Investigating the Potential for a User-Driven Electricity Monitoring Application to Provide Useful Electricity Consumption Patterns

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Plagiarism Declaration

I know the meaning of plagiarism and declare that all the work in the document, save for that which is properly acknowledged, is my own.

Abstract

Conventional electricity usage monitoring involves complex data collection via costly and intrusive hardware installation. There is a perceived need for a simple and affordable tool that provides users with feedback about their electricity consumption without the hardware installation.

This study involves the design and development of a user driven mobile and desktop application that provides users with information on electricity usage patterns and historical trends. The application was designed using Ionic Framework, a tool ideal for the design of hybrid applications that are compatible with both desktop Windows devices and mobile Android devices. The goal of the research will be that the user will track their appliance usage on the application whilst taking electricity meter readings at regular intervals to calculate appliance-specific consumption. The data is added to the mobile or desktop application, which then provides users with a comprehensive display of the electricity usage patterns and trends. The objective is to provide users with the information required so that they can start understanding their electricity consumption better and it is a first step towards empowering the user to make smart decisions at home that will reduce their electricity consumption. The USE (Usefulness, Satisfaction, Ease of Use and Ease of Learning) questionnaire was used to gather user experience feedback from participants about user experience. The USE questionnaire tests the perceived Usefulness, Satisfaction, Ease of Use and Ease of Learnability

The 31 individuals who initially volunteered to take part in the study are all residents of the City of Cape Town Municipality, aged between 20 and 80 years old. Not all participants are home owners; some are tenants in their premises. The sample group was selected on a convenience basis, and social media group posts were also used to reach individuals with a potential interest in the study. The two motivating factors that were considered to identify individuals who could potentially have an interest in the study were cost saving and environmental impact. 21 volunteers completed the study and returned the USE questionnaire.

The study findings showed that all participants believe that using the application helped them to better understand their electricity consumption.

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1. Introduction

1.1. Motivation

The topic of energy consumption in a residential setting has been researched over a long period of time (Vega et al. 2015) with studies about human behaviour and energy consumption dating back to 1975 (Guerin et al. 2000). A renewed focus on electricity consumption and the sustainability thereof has recently emerged because of factors such as:

1. A rising awareness of the impact of traditional sources of electricity, for example the burning of fossil fuels, on the environment. If there are no further international policies put in place and efforts made to reduce the consumption of resources, energy related carbon dioxide emissions are expected to rise by 78% between 2005 and 2050 (De Boeck et al. 2015).
2. Diminishing natural fuel reserves (Berges, 2011).
3. Growth in the demand for access to electricity (Beaudin, 2015).
4. The increase in the cost of electricity, which goes hand in hand with the increase in electricity demand and a diminishing supply.

These factors sum up two principal motivations for monitoring, understanding and controlling electricity consumption, namely environmental conservation and cost reduction.

The need to limit the consumption of electricity is applicable to all economic sectors, such as residential, industrial, commercial, transport, agriculture and services. As substantial as the electricity demand from the commercial or industrial sector may be, the total electricity demand from the residential sector is also a major contributor.

A large portion of the total energy that reaches the end user is consumed by the residential sector.

In developed countries like the USA, the residential sector accounted for 37% of the total energy consumption in 2009 (Berges, 2011). Similarly, according to Craig et al. (2014), households account for 32% of total energy consumption (including gas and other forms of energy) and 36% of the total electricity consumption in the United Kingdom.

As reported by Batra et al. (2013), buildings accounted for 30% of overall energy consumption and 93% of all buildings in India, a developing BRICS nation, are residential. In South Africa, another BRICS nation, the residential sector accounted for 16.5% of the total electricity consumption in 2002 (Rosin, 2006). As shown in Figure 1, according to the City of Cape Town's Saving Electricity portal (City of Cape Town. 2012), 37% of the municipality's electricity was consumed by the residential sector in 2012.

This demonstrates the sizeable contribution of residential electricity consumption to overall electricity consumption both locally and abroad.

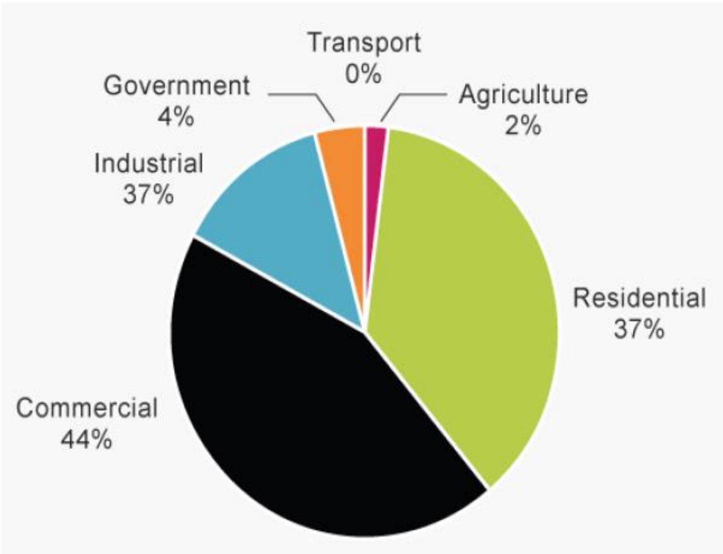

Figure 1: Pie chart showing a breakdown of Cape Town's electricity consumption in 2012.

(Source: City of Cape Town. 2012)

Electricity conservation efforts in the residential sector are even more important because of the sector's contribution to "peak" consumption periods during the day. Generally, there is a sharp increase in electricity consumption from 6am or 7am when residential users wake up in the morning and start switching on appliances while they get ready for the day. Then, at approximately 9am, the total consumption tapers off again until the evening at about 6pm when residents arrive home again and start turning on lights and preparing dinner. This makes it important to differentiate between the multitude of applications and their respective impact on total consumption (Bartels et al, 1996).

An electricity grid is in its most stable state if the total load on the grid is as uniform as possible. The daily peaks that are mentioned above are therefore not ideal, especially if the gradient of the peak is particularly steep. If the residential sector's total electricity demand were more controllable, not only would the overall electricity costs and environmental impact be reduced, but the electricity grid would also become more stable.

The first step towards better control of the residential sector's total electricity demand is to mobilise individuals to control their own electricity consumption. However, in order to encourage energy saving behaviour in individuals, it is first necessary to understand the current electricity usage trends that the individual displays (Ranjan et al. 2014). A common finding is that providing residents with frequent feedback about their electricity usage patterns, thereby making them more aware of how and where they are using electricity, results in a reduction of electricity consumption (Berges et al, 2010; Winett et al, 1979).

In particular, understanding the load profile of specific appliances is essential before effective actions can be taken to reduce electricity consumption in the home. Berges et al. (2010) mention that people often overestimate the impact of appliances with low energy consumption rates and underestimate the impact of appliances with high energy consumption rates. Further to this, they are not well informed about the effectiveness of conservation activities. In other words, people believe certain activities to be highly effective in reducing electricity consumption when they are in fact not effective at all.

This thesis is based on the premise that electricity users at home do not have a good understanding of the most effective methods for reducing their electricity consumption. The study puts forward the notion that providing users with a tool in the form of a desktop or mobile application that allows them to monitor their electricity usage and subsequently provides them with information on their electricity usage patterns will improve this level of understanding.

According to Guvensan et al (2013), there are several electricity monitoring systems already on the market for residential use but the reporting systems that are available require time consuming installations and are otherwise unable to provide device level reports. Financial constraints are considered one of the main reasons provided by residents for not embarking on energy saving actions such as buying energy efficient appliances and installing energy monitoring systems (Sundramoorthy et al., 2010).

This highlights the need for a cost-effective energy monitoring tool that provides home users with energy monitoring services. Many of the monitoring systems available on the market are also highly automated, which results in the end user being excluded from the process. Keeping in mind the importance of consumption awareness on behalf of the end user, it is important that they remain an active part of the value chain (Vega et al., 2015).

This tool is different from what appears to already be available to home users because it would require no complicated hardware installation, it would be affordable and it would provide the added benefit of involving consumers in the activity of monitoring their electricity usage themselves.

1.2. Scope of the Study

This study is a usability study conducted within the field of ICT4D, specifically focused on the topic of energy consumption in the home. This study involves the design, development and testing of a prototype for a user driven mobile and desktop application that provides users with information on electricity usage patterns and historical trends. The objective is to find out if it is possible to provide users with feedback that helps them to better understand their electricity consumption at home. The investigation into the conservation impact that providing residents with this feedback is not included in the scope of the study.

1.3. Problem Statement

The purpose of this study is to investigate whether self-collected electricity consumption data on a mobile (or desktop) device can provide useful per-appliance electricity usage patterns for homes.

1.4. Research Question

The following research question is posed to address the research problem:

Can user-collected electricity consumption data on a mobile or desktop device provide useful electricity usage patterns to home users?

The main goal of the research is to explore the possibility of providing home energy users with informative electricity consumption patterns using a mobile or desktop application that will aid their understanding of how they use electricity. The application has been created for home users to quickly and easily monitor electricity consumption and it is compatible with both mobile Android devices and desktop Windows devices. This study will provide evidence that feedback improves people's understanding of how to address consumption reduction and provide a prototype application for doing just that.

1.5. Research Design

The methodology followed to conduct this study consists of six major phases.

During phase 1, a literature review of related work was conducted to highlight gaps in what has already been done in the field and to explain how this study would attempt to fill part of that gap. The Literature Review is outlined in Chapter 2.

During phase 2, the mobile and desktop application was designed and developed using a tool called Ionic Framework. A cross platform electricity monitoring application was designed using a user-centred approach, with close user involvement throughout the design process. This development phase is described in detail in Section 3.2.

Phase 3 involved the iterative testing and improvement of the application with the use of Focus Groups. Two Focus Groups were conducted and these are also discussed in Section 3.2.

During Phase 4, the finalised application was then made available on the Android Play store and the Windows store and 31 voluntary participants were asked to install the application on their devices of choice and to participate in a "One Week Electricity Monitoring Challenge" involving use of the application to monitor their per-appliance electricity usage at home. The user sample was selected using convenience sampling. Once they had completed the week long "Challenge", participants were then asked to complete an online usability questionnaire based on the Usefulness, Satisfaction, Ease of Learnability and Ease of Use (USE) questionnaire. This phase is discussed in more detail in Section 3.3 and Sections 4.1, 4.2 and 4.3.

The user testing phase involved the use of a scientific procedure to test the hypothesis that user-collected electricity consumption data on a mobile or desktop device could provide useful electricity usage patterns to home users. It is therefore referred to as an experiment.

Phase 5 of the study involved the analysis of the results of the user testing. The approach taken and details of the analysis are outlined in Section 4.4. Phase 6, the results phase is also outlined in Section 4.4.

1.6. Thesis Outline

Chapter 2: Literature Review

Sections 2.2 to 2.8 of Chapter 2 discuss the work that has already been done in the field of electricity consumption monitoring and electricity conservation. The research that was reviewed covers the profiling of residents' characteristics and how this relates to their electricity consumption, the different approaches to electricity consumption monitoring in the home, from the design of automated home energy management systems to investigations involving user-centred electricity monitoring, and finally the use of simulated data or estimated electricity consumption patterns to address electricity conservation.

Section 2.9 then briefly outlines some of the research that has been done recently into electricity related information and communication technology being used for social development purposes and Section 2.10 mentions other examples of information and communication technology studies that have been conducted in the home environment.

Finally, Section 2.11 discusses the use of mobile or desktop applications for any monitoring purposes and Section 2.12 summarises the gaps and opportunities that have been uncovered in the chapter.

Chapter 3: Design and Implementation

Chapter 3 provides an outline of the design of the study, firstly addressing the design and creation of the application, and then addressing the design of the experimental procedure.

Chapter 4: Evaluation and Results

Chapter 4 details the various components of the experiment, the pilot study, the study participants, the data collection methods used and then the results and analysis is discussed.

Chapter 5: Conclusion

Finally, Chapter 5 presents the study’s conclusion. The conclusion is split up into three sections, namely:

5.1. Answers to Research Questions

5.2. Discussions and Implications

5.3. Future Work

2. Literature Review

2.1. Chapter Overview

This chapter provides an outline of the literature reviewed during this study. Sections 2.2 to 2.7 cover the different types of studies that have been conducted on electricity monitoring and electricity conservation methods within the residential sector:

Section 2.2 discusses studies that were conducted on the profiling of residents in order to try to categorise electricity consumer types.

Section 2.3 outlines the research that has been done on user-centred electricity monitoring at home, in other words, studies that actively involve the user in electricity monitoring activities.

Section 2.4 addresses Home Energy Management Systems (HEMS), which are automated systems for electricity consumption monitoring and control in the home environment.

Section 2.5 discusses Nonintrusive Load Monitoring (NILM), which is the monitoring of electricity consumption by studying changes in current and voltage readings over time.

Section 2.6 discusses the fixture assignment problem, which involves other methods of indirectly monitoring electricity consumption, including the use of radio frequency monitoring and audio sensory monitoring.

Section 2.7 addresses the use of estimations and simulations to predict electricity consumption patterns.

Then, Sections 2.8 to 2.11 cover other related categories of electricity and ICT related research.

Section 2.8 discusses models that are used for the improvement of energy efficiency in buildings.

Section 2.9 addresses electricity-related information and communication technology for development (ICT4D).

Section 2.10 addresses ICT in the home, which is not necessarily related to electricity.

Section 2.11 discusses the use of mobile and desktop applications for any monitoring purposes.

Finally, Section 2.12 highlights the gaps and opportunities that have been uncovered during this literature review and 2.13 provides a short chapter summary.

2.2. Resident Profiling in Relation to Energy Usage

The use of resident profiling seems to be a common method for gaining an understanding of electricity consumption in the home. Residents using electricity at home make a number of decisions on a daily basis that may seem insignificant, but the sum total of these decisions create the overall demand for electricity. Attempting to study these decisions is necessary to understand how electricity is consumed in the residential sector (Craig et al. 2014, Petersen et al. 2007, Guerin et al. 2000). The purpose of using profiling techniques is to try to identify patterns that are common within a sample group that can then be applied to situations in other households with similar circumstances to predict electricity consumption.

In five of the studies that were examined for this literature review, the approach used to compile these electricity consumption profiles involved the installation of smart monitors, wireless data loggers and networking hardware in homes so that the electricity consumption data could be collected locally and analysed remotely. A smart monitor is a self-monitoring, analysis and reporting device (Guerin et al. 2000; Kulkarni et al. 2014; Craig et al. 2014. Sundramoorthy et al. 2010; Batra et al. 2013).

The level at which the data is collected differs between studies, however. While some studies collected total household consumption data, others collected consumption data per appliance. Kulkarni et al. (2014) installed smart meters in an affordable housing complex in Bristol, England to collect total household consumption data for each apartment in the complex. Smart meters are electricity meters that record electricity consumption in hourly intervals and send this information to the utility company for monitoring and billing.

In a study conducted by Craig et al. (2014), appliance-level electricity consumption data was recorded using clip-on monitors in 215 households for the period of a year. Sundramoorthy et al (2010) used both electrical mains circuit sensing and individual appliance level sensing technologies to provide real time energy consumption patterns.

Another study, conducted by Batra et al (2013), deployed a sensor network in a 3 storey home in Delhi, India and measured electrical, water and ambient parameters for 73 days from May to August 2013. 33 sensors were used throughout the home and, from the perspective of electricity monitoring, measurements were taken at meter level, circuit level and appliance level.

The benefit of gathering electricity consumption data at an appliance level is the higher degree of accuracy and the ease of associating certain resident characteristics with a specific appliance's electricity consumption patterns. For example, if data is only collected for the total electricity consumption for the household, it is more difficult to confidently associate an early evening peak in electricity consumption with dinner preparations for a large family.

In addition to installing the relevant hardware and monitoring electricity consumption, the residents' characteristics needed to be identified so that they could be matched with the respective electricity consumption profiles.
During one study, a 'main resident' was identified in each dwelling who was asked to provide 'anecdotal evidence' explaining why there were increases in electricity consumption at certain times during the day or week (Kulkarni et al. 2014). The study cited some of the reasons for peaks in electricity consumption as new or additional people living in the household, variation in the use of the tool over time, people working different shifts, excessive use of electronic goods, ill health requiring residents to stay at home during the day and a seasonal component, each having an impact on consumption.

Craig et al. (2014) report that the total amount of energy consumed by a household over a time period was a function of socio-physical factors and occupant behaviour. The study defined specific household types by the number of rooms in the household, the number of occupants, the efficiency of the primary fuel source and the overall space heating requirement. They then associated each household type to a certain electricity consumption profile.

Another study finding reported by Craig et al (2014) was that there could also be a strong association between socio-demographics and occupant behaviour. For example, the presence of children in the household had an impact on electricity consumption patterns. Larger households and those earning more were also likely to use more electricity.

Guerin et al. (2000) did not conduct an energy monitoring study to identify resident profiles, but rather focused their research on a review of energy studies conducted since 1975 to identify a set of predictors of energy consumption behaviour and consumption change.
The study categorised occupant characteristics, actions and attitudes and their effect on energy consumption. This information was then applied to a theoretical energy consumption model to identify occupant predictors of consumption behaviour and energy consumption change.

The most frequently found predictors for behaviour related to user attitudes, included a desire to be comfortable, then health concerns, followed by motivation to save electricity and 'do the right thing'. Occupant actions most frequently found to be predictors of consumption change included weatherisation of the home, probably leading to a reduction in heating requirements.

2.3. Monitoring Household Electricity Usage with the Resident as an Active Participant

This section outlines how the personal choices of a resident impacts electricity consumption and shows that the provision of up-to-date feedback, when combined with education and incentives, can influence these choices and have a positive influence on conservation (Petersen et al. 2007).

Providing residents with both feedback on their electricity consumption patterns and suggestions as to how they can reduce that consumption should provide them with the knowledge required to implement electricity conservation (Craig et al. 2014).

Further, the lack of availability of electricity efficiency information to residents is considered a hindrance to the reduction of electricity usage (Sundramoorthy et al. 2010). Guerin et al. (2000) conducted an overview of research dating back to 1975 on the relationship between human behaviour and energy consumption. One of the study's main findings was that many people did not realise the effect their behaviour and energy habits had on their household energy consumption.

Several of the studies discussed in this section involve the active engagement of residents in electricity monitoring experiments and the provision of up-to-date electricity consumption feedback. As mentioned, electricity consumption has been a popular research topic for a long time, and this section compares electricity consumption monitoring experiments that were conducted in a 30-year period.

The medium used to provide feedback to residents on electricity consumption has changed with technological advancements over the last 30 years.

A study was conducted in 1979 in Washington wherein study assistants took meter readings for 12 households daily, and left feedback sheets for the residents in their post boxes every day (Winett. 1979). These sheets displayed details of the previous day's electricity consumption compared with today's consumption, an indication of the percentage increase or decrease and an estimated monthly consumption based on the readings taken so far.

Meanwhile, more recent user-centred electricity monitoring studies provided feedback that was collected using networked smart metering systems and displayed to residents on Web-based user interfaces (Petersen et al. 2007; Craig et al. 2014; Kulkarni et al. 2014).

Although the medium used to provide feedback to residents differs between the earlier study and the more recent studies, the experimental design is similar for two studies in particular. For both studies, the electricity reduction impact of the residents monitoring their electricity consumption for themselves is compared with the electricity reduction impact of remotely collected electricity consumption data that residents receive feedback on daily.

During the 1979 study conducted by Winett et al (1979), 71 residents living in triple storey townhouses in Washington were approached and asked to participate in the study. Of these, 29 residents declined to participate and were categorised as comparison non-volunteers, 14 were allocated to the comparison volunteer group, 12 were allocated to the feedback group and 16 were allocated to the self-monitoring group. The electricity monitoring study was conducted over a period of 28 consecutive days. Daily electricity meter readings were taken for each of the 71 households. However, only the residents from the feedback group were taught how to take the readings themselves; everyone else's readings were taken by a team of assistants who were also involved in the study.

During a study conducted in a student dormitory at Oberlin College in the USA in 2007, a two week long inter-dormitory energy saving competition was launched on campus to provide an incentive for students to reduce their consumption. Two dormitories were provided with an automated monitoring system that provided online feedback via a Webpage and, in 20 other dormitories, utility meters were manually read and feedback on electricity consumption was provided to students once a week. For both groups, electricity consumption was monitored during a baseline period and then during the dormitory electricity competition. Students were also provided with informative pamphlets and posters around campus detailing what they could do to reduce their consumption (Petersen et al. 2007).

Interestingly, during the 1979 study, the 12 participants from the feedback group reduced their consumption by 13% overall and the self-monitoring group reduced their consumption by 7%. These percentage reductions were based on the comparison group's usage, which did not alter at all while the study was conducted. (Winett et al. 1979).

The 2007 study found that the dormitories with the automated monitoring system and the up-to-date online feedback achieved electricity consumption reductions of 55% compared with their electricity consumption before the electricity consumption competition, whereas the dormitories that received weekly feedback based on manual electricity readings achieved electricity consumption reductions of 31%. These results show that providing residents with frequent electricity consumption feedback can provide them with the knowledge required to reduce their consumption.

Unfortunately, this increase in knowledge does not always translate into observable behaviour changes unless the general information is accompanied by behaviour changing tips and techniques (Craig et al. 2014).

However, other studies suggest that, from a long-term perspective, residents will not feel compelled to change their behaviour so that they conserve electricity unless they understand the direct and immediate link between their actions and the impact thereof (Petersen et al. 2007). The three interrelated factors that are required to provide this understanding and to encourage residents to actively conserve electricity on a long-term basis are knowledge, control and motivation.

Residents have adequate control over their electricity consumption as long as there are no external forces preventing their actions from being effective. Guerin et al. (2000) found that the electricity user's ability to successfully implement electricity conservation actions in the home was limited by the condition of the building's structure. In other words, if the building itself has been constructed in such a way that it is energy inefficient then the resident's control over electricity consumption will probably be limited.

Ensuring that residents are adequately motivated to conserve electricity may be the most difficult of these three factors to accomplish (Petersen et al. 2007). As mentioned, the two most common motivators for electricity, and generally resource, conservation are economic and environmental. It is important that household occupants come to believe that electricity conservation is relevant to their daily lives before any behavioural changes can be expected (Craig et al. 2014).

2.4. Home Energy Management Systems

Home Energy Management Systems (HEMS) are demand management tools that improve the energy consumption and production profile of a household on behalf of the end user (Beaudin et al. 2015).

Many of these tools do not involve the resident in the process and take considerations such as energy cost, environmental concerns, load profiles and consumer comfort into account. One study suggests that residential consumers do not want to spend the time required to analyse their consumption and to make decisions to manage their household devices. Instead, they want the system to do this for them (Beaudin et al. 2015).

However, another HEMS study is focused on the active role that a resident can play in controlling and reducing their electricity consumption (Srinivasarengan et al. 2014). The model operates in one of three states: automatic, semi-automatic and manual. This allows the user to decide how active they want to be in the electricity management process, but promotes active involvement nonetheless.

One view is that HEMS will change the end user's role from being a passive consumer to being an active user in the value chain. In a smart grid system, users can initiate real-time decisions about where and how their household consumes electricity (Vega et al. 2015).

Research into home energy management systems is an important contributing factor to the movement towards having better control of the timing and quantity of electricity demand. And this in turn is important in an electricity grid system because the ability to balance peak and off-peak demand periods allows for a more stable grid that is not susceptible to power shortages at certain times of the day and power surpluses at other times of the day. (Srinivasarengan et al. 2014).

During a study in Mexico, Toledano-Ayala et al. (2011) developed and tested a networked technological system aimed at helping residents to save water, gas and electricity. Although time-consuming, it was possible to install the networked system in existing houses as well as newly established houses. The system consisted of three components: electronic meters, data acquisition and network modules. The study reported electricity consumption savings of 13.43%.

