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Designing Effective Feedback of Electricity Consumption for Mobile User Interfaces

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ABSTRACT

This paper illustrates the approach of Energy Life, a pervasive household sensoring and feedbacking system aimed at improving the energy conservation practices of the inhabitants. The concept of EnergyLife takes into account state-of-the-art knowledge of what makes a feedback intervention effective, which – at this stage of its development – can be synthesized into two main features. First, knowledge and action are to be synergically addressed by visualizing electricity consumption on the one side, and providing conservation tips on the other. Second, the design should be centered on the users and undergo iterative usability tests. A more detailed description of the literature-based requirements informing the design of EnergyLife is offered at the beginning of the paper. The way in which they are embodied in the features of the mobile interface, epitomized by its intuitive 3D carousel, is then described. Finally, the rationale and results of the first usability evaluation are reported, describing the responses to a satisfaction questionnaire and the types of breakdowns that occurred during the users' interaction with the device. These results will guide the next development phase and the release of a new prototype.

Keywords: *energy awareness, feedback, mobile interface, breakdown analysis.*

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1. Introduction

The potential for saving energy relies on the involvement of consumers in conservation and waste reduction. Current solutions often pay limited attention to usability and engagement, which are prerequisites for the sustained impact of any feedback system. These are challenges for interaction design, namely to propose solutions to engage consumers and turn them into active players in order to develop energy conservation practices. Such challenges can be faced by considering their social and psychological aspects, together with state-of-the-art approaches to user interfaces.

The system presented here – called EnergyLife – tries to accept these challenges and deals with them by capitalizing on past attempts at improving energy conservation via the provision of feedback, and on their reported strengths and weakness. It also relies on current advances in technology, which make pervasive digital feedback systems tailored to consumers widely accessible. This system can be implemented in familiar tools, which do not require any special measures or learning process in order to be mastered by their users. The paper describes the requirements of this system, connecting them to the literature; it then illustrates the mobile user interface developed on a touch-enabled smart phone using 3D widgets; finally, it recounts the method and results of the usability tests.

1.1 Awareness tools

The identification of the requirements for EnergyLife started with a series of interviews with people who are assumed to possess wide experience in increasing energy awareness because of their position, job, or personal commitment. The interviews were integrated with a literature review of more than 70 scientific articles, which reported the results of interventions to reduce energy consumption by way of various feedback systems. The review allowed the characteristics of the interventions that proved more effective and that are worth being implemented to be singled out.

A total of nine Finnish and Italian stakeholders were interviewed according to a common protocol; in both countries, the stakeholders included prominent activists in environmentalist associations, members of governmental agencies, and house appliance producers. The interviews revealed the stakeholders' idea of consumers' energy conservation practices. According to them, consumers' knowledge barely consists of the bill they pay. Details, such as the amount of kW/h spent or the cost of a kW/h, escape regular consumers. In addition, people lack some basic knowledge of the proper use of an electrical device (e.g. the meaning of the term power class), or embrace wrong beliefs (e.g. switching on and off fluorescent bulbs any time they leave a room for a short while). According to the stakeholders, consumers lack information about the long-term impact of their behaviors, about the energy production process (e.g. energy re-use, when the energy generated by one appliance is used to feed another one) and about invisible consumption (e.g. devices in stand-by state), while the perception of the energy consumed can be based on superficial or misleading cues (e.g. usage time).[2]

Since the interviewees shared these concerns coherently, an intervention to increase consumers' awareness then seemed a necessary companion to the feedback system planned for EnergyLife. While the feedback was meant to depict the actual energy consumption, awareness tips could facilitate the acquisition of knowledge about electricity conservation practices with everyday home devices; this knowledge would allow consumers to interpret the feedback appropriately and to adopt effective countermeasures to improve energy conservation. This resolution was corroborated by the literature analysis, which highlighted the fact that any feedback must rely on a clear comprehension of the goal to be pursued (goal setting, e.g. McCalley & Midden, 2002; Becker, 1978; McCalley, 2006) and of the way to achieve it (task motivation level and corrective feedback, Kluger & DeNisi, 1996). Therefore, consumption feedback and awareness tools became two synergic pillars of EnergyLife.

Some ways to provide information have been reported as problematic, since advice tips and information packages did not improve performance with respect to sole feedback (Ueno, Inada, Saeki & Tsuji, 2006; Hutton, Mauser, Filiatrault & Ahtola, 1986; Wood & Newborough, 2003). A different solution could rely on contextualised and tailored information, coherent with the feedback provided, yet separated from it. There are indications that tailored information is sometimes effective (Abrahamse, Steg, Vlek, & Rothengatter, 2007). This solution will be attempted in EnergyLife through specific tips and quizzes and the scores deriving from them and customized to the users' behavior.

[2] More details on these interviews and their results can be found in Chapter 2 of the BeAware Projet Deliverable 2.1, available at: http://www.energyawareness.eu/beaware/uploads/deliverables/BeAware-D2.1-UNIPD-20081031.pdf

