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Jeroen Stragier^a, Jan Derboven^b, Lieve Laporte^b, Laurence Hauttekeete^a & Lieven De Marez^a

^a Department of Communication Sciences,, Research Group for Media and ICT (iMinds-MICT), Ghent University - iMinds, Korte Meer 7-9-11, Ghent, 9000, Belgium

^b Faculty of Social Sciences, Centre for User Experience Research (iMinds-CUO), Katholieke Universiteit Leuven - iMinds, Parkstraat 45 bus 3605, Leuven, B-3000, Belgium

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Kilowhat? A multidisciplinary approach on the development of a home energy management system

Jeroen Stragier^{a*}, Jan Derboven^b, Lieve Laporte^b, Laurence Hautekeete^a and Lieven De Marez^a

^aDepartment of Communication Sciences, Research Group for Media and ICT (iMinds-MICT), Ghent University - iMinds, Korte Meer 7-9-11, 9000 Ghent, Belgium; ^bFaculty of Social Sciences, Centre for User Experience Research (iMinds-CUO), Katholieke Universiteit Leuven - iMinds, Parkstraat 45 bus 3605, B-3000 Leuven, Belgium

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To a consumer, knowing how much energy you use is often a question mark. We get our energy bills and more often than not, they are surprisingly high. The coming of the smart grid and more specifically smart metering provides opportunities to create a better awareness on energy use among consumers. This research presents the user-centric development of a home energy management system. The focus of the research is not specifically on the functionalities per se, rather it lies on the inclusion of the energy end-user in the development process. Throughout the development, end-user research provided valuable input for the development of the system. Large quantitative surveys were alternated with small scale in-depth qualitative research. Each step generated the input for the next step in the research process, resulting in a system with functionalities tailored to the end-users needs and wants.

Keywords: user-centred design; usability; usability testing; user interface; user involvement

1. Introduction

Knowing how much energy you use is not straightforward. Consumers can make efforts to monitor the meters in their homes manually, but this is not always obvious due to a diversity of reasons: the inaccessibility of meters in basements or closets, a possible misinterpretation of the data, the impossibility of comparing with historical data, etc. As such, the yearly/monthly bill is the only reference point for the majority of households in Flanders, Belgium. This lack of knowledge often causes a lack of energy efficiency measures. Recently, however, higher levels of end-user efficiency have become possible because of the upcoming roll-out of smart grids. A real-time monitoring can deliver valuable feedback to households about the amount of energy used. Many studies have indicated that feedback can be an effective means of reducing energy use (McCalley and Midden 2002, Darby 2006, Fischer 2008, Grønhøj and Thøgersen 2011), but the possibilities go beyond delivering feedback. When smart meters are connected in a home area network with home energy management systems, new opportunities for energy efficiency monitoring arise. Personal energy use data can be used to provide guidance to households on how to become more energy efficient. Automation can make certain processes, such as scheduling household

tasks according to dynamic pricing rates, more feasible. In the development of such home energy management systems, the end-user is of great importance. Using such systems can result in drastic changes in household habits. Therefore, it is important to have information about current household habits in advance. It is crucial to know the wishes and desires of households, and to identify barriers that could prevent the adoption of home energy management systems. As a consequence, users must be addressed in the development of these systems.

This article describes an innovative user-centric methodological process combining both quantitative and qualitative researches in a logical succession, in which every step of the research process delivers valuable and constructive input for the next. The focus of this paper is not mainly on the results of each method, but rather on the process of involving users in the development of a home energy management system. The multidisciplinary research methodology combines overall market research, detailed user research and participatory design techniques in one combined flow. Through this combination of techniques and research methods, the overall methodology combines the strengths of the constituent approaches, and integrates them into a coherent, richer research framework.

*Corresponding author. Email: Jeroen.Stragier@UGent.be

2. Related work

2.1. Domestic energy use: current situation

Prior research points out that several factors can have an influence on the energy efficient behaviour of households. Bin and Dowlatabadi (2005) distinguish five interacting factors in their cyclical ‘consumer lifestyle approach’ to energy use and carbon dioxide emissions. The five factors interrelate in a cyclical way, in that the consequences (5) of specific behaviour and characteristics influence the behaviours and characteristics (1–4) themselves:

- (1) External environmental variables (cultural influence, technology development, etc.).
- (2) Individual determinants (attitudes and beliefs that influence decision making).
- (3) Household characteristics (household size, housing type and size, income, location, etc.).
- (4) Consumer choices (purchases, use of services and equipment).
- (5) Consequences (resource use and related environmental impacts resulting from consumer activities).

While these factors can be separated for analytical purposes, in practice, the factors tend to overlap and influence each other. We will not focus on the consequences of the domestic behaviour (5), limiting the discussion to the factors and characteristics influencing the behaviour (1–4). An external environmental factor can be culture, ethnic factors determining different use of lighting appliances, influencing the energy use: e.g. Norwegian households preferring a higher number of lamps in a room than Japanese households, who generally prefer one light bulb in the ceiling (Carlsson-Kanyama and Lindén 2007). Shove (2003) states that preferences regarding heating temperature have changed during history, parallel with the technological development of in-door climate technology. Apart from general cultural factors, individual determinants influence decision making: in general, older persons are less likely to adopt energy conservation strategies for reasons including a lack of education and know-how, older housing circumstances, diminished physical abilities, etc. (Sardianou 2007). The characteristics of households include many, interrelating factors. One major influence is the household’s infrastructure. The number of electric appliances in households has been rising in recent years, especially with the rise of information and communication technology (ICT)-related appliances such as gaming consoles, personal computers, and more recently tablet PCs. Especially computing devices often come in more than one per household. But also dishwashers and

tumble dryers continue their penetration into household dwellings, causing an ever-growing demand for power. Another big energy user is heating. In Flanders, depending on the surface of the heated area, the efficiency of the heating installation and the use by its owners, heating accounts for up to 85% of a household’s energy use. The other 15% is accounted for by electric appliances and lighting (MIRA 2010). Socio-economic, psychological and socio-demographic factors in the household can also be of influence (Raaij and Verhallen 1983, Marsh 1987, Burholt and Windle 2006, Carlsson-Kanyama and Lindén 2007). Poor insulation and the lack of resources to invest in energy-efficient appliances create high energy bills for low-incomes. In turn, these household characteristics are related to consumer choices, as low income households lack the resources to invest in efficient appliances or renewable energy. Apart from investment, socio-economic, psychological and socio-demographic factors also influence behaviour: women prefer higher room temperatures than men, and depending on household habits, heating routines might differ.

For households, it can be quite a challenge to keep track of their energy use. Research has indicated that receiving feedback on energy usage is quite effective in triggering more energy-efficient behaviour (Darby 2006, Fischer 2008). However, Darby (2006) also argues that continued feedback is necessary to sustain this behaviour. Currently, ‘regular’ electricity metering leaves a lot to be desired for various reasons. In most homes, utility meters are not easily accessible to the occupants. Even when the occupants have accessed their meter, the information is displayed in kilowatt hour (kWh), shown as one cumulative total – without any option to access historical information, or instantaneous information about current usage. Given such limitations, it is not surprising that most consumers have no idea about how much energy they are using, and what sort of difference they could make by changing day-to-day behaviour or investing in efficiency measures (Darby 2006, Fischer 2008). Moreover, energy use is also ‘socially invisible’ (Backhaus and Heiskanen 2009): people rarely talk about it. In the developed world, treating energy as relatively cheap, abundant, and without significant consequence is a still-pervasive view. Even as the public consciousness about climate change increases, this unsustainable conception persists. These issues suggest the need for a shift of our cultural notion about the way in which energy use affects our future: a new mental model has to be created (Pierce and Roedl 2008). In this cultural shift, smart metering provides numerous opportunities to change the current lack of information about energy use, and the resulting unawareness and maybe even lack of interest in methods to reduce one’s energy use.

