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Tablet interface for Smart Environments to Reduce Energy Consumption

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ABSTRACT

This thesis presents a sequential approach to the topics that led to the development of a mobile application, which interfaces with home electric appliances. This application contributes to create energy awareness, provide feedback on energy consumption, and engage users in energy conservation behaviors. The research focuses on the motivational factors, such as: self-comparison, comparison with others, goals and rewards. These factors are implemented in the application to exploit the human psychological need to conform the expectations of others, do things right, be liked and maintain a positive self-image. The application is developed, focusing on the factors that best drive people's behavior in reducing the use of electricity.

The evaluation of features in the application, such as: remote appliances switch, real-time energy consumption display, historical consumption graphs generation and energy rating in online social network share, demonstrate that the obtained feedback educates people creating energy awareness. This knowledge facilitates the making of decisions to reduce energy use. Several concepts that contribute to the reduction of energy consumption are proposed for further research, for example, the use of social dynamics, automation of tasks in the house and the display of units that show the environmental impact on energy use.

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Chapter 1

Introduction

Demand and production of energy has grown enormously in the last decades [3]. Traditional energy sources, like fossil fuels, produce great amounts of CO_2 and they still represent more than 85 % of all primary energy production on earth [28]. Nuclear power is CO_2 free, but it involves many other environmental risks. Alternative energy sources, like windmills and solar panels, do not generate much energy in comparison with the previous sources, which makes them an expensive option. If these technologies do not improve, the most obvious solution to the growing demand of energy is reducing our energy consumption.

In order to reduce energy consumption, increased knowledge on the use of energy is necessary. Users do not have a clear idea of how much energy appliances consume. Energy meters do not provide much information and are normally hidden in dark closets or basements out of sight. The clearest feedback comes in energy bills once a month or a year, and then it is too late to react and make changes. More feedback on energy consumption can create a clearer link between certain actions. The access to information on energy use and real-time feedback, let users make better decisions on how and when to consume energy.

With the increased availability of cheap sensors, actuators and displays; homes and offices are becoming every time more technologically advanced [4]. Smart Environment solutions [20] are becoming accessible for creating more secure and comfortable living spaces. Interconnecting appliances, controlling them remotely, measuring energy consumption, and getting energy prices are some of the possibilities to bring forward in-home energy consumption management to the users.

In the following chapters the presented work, focuses on the different ways to provide feedback on energy consumption using a tablet interface, to create energy awareness and motivate users to reduce energy consumption in a Smart Environment. This work is part of the EU FP7 founded project GreenerBuildings [54], which develops an integrated solution for energy-aware adaptation of public buildings.

1.1 Research question

Universities and companies are doing research to find new and innovative ways to produce energy with less environmental impact. More energy efficient devices and machines are being developed, and different methods are being tried to create energy awareness to contribute in reducing energy consumption.

The main goal of this project is to develop an application for tablet computers to interface with Smart Environments in order to create awareness in the use of energy and influence the reduction of energy consumption through behavioral changes.

The main research question is:

Can the use of a tablet interface, in a smart environment, contribute to the reduction of energy consumption?

In order to answer this question, the following sub questions are stated.

1. How effective is the reception of energy consumption feedback to modify people's behavior?

   Research is done on the effectiveness of displaying feedback on energy consumption to the user as a way to change its behavior.

2. What are the factors that drive people to consume less energy?

   Different people have different goals that could drive them to consume less energy. Some people want to spend less money, others feel an environmental responsibility and other groups just do it because they like it. The application is developed, focusing on the factors that best motivate people in reducing energy consumption.

3. What is the state of the art in Smart Environments, and interfaces with energy meters?

   There are many existent solutions in smart homes and interfaces to show energy consumption. We research the solutions, considering the advantages and disadvantages to take into account in the development of the application.

4. Which functionalities should a tablet interface have in order to effectively create energy awareness and persuade people to reduce energy consumption?

   Human-machine interaction is a very delicate issue in the development of a product. Some systems, with many functionalities and advanced technologies fail to interact with users because they turn to be too complex. It is very important to find a balance between complexity and usability of the implemented features.

1.2 Thesis contribution

In this report we show the role the developed tablet device application interfacing with a Smart Environment has on engaging users in energy conservation behaviors. The facilitation of feedback on energy consumption is a method to increase knowledge on energy use. Users learn which appliances consume the most, facilitating the making of decisions to reduce energy consumption. We introduce the concept of energy rating as a way to measure the efforts of users to improve their energy efficiency and have a point of comparison with others.

We explain the design and concepts implemented in the development of the application, which is part of this thesis work. We describe the use of the user centered design process, which combines input from different backgrounds such as engineering, psychology and interface design. This combination of knowledge improves the understanding of user needs and contributes in building a tailored solution to the proposed goal of reducing electricity use.

The performed evaluations prove the application to be a useful tool to approach users to their energy consumption. We explain the results of the survey that showed how the application is able to provide meaningful information on energy use, and the way in which users rapidly learn to interact with the application. The provided feedback proves to be very useful in increasing the knowledge on energy consumption, promoting energy conservation in different ways.

1.3 Thesis organization

The content of this work is organized in the following way:

In Chapter 2 we present the related work in the field of Energy Awareness. We explain the conceptualization of energy for the users. The difference between direct and indirect feedback is explained and the concept of energy labels implemented in the application is introduced.

Chapter 3 is dedicated to the potential methods to be introduced to persuade users to consume less energy. There are different motivational factors, for example, goal setting, rewards and social comparisons. These factors are combined to engage users in energy conservation behaviors. Special focus is put in the possibilities of social networks as a motivational factor.

Chapter 4 presents the research realized in related projects of Smart Environments and existent interface solutions. This chapter creates an image of the state of the art in interfaces with Smart Environments and provides a point of comparison with existent solutions.

The concepts developed and the design of the application is presented in Chapter 5. A user centered design approach is used, to improve the usability to adapt the requirements in the multiple design iterations. The system architecture that represents the system to be implemented is detailed.

Chapter 6 describes the decisions taken in the implementation of the application. The development environment selected is Xcode, using the iOS SDK and Objective-C. The main design pattern is the Model-View-Controller. The network configurations and the messages structure are introduced.

The evaluation of the application is presented in Chapter 7. We make a comparison of the existent solutions with the developed application. We perform a survey to test usability, creation of energy awareness and behavior change potential. Due to time restrictions it was not possible to test the continued use of the application over time.

Finally Chapter 8 presents the main discussions on the project and the conclusions for this work. We propose the directions for further research and development in the area of energy awareness and motivational factors to reduce energy consumption.

Chapter 2

Energy Awareness

Those with the greatest awareness have the greatest nightmares.

—Mahatma Gandhi

In domestic energy use it is not clear which appliances consume the most. The flow of energy is invisible to users. Energy meters display overall energy consumption. However this information is not enough to determine where to spend less. Feedback on consumption is necessary for energy savings. Not only to show where energy goes, but also to help users to interpret the values and to assist in making better decisions to reduce energy consumption. Without feedback it is impossible to learn about energy use effectively.

2.1 Energy conceptualization

There are three main ways in which individual consumers think about energy: as a commodity, a social necessity and an ecological resource [58]. They all can be used as a way of making energy consumption more visible, either showing the relation with carbon reduction, monetary savings or the social impact.

Commodity: People get an energy bill every month or year, but they do not have an idea of which actions caused it. There is no link between appliances, the energy consumed and the price. Those who pay for it in advance have a better understanding of energy consumption [12]. There are many ways to improve the feedback and create awareness on the amount of energy used.

Social necessity: Having electrical energy is taken for granted, and is only noticed when it is gone. Users that have to generate their own electricity or those warned to reduce their consumption due to energy shortages, have to find ways to understand and manage energy consumption.

Ecological impact: All energy use occurs with side-effects. The generation of electricity leads to fossil fuels extraction, dams construction, power lines, power stations, etc. There is an unclear idea of the ecological impact of energy, especially for electricity. Feedback and information systems can be created to make people aware of the link between energy use and environmental impacts.

These conceptualizations show the social, ecological and cultural aspects of energy. A behavioral change is required to reduce the energy use. This can be done by policy changes to increase energy efficiency, provision of information and feedback to create awareness [26].

2.2 Feedback on energy consumption

According to the Oxford English Dictionary, feedback is the modification, adjustment or control of a process or system, as a result of the same, especially by a difference between a desired and actual result. The process of learning shares a similar definition. That is the reason why feedback on energy consumption is needed to extend the expertise of people in the matter and connect them with their energy use [21].

2.2.1 Direct and indirect feedback

In the process of learning about energy consumption, feedback is an essential element. There are many possibilities to educate people with the use of feedback. These methods can play a significant role in creating energy awareness and reducing energy consumption [12]. The two main ways to get energy feedback are direct and indirect feedback. Below, an outline of the possibilities is presented.

Direct feedback: Information available on demand. Learning by looking or paying

- Direct display: Energy meters are normally hidden and provide scarce and hard to understand information. The display of energy meters in central locations, providing easy to read information increases awareness and leads to energy savings [49].
- Interactive feedback: Advances in technology facilitate the interaction of users with the consumption of energy. Web interfaces and mobile applications are obvious candidates for future means to interact with the energy use.
- Smart and prepayment meters: They facilitate the control of energy use and bring users closer to the real energy consumption.

- Self-meter reading and reading with an adviser: This method is valuable as part of a program to improve the understanding on energy consumption.

Indirect feedback: Raw data processed and sent to the customer. For many users the only way to visualize or receive feedback on energy consumption is through the invoice once a year or monthly at the end of the period. More frequent bills with historical feedback or comparisons with similar households, improve energy awareness. [65].

2.3 Energy use visualization

In order to be successful, energy feedback needs to capture the attention of users, create a relation between the performed actions and their effects and find the factors that motivate different consumer groups, e.g., save money, reduce environmental impact or compete with others [31]. Energy use display methods like Wattson[43] shown in Figure 2.1, help users to see the electricity use and make it easier to achieve savings. In Wattson, the display changes the glow color according to the level of consumption in relation to the average, showing the link between energy consumption and appliances use. The units used in the display method are, the current energy consumption in Watts hour, or in monetary units for persons more motivated towards saving money. Other example that proves how feedback on energy consumption changes people's behavior is hybrid cars. One of the important reasons why hybrid cars result on better mileage than regular cars, is that drivers suddenly have feedback on the various aspects of their driving habits that affect fuel consumption. Dynamic feedback can immediately increase the driver's ability to save energy [34]. It is also possible to obtain feedback on energy consumption through energy management software. Software products like Energy Lens [6] facilitate the visualization of energy use. The energy data obtained from the electricity providers is uploaded to the software. Energy Lens displays a set of features that helps turning that data into useful charts and figures for analyzing energy consumption.

These examples show the importance of making energy use available and easy to understand to the user, in order to create energy awareness and reduce energy consumption. Two types of behavior can be targeted by the display of feedback; *Efficiency behavior*, which involves influencing people to obtain more energy efficient goods and *Curtailment behavior* that aims to the repetitive efforts to reduce energy use such as turning off lights or appliances when not in use or taking shorter showers. Trying to save energy without seeing the information in a meaningful way is like trying to get somewhere in a strange city without a map.

Figure 2.1: Wattson energy monitor [43]

2.3.1 Energy labels

The energy labeling program was conceived as part of a large effort to attack the energy crisis [51]. Its focus is at the consumer level, providing energy consumption information at the point of sale. In energy labels, energy efficiency of appliances is rated according to a scale from A to G, being A the most energy efficient and G the least efficient. The labels also provide useful information to users as a way to compare various models of appliances in order to find which one is more environmentally friendly or more energy efficient.

What is really necessary, in view of this energy crisis is a fundamental change in energy use behaviors, given that in countries like Belgium and Denmark cars and home energy use represent one-third of the total energy consumption [30]. Educate consumers to acquire energy-efficient products provides a continuing structure, achieved through increased availability of relevant information, in order to reduce the overall consumption and create energy awareness.