1.2 Consumption Feedback

Regarding consumption feedback, it cannot consist of the kind of consumption information that users are currently offered and that is often ignored, such as pure kW/h, which is not immediately translatable into a conservation step other than simply cutting electricity use; it must be related to the conservation goal selected (McCalley & Midden, 2002; Becker, 1978; McCalley, 2006) and tailored to the household's actual consumption (Abrahamse, Steg, Vlek, & Rothengatter, 2007; Midden, Meter, Weenig, & Zieverink, 1983). On the one side, it should be as close as possible to the users' actions: it is easier to affect specific behavioral intentions than general ones (Van Raaij & Verhallen, 1983; Painter, Semenik, & Belk, 1983), and the user needs to understand which steps would fill the gap between their actual state and the targeted one (Kluger & DiNisi, 1996). Therefore, BeAware will provide consumption feedback device by device, appliance by appliance. On the other hand, feedback on the overall household consumption should be provided as well, since it could discourage a rebound effect, where the electricity saved with one device is spent on another new device and then the adoption of energy conservation practices does not lead to a final decrease in the overall energy consumption (Dillman, Rosa, & Dillman, 1983; Haas, Auer, & Biermayr, 1998; Herring, 2006). Finally, the information provided by the feedback must be remembered when needed (Ilgen, Fisher, & Taylor, 1979) in order to orient the prospective actor, and should be accessed at the same place where it is used without additional steps (e.g. such as turning off a dedicated terminal, as in Ueno, Inada, Saeki, & Tsuji, 2006). This is why no dedicated device will be proposed by EnergyLife, but rather the augmentation of ones that already exist.

All these aspects can be realized through well-designed information technology: sensors and algorithms can provide consumption data for specific devices, as well as the household; the feedback algorithm can express the information on the basis of several parameters, including the conservation goal; networks created between sensors and a server can update the feedback in quasi-real time on the basis of the usage of the individual devices in the household; awareness tools can be implemented in the system and exploit the electricity measurement in order to be tailored to the household.

Other recommendations on the type of consumption feedback can be distilled from the literature on energy conservation. First, historical feedback has proved to be more effective than a comparative type, in which the household's consumption is compared to that of others (Midden, Meter, Weeenig, & Zieverink, 1983; Schultz, Nolan, Cialdini, Goldstein, & Griskevicious, 2007; Kantola, Syme, & Campbell, 1984). This could be due to the fact that comparative feedback selected a term of comparison that was not relevant to the consumer, or because the comparison generated a boomerang effect: a consumer who saved more electricity than the other users might lose the motivation to improve further. Second, the feedback must be sensitive to small savings: interviews with 20 Finnish users who loaned the meter were carried out within the BeAware project revealed that meters made the energy consumption of a single appliance at any given moment appear too negligible to motivate any need for energy conservation practices (Liikkanen, 2009). Third, and contrary to common opinion, monetary feedback should be avoided: using financial savings as a motivator is not effective in the long run, since it is too closely connected to low incomes and financial crisis (Neuman, 1986; Monnier, 1983; Pfaffenberger et al., 1983; Black, Stern, & Elworth, 1985). In order to appeal to all types of households, especially those with the highest saving potential, the feedback system should appear as a nice piece of technology, serving efficiency and well-being,

In synthesis, historical, sensitive, and aesthetically attractive feedback is more likely to be effective. Table 1 shows the requirements examined in this section

Requirement	**Description**	**Relevance to User Interface**
Positive and negative habits	Feedback must encourage good habits, not just discourage bad ones (Kluger & DiNisi, 1997).	Important to include both rewarding and penalizing feedback
Feedback related to specific behaviors	It is easier to affect specific behavioral intentions than general ones (Van Raaij & Verhallen, 1983; Painter, Semenik, & Belk, 1983).	The feedback needs to allow the effects of specific behaviors to be learnt (Kluger & DiNisi, 1996)
Sustaining the impact	Trials must run for a long time in order to be effective (Van Raaij & Verhallen, 1983; Henryson et al., 2000; Wilhite, 1997)	The interface should be able to evolve in order to sustain the interaction
Accounting for variations in energy use	Amount of energy use and adoption of energy conservation practices are not directly related (Dillman, Rosa, & Dillman, 1983; Haas, Auer, & Biermayr, 1998; Herring, 2006).	By keeping a measure of general energy consumption in the household, one can verify if there is a rebound effect
Context-dependent feedback	Relevant data on households and geographical area must be inputted into the system to tailor the feedback to the user (Midden, Meter, Weening, & Zievering, 1983; van Houwelingen & van Raaij, 1989).	Corrections to energy use must be added to the algorithm for the production of the feedback (based on weather, appliance, region)
Tailored feedback	Tailored feedback and sometimes feedback plus tailored information are effective (Abrahamse, Steg, Vlek, & Rothengatter, 2007); individually tailored feedback is more effective than comparative feedback (Midden,	The feedback must be tailored to the actual consumption of the user, and to his/her profile

	Meter, Weenig, & Zieverink, 1983).	
Historical detailing	Historical feedback is more effective than comparative (Midde, Meter, Weeenig & Zieverink, 1983; Schultz, Nolan, Cialdini, Goldstein, & Griskevicious, 2007; Roberts, Humphries and Hyldon 2004; Kantola, Syme, & Campbell, 1984).	The feedback must be a historical index, not merely a cumulative calculation, and must be calculated so as not to show excessive variations
Format of feedback	Financial savings are not a long-term motivator compared to efficiency (Neuman, 1986; Monnier, 1983; Pfaffenberger et al., 1983; Black, Stern, & Elworth, 1985).	The main feedback should not express energy conservation in monetary units, but as efficiency or conservation

Table 1: Requirements for Consumption Feedback

1.3 Usability requirements

In addition to the above remarks, any feedback system should be usable in the sense that it should be easy to understand and adopt, and that it should support energy conservation practices effectively and efficiently. For instance, too much information on different appliances might lead to overload and drop-outs (Ueno, Inada, Saeki & Tsuji, 2006); thus, tests must ensure that the information provided and the functions displayed do not confuse the user. Additionally, computerized feedback is more effective than other methods (Brandon & Lewis, 1999), but should not require the inspection of too much data and long log-in procedures. Making sure that EnergyLife is usable facilitates the achievement of its final goal, which is not just to be adopted by the users, but to modify their habits.

