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Mobile Application for Energy Management Assistance

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Chapter 1

Introduction

Throughout history, humans have used available energy sources in their daily lives. For a long time, this was mostly limited to either readily available sources like the wind, water, or muscle power, both human and animal.

This changed in the time from around 1760 to somewhere in between 1820 and 1840 with the Industrial Revolution. The most prominent factor for this change was the invention of the steam engine. The invention, and application on large scale, of the steam engine enabled mass production on a scale never seen before. This meant a great reduction in price for all goods that could be produced this way, making them affordable for a lot more people than before.

Continuing this trend, the discovery of electricity and the invention of the turbine as well as the internal combustion engine combined with the upcoming oil industry in the United States at the end of the 19th century again made a lot of changes possible. These are the major contributors to the availability of automobiles as well as the availability of electricity.

This relatively rapid change is what made our current life style possible. The use of electricity is so common in the western countries that it is taken almost for granted, which can be considered a good thing. Conserving food had been made easier with the use of machines powered by electricity for example, and without electricity a lot of the current medical procedures would either be really difficult, or impossible: an MRI scanner simply does not work without electricity. Using a similar example but more simple, the availability of bright light sources make medical exams a lot easier too.

The availability and use of this much energy in our daily lives is relatively new. The time-interval during which we use the energy sources that give us the energy and its benefits, starting at the end of the industrial revolution around 1830, compared to the time-interval from the height of the Roman Empire around roughly 150 AD until now, is only 10% of that larger time-interval. Yet already a concern that has been in the news lately is that fossil fuels will run out. While that still leaves nuclear energy and natural energy sources which can be used to generate electricity, it does show the need to think if we really do need to use all the energy we are currently using.

The need for energy and the limited availability of the natural resources providing that energy was a predicament that was raised to the attention of the public already in 1972 by the Club of Rome with its book 'Limits to Growth.'

This report took into account world population, industrialisation, pollution, food production and the depletion of natural resources. The Club of Rome used 1900 to 1970 to extrapolate these variables, with results that were quite dramatic: considering the reference scenario stayed the same, the natural resources would begin to become depleted in the beginning of the 21st century. The result of this would first be a reduction in the economic growth, followed by good food supplies becoming less available and a reduction of the world population.

While this may be considered a doom scenario, the limited availability of natural resources used to create usable energy is a fact. This means that, in order to make these resources last as long as possible, we need to conserve energy usage. To make this task easier, we can use the electronic devices to make this task easier. This thesis focuses on how the current electronic devices can help us conserve energy.

1.1 Energy Conservation

Energy conservation is a very general topic and can be approached in different ways. While they all focus on the same idea, making something or someone use less energy, the methods differ. One way to conserve energy is to simply buy new appliances that use less energy, for example a low-energy light-bulb instead of the traditional light-bulb. Another way is to identify which appliances use energy at times when they are not really needed or work harder than is needed at the time, and turn them off at those times. These two methods do not exclude each other of course, because it is perfectly possible to first buy a low-energy light-bulb instead of a normal light bulb and then turn it off when nobody is in the room.

All methods of energy conservation have some thing in common though: they all suppose that the consumer who should apply them is motivated to do so. To decide to conserve energy, one must first become aware of how much energy is used and, more importantly, what proportion of that energy is used by each of the appliances. The energy consumer needs to be able to identify where in his house or office there is more energy used than the amount that is really needed. While it is important to know how much energy a household or office is using as a whole, this information is not needed to be able to pinpoint the appliances that use a lot of energy or use energy at times when it is not really needed.

Although electricity is not the only form of energy used by appliances, it is the most prevalent in a household. Natural gas is also used to heat households for example, but even though this is used a lot, it is not too difficult to pinpoint where it is used a lot and how one can conserve on it. Simply turning down the temperature in a house when one is not there, and heating the house to only 19 degrees instead of 20 degrees celcius for example are good ways to conserve energy.

Electricity, however, is used by a lot more appliances, so it can get more confusing to identify which appliances are using electricity at what times: for example, just how much energy is the tv using when it is on stand by?

1.2 The Human Factor

A first step in the process of energy conservation is to make people want to conserve energy. When someone really does not care about energy conservation nothing gets done, however easy it might be. This means that regardless of method, people must be motivated to conserve energy.

There are several reasons for energy conservation, but two popular reasons are environmental concern and the cost of energy.

An example of the environmental concern is global climate change due to carbon dioxide emissions. Climate change affects many regions. In Canada, the negative side of climate change is already noticeable and will increase climate-related risk in communities, infrastructure and exosystems [21].

Another environmental related concern is that fossil fuels are limited. While there are alternatives available, these are either not yet suited to completely fulfil our energy consumption need, like solar and wind energy, or in the case of nuclear energy have issues with waste disposal. The more energy we conserve, the longer we can last with the remaining fossil fuel reserves.

The costs of energy consumption is a much simpler reason, energy costs money. The more energy is used, the higher the bill. This means that conserving energy results in a lower energy bill.

An important element in the motivation of people to conserve energy is the presentation of the amount of energy that is used: it should be in a form that is understood by the user. Kilowatt hour (kWh) is a good unit for billing purposes to show the amount of energy that is used, but as a unit of energy it is very abstract. This makes kWh as a unit generally less suitable to show people the amount of energy they used because it is hard for them to interpret. In order to allow people to put it into perspective, the kWh unit first needs to be converted to a unit that is more tangible. Several examples would be:

- distance travelled by a vehicle (car or plane for example), possibly presented as part of a reference distance;
- size of a solar panel needed to produce the amount of energy used, which could be presented as number of unit solar panels replacing the kWh or in size of the panel in square meters;
- how long you can heat a sauna with the amount of energy used;
- how much bathtubs you can heat to a comfortable temperature with the amount of energy used;
- how often an elevator could be used to travel a given number of floors with the amount of energy used;

- how much marathons a marathon runner could run on the same amount of energy.

While all of these examples are less abstract, some are not practical for another reason. The example used need to be more understandable and therefore less abstract, but it also needs to represent a more or less constant amount of energy to be used as a unit. The distance travelled by car, for example, heavily depends on how much energy the vehicle needs to travel a standard distance, which changes over time since newer cars are generally more efficient. This constrains the choice of representation of the amount of energy that we should use since we do want our app to be robust to changes in the near future in this respect.

With this in mind, we can narrow our list of examples down to the following list:

- how long you can heat a sauna with the amount of energy used;
- how much bathtubs you can heat to a comfortable temperature with the amount of energy used;
- how often an elevator could be used to travel a given number of floors with the amount of energy used;
- how much marathons a marathon runner could run on the same amount of energy.

These examples share two important aspects: In the first place, they are all understood to cost a lot of energy. While you can not expect everybody, or even hardly anybody, to know exactly how much energy the average runner needs to run a marathon, as a unit of energy it conveys the amount of energy in a way that is easier grasped by most people, even if it is less precise.

Secondly, these units do not change very fast. A bathtub two years from now and a bathtub right now will cost roughly the same amount of energy to heat, provided they are of similar sizes of course.

A different approach would be not to concentrate on the energy used, but on the pollution that is produced by the energy consumption. This then could be expressed in a more understandable unit than the number of how many of what kind of particles is emitted. A good example is 'Leafully' (<http://leafully.com/>). This is a web-based utility which compares the pollution generated when producing the amount of energy used with the number of trees needed to offset the pollution that results from this production. By using this kind of representation, the user can better imagine the magnitude of his energy usage and the impact that energy conservation might have.

In order to see how one relates the amount of energy used to the number of trees needed to offset the pollution caused by the generation, one must know that it is possible to relate an amount of emission of greenhouse gasses to the number of trees needed to counterbalance this amount of emitted greenhouse gasses. This can be done by translating the amount of emitted gasses to 'teragrams of carbon dioxide equivalent' or Tg CO₂- equivalent (Tg = 1 million metric tons). As is well known CO₂ can be neutralized by trees. It is estimated that a single tree can absorb CO₂ at a rate of 48 lb. per year (48 lb. equals 21.8 kg). These facts can be found on the website of the Arbor Environmental

Alliance. This equivalence opens the possibility to relate the amount of energy used to a compensating number of trees. As we will see, this idea is used to give users an easily understood representation of the numbers of trees that would be equivalent to the amount of energy they use or to the amount they saved.

Comparing this approach to the previously mentioned aspects we conclude that this also is an approach that fits in that view.

According to the first aspect, the amount of trees needed to offset the emissions from the generation of energy is a unit of measurement that is understandable to everybody. It is not hard to understand that if only 10 trees are needed to offset the emissions generated to produce your energy is better than if 20 trees are needed.

According to the other aspect, the requirement that the unit of measurement needs to be relatively constant is also fulfilled. The number of trees that will be needed to offset a given amount of emissions is an indicator of the energy used that will not change over time.

1.2.1 Why not use money as a quantification metric?

In this section, money as a quantification metric for energy usage was not even mentioned, or considered as an option. This may be confusing at first, since it is a commodity made for trading and comparing value and, by proxy, amount. Studies have shown however, that not only is showing monetary value not productive to get the user to conserve energy, it can even be counter productive.

In a book by Michael Sandel, *What Money Can't Buy: The Moral Limits of Markets*, Sandel describes a phenomenon that is not exactly the same, but translates to this case. He also describes this in a video presentation on "Michael Sandel: What Money Can't Buy: The Moral Limits of Markets" at the ChicagoIdeasWeek channel.

He describes the case where the residents of a village high in the mountains in Switzerland were asked if they would allow the storage of nuclear waste near their village. Before this was allowed, a referendum needed to be passed. Of all the people asked, 51% said they would allow this.

Now, to get more people to allow the storage, a yearly sum that translates to about 8000 dollars a year was offered to each of the inhabitants. This made the percentage drop to 25%. At first this sounds like a paradox, usually, using money as an incentive produces a greater willingness, not a lesser willingness.

What happened was that offering money changed the nature of the request. While it used to be a civic and philanthropic endeavor, now was changed to a financial deal not dissimilar to a kind of job. In this case, and this is something that translates very well to energy conservation, turning it into a market transaction made it just another market transaction.

In energy conservation, by telling people how much money they saved, something similar is done. [10] Something where the user knows he is saving the

environment with his actions, is changed into just another way to have more money at the end of the month.

1.3 Research Question

Energy conservation is the result of the effort to reduce energy consumption. This reduction can be done in two ways:

- acquire appliances with more efficient energy use
- decrease energy usage from existing energy using devices

The first option, to acquire appliances with more efficient energy use than the ones you have in use at the moment, is a one time investment with no further effort required. The second one is the focus of this project. The goal of the project is to provide the user with a tool that guides him toward more efficient energy usage. Therefore, the first and most important question that must be answered is:

1. In a computer application to aid the user with energy conservation, what is a suitable way to present the energy usage data in order to stimulate households and small offices to conserve energy?

Now, some literature research will need to be done before doing testing this question. This literature research is covered in section 2.2.