2.3.2 Display Energy Certificates (DECs)

An extension of energy labels, to be used at a building level is the Display Energy Certificates (DECs). The purpose of introducing DECs is to increase the awareness on energy consumption and to make public the energy efficiency of buildings. DECs should be displayed at all times and clearly visible in the building [27]. The certificate shows the actual energy usage of a building. The label value results in the energy consumption of gas, electricity and other meters on the building over a period of 12 months.

The Operational Rating (OR), used to produce the DEC, is a numerical indicator of the actual annual CO_2 emission of the building. Various types of energy consumption of the building

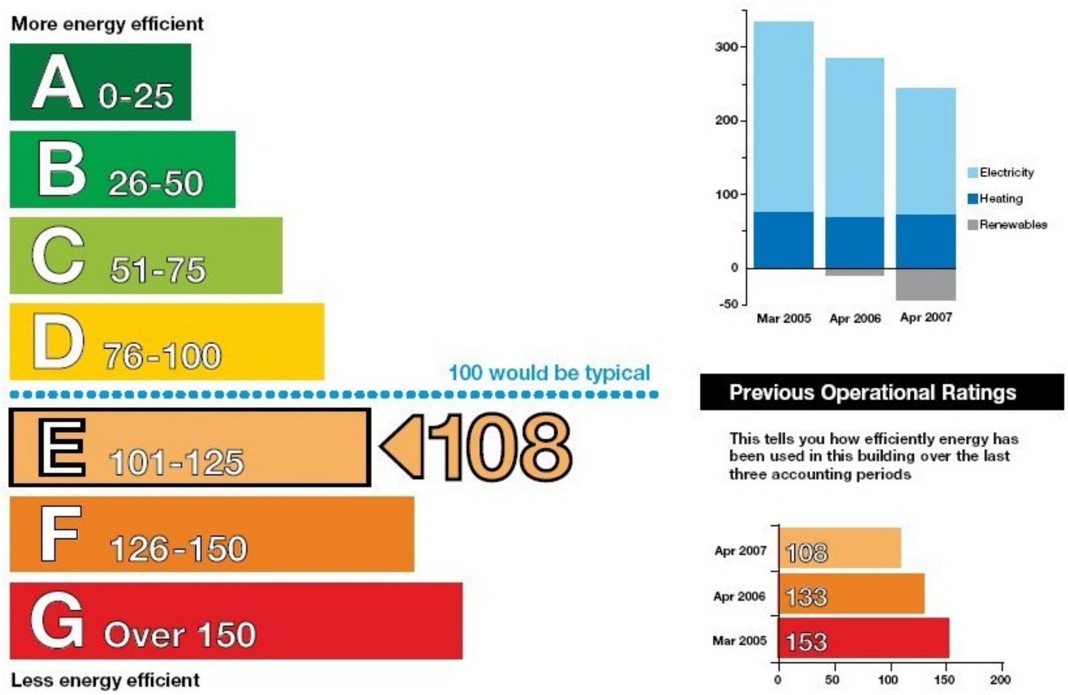

Figure 2.2: Display Energy Certificate [27]

must be brought together on a common basis in order to compare the performance of one building with that of another. The rating is shown on a scale from A to G just like in Energy Labels, where A is the lowest CO_2 emissions and G is the highest. The Operational Ratings for the two previous years are also provided as shown in Figure 2.2.

To calculate the OR, and produce the DEC for a building, the energy assessor will need to have access to certain information of the building. If that is not possible, the assessor will need to obtain it from other sources. The basic forms of information needed are:

- Identification of the building and the activities for which it is used
- The internal area of the building
- The energy consumed by the building over the year for which it is to be assessed
- Details of the buildings assets that affect energy consumption (e.g., insulation, building services, etc.)

The OR is based on the amount of energy consumed in a building over a period of 12 months; it is compared to the value of a hypothetical building with performance equal to one typical of its type used as benchmark. Typical performance for that type of building would have an OR of 100. A building that has zero CO_2 emissions would have an OR of zero, and a building with twice the CO_2 emissions of the typical one, would have and OR of 200.

The DEC comes accompanied with an advisory report that highlights the recommendations to improve the energy performance of the building; it may contain possible improvements, including cost-effective measures that may be implemented to improve the energy performance, possible upgrades to the building, and opportunities for the installation of Low and Zero Carbon (LZC) technologies. The information is personalized and is intended to educate people in the use of energy.

Chapter 3

Persuasion methods

Let he that would move the world, first move himself.

—Socrates

Persuasion is perceived as a skill used to sell things and close deals. TV commercials influence to buy things, we probably do not need. Salesmen pressure with limited time offers to make us buy their products, without time to think or compare. But used constructively and to its full potential, persuasion supersedes sales and is quite the opposite of deception [10]. Effective persuasion becomes a learning process through which the persuader leads to a problem's shared solution. Persuasion does certainly involve changing a person's attitude, but not by begging, or delusion. Instead by providing the proper information, framing of arguments and supporting evidence. In times of interactive media, persuasion can be more effective. Technology enables to immediately perform the desired behavior. For designing systems that persuade users to reduce energy consumption, it is necessary to understand the underlying psychology.

3.1 Motivational factors

Once the goal of creating energy awareness is achieved, it is necessary to engage users in behaviors to reduce the use of energy. Setting goals, obtaining rewards, and creating social challenges contribute to maintain people interested in reduce energy consumption and motivate others to change their behavior as well.

3.1.1 Self comparison

Displaying information from previous periods provides a point of comparison that motivates people to change behavior. Humphries and Hilden [55] performed experiments using focus groups to identify preferences in the presentation of information on charts displayed on electric bills. The total electricity consumption for the last quarter was presented in comparison with (a) the same quarter from previous years and (b) the last five quarters. The simple self-comparison of historical data is effective to improve the results.

Comparisons between appliances are probably the most basic and necessary ways of comparison [66]. When a user sees, for example, that the boiler uses more energy than the microwave, then he would try to make an effort to reduce the use of the boiler. This type of comparison is useful for most appliances. However, in the case of comparing the energy use of the microwave with the freezer, the microwave will tend to be much higher, and the user may feel that there is no point in making an effort to acquire a more efficient freezer, since its consumption is low, compared with the microwave. In order to compare energy consumption of different appliances it is necessary to create groups with similar characteristics to make comparisons more fare.

At a room level, after taking action towards saving energy, the user can observe, for example, that more savings were achieved in the living room, rather than in the kitchen. Then he might be more motivated to reduce the heating or lightning to control the energy use in the kitchen. Enabling users to prioritize their efforts to save energy continuously is a key benefit of energy consumption displays that show relative energy use.

3.1.2 Social influence

When the emotions, opinions, or behavior of a person are being affected by others we talk about social influence. Humans have the psychological need to conform the expectations of others [14], like the need to do things right, the need to be liked by others, and the need of maintaining a positive self-image [8]. These different ways are described below:

Informational: People desire to respond appropriately in social situations. They need to understand and react correctly to the incoming information. Looking at social norms gives an accurate understanding on how to respond in social situations, especially when they do not know what to do [7]. Social norms can influence the behavior of persons in a wide range of situations.

Normative: People are normally motivated to approach to others and create social relations. In order to be accepted and approved by the group, individuals adjust to the behavior of others. Being member of a group is part of their identity, which can have various psychological and behavioral consequences [61]. Information about the results of other groups emphasizes the existence of the own group, differentiated from the other group. This differentiation leads to competitive feelings and a desire to improve individual performance to contribute to the own group [59].

Positive self-image: People adjust their behavior for the strong need to maintain a positive view of themselves. They want to behave consistently with their actions, statements, commitments and beliefs in order to enhance, protect, or repair their self-esteem [39].

In the context of energy conservation, social comparison may be very effective when others performance is selected for comparison [1]. The comparison of individual feedback about energy performance, in relation with the performance of others, may be helpful in reducing household energy use. Comparative feedback evokes feelings of competition, social comparison and social pressure, which may be especially effective when important or relevant others are used as reference group [1].

The power of social norms

Regardless of the positive effects obtained in many studies using comparative feedback, there had been certain contexts, in which studies showed boomerang effects in the use of these practices [56]. Descriptive norms set a standard from which people do not want to deviate. People measure their performance depending on how far they are from the norm. Descriptive norms act as a magnet for the behavior of individuals that are both above or below the norm. People with energy consumption higher than the norm, will try to reduce it to approach to the value, but people with energy consumption lower than the norm value, will see themselves consuming less energy from what is the standard and they will increase energy consumption to approach to the norm value, producing the boomerang effect. This negative effect can be prevented with the introduction of a message explaining the desired behavior. People consuming more energy than the average; receive negative feedback, for example, a sad face or a red label indication. People consuming less energy than average, gets a small reward, for example, a happy face or a green label. The introduction of these messages, proved to have a positive effect by reducing the undesired boomerang effect of using comparative feedback in energy consumption [56].

3.1.3 Goal setting

There is no point in setting goals without commitment. Goal commitment is a key element in the general motivational theory [47]. Whether there is some confusion in the use of the terms goal acceptance and goal commitment, goal acceptance refers to the initial agreement, whereas commitment refers to the attachment to the goal and the determination to achieve it. Setting the goals is a delicate issue. Very hard goals lead to high performance, but they are generally accepted to a lesser degree. Easy goals may not motivate people to increase performance, loosing effectiveness and not being fully accepted [46].

Some factors that determine the commitment to goals are the following [47]:

External influence: This factor refers to the goals that are assigned to a person. People obey an authority figure when they judge the request to be legitimate. In industry, most employees consider the supervisor's right to tell them what to do, because doing what one is told is part of the employment contract. Group pressure also increases the commitment to the assigned goals. Other external influences are monetary incentives, punishments and rewards.

Interactive factors: An interactive factor is the participation in the establishment of goals. The effects participation has on goal commitment are contradictory. Latham and Yuki [45] found that the participation in the setting of goals led to higher performance than assigned goals by external influence. Other studies conclude that it is not important how a goal is set as it is that a goal, in fact, be set [29].

Internal factors: The choices of a person are affected by the perceived chances of performing the task well [11]. Commitment declines as the goal is perceived to be difficult to reach. The efficacy of a person is related to the expectations to succeed. The chance of accepting a hard goal is higher when the person feels that is capable to perform it. Self-administered rewards such as statements like ' did it very good', lead to improvements in the commitment to a goal and the achievement of the same [50].

3.1.4 Rewards

There are two kinds of rewards, extrinsic and intrinsic. Extrinsic rewards are the ones external to the person, such as money or verbal reinforcement. Intrinsic rewards are internal to the person. A person is intrinsically motivated to perform a task, if there is no apparent reward apart from the task itself, or the feelings to perform it. Both kinds of rewards can be combined in different ways. People with intrinsic motivation to perform an activity, decreased when receiving negative feedback about their performance, monetary reward does not affect intrinsic motivation and verbal reinforcement appears to enhance intrinsic motivation [13]. Every action of a person to save energy is expected to be rewarded in some way. There is no need for big rewards, even small ones are better than nothing.

3.2 Social networks as motivational factor

Social network websites have three important functions: create a connection between users providing the opportunity to take part in the production of content, help to determine a topic in common between users and contribute in shaping their decisions to become involved in the topic. Users in social network websites tend to associate with others who have similar values and interests [2]. The personality of the user is represented in an online profile. Multiple facets of personalities are not supported in online profiles as it is in the real world; this situation complicates the aggregation of environmental values that do not match that personality online. In social networks it is important to understand the social capital, for example, if being ecologically sensitive is perceived to affect negatively to the social capital, it will not be successfully spread in such an environment. It is important to think in the audience we are aiming to and create a solution they find interesting, fun, educative, etc. in such a way that affects their social capital positively [48].