Smart metering can change the way people think about their energy usage and the way they behave.

2.2. Energy management user studies

Developing user-friendly applications aiming to support users in keeping track of, and lowering their energy use has been the main focus of sustainable human–computer interaction (HCI). This subfield of HCI is one with a remarkable variety in methods, orientations and approaches; DiSalvo *et al.* (2010) offer a comprehensive literature overview of sustainable HCI. A subset of the prior research within the sustainable HCI community has already focused on user studies. A qualitative study by Chetty *et al.* (2008) researched 15 households, doing home visits and semi-structured interviews in order to get a better view of what added value ubiquitous computing could bring to energy management. Taking a slightly different approach, Woodruff *et al.* (2008) interviewed and conducted home visits to 35 selected households, in order to explore their existing sustainable lifestyles, their goal being to inform the design of new energy-efficient technologies by exploring current sustainable practices. In more narrowly targeted research, Chetty *et al.* (2009) studied 20 households, zooming in on power management in home computers. Apart from qualitative work, quantitative studies have been carried out, such as Hanks *et al.*'s (2008) study of the sustainable attitudes of undergraduate students.

The goal of this article is not to describe the features of a new home energy management system that offers user feedback, or to give a detailed account of the results of a user study. Instead, it aims to describe an innovative user-centric methodological process that is valid in the development of a home energy management system. Involving users is a common practice in the design and development of innovative technology (Reed *et al.* 2005, Bång *et al.* 2006, Chetty *et al.* 2008, 2009). While some authors contest the role user involvement can play in innovation (Norman 2010), it is generally accepted that user involvement is crucial in the development of usable technology that is tailored to the needs of end-users (Mayhew 1999, Cooper *et al.* 2007, Rogers *et al.* 2011). The description of the development of a home energy management system in this article especially focuses on the input and insights gained through such end-user involvement throughout the entire development process, and the way these insights have been used in the design of the application. As user feedback has been taken into account in every step of the iterative development process, this user-centred approach has led to a home energy management system that is tailored to the specific needs and wants of specific user groups.

3. An innovative user-centric methodological process

In this section, the methodology and the results of the research are presented. The study includes preliminary work, consisting of a user experience (UX) competitive analysis and the development of a general energy efficiency framework (Section 3.1). The main user research presented below consists of a description of field research and the further (both qualitative and quantitative) analysis of the field data (Section 3.2). The various components of this research and the interactions between the components are visualised in Figure 1.

The first phase of the main user research consisted of a large scale survey ($N = 1314$) held among the population of Flanders, Belgium (Section 3.2.1). One of the main purposes of this survey was to assemble a large and heterogenic panel of respondents who were willing to participate in the next phases of the research. A second purpose was to collect as much information as possible: structural (e.g. appliance ownership) and objective data (e.g. average energy use) as well as attitudinal and behavioural data.

For in-depth observation of energy use, 30 households were selected from the panel and invited to participate. The data collected in the survey allowed to select 30 households with very heterogeneous profiles. The research was executed in four parts. First, a series of introductory interviews was conducted to map people's household electronics equipment, and their current attitude and habits concerning energy use (Section 3.2.2). Second, a diary study was performed, during which the participants were asked to fill in a two-week diary of their energy use-related behaviour (e.g. their usage of different appliances, heating practices, etc. – Section 3.2.3). Third, based on the introductory interviews and the diary study, personas were created (archetypical representations of real or potential users, representing research-based patterns of users' behaviour and goals – Section 3.2.4). Fourth, a new round of interviews comprised the presentation of four scenarios to the interviewees, presenting a range of solutions that can help users become more aware of their energy use (Section 3.2.5). The scenarios were compiled with increasing technological complexity, ranging from a scenario illustrating basic smart metering applications such as detailed billing, to a scenario illustrating the possibilities of home automation in relation to energy conservation. Participants were asked to give their opinion and elaborate on these functionalities and applications. Finally, a second quantitative survey ($N = 858$) was held to obtain a large-scale evaluation of the scenarios. In what follows, we will describe each methodological step more in detail.

Figure 1. Research flow.

3.1. Preliminary research

3.1.1. User experience competitive analysis

In preparation of the user research presented in the remainder of this paper, a UX competitive analysis was executed. The aim of the analysis was to provide an overview of energy monitoring products that are currently available, and to provide best practices and recommendations for the development of a home energy management system (Brown 2007). For the analysis, 80 products and product websites have been brought together, serving as an overview of the current energy monitoring market. These applications have been structured according to their functionality and features, and divided into larger product groups. Based on this information, it was possible to position the future energy management system in the broader field of energy awareness and tracking technology. The analysis resulted in product groups ranging from simple hardware solutions monitoring the energy use in one power socket, over ‘eco-friendly’ domotics systems that

can adjust lighting and climate settings, to full-fledged home energy management systems. As especially this last category is very broad, further subdivisions were made according to user interface (web-based vs. in-home display), functionalities (global metering vs. local metering at appliance level) and data output (real-time energy usage only vs. historical comparisons with other households, etc.), etc. This preliminary analysis was useful in deciding about opportunities and challenges for a new energy management system. In later phases of the user study, information from the UX competitive analysis was used to decide which product features would be presented to respondents to get feedback about their usefulness. The following categories were used to divide the products.

3.1.1.1. Instructive websites. Websites that give information and tips, using, e.g. 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.

3.1.1.2. 'Eco-friendly' domotics. Domotics systems whose primary functionality consists of automating window blinds, controlling music and TV screens, burglar alarms, etc. 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.

3.1.1.3. Reinterpreted everyday objects. Some familiar objects 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).

3.1.1.4. Home energy management systems. These systems combine usage data collection with the provision of feedback through, e.g. 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 information (websites) and making people aware of their energy use, to guiding people by offering personalised energy saving tips and automating certain energy efficiency measures, such as turning off all lights upon leaving the house (several smart metering solutions; eco-friendly domotics). The UX competitive analysis made clear that in order to be innovative and to provide added value in comparison with products already available on the market, the inclusion of some specific functionalities was necessary. To add value to the existing market, the envisioned application still has to provide clear, intelligible background information on their energy use, and guide them by offering energy saving tips based on their personal usage data.

3.1.2. Framework development

Based on the characteristics of the systems that were reviewed in the UX competitive analysis, an exploratory classification was made of the functionalities of a Home Energy Management System. Besides giving a summary of a category of functionalities, each consecutive category can also be related to a person's current state of knowledge about energy use. Four categories, which represent different degrees of intrusiveness of a home energy management system, were distinguished and labelled 'information', 'awareness', 'guidance' and 'automation'. We rank them according

to their level of intrusiveness, Automation (A) being the highest level of intrusiveness.

