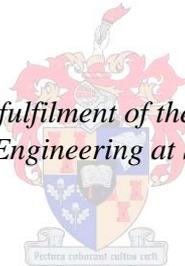


Development of an interactive energy management web application for residential end-users

by
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*Thesis presented in partial fulfilment of the requirements for the degree
Master of Science in Engineering at Stellenbosch University*



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December 2012

DECLARATION

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ABSTRACT

Energy efficiency, as the effective use of energy, is recognized as one of the simplest ways to improve the sustainable use of resources and by implication involves the end-user.

The 2008 power crisis which South Africa experienced, highlighted supply exigencies and prompted a subsequent emphasis on affordable, rapidly scalable solutions, notably energy efficiency. As the establishment of new supply capacity is both costly and time-consuming, the logical alternative has been to focus intervention on the demand side. Residential electrical end-use has been identified as an area where the potential for change exists and strategies to address residential demand have gained momentum. The vulnerability of energy systems affects energy security on technical, economic and social levels. South African consumers are confronted with rising living costs and a substantial increase in electricity prices according to the Integrated Resource Plan for Electricity (2010-2030).

Integral to addressing end-use is the ensuing behaviour of the end-user. End-use analysis aims to grasp and model customer usage by considering the electric demand per customer type, end-use category, appliance type and time of use.

This project has focussed on the development of an interactive web application as a tool for residential end-users to improve energy efficiency through modified consumption behaviour and the adoption of energy efficient habits. The objectives have been aimed at educating an end-user through exposure to energy efficient guidelines and consumption analysis. Based on a Time Of Use-framework, a consumer's understanding of appliance usage profiles can help realize the cost benefits associated with appliance scheduling.

In order to achieve the desired functionality and with extendibility and ease of maintenance in mind, the application relies on the provision of dynamic content by means of a relational database structured around end-use categories and appliance types. In an effort to convey only relevant information in the simplest way, current web technology was evaluated. The resulting design has favoured an interactive, minimalistic, graphic presentation of content in

the form of a Rich Internet Application.

The development process has been divided into two phases. The residential energy consumption context has been substantiated with a case study of which the main objective and outcome has been to devise a methodology to generate usage profiles for household appliances. Phase one of the development process has been completed, as well as the case study. The conceptualization and framework for phase two has been established and the recommendation is to incorporate the methodology and usage profile results from the case study for implementation of the second phase. The effectiveness of the tool can only be evaluated once phase two of the application is complete. A beta release version of the final product can then be made available to a focus group for feedback.

OPSOMMING

Energie effektiwiteit, gesien as die effektiewe aanwending van energie, word herken as een van die eenvoudigste maniere om die volhoubare gebruik van hulpbronne te bevorder en betrek by implikasie die verbruiker.

Die 2008 kragvoorsieningskrisis wat Suid-Afrika beleef het, het dringende tekorte aan die lig gebring en 'n gevolglike klemverskuiwing na bekostigbare, maklik aanpasbare oplossings, vernaamlik energie effektiwiteit. Aangesien die daarstelling van nuwe voorsieningskapasiteit beide duur is en baie tyd in beslag neem, was die voor die hand liggende alternatief om te fokus op vraag-kant toetrede. Huishoudelike elektriese verbruik is geïdentifiseer as 'n area waar die potensiaal vir verandering bestaan en strategieë om residensiële aanvraag aan te spreek het momentum gekry. Die kwesbaarheid van energiestelsels affekteer energie sekuriteit op tegniese, ekonomiese en sosiale vlakke. Suid-Afrikaanse verbruikers word gekonfronteer met stygende lewenskoste en 'n aansienlike toename in elektrisiteitspryse volgens die Geïntegreerde Hulpbron-Plan vir Elektrisiteit (2010-2030).

Eie aan die aanspreek van verbruik is die voortvloeiende gedrag van die verbruiker. Verbruiksanalise poog om verbruik te begryp en te modelleer deur die elektriese aanvraag na gelang van verbruikerstipe, verbruikskategorie, toesteltipe en tyd van verbruik in aanmerking te neem.

Hierdie projek het gefokus op die ontwikkeling van 'n interaktiewe web-toepassing as 'n instrument vir residensiële verbruikers om energie effektiwiteit te verbeter deur gewysigde verbruiksgedrag en die ingebruikneming van energie effektiewe gewoontes. Die doelwitte is gerig op die opvoeding van 'n verbruiker deur blootstelling aan riglyne vir energie effektiewe verbruik en verbruiksanalise. Gebaseer op 'n Tyd-Van-Verbruik-raamwerk, kan 'n verbruiker se begrip van toestelle se verbruiksprofile 'n bydrae lewer om die koste-voordele geassosieer met toestel-skedulering te realiseer.

Om sodoende die verlangde funksionaliteit te bewerkstellig en met verlengbaarheid en gemak

van onderhoud voor oë, steun die toepassing op die verskaffing van dinamiese inhoud deur middel van 'n relasionele databasis wat gestruktureer is rondom verbruikskategorieë en toesteltipes. In 'n poging om slegs toepaslike informasie in die eenvoudigste vorm weer te gee, is teenswoordige web tegnologie geëvalueer. Die vooruitspruitende ontwerp is 'n interaktiewe, minimalistiese, grafiese aanbieding van die inhoud in die vorm van 'n sogenaamde "*Rich Internet Application*".

Die ontwikkelingsproses is ingedeel in twee fases. Die huishoudelike energieverbruiks-konteks is bevestig deur middel van 'n gevallestudie waarvan die vernaamste doelwit en uitkoms was om 'n metodologie daar te stel om verbruiksprofiele van huishoudelike toestelle te genereer. Fase een van die ontwikkelingsproses is voltooi asook die gevallestudie. Die konsepsuele ontwikkeling en raamwerk vir fase twee is reeds gevestig en die aanbeveling is om die metodologie en verbruiksprofielresultate van die gevallestudie te inkorporeer vir implementering van die tweede fase. Die effektiwiteit van die toepassing kan eers geëvalueer word sodra fase twee afgehandel is. 'n Beta-weergawe vrystelling van die finale produk kan dan beskikbaar gestel word aan 'n fokusgroep vir terugvoer.

ACKNOWLEDGEMENTS

I would like to thank Prof HJ Vermeulen, Department of Electrical and Electronic Engineering at Stellenbosch University, for his contribution to this project. I would like to express my deepest gratitude to God and my family for their invaluable help and support. Special thanks also to Albert Alchin, Nelius Bekker, Adiel Jakoef, Jannes van der Merwe, Graeme Urban, Marius Bekker and Grant Botha for their assistance during various stages, and with various aspects, of this project.

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LIST OF ABBREVIATIONS AND SYMBOLS

1NF ... 5NF	First Normal Form ... Fifth Normal Form
A	Ampere
AC	Alternating current
AMF	Action Message Format
AR4	Fourth assessment report of the Intergovernmental Panel on Climate Change
BRICS	Brazil Russia India China South Africa
CFL	Compact fluorescent lamp/light
CO ₂	Carbon dioxide
COP17	17 th Conference of the Parties to the United Nations Framework Convention on Climate Change
CRUD	Create, Read/Retrieve, Update, Delete
CSS	Cascading Style Sheets
csv	Comma separated values
DBMS	Database Management System
DoE	Department of Energy
DSM	Demand Side Management
EE	Energy Efficiency
EER	Enhanced entity-relationship
EIA	United States Energy Information Administration
ER	Entity-relationship
ESMAP	Energy Sector Management Assistance Programme
EUTC	European Utilities Telecom Council
FK	Foreign Key
FTP	File Transfer Protocol
FXG	Flash XML Graphics
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIF	Graphics Interchange Format
GUI	Graphical User Interface
HSRC	Human Sciences Research Council
HTML	HyperText Markup Language