An interesting opportunity in the use of social network websites is the direct integration in their online profiles, of personalized data and dynamic suggestions provided from environmental sites. These online profiles are frequently visited by other people that may not have the environmental knowledge, becoming a mean to share environmental information. Existent profiles could be enhanced with information on individual energy use and environmental achievements. Users will be shown suggestions for reducing the environmental impact, but also be encouraged to produce new ideas [48]. Just being part of an environmental group in the social network is a good start to create energy awareness.

Chapter 4

Smart Environments

It was inevitable: science had become the new magic and common man believed in it, even when they could not understand it...

—Ernesto Sabato - Hombres y engranajes

According to Mark Weiser, a Smart Environment is "a physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network" [63]. Smart Environments are seen as a byproduct of pervasive computing and the availability of cheap computing power, making human interaction with in-house systems a pleasant experience. Some of the features that are possible to find in Smart Environments are: remote control of devices, communication with devices to get information, enhanced services by intelligent devices and predictive and decision-making capabilities.

4.1 Related projects

The field of domotics and Smart Environments has gained much interest in the last decades. Universities and companies are working in the research and development of various products to contribute to the field of Smart Environments. Some projects are directed towards e-health, others just trying to improve the comfort of users. Projects that can contribute to the goal of this research are described below.

4.1.1 HYDRA

Project HYDRA is a generic middleware for developing networked embedded systems [36]. It allows developers to incorporate heterogeneous physical devices into their applications, by offering web service interfaces for controlling any type of physical device independent of the network technology, such as Ethernet, Bluetooth, RF, ZigBee [5], Wi-Fi, etc. As generic middleware framework, Hydra offers high degree of flexibility, making it applicable in various domains, like home automation or e-health. The core component of hydra will be released as open source. This enables the possibility to adopt the middleware for personal or commercial purposes. HYDRA as a base for interconnecting appliances is a good platform for energy awareness systems [41].

4.1.2 eDIANA

The eDIANA platform is model-base architecture, implemented through an open middleware including specifications, design methods, tools, standards, and procedures for platform validation and verification [22]. The eDIANA platform will enable the interpretability of heterogeneous devices at the Cell and Macro Cell levels, and it will provide the link to connect the building as a node in the producer/consumer electrical grid.

The technology to be developed in the project will improve the energy efficiency and optimize buildings energy consumption up to 25%, providing real-time measurement, integration and control. eDIANA is also intended to improve comfort, making the user aware of the energy consumption and enabling user- controlled policies for household devices.

4.1.3 GreenerBuildings

GreenerBuildings [54] aims to the realization of an integrated solution that addresses the challenge of energy aware adaptation for basic sensors and actuators, up to embedded software for coordinating multiple smart objects, with the goal of reducing energy consumption. The vision of the project is that buildings can adapt to their occupants behavior [54].

The intent of the GreenerBuildings project is the development of an energy-aware framework based on embedded service middleware and a building-distributed architecture of smart objects. The framework relies on advances of ubiquitous ultra-low power sensing, sensor-based human activity recognition, and device orchestration, to guarantee responsiveness, scalability, and dependability in its goal to achieve energy savings at the whole building level.

The GreenerBuildings architecture specifically emphasizes occupant activity and behavior as key element for adaptation, but addresses other building context information as well. In Figure 4.1 the architecture is presented. The ubiquitous system layer consists of the physical devices, in particular the sensors, actuators and processors. The service composition layer comprises the abstract composition and orchestration functionalities of the energy-aware framework.

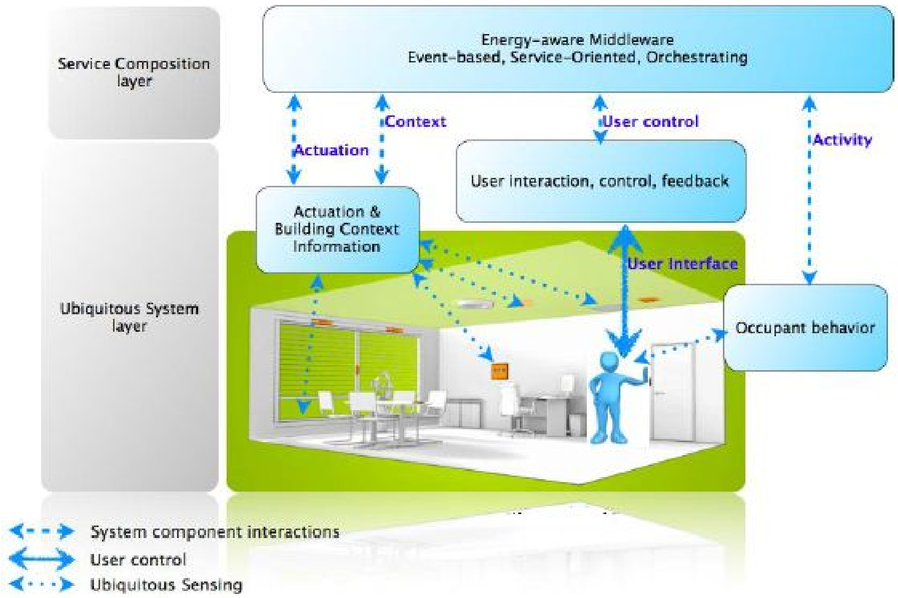

Figure 4.1: GreenerBuildings architecture [54]

4.2 Interfaces

In the field of computer science, an interface is a tool or concept that allows the interactions of components, both in hardware and software level. Components work independently from each other. The communication takes place via an input/output system and associated protocols. Changes in one component do not affect the other, as long as the interface does not change. In this report we present both hardware and software interfaces. We focus in the user interaction, control and feedback with the Smart Environment.

4.2.1 Available solutions

A key aspect for the development of interfaces is usability. The objective of an interface is not only to provide full functionality, but also adapt to the user needs and goals. It is possible to find plenty of products that allow interfacing with Smart Environments. These products implement various interesting features, to produce energy awareness and contribute in the reduction of energy use. The presented solutions bellow, are only the ones released in The Netherlands while performing the research for this work.

Essent E-thermostaat

Remote control of devices is one of the features of Smart Environments. The E-thermostaat from Essent [25] is a very simple solution to control the temperature in the house. A thermostat device is mounted in the wall and connected to the internet router. The user registers online and downloads the application for smart phone to control the temperature and receive feedback remotely. The product allows automatic control of the temperature by setting weekly programs. The display screen and the application are shown in Figure 4.2.

Eneco Toon

Toon [23] offers all the features expected from a modern thermostat. The product is able to control the heat in the house, show historical and real-time information on the current gas and electricity use and is really beautiful and easy to operate with a touchscreen as shown in Figure 4.2. Some of the features provided in Toon are:

- Visualization and comparison of past energy consumption
- Update of actual energy prices
- Messages to inform increases in energy price
- Identification of peaks in energy consumption
- Display differences in the high and low rate consumption
- Provision of information over the weather and traffic services

NUON E-manager

Feedback on energy consumption may contribute to reduce energy use. Information of the energy consumption of neighbors motivates people to improve even more. E-manager is the solution for energy awareness and home appliances control from the company NUON [52]. The basic kit consists of a reader to be connected to the regular electricity and gas meter, and a gateway to be connected to the internet router. Users can access their energy consumption information through personal computer, mobile and tablet devices. Additionally, it is possible to switch appliances states by installing controlling devices for each one of them. NUON E-manager kit is shown in Figure 4.2.

Zjools

Zjools is an energy coach, which visualizes energy consumption and provides advice to reduce energy use [44]. Through the combination of insight and advice, Zjools emphasizes in creating energy awareness and produce a behavioral change. This product is characterized by its simplicity and ease of use, which allows users to install it themselves and start getting financial insight in the use of energy. The Zjools kit consists of a sensor to install in the electricity meter

Figure 4.2: Existent solutions: Eneco Toon, Zjools, Essent E-thermostaat, NUON E-manager

at home, a wireless transmitter and the energy display. Zjools provides real-time information on the energy use in money, kWh and CO_2, displays energy consumption of previous days and allows the configuration of goals to stimulate uses to reduce energy consumption. The display is shown in Figure 4.2.

Chapter 5

Concepts and Design

> *A lot of people in our industry haven't had very diverse experiences. So they don't have enough dots to connect, and they end up with very linear solutions without a broad perspective on the problem. The broader one's understanding of the human experience, the better design we will have.*
>
> *—Steve Jobs*

For creating a good product it is not enough to apply standards, and use guidelines or checklists. It is important to understand the context and include users in the design process right from the beginning. What drives the design of this application is the desire to change the user behavior in order to reduce energy consumption. Many interesting investigations and ideas are found in this research that lead to the design of the concepts that are implemented in the application that is called GBPad.

5.1 System context

This application is developed as part of the GreenerBuildings project presented in Section 4.1.3. The laboratory settings of the project consist on a group of appliances consuming or producing energy in this environment. The appliances use a Plugwise Sting device [53] connected between the electric socket and the appliance plug. The Sting measures energy consumption and can switch the connected appliances remotely using a Zig-Bee mesh network. The GreenerBuildings's server records the energy consumption data from the Sting devices. The tablet interface is connected to the server through a Wi-Fi network. Remote access via internet connection is also possible. A diagram of the context is shown in Figure 5.1.

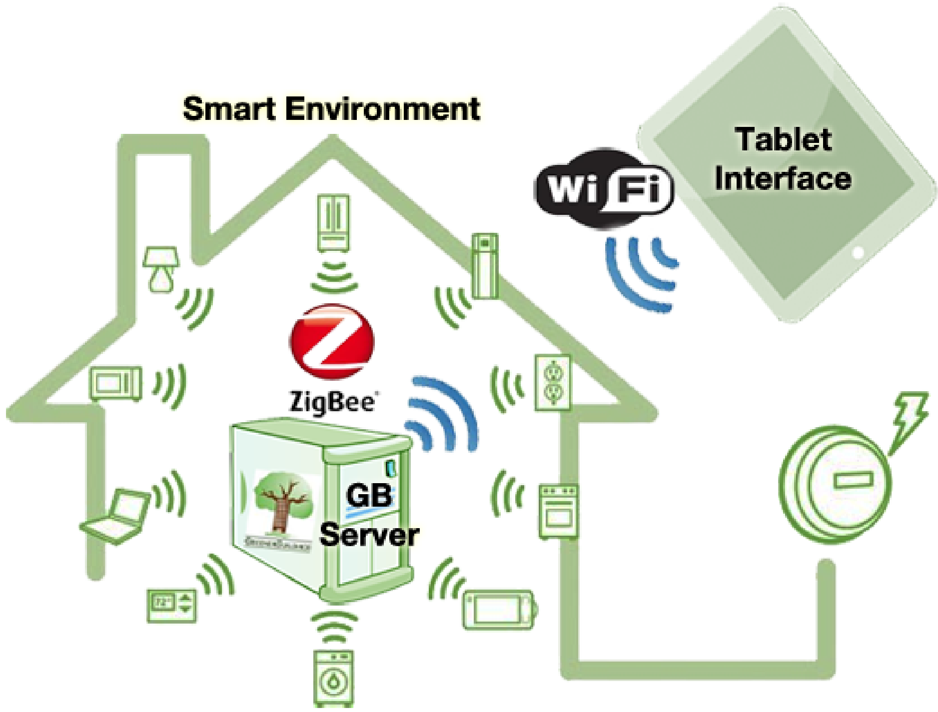

Figure 5.1: Context diagram

5.2 User centered design

Every product development process should be centered around the user [42]. In the design cycle shown in Figure 5.2 the usability can be improved in each cycle and adapted to the requirements of the user. This process increases the project costs but improves the user experience which can turn into competitive advantages.

The user centered design process requires people with different skills, to understand what the user wants, and to be able to build it. In this project, professionals such as interface designers, social psychologists, business experts, electrical and software engineers collaborated in the design cycles of the application.

In the initial stages of the project as well as in the finals, a number of methods to improve the quality and usability of the application are implemented. These methods are described in the sections below.