Mesaric (2015) present an interesting approach to home energy consumption reduction with demand side management at its core. The study suggests the potential use of electric vehicles (EV) as movable energy storage units that can be recharged at opportune times when electricity demand is relatively low, thereby stabilising the microgrid system. In the proposed model, small-scale photo-voltaic panels are the main source of energy generation. The demand side management also incorporates the categorization and optimal scheduling of the use of appliances at home.

There are several applications for the home energy management concept, for example the care of residents through the detection and recognition of health conditions, the capturing and storing of events in the home using multimedia and photos, surveillance for security reasons and finally reducing electricity consumption by controlling appliances according to energy demand and supply. (Vega et al., 2015).

2.5. Non-intrusive Load Monitoring

Electricity usage feedback for an entire household has been shown to motivate residents to reduce their consumption, but it is limited by its lack of specificity. Many residents would not be motivated to, or capable of, deducing which appliances were the main consumers of electricity based solely on the household's total electricity consumption, which is why a monitoring system that provides appliance-specific feedback is particularly useful. Unfortunately, the level of granularity or detail of the feedback is in direct proportion to cost of acquiring it.

Nonintrusive load monitoring (NILM) tracks and analyses electrical occurrences based on voltage and current readings obtained from the main circuit (Berges et al. 2010). Once the power is calculated using the voltage and current, event detection takes place, where significant changes in power consumption are noted and the system attempts to recognise the appliance that was likely to have caused it. This data is then used to classify the electricity consumption per appliance, utilising user input to improve performance and accuracy over time (Cominola et al. 2017).

The advantage of non-intrusive load monitoring is that highly detailed information can be collected without the cost and intrusion of installing a complete home energy management system for monitoring purposes (Cominola et al. 2017).

Berges et al. (2010) presented nonintrusive load monitoring as an approach to a reducing energy consumption. The first study was focused on the use of non-intrusive load monitoring to improve the outcome of energy audits on buildings that are conducted by trained technicians. The second study involved the use of non-intrusive load monitoring systems in residential areas with the resident being the focal point of the study.

An energy audit is carried out on a building to determine the amount of electricity used and to identify opportunities to reduce consumption without having an impact on the residents' comfort levels (Berges et al. 2010). There are many ways to reduce electricity consumption in buildings but the cost of identifying and quantifying the opportunities is generally perceived to be too high for most households.

The study conducted by Berges et al. (2010) explored the possibility of enhancing these electricity audits with the use of Non-Intrusive Monitoring techniques.
The study was conducted over 5 days and ultimately compared the fridge's measured consumption, at 15.48kWh, with the predicted consumption using the NILM technique, at

13,19kWh, and concluded that the NILM technique could be employed during electricity audits once more work is done to reduce the errors in the predicted consumption.

The approach for the second study conducted by Berges et al. (2011) was designed around the user and relies on input from the user to continuously improve the performance. This is the main difference between the 2010 study and the 2011 study.

Interestingly, in the average household in the USA, 12 types of appliances account for 80% of electricity consumption, so the study conducted by Berges et al. (2011) focused on the monitoring of just these appliances. The purpose of this adjusted focus was to reduce the study's scope, thereby reducing costs, without compromising accuracy or level of detail. The study findings were also positive, with an overall accuracy of the detection and classification of events at 82%.

2.6. Fixture Assignment Problem

Ranjan et al (2014) acknowledge that there are several new sensing technologies available that can detect energy usage in residences at fixture or appliance level.

However, a suggestion is made that the fixture assignment problem, the assignment of fixture energy usage to individual appliances, is largely an unresolved issue. This means that even though residents may have access to electricity consumption sensing technologies for their homes, it is still difficult for them to discover individual energy saving actions because the identification of the appliance that is actively consuming electricity is not obvious.

Guvensan et al. (2013) approached the issue by measuring indirect indicators of electricity consumption in the home. This study discussed the design and performance of the Tiny Energy Accounting and Reporting System (TinyEARS). This is an energy monitoring system that reports power consumption on a device level based on the sound of the appliances being turned on and off.

Ranjan et al. (2014) focused their study on the identification of electricity users at home by using radio frequency identification (RFID) location tracking. In other words, the monitoring system tracked the movements of the resident to make deductions about which appliance was consuming electricity.

The TinyEARS system consisted of wireless audio sensors with one sensor located in each room of the house, a real-time power meter and a configuration utility on a PC to manage the

TinyEARS algorithm. The design was tested during a deployment of the system in a two-bedroom apartment in Buffalo, New York. The residents were asked to record an accurate time log showing which appliances were switched on or off at what times during the day. (Guvensan et al. 2013).

The RFID study used real-time tracking information in parallel with the appliance level sensing to pinpoint exactly which appliance was consuming electricity at any given time. The study was conducted with 5 groups of 2 participants who lived together in a test home over the course of 7-12 days (Ranjan et al. 2014).

The proposed Tiny Energy Accounting and Reporting System (TinyEARS) could report on appliance level electricity consumption within a 10% error margin (Guvensan et al. 2013). Meanwhile, the findings of the RFID study proved an accuracy of 87% using room-level tracking and 97% using coordinate level tracking. (Ranjan et al. 2014)

2.7. Estimations and Simulations of Electricity Usage

The preceding sections of this chapter have outlined several approaches to monitoring electricity at home.

Some researchers acknowledge the importance of the resident's active involvement in the monitoring process (Srinivasarengan et al. 2014; Berges et al. 2011; Petersen et al. 2007). This is mainly based on the premise that the resident gains an understanding of their consumption patterns by actively engaging in the process. This knowledge is believed to be vital for electricity conservation.

However, other researchers are not actively involving residents in their studies (Guvensan et al. 2013; Beaudin et al. 2015). Instead they are tending towards the field of automated home energy management systems that use algorithms to analyse the consumption data collected.

Until these systems have been in operation for a prolonged period, there is only a small pool of data that these algorithms have access to (Srinivasarengan et al. 2014). This is disadvantageous for two main reasons. Firstly, there is a lack of seasonal data, i.e. the model does not encounter the variability of electricity usage due to differing weather conditions until a full years' worth of data has been collected.

Secondly, due to the unique characteristics of the residents and contents of a household, several possible scenarios may not be encountered often enough for the algorithm to recognise a slight variation in the pattern and it could interpret the data incorrectly as a result.

One solution to this problem is to incorporate an all-encompassing simulated data set into the smart meter's algorithm. Using this data set, the algorithm can better cater for any possible scenario from the first day of operation.

Srinivasarengan et al. (2014) developed a model with the capacity to discover appliance characteristics and contextualise information, thereby refining and improving the generated usage patterns. The proposed data simulation was applied to a non-intrusive load monitoring management system and the study found that the approach was useful and it should be tested for more applications in future works.

A simulation is a theoretical imitation of the real-world system that includes use cases for every conceivable scenario and an estimation is a rough calculation of the expected output based on a sample study (Srinivasarengan et al. 2014).

Estimated electricity consumption patterns are not applicable to the enhancement of home energy management algorithms (Craig et al. 2014). Rather, estimations can be used to arrive at ballpark target electricity consumption levels for an electricity conservation effort for a municipality or a town.

Whether simulated data or estimated data is used to build a model during the studies, checking for the correlation between the actual metered data and the model's output is an important step in the experimental design.

During a study conducted by Menezes et al. (2014), an electricity usage prediction model was developed and used to generate usage data predictions using several variable inputs which they then compared with actual metered data. The study found that the correlation between the two data sets was consistent, providing evidence that electricity usage patterns could perhaps be generated for a household based on a model as opposed to monitoring actual electricity usage.

A finding of the study conducted by Craig et al. (2014) was that a "carbon footprint calculator", a specially designed questionnaire, could successfully be used as a tool to predict or gauge electricity use when consumption data is not available or measureable. A significant association was found between estimated carbon footprint and actual electricity consumption Craig et al. (2014).

2.8. Models for Energy Efficient Buildings

As mentioned in Section 2.2, if residents do not have adequate control over their electricity consumption at home, they will find it very difficult to conserve electricity (Mastrucci et al. 2014). One major cause of this lack of control is energy inefficient buildings.

In Europe and other northern regions in particular, 68.4% of energy that is consumed in homes is used for space heating and 13.6% is used for water production. Only 3.8% of the total energy that is consumed in the home is actually used for cooking. 14.1% of the total energy consumed is required for lighting and other appliances.

Besides providing residents with enough control to implement electricity conservation behaviours, constructing energy efficient buildings can provide energy reduction potential without reducing the quality of life experienced by the residents.

During a study focused on estimating potential energy savings in buildings in Rotterdam based on Geographic Information System (GIS) data, an interesting discovery was made (Mastrucci et al. 2014). Older buildings were generally less energy efficient than newer buildings. However, apartment blocks that were built between 1965 and 1974 have higher energy consumption than older buildings because of the introduction of the use of a lightweight building material with poor thermal resistance. This highlights the importance of using thermal resistant building materials during construction.

Other trends discussed by De Boeck et al. (2015) during a review of recent studies conducted on the energy efficiency of buildings include:

1. The enveloping of appliances, for example applying geyser blankets.
2. Double glazing windows and shading windows.
3. “HVAC” systems (Heating, ventilation and air conditioning).
4. Use of energy efficient appliances and lighting.

2.9. Electricity-related Information and Communication Technology for Development

It is important to include a brief introduction to the ICT for Development (ICT4D) field in South Africa to provide local context to the development aspect of this study.

Besides the use of information and communication technology (ICT) for the monitoring of electricity consumption, ICT has also been applied in other ways for development within the electricity sector. Two South African electricity-related studies involving ICT are discussed in this section. The first study addresses the impact of the recent pilot rollout of prepaid electricity meters in the City of Cape Town and the second study is the iShack project in Enkanini near Stellenbosch.

Prepaid electricity metering has been introduced in South Africa as an alternative to billing customers for electricity previously consumed (Jack et al. 2016). This is an effort aimed at preventing unpaid accounts and lost revenue to the utility. This study used data from the City of Cape Town to determine the impact that prepaid electricity metering has had on residential consumption and the revenue made by the electricity utility.

Approximately 4000 customers were involuntarily selected by the municipality for a transferral from billed electricity accounts to prepaid electricity accounts (Jack et al. 2016). Analysis of the data shows that electricity consumption fell by 13% in the first year and this level of consumption was maintained during the following year as well. The study does not mention a measure of customer satisfaction but, as mentioned, the switch from billed electricity accounts to prepaid electricity accounts was involuntary.

The iShack project was set up in Enkanini outside Stellenbosch, South Africa by the Sustainability Institute Innovation Lab (SIIL) as a pilot study for delivering smart and sustainable off-the-grid utilities to poor communities in Southern Africa (iShack. n.d.). The iShack project demonstrates how solar electricity installations can be used to upgrade informal settlements in a modular way. This is so that capacity can be increased as needed and as the costs of solar PV panels are reduced with technological advances.

2.10. ICT in the home

Having thoroughly explored the related work that falls within the electricity sector, this section provides a brief look at the research that has been done on information and communication technology at home.

A discussion about studies focused on ICT in the home that are not necessarily related to electricity consumption monitoring is relevant to the scope of this study. This is because although the objectives of a Home network system may differ, the design requirements contain many similarities with the requirements for an electricity monitoring system or mobile application. Home network systems lend themselves to scenarios that require easy communication, quick information reference capabilities and time-based reminders, hints and tips. Similarly, these requirements can apply to an electricity monitoring system.

The studies discussed are both health related. The first is applicable to new parents who need assistance with their new-born baby and the second is applicable to elderly residents who need attention because of age related ailments, but who are eager to maintain an independent lifestyle.

A mobile health application called ‘Home but not Alone’ was developed by Shorey et al. (2017) in an effort to provide new parents with personalised educational content and real-time support once they were back at home with their new-born babies.

Research shows that this transition period with a new baby can be particularly stressful for both parents, whether the baby is the first-born or a sibling to a young toddler. The need for a tool like this was identified because of a lack of availability of educational programmes focussed on common issues faced during this time.

The application was designed to be mobile-based for easy availability to new parents. The application is highly interactive, encouraging parents to communicate with medical professionals when the need arises. Parents are also sent specific articles and videos based on their baby’s current age and stage of development. In addition, all the information available on the application has been prepared by medical professionals, which is an incentive for parents to follow the advice provided by the application rather than attempting to navigate the often contradicting and misleading oddments of information to be found on the Internet.
This study described the protocol for measuring the effectiveness of the application with a sample group, but the results of the study are yet to be published.

eWALL, a smart home environment, is an EU initiative aimed at improving the lives of elderly residents with age related impairments such as mild dementia or chronic obstructive pulmonary disease. The system monitors and assists with the health conditions of the resident, but it also provides the resident with the motivation and empowerment to live unassisted for as long as physically possible and as long as desired. The system prompts the resident with helpful suggestions and reminders via a computer monitor and monitors the resident’s state of health via sensors and networked communication channels (Koren, 2016).

2.11. Use of mobile or desktop applications for any monitoring purposes

As was the case for the previous section, discussing the use of a mobile or desktop application for any monitoring purpose is relevant to this study because there may be similar design requirements for an electricity monitoring application and a health care monitoring application.

Over the last few years, the use of Ubiquitous Healthcare (U-Healthcare) by patients for health check-ups has emerged as an alternative to attending check-ups at a centralized hospital (Jung et al. 2015). A U-Healthcare system enables the real-time monitoring of the state of a patient regardless of where the patient is located. It has been used in applications such as medical check-ups, monitoring of chronic conditions such as diabetes and in emergency medical situations.

Jung et al. (2015) propose a U-Healthcare system for the early detection of acute myocardial infarction (AMI) cases, commonly known as heart attacks. The system consists of a wearable detection device that the patient straps onto the wrist that houses a microneedle that extracts a blood sample from the patient when pressed downwards. The blood sample is then scanned for AMI cardiac markers using three-dimensional bio-electrical sensors (also housed within the wearable device). This system is controlled using an Android-based application, which also collects cardiac marker data. The application allows the patient and their medical personnel to review the information and determine the patient’s medical condition.

Having consulted the Android Play store, it appears that the use of an application for monitoring purposes has also been applied to the following:

1. Managing money
2. Weather updates
3. Tracking mobile data usage / cell phone battery monitoring / load monitoring / internet speed monitoring
4. Dental health monitoring
5. Medical monitoring (manual & sensor based)
6. Fitness monitoring
7. Baby monitoring
8. Home security monitoring
9. Power Failure monitoring
10. Privacy Monitor
11. Sleep Monitor and
12. Vehicle logger

2.12. Gaps and Opportunities

The main motivators for electricity conservation are cost savings and environmental conservation. The incorporation of these drivers in engaging electricity consumers in conservation activities is key. Residents also do not have a good understanding of the most effective methods for reducing their electricity consumption. Therefore, providing them with a tool that allows them to monitor their electricity usage and subsequently provides them with visuals of their electricity usage patterns will potentially improve this level of understanding.

There are several electricity monitoring systems available on the market for residential use, but the reporting systems that are available require expensive, time consuming installations and otherwise can’t provide device level reports. Further, financial constraints are considered one of the main reasons provided by residents for not conserving electricity.

Many of the monitoring systems available on the market are also highly automated which results in the end user being excluded from the process. Keeping in mind the importance of consumption awareness on behalf of the end user, it is vital that they remain an active part of the value chain.

2.13. Chapter Summary

This chapter outlined the literature review for the study. The various approaches to electricity monitoring in the home were discussed, from HEMS to user centred monitoring studies to electricity usage simulations. The chapter also discussed the work done on electricity-related information and communication technologies for development (ICT4D), the use of information and communication technologies (ICT) in the home and the use of mobile or desktop applications for any monitoring purposes. The chapter described a field of research that has been explored for many years, but the final section highlighted several gaps and opportunities to be taken advantage of, such as the misunderstanding among residents about their electricity consumption patterns and how to effectively conserve electricity.

3. Design and Implementation

3.1. Chapter Overview

This chapter is split into two main sections: the first section discusses the design of the application and the second section addresses the design of the experiment.

3.2. Design of the Application

3.2.1. User-centred design process

As mentioned in Chapter 1, the application was designed with the user in mind, with close user involvement throughout the process. A user-centred design process was followed to ensure that user input was acknowledged and incorporated in the design right from the outset of the design phase. Focus Groups were held at frequent stages of the design process for iterative feedback purposes.

A diagram showing the phases of the User Centred Design Process is shown in Figure 2.

Figure 2: User Centred Design Concept
(Source: User Centred Design Basics. 2017)

Firstly, the need for the design is identified, in this case the need for the design was identified because there were no electricity monitoring applications available on the app stores.

Then the next stage involves the specification of the user profile: who will use the tool, what will it be used for and in what context it will be most useful. In this case, people with a desire to reduce their electricity consumption for economic or environmental reasons were identified as potential users.

Stage 3 then identifies the user requirements that must be met in order for the tool to be classified as successful. This was done in the form of a focus group.

There is then an iterative design phase, where a stage-by-stage process is followed to develop the tool from a vague concept to a prototype with a satisfactory user interface and eventually to a complete and functional design. Again, there is close user involvement during this phase, also in the form of a focus group in order to ensure that the design does not stray too far away from the user requirements.

3.2.2. Identification of Requirements: Focus Group 1

The first step in the design process was to gather user requirements for an electricity monitoring application. A focus group was held with 6 participants to gather their input, specifically related to the look and feel of the user interface for the application.

1. Purpose of a focus group

The purpose of this focus group was to gather opinions, beliefs and attitudes about electricity consumption and to encourage discussions about the topic. During the first focus group for this study, the participants' understanding of their electricity consumption was explored, as well as their feedback on what they would want in a tool that was supposed to assist them to monitor electricity usage. The spontaneous combination of the participants' comments and feedback creates a helpful platform for testing assumptions about user requirements.

2. The Participants

The 6 participants volunteered to be involved in the focus group and, since they were all well acquainted with the researcher, they constituted a convenience sample rather than a random sample. However, the range of age categories represented in the small focus group was wide, with the age difference between the youngest and oldest member being approximately 50 years. It is therefore believed that electricity consumption perceptions from different generations of electricity users was well represented. 4 of the 6 participants were home owners, 1 participant was a tenant and the last participant lived in a student dormitory. 3 of the participants had prepaid electricity meters, 2 participants had billed electricity meters and the participant from the dormitory was not billed for electricity.

3. Procedure

The participants were informed of the purpose of the study and provided with the breakdown of the study's research question.

They were then briefed regarding the process of the focus group and asked the following questions regarding their current understanding of electricity consumption:

1. Do you have an idea of how much electricity you or your household consumes daily/weekly/monthly?
2. Do you know exactly what to do to reduce your electricity consumption?
3. Do you know to what extent different appliances contribute to your consumption?
4. What would drive you to try to reduce your electricity consumption?
5. Can you imagine an electricity consumption application working? What works and what does not work?
6. How would you feel about using this application for a week? For a month?
7. Do you think that it would be necessary for this to be a mobile application or would a web-based (desktop) application work just as well?
8. Exactly what information should be displayed to help the user reduce their consumption?

4. Feedback

In response to questions 1-4, roughly half of the focus group had no idea how much electricity they consumed over time. Also, half of the participants did not have suggestions as to how they would go about reducing their consumption and they were unclear about appliance-specific electricity consumption rates.

The other half of the focus group could provide either a rough estimate of their monthly electricity bill or knew exactly how many kilowatt-hours of electricity they were consuming per day. They also had suggestions regarding which appliances were the biggest electricity consumers, namely the geyser and the washing machine. Several people also suggested that turning off plugs and chargers that were not being used and installing energy saving light bulbs would reduce one's electricity consumption.

In response to question 4, the general consensus from the focus group was that a big motivator for reducing one's electricity consumption was monetary. In addition, the reduced impact on the environment was also mentioned as a driving factor.

In response to the later questions, the main feedback regarding the user interface was that it was important to them that they would not have to enter in too much data. Generally, participants said they would use the application intensively for a week but, for a time period of a month, the required user involvement would need to be reduced.

When asked about the type of device they would prefer to use, there were mixed responses. Some older participants said that they were less comfortable using their mobile devices for tracking purposes and that they would prefer a larger, more user friendly desktop screen size. Younger participants saw the benefits of the use of a mobile device because of their inherent ubiquity. Eventually it was concluded that if possible the application should be designed to be compatible with both mobile devices and desktop devices.

Finally, participants mentioned that they would prefer to be provided with a picture-per-appliance "dashboard" of high consumption appliances to track the electricity consumption instead of having to list all the appliances they had in their houses. This concept was seen as too time consuming for users. However, the group also discussed the option of collecting user details in order to create a household profile to make this dashboard more personalised. Another suggestion was for the application's dashboard to be organised "room-by-room", meaning that appliances that are generally located in the same rooms in a house should be grouped together.

For usage pattern feedback purposes, users mentioned that they would want to be provided with stacked bar graphs showing a block for the consumption per appliance for each day. They also mentioned that it would be most useful to them to know how much each appliance's daily consumption cost them rather than being given the electricity consumption in kWh for each appliance.

Some other useful suggestions gathered during the focus group were also provided during a last group discussion. Participants stressed the importance of not having to switch between different pages in order to complete the data entries and the importance of a step by step guide was also discussed. Finally, the focus group participants were keen on the idea of making the application more fun by introducing a game concept to it; introducing a neighbourhood leader board may appeal to users' competitive nature. There was also a suggestion that the application needed an animated mascot providing helpful hints to make it more interesting to users.

5. Conclusion

In conclusion, the feedback during the first focus group highlighted the importance of making the application as easy to use as possible without expecting users to spend too much time entering data. It also emphasised the importance of making the application fun and interesting to use. A clear idea of the kind of electricity usage patterns that should be provided was also formed; a daily comparison in the form of a stacked bar chart would be useful and consumption should be described in terms of cost instead of kilowatt-hours.

The decision to create a cross-platform application was made following feedback from the first focus group, where a case was made by several members of the group that older participants would be more comfortable with the use of a desktop application rather than a mobile application.

3.2.3. Exploring tools for application development

Having concluded the focus group and gained some insight into what users would potentially want from an electricity monitoring application, the focus of the study turned towards identifying an application development tool or service that best suited these requirements.

One of the findings that emerged from the focus group was that different types of users would have different device preferences, so it was decided that a cross-platform application should be developed. The idea was that one design could be implemented and deployed for multiple types of devices.

TouchDevelop was first identified as a useful tool for quickly developing application prototypes and a lot of time was spent exploring what the service had to offer (TouchDevelop, n.d.). Unfortunately, it became clear that, although it was a well-designed, interesting tool for learning how to create one's own application, ultimately it lacked several features, such as the capacity to successfully publish the application to the public domain. It would not therefore be possible to distribute the application to participants in the study.

Ionic Framework was eventually identified as an ideal tool for developing cross-platform applications and this tool was used for the study (Ionic Framework, n.d.). Ionic Framework is a free and open source Software Development Kit (SDK) that is Cordova-based (Ionic Framework, n.d.). Cordova packages Angular JavaScript (AngularJS), Hypertext Mark-up Language (HTML) and Cascading Style Sheet (CSS) to create Web-based mobile and desktop applications. Despite having a single codebase, Ionic applications are compatible with the three main operating systems that are commonly used today, namely iOS, Android and Windows.

There are a number of advantages of using Ionic Framework, such as:

1. Its ability to provide all the functionality that is available in native mobile application development kits including the provision of services such as push notifications and access to local device storage (Ionic Framework, n.d.).

2. The use of AngularJS as opposed to jQuery (Ionic Framework, n.d.) which allows the application to rely on native hardware acceleration and makes custom components such as scrollable containers called scroll views available.

3. The high performance of Ionic applications when compared with other hybrid applications due to the unique combination of front end and back end functionality provided by CSS and AngularJS respectively.

4. The availability of easy to use starter templates making the construction of the "outer shell" of the application quick and hassle-free.