This is embodied by a series of usability requirements, which are synthesized in Table 2.

Requirement	**Description**	**Relevance to User Interface**
Designing to avoid information overload	Too much information on different appliances might lead to overload and drop-outs (Ueno, Inada, Saeki, & Tsuji, 2006)	The information displayed should be self-explanatory; merely decorative elements should be avoided; the information must not be presented all at once, but on successive levels of detail.
Situated feedback	Feedback must orient the prospective actor and needs to be accessed at the same place where it is used and without additional steps	Feedback should be easily accessible on a mobile device that is always at hand and present actionable information (clear time span, advice on how to improve).
Non-intrusive	Sensors should not disrupt everyday family habits by requiring additional measures just to cope with them.	When feedback from the ambient and mobile interface is presented, its message should be communicated in a way that does not prevent the user's intended activity.
Intuitiveness	The interaction with the system is	Every interaction method should

	easy and intuitive	encourage the correct user input without the need for a manual.

Table 2: Main usability requirements

To these, we added two requirements that improve the system's credibility and trustworthiness (Table 3).

Energy efficiency	The feedback system should be energy-efficient (Darby, 2006)	A mobile device is always on; it should require less energy compared to a dedicated device or PC.
Privacy	The system should not be perceived as threatening to the users' privacy	Mobile devices with personal access give the opportunity to personalize the feedback and to protect privacy at the same time.

Table 3: Additional system requirements

The next section describes the way in which the requirements and remarks listed in this section are implemented; the results of the usability test follow.

2. EnergyLife

2.1 General concept

As anticipated, the system developed within BeAware, and called EnergyLife, bases its persuasive potential on two pillars, awareness tips and consumption feedback. Awareness tips are meant to increase the users' knowledge of the consequences of their electricity consumption in general and of that of specific devices; consumption feedback makes the actual energy consumption visible to the users in terms of the updated distance from the selected saving goal. The two kinds of information together would help the users to monitor the quality of their conservation practices, and would enable them to know what to change in these practices in order better to achieve their goal. Both types of information are tailored to the actual consumption of individual devices and of the whole household.

The resources provided by EnergyLife are meant to constitute a whole system that pervades the household and connects the different aspects of the use of electricity from the perspective of the user: from electricity consumption (lights dimming and the mobile interface), to the information that helps to modify the consequences of consumption (tips), to the verification that the information has been acquired (quizzes).

In order to create a coherent, familiar, and attractive rationale for the use of EnergyLife, the pursuit of the saving goal follows a game-like rationale: awareness and consumption (saving) are expressed in scores; goals are divided into sub-goals connected to different levels of the game, so that the fulfillment of the objective on one level gives access to a higher level; higher levels have greater difficulty and richer functionalities; the saving activity can be discussed with other people participating in the same program; knowledge is tested through quizzes and improved though contextualized tips, all of which contribute to increasing the awareness score.

This interface meets some of the basic usability requirements highlighted above; the system does not need the user to do anything special in order to access the feedback, since it can be received on the same mobile device s/he uses for telephone calls; or, even s/he does not want to turn on his/her mobile, minimal feedback is provided anyway by the lights in the house, which dim when switched on when the goal is not met. The input system is also very easy, consisting of touching the screen in ways similar to the action one would perform on the actual object: rotations, pressures, ticks.

2.2 The main interface metaphor: the Carousel

The idea of adopting a carousel as a closed-loop menu to select items is not new. Those of us that were playing video games in the ’80s on the Neo Geo arcade machine might remember that a lot of these games used such a carousel to ask the best players to enter their initials and appear on the high scores screen. An example of a more recent carousel can be seen in Microsoft’s Encarta 2004. As Wang, Poturalski, and Vronay (2005) explained, the carousel design provides a straightforward and great-looking layout, its mechanism is easy to understand, the 3D visualization enables its users to spot the selected item easily, and the rotation effect is engaging.

Such models are now widely used on web pages in order to display fancy image galleries or menus. With recent browsers it is possible to use different tools and languages to implement them, such as JavaScript, Adobe Flash, or Microsoft Silverlight. But even if these solutions are great options to display our 3D carousel on a desktop browser, they are not suitable when we use browsers on mobile devices because of technical restrictions. On the iPhone, using 100% “classic” JavaScript would be way too slow and Flash and Silverlight are not even supported by Safari for iPhone. In addition, these examples do not include any touch and movement recognition.

3D carousels have also been used in multi-touch installations. The Citywall project (Peltonen et al., 2008) used two 3D rings (one vertical and the other horizontal) to allow users to represent “time travel” and to display pictures taken in a specified period of time. Fingertapps (http://www.fingertapps.com) provides a software platform for delivering commercial multi-touch solutions. They implemented a 3D carousel menu for Lexus, very close to the one we made, to navigate between the different options to customize a virtual car. Once again, the technologies used by these installations cannot be used on the iPhone.

Even if some applications on the iPhone also have components that can be described as carousels, like the vertical rotating menu that is used to set up the alarm clock or the timer, they are among the native applications. As we did not want users to have to install anything on their mobile phone, we could not use this solution either.

2.3 Overview of the mobile Application

The EnergyLife application client is a Web application adapted for touch screen-enabled mobile devices. The current platforms are iPhone and iPod Touch, since they support the new web standards (HTML5, CSS3 with 3D manipulation) used in the application. The application client communicates with a server that delivers the data present in the application. The server is connected wirelessly via a base station to a variety of plug sensors in the households that send instantaneous power continuously with a lag of 1 to 2 minutes.

Figure 1: The 3D carousel

The carousel is part of an Energy Awareness application that displays the detailed power consumption for each appliance (Figure 1). Therefore each card in the carousel represents an appliance or electrical device in the house. In addition, the card can be tapped on and turned to offer additional information and functionality for the given appliance. The user interface and the 3D carousel component run in the client browser powered by JavaScript.