Discover

The determination of the context and the gathering of the initial requirements is the first step of every development project. Interviews with members of the GreenerBuilding project and po-

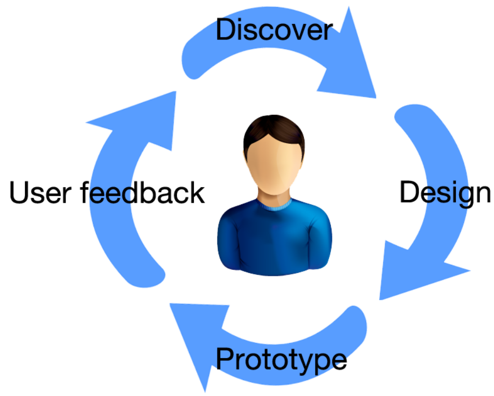

Figure 5.2: User Centred Design

tential users took place for gathering functional requirements, as well as usability requirements, which are non-functional requirements. They define how these functionalities are presented, to allow the user to perform the tasks in a more efficient way.

In the early stages of the Discover method, the research on energy awareness and persuasion methods led to open-ended interviews with social psychologists. The interviews helped to clarify concepts and get feedback on which is the best way to show the information to the users and which are the motivational factors to apply in this situation. When the concepts were clarified, a mind map was developed; this allowed the realization of semi-structured interviews with the social psychologists. These interviews helped strengthen the ideas and validate the concepts to be implemented in the application.

Design

As soon as sufficient requirements are gathered and an initial idea of the application is formed, the design stage starts. The user centered design is an iterative process. Many different possibilities are considered in the design, which in subsequent iterations can be discarded or improved. New requirements appear and some assumptions are made to come to a feasible design.

Style guides are applied to contribute in the creation of a consistent design and homogeneous look and feel of the application. One example of a style guide is the Apple Human Interface Guideline [17]. When an application works well in a device and responds to the gestures people know, the provided experience improves the satisfaction of the user.

Prototyping

The creation of a prototype allows the user to interact with the application before developing the final version. It is an easy way to validate requirements, obtain new ones and get an early usability test. The development cost of a prototype is relatively low and modifications can be done easily.

The realization of a low fidelity prototype facilitates the evaluation of different concepts and the presentation of different ideas to stakeholder. However, the interaction and the navigation of the application could not be tested, since the functionality was not implemented in the prototype.

User feedback

During the development of the project, user feedback was gathered. This was crucial for determining if the concept, design, and features in the application meet the requirements and visions of the user. Design is always based on assumptions and guesses at different levels. Users do not always react as expected. That is the reason why it is so important to interact with them at all stages of the development.

Experts in interface design provided feedback, regarding the distribution of the elements in the display, sizes and colors. The navigability was tested to improve the user experience, allowing the access to all the information in an intuitive way. Social psychologists were in charge of evaluating the way in which information is shown. The selected units and elements in the display were carefully selected, to create energy awareness and persuade the user to change its behavior and consume less energy. The GreenerBuildings team was in charge of providing technical feedback on the performance of the application, and the testing of errors and bugs that could appear in the execution.

The User Centered Design methodology was performed informally in this project. The cycles were realized but the starting and ending of the same was not formally registered, neither the amount of cycles. In any case it is a very valuable strategy to be used for further development.

5.3 Desired Attributes

The idea of this application is to bring energy consumption information close to the user. Teach users how much energy appliances consume and persuade them to reduce energy consumption. We found the most important attributes of the application to be usability, scalability and adaptability. The rationale for choosing each of these attributes is given below.

Usability: The application has to be easy to use and provide a pleasant experience. The interface has to be understood quickly and allow obtaining the desired information in the minimum amount of clicks. The information has to be shown in an easy to read manner, which transmits the meaning of energy consumption in a way that users can understand. The control of appliances must be simple and clear. Good usability can add long term advantages for a product or a company.

Scalability: The design of the application should require minimum effort to scale in the amount of appliances that is possible to connect. GBPad was designed initially for a lab environment with few appliances, but it is also intended to interface with public buildings, like offices, or schools where the amount of appliances could scale drastically.

Adaptability: The application should be adaptable to multiple environments and uses without major changes in its architecture. It should support grouping devices in different categories, and modifications in the way the information is displayed.

5.4 Use Cases

In Figure 5.3 the initial use case diagram of GBPad is shown. Five basic use cases are presented which represent the functionalities of the application and an additional use case related to subsequent updates to be done. A description of each use case is given in Table 5.1

Code	**Use Case**	**Rational**
UC1	Synchronize application with server	The application synchronizes the information with the server whenever it is started or when the user presses the Sync button
UC2	Show historical energy consumption	Statistical information on energy consumption of appliances and groups is displayed when the user selects the option
UC3	Show real-time consumption	Real-time consumption of appliances and groups is displayed when the user selects the device or group
UC4	Share results in social networks	The user presses the share button to publish his energy consumption improvements in the social networks
UC5	Control appliances	The user presses the ON/OFF button to switch the appliances in the environment remotely
UC	Update application	The maintainer update the application to its newer versions

Table 5.1: Primary use Cases

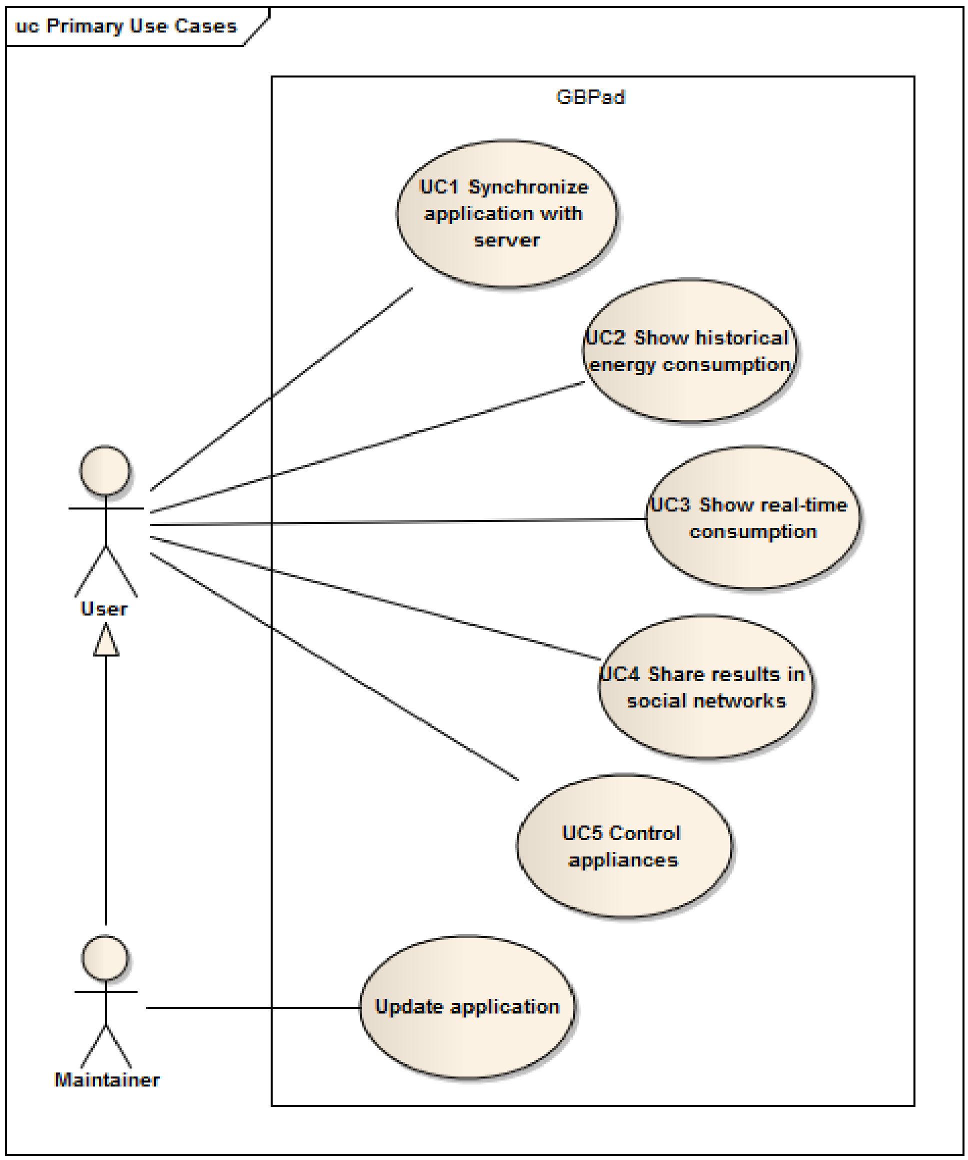

Figure 5.3: Primary Use Cases

5.5 Requirements

In this section the functional and non-functional requirements of the application are described.

5.5.1 Functional requirements

Below is a list of the implemented functional requirements of the application

- Configure the profile of the building
- Set server URL address
- Synchronize application with the server
- Receive real time consumption of appliances
- Switch appliances remotely
- Display statistical information of the consumption
- Share information in the social networks
- Group appliances

An extended version of the functional requirements prioritized by the MOsCow method is shown in the functional requirements section of Appendix A.

5.5.2 Non-functional requirements

The non-functional requirements are listed below

- To be effective the use of the application must reduce at least 10 % of the energy consumption for the average user
- The application must be easy to use
- The user should be able to have access to the desire information in no more than three clicks
- The application must be able to work with multiple appliances
- The privacy of the user must be preserved

An extended version of the non-functional requirements can be found in the non-functional section of Appendix A

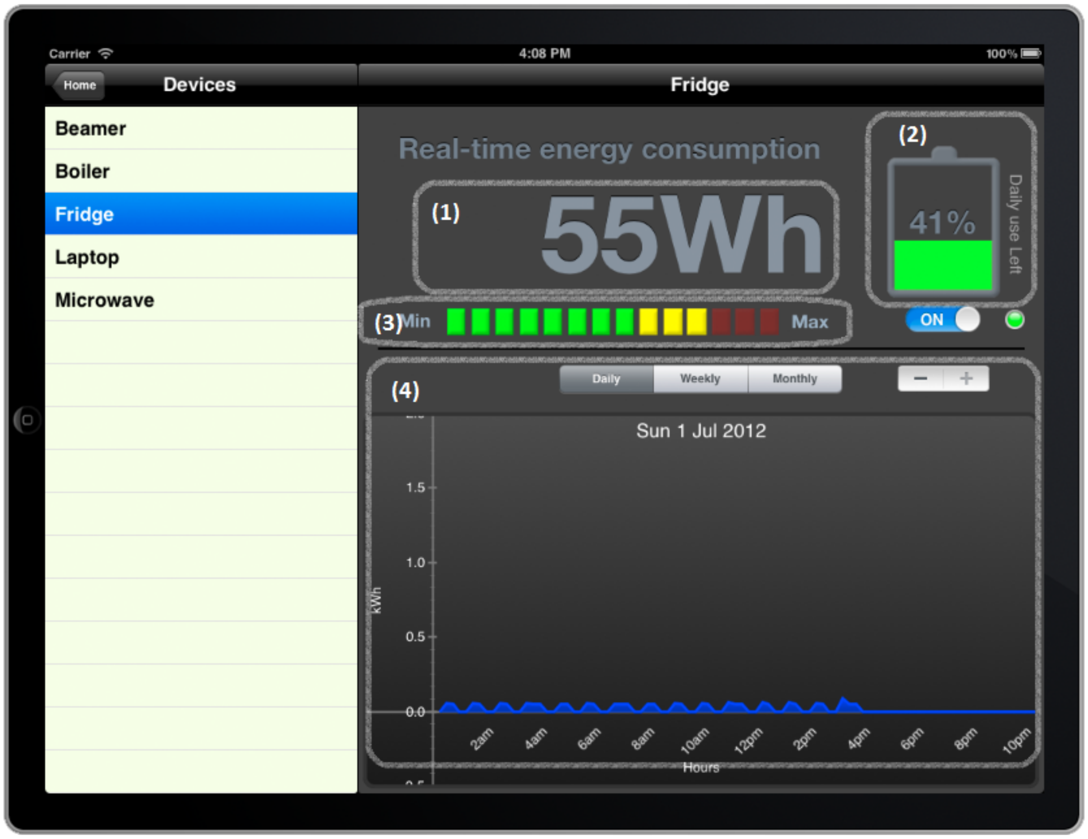

Figure 5.4: Real-time and historical data graph screen (1)real-time consumption, (2)remaining daily consumption, (3)maximum usage bar, (4)historical data graph.