HTTP	HyperText Transfer Protocol
HTTPS	HyperText Transfer Protocol Secure
IBT	Inclining Block Tariff
ID	Identification number
IDE	Integrated Development Environment
J	joule
JPEG	Joint Photographic Experts Group
KPI	Key Performance Indicator
kWh	kilowatt-hour
LAMP	Linux Apache MySQL PHP
LTMS	Long-term Mitigation Scenarios
LV	Low-voltage
MV	Medium-voltage
MYPD	Multi-year price determination
NEEA	National Energy Efficiency Agency
NERSA	National Energy Regulator of South Africa
OS	Operating System
pdf	Probability density function
PK	Primary Key
PNG	Portable Network Graphics
RDBMS	Relational Database Management System
RDP	Reconstruction and Development Programme
REST	Representational State Transfer
RIA	Rich Internet Application
RLC	Resistive Inductive Capacitive
RMS	root-mean-square
s	second
SALGA	South African Local Government Association
SANEDI	South African National Energy Development Institute
SCP	Secure Copy Protocol
SFTP	Secure File Transfer Protocol
SOAP	Simple Object Access Protocol

SQL	Structured Query Language
SSH	Secure Shell
Stats SA	Statistics South Africa
SVG	Scalable Vector Graphics
TOU	Time Of Use
UI	User Interface
UNDP	United Nations Development Programme
URL	Uniform Resource Locator
USB	Universal serial bus
V	Volt
VA	voltamperes
var	voltamperes reactive
VAT	Value Added Tax
W	watt
WAMP	Windows Apache MySQL PHP

1 PROJECT OVERVIEW

1.1 Introduction

The research documented in this thesis involves the development of an interactive, web-based application as a tool to educate residential end-users on energy efficiency and improve end-use energy efficiency. The energy debate spans a range of topics that include energy security, sustainable practices as well as the dynamic character of the energy landscape and future energy economy. The project work highlights the importance of energy efficiency and how it positively contributes to support both energy security and sustainability.

The improvement of end-use energy efficiency has gained prominence and is generally accepted as an obvious, simple and inexpensive measure to manage a consumer's energy demand. Energy efficiency can be defined from various perspectives including economic and technological perspectives. The more general definition relates to an improved, i.e. reduced, ratio of energy input for an expected output [1]. Further perspectives are alluded to in the literature review presented in chapter 2.

The direct correlation between economic growth and increased demand for energy means that most countries have a continuous need for additional energy. With the era of cheap and abundant sources of energy in the form of fossil fuels coming to an end, countries are experiencing increased pressure to augment their fossil-fuel energy supplies with renewable energy sources and to improve energy efficiency. Any electrical energy system should improve efficiency on both the supply and demand sides. Although the research which formed part of this project focuses on the South African residential context, the goal of improved end-use energy efficiency is a universal objective.

In addition to the growing demand for energy, consumption trends are changing globally. End-use energy profiles are changing as some countries are experiencing a decline in energy intensive industries with the rise of China as the world's production centre, whilst experiencing growth of knowledge-based industries and service sectors. In general, changing

demographics and increased personal mobility all contribute to the changing energy landscape [2]. Electricity consumers are changing and demand higher levels of reliability, efficiency and environmental performance [3].

From an electrical engineering viewpoint, energy usage is associated with the consumption of generated and distributed electrical power. According to O'Keefe et al., one aspect of the energy debate in particular that has received little attention is behaviour [2]. Supply side efficiency is driven by technology interventions such as the introduction of renewable sources to expand the energy mix and technological improvements to curb energy leaks and losses. However, *"lifestyles, how we view and use electricity services, is an increasingly important factor implying a significant role for social learning."*[2].

Although the notion of "trends" are often associated exclusively with social paradigms, observable changing energy trends require an approach that places energy end-use in the appropriate context of lifestyle, preferences and behavioural patterns. For the purposes of this research, the topic of residential energy usage required an interdisciplinary approach. Publications and research material have been consulted to substantiate the legitimate reference to consumers' behavioural trends. Findings from these are included in the literature review in chapter 2.

Technology which can be categorized as smart grid solutions assume that if customers and their appliances have the ability to make consumption decisions, price-driven incentives such as Time Of Use (TOU) pricing schemes will encourage a more judicious use of electricity thereby minimising peak hour consumption by means of appliance scheduling. In this regard, information and control are key to enable customers to manage their electricity costs [3]. Although not a smart grid solution per se, the web application developed as part of this research project, aims to both educate and provide useful and practical information on residential load management.

Section 1.2.2 discusses the South African context, and since the residential load represents

the biggest challenge in addressing capacity constraints, the research is aimed at a residential end-user. The case study discussed in chapter 4, focuses on load profiling and energy consumption for a middle-income South African residential household.

1.2 Project motivation

The main considerations as motivation for this research project are summarised within the context of energy security. A very important motivational factor for end-users to improve end-use energy efficiency is the reality of the rising cost of energy. Energy security and economic considerations are subsequently discussed from both a global and local perspective.

1.2.1 A global perspective on energy security

The supply and use of energy in a sustainable manner is now a global imperative to mitigate negative climatic impacts and to provide energy security. According to the World Energy Council energy security is defined as "*an uninterrupted supply of energy, in terms of quantities required to meet demand at affordable prices on a 24/7 basis.*" [2]. As discussed by O'Keefe et al., the vulnerability of energy systems is multi-dimensional, impacting energy security on economic, technical and social levels [2]. At a micro-economic level, this susceptibility is determined by how exposed consumers are to possible interruption of supply as well as an increase in price. At the social level, fuel poverty can affect the category of households whose fuel expenditure is in excess of 10% of the household income. Fuel poverty is caused by a combination of factors such as poorly insulated houses, in-house energy system-leaks or insufficient income compared to the cost of electricity [2].

According to the fourth assessment report of the Intergovernmental Panel on Climate Change (AR4) published in 2007, "*the most profound of findings lie with the firm assertion that the costs of early action far outweigh the costs of inaction: It is often more cost-effective to invest in end-user energy efficiency improvement than in increasing energy supply to satisfy demand for energy services. Efficiency improvement has a positive effect on energy security.*" [2]. One of the measures promulgated by the AR4 to aid environmental protection is demand-side management programmes.

The energy industry has come to realize that among all the measures to meet demand, energy efficiency is the simplest option offering benefits to both energy suppliers and consumers alike [3]. Although seemingly contradictory to the business model of generation and profitable retail sale of electricity, electricity suppliers can reduce the risk of vulnerability when disruptive options such as load-shedding are prevented.

1.2.2 Energy security in South Africa

As documented in the June 2011 report of the Energy Management Sector Management Programme (ESMAP) on the implementation of Energy Efficiency (EE) and Demand Side Management (DSM) [4], South Africa had to deal with a very serious power crisis during 2008. A number of supply-related issues contributed to the crisis, notably insufficient coal supplies, infrastructure requirements and supply disruption which severely depleted the country's electricity reserves and caused immense pressure on Eskom, the state-owned electrical supply utility. Falling into a middle-income category, South Africa has been able to benefit from the resources provided by the ESMAP, a technical assistance programme overseen by the World Bank. The ESMAP operates on a global scale and aids eligible countries to attain environmentally sustainable energy solutions through capacity-building [4].

The extreme power shortage which South Africa experienced during the 2008 crisis was estimated to be 3500 MW, approximately a tenth of daily peak demand. The presumption at the time was that the exigency would only be alleviated by additional capacity. In order to address the crisis, a number of steps were taken, notably the provision for low carbon investment planning through the formulation of South Africa's Long-term Mitigation Scenarios (LTMS). The LTMS resulted from the cooperative effort between the South African Department of Energy (DoE) and the University of Cape Town [4]. The World Bank, along with the United Nations Development Programme (UNDP) and the ESMAP also provided support for the LTMS [4]. The course of events underlined the pressing need for support of EE/DSM solutions that were realistically attainable within a short period of time as an affordable, rapidly scalable approach to mitigate the power shortage and reduce disruptive

measures such as load shedding [4].