Research question 1 assumes that a computer application is actually an effective method to aid the user with energy conservation. While it is something that has to be looked into as well, it also is a topic that has been extensively researched before and can be found in literature, this is covered in section 2.2.1 as well.

Provided that a computer application is an effective way to aid users with energy conservation, users still need to want to use the application. This can be stimulated by making the application as user-friendly as possible as well as by providing additional features that are useful to the user.

These considerations lead us to the following sub-questions:

2. What is a suitable platform to create the application, present the energy-usage data and stimulate its users to save energy?
3. What are useful features related to energy conservation to add to the application in order to tempt users to use the application?
4. People need to want to use the application. An important aspect of that is usability: if the application is easy and intuitive to use, people are more likely to keep using it to conserve energy. How can we make sure the application has a high usability?

With these questions answered there is a good basis to create the application. The choice made in answer to question 2 will strongly define the limitations on the application. Therefore this question must be answered before answering the questions 3 and 4.

When this question is answered, questions 3 and 4 will be limited regarding the possibilities that are on the chosen platform. On a desktop computer for example, users can not use the application anywhere at any time, while the usability requirements for a desktop computer application are different from the usability requirements for an application for a smartphone or tablet.

The result of all these research questions being answered, is a better understanding of how energy usage data should be presented to get the user to conserve energy.

Section 2.2 will go deeper into the problem that the application needs to address. Section 2.2.1 and 2.2.2 sketch the general research and conclusions regarding energy consumption interventions and the influences on user's energy consumption. Chapter 3 defines the requirements and key features for an application to aid in energy consumption conservation, keeping in mind the conclusions and research described in section 2.2.1 and 2.2.2.

Chapter 3 also features a section on user interactions. In this section important requirements, mostly non-functional, regarding the way the application handles user interaction. With these requirements, chapter 4 will provide an overview of the use cases for the application, followed by an explanation of the implementation in chapter 5. The test done with the application to answer the research question are described in chapter 6.

Chapter 2

State of the Art

To aid the user with energy conservation providing general information to him about his energy usage is a good start. But ideally, the user will receive more specific information regarding which of his appliances uses how much energy. This allows the user to gain more insight into the contribution of each of his appliances to the total of his energy consumption. Information regarding the total energy consumption per location of the home or office is also an useful insight.

In addition to this kind of useful information the user should also be given related control features. Powering the user with the possibility to remotely turn appliances on or off makes it more likely that the user actually turns off appliances that use energy when it is not needed.

Since there are already some applications out there enabling the user to both view how much energy is used and remotely switch appliances on and off, this chapter will first focus on researching the functionality offered by these existing applications.

In this section we look at a selection of the currently available energy management applications. This will give both an idea of what currently are the generally offered features as well as maybe suggestions for new features that might be added to our energy management application.

Additionally, we need to know how to motivate the user to conserve energy. Since there is already some really good research available, a literature review will suffice. This question is answered in section 2.2.

2.1 Existing Energy Management Applications

2.1.1 Nuon E-manager

N.V. Nuon Energy [3] is a utility company providing electricity, gas, and heat in the Netherlands, Belgium, and the United Kingdom. Recently they developed

an Energy Manager, Nuon E-manager, that became available on the Dutch market. Table 2.1 shows an image with the specifications for the three packages Nuon offers¹.

	Insight-package	OnOff-package	E-thermostat
Personal E-manager environment	yes	yes	yes
For PC, tablet and smartphone	yes	yes	yes
Real-time electricity and gas usage insight	yes	-	-
Set Saving goals	yes	-	-
Compare with neighborhood and periods	yes	-	-
Usage per appliance	-	yes	-
Remote control lamps and appliances	-	yes	-
Schedule lamps and appliances	-	yes	-
Remote control heating	-	-	yes
Weekly scheduling	-	-	yes
Wireless thermostat, placable anywhere	-	-	yes
Display temperature outside	yes	yes	yes

Table 2.1: Nuon E-manager specifications

The third package, the E-thermostat, focuses more on gas usage than on electricity usage. This is also energy usage monitoring, but outside the scope of this project, so only the first two packages will be considered. These two packages combined offer the following functionality:

- Show current total energy usage
- Show current energy usage per appliance
- Set saving goals
- Remotely switch appliances on/off
- Schedule appliances to switch on/off
- Compare with neighborhood

In order to view the total energy usage the Insight-package contains a meter that measures the total energy usage of the household. The OnOff-package contains several plugs that contain meters to measure energy usage per appliance. These are both one-time investments.

Additionally, to use the packages, a monthly subscription fee of €2.95 is required. Considering that the most expensive cost at Nuon for electricity per kWh is €0.2392 including energy taxes (in the Netherlands, at the time of writing), this means that to compensate for this monthly fee, a little over 12.33 kWh a month would need to be saved. The average month is $4\frac{1}{3}$ weeks, or $30\frac{1}{3}$ days. This amounts to 0.4 kWh a day, so the first 0.4 kWh a day you save in reduced energy usage, although good for the environment, does not result in a lower energy bill for the user.

¹taken from <http://www.nuon.nl/energie-besparen/e-manager/>

2.1.2 Essent E-inzicht

Essent NV is an energy company based in 's-Hertogenbosch, the Netherlands, and currently one of the larger energy company in the Netherlands. They offer an energy management system called E-inzicht (this translates to E-insight). Essent does not offer a table with an easy overview of the functionality as Nuon does (see figure 2.1), but on their website they do describe the functionality (<http://www.essent.nl/mijn-e/e-inzicht/>). Like Nuon, they also offer a separate package for a remotely controllable thermostat. E-inzicht offers the following functionalities to the users:

- show current total energy usage;
- show current energy usage per appliance;
- offer energy saving advice;
- remotely switch appliances on/off;
- schedule appliances to switch on/off.

The application is for use on a smartphone or tablet. This application also requires a monthly subscription fee, this is €3.95. On their website they list a price for electricity per kWh, which is €0.2208 including energy taxes (in the Netherlands, at the time of writing). This means the first 17.89 kWh a month that is saved is compensated for with the monthly subscription fee. This is 0.59 kWh a day.

2.1.3 Plugwise

The Plugwise system is not offered by an energy company. Like the other systems discussed, it measures appliance energy usage with a device you put between the socket and the plug of an appliance. They have an Android application, which offers the following functionalities:

- show current total energy usage;
- show current energy usage per appliance;
- compare with previous year and extrapolate current year's usage;
- remotely switch appliances on/off;
- schedule appliances to switch on/off.

The application can be used on pc, tablet or smartphone. With a subscription, it is possible to use the application when not at home.

Both providing the user with general energy consumption information and giving the user control to turn appliances off and on are two features that are very well supported by an energy management system that places adapters between the power socket and plug. Since the Plugwise system is one such system [4], this is an ideal basis for an energy consumption conservation tool.

2.1.4 Summary

All of the systems have roughly the same capabilities. You can view your energy usage, total and per device as well as switch devices on or off and schedule them to switch on or off later. With this in mind, the Plugwise system is not bound to an energy company, so this would seem to be an ideal system to base our application on.

They already have an application, but it still is useful to make an application that offers slightly different functionalities. One functionality that did not seem to come back in any of the applications looked at is the ability to view energy usage not only per appliance or the building as a whole, but also per room. This makes it easier to identify what parts of the building are using a lot of energy and when they do so. From this kind of overview, one can more easily determine the locations in the building where energy conservation will have the most effect.

Another reason to make a new application of this kind is to aid in researching what the user may look for in an application like this. With a version with the most basic functionalities available a questionnaire can be done to gain insight in the public's opinion on what functionalities would be useful in an application like this.

2.2 How to Influence Energy Consumption?

Extensive research has been done on how people can be influenced to consume less energy. Before an application to aid consumers with energy conservation is developed, it must be researched if applications of the kind are an effective means to aid energy conservation. Provided that computer applications are possibly an effective aid, then it still must be researched what requirements are important for such an application.

2.2.1 Energy Conservation Intervention Effectiveness

The concept intervention used in this section refers to the psychological intervention. A psychological intervention is an action supposed to change someone's emotional state, alter his behaviour or feelings.

This section will first discuss the emission of greenhouse gasses and the sectors that emit them. When it is established what sectors are a good target for energy management intervention, we will look at how this can be done and at two important type of interventions, namely behavioural interventions and consequence interventions.

In a review by Abrahamse et al. [5] 'the effectiveness of interventions aiming to encourage households to reduce energy consumption' was evaluated. In this review 38 studies related to household energy conservation are compared. In this section parts of the review relevant to our research questions are discussed. It is supposed that the reader of this text will not be pleased to read over and again

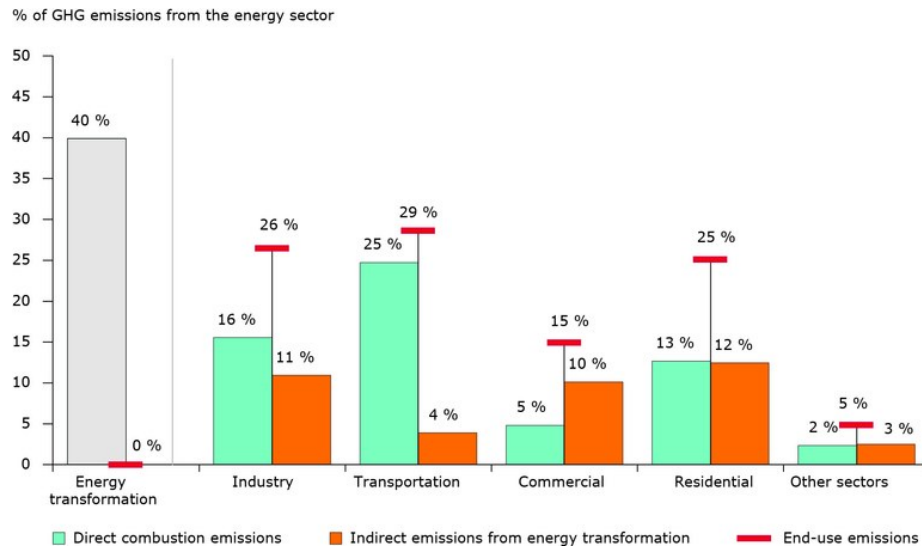


Figure 2.1: GHG emission by sector in the EU in 2010; Source: EEA, 2012

a reference to this review. Because of this, this review is not continually cited. But it should be mentioned that descriptions of publications in this section refer to studies that were included in Abrahamse et al. [5].

Households are a major contributor to the emission of greenhouse gases. In 2005 contributions to total energy use ranges between 10% and 20% in Western European households and it keeps rising. But this contribution expressed as a percentage of the total emission should not be used as an indication of the amount of emission of the households, of course. It is possible to have a closer look on the emission of greenhouse gases by households in the EU directly. In 2012 The European Environment Agency (EEA) published its 'End-user GHG emissions from energy: Reallocation of emissions from energy industries to end users 2005-2010', referred to as 'Technical report No 18/2012'. In this report, 'end-use greenhouse gas emissions from energy use in EU 27² in 2010' is shown (see figure 2.1). A full description is given in the report, but in the context of our study the interesting point to note is that household contribution to the emission of greenhouse gases (GHG) in the EU was 25% of the total emission of GHG in 2010.