5.6 Interface design

The notions in energy awareness and persuasion methods introduced in this report provide several concepts to be incorporated in the design and development of the application. These concepts correspond to the best practices in energy awareness and make emphasis on the most appropriate motivational factors, to be included in a project of this nature. The user is going to be able to focus on reducing energy consumption, rather than on dealing with the technical aspects of the system.

Advances in technology, facilitate excellent platforms for developing tools for the management of energy consumption. The cost of setting Smart Environments for using applications like GBPad is decreasing. Systems have to be built to maximize the participation of users and facilitate the understanding of energy consumption to influence in his behavior.

Real-Time energy consumption

There is plenty of research concerning the best form of unit to use on an energy display, for example, carbon units, money, watts hour, etc. The use of money as a unit could be ineffective or even unhelpful to motivate savings in the energy use [66]. People are not motivated to change a behavior for saving small amounts of money, e.g. if a person has to get shorter showers every day to save small amounts of money at the end of the month, he may not feel motivated to do it for that amount of money. Displaying energy consumption in grams of CO_2 produced for generating energy, encourage people to understand the relation of their energy use with the effects on the environment. The problem is the inaccuracy of the calculations to have a real relation between the CO_2 production and the energy use, especially for the electrical energy [62]. Persons mistrust these results when they need to have a point of comparison. The selected energy unit to be used in GBPad is the Wh (Watt hour) as shown in Figure 5.4(1). People are not aware of how many watts hour individual appliances consume. They are familiar with this unit in some of them, like for example, light bulbs or microwaves. Displaying real-time energy consumption is indented to strengthen the knowledge of the user in relation of the amount of Wh every appliance consume. It also gives users the possibility to compare the values of different appliances, to be more aware of which ones should be used more carefully. The display of dynamic real- time information keeps user interested in the display for longer periods of time.

Maximum usage bar

The concept of maximum energy usage bar in Figure 5.4(3) is a graphic display method that shows a limit in the amount of energy used at the moment. This amount is obtained from the server for each appliance, and calculated for the groups as the sum of the individual maximum of the appliances included in the same. When an appliance is used at its maximum power, all the lights in the bar are turned on. The display of this information motivates the user to configure the appliances to use less energy and avoid reaching the limit. This concept applied in groups, shows the individual contribution of each appliance to the energy consumption in the group. When all the lights in the bar are turned on for a group, it means that all the appliances in the same, are turned on at their maximum capacity. Showing this information to the user will make him aware of the situation and motivate him to turn off some appliances or reduce the amount of energy they use.

Remaining energy indicator

The remaining energy use indicator is based on the daily average energy use. The amount of energy each appliance consumes per day is calculated by the server and sent to the application every 40 seconds. The battery that is shown in Figure 5.4 (2) indicates the percentage of that energy used in the every day. When a new day starts, the battery goes again to its full capacity. When more energy than the average is used, a red battery is displayed and negative numbers show the percentage of energy used over the average value. The motivational factor is the self-competition on a daily based timescale. This is the favorite motivational factor according to Humphries and Hyldon [55]. This concept can also be used for setting goals, for example, the simplest one to not consume more energy than average. Once those goals are achieved the user gets small rewards to keep him motivated. Other possibility is to change the battery image to a more environmental unit like a tree. Most individuals maintain positive feelings towards trees in relation to the amount of CO_2 absorbed by them [35]. While more energy is consumed a tree with less leaves could be displayed.

Historical consumption graph

There are contradicting positions in relation of which is the most effective method to show statistical information. Pie charts can be useful for detecting patterns, but not for determining precise values or making comparisons, they should not be used when having more than 5 different categories [40]. Bar charts show values for separate entities facilitating comparison and determination of limits for the segments. Line graphs are the best way to show large amounts of values. They facilitate to determine the interrelation of data and the change over time [32]. The selected method for showing statistical information on energy consumption is the line graph as shown in Figure 5.4(4).

Energy rating

The most effective energy information is the one that captures the attention of the audience, produces engagement and is credible and useful [60]. It is not only the information content that is given, but the way in which that information motivates the person to change a behavior. Those attributes can be found in energy labels, introduced in Section 2.3.1. The decision to use Energy Labels in this project is based in the popularity of the concept, as a method to compare the energy efficiency of similar appliances and the facility to understand it.

The average shown in Figure 5.5 (4), is a representation of the monthly amount of kWh expected to be used. In this research we consider three formulas to estimate average energy consumption. The first one is based on the geographic location of the environment, type of building, amount of inhabitants, and its size in square meters. The elements present in the formula used for the EPC (energy performance certificate) are described in Section 2.3.2. The second formula uses a calculation based on the quantity of appliances in the house, type, size and the amount of persons in the environment. Every appliance type has an estimated monthly average consumption for a specific amount of persons. This value is calculated to obtain the monthly energy consumption in kWh [38]. Finally, the third and selected formula was obtained from The Energy and Sustainability Research Institute Groningen (ESRIG) [24]. It is a simple formula to roughly calculate electricity consumption without the need of many parameters. This formula is only valid in The Netherlands. The main parameters are household size, measured in the amount of persons living the same, and the net monthly income for the whole household. The formula is shown below.

Formula to calculate yearly electricity consumption

1 person : y = 0.6473 * x + 1444
2 persons: y = 0.6473 * x + 1537
3 persons: y = 0.6473 * x + 2046
4 persons: y = 0.6473 * x + 2286
5+ persons: y = 0.6473 * x + 2690

*Where **x** is the nett monthly income for the whole household and **y** is the yearly electricity consumption in kWh*

The result of this formula is divided by twelve, to obtain an approach of the monthly consumption. This value is set in a middle position of the label scale as the average value to compare with. GBPad gets the average electricity consumption of the previous month from the server. The percentage of improvement of this last value with respect to the one obtained using the formula is calculated to obtain the position on the energy label as shown in Figure 5.5 (3).

Energy label values are easy to read and understand. Sharing energy label value in social networks can give rise to endless social dynamics, for example, competitions between users, comparisons with neighbors, creation of groups and teams etc. The energy labels can also be used as a goal to motivate users to move upwards in the scale by reducing their energy consumption. The reward of obtaining a better label can also be shared in the social network as an achievement. Concept versions of the integration with the social networks are shown in Appendix B.

5.7 System Architecture

In this part of the document the system architecture is described. We start with an initial model, a description of the components and the logical view of the most important parts of the application.

Figure 5.5: Energy Labels (1) reward, (2) energy labels, (3) personal value, (4) average value.

5.7.1 Initial model

In Figure 5.6 is shown the initial model of the system architecture of the application. Each components of the system, its responsibilities and rational is described in Table 5.2.

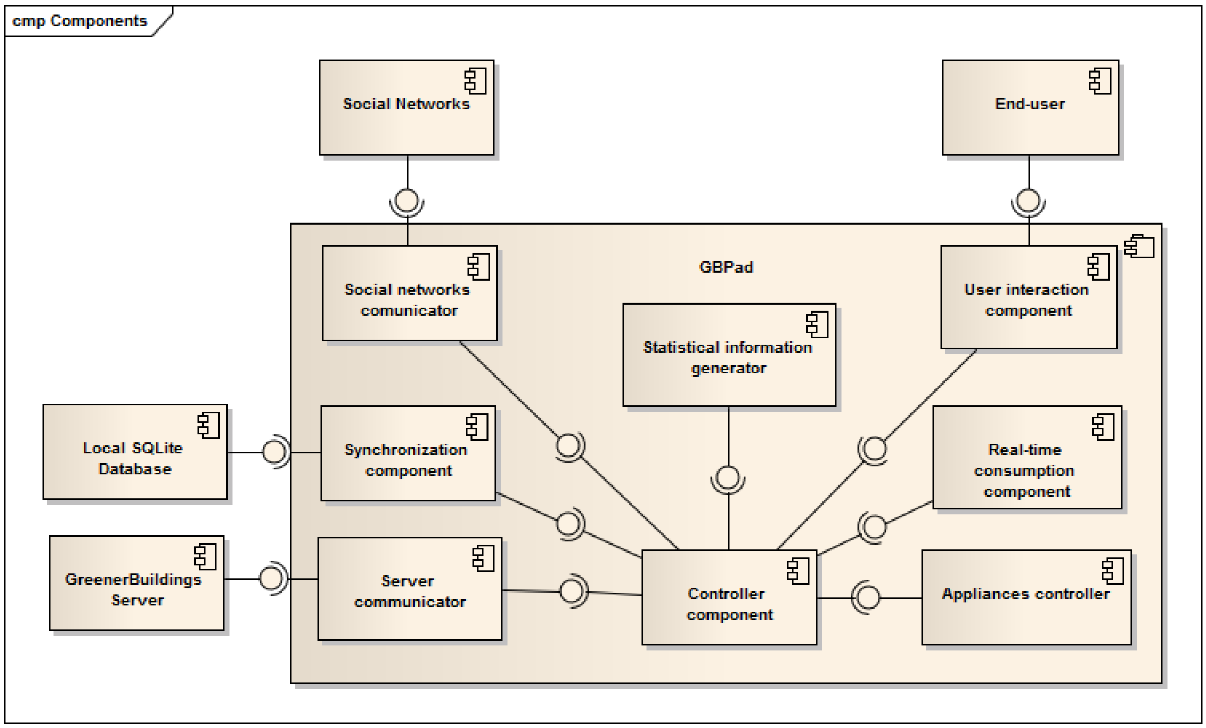

Figure 5.6: Initial Model

5.7.2 Logical view

In this subsection we analyze the logical view of the most important parts of the application, the synchronization with the server and the display of real-time consumption.

Synchronization

The synchronization feature in GBPad runs every time the application starts. It updates the local database with the latest information available in the server, eliminating the necessity for the user to configure appliances in the application. The class diagram that reflects the contents of the database is shown in Figure 5.7

Component	**Software**	**Rational**
Social network communicator	TCP/IP communication	This component is in charge of the direct communication with the social networks via internet connection. It communicates with the Controller component to get information.
Synchronization component	Synchronization manager	This component is in charge of updating the information in the local SQLite database of the application with the latest information in the server.
Server communicator	TCP/IP communication GET, POST messages	This component is responsible of the communication with the GreenerBuildings Server. It has the ability to send and receive XML messages via the TCP/IP protocol.
Statistical information generator	statistics manager	This component communicate with the Controller component to obtain the statistical information to be processes and presented to the user.
Controller component	System core manager	The Controller component centralize the control and coordination of all the functions in the application. It is responsible of sending the information between components, and to keep them informed of events occurring in other parts of the application.
User interaction component	User interaction manager	This component interact directly with the end user. It is responsible of managing the way in which the information is displayed and it is also in charge of receiving input from the user.
Real-time consumption component	Loop manager	This component communicate with the Controller component to obtain the real-time information of the devices on every loop. The component processes the information to update the local database and display the changes.
Appliances controller	Appliances manager	The appliances controller is responsible to create the XML messages to switch the appliances connected to the GreenerBuildings Server.