The EnergyLife application has the structure shown in Figure 2.The main screen shows the main menu Carousel Menu 0.0. The other main views show main menu 1.0, "Profile Setting", main menu 2.0 "General Advice & Quiz", and main menu 3.0 "Community Access".

By tapping on one card, several sub-screens become available (see Figure 4): sub-menu 0.1 Historic Analysis displays the consumption history of the device; sub-menu 0.2 shows Advice tips – all the advice on that specific device; sub-menu 0.3 is the Quiz, sub-menu 0.4 the Tools, and sub-menu 0.5 the Settings.

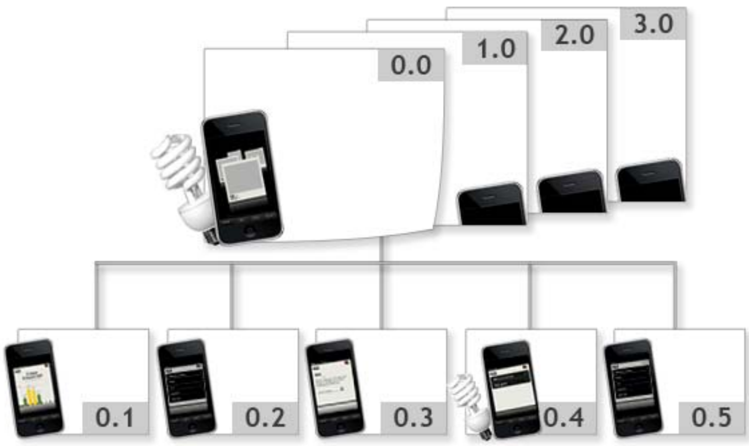

Figure 2: The main EnergyLife screen (up left) and its submenus (bottom)

2.4 The cards and blinking effects for overconsumption

Each card has a front and a back. The number of cards created for the menu varies in this application, according to the data that are fetched from a server. In the application that was developed, the cards represent the electrical appliances in the household. When a card is tapped, it flips around and shows a menu for that device.

When the circle is initialized, each card is created and positioned in an elliptical circle level to the plane. They are distributed around the circumference of the circle with their fronts facing the user. Each card is a div element consisting of two child div elements. They are placed in the same position, but one of them is rotated 180 degrees around the y-axis. In this way each card has a back and a front. Their container gives the impression of being a two-faced card.

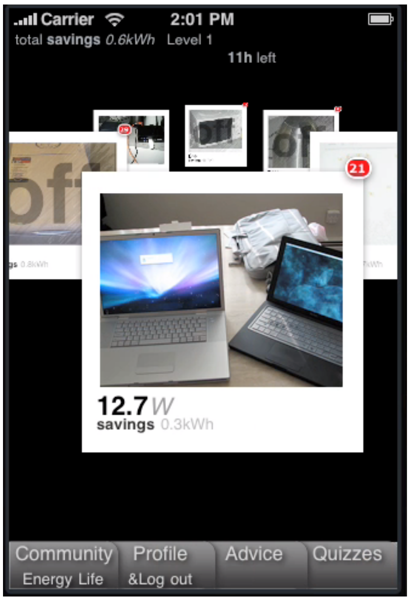

Figure 3: The main EnergyLife screen with the carousel

The fronts of the cards show a picture of the appliance, its current electricity consumption, and how much electricity the appliance is saving in relation to the average consumption from the beginning of the game. In order to help the user conserve energy and gain awareness, the system provides advice at certain times. The amount of unread advice is indicated with a small number in the corner of a card.

If an appliance is consuming too much, the ambient interface installed in the house will react. When the user turns on the light that is dedicated as an ambient interface it will slowly dim instead of instantly coming on. The mobile interface lets the user know which appliance is consuming too much by dimming the image of the appliances in a similar way to the ambient interface.

Figure 4: Front (left) and back (right) of one card in the carousel.

We now return to the requirements on feedback and on mobile interfaces. Table 4 shows how we addressed most of the requirements in Energy Life, although most are planned features that are not included in the usability trial.

Requirement	How it was addressed and improvements needed	Status
Positive and negative habits	At the time of testing the negative feedback was given via the dimming of cards, indicating a lack of energy conservation. The positive feedback was a high saving percentage. Later prototypes include the ability to gain awareness and saving points, allowing the user to gain levels.	Addressed
Feedback related to specific behaviour	The feedback relating to user behavior in the tested prototype is the dimming of cards in relation to a specific device. For the next release smart tips will be introduced that are triggered in response to the energy consumption of the appliances being measured.	Addressed
Sustaining the impact	This requirement will be considered in the future by adopting principles from games and accompanying the users through 3 levels of rising complexity, each with different goals, ending with open-ended goals.	Planned
Accounting for variations in energy use	In the prototype the variations in energy use were not accounted for. This is something that needs to be introduced into the design.	Missing
Context-dependent feedback	Context-related feedback needs to be improved in order to satisfy this requirement.	Planned
Tailored feedback	Tailored feedback is currently not supported and needs to be addressed,	Planned
Historical detailing	After this study a new historical analysis component was developed that shows the consumption historically and allows the user to examine the consumption history.	Planned
Format of feedback	Additional feedback formats are needed that allow the user to understand his/her habits and their effects on the environment and electricity consumption. The current methods show the user's savings in terms of a percentage deviation from the average at the beginning of the game. In future versions a balance sheet giving a breakdown of electricity consumption in different sectors is to be introduced.	Addressed for improvement

Table 4: Feedback content

Table 5 analyses the requirements for the user interface solution. All the requirements are addressed, while some can still be improved. The table also summarizes the added value of using a mobile and device and intuitive interfaces such as multi-touch.