The EEA report mentioned above also summarizes the emission of GHG in the EU over the years 2005-2010 expressed in Tg CO₂-equivalent (see figure 2.2). Now figure 2.1 gives us the share of the sectors as a percentages of the total emission in 2010, whereas figure 2.2 shows us the emission by sector as an amount by year, expressed in Tg CO₂-equivalent. We should realize that the fraction of the emission of the households in the total of GHG emission is not only dependent on the amount of emission by those households, but of course also dependent on the emission of the other sectors. So this figure tells us that the households were not able to decline to the extent that some of

²EU-27 stands for the EU with the 27 countries that are a member of the EU since January 1st, 2007.

Total (direct + indirect) GHG emissions by sector, 2005–2010

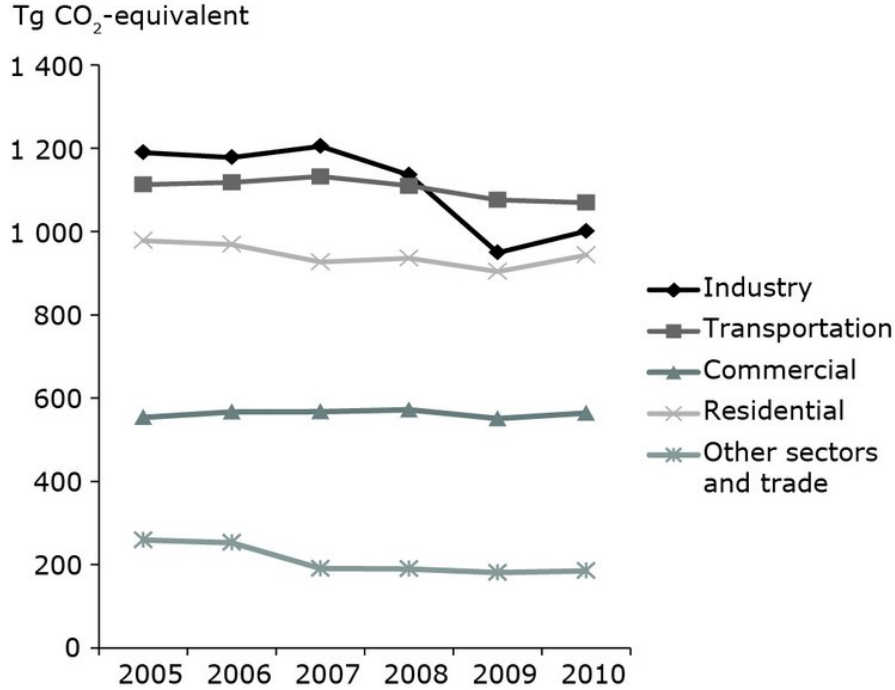


Figure 2.2: GHG emission by sector in the EU in 2010 (Tg CO₂-equivalent); Source: EEA, 2012

the other sectors did, especially the industry. *It seems that it is more difficult to motivate individuals to energy conservation behavior, than it is to get the industrial sector at a lower level of energy use due to the organized structure of that sector.* In considering how to construct an application to motivate subject behavior, psychological considerations must therefore be part of the ground on which requirements should be based.

On the macro-level, TEDIC factors (Technological developments, Economic growth, Demographic factors, Institutional factors and Cultural developments) contribute to this growth in energy usage of households [15]. The TEDIC factors in turn shape the micro (individual) level. When trying to reduce households' energy consumption patterns, both the macro- and the micro-level need to be considered [14]. Behavioural interventions can either influence the behaviour of the individual, or change the context in which the individual makes decisions. Interventions regarding social and environmental psychology primarily focus on voluntary behavioural change, rather than changing the context.

The behaviour regarding household energy conservation can be categorized into two categories: efficiency and curtailment behaviours [13]. This distinction is very similar to the distinction presented before in section 1.3. Efficiency behaviours are one-shot, an example would be replacing the shower head with one that uses less water. Curtailment behaviours are behaviours that must be

repeated to reduce energy use, for example washing at lower temperatures when possible. Studies reviewed by [5] show that efficiency behaviours have a higher potential of energy saving. With efficiency behaviours however, there is the risk of the so-called rebound effect [9]. In that case people use the devices they replaced with more energy-efficient ones more often, just because they are more efficient.

Interventions to promote energy conservation among households have had a varying degree of success. Antecedent interventions commitment and goal setting seem to be successful at changing energy use, even more so when combined with other interventions [7]. Overall, only providing information is not a very successful strategy [19]. Information about energy problems as conveyed by mass media does not result in an increase of knowledge of conservation behaviours in general, but there is not much known about its actual effect on energy saving [24]. Providing households with tailored information through home energy audits, on the other hand, was successful at achieving energy conservation [25].

These effects also apply to consequence interventions. An intervention that has proven to be successful for energy conservation is providing households with feedback [8].

This means that giving the user accurate feedback about his energy consumption does help him to conserve energy. Additionally, regarding consequence interventions, in a study in which one group received computerized feedback and a second group received feedback on leaflets computerized feedback appeared to be relatively successful. The number of conservers in the group with computerized feedback was significantly higher than the number of nonconservers [11].

The conclusion from these results seems to be that an application giving accurate up-to-date feedback regarding the users' energy consumption is an effective way to aid them with their energy conservation.

2.2.2 Energy Consumption Awareness

An important question to answer is if awareness of the energy consumption changes the users' energy consumption. Conventionally, the way ICT is used to conserve energy is to make appliances run more energy efficiently. An example of this is a computer going into stand-by mode when not used for a while.

“While automation and energy-optimized systems will doubtless be essential for achieving savings, the adoption of these systems and user behaviour in general will have a major influence on the demand for energy. ICT can play an important role here because it can assist individuals in making more informed decisions and reward socially desirable behaviour in daily life.” [23] There are many cases in which the user of electronic devices, despite all good intentions about conserving energy, still uses more energy than they actually need. These needless energy sinks can be mainly attributed to a lack of transparency in energy consumption [12].

Friedemann Mattern, Thorsten Staake and Markus Weiss compiled a set of measures which can be taken to induce behavioural change. “These measures can be categorized into two groups, a group of measures supporting rational behavior (informational support) and a group of measures leveraging somewhat irrational motivators (intrinsic motivation and social positioning).” [23]

Informational Support

For most people, presenting energy consumption in the form of a mere value is meaningless [22]. Using analogies to present the user with an image portraying the amount of energy needed for a given task helps. The used image must give a sense of largeness through to get users to conserve energy [23].

Another way is to compare the energy consumption of the user with other users' energy consumption. “Care must be taken when choosing average values – showing individuals that they perform better than average – regularly leads to a reduction in effort and ultimately to higher energy demand. The same effect occurs when recipients are confronted with average values that are much better than their own performance, as they often perceive the goal as being too difficult to achieve and therefore not worth pursuing.” [23] This means that while presenting the information in an understandable way regarding energy use helps the user conserve energy, analogies must be chosen with care.

Intrinsic Motivation and Social Positioning

Another problem is the lack of personal motivation regarding their engagement in energy conservation. To motivate people regarding engagement in energy consumption conservation goal setting, the use of virtual budgets, and social comparisons can be used.

Goal setting theory states that goals motivate someone to give more effort and show increased persistence. Attainability and the belief that they are capable

of achieving the goal are important factors. If someone has set a goal himself, he is more likely to attain that goal [20].

Energy budgets also have shown to be a likely method of increasing intrinsic motivation. A British pilot project using pre-paid electricity tariffs with a simple way to view the current balance positively influenced saving efforts [23].

Social comparison is another method of getting people engaged in energy conservation. This is even more effective when the selected peer is comparable to the recipient of the information. "They are especially effective when the selected peer is similar to the recipient of the information, lives in close proximity (e.g., the same village), has the same profession, or is a member of a familiar or admired group [23]." This can be achieved by introducing a competitive element in the energy conservation.

2.2.3 Determinants of Consumer Behaviour

In 2010 Accenture, a multinational management consulting, technology services and outsourcing company headquartered in Dublin, started a multiyear global research regarding understanding of consumers' attitudes, opinions and preferences toward energy efficiency, energy management and value-added products and services. Each year it published a report, with the third and latest publication being published in 2012, titled Actionable Insights for the New Energy Consumer [17]. This report contains the results of a survey with a sample of 10158 respondents in 19 countries.

Their first study, Understanding Consumer Preferences in Energy Efficiency, was completed in 2010. It focused on "providing insights into consumer behaviours, preferences and attitudes toward energy efficiency, awareness, readiness and willingness to take action" [17]. Following this research was the study completed in 2011, Revealing the Values of the New Energy Consumer. This study focused on "consumer preferences, opinions and priorities related to beyond-the-meter products and services offered by utilities or other emerging providers" [17].

The third phase was aimed at developing actionable insights and tactical implications for providers. Keeping in mind that smart technology is just one aspect of the trends that create opportunities and challenges for providers, Accenture had approached the problem from multiple angles to address consumer preferences and behaviours. Especially interesting with reference to the Energy Management app are questions they asked like "What energy and nonenergy-related products and services are consumers interested in receiving from their providers?", "How can utilities differentiate themselves to more effectively acquire and retain consumers or increase participation in specific programs?" and "What are the preferences and behaviours of the next generation of energy consumers?"

Nonenergy-related Products and Services

Consumers currently receiving electricity from their energy provider were asked if they would be interested in receiving additional products and services from their energy provider. From this group a significant amount of consumers expressed interest: 57% was interested in making simple improvements to their home in order to save electricity, 55% was interested in home energy audits/consultations to identify energy saving opportunities and 52% showed interest in home automation devices [17].

These services can all three be aided by energy management software. Both in the case of making simple improvements to save energy and in the case of home energy audits/consultations, the energy management system does not need to be permanently owned by the customers. Instead it can be part of a consultation program that identifies points of improvement regarding energy saving.

With respect to the home automation devices the relation to the energy management system is more direct: the system allows to remotely switch appliances on or off and to schedule them to switch on or off at a later time.