(D) Information refers to applications such as websites with basic provision of information about, e.g. how to conserve energy. These applications are especially relevant for users with no sufficient knowledge on energy use-related matters.

(C) Awareness refers to applications offering basic feedback, such as real time meter readings (basic smart metering). The aim of this functionality is to give personalised feedback to the user about what he is using on a daily/weekly/monthly/... basis. These applications are especially relevant for users that are somewhat involved in their energy use, and that want to know the effect of energy efficiency measures.

(B) Guidance goes a step beyond awareness. Applications providing this functionality give tailored feedback on overall and appliance level in order to 'guide' the user to a more efficient energy use.

(A) Automation is the final and most advanced category in terms of intrusiveness. Applications providing this functionality resort under home automation or domotics. Smart thermostats and lighting control are only a few of the possibilities of automation with regard to energy efficiency.

This classification framework will be used extensively in the development of the personas. Figure 2 gives an overview of the framework.

3.2. User research

3.2.1. Large-scale survey

As a first step in the actual user research, a survey was held in Flanders. This sample would be the base of recruitment for the next phases of the research. In the large-scale survey, structural, objective, behavioural and attitudinal data were collected. Moreover, a preliminary estimation of the adoption potential of home energy management systems was made, using the Product Specific Adoption Potential scale (PSAP) (De Marez and Verleye 2004, De Marez 2006, Evens *et al.* 2010). The scale measures the interest and purchase intention of energy monitoring tools (as described in the UX competitive analysis) in terms of adopter segments as formulated in diffusion theory (Rogers 1995). According to diffusion theory, the diffusion of an innovation in a social system follows an S-shaped curve. Rogers (1995) distinguishes between five adopter segments, with theoretical approximations of the segment sizes. The Innovators (2.5% of the population) are the most innovative group of adopters. They will be among the first to adopt an innovation, followed by the categories of Early Adopters (13.5%), Early Majority (34%), Late Majority (34%) and Laggards (16%). In order to assign the respondents

to one of the adopter segments for energy monitoring tools, the PSAP scale (De Marez and Verleye 2004, De Marez 2006, De Marez *et al.* 2007) was used. The scale was developed as a valid alternative to traditional single-intent questions used in traditional market research, which systematically lead to over- or underestimation of the adoption potential of innovations. Instead of a single-intent question asking for the adoption likelihood of an innovation, three questions are asked in the PSAP method. First, the respondents received an introductory text about energy monitoring tools and their possibilities. The tools were described as devices that offer households the ability of closely monitoring their energy use. After reading this text, a first (traditional) intention question was asked (PSAP question 1): 'If you would have the opportunity tomorrow to buy an energy monitoring tool, to what extent do you think that you would buy this device'? The question had to be answered on a five-point scale ranging from 'I would immediately buy this' to 'I would definitely never buy this'.

Second, the respondents were asked to rate 10 applications of energy monitoring tools on a five-point scale ranging from 'not interested at all' to 'very interested'. The applications were:

- Receiving personalised tips to save energy based on your energy usage data.
- Insight in your energy use in real time at every moment of the day.
- Receiving graphs and reports with an overview of the total energy use in a certain period.
- Postulate goals to save energy in the future.
- Making an estimation of the future energy use during a certain period.
- Comparing your energy use with other (comparable) households or houses (e.g. in your neighbourhood).
- Receiving feedback when the energy use exceeds that of a previous comparable period.
- Entering in competition with other households to keep the energy use low.
- Graphs and reports with detailed energy use data per appliance.
- Automatic switch-on/-off of appliances, based on time of the day (e.g. day/night).

Furthermore, the respondents were asked to specify an 'acceptable price limit' they are willing to pay for an energy monitoring tool that is capable of providing the 10 applications that we provided in the previous question. No limitations were imposed. The respondents were free to give any price they thought was acceptable.

After these questions, a second more personalised intention question was asked (PSAP question 2). This

time, an ideal product was composed using those system functionalities from the aforementioned list of 10 that the respondent was either 'interested' or 'very interested' in. This ideal product was then presented at a price that was acceptable for the respondent, according to the price limit (s)he had indicated, and containing all the applications (s)he was interested in. Hence, every respondent had to give their adoption intention for this ideal product at their ideal price (which was different for every respondent).

Finally, a third intention question was asked (PSAP question 3). This time, the adoption intention for a 'suboptimal product' was measured. Again, their ideal product was provided, but at a higher price than the limit they indicated (their ideal price was raised with 20%).

Each of the respondents was assigned to one of the adopter segments: Innovators, Early Adopters, Early Majority, Late Majority and Laggards based on their answers to the three PSAP scale questions. For example, if the respondent answers all three PSAP scale questions with 'I would immediately buy', he/she is assigned to the segment of the innovators (Verleye and De Marez 2005). Furthermore, two more segments were added to the segmentation: 'Current Owners' and 'Out of Potentials'. Current Owners are those who indicated that they already possess energy monitoring tools. Out of Potentials are respondents that showed no interest in any of the 10 applications that were provided. Late Majority and Laggards were merged into one single segment labelled 'Later Adopters' due to small socio-demographic and attitudinal differences. This segmentation allowed us to get an initial insight on those who are interested in monitoring their energy use and those who are definitely not interested. The segmentation would be an important parameter in the next steps of the user research (cf. *infra*). Table 1 summarises a socio-demographic overview of the segments.

The fact that 3% of the sample is Current Owners means that a small percentage of Flanders already has some experience with energy monitoring; 4.6% being innovators indicates that there is a reasonable base of people that are very interested in energy monitoring tools and potentially willing to adopt them in the short term; 47.7% being Early Adopters or Early Majority means that energy monitoring might easily find its way to mass market adoption. This is of course depending on the price. In the survey, the respondents were free to give any price they were willing to pay. The average price in the sample was €87. While this is reasonable for basic energy monitoring tools, this is definitely far below what would be the market price of home energy management systems. However, the segment sizes do indicate that a substantial interest in energy monitoring exists in Flanders.

Table 1. Socio-demographic overview of the segments.

Segment	% of sample	Average age	Average family size	Educational level	Interest in smart metering	Average willingness to pay
Current Owners	3.0	44.3	2.9	Average-high	High	N/A ¹
Innovators	4.6	44.8	3	High	High	€141
Early Adopters	28.9	46.3	2.9	High	Average	€109
Early Majority	18.8	46.5	2.9	Average-high	Average	€75
Later Adopters	26.7	50.5	2.6	Average-high	Low	€63
Out of Potentials	17.9	54.6	2.6	Low	Low	N/A

Note. ¹Current owners and out of potentials were not asked for their willingness to pay. For current owners, this was due to the fact that they already own certain tools. For Out of Potentials, this was because they indicated to be 'not interested at all' in all of the applications listed.