Requirement	How it was addressed and improvements needed	Status
Energy efficiency	The energy consumed by the mobile device is small compared to that of a PC.	Addressed
Privacy	Each user has their own login and cannot access the private data of other households.	Addressed

Designing to avoid information overload	The information is not presented "all at once" and the user is given the ability to browse for the desired data. An additional level of abstraction would be needed for the advice in order for the system to know if advice has been read or not.	Addressed
Situated feedback	Feedback relating to energy consumption is present on the device cards and available tips and quizzes are notified via visual cues. The mobile device (iPod touch) can be carried in the pocket and consulted any time; however, a smart phone with a GSM connection could work anywhere.	Partially
Non-intrusive	All feedback from the system is presented in a way that neither interrupts the user, nor prevents any ongoing activity. The iPod touch solution is an additional device. By using an iPhone, for example, the solution would not require the user to carry an additional device.	Partially
Intuitiveness	The application has been designed with intuitiveness in mind. One thing that might need an additional affordance is the feature of tapping on a card to flip it. The interface paradigm is intuitive; users had conceptual issues with the labels.	Partially

Table 5: System usability and user interface

3. Usability Evaluation

To refine the interface and the feedback offered by EnergyLife, and make it simpler to use, usability tests were performed on the prototype. They cover four dimensions of usability, i.e. effectiveness, learnability, efficiency, and satisfaction, relating to the requirements reported in Tables 1 and 2.

3.1 Method

The evaluation procedure is based on a series of simple tasks similar to the basic tasks that the user is supposed to perform with the help of the interface. After some piloting the procedure and equipment were defined. Users sign an informed consent and sit comfortably on a sofa in a user experience lab. They are handed an iPod showing the actual electricity consumption recorded in an instrumented house, where sensors and a base station were installed weeks earlier. The house is monitored every day by the research team, so that any technical problem preventing the tests from taking place is reported right away. After signing the informed consent, the user is shown a video illustrating the elements of the interface and their meaning. The user can ask more questions and require clarifications; when s/he is ready s/he can start the actual task series (Table 6). The task instructions are read out by the experimenter, task by task.

TASK NAME	INSTRUCTIONS
Log in	*Start the EnergyLife application (turn the device on, start the application, complete the log-in)*
Finding the microwave	*Find the microwave in the card carousel*
Counting the devices	*Rotate the carousel and count the devices*
Navigating the carousel	*By rotating the carousel, go 1 card forward, go 3 cards back, go 1 card forward, go 1 card back*
Over-consuming devices	*Which devices are over-consuming?*
Devices off	*Which devices are off now?*
Fridge consumption	*How much energy is the fridge consuming now?*
Highest consumption	*Which device is consuming the most energy?*
Saving washing machine	*How much energy did the washing machine save?*
Negative value	*Consider device x; is it saving energy? How much? (using a device that has a negative saving value)*
Horizontal view	*Rotate the iPod touch from a vertical to a horizontal position. How much is the fridge consuming? How much energy did the fridge save?*
Log out	*Log out from Energy Life*

Table 6: Tasks.

Afterwards, users are asked to rate their experience with the EnergyLife interface by expressing their level of agreement with a series of written statements on a questionnaire on a scale ranging from 1 to 6 (1 = “totally disagree”, 6 = “totally agree”). The analysis of the responses is carried out through a T-test comparing the average response to each item from all users with the middle value of the response scale (middle value = 3). The 41 items composing the questionnaire are taken from existing repositories (“Practical Heuristics for Usability Evaluation”, Perlman, 1997; “Information Services and Technology Usability Guidelines; Heuristic Evaluation. A System Checklist”, Pierotti, 1994; “USE Questionnaire Resource Page”, Lund, 1998), and some were built especially for this test by the research team. The items allowed the user to assess the interface from some main perspectives, i.e. Navigation, Semantic Comprehensibility, Structural Clarity, Pleasantness, Satisfaction, Learnability, Feedback, Consistency, User Control, and Usefulness. The full list of items is in the Appendix (Section 6).

Regarding the task performance, data were collected by way of two synchronized video cameras that recorded the participant and the mobile device respectively. The video recordings were then systematically analyzed with Noldus The Observer, in order to evaluate the effectiveness and efficiency with which the system is used, and to identify the main issues encountered by the users in the form of ‘breakdowns’. Breakdowns are interruptions or delays in the projected development of the action, which reveal to the user (and the analyst) the inappropriateness of the action possibilities identified up to that moment[3].

In order to perform the analysis quickly, as required from a formative evaluation, a first analysis of the videos identifies a series of these breakdowns; the list is then transformed into a coding scheme for a second and detailed analysis. The coding scheme associates specific categories to stretches of the video, and identifies:

- TASK and its outcome in terms of success, failure, or abandonment;
- BREAKDOWN and its outcome (solved or not solved);
- OPERATIONS carried out to solve the breakdown:

1. TOUCHING. Pressing the finger against the screen on: card/ main menu/ “close” button/ “back” button/ “log in” button/ “log out” button/ iPod “on-off” button/ menu “log in” button/ menu “log out” button/ “undo” button
2. SLIDING a card in one of the following directions: Forwards (the carousel rotates counterclockwise)/ Backwards (the carousel rotates clockwise)
3. ROTATING THE IPOD from a vertical to a horizontal position and back
4. WAITING
5. TALK. The user says something, namely: Help request/ Comments on the interface/ Solution description
6. DRAGGING A CARD
7. DRAGGING THE LAYOUT

The length and occurrence of each event are then counted, and the breakdowns are described and ranked.