Once Ionic Framework had been chosen as the tool for the development of the application, the next phase of the study focused on the application's user interface. An effort was made to ensure that the user requirements mentioned in Section 3.2.2 were prioritised.

Although the creators of Ionic seem to want to eventually provide users with a drag-and-drop template-based design environment for quick and easy application development from beginning to end, this service is limited now and the application design and development required a reasonable understanding of JavaScript, HTML and CSS coding and/or file structuring.

There were several highly useful application starter templates available via an online service called Ionic Creator (Ionic Creator, n.d.). A template that included a side menu function was used as the basis of the electricity monitoring application. This template was then downloaded, incorporated into an Ionic Framework project and edited.

A screenshot of the Ionic Creator dashboard is shown in Figure 3. The components on the left panel can be selected as required and dragged and dropped onto the mobile screen. The screenshot shows the design for the mobile application, but as mentioned, the structure of the Ionic code structure allows for the simultaneous development of both mobile and desktop applications. These components are then edited further in the right panel.

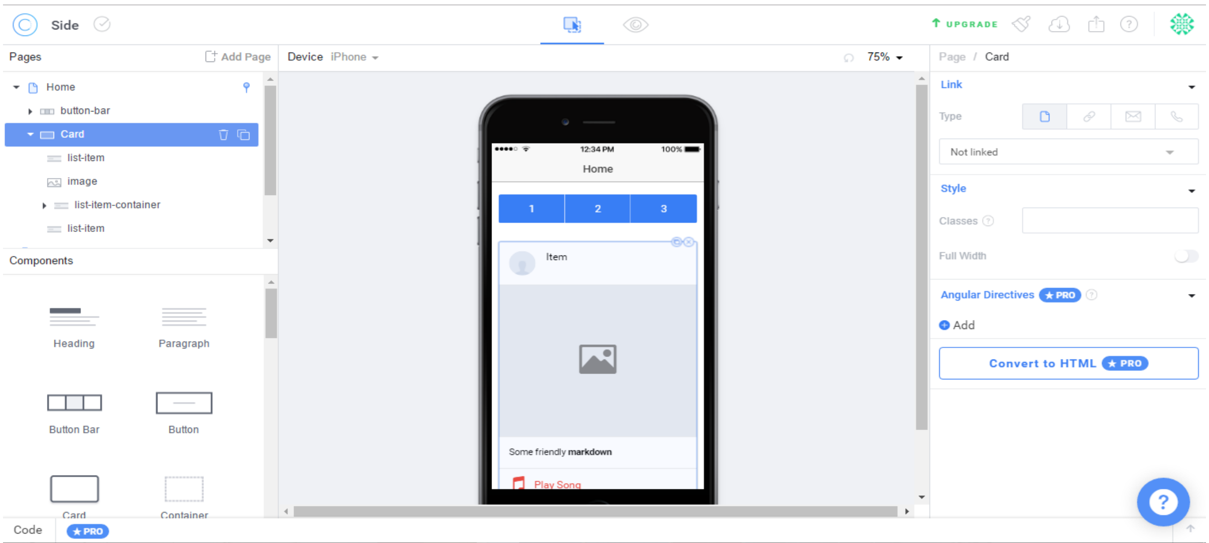

Figure 3: Screenshot of the Ionic Creator dashboard (Ionic Creator, n.d)

An advantage of using the Ionic Creator side bar template is that it gives the application the look and feel of a native Android or iOS application.

The Ionic Creator template was developed further to produce the application that was eventually used for the study. As mentioned, attention was first given to the layout of the application and shown to users during another focus group before most of the functionality was built into the design.

The Ionic file structure is Cordova-based and subdivided into folders according to file types (Ionic Framework. n.d.). Most of the application development happens within a folder called WWW. Although the file structure can be edited, Ionic initially organises the application into the following directories inside the WWW folder: CSS, IMG, JS, LIB and TEMPLATES. The file structure for the application is shown in Figure 4.

```
WWW:
│    index.html
│
├────css
│        ionic.app.css
│        ionic.app.min.css
│
├────img
│
├────js
│        app.js
│        controllers.js
│
├────lib
│    ├────angular
│    │
│    ├────d3
│    │
│    ├────ngstorage
│
│
└────templates
         graphsPage.html
         HelpPage.html
         SettingsPage.html
         switchAppliancesOnOff.html
         tabsController.html
```

Figure 4: File Structure of the Application

1. The CSS folder contains the application's specific CSS file which centrally houses all the code that is required to apply style rules to the content of the application.
2. The IMG folder is where all images that need to be included in the application's display are saved.
3. The JS folder contains all the files written in AngularJS code which control how the application operates. The two most important subfolders in this application's JS folder are app.js and controllers.js. App.js defines the application's configuration and routing setup, as well as the tab styles that are used for navigation purposes. Controllers.js contains a separate portion of code for each tab in the application and it dictates how the application needs to respond to the user's inputs.
4. The LIB folder contains all the Ionic libraries and added plugins, such as the d3.js and SQLite plugins which are mentioned in this chapter.
5. Finally, the TEMPLATE folder contains an HTML file for each page view in the application.

3.2.4. Design of the User Interface

Figures 5 and 6 show the user interface for the main Appliance Timer tab of the mobile and desktop application respectively.

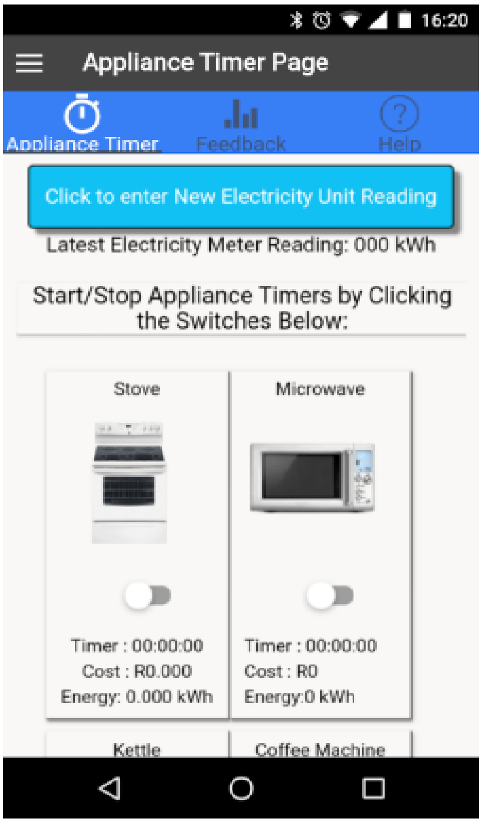

Figure 6: Screenshot showing the final user interface design for the mobile application

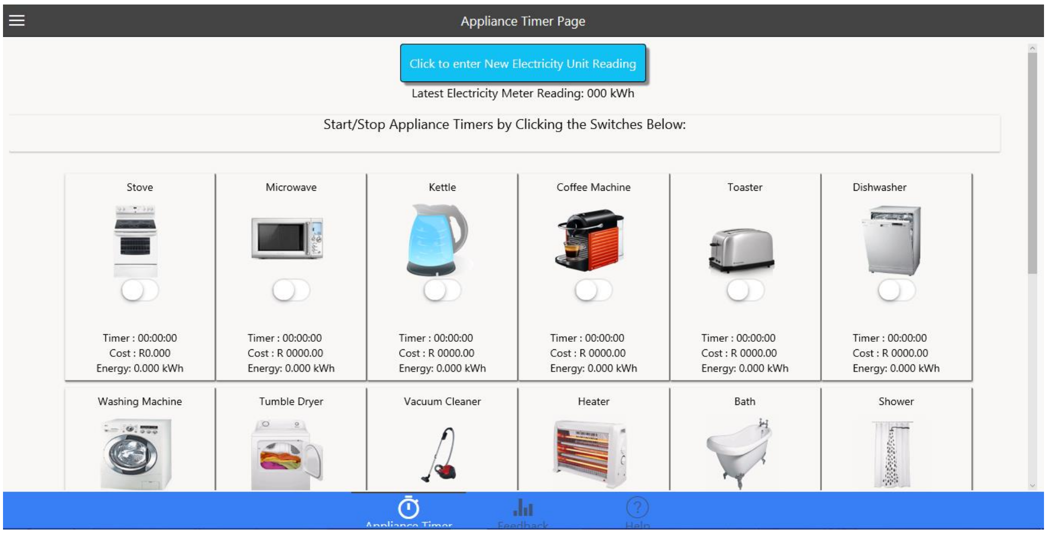

Figure 5: Screenshot of the user interface on the desktop Electricity Monitoring Application

The feedback from the first focus group showed that users wanted an application that did not require a lot of data capturing on their part. Therefore, the user is not asked to list or select the appliances they have in their homes. Instead, a generic home appliance dashboard was decided, based on assumptions regarding:

1) Appliances with relatively low electricity consumptions are not included in this application as they do not have a significant impact on overall electricity consumption. Some examples of the appliances that are not included are the fan, lightbulbs and small battery chargers.
2) The probability that the appliance would be found in the majority of households; for example, although a Jacuzzi would have a big impact on the overall electricity consumption results, it is an uncommon household possession.

The order in which the appliances appeared on the dashboard was also considered so as to try to reduce the total scrolling time each time the user switched an appliance off or on. An attempt was made to group like appliances together. For example most appliances found in the kitchen were listed together, then several appliances with cleaning objectives were grouped together, then heat- related appliances were grouped together and finally came the last few luxury appliances. Eventually, the dashboard of appliances included the following:

1. Stove
2. Microwave
3. Kettle
4. Coffee machine
5. Toaster
6. Dishwasher
7. Washing machine
8. Tumble dryer
9. Vacuum cleaner
10. Heater
11. Bath
12. Shower
13. Hair dryer
14. Television
15. Pool pump
16. Air conditioner

A photograph, the appliance's name, a toggle button and text displaying Time, Cost and Energy timers were arranged on an individual card representing each appliance. A toggle button below each appliance's picture is supposed to be clicked on to switch appliances on and off as they are used at home. The timers below the toggles are updated every second, starting when the toggle is switched on and stopping when it is switched off again. This has the added benefit of showing the user evidence that the application is reactive to their inputs.

The cards were then arranged in a grid-layout. Since the application was designed for both mobiles and desktops, "Responsive Web Design" techniques were used to ensure that the user interface worked well for both the tall, narrow screens of mobile phones and the shorter, wider screens of desktop computers (Responsive Web Design Techniques, Tools and Design Strategies. 22 July 2011).

Generally, the content within a screen was automatically wrapped so that once a row was full the next items fell onto the next row. Otherwise, the screen width of the device was detected and used as a variable in the code to ensure that the size of the content is adjusted for the screen size.

Grid-layouts tend to work well for responsive Web designs since the number of cards or blocks in each row and column can quite easily be adjusted according to screen sizes. In other words, a mobile application will have more cards in each column and fewer in each row than the desktop application. Most advice that can be found on online coding forums suggests designing cross-platform applications for the mobile version first and then to make adjustments for the larger screens.

The application was structured with three tabs:

- The "Appliance Timer" tab; for data capture.
- The "Feedback" tab; for graphs to give users feedback about their consumption.
- The "Help" tab where users can swipe through the step-by-step guide.

Icons were specially chosen to try to give the user clues as to the function of each tab. The icon used for the Appliance Timer tab is a stopwatch, the icon used for the Feedback tab is a horizontal bar chart and the icon used for the Help tab is the universally recognised question mark icon.

3.2.5. Iterative Design – The Second Focus Group

The second focus group was held once the layout of the application had been completed. Three participants took part in this focus group and they were shown the application and given some time to test out the look and feel of the user interface. Again, discussions about the user interface were encouraged.

There were fewer findings for focus group 2 and these findings were less detailed than those of focus group 1, but they were useful and concise. Participants in focus group 2 pointed out that it needed to be more obvious to users what they needed to do when they first launched the application. In addition, they were confused about what the toggles were for and said that they needed evidence of what was happening behind the scenes when they clicked on the toggles. In other words, the immediate effect of their actions on the user interface was not obvious.

As a result of the findings of the second focus group, several changes were made to the user interface. Firstly, a step-by-step guide was introduced to the application design, which led the user through the experiment and explained how they would be using the application to monitor their electricity usage. Secondly, to immediately inform the user what was happening when they turned a toggle on or off, timers were added below each appliance's picture, which began as soon as the toggle was switched on and stopped every time the toggle was switched off. In addition, just to be certain that there was no confusion when identifying appliances, the names of the appliances were also displayed above the pictures of the appliances.

3.2.6. Refinement of the Functionality of the Application

Once the user interface was deemed satisfactory, the functionality of the application was developed further. Cordova, and therefore Ionic Framework, uses a plugin architecture to allow the application to have access to native device features that would not be accessible to Web applications (Ionic Framework, n.d.). Access to Cordova plugins was essential for providing the application with features such as feedback in the form of graphs and database functionality for managing the storage of historical appliance usage data.

The plugins that were used for this application included d3.js (Data-Driven Documents, n.d.) for the creation of the stacked bar chart on the feedback page and Cordova's SQLite storage plugin (SQLite Storage Plugin, n.d.) for database management of the data that is collected during the monitoring process.

The open source D3.js JavaScript library was added to the application's file structure and used to display the user's electricity consumption cost per day graphically. D3.js uses HTML, Scalable Vector Graphics ("SVG"), and CSS to create graphical displays of the data.

Offline storage is needed to store the state of the application, appliances and appliance usage. SQLite, which is a compact, embedded SQL database engine was chosen for this function and added as another library in the application's file structure. It uses the device's own storage and provides easy access to that data when it is needed again to perform a function. Three tables were created in the SQLite database, namely the Electricity Reading Table, the Appliance Table and the Log Table. The data saved in each of these tables in the database is arranged in the columns shown in Table 1.

Table 1: Contents of the application's database in SQLite

Table Name	Appliance Table	Log Table	Electricity Reading Table
Column Name	ID	ID	ID
	Appliance Name	Appliance Name	Start Date Time Reading
	Wattage Estimated	Appliance Duration	Start Elec Reading
	Wattage Measured	Appliance Consumption	End Date Time Reading
	Date Time On	Date	End Elec Reading
	Date Time Off	Time	
	Appliance Status		

1. Appliance Table

The appliance table consists of one row for every home appliance that was included in the application, so there are 16 rows in total.

Each time the user toggles an appliance's switch on the application's user interface, the "Date Time On", "Date Time Off", "Appliance Status", and, where applicable, the "Wattage Measured" values for the relevant row are updated.

Each row contains the following:

1.1. A unique identification number in the "ID" column. This is a permanent value.
1.2. An estimated value for the appliance's wattage, e.g. 2.5kW for the stove, in the "Wattage Estimated" column. This is a permanent value.
1.3. A measured value for the appliance's wattage, which is calculated using the data in the electricity reading table, in the "Wattage Measured" column.

1.4. A date time value in the “Date Time On” column, which is updated every time the user switches an appliance on via the application’s user interface.
1.5. A date time value in the “Date Time Off” column, which is updated every time the user switches an appliance off via the application’s user interface.
1.6. An “Appliance Status”, which is either populated with an “off” or “on”.

Each time the user switches a home appliance on via the application’s user interface:

- The “Date Time On” value is updated.
- The “Appliance Status” is changed from off to on.

Each time the user switches a home appliance off via the application’s user interface:

- The “Date Time Off” value is updated.
- The “Appliance Status” is changed from on to off.

2. **Log Table**

Every time an appliance is switched off, a new row is also created in the Log Table:

2.1. SQLite automatically generates an identification number in the “ID” column.
2.2. The relevant “Appliance Name” text is copied from the Appliance Table to the “Appliance Name” column in the new row of the Log Table.
2.3. The “Appliance Duration” is calculated using the “Date Time On” and the “Date Time Off” values from the relevant row in the Appliance Table.
2.4. The “Appliance Consumption” is calculated using the “Appliance Duration” value in the Log Table and the “Wattage Estimated” in the Appliance Table.
2.5. The current “Date” and “Time” values are accessed from the mobile or desktop device.

3. Electricity Reading Table

When the status of the electricity meter reading is updated by a user via the application’s user-interface, the application saves a new row to the electricity reading table:

3.1. SQLite automatically assigns a unique identification number named “ID” to each new row.
3.2. SQLite accesses the mobile or desktop device’s current date and time and saves this to “Start Date Time Reading”.
3.3. The electricity reading that is entered by the user is also saved in the “Start Elec Reading” column.

The last two columns of the row are filled when the next electricity reading is entered by the user. In other words, for the second electricity reading entry and every entry after that:

3.4. The electricity reading that is entered by the user is saved in the “End Elec Reading” column of the previous row and to the “Start Elec Reading” column of the new row.
3.5. SQLite accesses the mobile or desktop device’s current date and time and saves this to the “End Date Time Reading” column of the previous row and to the “Start Date Time Reading” column of the new row.
3.6. If only one appliance has been used since the “Start Date Time Reading” in the previous row, the difference between the “Start Elec Reading” and the “End Elec Reading” is saved as the “Wattage Measured” in the Appliance table for that specific appliance.
3.7. The “Appliance Consumption” in the Log Table is also updated to reflect the “Wattage Measured” rather than the “Wattage Estimated”.

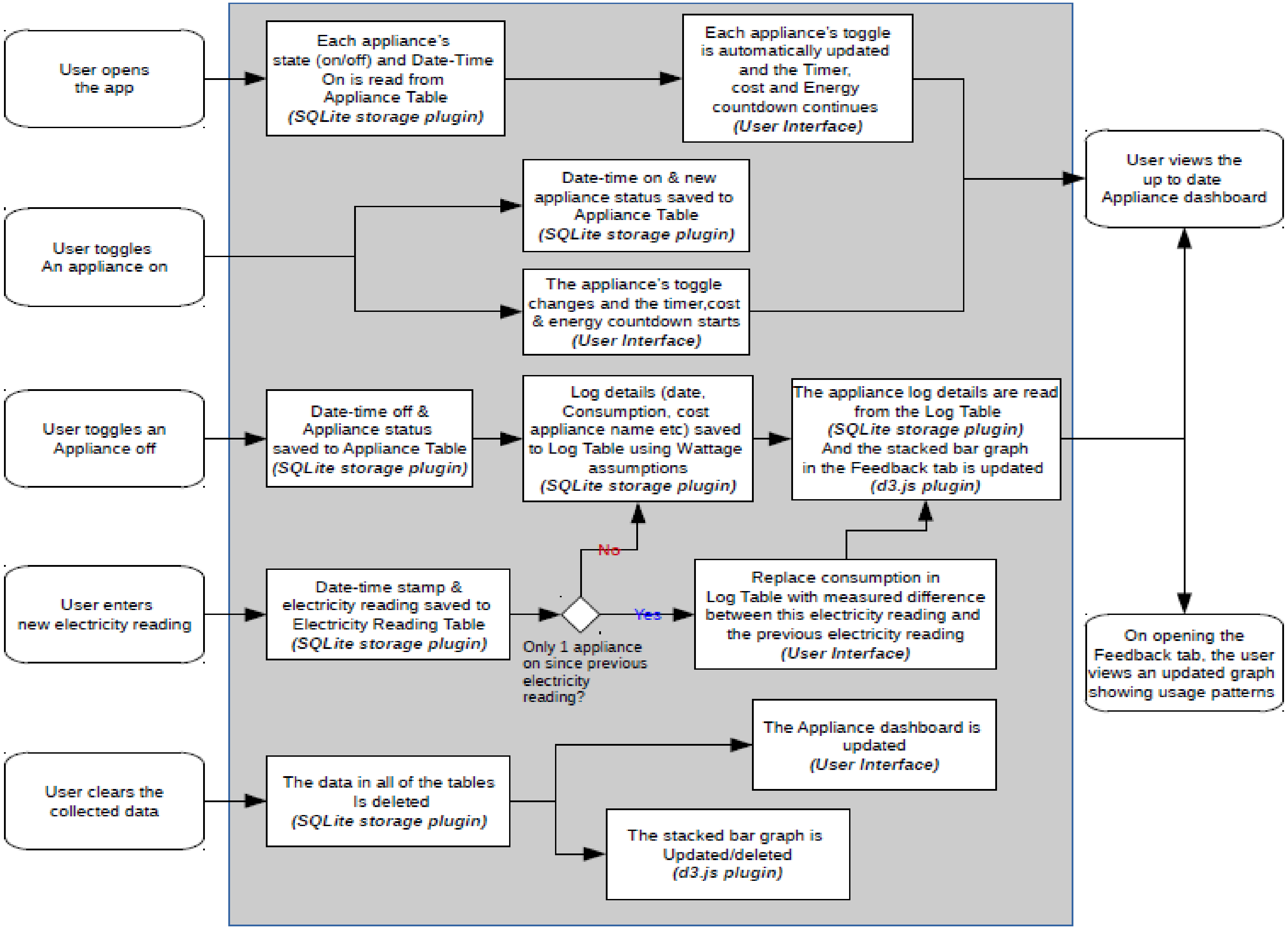

Figure 7: Schematic of the Electricity Monitoring Application

Figure 7 is a high level overview of the electricity monitoring application's process flows. All of the process steps to the left of the grey block represent user inputs and all of the process steps to the right of the grey block represent feedback that is relayed to the user. The process steps within the grey block itself represent a breakdown of how the application works. Although this may not be an exhaustive description of the code, it provides a good overview of the application's functionality.

A. "User opens the app": every time the user opens the application, the following process is triggered:

   1. The "Appliance Status", i.e. on or off, and, in the case of an appliance that is on, the "Date Time On" of each appliance is queried from the Appliance Table of the SQLite database.
   2. On the Appliance Timer tab of the application's user interface, each appliance's toggle is automatically updated to reflect the appliance status and time, cost and energy countdowns below the appliance's toggle button also continues to update.

Figures 8 and 9 show screenshots of the application's "Appliance Timer" tab when the user opens it in the mobile and desktop versions of the application respectively.

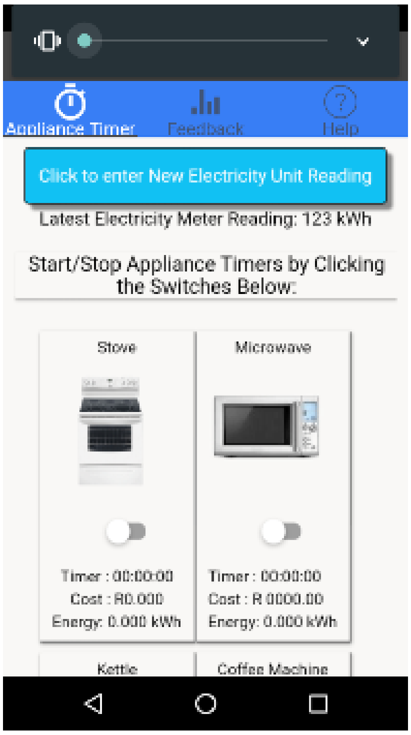

Figure 8: Mobile Screenshot - Appliance Timer tab when the application is opened

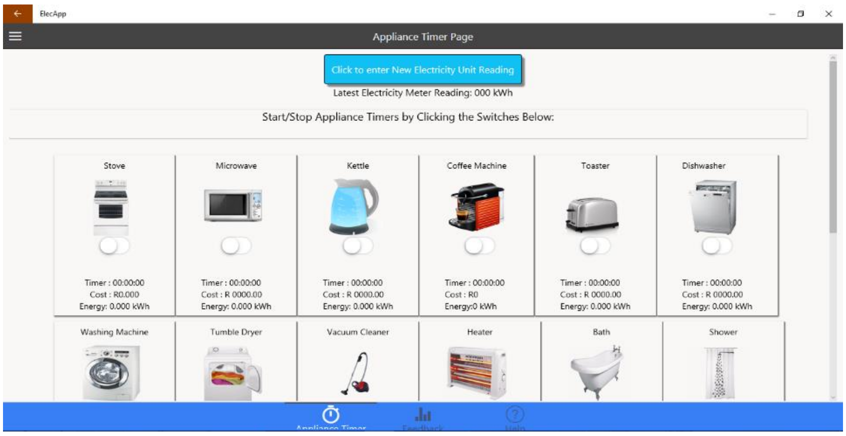

Figure 9: Desktop Screenshot - Appliance Timer tab when the application is opened

B. "User toggles an appliance on": In the Appliance Timer tab of the application, every time the user swipes an appliance's toggle to the right to indicate that the appliance is "on", the following process is triggered:

1. The "Date Time On" and the new "Appliance Status" in the Appliance Table of the SQLite database is updated
2. The appearance of the toggle changes to indicate that the appliance is on and the timer, cost and energy countdowns below the appliance also start timing. The timers are updated every second. The timers were added to provide the user with confirmation that the application has registered their actions and it also provides a live update on the amount of electricity currently being consumed. If the user had multiple appliances on, the dashboard would display this information in an accurate, concise manner.