In contrast, 26.9% of the Flemish population are not immediately interested in energy monitoring and 17.9% indicate that they would never adopt energy monitoring tools. The table makes it clear that the older the respondents are, the less interested they are in adopting energy monitoring tools: the Later Adopters and Out of Potentials have the highest average age of all segments. They also have smaller family sizes in comparison to the 'younger' segments. There is a significantly higher proportion of couples without children still living at home among the Out of Potentials (and to some extent also among the later adopters) compared to the other segments. Current Owners, Innovators, Early Adopters and Early Majority on the other hand have a higher rate of families with children that are still living at home. Few differences can be seen regarding education. This is partly due to a slight overrepresentation of higher educated respondents in the whole sample. The Out of Potentials, however, have a lower educational level than the other segments.

Eventually, 74.7% of the sample was willing to further participate in the research process, giving us a panel of 968 members; 3.3% of those willing to participate were Current Owners, 5% were Innovators, 33.1% were Early Adopters, 20.1% were Early Majority, 24.2% were Later Adopters and 14.3% were Out of Potentials. This panel would be used as a means of recruitment for each stage of the user research.

3.2.2. Introductory interviews: mapping respondents to the energy consciousness scale

Based on their membership to one of the six adopter segments, a subsample of households was composed from the panel and contacted. These respondents were invited to participate to the interview and the diary study. Seventy-two households agreed to participate in the study. Thirty of them were selected based primarily on their adopter segment membership. Secondary selection criteria were age, educational background

Figure 2. Classification framework of the applications of energy monitoring tools.

and family type. The goal of the introductory contextual interview was to get a clearer view on the specific situation and context in which the diary study would take place (Beyer and Holtzblatt 1997). During the semi-structured interview, several topics were addressed, such as the ownership of household appliances and their energy efficiency, the energy efficiency of the residence, the presence of photovoltaic solar panels, solar boilers and heat pumps, etc. While the general structure of the interviews was fixed, specific topics were dealt with in more or less detail depending on the specific situation and habits in the household. After the interview, a tour of the house was made and pictures were taken to give the researchers a better view of the housing context. Third, the attitudes and habits regarding energy use of the participating household were looked at. Underlying motivations such as environmental concern or financial profit were also addressed. The main topics of this conversation were the attention paid to the energy bill (do they look at it,

compare it to previous bills,), how actively they seek information on energy-related topics (and how) and how closely they monitor their usage throughout the year. Further questioning gave us insights in how often people talk about energy use with friends and relatives, where they find their information (for example, which websites related to energy use they visit), how they keep track of their usage throughout the year (basically by keeping meter reading on a regular basis like two weeks or monthly) and what they do with these data (forecasting their energy bill, comparing to others, comparing to previous periods, etc.).

As a second dimension to the adoption intention segmentation resulting from the large scale survey, a basic classification of the energy consciousness of the 30 participants was made. These two dimensions will form the basic framework for the persona development (cf. Section 3.2.4). They were given a score on a 1–4 scale of energy consciousness, ‘4’ representing a high energy consciousness. Respondents were given a score of ‘1’ when they were clearly not interested in their energy use whatsoever. Indicators for this score were paying not much attention to energy bills, hardly talking about energy use, and rarely taking energy efficiency measures. A ‘2’ was given when some interest was shown towards energy use. An indicator for this score was, for instance, search behaviour: participants in this group indicated that they do not really take measures to save energy, but they are looking around, searching for possible solutions. They typically also have unanswered questions on how to be more efficient. A ‘3’ was given to those participants that already take energy-efficient measures to decrease their energy use significantly. Typically, they actively search for information, address their relatives or friends about it and try to find solutions to their questions. A ‘4’ was given when a participant was very engaged into his or her personal energy use. The main indicator for this group was monitoring energy use and acting accordingly. These respondents typically keep track of their meter readings on a regular basis (weekly, monthly, etc.) and use this information to compare or detect anomalies in their usage, in order to get it to the most efficient level of energy use given their housing. Four participants were given the lowest score on the scale, 2 participants received a ‘2’, 9 participants were given a ‘3’ and 15 of them received the highest score. Given the voluntary participation to the research, it is obvious that the majority of the participants are quite highly interested in their energy use. The participants with high scores were also expected to provide substantial input to the development of the energy management system. The other participants, with lower scores, were expected to be very valuable in the process of identification of needs and wants.

The introductory interview described above resulted in a general overview of the participants’ housing and family situations, and their attitude towards energy use. However, for the development of a home energy management system targeted at specific user needs, a more detailed picture of the users’ daily lives, their habits and routines was necessary. To obtain this more detailed information, a diary study was conducted in all 30 households.

3.2.3. Diary studies

The diary study was conceived as a small snapshot of the participants’ daily energy use habits, the main goal being to get a broad overview of the use of the most important appliances, and the role of specific routines in it (e.g. doing laundry on Saturdays, etc.). 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-h time window to specify when an appliance was used (see Figure 3), 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.). This had to be filled in every day during the two weeks. The daily section was the core part of the diary. A 24-h time window was provided in a template, allowing participants to record start and end time of the most important household appliances

Figure 3. Electric appliance usage in the diary study.

(washing machine, dishwasher, TV, etc.) in the diary. The diary was filled in primarily by the 'head of the family' or by the person most active in the household work, although in several households, the entire household collaborated, including the children.

The results from the diary study can be divided into two parts: a high-level energy-use analysis of the energy use within the household, and a qualitative evaluation of observed behaviour, values and beliefs.

The energy use analysis comprised a snapshot of the participants' actual energy use during the two-week period, combining the list of appliances owned by the household (compiled during the introductory interviews) and the information from the daily section of the diary. Combining these figures with the estimation of the energy use per appliance, we were able to calculate the approximate electricity use per participant during the two-week diary period (for the appliances monitored in the diary). More specifically, these calculations presented a picture of appliance usage in the family (offering information on, e.g. the relative share of doing laundry in the energy use), the participants' knowledge regarding their energy use, the participants' use of their heating systems and their behaviour towards the restriction of their energy use during this observation.

On a more qualitative level, the diary results offered more detailed insights in the participant's routines and in the reasons participants have for their specific behaviour. In the diary, text boxes were included per appliance, where the participants were asked to provide us these reasons. Although the diaries reflect the participants' reported behaviour (which is not always the same as their actual behaviour), the different sections of the diary (such as daily usage reports and text boxes) reinforced each other, making the overall account more credible. For instance, participants would explicitly mention drying their laundry outside depending on the weather conditions – this behaviour was also reflected in the detailed diary entries: in sunny periods, these households did not report any use of the tumble drier.

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 drier when the weather is good, or only turning on the dishwasher

when it is full. Participants that went one step further in their energy saving behaviour often focused on small improvements, such as unplugging specific devices to reduce standby and off mode energy use. 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, convenience considerations prevent people from going further in energy efficiency. These considerations, which had already been observed during the intake interviews, were also apparent in the diary study.

3.2.4. *Persona development*

The detailed information gathered in the interviews and the diary study presented above was used to compile six personas. Personas, as originally described by Alan Cooper (2004), can be defined as an archetypical representation of real or potential users. They are not descriptions, single or average users, but they represent research-based patterns of users' behaviour, goals and motives, combined into a description of a single person. Personas are user models representing complex user data with a useful level of abstraction (Cooper *et al.* 2007). This abstraction can help making informed decisions in the design process of an application. Since their introduction, several quantitative as well as qualitative methods have been explored for persona creation, such as cluster analysis (Tu *et al.* 2010), factor analysis (McGinn and Kotamraju 2008) and Grounded Theory (Faily and Flechais 2011).