How can utilities differentiate themselves

A familiar method to determine the value that people attach to a product or service is to ask what they would be willing to pay for it. If someone is willing to pay for a service or product, it means that he is interested. It is well known from decision theory that the method is more complicated than it seems to be at first sight. Interpersonal comparisons are tricky. A rich man might be prepared to pay twice the amount of money that a poor man would pay and still be less than half as interested to obtain the product or service, simply because the scarcity of a good, in this case money, to a great extent determines its value. Another problem with this method is that people differ according to their attitude toward uncertainty, but since the risks involved in this kind of decisions are small, this argument is of less importance in our discussion. In the case of energy related services, 54% of the people questioned were interested in premium services or tools that aid them regarding electricity usage. Of all the people questioned, 5% was certainly willing to pay for premium services including an energy management product or service and 26% was most likely willing to pay. It is worth noting that "consumers in emerging countries such as Brazil, China, South Africa and South Korea are most willing to pay for the premium service, with 50 percent or more of consumers reporting they are "certainly" or "probably" willing to pay a premium. That result is significantly above the average and a marked contrast to consumers in Sweden, Belgium and the Netherlands, which trail the pack in their willingness to pay for a premium electricity service at 17 percent each." [17]

Again, an energy management system fits the bill here: it shows energy usage per appliance and can help reduce the energy usage by making it easier to only turn them on when needed. It is key here though that anyone using the tool must be able to use it with minimal effort though, People need to want to use

it, and the lower the effort needed to use it, the higher the chance that the users will keep using it.

Next generation energy consumers

Social media like twitter and facebook have already been around for a while, but still an increasingly amount of people use them and the variety of their uses keeps growing. For energy conservation these media should not be an underestimated tool. Accenture asked people the question “Have you used or do you plan to use social media to discuss or learn about energy-related issues or to interact with your electricity provider,” and 36% of the respondents affirmed that they either already have used social media for this purpose or plan to use it for this purpose in the next 12 months. Even though this is not a direct answer to the question ‘if they want to use social media for energy conservation related matters’, it is very close to it, and does show that there is a real interest in this functionality.

2.3 Social Impact of Changing Energy Provision

Until recently, the energy sector has traditionally been a closed market, with only one large energy company producing energy and owning the infrastructure. This monopolistic structure of the market has changed recently, with more and more smaller players producing energy and with a split between producer and owner of the infrastructure. With solar panels and wind energy generators becoming more widely available, there has been an increasing trend to the emergence of the energy producing consumer as well. Organizations like ‘Grunneger Power’ [1] have started to emerge, where the members work together in a collaboration to produce as much green energy as they consume energy without profit motive.

Someone who both consumes and produces energy is called a prosumer. This trend matches well with the smart meter and energy management approach. When you not only consume energy but also produce it, it is important to keep track of both your usage and production. Without having this information real time, it is very difficult for a prosumer to keep track of his current state in the energy market. Knowing the information real-time removes surprises at the end of a given time-period when energy production was lower than expected.

Knowing the amount of energy produced is just as important for organisations of prosumers collaboration as for the prosumer himself, however. To be able to run an energy provider service, it is important to know how much energy is used as well as produced. For these reasons, smart metering is an important aspect in the new trend of small players emerging on the energy market. In order to assist users with managing their own energy usage, an application to monitor their energy usage can be very useful for prosumers as well.

Chapter 3

Requirements for an Energy Management Tool

To create an application for a mobile device aiding with energy conservation it is important to first know the reasons why one would want to conserve energy. In the previous chapters we have taken a look at these reasons. In this chapter, we are going to look at one of the more important requirements resulting from the research question, an important one being usability.

3.1 Requirements resulting from the research question

From the research question alone, important requirements can already be elicited. To repeat, the following were the main and sub research questions.

1. In a computer application to aid the user with energy conservation, what is a suitable way to present the energy usage data in order to stimulate households and small offices to conserve energy?
2. What is a suitable platform to create an application for energy conservation?
3. What are additional useful features to add to an application for energy conservation that will tempt users to use the application?
4. What are important aspects to make an application for energy conservation have a high usability?

The target for this project is the energy consumption of households and small offices. This means that the application must be wanted to be used by this target audience. To this end, the application must be accessible, easy to use and useful. Especially with households as target audience, because this target audience includes people who are not used to using computers or smartphones.

Additionally, the application must have additional value, besides being a glorified energy meter. To achieve this, we have chosen to not just aid in monitoring energy usage, but actively aid in lowering energy usage by making it easy to turn devices on and off remotely, as well as schedule them, using a mobile device. This also adds a convenience factor to using the application, which will make it easier for people to want to use it.

Not unimportant is also the ability to compare energy usage to past energy usage. This is needed to allow the user to gain insight in his efforts to conserve energy.

This means the application will now have the following requirements:

1. Provide insight in energy usage in an easy to understand manner
2. Allow the user to gain insight in energy usage compared to past usage
3. Remotely turn devices on
4. Remotely turn devices off
5. Schedule devices to turn on at a specified date remotely
6. Schedule devices to turn off at a specified date remotely
7. Easy to navigate through the list of appliances to find the appliance the user is looking for
8. The user must not need a user manual to understand the application.

Additionally to these functional requirements, usability is a very important aspect of the application. To realize all these points, we have chosen the Plugwise system as a base, and will provide an application for mobile devices that uses the Controller part of a solution described in *Optimizing Energy Costs for Offices Connected to the Smart Grid* [16] as server. This server in turn uses the Plugwise system to both provide more information regarding current and past energy usage as well as turn devices on and off and schedule devices.

3.1.1 Usability

Usability is an important quality attribute for the application. Before we study how this influences the design however, we will study the quality attribute itself. Important questions that need to be studied are:

- How is the concept defined in literature?
- What are the closely related quality attributes?
- What are the different aspects of usability?

Finally, when these questions are answered, the impact of usability on the requirements and design of the application can be studied.

3.1.2 Usability as defined in literature

While it is not a software engineering resource, looking at the definition of usability in the Oxford English Dictionary (OED) is still useful, it still gives us the core idea of the usability quality attribute. It gives a very general impression of the meaning of the term. In the OED, usable is defined as follows:

adjective
able or fit to be used:
usable information

The application must be fit to be used. While this is still a very wide definition, it already gives a few general ideas:

- The application must be responsive and if it is not, while loading for example, always give feedback why
- The user must not be confronted with too many options at once
- The user must not have to search for the option he wants

These ideas are supported when looking at a definition for usability in a source more related to software engineering, the IEEE Standard Glossary of Software Engineering Terminology [2]:

The ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component.

While still a very general definition, it is phrased a lot more toward software applications. This definition also supports the points inspired by the definition in the OED. From these ideas, three quality attributes that contribute to usability can be derived:

- **Reliability:** when the application becomes unresponsive, for any reason, the user must be given feedback why. Ideally, prevent the application becoming unresponsive altogether.
- **Learnability:** the application should be easy to learn to use. Each part of the application must have a clear purpose and only work to fulfil that purpose, any additional options will only be confusing and should be in a separate part of the application.
- **Consistency:** once users have gotten to know the application, they should be able to easily find the option they need.

3.1.3 Reliability, Learnability and Consistency

As discussed in the previous section, reliability, learnability and consistency are closely related with usability. This means that in order to better understand how a system can fulfil the usability quality attribute, it is useful to take a look at what each of these quality attributes mean.

Each of these aspects also has an impact on the design of the application. This will be discussed in the chapter discussing the realization of the application.

Reliability

Reliability is defined by the IEEE Standard Glossary of Software Engineering Terminology [2] as follows:

The ability of a system or component to perform its required functions under stated conditions for a specified period of time.

This means that the system should never become unresponsive as long as it is supposed to function. For the kind of application we are concerned with in this study it could be added as a requirement that if the user needs to wait for the system to perform certain tasks, feedback should be given to inform the user about the state of the application.

Learnability

According to A. Alvaro et al. [6], learnability is described in the following way:

Time and effort to (use, configure, admin and expertise) the component.

The application as a whole can be viewed as the component with this description. In this case, the lower the time and effort needed to learn to use the application, the better.

Consistency

Consistency is defined by the IEEE Standard Glossary of Software Engineering Terminology [2] as:

The degree of uniformity, standardization, and freedom from contradiction among the documents or parts of a system or component.

This means at least that throughout all of the application, similar tasks must be handled in a similar way. This makes it easier for the user to interact with the application.

3.1.4 Impact of Usability

Usability is an important quality attribute of the application. There are several aspects of usability that will effect the design, each of which needs to be taken into account during the design and development.

One of the most important aspects is **responsiveness**, as part of the reliability requirement discussed earlier. When a user has given input, the application

should give feedback right away. Either the result of the given input, or at least show the user that it is busy processing the input. When the application is busy with an operation, the user should be prompted with a visual indication that the application is busy.

Visually the design should also be **attractive**. This does not mean it should be a work of art, but the application should be visually pleasant to use. This is, however, a highly subjective criterion and therefore hard to measure. Android, however, has some standardized GUI themes available, making the user interface and its components at least recognizable for the user.

The user interface must be **intuitive**. This means that the user should not need a manual to find out about the functionality he looks for, or to understand what each of the parts of the application does. In order to make sure this is the case, a test will need to be done during the design phase that asks potential users to group the functionalities by how they expect them to be grouped together. During the test phase another test is needed to find out how long it takes a user to find a specific functionality.

3.1.5 Measuring Usability

Before usability can be tested, a suitable measuring method must be defined. The basis of this project is an application for a mobile device. This is an ideal platform for applications that a user can quickly use in between other activities. For this reason the main focus will be on efficiency testing.

One of the commonly used methods for efficiency testing is use patterns, or measuring the number of times the user makes use of the interface [18]. The reasoning behind this method of measuring is that the usage of the interface indicates the amount of resources the user spends when performing a task.

A commonly used use pattern in web sites is the number of clicks it takes the user to perform a certain task. This method of measuring is also suitable for mobile applications: most input is limited to clicking on a button, like a link in a website, that will take the user to another screen. The actual amount of text the user needs to type is very limited.

It follows that during the testing the number of clicks the users takes to perform certain tasks will be recorded. Different tasks however will require a different number of minimal clicks needed to perform the task. For this reason, the number of clicks made for a specific task will be measured as the number of clicks, normalized to the minimal number of clicks required. After this normalization of the number of clicks for all tasks the test users are presented with the tasks are directly comparable according to the difficulty to perform them.

3.1.6 Usability Testing

To test the usability of the application subjects are given a questionnaire. They are given tasks to measure the usability. There are two aspects of the application that need to be tested:

1. Given a specific task, how long does it take the user to perform this task?
2. Given a specific question about energy usage, how long does it take the user to get the relevant information?

In both cases time is measured by the amount of clicks it takes the user to perform the task.

The answer to the first question measures how effectively the application guides the user through the user interface. Each task has a minimum number of clicks required to perform it. If the results of the survey show that users use significantly more clicks than this minimum number of clicks, then this part of the application needs to be improved to provide a better guidance to the user.

The second task concerns the presentation of information and the ease with which the user can find the information he needs. Like with the first task the number of clicks to get to the relevant screen that shows the information is measured.

In addition, the test users rate how clear the information is presented, as well as how useful the presented information is to them. Based on these ratings the presentation may need to be improved.

Chapter 4

Use Cases

Before the actual implementation, it is important to know what the use cases that we want to implement are. The use cases described here are the most important interactions of the user with the application. The use cases in figure 4.1 are resulting from the requirements in section 3.1.