Figures 10 and 11 show screenshots of the application's "Appliance Timer" tab when the user switches an appliance's toggle on in the mobile and desktop versions of the application respectively.

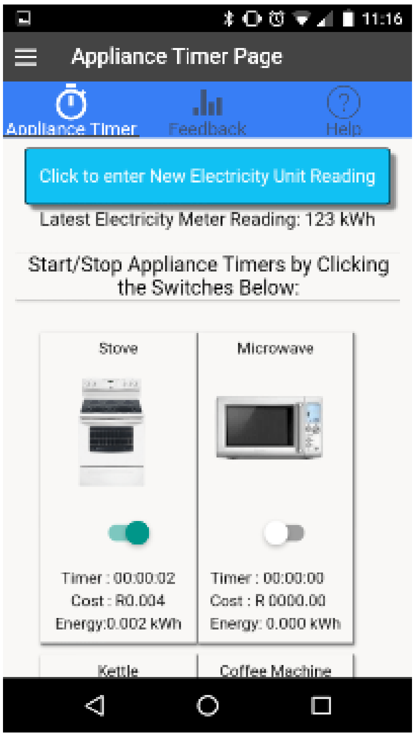

Figure 10: Mobile Screenshot - Appliance Timer tab when an appliance's toggle is switched on

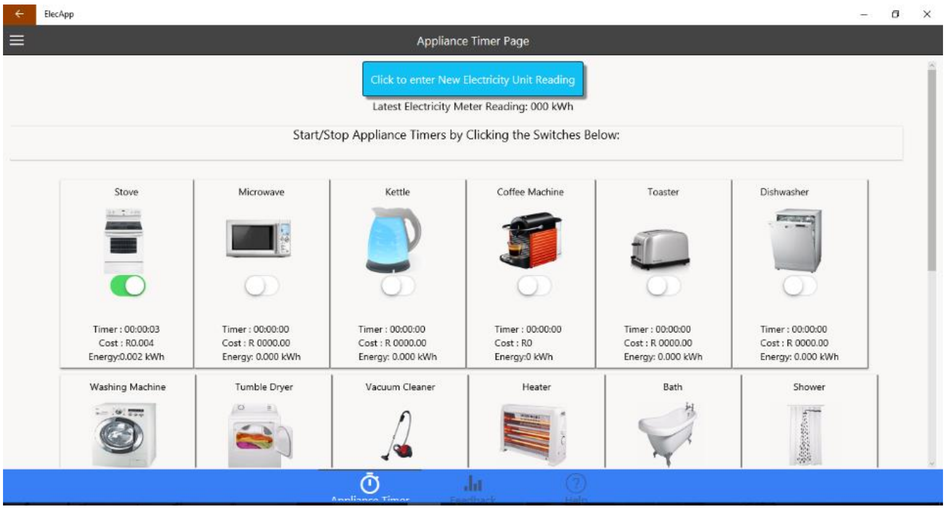

Figure 11: Desktop Screenshot - Appliance Timer tab when an appliance's toggle is switched on

C. "User toggles an appliance off": In the Appliance Timer tab of the application, every time the user swipes an appliance's toggle to the left to indicate that the appliance is "off", the following process is triggered:

1. The "Date Time Off" and the new "Appliance Status" in the Appliance Table of the SQLite database is updated.

2. The consumption and cost of the electricity used by the appliance needs to then be calculated. The “Date”, “Appliance Consumption” & “Appliance Name” are then saved to the Log Table of the SQLite database.
3. Finally, the D3.js stacked bar graph in the Feedback tab of the application is updated with the new information in the Log Table of the SQLite database to calculate the cost of the electricity consumed over time.

Figures 12 and 13 show screenshots of the application’s “Appliance Timer” tab when the user switches an appliance’s toggle off in the mobile and desktop versions of the application respectively.

Figure 12: Mobile Screenshot - Appliance Timer tab when an appliance’s toggle is switched off

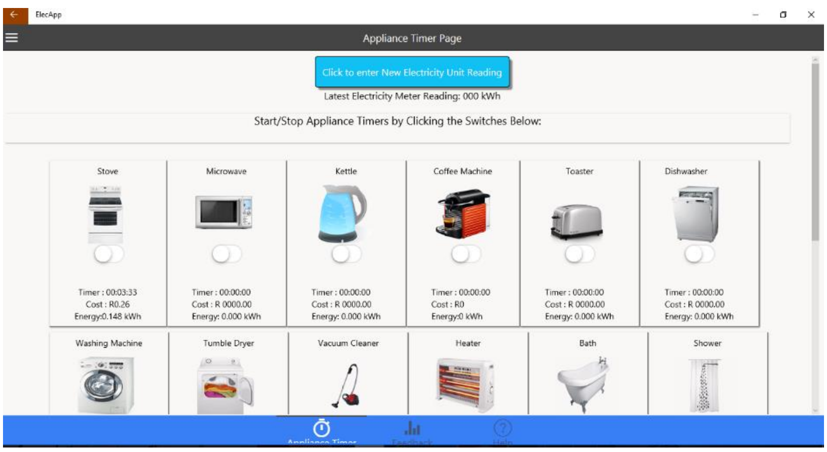

Figure 13: Desktop Screenshot - Appliance Timer tab when an appliance’s toggle is switched off

Figures 14 and 15 show screenshots of the application's "Feedback" tab. The bar graph is updated in the mobile and desktop versions of the application when the user switches an appliance off. The bar graph allows the user to see the total cost of electricity per appliance per day. Each appliance is colour coded and a legend is displayed below the graph.

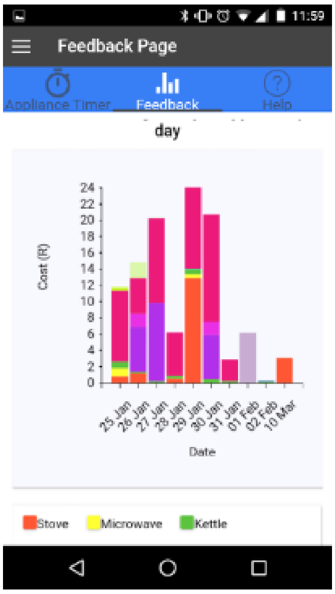

Figure 14: Mobile Screenshot - updated stacked bar chart in the Feedback tab

Figure 15: Desktop Screenshot - updated stacked bar chart in the Feedback tab

D. "User enters new electricity reading": In the Appliance Timer tab of the application, every time the user enters a new electricity reading from their electricity meter into the application, the following process is triggered:

1. The “Date Time” and the “Electricity Reading” are saved to the Electricity Reading Table of the SQLite database.
2. If there has only been one appliance on since the previous electricity reading was taken, then the measured “Appliance Consumption”, the difference between the current electricity reading and the previous electricity reading can be used to replace the estimated “Appliance Consumption” in the Log Table. The user is first presented with a pop-up asking if the measured consumption should replace the estimated consumption. If the user answers positively, then the measured value is saved to the Log table.
3. The graph showing the cost of the electricity consumed over time in the “Feedback” tab is automatically updated.
4. The “Latest Electricity Meter Reading” information above the appliance dashboard is also updated to display the user’s data entry.

Figures 16 and 17 show screenshots of the application’s “Appliance Timer” tab when the user enters a new electricity reading in the desktop and mobile versions of the application respectively.

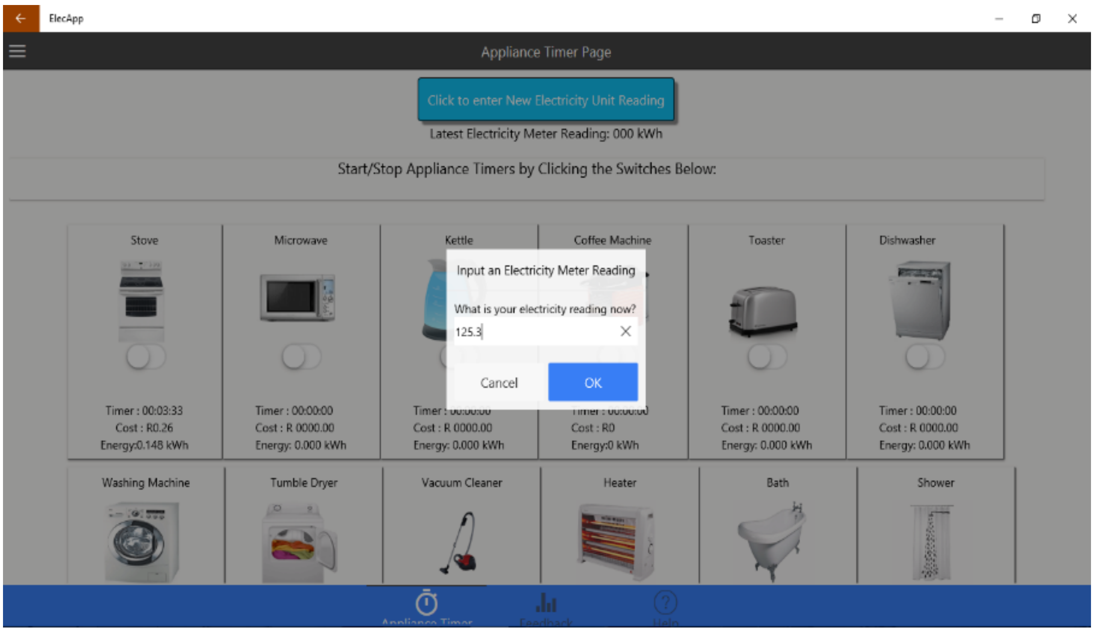

Figure 16: Desktop Screenshot 5 - capturing a new electricity reading in the Appliance Timer tab

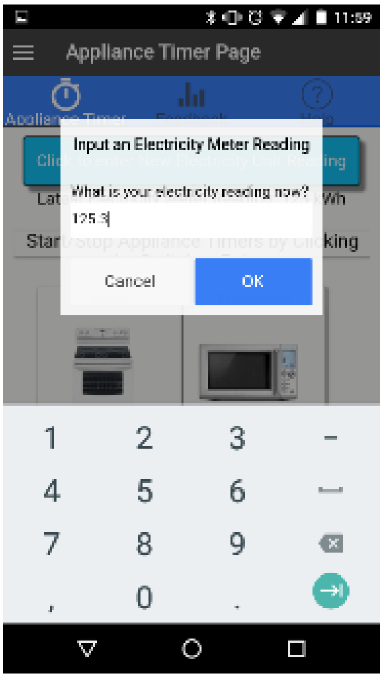

Figure 17: Mobile Screenshot - capturing a new electricity reading in the Appliance Timer tab

Figures 18 and 19 show screenshots of the application's "Appliance Timer" tab once the appliance's "Latest Electricity Meter Reading" above the dashboard has been updated in the mobile and desktop versions of the application respectively.

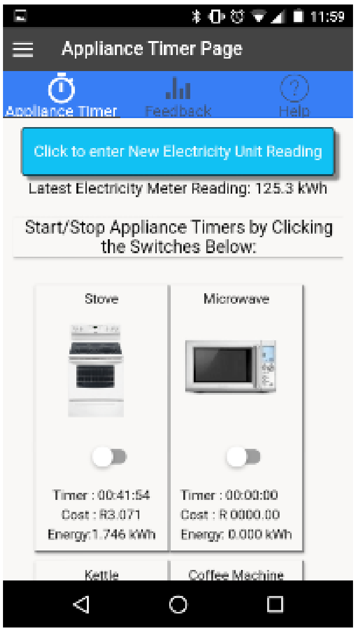

Figure 18: Mobile Screenshot showing the updated Appliance Timer tab once a new electricity meter reading has been captured

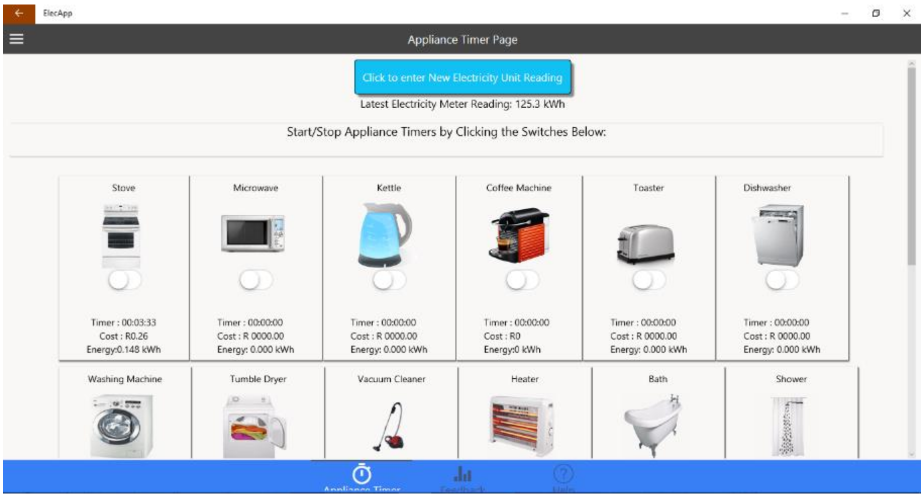

Figure 19: Desktop Screenshot showing the updated Appliance Timer tab once a new electricity meter reading has been captured

E. “User clears the collected data”: In the Appliance Timer tab of the application, every time the user clicks on the red button at the bottom of the screen labelled “Click to clear all stored data”:

1. All the data in the tables of the SQLite database is deleted.
2. The appliance dashboard in the “Appliance Timer” tab is reset.
3. The graph in the “Feedback” tab is reset.

Figures 20 and 21 show screenshots of the application’s “Appliance Timer” tab when the user deletes the data that has been collected so far in the desktop and mobile versions of the application respectively.

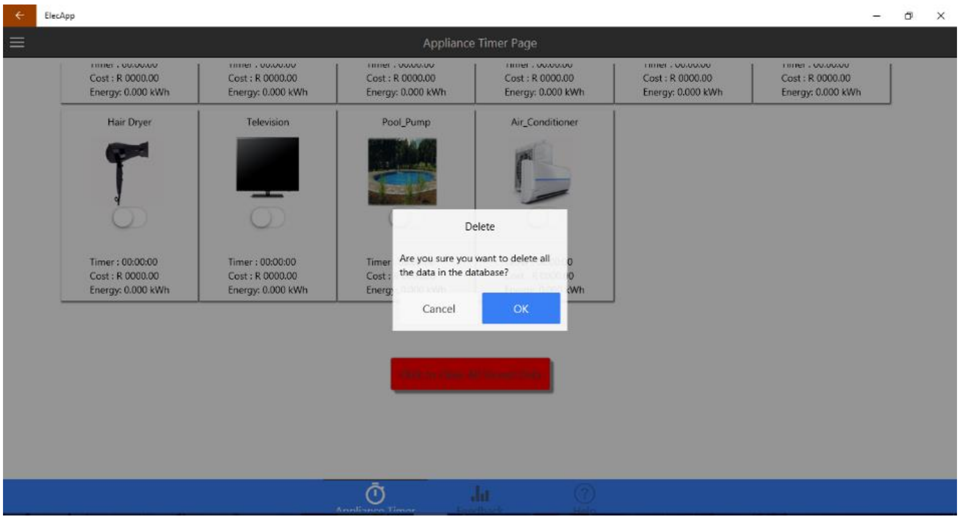

Figure 20: Desktop Screenshot of the Appliance Time tab demonstrating the clearing of the all data

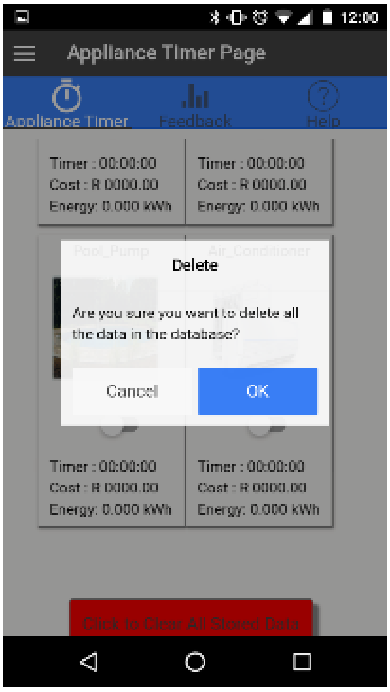

Figure 21: Mobile Screenshot of the Appliance Time tab demonstrating the clearing of the all data

Figures 22 and 23 show screenshots of the application's "Feedback" tab once the data has been cleared and the graph is removed in the mobile and desktop versions of the application respectively.

Figure 22: Desktop Screenshot showing the cleared graph in the Feedback tab

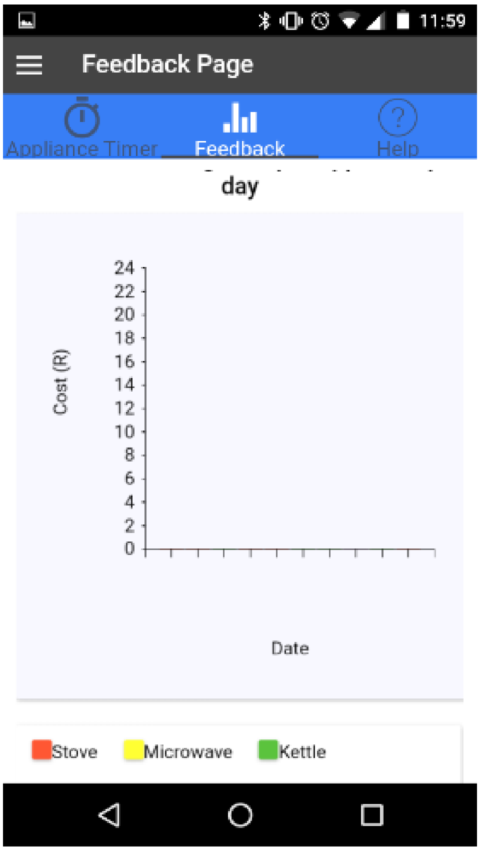

Figure 23: Mobile Screenshot showing the cleared graph in the Feedback tab

F. There is also a "Help" tab in the application. The user can open the "Step-by-Step" guide, which is a scrollable slide show, for a comprehensive overview of how to use the application. Figures 24 and 25 show screenshots of the guide in the "Help" tab of the application, but the full guide can be found in Appendix 1.

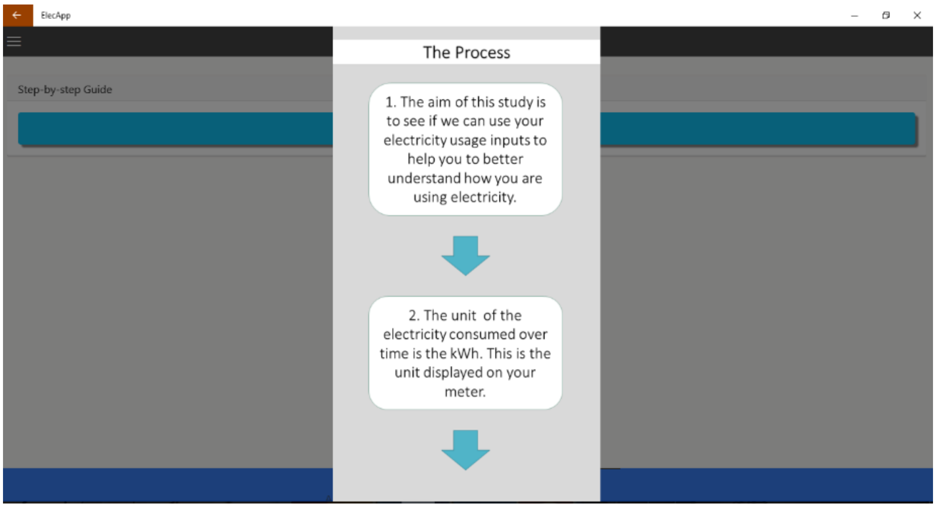

Figure 24: Desktop Screenshot showing a slide in the step-by-step guide in the Help tab

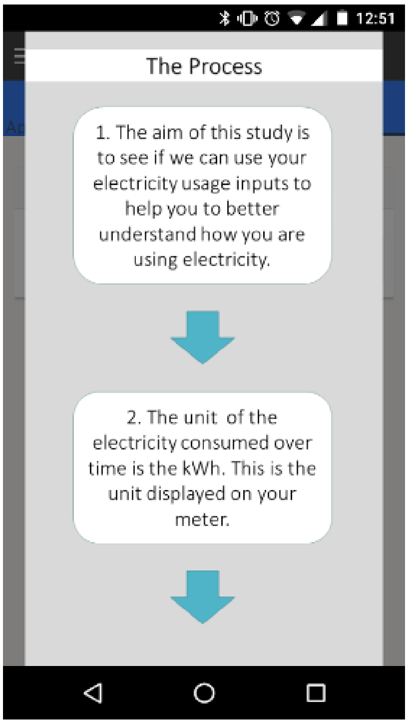

Figure 25: Mobile Screenshot showing a slide in the step-by-step guide in the Help tab

3.2.7. The Algorithm used to Calculate Electricity Consumption

During the proposal stage of the study, the intention was to incorporate an equation solving algorithm into the design so that, as users acquired more electricity readings and appliance usage times relative to those readings, the algorithm could solve for the unknown appliance-specific consumption values. For example, a user takes an electricity reading at 7am (50.100 kWh), 8am (50.000kWh) and 9am (49.826kWh). The total consumption between 7am and 8am is 0.100 kWh and the total consumption between 8am and 9am is 0.174kWh. Only two appliances are on during that time, namely the kettle and the toaster. The kettle is on for 3 minutes from 7:15 and again for 3 minutes from 8:30 and the toaster is on for 4 minutes at 8:45am. There are two unknowns in this scenario: the wattage of the kettle and the wattage of the toaster. However, there are also two solvable equations, since we know what the electricity consumption was for two periods. Since the number of unknowns equals the number of equations, the unknowns (call them x: kettle and y: toaster) can be calculated as follows (Note that the time per appliance needs to be converted from minutes to hours, which is why the number preceding the unknowns are divided by 60):

1. (3 min / (60 min/1hour)) X = 0.1 kWh
2. (3 min / (60 min/1hour)) X + (4 min / (60 min/1hour)) Y = 0.174 kWh

Equation 1 can be solved first to get the wattage of the kettle:

1. 3/60 X hour = 0.1kWh
   X = 0.1 x 20 kW
   X = 2kW

This value can now be substituted into equation 2 as follows to solve for Y:

2. (3 min / (60 min/1hour)) 2 + (4 min / (60 min/1hour)) Y = 0.174 kWh
   (4/60) Y hour = (0.174 - 0.1) kWh
   Y = 0.074 / (4/60) kW
   Y = 1.11 kW

This is an interesting approach and one that should be explored further. There are several complexities that need to be considered with this approach and unfortunately time did not allow for these complexities to be resolved in addition to completing the design of the application and conducting the experiment.