In our research methodology, we used a combination of data sources to create personas, resulting in a two-dimensional framework. The adoption intention estimation from the large-scale survey, described in Section 3.2.1, was used as one dimension. The other dimension is the energy consciousness scale described in Section 3.2.2. The diary study participants were mapped on this two-dimensional map based on the data gathered in the survey, interviews and the diary study. The resulting graph (Figure 4) shows 'clusters' of respondents with similar attitudes towards innovative technology (survey) and similar levels of energy consciousness in their daily lives (interviews). This qualitative clustering of the participants in the framework formed the empirical base for the development of the six personas. The combination of several data sources in the clusters (quantitative segmentation data as well as qualitative data from the interviews and diary studies) made sure the personas were solidly founded in empirical research findings, thus avoiding known issues in applying quantitative user segmentation as the sole source for persona development (Siegel 2010).

Figure 4. Persona development framework.

As already has been mentioned, the persona descriptions were based on the results of the prior user research phases. The final persona descriptions contained (see Figure 5):

- A (fictional) picture of the persona.
- The name of the persona, a relevant quote, and some demographic information (based on the interviews).
- Short facts about the house type the persona lives in, and relevant information about heating, household appliances or renewable energy equipment (based on the diary study).
- A short text describing the persona's views on energy use (based on the interviews).
- An indication of the persona's current awareness concerning energy use (a mapping of interview and diary data onto the framework described in Section 3.1.2).

The personas' general characteristics are ranging from a persona interested in saving energy, but not in technology, to a persona that currently does not have the time to keep track of the energy use, but would welcome an IT solution to facilitate energy monitoring (see Table 2 for a more detailed overview). These personas served as a high-level validation of the previous research: in a final interview with the diary study respondents, it was possible to check whether the persona provisionally 'assigned' to respondents was actually a good estimate. The respondent's answers were 'checked' against the behaviour and values represented by the personas assigned to them. In a later stage of the project, during the actual

development of the home energy management system, the personas were particularly useful in deciding for which target group the system would be developed. Table 1 provides an overview of the six personas and their description, including the ranking on the two dimensions of the persona development framework (see Figure 4). On the one hand, it shows corresponding application types that would be adapted to the persona's current state of knowledge about energy use, based on the application classification framework (see Section 3.1.2, Figure 2). Only the lowest levels of application functionality are present, since the more advanced levels (Guidance and Automation) are only achievable using advanced energy monitoring systems. None of the personas already possessed these (only the blue persona has some basic tools, but these cannot provide the Guidance or Automation functionalities).

Table 2 shows two important points about the relationship between the personas and the classification of applications according to the framework explained in Section 3.1.2. These observations are important in the design decisions that have been made when deciding upon the functionality of the energy management system under development. First, none of the personas rise higher than the C-level of 'awareness'. As the personas are based on user research, this is a logical outcome, since solutions that provide guidance and automation are expensive and not widely available yet. None of our respondents had the technology to put them in the 'guidance' or 'automation' sections of the framework. Another observation is that people can rise to the 'awareness' level in the framework without using any technology at all: the grey persona is interested to learn about his energy use, and willing

Table 2. Summary of the six personas based on prior user research.

Persona + colour code	Short description	Persona development framework		Application classification framework
		Corresponding adopter segments	Energy conscious level	
Mark Dupont (blue persona)	Concerned with energy efficiency, but does not make efforts to change his behaviour. Buys new devices and infrastructure (new efficient appliances, solar panels) to keep his energy use under control	Current Owners	4	C. Awareness
Bart De Wilde (purple persona)	Interested in new technologies and gadgets. Because of a busy professional life, and his little children, he does not have time left to track his energy usage. Maybe an ICT solution would make it easier and faster for him to track his energy usage	Innovators/Early Adopters	1–2	D. Information
Anita Mariën (green persona)	Housewife, regularly checks if she can do anything to lower her energy use. She already manually tracks her energy use by writing down meter readings. Primarily concerned with lowering her energy bills, with a rather strong environmental orientation	Innovators/Early Adopters/Early Majority	4	C. Awareness
Hilde Vandeven (orange persona)	Does not make a lot of effort to gather information on energy efficiency – thinks it hard to find any reliable answers to her energy-related questions. Is willing to make some (financial) efforts to lower her energy use, but is reluctant to give up on any luxury	Early Adopters/Early Majority	3	D. Information
Mia Dewulf (yellow persona)	Energy efficiency matters are a matter of routine: turning off lights when leaving the room, lowering the heating at night. Not uninterested in environmental issues or energy use, but not a conscious part of her daily life	Later adopters/Out of Potentials	1–2–3	D. Information
Gerard Jupille (grey persona)	Retired, tracks his energy use in detail and takes quite a few measures to keep the use down: disconnecting appliances to keep them from using energy in standby mode, turning of the heating in unused rooms, etc. Is, however, not interested in ICT solutions for energy efficiency, as he does not see what they could contribute to his current situation	Later adopters/Out of Potentials	4	C. Awareness

to take energy-efficiency measures, but does not need an ICT solution to do so. These observations about the personas' level in the framework, and their potential to rise one or more steps on the framework influenced the design choices that were made in the development of the system. In designing the application, it was important not to create one solution that tries to fit the needs of everyone, but pick out the most interesting target group (persona), and to accommodate its needs

in the best possible way, maximising its potential rise on the energy efficiency scale.

3.2.5. Final interview: scenario development and evaluation

All participants from the diary study agreed to participate in a final interview. In this interview, the personal results of the diary study were discussed with

the participants. The main topic of the interview was the discussion of four scenarios containing different functionalities of a home energy management system. 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 visualisation 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 visualised through an in-home display. The fourth and most advanced scenario illustrated the possibilities of home automation in relation to energy conservation. An example of a scenario can be found in Appendix 1.

In general, scenarios 1 and 2 mainly consist of elements that correspond to the ‘information’ and ‘awareness’ level of the framework scale developed and were discussed above. Table 3 presents the applications in scenarios 1 and 2. Scenario 1 is only marginally related to home energy management systems since the functionalities can simply be delivered on a detailed paper bill (as it was described). Scenario 2, however, does implicate the use of a basic form of home energy management. A personal computer is used as the interface for the home energy management system and more detailed information is provided through more advanced visualisations as compared to scenario 1.

Table 3. Overview of the functionalities in scenarios 1 and 2.

Scenario 1: detailed bill	Scenario 2: creating awareness
<i>Applications used in the scenario</i>	
1. Monthly energy use in kWh	1. Overall overview of the households’ energy use (on personal computer)
2. Monthly energy use in Euro	2. Visual indication of the amount of energy used in the house at a given moment using non-intrusive devices (such as a lamp that changes colour)
3. Forecast of electricity bill on a yearly basis	3. Visual overview/comparison of local electricity production (PV) and use (on personal computer)
4. Monthly payment of the electricity bill	4. Real time checking of energy use (mobile, smartphone, tablet)
5. Comparison of monthly use with a comparable household	5. Possibility to impose a (non-binding) usage limit per month
6. Historical energy use (past months, years)	

Remote checking of energy use is possible through use of a smart phone.