Table 5.2: GBPad software decomposition

Adding or removing appliances, changing their values, creating or modifying groups, is transparent for the user. Every time the application starts it is synchronized with the server, eliminating the need to enter or modify data in the application. It practically eliminates all the configuration options, and reduces the amount of steps needed to start using the application

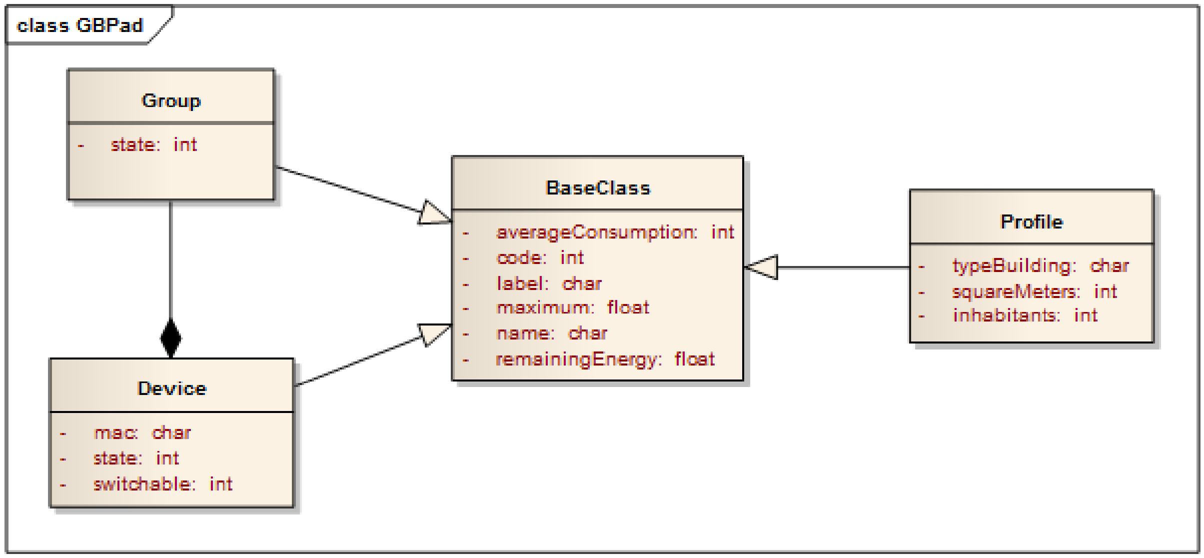

Figure 5.7: GBPad Class diagram

once installed. The activity diagram of the synchronization activities is shown in Figure 5.8.

Real-time consumption

When the application is in the real-time consumption screen as shown in Figure 5.4, a loop starts, for updating the real-time energy consumption every 6 seconds. Other loop for updating the remaining energy left, to be displayed in the battery also starts every 40 seconds. There is no point in making the loops shorter since the information in the server is updated also every 6 seconds, and reducing the time between loops would just increment the amount of processing and the load in the network.

The activities in the loop include updating:

- State of the devices to display if it is consuming energy, standby or if it is turned off
- Amount of energy that is consuming at the time in Wh
- Remaining energy use left (Battery)
- Maximum usage bar

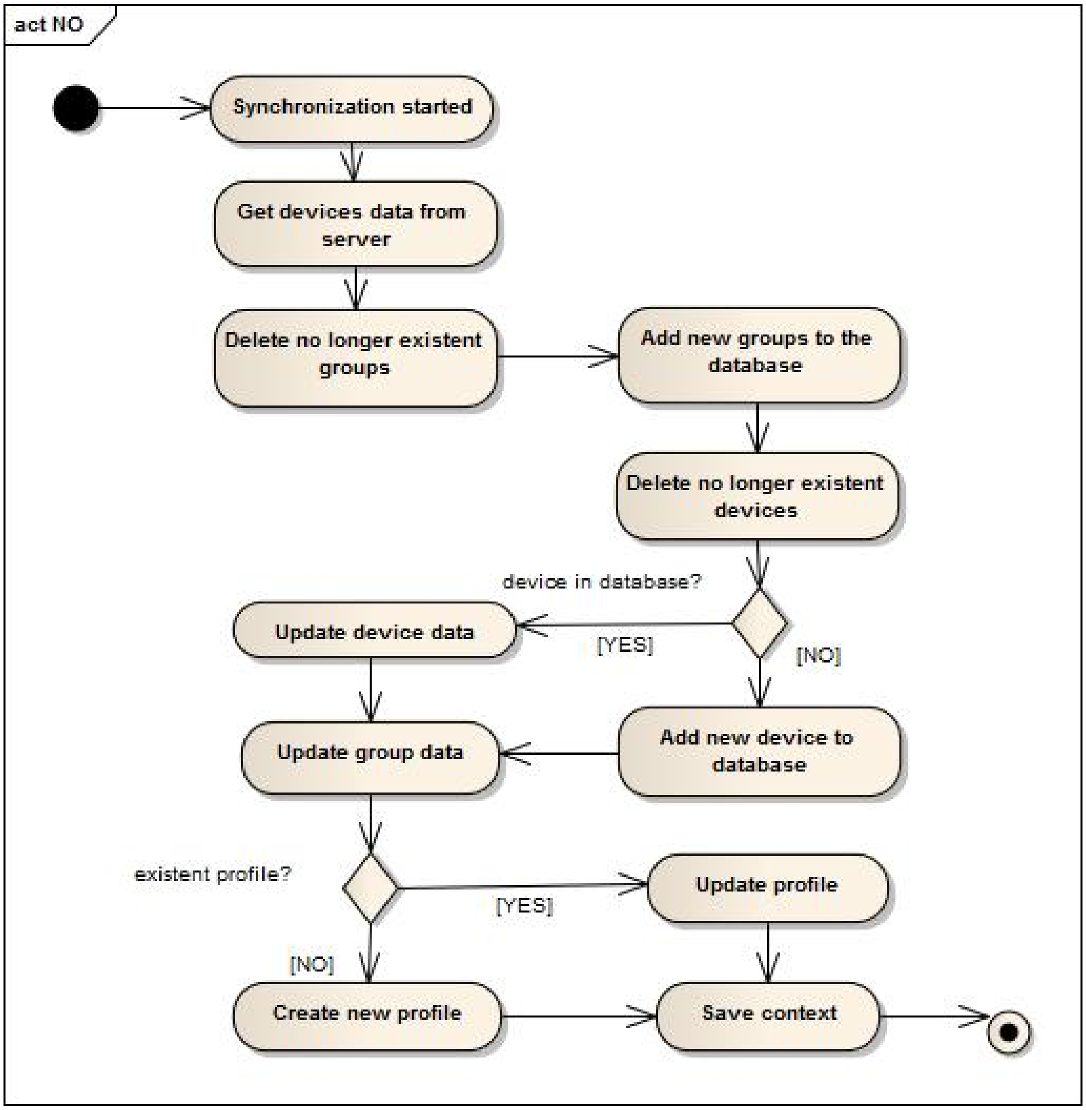

Figure 5.8: Activity diagram: synchronization.

Chapter 6

Implementation

A good idea is about ten percent and implementation and hard work, and luck is 90 percent.

—*Guy Kawasaki*

Implementation is the process of moving an idea from concept to reality [64]. Different ideas were considered in the design of the application that shaped the way in which the application looks and work. Implementation decisions have great influence in the future of projects.

6.1 Development tools

In the realization of GBPad the best development environments and programming languages for the development of iOS applications were considered. The project is going to be the base for further research and development inside the GreenerBuildings project and it was necessary to choose tools that allow flexibility and scalability for further development.

6.1.1 Xcode

Xcode is the Integrated Development Environment (IDE) for the development of software for OS X and iOS [19]. It is designed to maximize programmer productivity by providing all the necessary components in the same environment. The Xcode suite includes plenty of official documentation from Apple, which facilitates the understanding of tools and classes. The graphical user interface can be easily designed in the suite with the use of Interface Builder. The source code management system and distributed revision control, is effectively integrated in Xcode with the use of Git [57]. Xcode includes a modified version of the GNU compiler collection.

The resulting application can be easily tested with the iOS simulator, to get an idea of how the application will finally work on a real mobile device.

6.1.2 iOS SDK

The selection of programming language and development environment for mobile applications has a strong influence on the future of the project. It impacts in the development time, costs, flexibility, etc. The decision between the different mobile development frameworks is usually based on the desired complexity of the project and the time needed for development, as well as in the expertise of the development team.

The learning curve for Objective-C as the programming language for iOS SDK is very long, making it difficult to master in a short time. The advantages are the possibility to access all the APIs and functions of the iOS operating system and the performance is optimal. iOS SDK is the selected option for the implementation of GBPad. The application is part of the GreenerBuildings project and is going to be developed for research purposes. There is no need to run the application in other platform than iOS. The code will remain open for the team and it will be used for further development and experimentation. It is important to ensure that there will not be any limitations or dead ends in the programming possibilities of the platform to expand the project.

6.2 Model View Controller

The main design pattern used for iOS development is the Model View Controller or MVC shown in Figure 6.1. This design pattern separates aspects of an application into three distinct parts, and defines how the three communicate. The main purpose of MVC is reusability, where is possible to have the same model for different views with minor changes in the code.

Model

The classes in the model do not communicate directly with the view; instead they are available to the controller, which accesses them when needed. In the case of the access to data, a *Device* object containing information such as MAC address or state could be related to a *Category* object to obtain data either from a database or a file, which could be located locally or externally. In the case of Core Data [15] the classes in the model are subclasses of *NSManagedObject*. They interface directly with SQLite, insulating the developer from the underlying SQL.

All the connections with the server take place in the class *ServerLink*, located in the model. This separation facilitates the isolation of bugs in the communication with the server, and facilitates reusability. In the case of other application needing to communicate with the server,

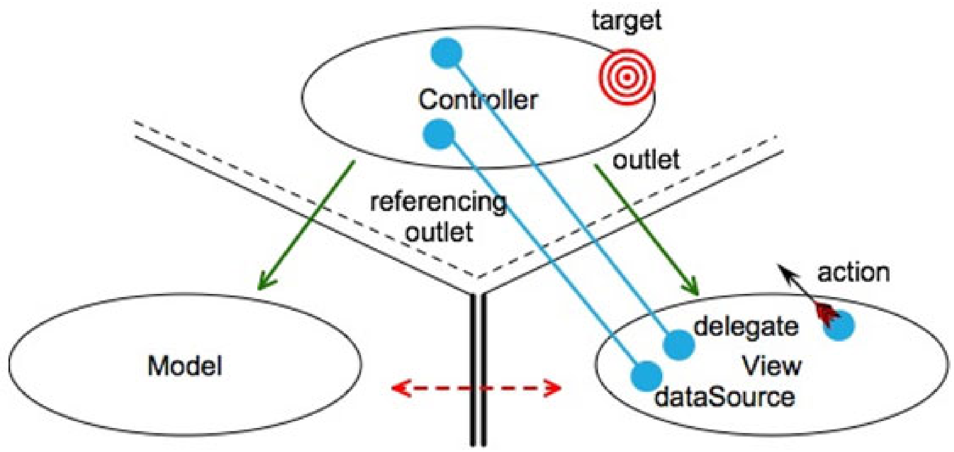

Figure 6.1: iOS Model View Controller design pattern [33].

it is only necessary to copy this class. If changes occur in the server, like for example, using JSON messages instead of XML, the only class that would be affected is ServerLink. The rest of the application remains intact.

It is also possible to find in the model, the libraries that assist in the creation of the statistical graphs in the application. Core Plot is a plotting framework for iOS, that provides 2D visualization of data and is closely integrated with Apple technologies like Core Animation, Core Data and Cocoa Bindings [9].

View

The view displays the information contained in the model. For example, the view is in charge of displaying the lists of devices or the remaining daily energy left. Although the view does not obtain the information directly from the model, it uses the controller as a mediator which instructs it when and what to display. In iOS, most views subclass from *UIView* which provide the capability for handling touch events as well.