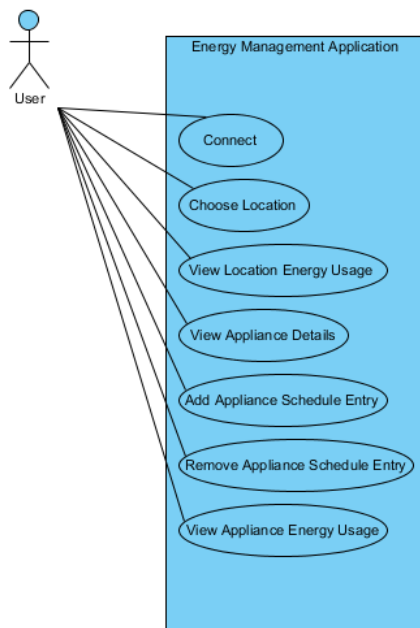


Figure 4.1: Use Case Diagram

4.1 Connect

The Connect use case is the first action the user has to do. Since all the data is stored on a server, to be able to view energy usage data and turn devices on

and off, the application first need to be connected to the server.

Identifier	UC-01
Name	Connect
Actor(s)	Plugwise Server
Trigger	User starts the application
Pre-condition	The application has started
Post-condition	The application has started and is connected to the specified Plugwise server
Steps	<ol style="list-style-type: none">1. The application asks the user for the Plugwise server url2. The user enters the url and clicks connect3. The user is presented with a message the application is connecting4. The application connects to the Plugwise server and polls for device locations5. The user is presented with the locations screen <u>with the locations overview tab selected</u>
Alternative flow(s)	<ol style="list-style-type: none">4. The application can not connect to the specified url5. The user is presented with a message that the connection failed, specifying why.

4.2 Choose Location and View location energy usage

After logging on, the user is presented with a list of locations. These locations are defined on the server. This step is to prevent the user from being presented with a huge list of appliances connected to the system right away.

Here, the user also has the option to view the energy usage of all the appliances in this location and compare them, in order to identify what appliance has the biggest possibility of being a source of energy saving. By turning it off more often for example.

Identifier	UC-02
Name	Choose Location
Actor(s)	
Trigger	The 'locations overview' tab in the locations screen is selected
Pre-condition	The application is connected to a Plugwise server The 'choose location' screen is active
Post-condition	The application shows the details about a chosen location
Steps	<ol style="list-style-type: none">1. The application presents the user with the available locations2. The user selects a location3. The application switches to the location details screen, showing the available devices tab
Alternative flow(s)	

Identifier	UC-03
Name	View location energy usage
Actor(s)	
Trigger	The user selects the 'energy usage' tab
Pre-condition	The application is connected to a Plugwise server The location details screen is active
Post-condition	The application shows the energy usage of the currently selected location
Steps	<ol style="list-style-type: none"> 1. The application presents the user with a screen informing the user it is loading the location energy usage details from the Plugwise server 2. The application updates the locally stored energy usage details from the Plugwise server. 3. The location energy usage screen has finished loading, showing the current device state and updated schedule
Alternative flow(s)	<ol style="list-style-type: none"> 2. The server does not respond, the application notifies the user 3. The application returns to the connect to server screen.

4.3 Appliance Use Cases

These use cases are all related to specific appliances, not a location. They allow the user to switch an appliance on or off as well as schedule an appliance to switch on or off at a later time.

This also gives the user the option to view the energy usage data of a single appliance.

Identifier	UC-04
Name	View appliance details
Actor(s)	
Trigger	The appliances overview tab in the location details screen is selected
Pre-condition	The application is connected to a Plugwise server The location details screen is active
Post-condition	The application shows the details about a chosen appliance
Steps	<ol style="list-style-type: none">1. The application presents the user with the available appliances2. The user selects an appliance3. The application switches to the device details screen, showing a message that the application is loading the appliance details from the server4. The application loads the device details from the server5. The appliance details screen has finished loading, showing the current device state and schedule
Alternative flow(s)	<ol style="list-style-type: none">3. The server does not respond, the application notifies the user4. The application returns to the connect to server screen.

Identifier	UC-05
Name	Add appliance schedule entry
Actor(s)	
Trigger	The user clicks the 'add schedule entry' button
Pre-condition	The application is connected to a Plugwise server The appliance details screen is active
Post-condition	The schedule of the currently selected appliance has updated
Steps	<ol style="list-style-type: none"> 1. The application presents the user with a form asking the date and time the scheduled event should take place and the state the device should be in (on or off). 2. The user fills out the form 3. The application updates the locally stored schedule temporarily and updates the schedule on the Plugwise server. 4. The application reloads the device details from the server 5. The appliance details screen has finished loading, showing the current device state and updated schedule
Alternative flow(s)	<ol style="list-style-type: none"> 3. The server does not respond, the application notifies the user 4. The application returns to the connect to server screen.

Identifier	UC-06
Name	Remove appliance schedule entry
Actor(s)	
Trigger	The user clicks the 'remove schedule entry' button
Pre-condition	The application is connected to a Plugwise server The appliance details screen is active
Post-condition	The schedule of the currently selected appliance has updated
Steps	<ol style="list-style-type: none"> 1. The application asks the user if the selected schedule entry should really be removed 2. The user selects 'yes' 3. The application updates the locally stored schedule temporarily and updates the schedule on the Plugwise server. 4. The application reloads the device details from the server 5. The appliance details screen has finished loading, showing the current device state and updated schedule
Alternative flow(s)	<ol style="list-style-type: none"> 2. The user selects 'no' 3. The application returns to the application details screen.
	<ol style="list-style-type: none"> 3. The server does not respond, the application notifies the user 4. The application returns to the connect to server screen.

Identifier	UC-07
Name	View appliance energy usage
Actor(s)	
Trigger	The user selects the 'energy usage' tab
Pre-condition	The application is connected to a Plugwise server The appliance details screen is active
Post-condition	The application shows the energy usage of the currently selected appliance
Steps	<ol style="list-style-type: none"> 1. The application presents the user with a screen informing the user it is loading the appliance energy usage details from the Plugwise server 2. The application updates the locally stored energy usage details from the Plugwise server. 3. The appliance energy usage screen has finished loading, showing the current device state and updated schedule
Alternative flow(s)	<ol style="list-style-type: none"> 2. The server does not respond, the application notifies the user 3. The application returns to the connect to server screen.

Chapter 5

Implementation

With the requirements and use cases described, we have the basis on which the application itself can be designed. This chapter will first detail the reasoning behind the platform choice.

With a platform chosen and the requirements and use cases known, the application itself can be designed. This is what the second part of this chapter will detail.

Finally, there will be a section on why plugins are not a good method to support different types of servers. This section will also feature a description with example on the way plugins could be implemented if it would have been a good way to support different servers.

5.1 Platform Choice

The platform choice for the application is an important decision to make. The initial choice is between a mobile platform, like smartphones and tablets, or a computer. This choice can be made based on the fact that the application must be very accessible. The less work and time it takes to use it, the higher the chance that the user will use it. Possibly of more importance is the desideratum to have the option of control at distance.

While the computer still possesses far superior processing power, smartphones of the current generation are more than capable of running multi-threaded applications and have enough processing power. And of course the smartphone is designed to take it with you. The computer is not the choice if control at distance is a deciding requirement.

This narrows the platform choice down to mobile devices, but this still leaves the choice for which operating system the application will specifically be developed. From section 3.1.4 it might already be clear that Android became the actual choice, but this choice needs to be supported by good arguments.

5.1.1 Android versus iOS

The two operating system choices to develop an application for a smartphone are Android and iOS. Symbian and Windows Phone OS are also available platforms to write an energy management app for, but these are at the time of writing this thesis much less used. This makes the target audience much smaller, and as such less interesting.

Android and iOS are both widely used. They both have a similar look and feel. To make a choice, we will discuss both operating systems and finally make our choice based on the differences found.

Both Android and iOS have a sizable market share regarding the operating system used on the current smartphones, so even if one has a slightly bigger market share than the other, the ideal case for a commercial application would be to develop the application for both operating systems. Due to time constraints, however, this was very difficult to realize.

Both operating systems have a fair amount of tools available to the developer to make the application user friendly, and as such Usability will not suffer regardless of choice. This means that this criterion is not an issue either when making the choice.

When making a choice, the only real difference is with concern to the available development tools. While both Android and iOS have development tools available which more than suffice for making an application for a smartphone, at the time of writing there was more experience with programming for Android than with programming for iOS. This is the pragmatic reason that Android the platform of choice instead of iOS.

5.2 System Architecture

The use of a mobile device controlling and monitoring home appliances and energy usage already implies the use of a client-server architecture, at least if scheduling is one of the options. Even when the mobile device is turned off or for some reason does not have an internet connection the devices must still be monitored and turned on or off according to the set schedule.

Another factor that makes a client-server architecture favourable is the fact that even when currently most smartphones have internet available, it is still preferable to limit the traffic to make sure the appliance does not use more of the monthly data bundle than is really needed.

5.2.1 Server

The system that this application will use to monitor energy usage of appliances is the Controller part of a solution described in Optimizing Energy Costs for Offices Connected to the Smart Grid [16] in turn using the Plugwise system. The Plugwise system will also be used to turn appliances on or off remotely, as well as for scheduling.

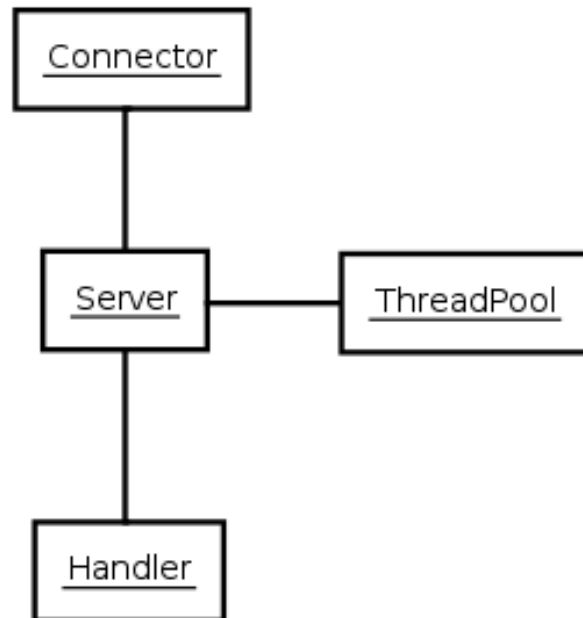


Figure 5.1: Jetty High Level Architecture (source: <http://www.eclipse.org/jetty/documentation/current/architecture.html>)

The control of the Plugwise system is done with web services. All web services are implemented as REST services, in particular, GET and POST. These web services respond using XML data. This is best done on a mobile device, since users then can control their own system anywhere, as long as they have an internet connection on their mobile device.

The availability of this system means that the first focus of the project will be to allow the user to control the appliances connected to the Plugwise system and to inspect the power usage of these appliances.

5.2.2 Server Architecture

The Server consists of roughly two parts, a collector collecting the energy usage data from the meters, and a Java servlet based Jetty http server. Figure 5.1 shows the high level architecture of a Jetty servlet.