Scenarios 3 and 4 mainly consist of elements that correspond to ‘guidance’ and ‘automation’ (Table 4). The third scenario contains applications that go more into detail on the energy use per appliance level, whereas scenario 2 only gave information on overall meter readings. The functionality included notifications of appliances that were left on when they should not be. An in-home display was added to the scenario as the interface of the home energy management system and dynamic pricing was introduced into the system. No automation was available in scenario 3. The system provided the user with personalised information, but the decision to use the information was still up to the user. The fourth scenario added this automation to the system as the home energy management system became integrated in a complete home automation system. Local production through photovoltaic solar panels (PV) and battery storage was also assessed in the fourth scenario.

Although it has to be noted that the participants were quite positive about most of the applications in the scenarios, the participants 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 visualisation 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 (Respondent 5, Male, Blue Persona)

Still scenario 2 was found to be interesting, because it offers a quick visualisation of their energy use, something that is clearly lacking in most families. Scenario 4 was also thought to be interesting, but more as something ‘of a distant future’, especially due to the battery and level of automation. This last feature was an item of discussion amongst the participants. Several of them were opposed to the idea of leaving the home energy management system in control, even if it would save energy, while others liked this idea. To them, it is an asset compared to scenario 3, which was largely

limited to personalised information and suggestions of use based on dynamic pricing.

3.2.6. The longlist: compilation and evaluation

Based on the input from literature review, the two interviews and diary studies, a final longlist of 25 system functionalities was compiled. All system functionalities generated during the research process were entered in the list. The functionalities were again structured according to the different levels in the framework (Section 3.2.1). As a last evaluation phase of the longlist of applications, an online quantitative survey was held with a representative sample of Flanders ($N = 858$). The aim was to get a view on which applications are of high interest to people and which are not. A quite elaborate introduction to home energy management systems was given to the respondents. This introduction was structured using the four-staged framework which structures the longlist of system functionalities into four categories: applications that give basic information, applications that help to build awareness about energy use, applications that give guidance to the user, based on his personal energy-use data and finally applications with regard to automation of energy using processes in the household.

After this introduction, the longlist of system functionalities based on the qualitative research was presented to the respondents. Per individual use case, the respondents had to indicate how interesting they think the use case is to them. They expressed this interest on an 11-point scale ranging from 0 (totally not interesting) to 10 (very interesting). Based on the ratings of the respondents, for each of the system functionalities, a mean score per use case could be calculated.

- Highest rating (more than 8/10):
 - The system shows the share of your devices in the total electricity use of the house',
 - You get an estimate of what the annual cost of your electricity use in the home will be',
 - You get a warning if an appliance is left on when leaving the house (e.g. units that are normally turned off, such as a coffee maker)',
 - You get a visual representation of the electricity use in your home, expressed in Euros'.

This represents what people in general want: a basic set of information that tells them how much energy they are using, which appliances are using this energy and what it costs. For PV owners, getting an overview of their production/use ratio is of high interest. These results also reflect the information obtained from the personal interviews, in which these

applications, especially the information on appliance level, were found to be the most interesting.

- Receiving somewhat lower scores (7–8/10), but still interesting to the respondents:
 - You get a comparison of your current energy use with your energy use of the past months and years',
 - You can compare your energy use with that of a comparable family in a similar property'.

People want to compare to themselves in the first place: comparing to historical data received significantly higher scores than comparing to similar households. In the personal interviews, this also was apparent. One reason for this is that interviewees indicated that a comparison to another family is hard to make because every household has its own very specific situation, not only with regard to their property, but also regarding certain habits, work-related routines, etc.

The idea of a battery used for storing energy was also thought to be very interesting. From the interviews, however, we know that people consider this to be something of a distant future. Electric vehicles might change this view in the future though. Visual representations in kWh of both electricity ($m = 7.17$) and gas use ($m = 6.68$) are deemed less important than the representation in Euros. Most system functionalities related to automation (the highest level of the framework) were rated rather low (in general). While the use of mobile devices, such as smart phones or tablets, for remote monitoring or control of the energy

Table 4. Overview of the functionalities in scenarios 3 and 4.

Scenario 3: guidance provision	Scenario 4: automation
<i>Applications used in the scenario</i>	
1. Notification of appliances that are left on	1. Automatic setting of lighting and heating in the house when present or absent
2. Dynamic pricing	2. Remote control (mobile) of thermostat and/or household appliances
3. Monitoring energy use per appliance	3. Battery taking over power use at times of peak prices
4. Heating tips based on weather forecasts	
5. Information about the physical condition of appliances	
6. Receiving warnings when approaching an imposed energy use limit	

use are rated rather low, it has to be noted that an important factor in this case is the actual ownership of a tablet or smartphone. Owners of a tablet or smart phone are significantly more interested in monitoring and controlling their energy use from locations outside of the house.

3.2.7. Application design

The user research presented above resulted in a design for a home energy management system primarily

targeted at a specific segment of the potential user population. The personas described in Section 3.2.4 helped in deciding that the most interesting user segment for the system would be the segment represented by the purple persona (see also Table 2), representing the user group that currently does not track energy use, but would welcome an IT solution to facilitate monitoring energy use. As this persona is currently not acting energy efficiently, but welcomes ICT solutions to improve energy use knowledge, this persona was considered the most promising. To

" Als het zuiniger moet, koop ik wel een zuiniger koelkast. "

**38 jaar
ploegbaas in een chemisch bedrijf
gehuwd, met kinderen**

current owners en innovators

**cv met radiatoren open bebouwing zonnepanelen
warmtepomp**

Onlangs hebben mijn vrouw en ik een nieuwe afwasmachine aangeschaft. Het is een machine met energielabel A . Prijzig, maar wel een van de zuinigste op de markt. Omdat we dat toestel toch dagelijks gebruiken dachten we dat we op deze manier toch wat zouden kunnen besparen. We zetten het toestel meteen aan na het avondeten: met de zonnepanelen die sinds kort op ons dak liggen, maakt het toch niet zoveel uit wanneer het toestel precies draait. Er staat ook een eco-stand op: als we toestellen kopen, is dat toch iets waar we zeker op letten.

Als we iets nodig hebben, dan schaffen het ook wel aan. Onze oudste dochter zit nu in haar eerste jaar aan de universiteit, en zit vaak op haar kamer te studeren. Om specifiek haar kamer te verwarmen hebben we een oplossing gevonden van Honeywell. Niet goedkoop, maar het houdt onze dochter warm.

Efficient

automatisation

guidance

awareness

information

Inefficient

X

Figure 5. Example of a persona summary.

present the purple persona with an energy management system tailored to its specific needs, a relevant subset of system functionalities was combined.

Even though the primary persona is at the lowest stage of the framework, it was decided that the system should also include more advanced functionality that corresponds to the 'guidance' (B) and even 'automation' (A) level of the framework. This decision was made because of two reasons. Firstly, the purple persona is the most open to ICT solutions, and most likely to adopt solutions that are more advanced than giving only graphs and information on energy use. Secondly, adding more advanced functionality creates a broader application concept that can 'grow' with its user. While novice users will be more interested in high-level graphs to track their overall energy use, users that have used the system for a longer period can go a step further, and check graphs per power socket to track the use of individual devices, or use the application to set a target energy use value they can aim for, in an attempt to save energy.