One of the new features of the selected development environment that we make use of, is Storyboarding. This feature eases the development by managing the view controllers automatically. It is possible to specify transitions and segues used when switching between views without having to make any code by hand [18]. GBPad follows the *Master-Detail* application template. Selections in items from the master area, update the detail area.

```
dispatch_queue_t loopQueue = dispatch_queue_create("loop queue", NULL);
dispatch_async(loopQueue, ^{
    NSMutableDictionary *deviceData =
    [ServerLink initialStateForDevice:self.selectedDevice.mac];

    dispatch_async(dispatch_get_main_queue(), ^{
        Device *tempDev = [[deviceData objectForKey:@"state"] intValue];
        [self updateState:tempDev];
    });
});
dispatch_release(loopQueue);
```

Figure 6.2: Multiple threads dispatcher

Controller

The controller is responsible for accessing data from the model and displaying it on the view. The same controller can be used as an intermediate between several views and models. The controller monitors user interaction with the view and communicates any changes to the model. On the other hand, changes in the model are observed by the controller and subsequently reflected in the view. In iOS, the controller is generally a subclass of *UIViewController* that manages a view. The controller is where most of the application efforts lie on.

In the generation of lists to be displayed in the application the *UITableViewController*, which is a subclass of *UIViewController* fetches the data from the database and dynamically generates the *UITableView* to display the table. When the detail area view of an item is displayed, the controller gets notified and starts the *NSTimer*, responsible of the loop that updates the information every x seconds. When the detail view is no longer displayed, the timer is stopped. There are situations in which the tasks performed by the controller take a long time, or it is necessary to perform them concurrently. Grand Central Dispatch (GCD)[16] is implemented in the controller to execute arbitrary blocks of code either asynchronously or synchronously with respect to the caller. GCD can be used to dispatch queues, to perform nearly all of the tasks used on separate threads, avoiding the display to freeze. The code for working with multiple threads is shown in Figure 6.2.

6.3 Connection with server

The connection of the application with the server takes place through REST WS requests. XML packages are sent with the POST command or received with the GET command. For example, to switch the state of an appliance, GBPad sends a POST command with the following XML structure to the defined URL as shown in Figure 6.3. The server's Gateway running in the background receives the request. The Collector and Executor (CE) subcomponent provides the

```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<istates>
    <istate>
        <macID>B814FB</macID>
        <stateID>0</stateID>
    </istate>
</istates>
```


Figure 6.3: XML messages structure to change state.

basic tools for gathering information and controlling appliances. The CE uses its wrapper to interact with the Gateway in order to send the execution commands to the physical layer [37].

All the communications of the application with the server take place through the ServerLink class, belonging to the Model of the application. Figure 6.4 shows a simplified activity diagram of how the communication with the server takes place in the application.

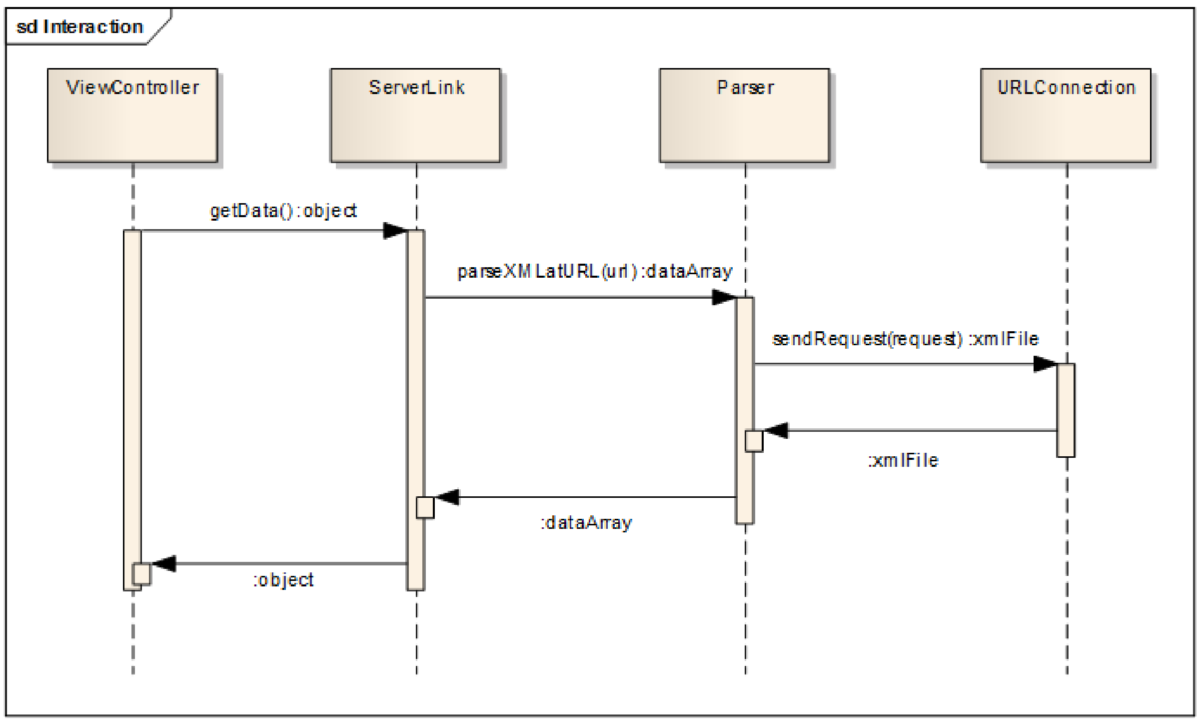

Figure 6.4: Sequence diagram sending messages to server.

Chapter 7

Evaluation

Good critical writing is measured by the perception and evaluation of the subject; bad critical writing by the necessity of maintaining the professional standing of the critic.

—*Raymond Chandler*

Evaluation is the comparison of the actual results against the desired plans. We have to look at the original objectives of the project, and see what was accomplished and how was it done. GBPad was designed to answer the question if a tablet interface, in a smart environment, can contribute to the reduction of energy consumption. In order to prove if this is possible, we compared the application with other solutions and performed a survey to capture the opinion of users on the application.

7.1 Design choices

The factors influencing the design of energy-information display systems to be used in Smart Environments are summarized in Figure 7.1. In the design of the application all these factors are analyzed according to the theory of Woods on energy-use information transfer [66]. The combination of choices that best serve our target are selected and implemented in the application.

In Table 7.1 is shown a comparison of the existent solutions presented in section 4.2.1 with the GBPad solution, according to the design choices of Figure 7.1. GBPad is a mobile application that puts special focus on the motivational factors, in order to engage users in the behavior of reducing energy consumption. Unlike the other solutions, GBPad introduces the concept of energy use rating, not only to create a self-competition or a self-set goal, but also to share this rating in the social networks and compete with other users. The easy to

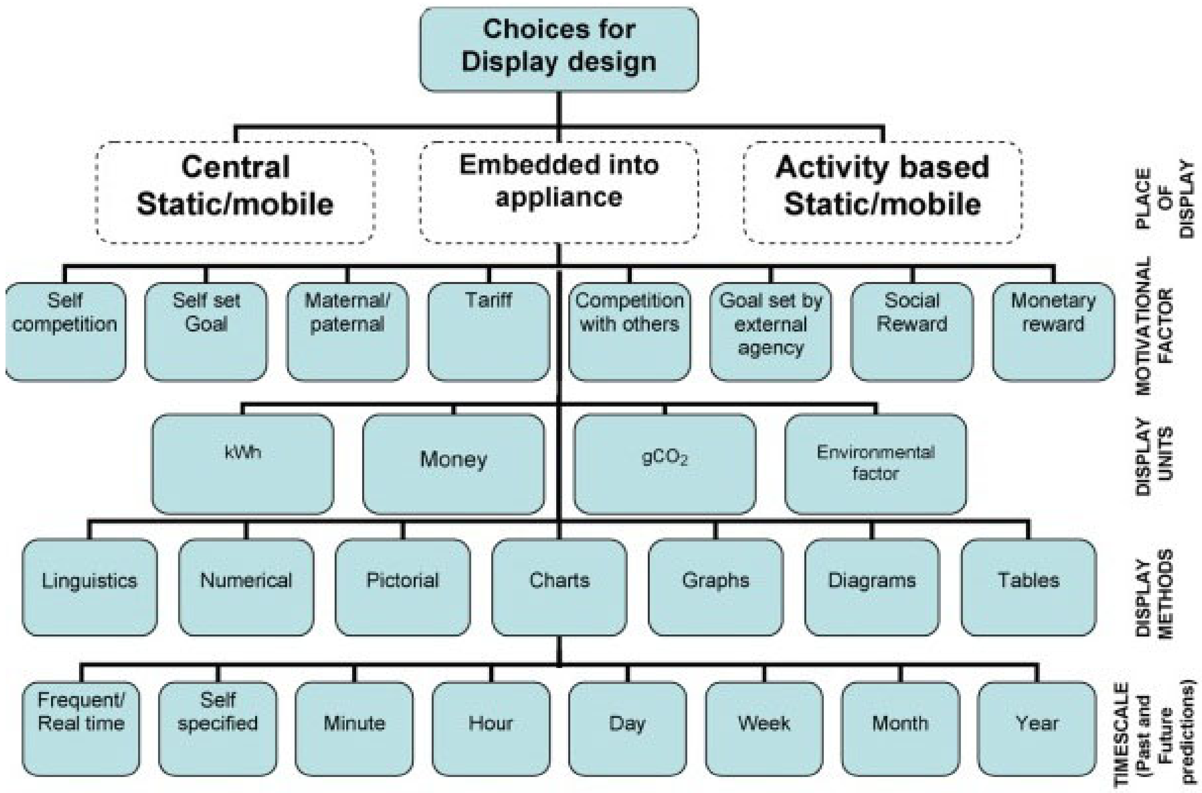

Figure 7.1: Summary of influencing factors [66].

understand energy use rating concept reflects the efforts of the user to save energy and has the potential to lead into diverse social dynamics to contribute in the reduction of energy use. The selection of Watt hour as a display unit is based on the fact that it is the unit of energy users are more familiarized with. Small amounts of money do not motivate people to change and the presentation of the link between energy use and CO_2 is not very accurate, producing mistrust in people. In the selection of display methods, apart from numerical units and charts, we emphasized the use of pictures to provide enhanced feedback. The energy bar to display the maximum energy use is introduced to show feedback on the limit of energy used for each appliance or group. The battery concept gives a clear idea of the remaining energy to use in the day to stay within the average daily energy consumption.

Solution	**Place of display**	**Motivation factor**	**Display units**	**Display methods**	**Timescale**
E-thermostaat	Central and mobile	n/a	Temperature in degrees	Numerical	Real-time
Eneco Toon	Central	Self competition, tariff, money	Wh, money	Numerical, chart	Real-time, day, month, year
E-manager	Mobile	Self and self-others competition, self-set goal	kWh, gas in cubic meters	Numerical, chart	Real-time, hour, day, month, year
Zjools	Central	Self competition, self-set goal, money	kWh, money, CO_2	Numerical, charts	Real-time, day
GBPad	**Mobile**	**Self and self-others competition, self-set goal, social reward**	**kWh**	**Numerical, pictorial, chart**	**Real-time, hour, day, month**

Table 7.1: Existent solution categorization

7.2 Experimentation

Experimentation was performed to find out the opinion users have of the application. We evaluated the usability and the potential to change the behavior of users to reduce energy consumption. The questionnaire can be filled with the supervision of a pollster in about 10 minutes. The questionnaire starts with a small introduction to the context of the project, followed by tasks to be performed in the application and finally questions regarding the opinions on the learned aspects of using GBPad. The questionnaire was performed by 20 randomly selected persons in the canteen of the library at the University of Groningen and at the canteen of Logica Groningen. The model of the questionnaire is presented in Appendix C.

7.2.1 Usability

The usability test part of the questionnaire is performed in two different ways. In the first group the surveyed subjects are introduced to the application, meticulously shown all the features, concepts and functionalities. After the training users have to perform three different tasks in the application: (1) Turn ON the Beamer, (2) Get daily consumption graph of the Common area and (3) Share energy rating in the social networks. The amount of clicks performed on each task is counted for each subject. In the second group the same tasks are performed, and the amount of clicks counted, but in this case there is no introduction or training in the application performed beforehand. It is expected that the group that was previously trained in the use of the application would find easier to perform the tasks, and therefore perform less clicks than the group without training. If the amount of clicks for both groups is similar or the same, it could mean that the application is intuitive and easy to use.