In this architecture, the handler is the part that is custom written, the Connector, Server and Threadpool are provided by Jetty. The current implementation has one class with a method acting as handler for each functionality needed.

5.2.3 Server Modifications

Because the server that we used had to be replaced, it was taken offline. The new server, however, was not available at the time the research took place, so we had to make some modifications to the old server that allowed us to use the old server software together with the historical data to simulate turning devices off and on and see real usage data. This section will describe the new features used by this modified server. Each of the modified sections is a separate handler in the Jetty server.

Remove Scheduled Entry

Although the server had the ability to schedule a device to switch on or off at a specified date and time, once this setting was added to the schedule, there was no way to remove the entry.

The way scheduled entries were implemented was problematic. When a device was scheduled, then an entry was made in the schedule specifying when the device was going to be switched on or off. Completely separately from this was a `TimerTask` created to actually turn the device on or off. Because of limitations in the way Java handles these `TimerTasks`, it was difficult to keep a reference to them after the webserver went into hibernation due to inactivity.

This problem was solved by not actually removing the `TimerTask` when a scheduled entry was removed. Every scheduled entry was just given a unique id. That way, at the time a `TimerTask` is scheduled to be executed, it will check if the scheduled entry it belonged to still exists, and only turn the device on or off if this is the case.

Get Device Status

Because there were no actual devices connected to the server anymore (see above), the device status had to be completely simulated. If it has no record of a device being on or off that device is assumed to be switched off. When a change is made it internally keeps track of the current status.

Energy Usage Data

The energy usage data are real data as collected. This has not changed, except that no new data are being generated. This had no consequences: the only thing that needed to be done was to import the collected data into the database.

5.2.4 Client

The client has roughly three functions that it must be able to perform:

1. Provide the user with a user interface to control the system

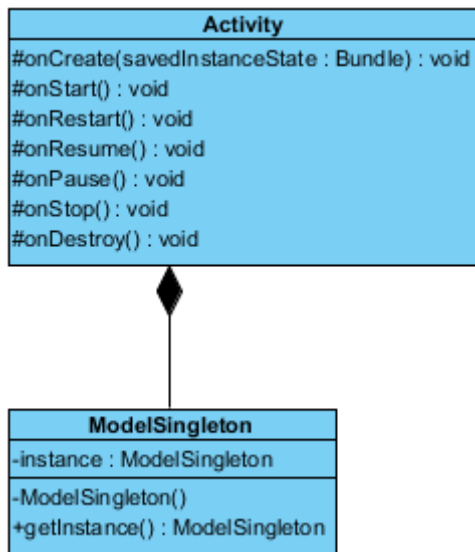


Figure 5.2: Activity and Model class diagram

2. Process the data retrieved from the server and present it to the user in an understandable way
3. Connect with the server to get the appliance data and set the schedule

To separate these three functions, the Model-View-Presenter (MVP) architectural pattern is ideally suited. The user interface is provided by the View, the Model takes care of retrieving data from the server and storing it in the client and the Presenter part. The classes that are going to become the View part of this architectural pattern will all be subclasses of the Activity class, provided in the Android API. The definition of an activity is: “An activity is a single, focused thing that the user can do.” The model will be used by several activities. In order to make sure each activity will access the same data it will be modelled as a singleton class. Applying this pattern to the application, we get a structure as shown in the class diagram in figure 5.2. This is the general setup for the application.

The Model

Every appliance connected to the Plugwise system also needs to be represented in the software. On the client side this is done by the Device class. The Device class is a class that is used as an internal representation for a device that is controlled by the Plugwise system. It is a subclass of the Observable class. Any Activity that is currently showing information regarding a device subscribes to the Device object. This way, each time the device is updated, the Activity classes that are showing information regarding this device are automatically updated.

The ModelSingleton class is a singleton class that takes care of connecting to the server and keeping track of the Device objects. It serves two purposes: connecting to the server to update the local representation of the devices and as a facade for accessing and modifying the device objects representing appliances connected to the Plugwise system. Both these purposes benefit from it being a singleton class. When connecting to the server it is good to have only a single object doing this to prevent lots of connections being made to the server. Managing the Device objects with a single object for all classes means that it is easier to prevent multiple different, possibly conflicting, representations of an appliance.

It is never called directly from the UI-thread. If the server is slow to respond, this would cause the whole User Interface to freeze until the application has gotten a response.

Instead, if an Activity class needs to use the ModelSingleton class, it is done using an AsyncTask. The AsyncTask class is used by making a private subclass in the class that needs it to perform a function. This private AsyncTask subclass will then run in a separate thread. When finished, it will perform a function running in the UI-thread, to switch to a different Activity for example.

When the connect() method of the ModelSingleton class successfully connects to the specified server and retrieves a device list, it also automatically creates a DeviceUpdater object. This DeviceUpdater creates a TimerTask that, in a separate thread, polls the server every 10 seconds to make sure any changes to any devices are seen by the application within 10 seconds.

Figure 5.3 shows the sequence diagram for connecting to the server. In this diagram, step 2.1 runs in the UI-thread. From that point on, all steps run in a separate thread, until step 2.1.3, which runs on the UI-thread again. In this step, if the connection to the server has been successful, DeviceListActivity will be made the active Activity.

Putting this together we obtain the class diagram shown in figure 5.4. This is an almost complete class diagram, but it misses one important detail. Each activity that uses the ModelSingleton class in a way that it needs to communicate with the server uses a private inner AsyncTask class for this purpose. This is difficult to model in UML however, since it is a java specific construction, and it is still the Activity class that makes sure the ModelSingleton is accessible.

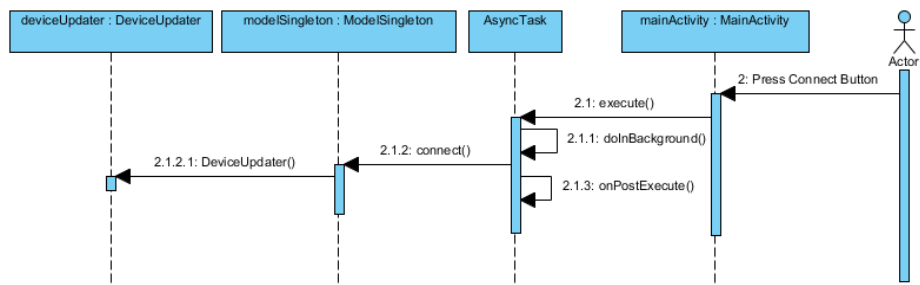


Figure 5.3: Connect Sequence Diagram

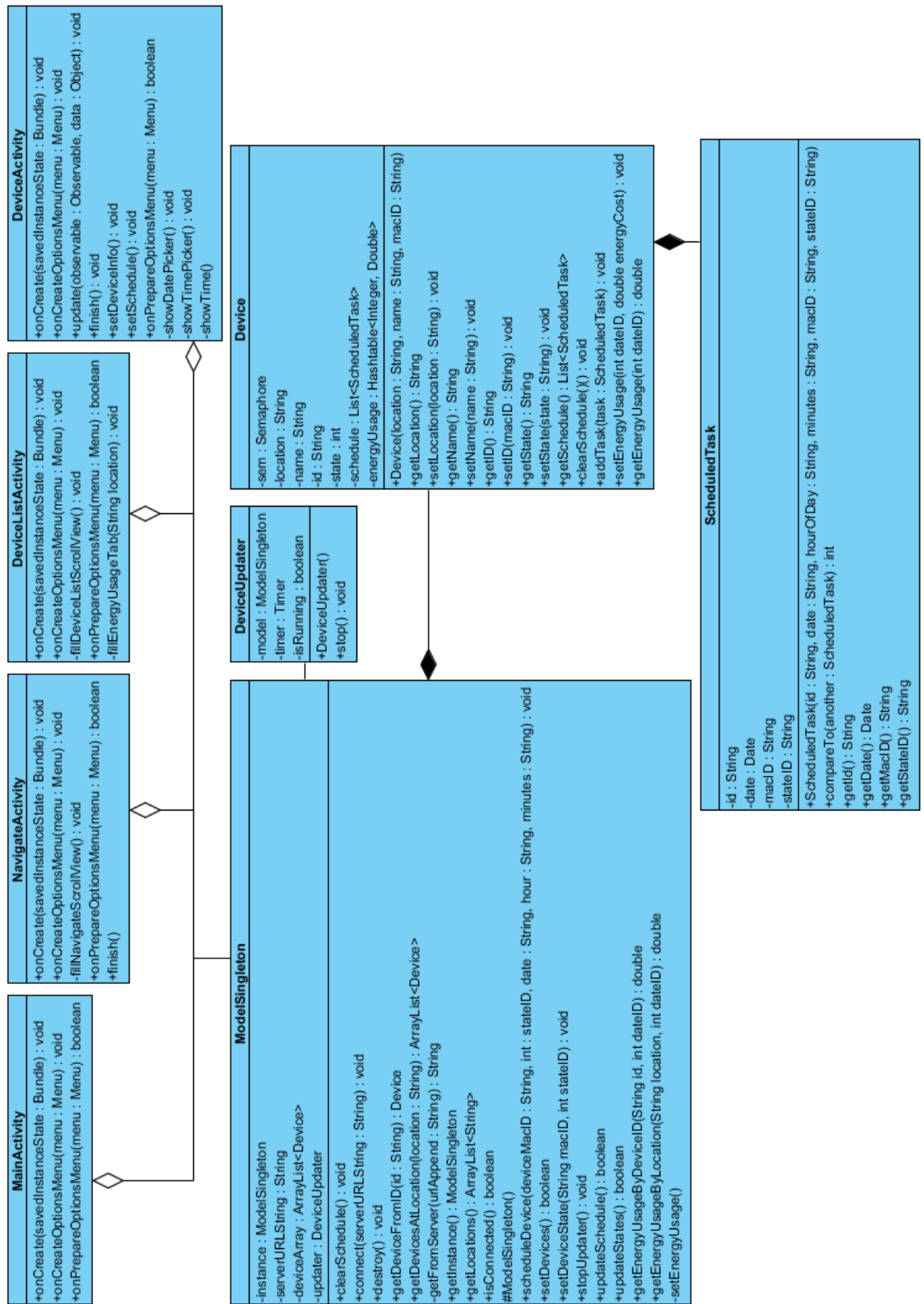


Figure 5.4: Energy Manager Class Diagram

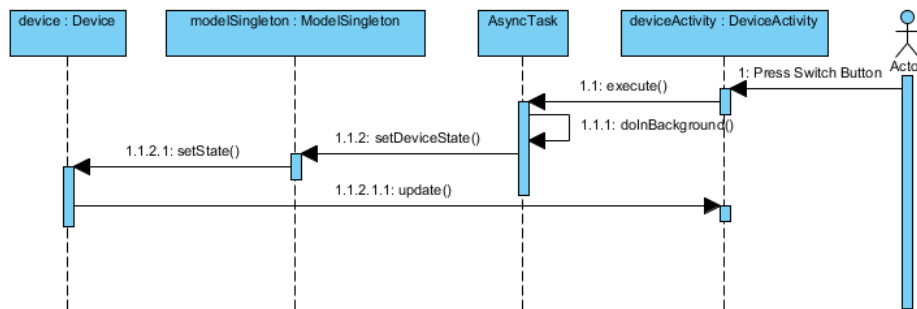


Figure 5.5: Switch Sequence Diagram

The View and Presenter

The Activity classes take care of showing the user the current state of the model and make sure the model is changed according to the commands of the user. They should not, under any circumstance, take care of actually changing the model. Changing the model is the task of the classes related to the model, preferably in a thread that is not the UI-thread.