The first complexity is related to the resolution to which electricity is measured on a household electricity meter. A typical electricity meter will only display the kilowatt hours used or remaining down to a resolution of one decimal point. Therefore, to accurately record the consumption of one appliance with 90% accuracy you need to consume at least 1kWh of electricity since a rounding error of 0.1 equates to 90% accuracy. Furthermore, if the appliance has a wattage of 1.11kW, like the toaster in the example above, you will need to leave that appliance on for 54 minutes before an accuracy of 90% can be achieved. This is clearly not possible for an appliance like a toaster, which is typically used for short periods at a time.

Instead, the final design for the application uses measured consumption readings where possible and otherwise it substitutes appliance-specific wattage estimates into the equations above to calculate a consumption value. In cases where an electricity reading is taken before and after the use of a single appliance, the measured consumption is recorded. In cases where there are not enough electricity readings taken, or more than one appliance is used at the same time, the application applies the pre-determined wattage estimates that are saved in the Appliance Table of the SQLite database (see Table 1). One of the benefits of taking this approach is that the application could be used by participants who had access to their electricity meters at home and by participants who did not have access to their electricity meters at home.

3.3. Experimental Design

One experiment was conducted over a period of one week. Participants were asked to install and use the application in their homes whilst continuing with their daily routines. Once the week was over, participants were asked to complete a user experience questionnaire.

3.3.1. Experimental procedure

Participants received an email describing the purpose of the study and an outline of what is expected of them. The email also contained links to the app stores where they could download the app and a pdf version of the Step-by-step guide (see Addendum 1) was sent as an email attachment. Participants were asked to install the application on their device of choice since the application should be compatible with Android and Windows.

Once the application was installed and successfully launched for the first time, the participants were guided through the use of the application with the Step-by-step guide whilst they performed their daily household tasks. If help was required at a later stage, the user could also revisit the guide by clicking on a help button. All of the features of the tool on each of the two tabbed pages are clearly described to the user in the step-by-step guide.

The participant was asked to complete the following actions whenever they use appliances at home that consume electricity:

1. Capturing the balance of electricity units on the electricity meter:

The experimental procedure requires that participants take regular electricity consumption readings in kWh from their electricity meters at home so that consumption data can be gathered for the entire dwelling over time. The procedure is as follows:

1.1. The user opens the application.

1.2. Depending on the length of time since the last electricity reading was taken, the user may want to check the number of units (kWh) on their electricity meter at home and capture the value in the Appliance Timer tab by clicking on the “Click to enter electricity unit reading” button.

1.3. If the user wants to input an electricity meter reading regardless of the length of time since the last reading was taken, they can do so as well by clicking a button to open the input form.

2. Turning appliances on:

The experimental procedure requires that participants enter information about which home appliances are being used over time as well. This information is then used alongside the overall consumption readings for the real-time monitoring of per-appliance consumption.

2.1. As the user physically turns on their appliances at home, they need to feed this information to the application. This is done by sliding or clicking on toggle switches shown below an image of the respective appliance.

2.2. When the toggle is toggled “on”, a current date and time value is saved to the application’s database.

3. Turning appliances off:

3.1. Similarly, as the user physically switches off the appliances at home, they are required to switch the appliances off on the application’s user interface using the toggle switches shown below an image of the respective appliance.

3.2. When the toggle is toggled “off”, a current date and time value is also saved to the application’s database. In addition, a duration value, which is calculated by subtracting the appliance’s time on from the time off, is also saved to the database.

4. Viewing the Usage Patterns:

4.1. The user can open the Feedback page at any time by selecting the labelled tab. On the Feedback page they can view the stacked bar chart showing their updated electricity usage.

5. Clearing data:

5.1. The user can also delete the data collected to date by clicking on a red delete button placed at the bottom of the Appliance Timer page.

3.4. Chapter Summary

This chapter provided an outline of the design of the application and the experiment. The user-centred design process that was adopted was discussed in detail. Feedback about the focus groups that were held during the design process was also given, and this feedback formed the foundation of the requirement identification process. The next section described which application development tools were tried before Ionic Framework was decided on. The approach taken to first finalise the user interface, then to hold a second focus group for another iteration of feedback and then to build in the functionality of the application was then discussed. Finally, the experimental design was outlined.

4. Evaluation and Results

The success of the experiment is measured using a USE questionnaire, which tests the Usefulness, Satisfaction, ease of use and Ease of Learning experienced by participants.

4.1. Pilot Study

Before the application was published to the app stores for distribution to the participants in the experiment, three potential users who volunteered to take part in the pilot study were sent the unpublished Android APK file and asked to install the app on their mobile devices to test the application.

The pilot study participants were also briefed regarding the outline of the experiment and asked to run a trial of the experimental protocol in order to eliminate the risk of any major flaws during the experiment itself.

There were no fatal flaws found during the pilot study but the main feedback from participants during the pilot study was that more guidance through the functions of the application was needed. The "Step-by-Step Guide" was therefore amended accordingly. There were also a few suggestions regarding the aesthetics of the graphs page of the application, which were incorporated before the final experiment.

4.2. Study participants

A convenience sampling strategy used was used for this study. Participation in this study was voluntary and not incentivised. Instead, specific target groups with an interest in saving the environment and/or reducing monthly electricity costs were identified via social media, namely Facebook. Wherever possible, a group broadcast message was used to promote the study to members of the identified social media groups. In addition, students from the Computer Science Department at the University of Cape Town were also informed of the study and asked to volunteer if they were interested in participating. Other participants are known to the researcher and were involved on a convenience sampling basis.

Participation in the study was limited to volunteers living in and around Cape Town and to people who buy either prepaid electricity or receive electricity bills on a monthly basis. Not all participants are home owners; some are tenants in their premises. Participants were required to install the application on their chosen device and to interact with the application to monitor their electricity usage as per their usual schedule.

The targeted number of participants was 30 and 31 people volunteered to participate in the study; however there were only 21 survey responses received. There were several reasons for smaller than expected participant turnout, including Android and Windows incompatibilities with older operating system versions and the lack of an iOS version of the application; unfortunately a number of participants did not respond to early queries as to the type of device they intended to use but they assumed that the application would be available on any device type. As mentioned, the intention was to make the application available on all three platforms and the iOS version was compiled and tested but it was decided that the required iOS license was too expensive for the purposes of this study.

The relevant ethics approval for the involvement of people in the experiment was applied for and granted by the University of Cape Town's (UCT's) Department of Science. In addition, permission to involve UCT students in the study was also applied for and granted. These approvals are shown in Appendices 4 and 5 respectively. Participants were also sent consent forms to sign (see Appendix 3) that described the requirements from participants during the study.

4.3. Data Collection Methods

For this experiment, user feedback was gathered using a post-experiment online questionnaire following the Usefulness, Satisfaction, and Ease of use (USE) User Experience model - see Appendix 2 (Lund, 2001). A website called QuestionPro was used for the creation, distribution and management of the questionnaire (QuestionPro. n.d.).

This questionnaire uses a Likert scale to gauge the participant's level of agreement with a collection of statements about the usefulness, ease of use, ease of learning and satisfaction related to their experience with the application. A 7 point Likert scale was used in the questionnaire, where 1 represents "Strongly Disagree" and 7 represents "Strongly Agree". To evaluate feedback provided on a Likert scale, the median or the mode of the total responses is used, as opposed to the average of all responses.

To give users more freedom to provide specific feedback, users were also asked to list the most positive and the most negative aspects of the application and their experience during the experiment. The questionnaire used to gather the participants' feedback can be referred to in Appendix 2.

4.4. Results and Analysis

The research question is as follows:

Can user-collected electricity consumption data on a mobile or desktop device provide useful electricity usage patterns to home users?

The research question leads to the following sub questions:

1. Was the feedback useful to users?
    - This question is addressed in the “Useful” section of the USE questionnaire.

2. What was the user’s experience while using the application?
    - This question is addressed in the “Satisfaction” section of the USE questionnaire as well as the final question about the most positive and the most negative aspects of the application and the experiment.

4.4.1. Analysis of the USE Questionnaire

The data analysis methodology for Likert-based questionnaires differs depending on whether the responses are treated as Likert-type items or as Likert scales. While Likert-type items refer to the singular questions in the survey, a Likert scale is composed of a series of four or more Likert-type items that represent a certain characteristic and can therefore be combined into a single composite score (Boone et al. 2012).

Likert-type items produce ordinal data, meaning that responses can be ranked but it is not possible to measure the distance between each notch on the scale (Allen et al. 2007). Ordinal data cannot be measured based on a normal distribution; instead of measuring the mean and the standard distribution of the dataset, it is best to work with the median (the middle score) and the mode (the score that occurred most often).

The Likert-type items are considered individually in this case and the mode and median is displayed for each question, but the questions are very clearly grouped into four categories:

- Usefulness
- Satisfaction
- Ease of Use
- Ease of Learnability

The results for each category are also displayed in comparative frequency bar graphs.

Participants were asked to indicate their level of agreement with each statement in the questionnaire by giving it a score between 1 (strongly disagree) and 7 (strongly agree), with 4 indicating a neutral stance on the statement.

In addition, it is important to measure the reliability of the Likert-type items. Cronbach's Alpha is measured for each category of questions to ensure internal consistency. This analysis was done using the "Anova: two-factor without replication" function in excel for the dataset to find the mean square error and the mean square for the row (each row representing each participant's scores for the questions in the category). Cronbach's alpha is finally calculated by dividing the mean square error by the mean square for the row and then subtracting that from 1. Cronbach's alpha varies between 0 and 1, and a result greater than 0.8 represents an acceptable reliability (Grande. 2016).

4.4.1.1. Usefulness

Cronbach's alpha for the Usefulness Likert-type items was calculated as 0.858, which depicts a good internal data consistency. Table 2 displays the median and mode for all usefulness-related Likert type items and Figure 26 shows a bar chart of the frequency of responses for each item.

Table 2: Median and mode for each usefulness-related question

Usefulness Likert-type Items	Median	Mode
1. It helps me to be more effective.	6	6, 7
2. It helps me to be more productive.	6	6
3. It is useful.	6	6
4. It gives me more control over the activities in my life.	6	7
5. It makes the things I want to accomplish easier to get done.	4	1,4,7
6. It saves me time when I use it.	3	1
7. It meets my needs.	5	5
8. It does everything I would expect it to do.	5	6

As shown in Table 2, both the median and mode for the first four Likert-type items were relatively high, scoring between 6 and 7. The participants indicated that the application helped them to be more effective and productive, that it was useful and that it gave them control over their lives. As shown in Figure 26, a cumulative 75% of the participants indicated that they agreed that the application made them more effective, a cumulative 56% agreed that it helped them to be more productive, a total of 95% agreed that the application was useful and 74% agreed that it gave them more control over their activities.

Participants' responses to item number 5, namely "It makes the things I want to accomplish easier to get done", were inconclusive, with modes of 1, 4, and 7.

Responses to item 6 however were conclusively negative, with a median of 3 and a mode of 1. As shown in Figure 26, only 33% of the participants responded positively. Item 6 dealt with the time saved when the application is used. This is an interesting finding, since participants appeared to believe that the application was useful, productive and effective.

One possible explanation for the negative feedback regarding the time saving aspect of the application despite the positive feedback regarding the usefulness, effectiveness and productiveness of the application could be linked to the complexity of the application design or the time spent by participants trying to learn how to use the application. Feedback on ease of use and ease of learning are discussed in Sections 4.3.1.3 and 4.3.1.4 respectively.

Otherwise, the negative feedback to this item shows evidence that participants do not appreciate having to spend time manually switching appliances on and off via the application's user interface.

Finally, items 7 and 8, namely "It meets my needs" and "It does everything I would expect it to do" each scored acceptable medians of 5 and modes of 5 and 6 respectively. 33% of the participants did not agree that the application did everything they expected it to.

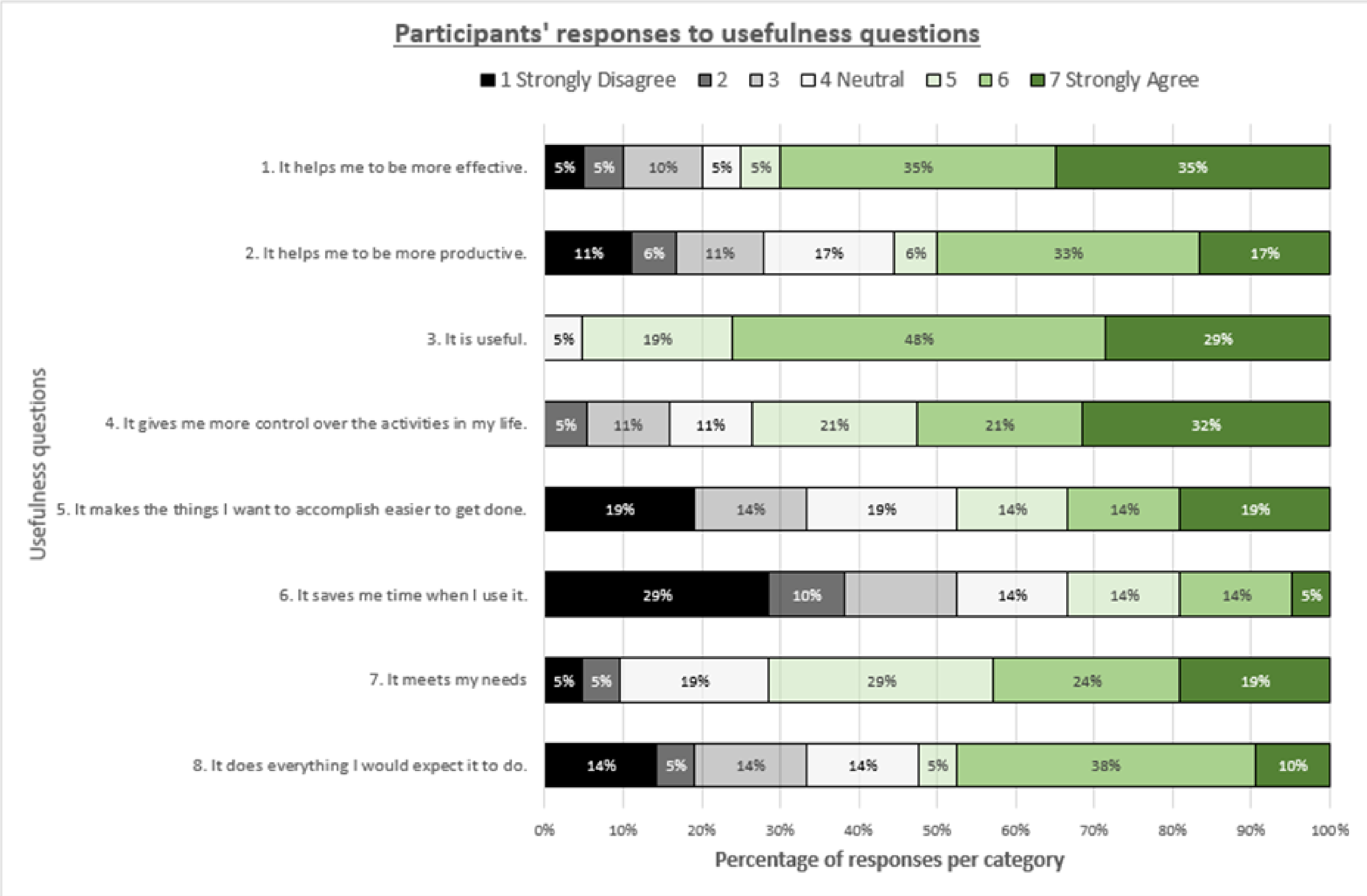

Figure 26: Participants' responses to usefulness-related questions

4.4.1.2. Satisfaction

Cronbach's alpha for the Satisfaction Likert-type items was calculated as 0.896, which depicts a good internal data consistency.

The responses to satisfaction related Likert type items are displayed in Table 3 and Figure 27 respectively. Participants were generally positive in their responses, with modes and medians of 5 and 6 for all but 2 statements. Most participants responded with a neutral score of 4 for the statements "It is wonderful" and "I feel I need to have it". Figure 27 shows the frequency of responses in more detail, over 70% of the responses indicated that participants were satisfied with the application, would recommend it to a friend, found it fun to use, agreed that it worked the way they wanted it to work and found it pleasant to use.

Table 3: Median and mode for each satisfaction-related question

Satisfaction Likert-type Items	**Median**	**Mode**
9. I am satisfied with it.	6	6
10. I would recommend it to a friend.	6	6
11. It is fun to use.	6	6
12. It works the way I want it to work.	5	5
13. It is wonderful.	4	4
14. I feel I need to have it.	4	4
15. It is pleasant to use.	6	5, 6

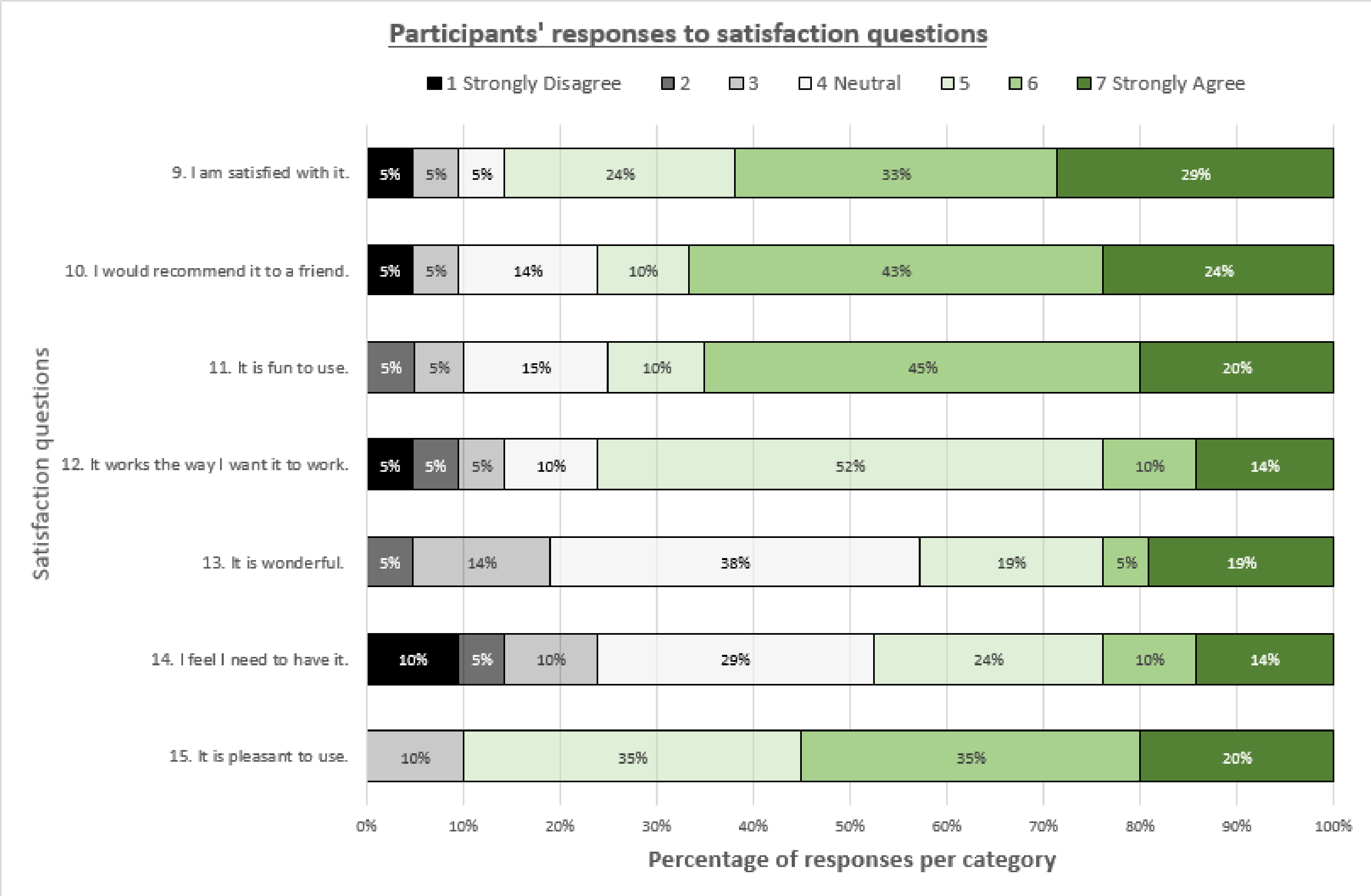

Figure 27: Participants' responses to satisfaction-related questions

4.4.1.3. Ease of Use

Cronbach's alpha for the Ease of Use Likert-type items was calculated as 0.880, which depicts a good internal data consistency.

Table 4 and Figure 28 display the participants' responses to Likert type items related to ease of use. Although most items scored well with medians and modes of 6 and 7, items 20, 21, 25 and 26 had a median score of only 4 or 5 and the modes varied between 4 and 7. This indicates a lack of consensus in responses. The statements being discussed were: "It is flexible", "Using it is effortless", "I can recover from mistakes quickly and easily" and "I can use it successfully every time".

It is believed that these responses are related to an issue with the design of the application that was also raised by some participants in a comments section of the questionnaire (see Section 4.4.1.5). Unfortunately a few participants raised a concern that it was difficult to recover from an error made while using the application. A few participants selected a toggle button erroneously whilst scrolling through the application's "Appliance Timer" tab and the application lacked the function to delete previous data entries. While it is possible to clear all of the data entries, it is not possible to select one data entry to delete. Not all participants made this error, however, which explains the lack of unanimity in responses for these questions. This design error can be corrected quite easily by including a function enabling users to select which data entry they want to delete.

Table 4: Median and mode for each ease of use-related question

Ease of Use Likert-type Items	**Median**	**Mode**
16. It is easy to use.	7	7
17. It is simple to use.	7	7
18. It is user friendly.	6	7
19. It requires the fewest steps possible to accomplish what I want to do with it.	6	7
20. It is flexible.	5	4, 5, 6
21. Using it is effortless.	5	7, 5, 6
22. I can use it without written instructions.	7	7
23. I don't notice any inconsistencies as I use it.	7	7
24. Both occasional and regular users would like it.	6	7
25. I can recover from mistakes quickly and easily.	4	7, 4
26. I can use it successfully every time.	5	7, 5

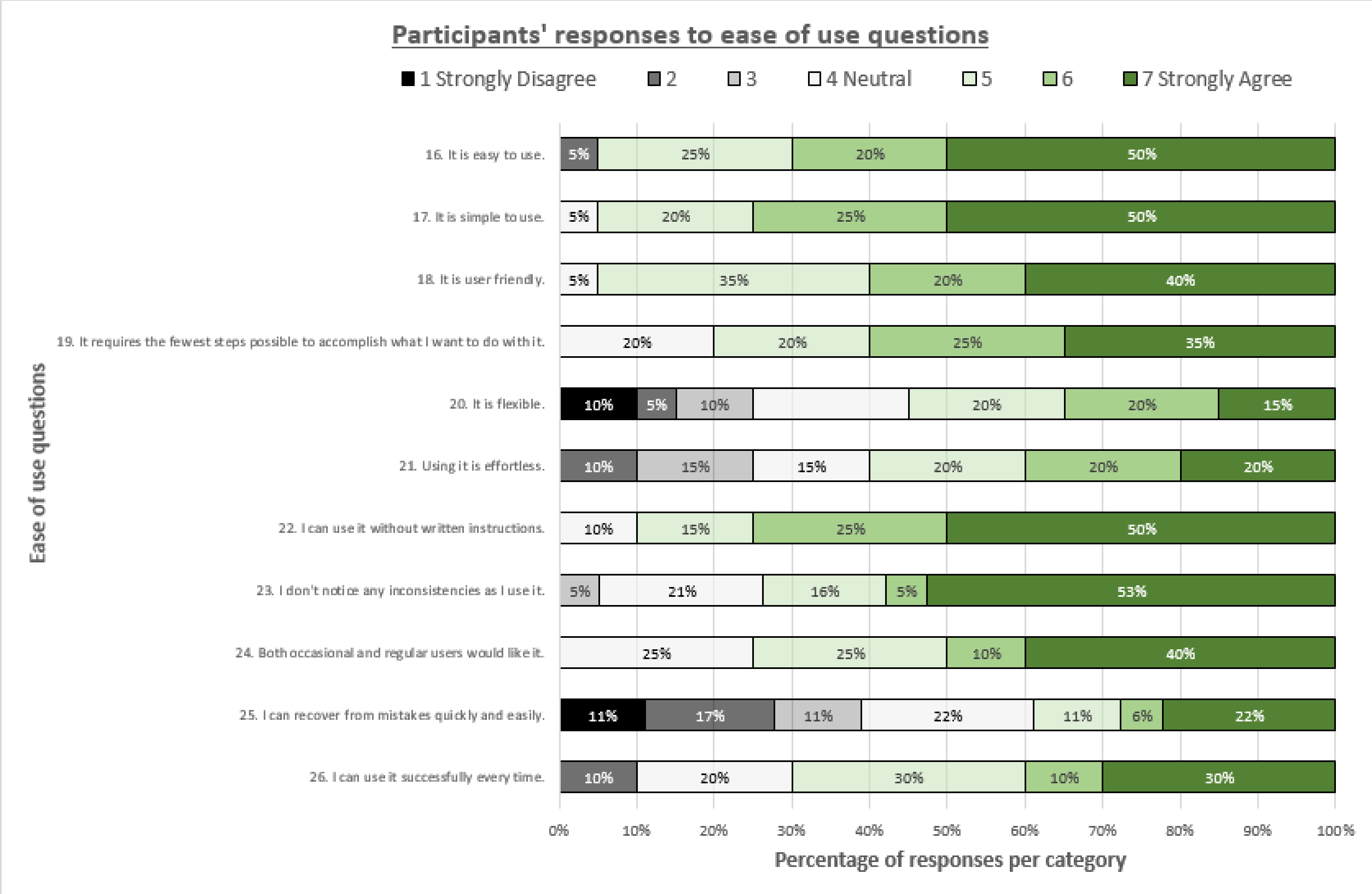

Figure 28: Participants' responses to ease of use-related questions

4.4.1.4. Ease of Learning

Cronbach's alpha for the Ease of Learning Likert-type items was calculated as 0.910, which depicts a very good internal data consistency.