3.2 Results

A group of 20 users (mean age = 24.65, SD = 3, 10 women and 10 men) tested the application with the procedure described above. The results of the tests were then reported to the developers and designers.

Questionnaire. In all dimensions the responses are significantly higher than the middle value of the scale (Table 7), showing that the application was positively evaluated, regardless of the specific problems that were found.

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3 More information on the technique of breakdown analysis and its theoretical foundations can be found in a paper currently under review, whose contact author is Luciano Gamberini. Please contact him if you are interested. A previous work on the subject was by Spagnolli, Gamberini, and Gasparini (2003).

	Mean	SD	t	Sig. (2-tailed)
Navigation	4,26	0,89	6,36	0,00
Comprehensibility	4,22	0,94	5,83	0,00
Structural clarity	3,85	1,33	2,86	0,01
Pleasantness	4,01	1,10	4,11	0,00
Satisfaction	4,00	1,37	3,26	0,00
Learnability	4,44	1,11	5,78	0,00
Feedback	4,65	1,14	6,46	0,00
Consistency	4,73	1,01	7,67	0,00
Control	3,69	1,14	2,69	0,02
Usefulness	4,29	1,47	3,92	0,00

Table 7: Results of the t-test for the rates obtained from the questionnaire (DF=19, $p<.05$); mean, standard deviation, t value, and significance are reported.

Effectiveness in task completion. Figure 5 below shows the results of each task, identifying how many of the 20 users completed the tasks successfully, how many failed in the tasks, and how many abandoned them after several attempts.

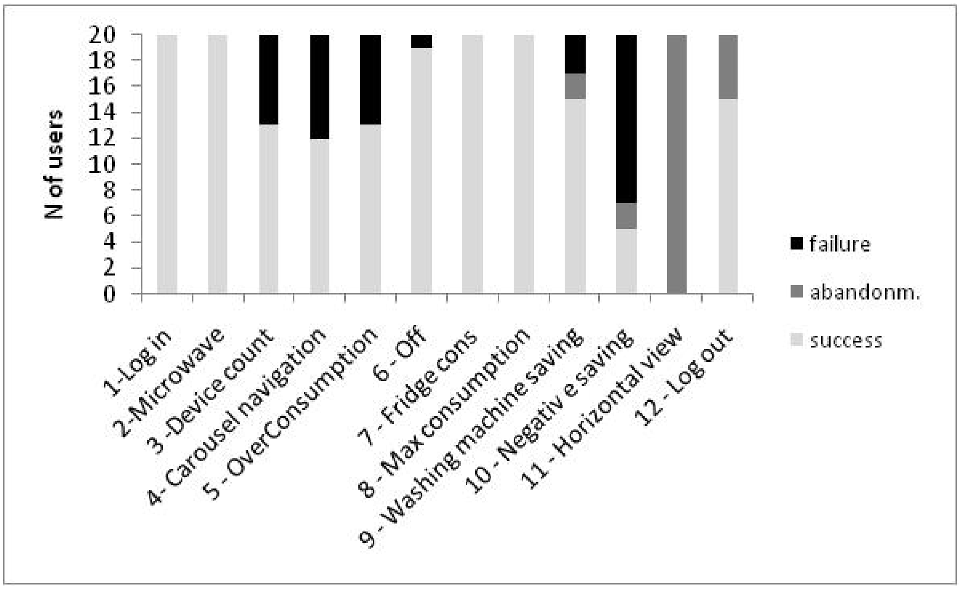

Figure 5: The number of users who completed each specific task with success or with failure or who abandoned it.

None of the participants completed all the tasks successfully; each user completed 8.6 tasks on average. The least difficult tasks were logging in, finding the image of a device, finding the consumption of a device, and identifying the device with the highest consumption. The average number of breakdowns for each task was 18.8, distributed over the tasks as shown in Figure 6. The most problematic seem to be 4 and 11.