This is done using the AsyncTask classes. For every task that an Activity needs to do on the model, a separate private AsyncTask subclass is created for that activity, which runs in a separate thread when executed.

An example of what happens when a user presses the button to turn a device on or off in the DeviceActivity screen is shown in figure 5.5.

In this sequence, step 1.1 execute() runs in the UI-thread, all the other steps, including step 1.1.1.2.1 update() run in a separate thread. After the update() method has been executed, the Activity has been notified that the UI settings have been changed and it will redraw.

Multithreading

In order to keep the application responsive, several threads are used. In part, this is enforced by Android. If an application tries to do a network operation in the main thread for example, a NetworkOnMainThreadException is thrown. By making the main thread only handle user interaction, the application keeps being responsive.

The first measure taken in order to achieve this is making the DeviceUpdater run in a separate thread by using a TimerTask. This way, the application keeps polling the server to keep the appliance station up to date, while not interrupting the main thread. This thread keeps running until the user disconnects from the server.

When working with multiple threads, steps need to be taken to make sure no deadlocks occur. This is done using semaphores, making sure that a variable can not be changed multiple times from multiple threads at once. Below is an example piece of code of how a semaphore is used to prevent more than one

thread changing the state of the Device class. Please note that this is not the complete definition of the Device class, just a snippet of code to show the usage of a semaphore here.

```
public class Device extends Observable {
    private Semaphore sem;
    private String location;
    private String name;
    private String id;
    private int state;
    private List<ScheduledTask> schedule;
    private Hashtable<Integer, Double> energyUsage;

    public Device(String location, String name, String id) {
        super();
        this.sem = new Semaphore(1);
        this.location = location;
        this.name = name;
        this.id = id;
        this.state = -1;
        this.schedule = Collections.synchronizedList(
            new ArrayList<ScheduledTask>()
        );
        this.energyUsage = new Hashtable<Integer, Double>();
    }

    public void setName(String name) {
        try {
            sem.acquire();
            this.name = name;
            sem.release();
        } catch (InterruptedException e) {
            e.printStackTrace();
        }
    }
}
```

To Plug-in or not to Plug-in

Late into the development process, we played with the idea of making the application able to support plug-ins to be able to connect to different kinds of servers. This would make it very easy for the developer to allow different kinds of servers to be supported by it.

While this may sound like a good idea, and is even, to some degree, possible in android, there was a very big downside to this idea: The application is not a simple click and go application anymore. Instead of installing the application and it being ready to go, the user has to select which plugin to use, introducing another problem: we now need an extra screen, a settings screen.

While this all may sound simple enough, it is rather counter intuitive to add in a program where shaving just one click off the number of clicks a user has to make is a big thing. So instead of plugins, the design now at least has all the communication with the server localized in one single class. Should the server method of communication change, then at least there is not much in the source code that needs to be changed.

The plugins were created as services that were installed separately. A specific intent was defined, and with the package manager a list of services (our plugins) is returned that are bound to a predefined action. Now that the application has a list of the available plugins, one can be chosen and used.

Chapter 6

Evaluation and Results

During the course of creating the application, there have been user tests to test the design and usability of the design at that point. This chapter will explain what research has been done regarding user testing, as well as the results this provided.

6.1 Expected User Interface Layout questionnaire

The first questionnaire was taken during the design phase of the application. First a selection was made of the functionalities that need to be in the application. This set of functionalities would need to be divided over different parts of the application, however. The purpose of this questionnaire was to learn how the users of the application did expect the functionalities to be grouped together. With this information it would be possible to make the looking for the functionality by the users more intuitive to the users.

First we made a set of cards, each card with a description of a basic functionality, a functionality that could not be split into even more basic functionalities. Then two people were presented with these cards and asked to make multiple stacks of cards with functionalities they believed belonged together. The results of their card grouping activities are listed below. It can be seen that the groupings they made are not exactly the same of course, but really quite similar. While two people is quite a small group to test this on, it still gives some valuable information to base the initial layout on.

person one:

- current energy usage
- weekly average energy usage
- monthly average energy usage
- view next three schedule entries
- view full schedule
- current state (on/off)
- switch on/off
- add schedule entry

person two:

- current energy usage
- switch on/off
- current state (on/off)
- monthly average energy usage
- weekly average energy usage
- current energy usage
- view full schedule
- add schedule entry
- view next three schedule entries

This input was used in the creation of the initial design of the user interface. After some usability testing this interface was slightly changed, but this made this input not less valuable. It gave a place to start with the user interface design. The final design was as follows:

- switch on/off
- current state (on/off)
- view full schedule
- add schedule entry
- total energy usage this month
- total energy usage this month compared to the total energy usage of the whole location
- total energy usage this month compared to last month
- total energy usage this month compared to this month last year

6.2 Influences of Usability

As mentioned earlier, the design of the application is heavily influenced by the usability quality attribute. Reliability, learnability and consistency, which are considered aspects of usability, each have a different influence on the design. We will now discuss each of these different influences.

Reliability

Reliability influences the application at the technical level in the first place. It not concerned with how the system should interact with the user, but it prevents that the system might ever stop interacting with the user for whatever reason.

The most important aspect of the application to prevent it becoming unresponsive is the use of multi-threading. As mentioned in section 5.2.4, all the UI functionality is handled in a single thread, with all the other aspects of the application, like polling the server, being done in separate threads. This makes sure that whatever happens, it is unlikely for the application to completely freeze.

Another aspect of reliability is that, should an error occur, the application handles this gracefully. The user should be notified and the application should change to a state where it can function again. An example of this would be to fall back to the connect to server screen when the server becomes unresponsive, and notify the user.

Learnability

Learnability is more about the layout of the user interface. Users should not have to spend a lot of time to figure out how to do what they want to do. In order to achieve this two tests were done. First a basic version of the application was tested without much thought given to learnability and then an improved version of the application that was changed based on the results of the first test.

6.3 First Usability Test

The purpose of this first test is to identify parts of the application that benefit from additional guidance by the application. To this end, ten testers performed various tasks, listed in the table below. These testers were ranging from the ages 20 to 30 years old, with schooling ranging from High School to University. At any time, when they were stuck and needed help they would say so. The case in which people were no longer motivated to finish the task should also be observed. In order to test this, it was always an option to stop the task they were doing and say “This is too much work, I really don’t like doing this.”

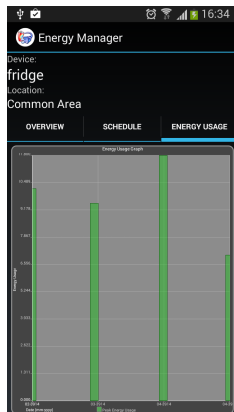


Figure 6.1: Peak Energy Usage Graph

In order to test how effective graphs are to show information, We set up the test differently. The problem was to find the appliance with the highest peak energy usage, the information shown by the graph however, was the total monthly energy usage. Only two of the ten people noticed this mistake. Unfortunately, there are no actual screenshots of the application during these tests. However, it was possible to change one of the backups from the time of this tests to a working copy to make a screenshot. This screenshot is shown in figure 6.1. The actual data shown in this graph is the highest total energy used over a one second interval. The data asked in the question, was the total energy used over a one month interval.

Table 6.1 shows the results. The values shown are the number of clicks, as discussed in section 3.1.6, a user takes from the connection screen until the

asked task is performed. The users all showed the same result.

appliance control	Number of Clicks
Turn on the coffee machine	4
Schedule the beamer to turn on in 30 minutes.	Could not finish
Remove scheduled entry for the beamer you just added.	4
Information	Number of Clicks
Find the appliance with the highest peak energy usage.	Would not finish, too much work

Table 6.1: Usability Testing Number of Clicks

While they performed the tests we also observed the behaviour of the testers. The first observation we made is that nobody noticed that he had to scroll down in the “Add schedule entry” screen, even if one of the elements was cut off at the bottom of the screen. This is probably because in Android scroll bars are only visible when you are actually scrolling. A result is that this screen has to be redesigned to fit on the screen without scrolling.

A second observation is that actions that change the state of an appliance, like switching it on or adding a schedule entry, need a confirmation pop-up. This, however, was an expected result.

Another point of interest is that most of the users had some difficulty reading the energy usage from the graph. This was a simple bar graph, each bar representing a month and the energy usage set out on the Y axis. The most obvious problem was reading the numbers alongside the axis. To solve this, first the presentation must be changed to make the numbers more readable. In addition to this, the presentation must be changed so that every graph in the program uses the same scale, instead of changing the scale to the maximum value currently shown. This might make the graph less readable when only small values are shown, but will increase the ability of the user to compare values between different graphs.

Alternatively, a completely different method of presentation can be chosen. The most important property of a graphical presentation is that it can be easily compared. A progress bar could for example be used to show the energy usage compared to the location of the appliance as a whole and the energy usage last month and the same month last year. This approach minimizes the effort users need to understand how to read the energy usage. In 2.2.3 we have already seen that this is key to making people want to use the application, so this is a very promising alternative.

Additionally, the testers were asked to rate certain functionalities in usefulness, the results are shown in table 6.2. The values shown are the averaged ratings given by the users, as well as the standard deviation. The results from this rating is taken into account when improving the application. Noteworthy is

that users found peak usage and highest minimum usage not very important. Additionally, while scoring 4 out of 5, average usage still scored the third lowest with a low standard deviation, meaning that not many of the users found this definitely useful.

	Item	Average	Standard Deviation
Appliance Control	Turn on appliance	4.10	0.88
	Schedule appliance	4.00	1.15
	Remove schedule entry.	4.40	0.70
Information	Peak usage	3.50	1.18
	Average usage	4.00	0.94
	Highest minimum usage	3.60	1.26

Table 6.2: Usability Testing: Rated Importance of Functionality; N = 10

Additionally we asked the users testing the application to name some features that might be useful to be added, this was their response:

- confirmation popup for schedule entry added
- is the appliance on check
- minimum/stand-by energy usage
- random schedule (prevent burglary while on vacation)
- high/low energy level with temperature “overrule”
- average monthly energy usage
- energy overview (mentioned three times)
- visible scrollbar
- energy compare
- group not just by location, but allow types too (lights, computers, washing machines for example)
- overview usage (all)
- bottom buttons category
- edit schedule appliance

As can be seen, most of these relate to the earlier mentioned functionalities that had less than ideal usability. Should the application be more user friendly after the improvements, these test users should list less suggestions, or at least not related to current functionalities.