The results of the task perform test are shown in Table 7.2. The average amount of clicks to perform the first task in the group with previous training was higher than the one of the group without training. For tasks 2 and 3 the average number of clicks for the group previously trained is lower. The most similar results occur in the second and third task. It is not possible to identify the reason why the first task is more difficult to perform for the previously trained group. We see that the total values are identical for both groups. We note that the functionalities of the application are learned very intuitively in both cases.

Task #	**With training**	**Without training**	**Ideal**
1	3.8	3.4	3
2	3.2	3.4	3
3	3	3.2	3
Total	10	10	9

Table 7.2: Task performance in average number of clicks

The second part of the usability test consists of the identification of meaningful information on energy consumption with the use of the application. We want to find out if the displayed information is easy to read and access by the user in order to make decisions to reduce energy use. The information to be found is: (a) the group where the user should focus the saving efforts today and (b) the device with the highest consumption peak today. The difficulty to find the information is rated with numbers from 1 to 7, being 1 very easy and 7 very hard. The average result for the first request is 2.6 and for the second request is 2.5. The results of this test were rather satisfactory, tending to the very easy side of the scale.

7.2.2 Behavior change potential

The last part of the questionnaire is intended to find out if the application is able to provide valuable feedback in the usage of energy and educate people, creating energy awareness in a way that they could change their behavior to reduce energy consumption. The first question performed to the respondent subjects is to determine in a scale from 1 to 7 to what extend did they find the energy rating comparison useful. The average value of the responds is 5.6, being 1 not useful and 7 very useful. The concept of the energy rating was not completely understood or not accurate enough for some subjects. Some people are not familiar with the energy labels concept or just cannot see their home performance reflected in that scale. Other respondents could easily identify the energy rating from the energy labels used in commercial products and value the potential of having an energy rating implemented in their homes and shared in the social networks as a way to create competition between users. The second question is related to the level of awareness on energy consumption created with the use of the application. The average value of the responds is 6, being 1 very poorly and 7 very well. In general the answer to this question is very positive. People found interesting the interaction with the application and felt they have learned about energy use. It is interesting to notice that after using the application most of the users were surprised to contrast the energy consumption between different appliances and even between the different rooms in the environment.

7.3 Continued use

Due to time restrictions it was not possible to perform experiments in the amount of time users spend in the application a day or the real percentage of energy savings achieved. It is expected that users spend much time in a new application only the first months they use it and then probably stop using it. It would be a great success to design an application that people continue using over time, as they do with the e-mail, or the calendar.

Chapter 8

Discussion and conclusion

The presented work gradually introduces the topics to understand and give a solution to the problem of creating a mobile interface for Smart Environments in order to contribute to reducing energy consumption. The sub questions that contribute to finding an answer for the main research question are restated below.

1. How effective is the reception of energy consumption feedback to modify people's behavior?

   The reception of feedback on energy consumption is necessary to produce savings. The access to this information creates a link between the actions of the user and the actual effects, allowing effective learning on the use of energy. Continuous feedback results in increased awareness, which then leads to a change in the user's behavior.

2. What are the factors that drive people to consume less energy?

   There are multiple factors that motivate people to change behavior to reduce energy consumption. The simple self-comparison with previous results is probably the most basic and useful way of motivating people to improve. The introduction of the energy rating concept, based on Energy Labels, facilitates the competition with other users. Humans have the psychological need to conform the expectations of others, like the need to do things right, the need to be liked by others, and the need of maintaining a positive self-image. The correct use of these motivational factors contributes to the reduction of energy use.

3. What is the state of the art in Smart Environments, and interfaces with energy meters?

   Many universities and companies have gained interest in Smart Environments and domotics. Some of their products are slowly finding their way in the market, and becoming accessible to many users, covering needs from safety and comfort to e-health. It is possible to find multiple projects to interface with energy meters and manage the consumption of energy in-house. GBPad stands out in comparison with other solutions, for the special focus put on the use of motivational factors to engage users in conservational behaviors.

4. Which functionalities should a tablet interface have in order to effectively create energy awareness and persuade people to reduce energy consumption?

   GBPad introduces many concepts to effectively create energy awareness and persuade users to reduce energy consumption. The display of real-time feedback on energy consumption facilitates understanding the energy use of different appliances. Dynamic feedback also keeps users interested in the application for longer periods of time.

   The visualization of the average daily consumption facilitates the creation of self-competition. Self-stated goals to the user arise from this competition; they are rewarded to motivate performance improvements. The display of historical consumption graphs provides information to comprehend the interrelation of energy consumption and the change over time. Finally, the introduction of the energy rating, based on Energy Labels, is an easy to understand concept that represents the efforts of the user to save energy. The energy rating is shared in social networks, in order to create competition with other users and facilitate the creation of diverse social dynamics.

Results of evaluations proved the usability of GBPad to be very satisfactory. People learned to use the application in short periods of time. It is easy to find in the application, meaningful information on energy consumption to make better energy use decisions. The application provides valuable feedback on energy use and educates people, creating energy awareness in a way they could change their behavior to reduce energy consumption.

The reception of feedback on energy consumption in a tablet interface promotes energy conservation in two different ways: 1. *Efficiency behavior*: people learn which appliances consume much energy and are motivated to obtain more energy-efficient ones or 2. *Curtailment behavior*: people use less energy, for example, using less certain appliances and turning off others. For that reason we conclude that is possible to reduce the energy consumption in a Smart Environment with the use of a tablet interface.

8.1 Further research

In the realization of this work there are many interesting topics that had to be left aside to be able to fulfill time restrictions. Even if the research realized in this report is already wider than what was possible to implement in the application, there are many other concepts contributing to the reduction of energy consumption that are interesting to mention.

In several sections of this report the environmental problem is mentioned. Some people are motivated towards reducing their environmental impact, others to save money, or to receive social rewards. In the development of the application we experimented with the motivational factors of self-competition and competition with others to reduce energy consumption. I will be interesting to base that competition in units that reflect environmental impact of energy use. Instead of displaying a battery for the average energy use, a melting iceberg could be shown, and the rewards could be the amount of trees saved in a period of time by a change in the user behavior to save energy. One of the attributes of the application is adaptability, and it will be easy to integrate these concepts in the future.

The developed application is a starting point to implement new features derived from the communication with the GreenerBuildings server. It could be possible to interact with the planning and scheduling capabilities of the server. The application could be capable to send tasks to be performed by the server and receive feedback on the way the tasks are being performed. Push messages could be received to inform the user of changes in the environment, drops of energy price and alerts on energy consumption peaks.

The interaction with social networks leads to endless social dynamics. The application could facilitate the comparison of energy rating results between users. It could be possible to create teams as a way to attach users to their behaviors to save energy and have the feeling of belonging to an environmental group.

It will be very valuable the possibility to realize an evaluation on the use of the application for longer periods of time. The non-functional requirement of reducing at least 10% of the energy consumption could not be proved. It is not possible to know, if people will go on saving energy when meters, diagrams and ratings shown in the application are part of their everyday life, or if they will grow 'blind' and return to ever more lazy behavior.

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APPENDICES

Appendix A

Extended requirements

In this appendix an extended list of requirements is shown

A.1 Functional requirements

In the table A.1 the functional requirements are defined providing an ID, a rationale and a priority. The priority is based on the MoSCoW prioritization method: must, should, could and wont have.

A.2 Non-functional requirements

In the table A.2 we list the Non-Functional requirements, with a short explanation and the priority.

ID	**Requirement**	**Rationale**	**Priority**
Configuration			
FR1.1	The user could be able to configure notifications	In order to configure the reception of local or push notifications	Could
FR1.2	The user must be able to configure user/building profile	In order to calculate average energy consumption	Must
FR1.3	The user must be able to configure connection with server	In order to send and receive information from the server the connection must be configured	Must
FR1.4	The user must be able to Synchronize application with server	In order to update existent appliances and groups changes	Must
Server interaction			
FR2.1	GBPad must be able to receive real-time information of the appliances	In order to see the actually real-time energy consumption of appliances	Must
FR2.2	GBPad could be able to receive push notifications from the server	As a way to inform changes in the context the system could send push notifications to the application	Could
FR2.3	GBPad could be able to send tasks to the server	In order to make the server prepare the environment for the selected task	Could
FR2.4	GBPad Must be able to turn appliances ON/OFF	In order to control the state of the appliances	Must
Feedback generation			
FR3.1	GBPad could be able to generate dynamic tailored suggestions on energy consumption	In order to reduce the energy consumption; GBPad could be able to generate dynamic tailored suggestions	Could
FR3.2	GBPad could create goals and rewards to encourage users to reduce energy consumption	The application sets goals and rewards to motivate the user to reduce energy consumption	Could
Social interaction			
FR4.1	The user could be able to compare his energy consumption with the one of others	To motivate the reduction of energy consumption a social comparison is a good practice	Could
FR4.2	The user must be able to share his results in the social networks	As a simple way to compare energy consumption with others	Must
User interaction			
FR5.1	The user must be able to see real-time consumption of appliances	To be aware of the amount of energy each appliance consumes	Must
FR5.2	The user must be able to see historical energy consumption of appliances	To have a time based notion of how much energy each appliance consumes	Must
FR5.3	The user could be able to compare energy consumption between appliances	To improve the awareness on energy consumption; the user could be able to compare energy consumption of appliances	Could
FR5.4	The user could be able to receive tips from internet	To notify the user with environmental tips obtained from the internet	Could

Table A.1: Functional requirements

ID	Requirement	Priority
Commercial		
CNR01	To be effective the use of the application must reduce at least 10 percent of the energy consumption of the average user	Must
CNR02	The application must be easy to use	Must
CNR03	The user should be able to access the desired information in no more than three clicks	Must
Technical		
Scalability		
TNR01	The application must be able to work with multiple appliances	Must
Adaptability		
TNR02	The application should adapt to different environments, like offices, schools, houses, etc.	Should
TNR03	The display could adapt to the preferences of the user	Could
Interoperability		
TNR04	The application must communicate with the smart server to send and receive information	Must
Security		
TNR05	The access to the server could be restricted by the use of digital keys	Could
TNR06	Network communications could be encrypted	Could
Privacy		
TNR07	The privacy of the user must be preserved	Must
Evolution requirements		
EVR01	It could be possible for the application to interact with other servers	Could
EVR02	It must be possible for the application to interact in the future with other type of appliances and sensors	Must
EVR03	It must be possible for the application to get price change information	Must

Table A.2: Non-Functional requirements

Appendix B

Social features

In the Figure B.1 is shown the ranking of energy ratings. The value of different user is compared to have a notion of the consumption of others.

In the Figure B.2 is shown the challenge feature. Different users participate in a challenge to reduce energy consumption for a period of time.

Figure B.1: Ranking.

Figure B.2: Challenge.

Appendix C

Survey

The performed survey is shown in Figure C.1.

Previous Training ☐YES ☐NO

Context introduction

This research is related to Smart Environments (Smart Homes) in the framework of the GreenerBuildings project from the University of Groningen. It is specifically oriented to energy feedback, persuasion methods and mobile interfaces. The main goal of the application is create energy awareness to change people behaviour in order to reduce energy consumption with the use of a tablet interface.

Perform tasks

#	Tasks	# of clicks
1	Turn ON the Beamer	
2	Get daily consumption graph of the Common Area	
3	Share your energy rating in the social networks	

Get meaningful information

1- Finding In which group should I focus my saving efforts today?
Easy ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 Hard

2- Identifying the device with the highest consumption peak today?
Easy ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 Hard

Awareness questions

To what extent did you find the energy rating comparison useful?

Not useful ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 Very useful

How well do you think the application creates awareness on energy consumption?

Very poorly ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 Very well

Suggestions

Figure C.1: Survey.