Table 5 and Figure 29 display the responses to the Likert type items related to the ease of learning for the application. All four statements scored medians and modes of 7, with 80% of participants strongly agreeing that they learned to use the application quickly, 75% strongly agreeing that they could easily remember how to use it, 70% strongly agreeing that it is easy to learn how to use it and 60% strongly agreeing that they quickly became skilful with it.

Table 5: Median and mode for each ease of learning-related question

Ease of Learning Likert-type Items	**Median**	**Mode**
27. I learned to use it quickly.	7	7
28. I easily remember how to use it.	7	7
29. It is easy to learn to use it.	7	7
30. I quickly became skilful with it.	7	7

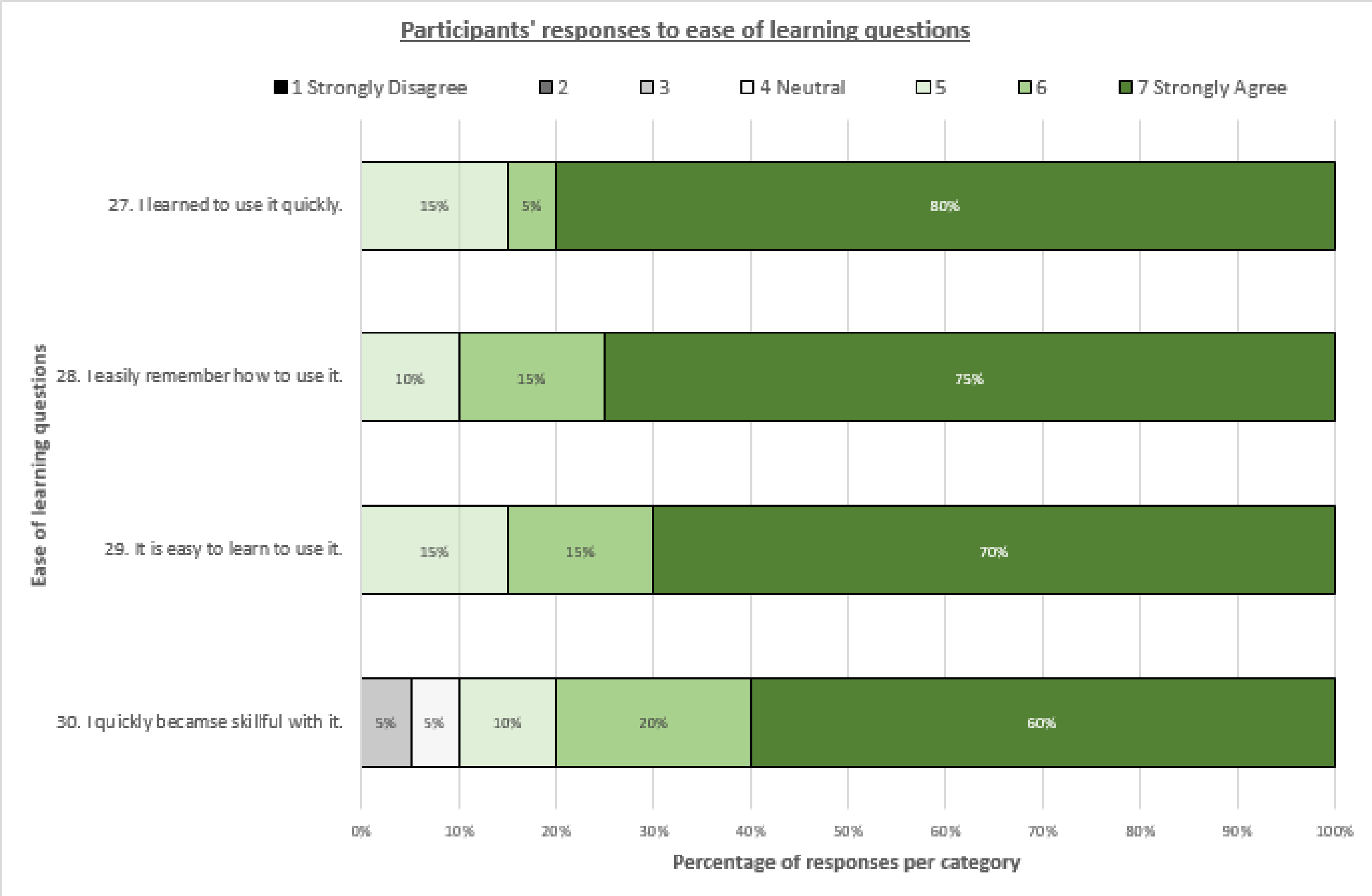

Figure 29: Participants' responses to ease of learning-related questions

4.4.1.5. Other Findings

When asked the question “Do you feel that the [electricity monitoring application] has helped you to better understand your electricity usage?” 100% of the respondents replied “yes”.

Respondents were also asked to list the most negative and the most positive aspects of the application. It is important to note that it was not compulsory for participants to answer questions in the comments section.
These responses can be found in Appendix 6, but the most frequent comments are listed as follows:

Most Negative Aspects:

1. 8 participants mentioned forgetting to use the application or forgetting to turn an appliance off on the Appliance Timer dashboard.
2. 7 participants mentioned that there was no way to delete erroneous data entries.
3. 6 participants wanted to be able to add other appliances to the Appliance Timer dashboard.

Most Positive Aspects:

1. 10 participant mentioned that the application made them more aware of their electricity consumption.
2. 6 participants mentioned that the application could help them to save electricity or reduce costs.
3. 6 participants mentioned that the application was simple to use.

4.4.2. Discussion of Two Case Studies

Figures 30 and 31 below display the electricity consumption patterns displayed by two participants during the experiment. Figure 30 originates from the Android mobile version of the application and Figure 31 originates from the Windows Desktop version of the application. The graphs show the total costs in Rand per day but, for the purposes of comparing daily patterns, the values are interchangeable with electricity consumed. The application assumed an electricity tariff of R1.759/kWh.

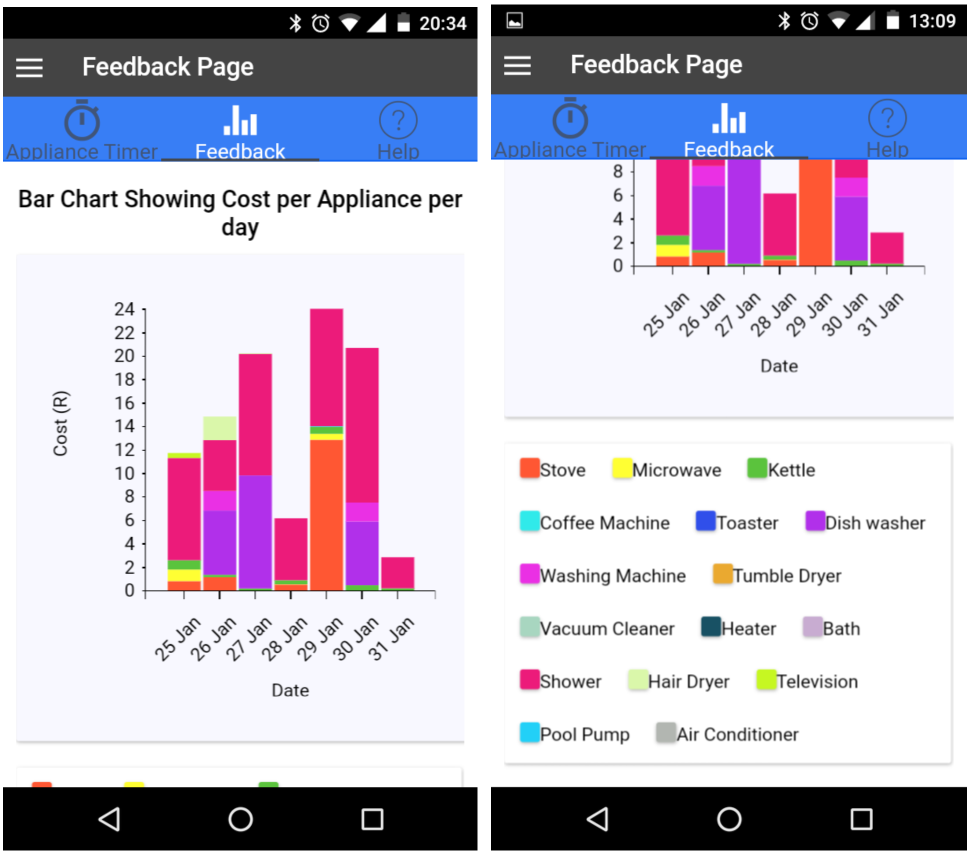

Figure 30: Use Case 1 - Graph showing a study participant's electricity costs for the week

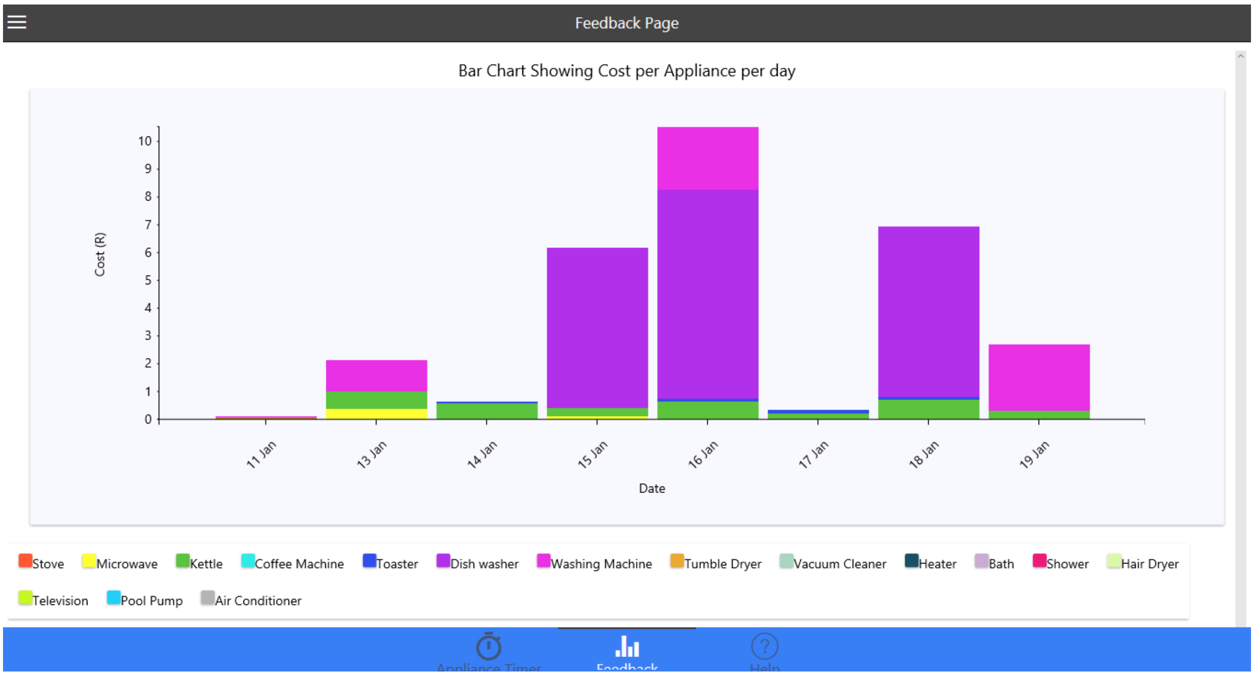

Figure 31: Use Case 2 - Graph showing a study participant's electricity costs for the week

As can be seen in these graphs, it appears that the participants could track their consumption on a daily basis.

The variation in daily electricity consumption is obvious in both graphs and there were clearly days where electricity costs were considerably lower than the costs recorded for the rest of the week. in Figure 30, the consumption for 28 January and 31 January were comparatively low while, in Figure 31, the electricity consumption on 11 January, 14 January and 17 January is particularly low.

It is possible that the participants simply did not need to use the appliances that they had used on other days of the week.

It is also possible that the application was not used often on those days because the user forgot to use it. As highlighted in Section 4.4.1.5, a total of 8 participants did mention in the comments section of the questionnaire that they sometimes forgot to use the application. This implies that there may be a risk that, as useful as the application may be in collecting consumption data and displaying useful feedback, some work still needs to be done to either remind users to use the application or to motivate users to use the application.

Another interesting observation to make for both graphs below is the total number of appliances that are used over the course of a week.

Although there are 16 appliances displayed on the “Appliance Timer” dashboard, Figure 30 shows that the first participant used only 7 appliances - 44% of the total number of appliances available, namely the stove, the microwave, the dishwasher, the washing machine, the hair dryer, the kettle and the shower.

Meanwhile, Figure 31 shows that the second participant used only 5 appliances - 31% of the total number of appliances available, namely the dishwasher, the washing machine, the microwave, the toaster and the kettle.

With this in mind, it is definitely worth personalising the collection of appliances that appears on the dashboard to reduce scrolling time for the participant, to reduce storage requirements and to allow the inclusion of a longer initial list of potential appliances.

Further, in both cases it is easy to assess by studying the graphs which appliances are the biggest contributors to electricity consumption. In Figure 30, the shower and the dishwasher were the biggest consumers. Meanwhile, in Figure 31, the dishwasher is by far the biggest consumer, followed by the washing machine.

This demonstrates that the application could be helpful with the identification of potential electricity conservation actions. In both cases, one could consider adjusting the temperature settings on the dishwasher to conserve electricity, or alternatively it might urge the user to consider using the dishwasher only every second day. Regarding Figure 30, that respective user may consider ways to reduce the amount of time spent in the shower in order to conserve electricity and costs.

4.5. Chapter Summary

This chapter outlined the process followed to collect and analyse the results of the study. The protocol and outcome of the pilot study, the sampling strategy and the profiles of the study participants, and the methods used to collect the participants' feedback were discussed. Then, finally, the results of the study were outlined.

5. Conclusion

This study involved the design and development of a user driven mobile and desktop application that provides the users with information on electricity usage patterns and historical trends. The purpose of the study was to find out if users found the feedback useful and if the feedback helped them to gain a better understanding of their electricity consumption.

The study involved a week long experiment during which the application was tested by participants in their homes while they continued using their home appliances as usual. Feedback was then gathered from the participants using a USE questionnaire. This chapter discusses the answers to the research question, the implication of the feedback from the participants and potential future work.

5.1. Answers to Research Question

Analysis of the feedback from the participants in this study showed that it was possible to provide people with useful electricity consumption patterns with an electricity monitoring application. The study findings showed that all participants believed that using the application helped them to better understand their electricity consumption.

5.2. Discussion and Implications

The application scored well in all four aspects of the USE questionnaire, namely Usefulness, Satisfaction, Ease of Use and Ease of Learning.

The participants' feedback did indicate that the application's error recovery capabilities were not satisfactory and that the home appliances included in the application's dashboard should be more personalised or flexible.

Finally, there was also an indication that the application needed to include prompts for the user as reminders to interact with the application or to switch off appliances that had been left on for too long.

5.3. Future Work

Testing the accuracy of the electricity consumption data collected during the experiment was not within the scope of this study, but herein lies another opportunity for future work. This could also involve further development of the algorithm used to calculate the electricity consumption which was discussed in Section 3.2.7.

There is an opportunity for the further examination of the ideal levels of user involvement in electricity monitoring. This is in order to achieve the optimal balance between minimising the amount of time required of the user and maximising the user's levels of understanding of their electricity consumption. Perhaps a comparative analysis of the knowledge gained by users of several electricity monitoring applications, each with varying levels of user involvement, could be conducted.

Finally, another opportunity for future work is to improve the functionality of the application that was designed for this study by ensuring that the user can easily recover from a mistake, to make the appliance dashboard more personalised (perhaps by including user preferences) and finally, by including prompts to remind the user to interact with the application or to undertake specific electricity monitoring activities.

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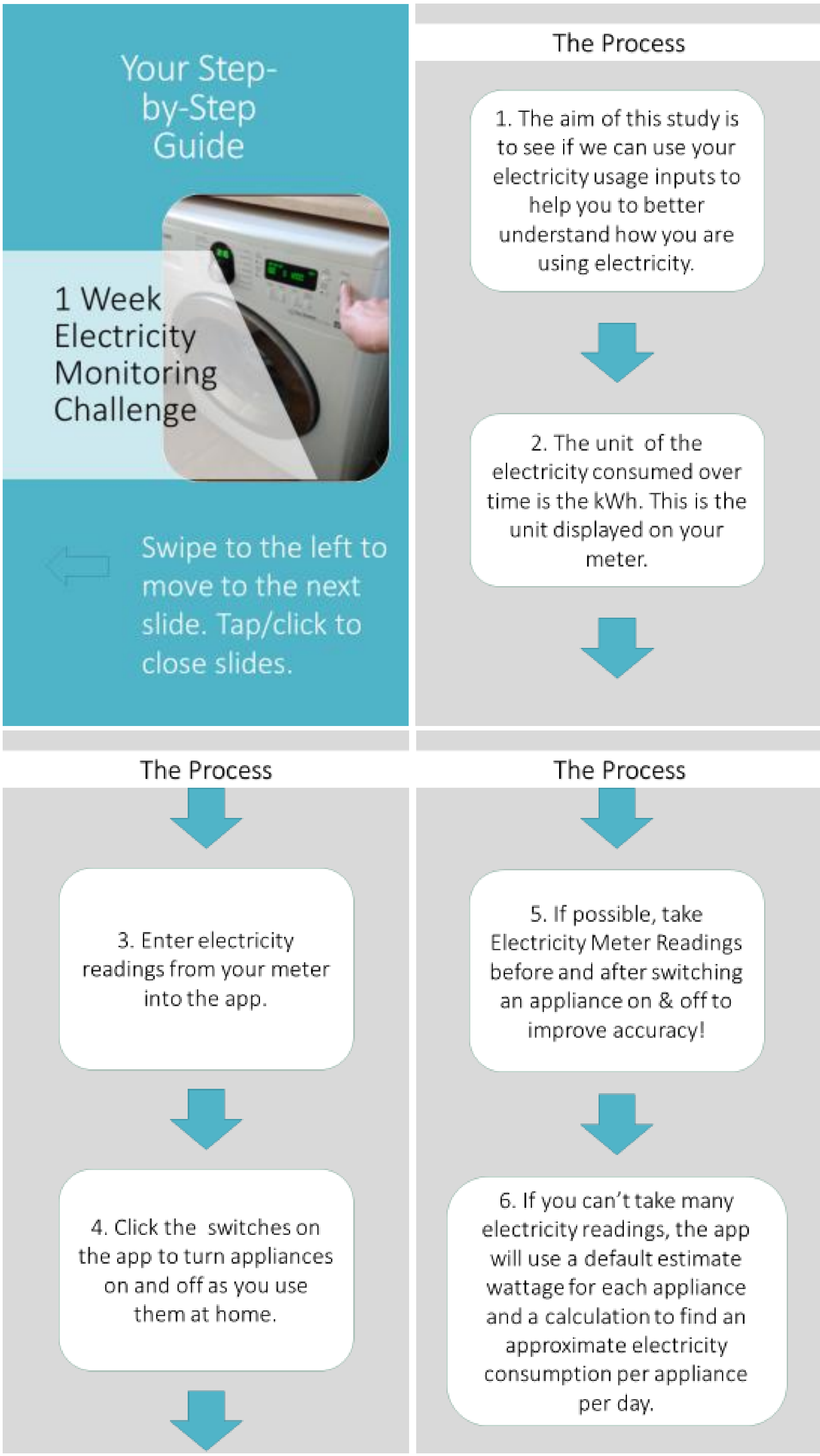
7. Appendices

7.1. Appendix 1: Step-by-step guide



A. Taking Electricity Readings

1

Look up the current electricity reading on your meter.

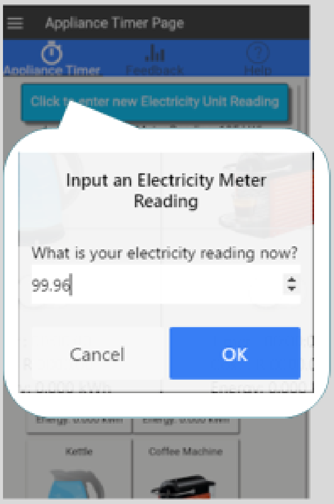
A. Taking Electricity Readings

2

On the "**Appliance Timer**" tab of the App, Click the "**Enter new Electricity Unit Reading**" button.

A. Taking Electricity Readings

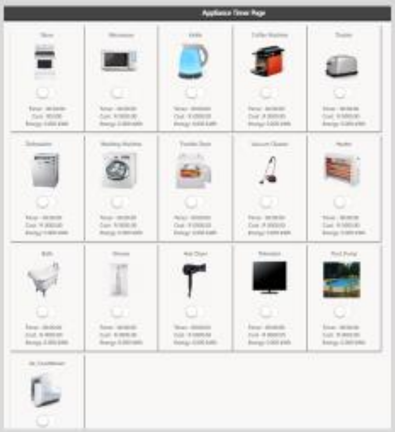
3



Type the electricity reading into the Text Box that pops up and click OK to save.

B. Timing Your Appliance Usage

1



Also on the "**Appliance Timer**" tab of the App, you can see a collection of pictures of 16 home appliances, with switches below each appliance.

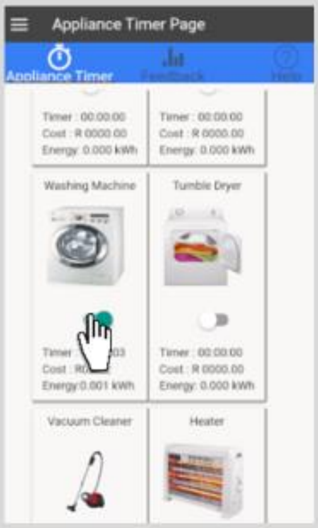
B. Timing Your Appliance Usage

2

Whenever you switch on your appliances at home..