6.4 Improved User Interface

The result of the improvements after the first usability tests is shown in figures 6.2, 6.3 and 6.4. As can be seen in figures 6.3 and 6.4, The energy usage is shown mostly relative to the location or previous months using a progress bar,

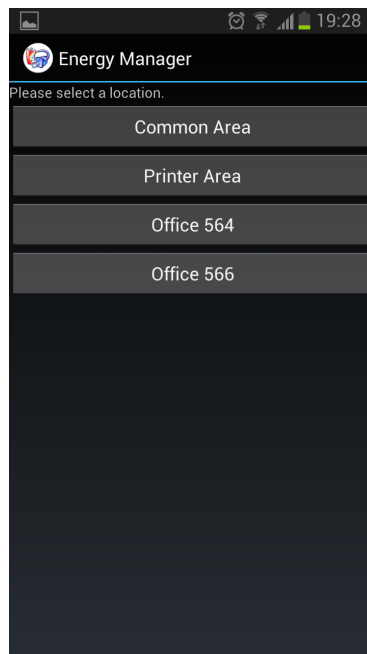


Figure 6.2: Select Location Screen

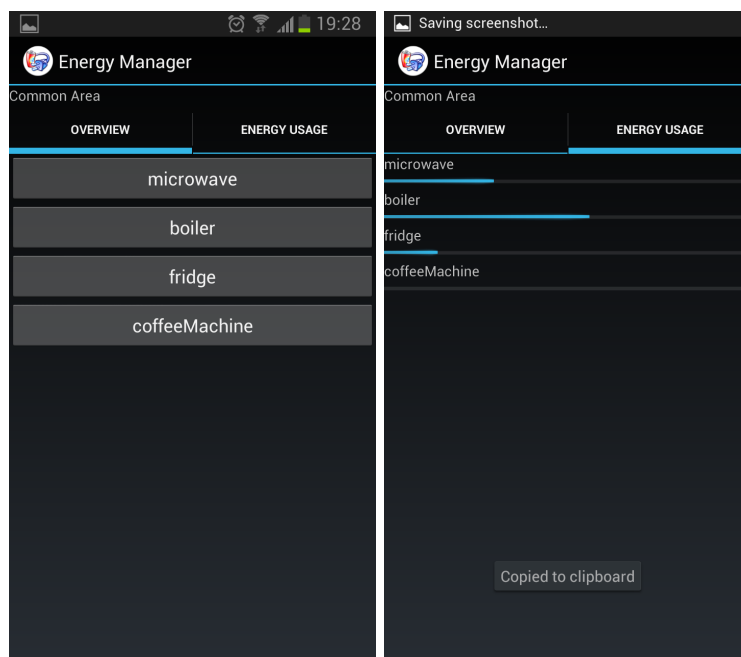


Figure 6.3: Select Appliance Screen

meaning that users have an easily recognizable user interface element to lessen the effort needed to understand what the screen is showing, conforming to our

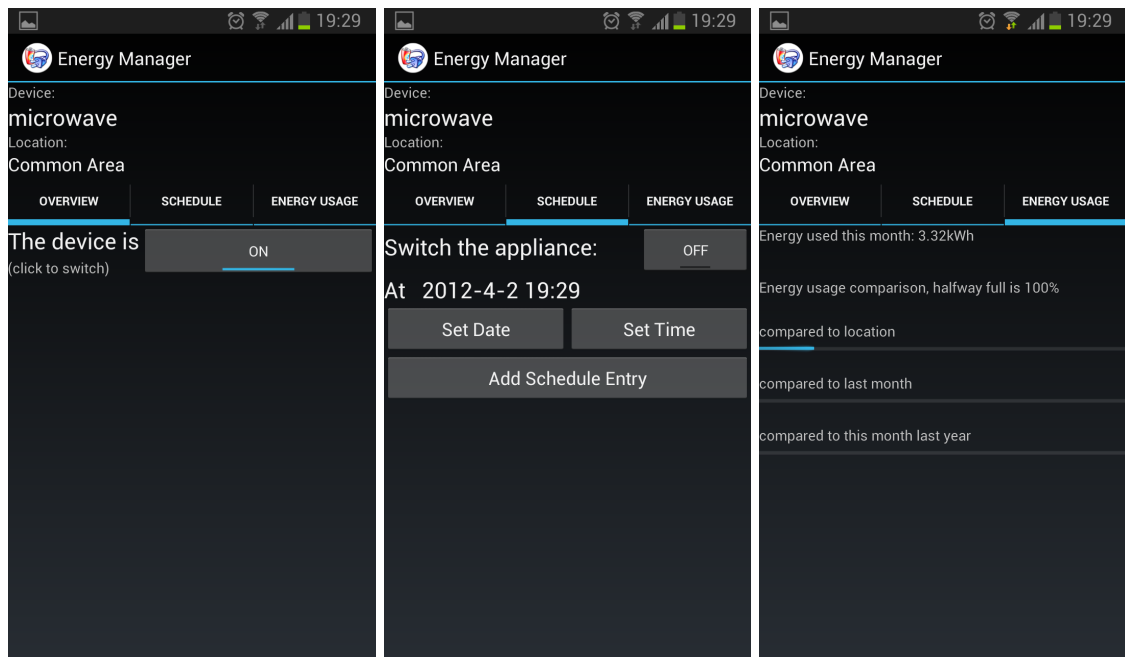


Figure 6.4: Appliance Details Screen

findings in section 2.2.3.

6.5 Second Usability Test

This test has the same set-up as the first usability test: five testers performed various tasks, listed in the table below. At any time, when they were stuck and needed help they would say so. The case in which people were no longer motivated to finish the task should also be observed. In order to test this, it was always an option to stop the task they were doing and say “This is too much work, I really don’t like doing this.”

Table 6.3 shows the averaged results of this second test. This time not all users scored the same, but never needed any help navigating through the application.

Also noteworthy is that when asked what extra features they wanted, only two of the five users could think of something. This means that it indeed is probable that, when confronted with an application that is more user friendly, users can have more trouble thinking of extra features they want. Note though that, in order to prove this, more extensive research needs to be done. The following features were listed:

- overview of the complete schedule, not just per appliance
- total energy usage, but the user noted that he thought this was of less importance

appliance control	Number of Clicks
Turn on the coffee machine	4
Schedule the beamer to turn on somewhere in 2014.	8.6
Remove scheduled entry for the beamer you just added.	6.2
Information	Number of Clicks
Find the appliance with the highest energy usage in the common room.	4.6
Find the appliance with the lowest energy usage in the common room.	2

Table 6.3: Usability Testing Number of Clicks, test 2

Again, the users were asked to rate the usefulness of several features in the application, with their response given in table 6.4. As can be seen, overall, the scores increased.

	Item	Average	Std Dev
Appliance Control	Turn on appliance	4.60	0.55
	Schedule appliance	4.40	0.55
	Remove schedule entry.	4.40	0.55
Information	per location energy usage comparison	4.20	1.10
	energy usage compared to last month	4.40	0.55
	energy usage compared to last year	4.20	0.84

Table 6.4: Usability Testing: Importance of Functionality, test 2; N = 5

6.6 Discussion and Future Work

While the usability testing proved very useful at increasing the application's usability, there is always room for improvement. The most important improvement would be testing different methods of visualizing energy usage. Currently the application shows energy usage of appliances relative to the energy usage in the past and to the location it is located in. As mentioned before, comparing this energy usage to the average energy use of an appliance of its kind would be very useful to give the user an idea of how wasteful or conservative their use is.

Another feature that might be useful is to add a new kind of overview, where appliances are sorted by type instead of by location. This was also a suggested feature by one of the test users.

Also, because the server we use was discontinued and a new server is being developed, to be useful in the future the `ModelSingleton` and `MainActivity` classes will need to be changed to be able to connect with the new server.

Regarding research question 3, if there are additional useful features, the answer is the following. There were not too many additional features that were useful and related to energy conservation. The most important one was just making it easier for the user to switch appliances on or off remotely.

More important was the way the application interacts with the user, which answers research question 4. The most important aspect for usability was predictability: having the application look like a standard android application made the user look in the right places for the different functionalities. Similarly, giving a confirmation popup when expected his action to be confirmed by the application was also important.

From the research done, it follows that a non-numerical representation of the energy usage was the best suited. In this case, we chose for a representation that compared current energy usage to previous months. This allows the user to see if he is succeeding in his efforts to reduce his energy usage, while avoiding the comparison to money to make it seem like just another way to save money and keep the image of saving the environment.

Chapter 7

Conclusion

We have seen that energy management applications are useful to aid users with energy conservation, however the user will need to want to use the application. In order to make the users want to use the application, some extra usefulness needed to be added. In this case was chosen for the ability to remotely switch appliances to be scheduled on and off as well as schedule them to be switched on or off.

During the usability testing, it was found that graphs were not truly a suitable way to show the energy usage, partly due to the relatively small size of the screen on a smartphone. The alternative way of showing energy usage chosen was a progress bar, to give an easily comparable graphical representation of the energy usage.

In section 2.2 we have discussed energy consumption influence in general and found that computer aid is indeed useful regarding energy consumption influence. This answered the research question “In a computer application to aid the user with energy conservation, what is a suitable way to present the energy usage data in order to stimulate households and small offices to conserve energy?”

The research question “What is a suitable platform to create an application for energy conservation?” was an important question since the platform influences both the look and the technical design. The most general answer would be that the smartphone is a very suitable platform, in our case an Android smartphone, but iOS would not be less suitable.

The research question “What are additional useful features to add to an application for energy conservation that will tempt users to use the application?” has been implemented with two features. The first is the ability to remotely switch appliances on or off. The second is the ability to easily compare the current month’s energy usage to the energy usage last month and the same month last year, in order to allow the user to easily view if he is actually conserving energy.

The result is an application that is usable without consulting a manual first, with a graphical representation of energy usage that is understandable without

much explanation.

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Appendix: Usability Test

appliance control	Number of Clicks
Turn on the coffee machine	
Schedule the beamer to turn on in 30 minutes.	
Remove scheduled entry for the beamer you just added.	
Information	Number of Clicks
Find the appliance with the highest energy usage in the common room.	
Find the appliance with the lowest energy usage in the common room.	

Additional Questions

- Would you like the addition of other functionality? If so, which ones (at most three)?
- Are there options that might be excluded from the application? If so, which ones?
- Rate the desirability of each of the possibilities, including the choices you just added, on a scale from 1 to 5.

1. not useful
2. probably not useful
3. possibly useful
4. probably useful
5. definately useful

	Item	1	2	3	4	5
Appliance Control	Turn on appliance					
	Schedule appliance					
	Remove schedule entry.					
Information	Per location energu usage comparison					
	Energy usage this month compared to last month					
	Energy usage this month compared to last year					
Options you added						