.

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