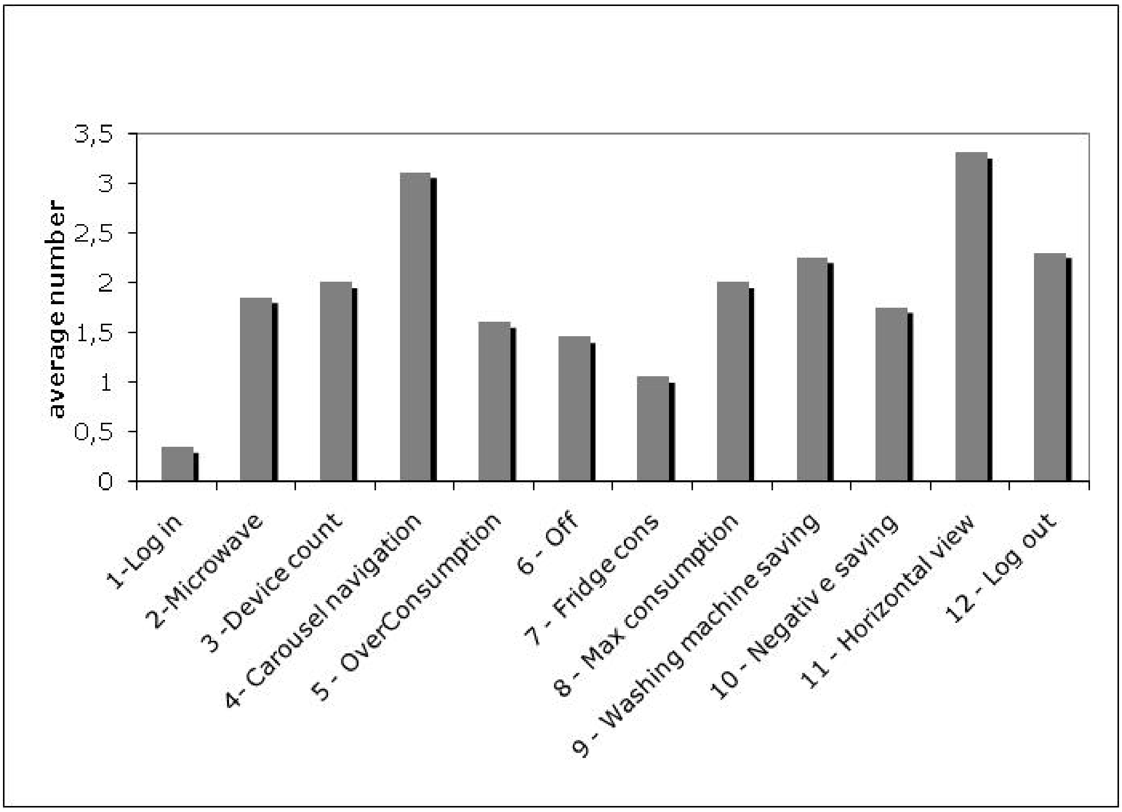

Figure 6: The average number of breakdowns per task

The breakdowns found by the users were the following:

1. Inadvertent opening of main menu: while sliding the carousel, the user inadvertently opened up one of the main menus of the application (setting, help, etc.).
2. Missed recognition of log-out: the user continued to try to log out once s/he had already logged out of the application; the screen became black except for the menu bar at the bottom.
3. No response: the user touched one button of the interface, but the system did not respond to the input.
4. Accidental turning of central card: while performing a task not involving the central card of the carousel, the participant touched the central card by accident, making it turn. Pressing any point of a card made that card flip; so if the user operated in an area close to a card, it was likely that his/her finger might inadvertently touch a portion of the card, making it turn.
5. Excessive carousel rotation: while the carousel was being rotated, it did not stop at the card next to the original one, but at one of the cards past it, since the rotation was greater than expected.
6. Turning a card to one side: the task was focused on a card, but inadvertently the user touched a card next to it, making it turn.
7. Missed recognition of saving: the writing was so light that sometimes it was not spotted by the user.
8. Freezing of a turning card: while a card was turning from the back to the front view or vice versa, the turning process froze.

9. De-centered layout: The margins of the layout appeared de-centered with respect to the screen, either towards the right or towards the left.
10. Layout dragging: When one part of the layout to slide the carousel was touched, the whole layout was dragged in the same direction. The dragging stopped once the finger stopped touching the layout.
11. Dropped Layout: when the mobile device was in a horizontal position, the menu bar covered part of the carousel.

Figure 8 below synthesizes the main indices of severity for each breakdown type. On the basis of the total severity rates, we can rank the breakdowns as shown in Figure 7. This ranking takes into account the various ways in which a problem can hamper the interaction, namely by appearing frequently, by being impossible to solve, and by taking a long while to resolve.

	FREQ	FAIL	ATT
1-Inadvertent opening of main menu	0,9	0,00	1,28
2-Missed recognition of log out	0,2	1,00	0,00
3-No response	1,3	0,73	0,71
4-Accidental turning of central card	2,5	0,06	1,94
5-Excessive carousel rotation	8,4	0,86	1,57
6-Turning of a side card	0,3	0,17	5,40
7-Missed recognition of saving	0,2	1,00	0,00
8-Freezing of turning card	0,3	0,50	1,67
9-De-centred layout	1,6	0,28	7,17
10-Layout dragging	2,25	0,00	2,51
11-Dropped layout	0,85	1,00	0,00

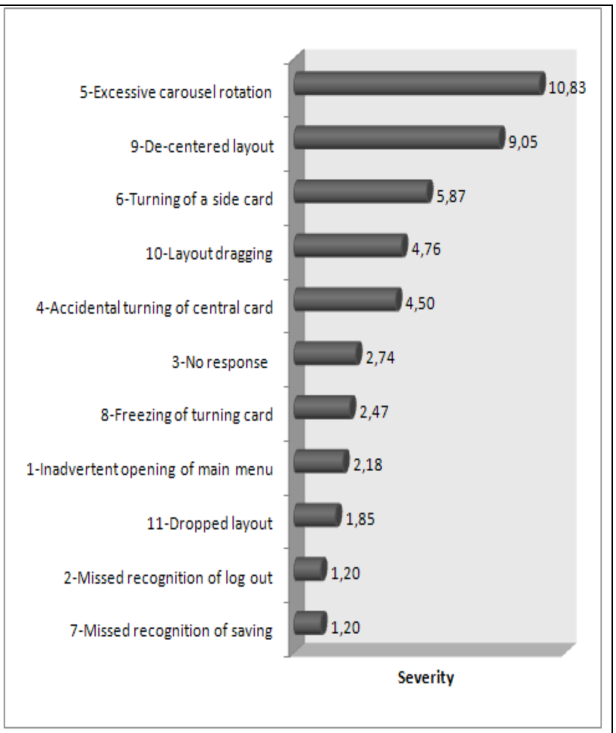

Figure 7: On the left, the data on which severity rates are defined: average frequency per participant ("FREQ"), proportion of breakdowns that are not closed successfully ("FAIL"), and average number of attempts needed to successfully close a breakdown ("ATT"); on the right, the breakdown types ordered according to the resulting severity rate

From the analysis it emerged that there is great potential for this system and that the key elements of the interface design appear to be the right choice. The carousel structure and the navigation interface appear to be excellent solutions that only need some refinement.

Some of the problems are merely technical; others require a redesign because they signal a problem in the input system, a lack of feedback in the operations result, or problems in the comprehension of the meaning of some features.