The South African economy largely depends on energy intensive industries such as mining, which are reliant on coal as the main fuel source. The South African government's Reconstruction and Development Programme (RDP) has also placed an emphasis on the electrification of previously disadvantaged areas, including rural areas. The electrification targets intensified the burden on Eskom and consequently on predominantly fossil fuel resources required for coal-fired generation. South Africa's dependence on this form of fuel has not only had an adverse polluting impact on the local environment but has caused South Africa to be one of the highest contributors to greenhouse gas (GHG) emissions per person in the world and the highest emitter in Africa [4]. From the perspective of good global citizenship, South Africa, as the 2011 host for the 17th Conference of the Parties (COP17) to the United Nations Framework Convention on Climate Change, is under pressure to make good of a commitment to contribute to the global effort to implement strategies towards reducing GHG [5]. Within the South African context, the significant contribution which EE and DSM can make towards that end has been noted and supported by the government [4].

According to the World Bank [6], South Africa is categorized as a developing country. As emphasised in the Bank's recent Economic Update [7], South Africa's foreseeable economic outlook holds promise for an upturn, against the backdrop of the recent global recession, with projected Gross Domestic Product (GDP) growth [7]. South Africa formally entered the BRICS grouping of countries (with Brazil, Russia, India and China) on April 13, 2011. This group of countries are recognized for their emergence as key role players in economic cooperation and development. South Africa is considered the gateway to the African continent, possessing the largest and most sophisticated economy.

The South African government set a goal to connect every household to the electrical grid by 2012 through its mass electrification programme. Pre-empting the 2012 deadline, a progress evaluation was documented on how the rollout of Universal Access by 2012 was faring, concluding that the initial goal set for 2012 was practically impossible [8]. A new deadline has been set for 2014. The South African government has also committed to a multi-billion

rand subsidy in order to provide 50kWh per month of free basic electricity to indigent households [9]. An increase in the demand for energy places South Africa in a position where Eskom, the electrical supply utility dominating the South African energy landscape, will face ongoing pressure to guarantee energy security.

Eskom generates 95% of the electricity used in South Africa. The National Energy Regulator of South Africa (NERSA) is authorized to oversee the adequate provision for future electricity demand through installed generation capacity. NERSA was "*established in terms of the (South African) National Energy Regulator Act, 2004 (Act No. 40 of 2004) to regulate the energy industry in accordance with government laws, policies, standards and international best practices in support of sustainable development.*" [10].

In the context of Eskom's diminishing reserve margins, NERSA has emphasized the need to intensify EE/DSM programmes [4]. Since the building of additional power stations and major distribution infrastructure requires an enormous capital investment, and in order to maintain the pivotal balance between supply and demand, Eskom is facing a scenario where they can no longer afford the cost of consumer passivity and apathy. The utility must leverage the benefits to be reaped from end-user EE initiatives.

The energy challenges which South Africans currently face and will continue to face over the next few years, stem from the country's historically low electricity price. In the 1970s and early 1980s excess generation capacity was added and the utility had no incentive to create additional capacity to meet future demand. The 2008 power shortage motivated the need for Eskom to reassess its strategy in terms of capacity building and budgetary requirements to meet the country's rising electricity demand. The initial expectation was for the shortfall to be corrected by escalating the price of electricity appropriately over a relatively short and limited period and thereafter align adjustments with inflation [11].

According to Rycroft et al., "*Eskom's multi-year price determination (MYPD2) application, lodged with NERSA in September 2009, was for an annual increase of 45% p.a. for 2010,*

2011 and 2012." [11]. This followed on a 27% increase in 2008 and a 31% increase in 2009. At the time, Eskom had envisioned that a considerable once-off escalation would align prices with regulations proposed by the DoE, but to implement a gradual price adjustment phased in over a period of three years. Such a scenario justified an expectation that from 2013 Eskom's proposed increases would be in accordance with inflationary trends. The reaction to the utility's initial request was widely contested and in early 2010 a revised build programme was proposed and accepted for the MYPD2 period. The revised programme lobbied for an even more gradual phasing in of threshold price increases to keep Eskom profitable. Subsequently, only a 25% p.a. rise was approved for 2010, 2011 and 2012.

In the Final Report of South Africa's Integrated Resource Plan (IRP) for Electricity 2010-2030 [12], expected future electricity prices are outlined as shown in Figure 1-1. Price fluctuation is based on different generation options with a peak price of R1,12/kWh in 2021 [12].

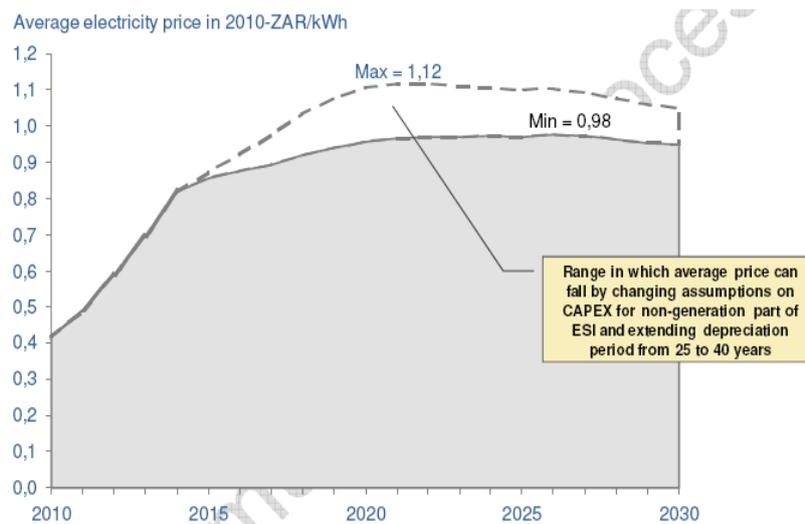


Figure 1-1: South Africa's expected future electricity prices: 2010-2030 [12]

Eskom distributes electricity directly to some consumers and also sells wholesale electricity to municipal authorities who in turn re-sell to consumers at a profit. NERSA is tasked to set guidelines for municipalities as to the percentage margin addition to electricity tariffs.

In terms of social vulnerability from an energy security perspective, fuel poverty is a reality

for many South African households. In a July 2012 news report [13], South African economist Mike Schüssler warned that South African consumers whose municipal account (which includes electricity costs), currently exceeds 10% of their remuneration will face a scenario where that will increase to 20%. Schüssler's statement was issued in reaction to information about Eskom's plans to nearly double its selling price of electricity from the 2012 price of 50.27c/kWh to 97.51c/kWh by 2016/17 [13].

South Africans, as part of the global population, are equally impacted by global conditions which adversely affect staple grain supplies. In a recent report by the World Bank Group on global food prices, mid-year indicators attest to a 10% increase due to the severe droughts in major wheat production locations, which led to harvest failures and consequent price increases for maize and soybean as replacements [14]. The same source also states that sharp domestic price increases have continued in Africa and the impact was notable in South Africa. Long term prospects indicate that there will be no immediate relief and that the market will continue to be characterized by instability and steep costs as a consequence of supply uncertainties [14]. In the South African context, these challenges translate to increased pressure on many household budgets as well as increased vulnerability, implicating the affordability of energy security.

1.2.3 Energy efficiency and demand-side management

To establish energy security within the energy provision-consumption context, DSM involves all interventions that occur on the demand side (as opposed to the supply side) where the end-user resides.

Eskom's implementation of a designated EE/DSM fund has been beleaguered by numerous bureaucratic issues and concerns [4]. In view of the context sketched in 1.2.2, the utility subsequently adjusted its strategy to pursue and realize projects which could produce results more rapidly, for example the launching of a nation-wide incentive targeted at residential consumers to replace incandescent light bulbs with energy efficient compact fluorescent lamps (CFLs) [4]. At the time of the 2008 power crisis, Eskom embarked on its "*Accelerated*

Demand-Side Management Plan" whereby the utility initiated a sustainable electricity-savings strategy with an initial goal of 3000 MW by March 2011 and a further 5000 MW by March 2026 [4].

In accordance with the 2008 National Energy Act, the South African National Energy Development Institute (SANEDI) was founded as an agency assigned to raise the profile of EE and tasked to ensure its implementation. In addition, SANEDI was mandated to oversee two existing organizations, namely the National Energy Efficiency Agency (NEEA) as well as South Africa's National Energy Research Institute. The objectives contained in the NEEA's business plan for its *"Three-Year Strategic Outlook, 2009–2012"* are concerned with matters such as the following:

- To promote EE and DSM projects as a first priority.
- Awareness campaigns in support of that.
- The overseeing of training and capacity building in the field of EE.
- Cooperation with entities undertaking EE programmes in other countries, to ensure South Africa's adoption of international best practices [4].