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). As a first exercise, the final interview with the scenario evaluation (see Section 3.2.5) contained a section where the respondents were asked to select a subset of 'application widget' visualisations (with functionality from the four scenarios) that they evaluated as most interesting. This exercise allowed respondents to evaluate the application ideas in a more concrete, visual way, and allowed them to compile their 'own' ideal energy management system.

While the technique presented above still guides respondents, in that they get to choose from a limited set of application widgets, additional focus group sessions allowed for a more 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 and the focus on the purple persona as the primary persona were used to create the design of the final application for smartphones 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 (Figure 6, left). 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 and 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 (Figure 6, right), estimates of the yearly energy bill, etc. Apart from visualising and comparing usage information (which corresponds to the 'information' (D) and 'awareness' (C) stages in the framework), the system gives users advice on their energy-use behaviour in the system messages ('guidance stage'), and warns them when an energy use threshold has been reached.

4. Discussion: the value of a multidisciplinary approach

As already discussed in Section 2.2, a subset of research within the sustainable HCI community already focuses on user studies. Some of these studies are qualitative, whereas others have a quantitative background. However, a combination of both methods to study the development of a home energy management system is missing and this article tries to fill this gap.

Qualitative in-depth research often allows a thorough reasoning, whereby end-users can be questioned in a more interactive way. For a rather small group of respondents, social processes, behaviour and attitude can be clearly analysed. Quantitative research, on the other hand, offers a broad view of the entire target population and allows a fast collecting of a diverse array of data. Moreover, statistical data management and analysis are possible, as to reveal different clusters or interrelating factors.

The multidisciplinary approach proposed in this article offers the best of both worlds. While the individual stages in the methodology are not innovative as such, the combined methodology allows researchers to get a clear in-depth picture of the behaviour of the target audience, while at the same time providing an abstraction that is useful for design decisions that need to be made for specific applications.

Moreover, the stages in this innovative user-centric methodological process interrelate closely. This way, results are tested and retested, and above all, each stage provides input for the next stage.

The integrated approach becomes clear in several stages of the methodology. The initial large scale study gave us a broad view of energy-use behaviour in

Figure 6. Screenshots from the interface. Left: home screen with a short summary of the game concept, navigation and an overview of new messages. Right: visualisation of the user's energy use (bar graph) together with the dynamic energy prices (line graph).

Flanders. By deepening our insights through the interview and diary studies, we were able to identify different household profiles, pick out interesting ones and study their behaviour more closely. Based on these insights, we were able to design four distinct yet related scenarios that match household behaviour. These scenarios could then be presented to and evaluated by these households. Their reflections could then be incorporated in a new large scale survey, which allows to draw general conclusions on what aspects or features are appealing to the population. This information is in turn crucial to the development phase.

To summarise, each step of the research process delivers necessary insights for the next one and the alternation between quantitative and qualitative phases guarantees in-depth information that can be validated for a broader population. Limiting the process to only qualitative research could result in interesting ideas that, however, are only of interest to a small part of the population. Doing only quantitative research could result in overlooking possible killer applications. Combining the two creates a rigorous, integrated research methodology where outcomes of both worlds complement each other.

The methodology was applied to the development of a home energy management system in this study, but is easily transferable to other product categories,

especially when dealing with new product or innovation development. While the methodology described here did use some domain-specific tools, such as the classification framework of energy monitoring tools, the main interaction between large-scale, quantitative methods and in-depth qualitative methods described above can be used for other application domains as well. Specifically, the large-scale, quantitative parts of the methodology make the methodology especially suitable for research into the development of consumer technology, typically targeted at a large target user group, rather than specialised niche applications.

While offering a very detailed and rich overview of user behaviour and expectations, the methodology, consisting of several consecutive stages, does require an intensive user research effort from an interdisciplinary team. The fact that the methodology can be quite time-consuming and work-intensive can be seen as the most important drawback. The interdisciplinary methodology requires various skills in market segmentation and adoption forecasting on the one hand, and user-centred design on the other. Moreover, the market studies and the user-centred design aspects are integrated tightly, each aspect providing crucial input to the other. Most stages in the methodology depend on input from the previous stage. While the user research can be conducted in a less comprehensive way than discussed in this paper

(interviewing, for instance, fewer respondents, targeting a smaller audience in the surveys, etc.), the overall methodology will probably remain time-consuming, due to the number of consecutive stages. However, as outlined above, the combined methodology adds up to more than the sum of its constituent parts, as evidenced by the detailed, rich insights gained in the case study. In this respect, the richness of the results does justify the process.

5. Conclusion

The research presented above discusses the user-centric methodological process leading up to the development of a home energy management system. The final stage of the research process will consist of testing the energy management system in a field trial. The application will be tested in a six-month field trial, which will provide us valuable information on the usage of the system, user feedback and the effectiveness of the system in reducing the actual energy use of the participating households.

In sum, the methodology presented above provides the advantage of resulting in concrete, actionable results, and design concepts and ideas culminating in the six-month field trial. At the same time, the methodology is firmly rooted in quantitative research of the target population at large. Whereas other research approaches commonly restrict themselves to either a broad view of the entire target population or an in-depth qualitative study of a small subset of users from the target population, this paper presents a research methodology that combines the strengths of both approaches, and integrates them into a coherent, richer research framework.