B. Timing Your Appliance Usage

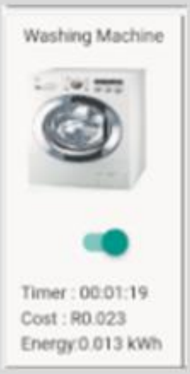
3



You need to click on that appliance's switch on this page to show that the appliance is on.

B. Timing Your Appliance Usage

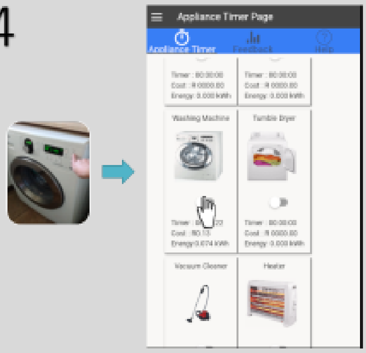
4



Below the switch, you can also view the Timer, Cost and Energy consumed for this appliance. These counters update every second, showing you up to date appliance usage details.

B. Timing Your Appliance Usage

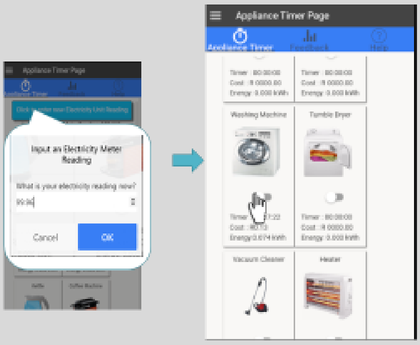
4



When you switch off that appliance again…
You need to click again on that appliance's switch to switch it off. Below the switch, you can also view the final timer, cost and energy consumed for this appliance.

B. Accuracy

5



If you want to measure the Electricity usage more accurately and reduce the number of estimates used, remember to take electricity readings before and after turning the appliance on and off again.

C. Check Graphs and Feedback

1

On the **'Feedback'** tab, a stacked bar chart displays the cost (in Rands) per appliance per day. The key/legend is shown below the chart.

D. Clear Data

You may also want to clear the data that you have collected so far and start afresh.

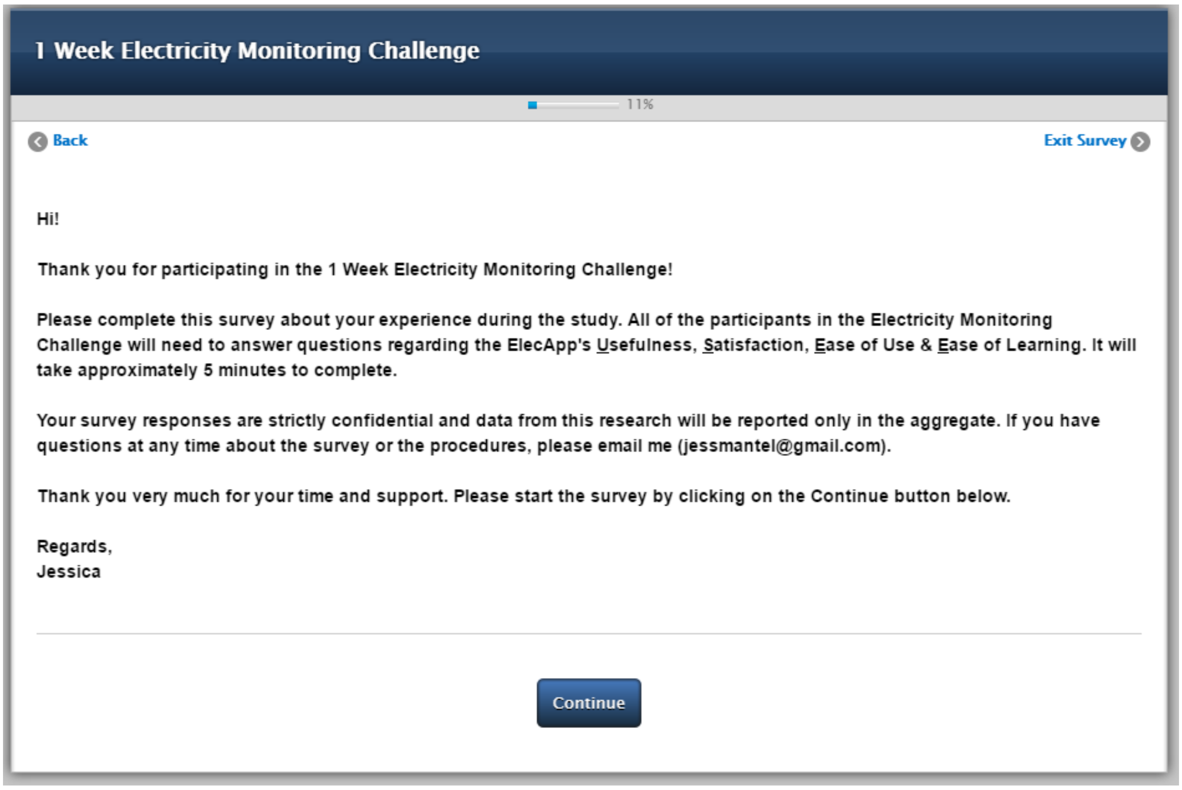
Right at the bottom of the 'Appliance Timer' tab, click on the "Click to Clear All Stored Data" button to do this.

That concludes Your Step-by-Step Guide

1 Week Electricity Monitoring Challenge

If you have any questions, please email: jessmantel@gmail.com

7.2. Appendix 2: USE Questionnaire



1 Week Electricity Monitoring Challenge

11%

Back

Exit Survey

Hi!

Thank you for participating in the 1 Week Electricity Monitoring Challenge!

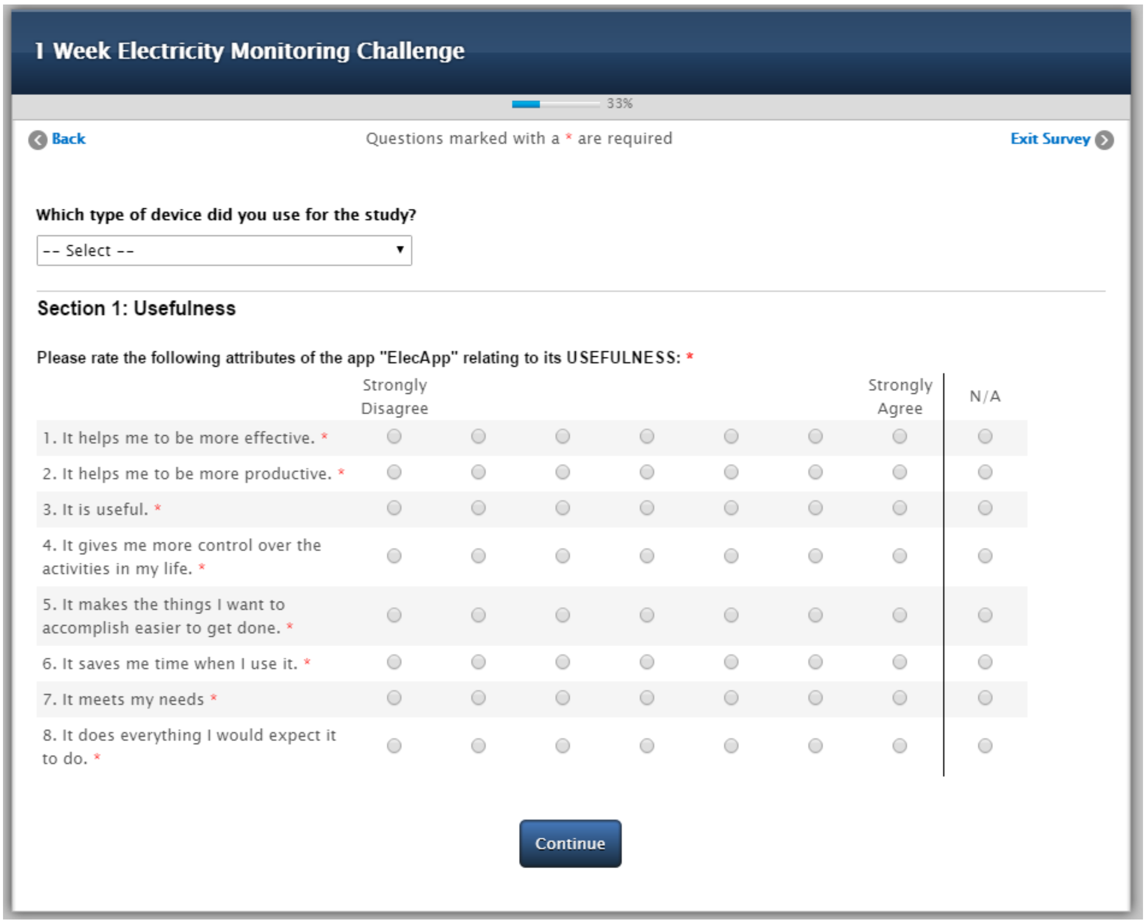
Please complete this survey about your experience during the study. All of the participants in the Electricity Monitoring Challenge will need to answer questions regarding the ElecApp's Usefulness, Satisfaction, Ease of Use & Ease of Learning. It will take approximately 5 minutes to complete.

Your survey responses are strictly confidential and data from this research will be reported only in the aggregate. If you have questions at any time about the survey or the procedures, please email me (jessmantel@gmail.com).

Thank you very much for your time and support. Please start the survey by clicking on the Continue button below.

Regards,
Jessica

Continue



1 Week Electricity Monitoring Challenge

33%

Back

Questions marked with a * are required

Exit Survey

Which type of device did you use for the study?

-- Select --

Section 1: Usefulness

Please rate the following attributes of the app "ElecApp" relating to its USEFULNESS: *

	Strongly Disagree						Strongly Agree	N/A
1. It helps me to be more effective. *	○	○	○	○	○	○	○	○
2. It helps me to be more productive. *	○	○	○	○	○	○	○	○
3. It is useful. *	○	○	○	○	○	○	○	○
4. It gives me more control over the activities in my life. *	○	○	○	○	○	○	○	○
5. It makes the things I want to accomplish easier to get done. *	○	○	○	○	○	○	○	○
6. It saves me time when I use it. *	○	○	○	○	○	○	○	○
7. It meets my needs *	○	○	○	○	○	○	○	○
8. It does everything I would expect it to do. *	○	○	○	○	○	○	○	○

Continue

1 Week Electricity Monitoring Challenge

44%

Back | Questions marked with a * are required | Exit Survey

Section 2: Satisfaction

Please rate the following attributes of the app "ElecApp" relating to your SATISFACTION:

	Strongly Disagree						Strongly Agree	N/A
9. I am satisfied with it. *								
10. I would recommend it to a friend. *								
11. It is fun to use. *								
12. It works the way I want it to work. *								
13. It is wonderful. *								
14. I feel I need to have it. *								
15. It is pleasant to use. *								

Continue

1 Week Electricity Monitoring Challenge

55%

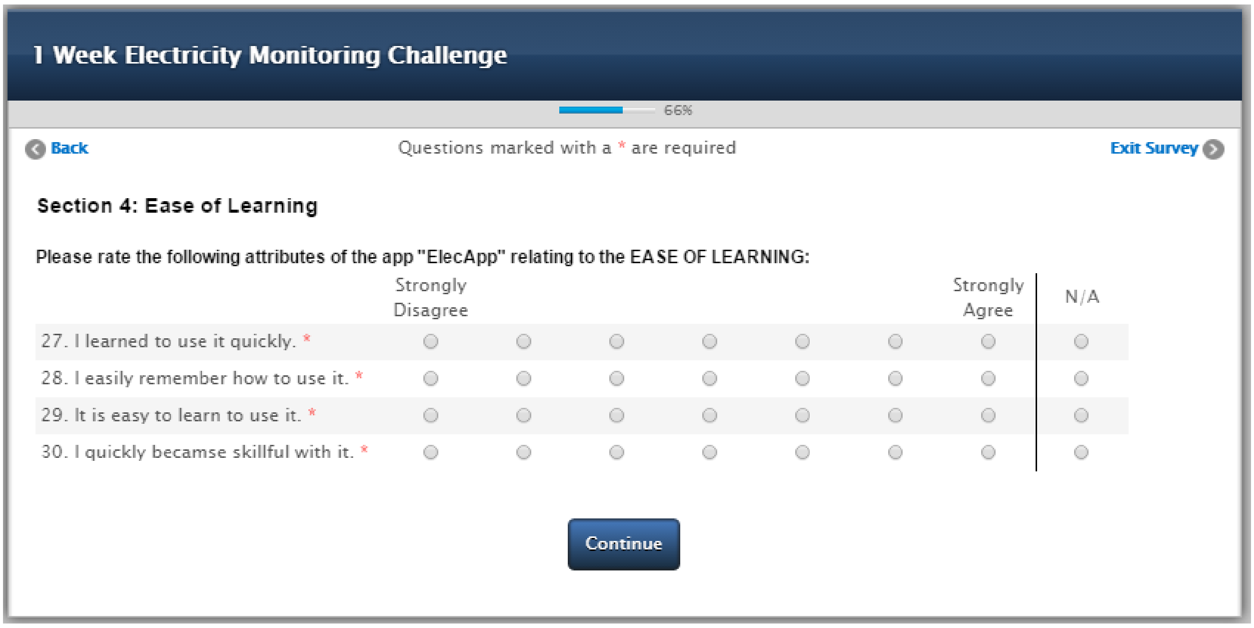
Back | Questions marked with a * are required | Exit Survey

Section 3: Ease of Use

Please rate the following attributes of the app "ElecApp" relating to its EASE OF USE:

	Strongly Disagree						Strongly Agree	N/A
16. It is easy to use. *								
17. It is simple to use. *								
18. It is user friendly. *								
19. It requires the fewest steps possible to accomplish what I want to do with it. *								
20. It is flexible. *								
21. Using it is effortless. *								
22. I can use it without written instructions. *								
23. I don't notice any inconsistencies as I use it. *								
24. Both occasional and regular users would like it. *								
25. I can recover from mistakes quickly and easily. *								
26. I can use it successfully every time. *								

Continue



1 Week Electricity Monitoring Challenge

66%

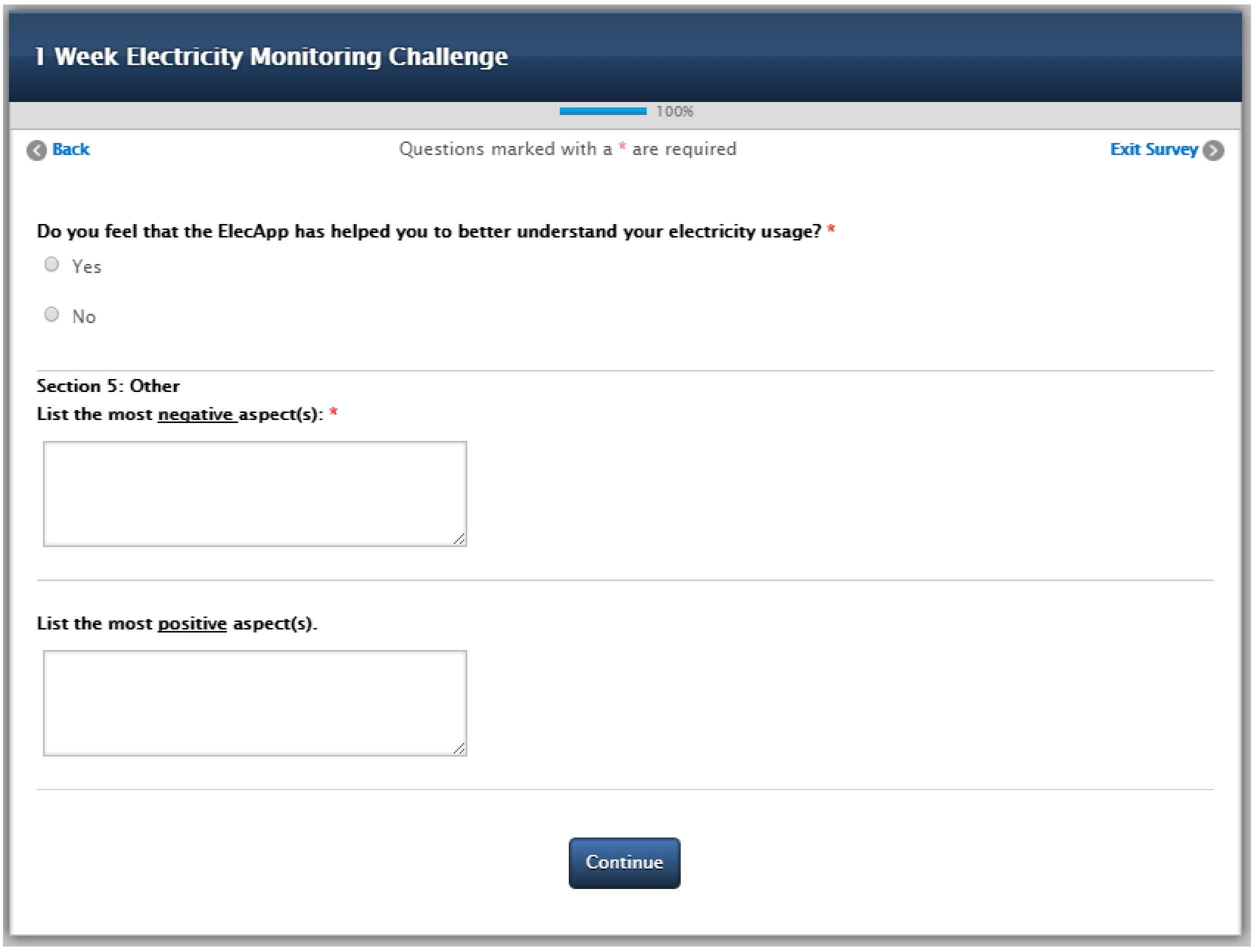
Back | Questions marked with a * are required | Exit Survey

Section 4: Ease of Learning

Please rate the following attributes of the app "ElecApp" relating to the EASE OF LEARNING:

	Strongly Disagree						Strongly Agree	N/A
27. I learned to use it quickly. *	○	○	○	○	○	○	○	○
28. I easily remember how to use it. *	○	○	○	○	○	○	○	○
29. It is easy to learn to use it. *	○	○	○	○	○	○	○	○
30. I quickly becamse skillful with it. *	○	○	○	○	○	○	○	○

Continue



1 Week Electricity Monitoring Challenge

100%

Back | Questions marked with a * are required | Exit Survey

Do you feel that the ElecApp has helped you to better understand your electricity usage? *

○ Yes

○ No

Section 5: Other

List the most negative aspect(s): *

List the most positive aspect(s).

Continue

7.3. Appendix 3: User Consent Forms

DEPARTMENT OF Computer Science

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SOUTH AFRICA

RESEARCHER'S
TELEPHONE: +27-73-220-3353
FACSIMILE:
E-MAIL: jessmantel@gmail.com / MNTJES002@myuct.ac.za
URL:

Informed Voluntary Consent to Participate in Research Study

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I agree to participate in this research (tick one box)

☑ Yes ☐ No ______ (Initials)

Jade Mathieson	[signature]	06/12/2016
Name of Participant	Signature of Participant	Date
Jessica Mantel	[signature]	06/12/2016
Name of Researcher	Signature of Researcher	Date

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I agree to participate in this research (tick one box)

☐ Yes ☐ No ________ (Initials)

Name of Participant	Signature of Participant	Date
Jessica Mantel		29/11/2016
Name of Researcher	Signature of Researcher	Date

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I agree to participate in this research (tick one box)

☑ Yes ☐ No RCW (Initials)

Renate Wilfinger	[signature]	29.11.2016
Name of Participant	Signature of Participant	Date
Jessica Mantel	[signature]	30/11/2016
Name of Researcher	Signature of Researcher	Date

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I agree to participate in this research (tick one box)

☒ Yes ☐ No BO (Initials)

Bridget Oelbüttel	BOelbüttel	09/12/2016
Name of Participant	Signature of Participant	Date
Jessica Mantel	JKM	09/12/2016
Name of Researcher	Signature of Researcher	Date

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I agree to participate in this research (tick one box)

☑ Yes ☐ No OT (Initials)

OLIVIA O'BRIEN	[signature]	06/12/2016
Name of Participant	Signature of Participant	Date
Jessica Mantel	[signature]	07/12/2016
Name of Researcher	Signature of Researcher	Date

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I agree to participate in this research (tick one box)

☑ Yes ☐ No MVS (Initials)

MEGAN VAN STER	[signature]	6/12/2016
Name of Participant	Signature of Participant	Date
Jessica Mantel	[signature]	07/12/2016
Name of Researcher	Signature of Researcher	Date

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I agree to participate in this research (tick one box)

☒ Yes ☐ No GCM (Initials)

Gisela C Madden	[signature]	01-12-2016
Name of Participant	Signature of Participant	Date
Jessica Mantel	[signature]	01/12/2016
Name of Researcher	Signature of Researcher	Date

DEPARTMENT OF Computer Science

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I agree to participate in this research (tick one box)

☑ Yes ☐ No PS (Initials)

Philiswa Sikhilongo

Name of Participant

Signature of Participant

05/12/16

Date

Jessica Mantel

Name of Researcher

Signature of Researcher

05/12/2016

Date

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I agree to participate in this research (tick one box)

☑ Yes ☐ No ________ (Initials)

DANE MCGILLEWIE	[signature]	30/11/2016
Name of Participant	Signature of Participant	Date
Jessica Mantel	[signature]	30/11/2016
Name of Researcher	Signature of Researcher	Date

7.4. Appendix 4: Ethics Approval

UNIVERSITY OF CAPE TOWN

IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

Faculty of Science
University of Cape Town
RONDEBOSCH 7701 South Africa
E-mail: timm.hoffman@uct.ac.za
Telephone: + 27 21 650 5551

18 November 2016

Jessica Mantel
Department of Computer Science

Prototype for an Application for User-collected Residential Electricity Usage Monitoring

Dear Jessica Mantel

I am pleased to inform you that the Faculty of Science Research Ethics Committee has approved the above-named application for research ethics clearance, subject to the conditions listed below.

- Implement the measures described in your application to ensure that the process of your research is ethically sound; and

- Uphold ethical principles throughout all stages of the research, responding appropriately to unanticipated issues: please contact me if you need advice on ethical issues that arise.

Your approval code is: **FSREC 071 – 2016**

I wish you success in your research.

Yours sincerely

Prof Timm Hoffman
Chair: Faculty of Science Research Ethics Committee

Cc: Prof Hussein Suleman (supervisor)

7.5. Appendix 5: Permission to involve UCT students in the experiment

	RESEARCH ACCESS TO STUDENTS	DSA 100

NOTES

1. This form must be FULLY completed by all applicants who want to access UCT students for the purpose of research or surveys.
2. Return the fully completed (a) DSA 100 application form by email, in the same word format, together with your: (b) research proposal inclusive of your survey, (c) copy of your ethics approval letter / proof (d) informed consent letter to: Moonira.Khan@uct.ac.za. You application will be attended to by the Executive Director, Department of Student Affairs (DSA), UCT.
3. The turnaround time for a reply is approximately 10 working days.
4. NB: It is the responsibility of the researcher/s to apply for and to obtain ethics approval and to comply with amendments that may be requested; as well as to obtain approval to access UCT staff and/or UCT students, from the following, at UCT, respectively: (a) Ethics: Chairperson, Faculty Research Ethics Committee' (FREC) for ethics approval, (b) Staff access: Executive Director: HR for approval to access UCT staff, and (c) Student access: Executive Director: Student Affairs for approval to access UCT students.
5. Note: UCT Senate Research Protocols requires compliance to the above, even if prior approval has been obtained from any other institution/agency. UCT's research protocol requirements applies to all persons, institutions and agencies from UCT and external to UCT who want to conduct research on human subjects for academic, marketing or service related reasons at UCT.
6. Should approval be granted to access UCT students for this research study, such approval is effective for a period of one year from the date of approval (as stated in Section D of this form), and the approval expires automatically on the last day.
7. The approving authority reserves the right to revoke an approval based on reasonable grounds and/or new information.