EE and DSM have also been identified as significant contributors in the IRP's approach to address future resources [4]. In May 2010, the DoE announced a *"New National Policy on EE and DSM"* aimed to achieve objectives such as the following [4]:

- Set the framework concerning NERSA's tasks with regards to various types of EE/DSM implementation.
- Include a resource standard for EE in the Integrated Resource Plan, to ensure that energy efficient *"first fuel"* alternatives are considered and developed as preliminary options rather than costly supply-side alternatives.
- A sliding-scale for electricity charges as a stimulus for EE, as well as a target-based structure pertaining to different EE/DSM interventions, notably also for the residential sector.

There is ample evidence of the high standing which EE has gained in South Africa to

promote energy security, which makes for a compelling argument for Eskom to consider the advantages of rallying consumer cooperation and participation for its EE initiatives.

1.3 Project description

As discussed, the project work is motivated on the premise that in the case of South African residential end-users, not only do many already experience fuel poverty, but the expected future price increase of electricity will place most household budgets under pressure. In further support of the promotion of EE is the need for South Africans, as part of the global population, to participate in efforts to mitigate negative climatic impacts and respond to the need to improve sustainability.

The project involves the development of a web application aimed as a tool to both educate and empower residential end-users to promote and improve EE [15]. As indicated in the project demarcation provided in Figure 1-2, the project was divided into a number of main components.

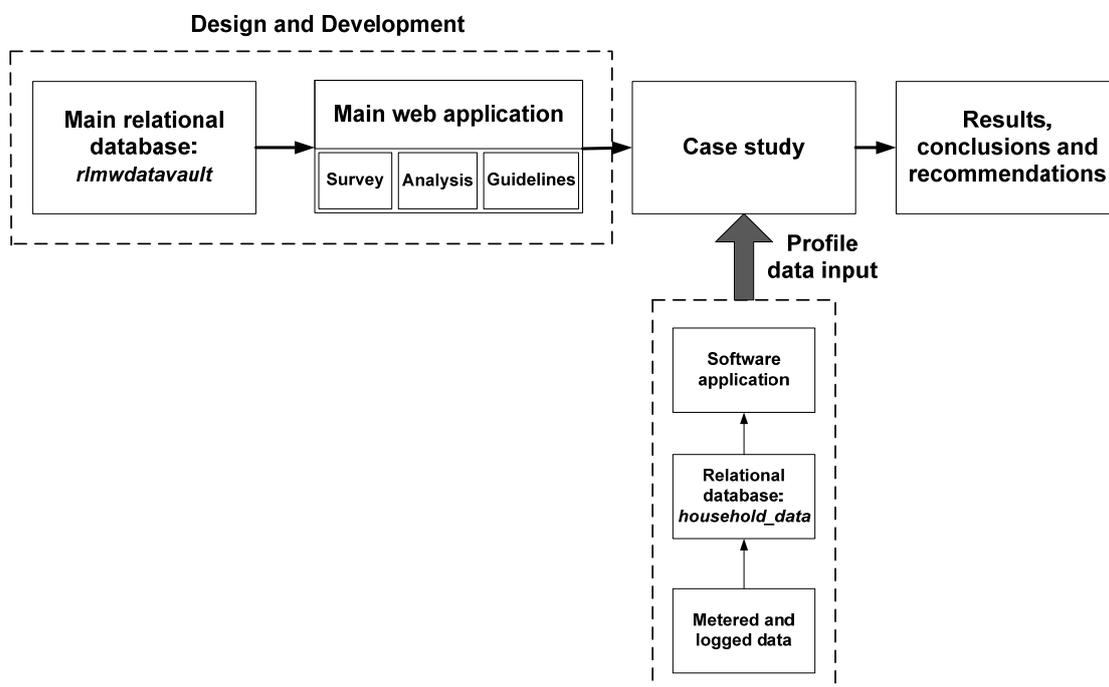


Figure 1-2: Main components of the research project

The sequence of steps performed during the project involved the following:

- Firstly, a relational database was designed and developed to provide the required data for the dynamic web application. Research was conducted to collect data on common household appliances and their electrical power ratings.
- Secondly, and in parallel with the database development, the main web application was designed for a residential end-user with a reasonable level of computer literacy. The application was developed to enable the user to perform certain energy auditing tasks, analysis and to access educational material such as energy saving guidelines.
- Thirdly, a case study was conducted.
- Finally, as part of the recommendations for further work, Phase 2 of the analysis section must be implemented in order to finalize this component of the project.

The project workflow, in terms of the sequence of completion, is indicated in Figure 1-3.

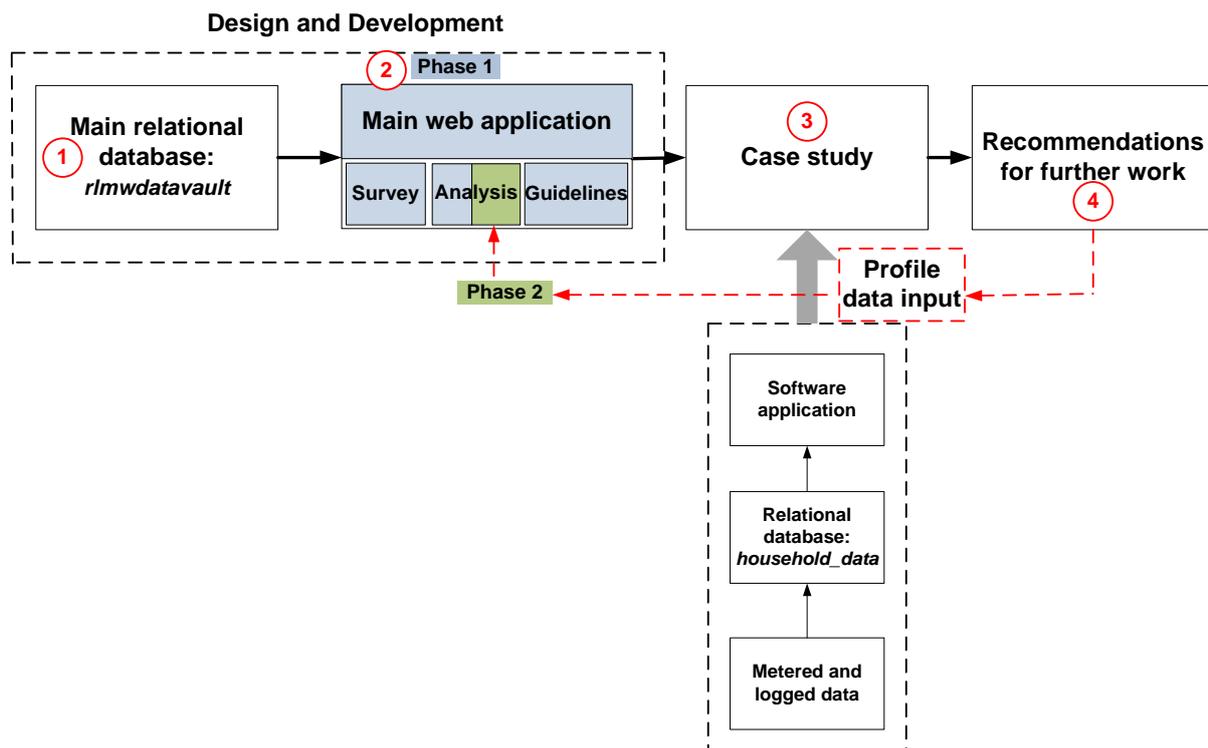


Figure 1-3: Project workflow

In order to create a tool for an end-user to realise the benefits of improved energy efficiency through changed attitudes and behaviour, the following three components and associated

outcomes were identified during the development of the web application:

- *Survey:*
 - Creation of a residential project.
 - Identification of electrical loads within the residence by means of an appliance audit or survey.
- *Analysis:*
 - Analysis of installed capacity and appliance usage by means of appliance usage profiles.
 - Education on the load characteristics of common household appliances.
 - Cost analysis based on Time Of Use tariffs.
- *Guidelines:* Exposure to practical energy efficient guidelines.