4. Conclusions

The hallmark of EnergyLife is represented by the emphasis on usage practices. Within an articulated educational process organized into stages within a game-like metaphor, it is meant to support electricity conservation. The system developed within the BeAware project is pervasive in the household through sensor layers and ambient and mobile interfaces; it provides its users with the necessary tools to conserve energy, namely feedback on the consumption level with respect to a target level and tips to facilitate the achievement of the target. These results of the usability evaluation reported here will guide the next development phase and the release of a new prototype. The updates on this process of developing and testing, which will soon also include longitudinal field trials with users, can be obtained from the project website www.energyawareness.eu.

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6. Appendix: the satisfaction questionnaire.

Answers to all items are expressed on a scale ranging from 1 to 6 (1 = “totally disagree”, 6 = “totally agree”).

A. NAVIGATION

1. E' facile trovare le informazioni di cui ho bisogno [*It is easy to find the information I need]*
2. Sono riuscito a trovare velocemente le informazioni che cercavo [*I was able to find the information I needed rapidly*]
3. In ogni situazione riconosco in che sezione mi trovo [*In each situation I can recognize in which section I am*]
4. La possibilità di tornare alla pagina principale è sempre riconoscibile [*The possibility of going back to the main page is always recognizable*]
5. Le sezioni più importanti dell' interfaccia sono raggiungibili dalla pagina principale [*The main sections of the interface are reachable from the main page*]
6. Il tasto per tornare indietro in ogni pagina è individuabile [*The back button is recognizable on each page*]
7. Le aree cliccabili sono distinguibili da quelle non cliccabili [*Clickable areas are well distinguishable*]

B. COMPREHENSIBILITY

1. Le immagini sullo schermo sono comprensibili [*The images on the screen are comprehensible*]
2. Le informazioni fornite dall'interfaccia sono efficaci nell'aiutarmi a completare il compito [*The information provided by the interface helps me to complete the task*]
3. Il linguaggio utilizzato è semplice e comprensibile [*The language is simple and comprehensible*]
4. I valori che mi indicano la quantità di energia risparmiata sono comprensibil [*The values showing the amount of energy saved are comprehensible*]
5. I valori che mi indicano quanto sto consumando sono comprensibili [*The values indicating how much I'm consuming are comprehensible*]

C. STRUCTURAL QUALITY

1. Le immagini sono ben distribuite nello schermo [*Images are well distributed on the screen*]
2. Le informazioni sono ben distribuite nello schermo [*Information is well distributed on the screen*]

D. PLEASANTNESS

1. Il Design dell'interfaccia è piacevole [*The interface design is pleasant*]
2. Mi sento a mio agio utilizzando questa interfaccia [*I feel at ease while using the interface*]
3. Mi piace utilizzare questa interfaccia [*I like to use this interface*]
4. L' interfaccia ha tutte le funzioni che mi aspettavo avesse [*The interface has all the functions I expected it to have*]

E. USER SATISFACTION

1. In generale sono soddisfatto del sistema [*In general I'm satisfied with the system*]
2. Lo consiglierei ad un amico [*I would recommend it to a friend*]
3. Questa applicazione può cambiare il mio stile di vita in modo soddisfacente [*This application can satisfactorily change my lifestyle*]
4. Questa applicazione mi aiuta a risparmiare energia [*This application helps me to save energy*]
5. Questo prodotto può incentivare comportamenti sostenibili [*This product can enhance sustainable behaviours*]
6. Questo prodotto può contribuire a migliorare le condizioni dell'ambiente [*This product can contribute to improving environmental conditions*]

F. LEARNABILITY

1. Imparare a utilizzare questa interfaccia è semplice [Learning to use this interface is simple]
2. Imparo a usare questa interfaccia velocemente [*I learned to use this interface quickly*]
3. È facile ricordare come usare l'applicazione [*It is easy to remember how to use the application*]
4. Mi sono sentito subito competente nell'interazione con l'interfaccia [*I immediately felt competent in the use of the interface*]

G. FEEDBACK

1. E' sempre comprensibile ciò che sta accadendo sul display [*What is happening on the display is always understandable*]
2. Riconosco immediatamente quando un dispositivo elettrico sta consumando più del dovuto [*I can immediately recognize when an electric device is consuming too much*]
3. Riconosco immediatamente quando un dispositivo elettrico è spento [*I can immediately recognize when a device is off*]

H. CONSISTENCY

1. Il significato dei termini è coerente con l'informazione ad essi associata [*The meaning of a term is consistent with the information associated with it*]
2. Le informazioni energetiche sono coerenti con l'immagine selezionata [*The energy information is consistent with the selected image*]

I. USER CONTROL

1. Quando faccio un errore usando l'interfaccia, posso riparare facilmente [*When I make a mistake using the interface, I can easily remedy it*]
2. Sono sempre in grado di controllare l'applicazione durante l'interazione [*I'm always able to control the application during the interaction*]
3. È facile annullare ogni mia operazione [*It is easy to undo all my operations*]

4. Riesco sempre a far eseguire all'applicazione ciò che desidero [*I can make the application do what I wish*]

L. USEFULNESS

1. L'applicazione mi permette di avere maggior controllo sulle attività legate alla vita reale [*The application allows me to control the activities of my real life better*]
2. L'applicazione incontra la mia volontà di ridurre gli sprechi energetici [*The application meets my wish for reducing energy wastage*]
3. L'applicazione rispecchia la mia volontà di salvare l'ambiente [*The application reflects my will to save the environment*]
4. Utilizzando Energy Life posso ridurre i tempi necessari per adottare una condotta sostenibile [*Using EnergyLife I can reduce the time needed to adopt sustainable habits*]

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