SECTION A: RESEARCH APPLICANT/S DETAILS

Position	Staff / Student No	Title and Name	Contact Details (Email / Cell / land line)
A.1 Student Number	Mntjes002	Ms Jessica Kirsten Mantel	jessmantel@gmail.com 073 220 3353
A.2 Academic / PASS Staff No.			
A.3 Visitor/ Researcher ID No.			
A.4 University at which a student or employee	University of Cape Town	Address if not UCT:	
A.5 Faculty/ Department/School	Computer Science Department		

A.6 APPLICANTS DETAILS if different from above	Title and Name	Tel.	Email

SECTION B: RESEARCHER/S SUPERVISOR/S DETAILS

Position	Title and Name	Tel.	Email
B.1 Supervisor	Prof Hussein Suleman	021 650 5106	hussein@cs.uct.ac.za
B.2 Co-Supervisor/s			

SECTION C: APPLICANT'S RESEARCH STUDY FIELD AND APPROVAL STATUS

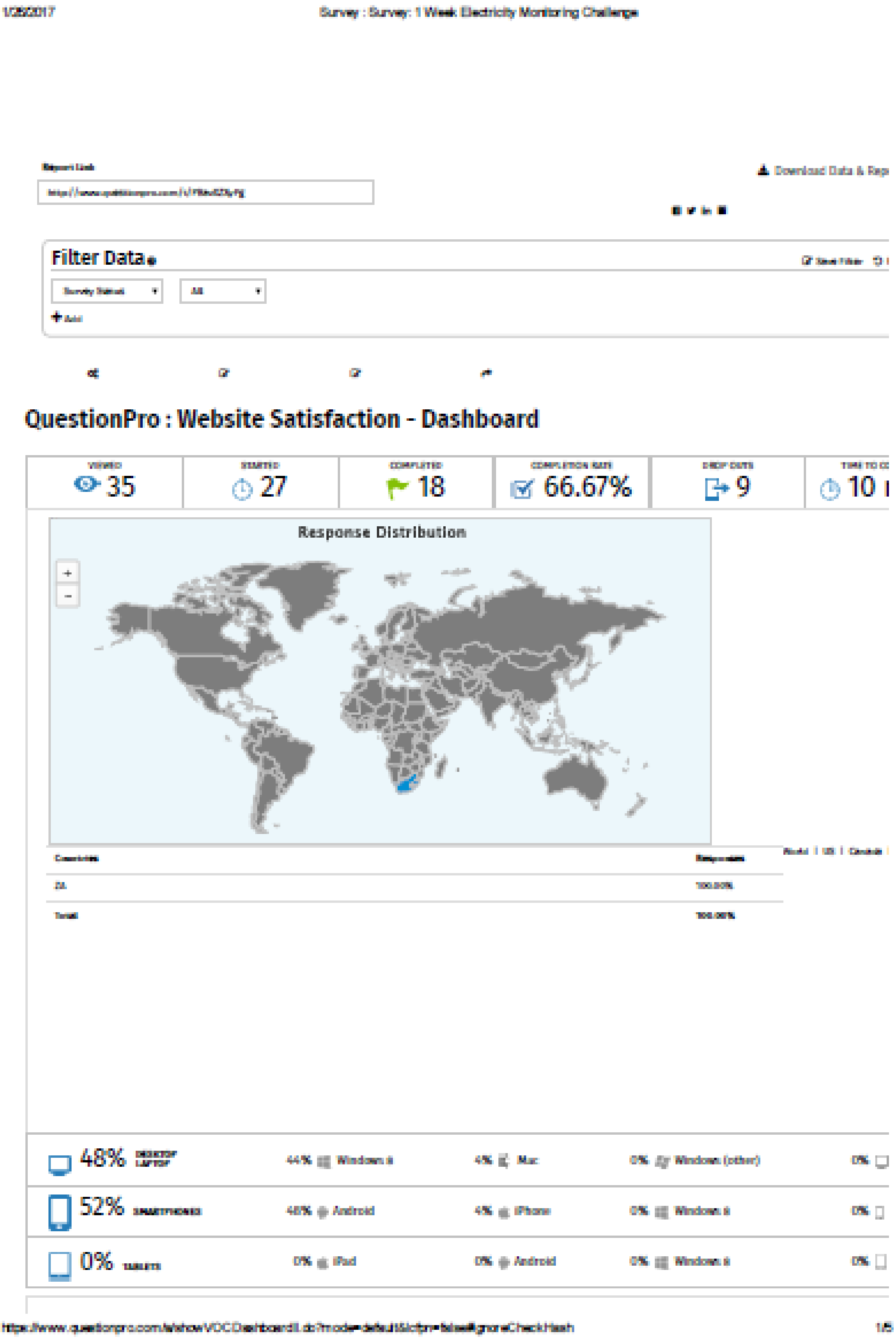
C.1 Degree – if applicable	M(IT)
C.2 Research Project Title	Prototype for a cross-platform Application for User-collected Residential Electricity Usage Monitoring
C.3 Research Proposal	Attached: Yes ■ No □
C.4 Target population	UCT Students and others outside UCT
C.5 Lead Researcher details	If different from applicant:
C6. Will use research assistant/s	Yes □ No ■ If yes- provide a list of names, contact details and ID no.
C.7 Research Methodology and Informed consent:	Research methodology: Attached – Survey Informed consent: - will be obtained; confidentiality is assured, participation is voluntary.
C.8 Ethics clearance status from UCT's Faculty Ethics in Research Committee /Chair (EIRC)	Approved by the UCT EIRC: Yes ■ With amendments: Yes □ No ■ (a) Attach copy of your UCT ethics approval. Attached: Yes ■ No □ (b) State date / Ref. No / Faculty of your UCT ethics approval:18/11 /2016 Ref. : FSREC 071 – 2016

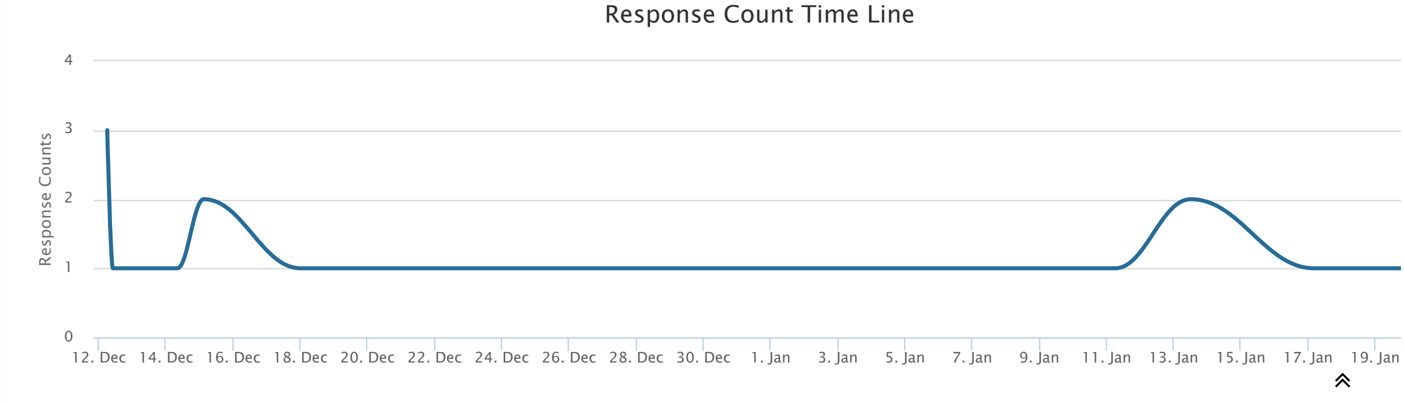
SECTION D: APPLICANT/S APPROVAL STATUS FOR ACCESS TO STUDENTS FOR RESEARCH PURPOSE
(To be completed by the UCT - ED, DSA or Nominee)

D.1 APPROVAL STATUS	Approved / With Terms / Not (I) Approved ■ ~~(II) With terms~~ ~~(III) Not approved~~	* Conditional approval with terms (a) Access to students for this research study must only be undertaken after written ethics approval has been obtained. (b) In event any ethics conditions are attached, these must be complied with before access to students.	Applicant/s Ref. No.: Mntjes002/ Ms Jessica Kirsten Mantel	
D.2 APPROVED BY:	Designation Executive Director Department of Student Affairs	Name *Dr Moonira Khan*	Signature	Date of Approval 21/11/2016

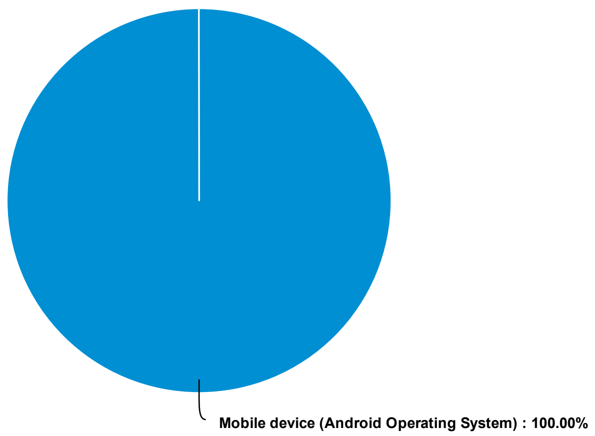
Version. DSA 100.2016 Page 1 of 1 DSA 100

7.6. Appendix 6: Questionnaire Responses





Which type of device did you use for the study?

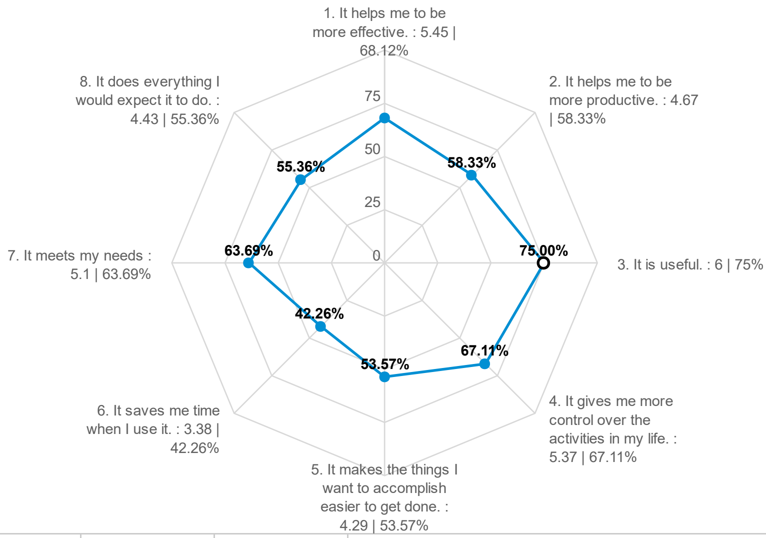


Answer	Count	Percent	20% 40% 60% 80
Mobile device (Android Operating System)	14 (/a/showResponseEditor.do?mode=execute&questionID=50810070&answerID=265650731&globalResultMode=0)	100%	
Desktop device (Windows Operating System)	0 (/a/showResponseEditor.do?mode=execute&questionID=50810070&answerID=265650732&globalResultMode=0)	0%	
Total	**14**	**100 %**	

Mean: 1.000 **Variance: 0.000** **Standard Deviation: 0.000** **Standard Error: 0.000** **Confidence Interval: [1.000 - 1.000]**

Section 1: Usefulness

Please rate the following attributes of the app "ElecApp" relating to its USEFULNESS: *

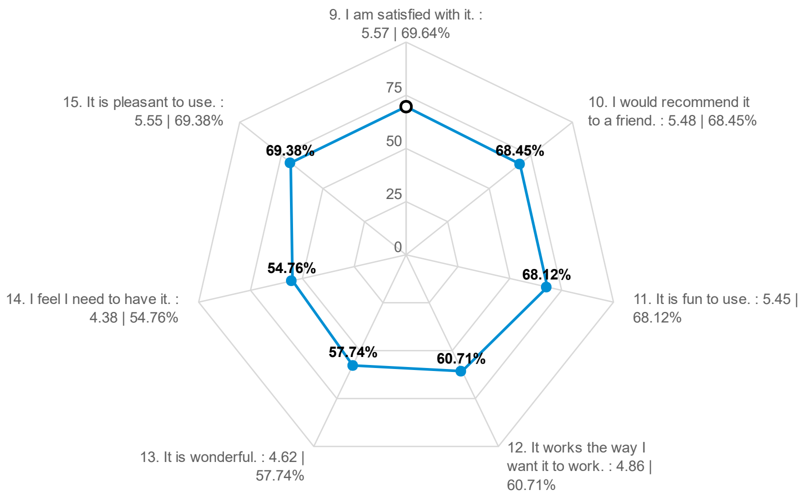


Question	Count	Score	Strongly Disagree	Strongl Agre
1. It helps me to be more effective.	21	5.45		

2. It helps me to be more productive.	21	4.67
3. It is useful.	21	6
4. It gives me more control over the activities in my life.	21	5.37
5. It makes the things I want to accomplish easier to get done.	21	4.29
6. It saves me time when I use it.	21	3.38
7. It meets my needs	21	5.1
8. It does everything I would expect it to do.	21	4.43
	Average	**4.84**

Section 2: Satisfaction

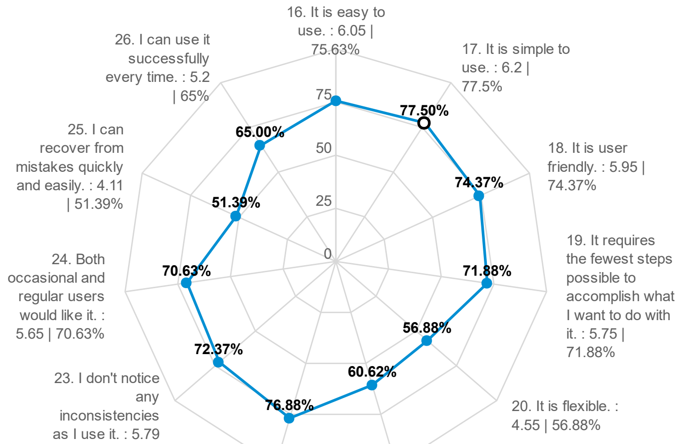
Please rate the following attributes of the app "ElecApp" relating to your SATISFACTION:

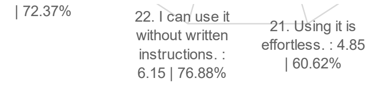


Question	Count	Score	Strongly Disagree	Strongl Agre
9. I am satisfied with it.	21	5.57		
10. I would recommend it to a friend.	21	5.48		
11. It is fun to use.	21	5.45		
12. It works the way I want it to work.	21	4.86		
13. It is wonderful.	21	4.62		
14. I feel I need to have it.	21	4.38		
15. It is pleasant to use.	21	5.55		
	Average	**5.13**		

Section 3: Ease of Use

Please rate the following attributes of the app "ElecApp" relating to its EASE OF USE:

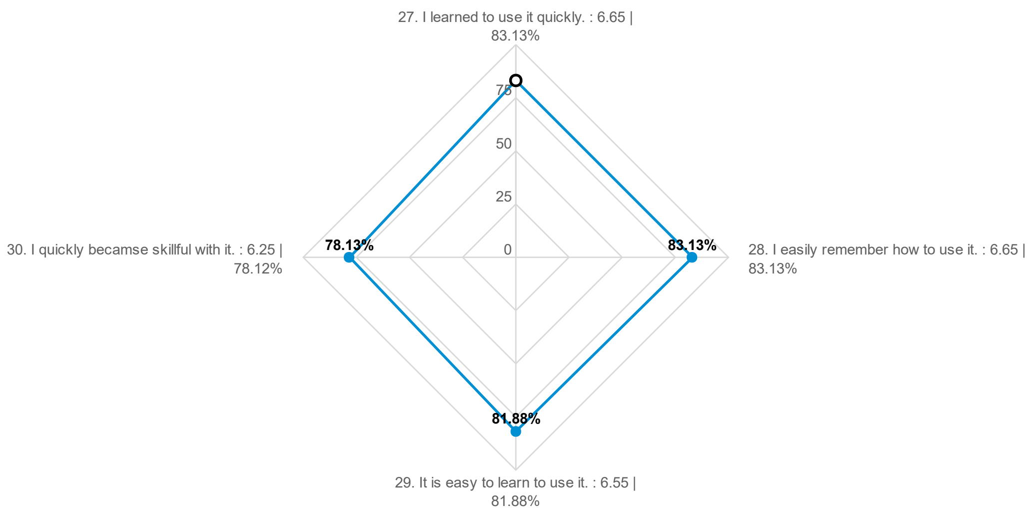




Question	Count	Score	Strongly Disagree	Strongl Agre
16. It is easy to use.	20	6.05		
17. It is simple to use.	20	6.2		
18. It is user friendly.	20	5.95		
19. It requires the fewest steps possible to accomplish what I want to do with it.	20	5.75		
20. It is flexible.	20	4.55		
21. Using it is effortless.	20	4.85		
22. I can use it without written instructions.	20	6.15		
23. I don't notice any inconsistencies as I use it.	20	5.79		
24. Both occasional and regular users would like it.	20	5.65		
25. I can recover from mistakes quickly and easily.	20	4.11		
26. I can use it successfully every time.	20	5.2		
	Average	5.48		

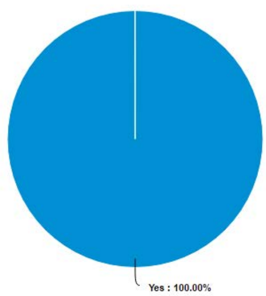
Section 4: Ease of Learning

Please rate the following attributes of the app "ElecApp" relating to the EASE OF LEARNING:



Question	Count	Score	Strongly Disagree	Strongl Agre
27. I learned to use it quickly.	20	6.65		
28. I easily remember how to use it.	20	6.65		
29. It is easy to learn to use it.	20	6.55		
30. I quickly becamse skillful with it.	20	6.25		
	Average	6.53		

Do you feel that the ElecApp has helped you to better understand your electricity usage?



Answer	Count	Percent	20% 40% 60% 80
Yes	18 (/a/showResponseEditor.do?mode=execute&questionID=50834721&answerID=265796346&globalResultMode=0)	100%	
No	0 (/a/showResponseEditor.do?mode=execute&questionID=50834721&answerID=265796347&globalResultMode=0)	0%	
Total	**18**	**100 %**	

Mean: 1.000 **Variance: 0.000** **Standard Deviation: 0.000** **Standard Error: 0.000** **Confidence Interval: [1.000 - 1.000]**

List the most negative aspect(s):

List the most negative aspect(s):

01/17/2017	20824094	I sometimes forget to use it :(
01/13/2017	20801529	You have to remember to use it.
01/09/2017	20733139	It took a while to get into the swing of things - simply due to the timing though - leaving the house before 1st week of trial was completed interrupted the usage.
01/09/2017	20732762	I could not add appliances. I would have liked to set limits and receive push notifications.
12/23/2016	20673208	Needs a function to delete a wrong entry
12/22/2016	20666666	Just one small thing, the buttons to turn on which appliance you're using are quite small. I've got fat fingers, so at one point I accidentally turned on the heater - not as it's the middle of summer.
12/20/2016	20647071	Insufficient appliances No ability to edit a recording if mistakenly left on
12/20/2016	20638852	I couldn't edit the time I used something afterwards. For example I put the dishwasher meter on and only remembered to switch it off the next day.
12/20/2016	20638133	Continues calculating all day if you forgot to switch off on the App
12/19/2016	20637040	Did not have complete appliance type flexibility (no iron). Did not have a predictive meter reading counter to compare or adjust with reality. Does not allow all usage (geyser on/off).

1 2 Next »

List the most positive aspect(s).

List the most positive aspect(s).

01/17/2017	20824094	It makes me aware of my electricity consumption and how I can save more.
01/13/2017	20801529	I'm more aware of my electricity usage.
01/09/2017	20733139	It was quick once set up and informative to use to adjust electricity usage.
01/09/2017	20732762	Easy to use and monitor.
12/23/2016	20673208	It helps me understand how much electricity i use per aplliance
12/22/2016	20666666	It's incredibly simple, which to me is a good thing. I feel I became more vigilant and mindful about my electricity and water usage, even addicted! Not only a great wa conscious about wasting, but ideal for saving money.
12/20/2016	20647071	Made me more aware of what appliances use the most electricity Helped me to be more careful with what appliances I used and for how long Helped me remember to switch appliances off after use.
12/20/2016	20638852	Simple interface. Interesting to see how much things cost.
12/20/2016	20638133	Serves the purpose when done right
12/19/2016	20637040	Shows a comparison of appliance usage, thereby facilitating effective prioritisation.

1 2 Next »

List the most negative aspect(s):

List the most negative aspect(s):

12/19/2016	20631624	1) You need to remember to switch the app off when the appliance goes off. This is the main problem. I forgot to switch it off a few times and therefore produced incorrect results. Ideally, it would automatically switch off when the appliance switched off. 2) The clear all data is a dangerous button. This should be per appliance / day / hour.
12/18/2016	20627096	I kept forgetting to switch off the appliances. Hence my kettle was running for "8 hours". Maybe having a notification/reminder that the app is recording would be useful. Stove and oven not separate - oven uses more electricity, doesn't it?
12/13/2016	20581892	- Not all household appliances are linked to the app and there is no way to add them. For example an iron or borehole pump. - The app would be more effective if I could calibrate all my appliances in my household before using the app. By doing this, I wouldn't have to constantly log meter readings before/ after every appliance usage. In addition, multiple appliances can be used since the app would then be able to recognize the electricity usage of the individual appliances. - It would be beneficial if multiple devices could be linked to one account. Then all the users in the household can log appliance usage without having to be limited to one device.
12/13/2016	20579084	Difficult to turn appliance application off, easy to turn on but took several attempts to turn off.
12/12/2016	20570506	B attled to remember to toggle off..maybe if possible to input time expected to use appliance I would be a better user
12/12/2016	20569255	1) That you can't alter the time you used an appliance if you forgot to turn it off on the app when you turned it off in reality. 2) it's a hassle to update the electricity meter reading before using an appliance 3) You always have to have your phone/ computer with you to use it accurately 4) The on-off switch for the appliances on the app is a bit too sensitive 5) It seemed to increase my battery consumption
12/12/2016	20564356	Time consuming...maybe a have a beeper as reminder to switch off timer.
12/12/2016	20564390	1. There is no opportunity to manually input pre-known usages eg pool pump on for 3 hours a day 2. Need more generic categories to include unlisted items such as irons etc 3. Need facility to correct mistakes if you forget to turn off an appliance on the app

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List the most positive aspect(s).

List the most positive aspect(s).

12/19/2016	20631624	It is easy to use, the interface looks good with the icons for different appliances. I like the cost and usage figures.
12/18/2016	20627096	I like the per appliance chart. I didn't know how much electricity my tv uses
12/13/2016	20581892	This is one of the most beneficial apps I have ever used. It is so easy to use. With a little modication, every household will benefit from this app.
12/13/2016	20579084	
12/12/2016	20570506	Easy use, useful to see electricity usage
12/12/2016	20569255	1) Quite user friendly 2) It's nice that it works on estimates if you don't update the meter reading 3) The feedback page is a good graphic to get an idea of your usage 4) Increases awareness of which appliances use a lot of electricity
12/12/2016	20564356	Bring consciousness on saving electricity.
12/12/2016	20564390	1. Well laid out and easy to use 2. Good feedback showing where electricity usage can be reduced 3. Good use of graphics showing daily usages 4. Accurate as total daily usage does agree back to meter

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