These tasks in turn prompted and necessitated the formulation of a number of questions on how to achieve the desired end result. The following key questions pertaining to the application's structural and functional requirements emerged from the criteria:

- What type of experience will be effective and appropriate for a user with a reasonable level of computer literacy?
- In what format should the content be presented in order to realise a successful user experience?
- What is the most optimal way to convey the desired information?
- What type of technology can provide a dynamic, interactive user experience?
- What type of data storage will be most appropriate to ensure flexibility and data integrity?

A case study was conducted in support of the main application to record actual household data in order to generate usage profiles for a number of household appliances. The case study consisted of three main tasks:

- A survey and audit of some of the main household appliances to collect nameplate rating information and identify which appliances and equipment to be logged.
- The recording of log data related to measured supply and appliance usage.

- The processing of the data logs by firstly storing the data in a database and secondly processing the data by means of SQL queries and charting solutions to create a visual presentation.

The research concludes with results and recommendations for further work.

1.4 Research objectives

In the general sense, the research objectives have been formulated to promote Energy Efficiency (EE) stewardship amongst South African residential end-users, as it is believed that consumers, or end-users, who have adopted EE practices can make a positive contribution towards energy security. The aim of the research also incorporates an objective of the Department of Energy (DoE) to develop energy efficient alternatives as preliminary options, in favour of costly supply-side alternatives.

In view of Eskom's strategy to prioritize EE and Demand Side Management (DSM) projects that are able to produce tangible results more rapidly, it seems only logical to focus interventions where the potential for change exists [30]. This latter statement identified the target context for this research project, namely the residential household since the domestic load represents the biggest challenge in addressing capacity constraints.

The ability of an interventionist strategy to fully explore and harness this potential for change, determines its effectiveness to deliver desired results. In this respect, promising research outcomes alluded to in the literature review highlight the use of technology in the form of an Internet-based tool aimed at residential end-users. The applied technology combined selective information, goals and feedback to achieve a reduction in domestic energy consumption [32].

The specific research objectives have been formulated and defined as follows:

- To make available, as a means of intervention, an intuitive, interactive web

application tool to empower and educate South African end-users on residential load management.

- To raise awareness of practical EE practices and promote the adoption thereof.
- To employ a development methodology with ease of maintenance and extendibility in mind, by means of the following:
 - Utilising currently relevant and appropriate web development technology.
 - Dynamic data exchange facilitated by database-driven content.
- To conduct a case study of a middle income residential household in order to achieve the following:
 - Investigate and substantiate the residential energy consumption context.
 - To establish an overall methodology to log appliance usage in a typical middle income residence.
 - Implement the methodology in order to record residential load usage data.
 - To establish a methodology for processing the logged data in a meaningful way with the view to obtain usage profile and duty cycle data that is compatible with the software application.
 - To determine a strategy to correlate electrical supply log data with appliance usage log data and produce a visual display that incorporates both sets of data.
 - Utilise the household case study as a test case scenario for the web application in terms of a user-defined project.

In view of the main objective of the application of improving energy efficiency through promotion of energy efficient habits and changed behaviour, one of the key outcomes has been to enable the user to make informed decisions. A user's decisions to improve energy efficiency would be based on aspects such as the following:

- A reduction in consumption and associated costs through the implementation of more energy efficient usage guidelines.
- A better understanding of the cost benefits of appliance scheduling in terms of a Time Of Use (TOU) tariff structure.
- Replacing energy *inefficient* appliances with more efficient models.

1.5 Thesis structure

This thesis is structured into five chapters and three appendices.

- Chapter 1 has presented the project overview, motivation and description along with the research objectives of the study.
- Chapter 2 presents a literature review on the main components of this study, namely:
 - End-use energy efficiency as it applies to residential end-users with special focus on South African residents.
 - Understanding the residential electric energy load and household energy profiles.
 - Interactive web technology options for the end-user, which includes a discussion on effective design for the end-user and dynamic client-server data exchange technology.
 - Software modelling.
- Chapter 3 describes the relational database backend that provides the dynamic-driven content for the web application. This chapter also outlines the software framework and explains aspects of the web application such as the graphical user interface (GUI) and data visualization.
- Chapter 4 presents a description of the case study that was conducted for a residential household.
- Chapter 5 contains the project conclusion and gives recommendations for further work.

2 LITERATURE REVIEW

2.1 Introduction

The study focuses on using a web application as a tool to raise awareness of EE by educating South African residential end-users on EE measures which can be practically implemented. In acknowledgement of the association between the behavioural and engineering components of power consumption, the literature review addresses both aspects: firstly EE as it concerns the end-user and secondly, suitable technology options which were considered for the web application.

The following elements are afforded a closer look:

- End-use energy efficiency as it applies to residential end-users with special focus on South African residents.
- The residential electric energy load and household energy profiles.
- Interactive web technology options for the end-user, which includes a discussion on effective design for the end-user and client-server data exchange technology.
- Software modelling.

2.2 End-use energy efficiency

End-use analysis is defined by Willis as the study of basic causes of electric demand by customer type, time, end-use category, and type of appliance [16]. End-use analysis is proposed to be the best way to study load usage in order to fully grasp and model customer usage. Integral to end-use analysis is the ensuing behaviour of the end-user, which is discussed in more detail in section 2.2.2.

Depending on the context, different perspectives apply when referring to EE. According to the World Energy Council, "*EE improvements refer to a reduction in the energy used for a given service or activity.*" [1]. To economists, EE is linked to economic efficiency to encompass "*all kinds of technological, behavioural and economic changes that reduce the*

amount of energy consumed per unit of GDP." [1]. For energy efficiency experts, improving energy efficiency exhibits the results of actions that aim at reducing the amount of energy used for a given level of service such as lighting or heating, through investing in more efficient equipment, retrofitting and greening buildings and facilities to reduce energy consumption, or avoiding unnecessary consumption and energy waste [1].

The following definition for energy efficiency is provided by the DoE, namely, "*from a consumer point of view energy efficiency refers to the effective use of energy to produce a given service. A more energy-efficient technology is one that produces the same service with less energy input.*" [12]. For the purposes of this study, the DoE definition of EE is adopted as it applies to a South African residential end-user.

An appropriate interpretation of end-use efficiency warrants consideration of the end-users as the role-players on the demand side. Since the residential load in South Africa is high on the priority list in addressing capacity constraints, the research is aimed at a residential end-user.

2.2.1 South African residential end-users

Household energy usage is intimately linked to affordability, lifestyles and preferences. From a residential perspective, a small portion of South African households are considered affluent and enjoy all the energy security on offer with no impediments to accessing and consuming energy. Similarly, the middle-income group are also beneficiaries of available energy security with few constraints. However, a large portion of South Africans lack energy security and fall into the category that experience fuel poverty as a daily reality.

In addition to having consulted appropriate literature, the review draws on relevant demographic results of the national Community Survey of 2007 and Census of 2011 provided by the country's national statistical service, i.e. Statistics South Africa (Stats SA).

South Africa has its fair share of complex development challenges. According to the World

Bank, inequality in South Africa not only persists, but has been increasing despite the adoption of a democratic dispensation. In 2008, South Africa's Gini coefficient was 0.70 - debated to be the highest in the world [17]. The Gini-coefficient is generally considered the defining measure to quantify inequality by contrasting the scenario of "*one person has all the income or consumption*" against "*all others have none*" [18], [19]. The coefficient ranges from 0 to 1, in which case 0 implies complete equality and 1 reflects complete inequality.

The inequality in South Africa is largely attributed to the economy's inability to generate sufficient jobs [17]. A lack of provision of proper education and a shortage of entrepreneurial skills have hampered employment growth. Factors such as skewed labour policies, power wielding by labour unions and poor governance have contributed to the stalemate. Established divides in the form of township areas, informal settlements and former homelands, have preserved spatial segregation stemming from the apartheid-era. Almost 40 percent of South Africans reside in these marginalized locations as well as a much higher portion of the unemployed [17]. Despite substantial increases in public spending on basic public services and efforts to expand service delivery, the South African government is under scrutiny to address the severe shortcomings, especially with regard to services to indigent members of the population [17].