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References

- Backhaus, J., and Heiskanen, E., 2009. Rating expert advice on how to change energy behaviour. Research Note 2, Changing Behaviour Project, European Commission.
- Bång, M., Torstensson, C., and Katzeff, C., 2006. The PowerHouse: a persuasive computer game designed to raise awareness of domestic energy consumption. In: *Proceedings of first international conference on persuasive computing for well-being*, 18–19 May, Eindhoven, The Netherlands. Berlin, Heidelberg, Germany: Springer-Verlag, 123–132.
- Beyer, H. and Holtzblatt, K., 1997. *Contextual design: defining customer-centred systems*. San Francisco, CA: Morgan Kaufmann.
- Bin, S. and Dowlatabadi, H., 2005. Consumer lifestyle approach to US energy use and the related CO₂ emissions. *Energy Policy*, 33 (2), 197–208.
- Brown, D.M., 2007. *Communicating design: developing Web site documentation for design and planning*. Berkeley, CA: New Riders.
- Burholt, V. and Windle, G., 2006. Keeping warm? Self-reported housing and home energy efficiency factors impacting on older people heating homes in North Wales. *Energy Policy*, 34 (10), 1198–1208.
- Carlsson-Kanyama, A. and Lindén, A.L., 2007. Energy efficiency in residences – challenges for women and men in the North. *Energy Policy*, 35 (4), 2163–2172.
- Chetty, M., Tran, D., and Grinter, R.E., 2008. Getting to green: understanding resource consumption in the home. In: *Proceedings of the 10th international conference on Ubiquitous computing (UbiComp '08)*, 21–24 September, Seoul, KR. New York, NY: ACM, 242–251.
- Chetty, M., et al., 2009. It's not easy being green: understanding home computer power management. In: *Proceedings of the 27th international conference on Human factors in computing systems (CHI '09)*, 4–9 April, Boston, MA. New York, NY: ACM, 1033–1042.
- Cooper, A., 2004. *The inmates are running the asylum: why high tech products drive us crazy and how to restore the sanity*. Indianapolis, IN: Sams.
- Cooper, A., Reimann, R., and Cronin, D., 2007. *About face 3: the essentials of interaction design*. Indianapolis, IN: Wiley.
- Darby, S., 2006. *The effectiveness of feedback on energy consumption: a review for DEFRA of the literature on metering, billing and direct displays*. Oxford: Environmental Change Institute, University of Oxford, 1–21.
- De Marez, L., 2006. Diffusie van ICT-Innovaties: Accurater Gebruikersinzicht Voor Betere Introductiestrategieën. Unpublished PhD dissertation. Universiteit Gent.
- De Marez, L. and Verleye, G., 2004. ICT-innovations today: making traditional diffusion patterns obsolete, and preliminary insight of increased importance. *Telematics and Informatics*, 21 (3), 235–260.
- De Marez, L., et al., 2007. Adopter segments, adoption determinants and mobile marketing. *Journal of Targeting, Measurement and Analysis for Marketing*, 16 (1), 78–95.
- DiSalvo, C., Sengers, P., and Brynjarsdóttir, H., 2010. *Mapping the landscape of sustainable HCI*. In: *Proceedings of the 28th international conference on human factors in computing systems (CHI '10)*, 10–15 April, Atlanta, GA. New York, NY: ACM, 1975–1984.
- Evans, T., et al., 2010. Forecasting broadband Internet adoption on trains in Belgium. *Telematics and Informatics*, 27 (1), 10–20.
- Faily, S. and Flechais, I., 2011. Persona cases: a technique for grounding personas. In: *Proceedings of the CHI'11*, 7–12 May 2011, Vancouver, BC. New York, NY: ACM, 2267–2270.
- Fischer, C., 2008. Feedback on household electricity consumption: a tool for saving energy? *Energy Efficiency*, 1 (1), 79–104.
- Fogg, B., 2003. *Persuasive technology. Using computers to change what we think and do*. San Francisco, CA: Morgan Kaufmann.

- Grønhoj, A. and Thøgersen, J., 2011. Feedback on household electricity consumption: learning and social influence processes. *International Journal of Consumer Studies*, 35 (2), 138–145.
- Hanks, K., et al., 2008. Sustainable millenials: attitudes towards sustainability and the material effects of interactive technologies. In: *Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems (CHI '08)*, 5–10 April, Florence, IT. New York, NY: ACM, 333–342.
- Kester, J.C.P., Burgos, M.J.G., and Parsons, J. (2009). European smart metering guide energy saving and the customer *Edition 2009*: Energy research Centre of the Netherlands (ECN).
- Marsh, H.W., 1987. The hierarchical structure of self-concept and the application of hierarchical confirmatory factor analysis. *Journal of Educational Measurement*, 24 (1), 17–39.
- Mayhew, D.J., 1999. *The usability engineering lifecycle. A practitioner's handbook for user interface design*. San Francisco, CA: Morgan Kaufmann.
- McCalley, L.T. and Midden, C.J.H., 2002. Energy conservation through product-integrated feedback: the roles of goal-setting and social orientation. *Journal of Economic Psychology*, 23 (5), 589–603.
- McGinn, J. and Kotamraju, N., 2008. Data-driven persona development. In: *Proceedings of the CHI 2008*, 5–10 April, Florence, IT. New York, NY: ACM, 1521–1524.
- MIRA, 2010. *Flanders environment report: indicator report 2010*. Mechelen, Belgium: MIRA, VMM.
- Norman, D.A., 2010. Technology first, needs last: the research-product gulf. *Interactions*, 17 (2), 38–42.
- Pierce, J. and Roedl, D., 2008. Changing energy use through design. *Interactions*, 15 (4), 6–12.
- Raaij, W.F.v. and Verhallen, T., 1983. Patterns of residential energy behavior. *Journal of Economic Psychology*, 4 (1–2), 85–106.
- Reed, C., Wang, H.W., and Blevis, E., 2005. Recognizing individual needs and desires in the case of designing an inventory of humanity-centred, sustainability-directed concepts for time and travel. In: *Proceedings of the DPPI '05*, 24–27 October, Eindhoven, The Netherlands. Technische Universiteit Eindhoven, 181–212.
- Rogers, E.M., 1995. *Diffusion of innovations*. 4th ed. New York, NY: Free press.
- Rogers, Y., Sharp, H., and Preece, J., 2011. *Interaction design. Beyond human-computer interaction*. 3rd ed. Chichester, UK: Wiley.
- Sardianou, E., 2007. Estimating energy conservation patterns of Greek households. *Energy Policy*, 35 (7), 3778–3791.
- Schuler, D. and Namioka, A., 1993. *Participatory design: principles and practices*. Hillsdale, New Jersey: CRC/Lawrence Erlbaum.
- Shove, E., 2003. *Comfort, cleanliness and convenience: the social organization of normality*. Oxford and New York: Berg.
- Siegel, D.A., 2010. The mystique of numbers: belief in quantitative approaches to segmentation and persona development. In: *Proceedings of the CHI 2010*, 10–15 April, Atlanta, GA. New York, NY: ACM, 4721–4732.
- Tu, N., et al., 2010. Using cluster analysis in Persona development. In: *Proceedings of the SCMS 2010*, 6–9 October, Hong Kong, CN. The Hong Kong Polytechnic University, 254–258.
- Verleye, G. and De Marez, L., 2005. Diffusion of innovations: successful adoption needs more effective soft-DSS driven targeting. *Journal of Targeting, Measurement and Analysis for Marketing*, 13 (2), 140–155.
- Woodruff, A., Hasbrouck, J., and Augustin, S., 2008. Bright green perspective on sustainable choices. In: *Proceedings of the twenty-sixth annual SIGCHI conference on Human factors in computing systems (CHI '08)*, 5–10 April, Florence, IT. New York, NY: ACM, 313–322.

Appendix 1: Scenario 3 (Guidance)

John will be on the road for his job all day: upon leaving the house, he uses the wall-mounted display in his living room to indicate that he is leaving, and that he is the last one to leave the house. The display indicates that there is a device that is normally turned off when the occupants are absent: the coffee maker. John sees a warning that it could be dangerous for the unit to be left on, because the heating element will continue heating up. He remembers that he forgot to turn the unit off, and quickly returns to the kitchen to turn it off before he leaves.

During the afternoon, John's wife Rebecca arrives home. When she uses the living room display to indicate that she is back home, she sees a notification that it is a windy afternoon. This is important, as John and Rebecca's energy supplier uses green power. If there is a lot of wind,

production of wind energy is high, and electricity is cheaper. Rebecca decides at once to turn on the washing machine. The display also shows her the weather forecast for tomorrow and the day after. The forecast shows her that the temperature will be quite a lot higher than the previous days, and therefore the systems suggests to change the current program on the thermostat.

The washing machine has finished its program by the time John also comes home from work. John enters the house, and takes a look at the living room display. He gets a message that tells him the energy use of his washing machine has been rising over the past few weeks. Due to this increased power consumption, he also gets the notification that his monthly energy bill is already close to the consumption limit he had set beforehand. Maybe it is time to replace the 10-year-old machine?