In this regard it is noteworthy that one of the key benefits proffered by energy efficiency is the fact that it buys time, which in turn permits a process of implementing improved strategies and more efficient technologies, resulting in wiser and more robust choices. Conversely, a crisis management approach driven by supply exigencies, often "*waste resources and foreclose important options*" [20]. The importance of doing things in the right sequence is also emphasized. To demonstrate, the following example is cited by Lovins, namely that "*most practitioners designing lighting retrofits start with more efficient luminaires – improving optics, lamps, and ballasts. But for optimal energy and capital savings, that should be step six, not step one. First comes improving the quality of the visual task, optimizing the ... space, optimizing lighting quality and quantity and harvesting daylight.*" [20].

To illustrate how oversight in planning, lack of judicious sequencing, basic know-how and resources can lead to widespread fuel poverty, it is worthwhile to mention the South African residential sector, in particular the establishment and growth of South Africa's townships and informal settlements. Since the objective is to influence South African residential end-users, it is important to gain a better understanding of the meaning associated with a residence. Many South Africans have rudimentary housing structures, commonly referred to as "shacks" as their main dwelling as shown in Table A-2 of APPENDIX A.

As mentioned in section 1.2.1, the matter of fuel poverty is the result of a compounded problem with some of the main contributors being poorly insulated houses and inefficient in-house energy systems. "*Houses in the southern hemisphere should face geographic north ($\pm 15^\circ$) in order to obtain optimal solar benefit*" since north-oriented homes can more effectively temper extreme seasonal conditions [21]. According to Klunne, international renewable energy, climate change and energy efficiency expert, housing structures in the form of shacks and low cost housing are very inefficient due to poor insulation that cause energy leaks [21]. Such living conditions lead to fuel poverty amongst South Africans who have to incur unnecessary costs to facilitate lighting, cooking and heating. A dependency on air polluting fuel sources is also intensified to compensate for that which the home is deficient in providing or what cannot be afforded [21]. This reliance on fuels such as paraffin, coal and wood is depicted in section A.1 of APPENDIX A [22].

In order to address fuel poverty, the introduction of simple EE measures can significantly benefit poor households in particular. A seemingly obvious measure is for example climatic or passive solar design, which reduces the energy-input to the minimum for attaining suitable thermal conditions within a residence, thereby dramatically improving quality of life. Passive solar design involves design to utilise a home's intrinsic structural features to gather, filter and redirect heat according to seasonal fluctuations [23]. Climatic design is not reliant on energy-consuming equipment such as air conditioning to create a suitable ambient environment in a home [23].

Relatively simple interventions to improve EE would be correct orientation for new houses,

or retrofitting existing houses by using insulation material and providing ceilings. A reduction in expenditure on space heating can thus be achieved, in addition to creating healthier living conditions and curbing carbon dioxide (CO₂) pollution.

In recognition of a recent advance to enhance EE and improve the wellbeing of low-income people through application of cost-effective, appropriate technologies, the Eskom ETA Residential Energy Award was awarded in 2009 and in 2011 to the Witsand Sustainable Human Settlement project. The award is Eskom's reward for excellence in the field of energy efficiency and the Greek symbol η (*eta*) is for efficiency, hence the name of the awards [24]. The project was showcased at the COP17 and designated a "Flagship Project" by the South African Government [25] - [27]. Contributing to the success of the project is the fact that it was accomplished in consultation with, and with the cooperation of the community, thus underwriting the importance of active participation and support from the end-users intended to benefit.

In terms of residential energy consumption, the more affluent households would be the energy gluttons, on the basis of having access to more household appliances and being exposed to fewer or any constraints. Although income levels are indicative of consumer expenditure and energy consumption, a high earning household does not necessarily waste energy. Similarly, an indigent household does not necessarily consume energy prudently. These anomalies are precisely what contribute to the complexity of the challenge to appropriately and successfully address energy inefficiency.

Apart from consideration of the immediate environment of the residential end-user, it is also meaningful to take into account the profile of residential end-users. In February 2007, Stats SA performed a comprehensive "*Community Survey*" in all provinces on behalf of the South African government with the aim of collecting "*demographic and socio-economic data at municipal level*" [28]. A total of 246 618 households were covered during enumeration [28]. Shown in Figure 2-1, are the 2007 Survey results with regards to the percentage of households with appliances in working order.

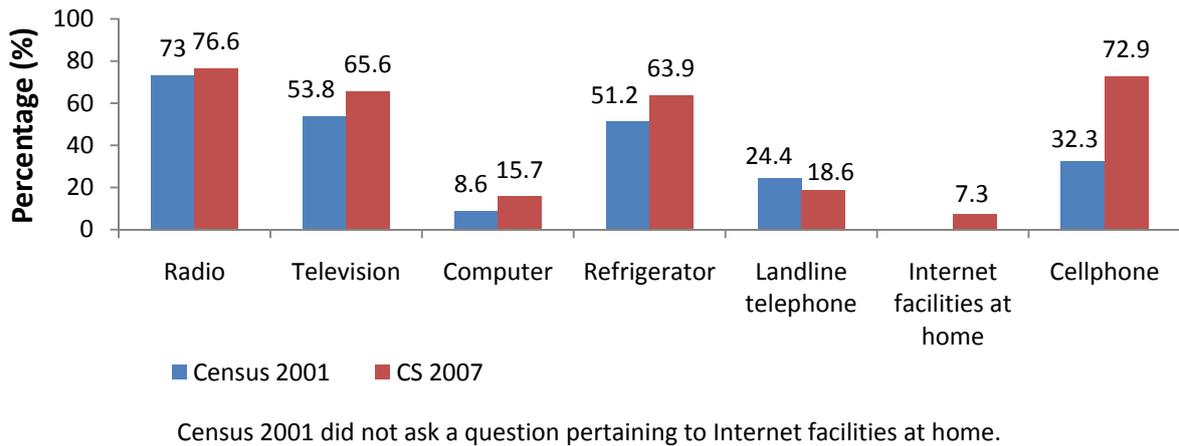


Figure 2-1: Percentage of households with household goods in working order (adapted from [28]).

Provincial mid-year population estimates for 2011 were published by Stats SA. Summarised here in Figure 2-2, is the age distribution of the estimated South African population as per the mid-year figures.

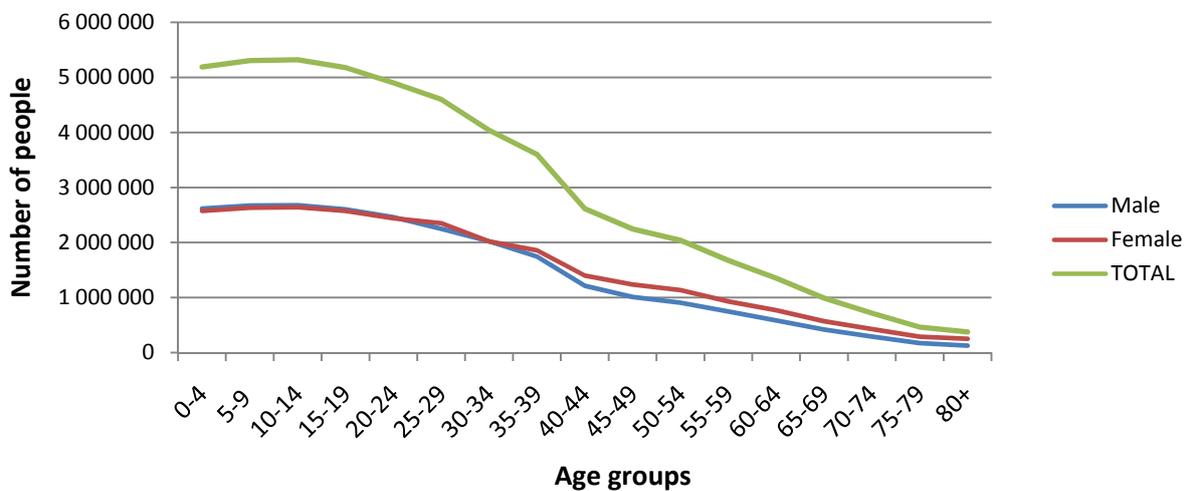


Figure 2-2: Summary of the 2011 total provincial mid-year population estimates by age and sex [28]

In 2011, Stats SA conducted a population census on behalf of the South African government. The processed household-count results from Census 2011 reveal more specific detail about the demographic profile of South African households, for example the age distribution of the

entire population as well as age distribution per household. Included in Table A-1 of APPENDIX A are the tabled results for the General Household Survey of 2011 [29], with specific reference to the distribution of children 17 years of age and younger per household. For easy reference a summary of the totals are provided in Figure 2-3.

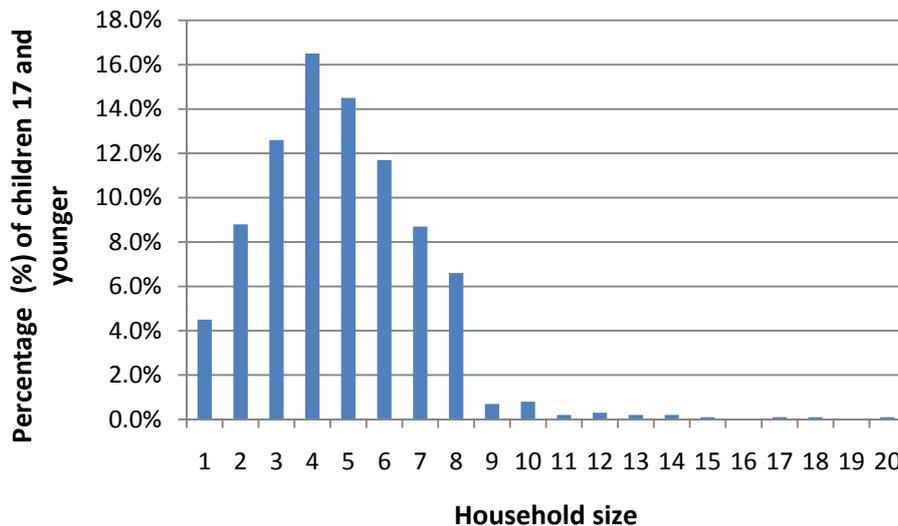


Figure 2-3: Summary of the 2011 census totals of number of children 17 and younger per household [29]

It is evident that the youth, comprising children and young adults, form a large portion of the fabric of the South African society. The youth is therefore deemed a worthwhile target audience to channel efforts towards in an attempt to modify energy consumption behaviour and cultivate awareness of EE habits. It is envisaged that the target audience of end-users who can gain access to the web application should not only be home owners, but also include computer literate school going children. In South Africa, many schools in metropolitan areas provide computers with Internet access. Included in Table A-6 of APPENDIX A, are details on Internet accessibility based on the 2011 Census data.

By considering the statistical results it is possible to gain a better understanding of the South African population at large, albeit only at a glance. It is important to obtain a certain level of insight into the day to day lifestyles and associated challenges of the population in order to make the most of the "low-hanging fruit" on the demand side, which EE is believed to be. It

is necessary to prioritise the involvement and education of consumers as a preliminary step, thus aligning the introduction of new EE ideas, however simple, with the needs and lifestyles of the target audience of users. The choice of technology, as discussed in section 2.5, along with the detailed software design process, included in chapter 3, attempted to keep this fact in mind, along with the capabilities of potential users.

2.2.2 End-user behaviour

Increasingly, strides are made towards researching ways to provide a more inclusive view of energy consumption. Energy efficiency researchers acknowledge the importance of behavioural attitudes. Higginson et al. argue in favour of an interdisciplinary (socio-technical) approach that takes into account the interaction that exists between a person and the technology being used [30]. The authors propose that an analysis of end-use consumption behaviour and habits can provide a more accurate contextual representation at household level. Practices are seen to be routine behaviours associated with social parameters that are not easily quantifiable. The challenge that arises is how to model the complexity of practices by some quantitative representation. It is argued that interventions should be focussed where the potential for change exists [30].

Human behaviour is influenced by non-technological factors such as price, convenience, familiarity, fashion and transparency [20], which affect the interaction between members of a household and the household appliances. Davis concludes that there is much to learn about the drivers of behaviour at the household level and at the top of the list is a directive to identify which aspects of attitude and behaviour affect household electricity consumption [31].

Abrahamse et al. reports on the effectiveness of an Internet-based tool which combined selective information, goals and selective feedback to promote a reduction in domestic energy consumption. The research outcome stated that within a relatively short period (5 months), *"households that were exposed to the interventions saved significantly more, had adopted a number of energy-saving behaviours and had significantly higher knowledge levels of energy*

conservation." [32].

2.3 The residential electric energy load composition

No customer wants electric energy by itself, but residential customers purchase electricity from an electric utility as a means to an end, for example, to have a cool home during summer, a warm one in winter and hot water on demand [16]. The cumulative residential load on a power system or part thereof, is determined according to different residential customer types whose household activities are unique yet in accordance with certain predictable usage patterns. Although there is not a typical residential load, demand in most households can be directly correlated with family activity peak times [16]. With few exceptions, the domestic load profile will fluctuate on an hourly, daily and seasonal basis [16]. Time of day is one of the causes for variation in demand for lighting for example, since demand for it is characterized by a daily pattern, i.e. usually highest in the early morning and after dusk. Some end-uses such as cooling and heating exhibit seasonal variations as accompanying weather conditions impact daylight hours and ambient temperatures.

As described by Willis, annual peak load is the maximum demand seen during a year and is important since it indicates the upper boundary in terms of electricity to be delivered by a utility [16]. The accumulated electric demand for all the residential customers being served by a utility can be represented with load curves. Load curves are comprised of diagrams which represent a load as a function of time.

Demand is quantified in terms of a load-average for a given time period referred to as the "*demand interval*" [16]. Demand can, for example, be measured for 15 minute intervals, 30 minute intervals, on an hourly, daily, monthly or annual basis. A load curve may represent demand measured and recorded on an hourly or half-hourly basis for one day. If measured half-hourly, there are 48 intervals and each of the values is an indication of the average demand for that interval. Daily peak demand can be defined as the maximum demand recorded per interval [16]. Supply capacity constraints imposed by the residential load are due to the time, and duration, of cumulative peak demand.

A typical load curve portrays what most residential customer loads look like over a 24 hour period. Daily load behaviour is characterized by high "needle peaks" caused by joint operation of major appliances and erratic shifts in load as various appliances switch on and off [16]. A load curve for an extended period such as a week or longer, is the combined result of a number of accumulated 24-hour periods and similarly displays these needle peaks as shown in Figure 2-4.

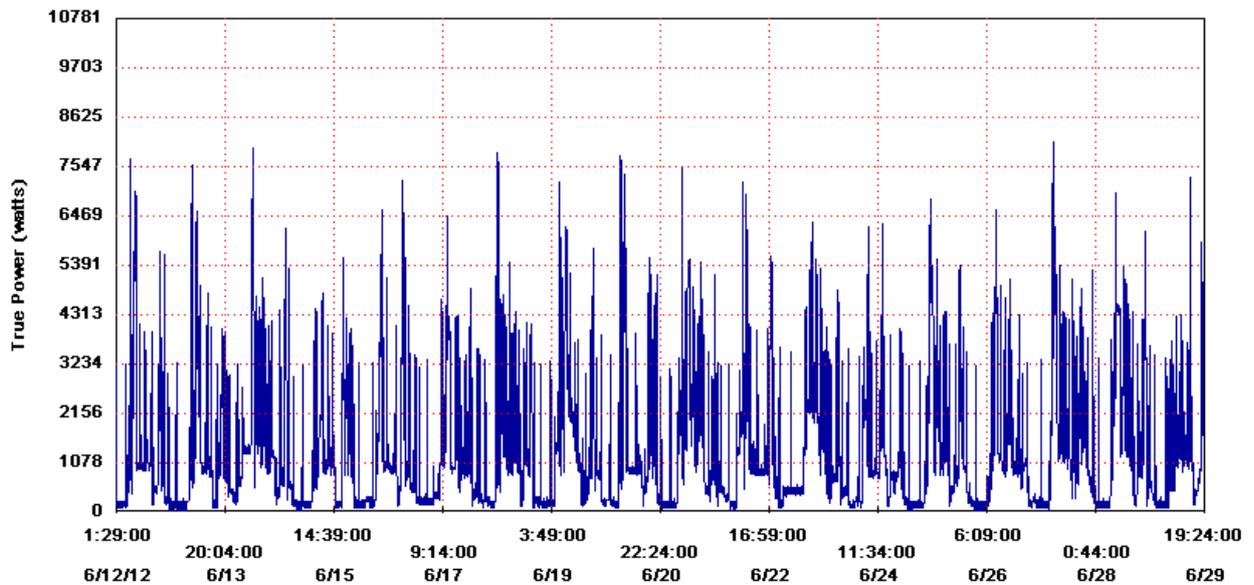


Figure 2-4: Load curve to depict fluctuation in power consumption for an individual household

Sampling rate refers to the frequency of measurement, i.e. the number of times per hour that load data are recorded. The sampling method refers to the quantity being measured, whether instantaneous load or total energy used during each sampling period. High sampling rates are essential when trying to accurately capture or characterize the load curve behaviour of individual customers [16]. Distribution load behaviour is governed by coincidence which leads to individual customer load curves being erratic, formed of fast, sharp shifts in power usage. As both the sampling rate and sampling method significantly impact the form and appearance of the load curve, it is advised that the data sampling period should be quite short, generally less than 15 minutes [16].

Two sampling methods are primarily used, namely sampling by integration and discrete instantaneous sampling [16]. Sampling by integration always produces valid results. Hourly

load data gathered by period integration for an individual customer will accurately reflect that customer's average energy usage on an hourly basis. Suitability of the sampling rate is, however, another matter, but the hourly data will be a valid representation of hourly behaviour. On the other hand, discrete instantaneous sampling measures and records the actual load power at the beginning of each period, often resulting in erratically sampled data that misrepresents load curve behaviour [16].

Load metering equipment which measures a load every 15 minutes, means that the equipment measures and records the total energy used during each 15 minute period. If measurements are taken every 15 minutes during a 24-hour period, a 96 (24 x 4) point load curve results to give the energy used during each quarter hour of the day. When plotted, the 96 points forms a 24 hour demand curve. This method of recording is sampling by integration since the measuring equipment integrates the area under the load curve during each 15 minute period and stores this area, even if the actual load is varying up and down on a second-by-second basis [16].

Peak-hour consumption is most expensive when the total load reaches its highest level and utilities must incorporate plants that use more expensive resources such as coal or natural gas. Demand-side energy management schemes and smart metering endeavour to minimise peak hour consumption by means of appliance scheduling so that users are able to make prudent decisions about either switching certain electrical appliances on or off during peak times. Section 1.2.3 provided a review on demand-side management strategies in South Africa.

Smart metering allows for the presentation of time related consumption data which is used in Time Of Use (TOU) pricing. A TOU pricing scheme correlates electricity price with time of consumption. On February 24, 2010, NERSA approved the implementation of a sliding-scale tariff-based structure for the residential customer base in the form of the Inclining Block Tariff (IBT). According to the tariff structure, higher consumption customers will be charged more based on their electricity usage. *"The objective of the tariff (structure) is to provide a cross-subsidy for lower usage customers against high price increases resulting in a reduction in tariff to these customers. The structure is divided into four consumption blocks and each*

subsequent block has a higher price per kWh of energy." [33]. The time-based pricing scheme for the suburban residential sector with relatively high consumption, will be phased in once advanced smart metering infrastructure is in place [33].

2.3.1 Household energy profiles

End-use energy models serve to qualify domestic demand by considering particular end-uses. Knowledge of household consumer loads is considered essential in order to forecast demand at utility level and to predict potential savings through DSM schemes. Accurate estimates of domestic consumption are required to design power distribution networks for the residential sector. The design task involves an engineered approach based on predictions to correctly size and place electrical infrastructure, such as substations, to supply power to residential areas and accompanying consumer loads.

An energy profile is associated with an appliance by depicting its usage over a designated period of time such as half-hourly energy consumption profiles. A number of researchers apply a bottom-up approach as a means to model residential demand and create end-use models. In this regard, electric usage is distinguished by three levels of categorization, namely consumer classes (residential versus business for example), end-use classes within each consumer class and appliance categories within each end-use [16]. The bottom-up approach is also used for household load modelling to generate electricity profiles for an entire household [34] - [36]. There is a fair degree of incidence amongst the research in terms of application of the principle of load composition by combining consumption data of individual appliances to achieve an end-use model.

According to Paatero and Lund, domestic electricity consumption data which electric utilities use for planning purposes, typically represent accumulated and averaged consumption of several households. The data thus provides very little insight in the form of end-use events at household-level to determine how a particular household load is distributed [37]. *"The fluctuation of electricity consumption concerning an individual household remains unrevealed as well as the division of consumption between different types of household*

appliances." [37]. The accuracy of end-use models is dependent on grass-root level consumption details such as appliance inventories and associated usage profiles. One of the difficulties which presents itself, is the need for information on consumer behaviour to avoid compromising accuracy [37]. There is general consensus that the drawback for using the bottom-up approach, is the extensive demand for input data, such as detail information about the characteristics of residential customers. This information is often linked to life-style related factors which cannot always be easily found [36].

The indiscriminate nature of consumption is most often modelled by means of stochastic processes and probability distribution functions whereby statistical averages of representative data samples are used [37]. Although research by Capasso et al. [34] is much more dated, both Richardson et al. [35] and Capasso et al. adopt a socio-technical approach to energy consumption by proposing an energy demand model for domestic electricity whereby active occupancy and the associated daily activity profiles are included in the modelling process.

2.3.2 Electrical and statistical descriptions of loads

In the South African National Standard for electricity distribution to residential areas, two ways of describing loads are reviewed, namely an electrical description and a statistical description [38].

The task of load modelling is characterized by uncertainty since the estimation of end-use energy consumption recognizes the fact that consumer behaviour is intrinsically non-deterministic. This uncertainty requires a probabilistic description rather than a deterministic approach [38]. A deterministic approach predicts future values from past values whereas a non-deterministic approach implies the contrary [39].

In order to represent the stochastic characteristics exhibited by domestic loads, a non-deterministic qualification is required. A statistical description is commonly applied and research has produced a probabilistic representation in the form of the Beta probability density function (pdf) [38]. Stochastic behaviour implies a random variation with respect to

time. The probability of an event that depends on a variable x can be expressed as a function called the distribution function. The derivative of the distribution function is called the probability density function [40], [39].

Measures of central tendency and measures of distribution are also used to describe data statistically where central tendency indicates a tendency of the data to be distributed in close proximity to a central value. If a data set exhibits such a central tendency, it becomes useful to characterize the set by moments. Two types of moments are of interest, namely those about the origin and those about the mean. The function's "width" or "variability" around the central value can be characterized. The most commonly applied measure is the second central moment, i.e. variance, or its square root, the standard deviation. The skew of a density function is the third central moment and a measure of asymmetry around the mean value. Skewness is defined as a dimensionless quantity that denotes the density's outline or shape [39], [40].

2.3.2.1 Electrical description of loads

According to Herman and Gaunt, there are three possible load descriptors from an electrical perspective, namely a representation as either resistance, current or power [41]. Depending on how domestic loads consume energy, the authors elaborate on how these consumer loads may be assigned to one of two groups [41].

The first group of loads are described as constant resistance loads such as incandescent lights [41]. The second category of loads may be categorized as constant power loads and is characterized by temperature controlling thermostats such as in a geyser or an automatic kettle [41]. While the kettle is switched on, it displays similar qualities as that of a constant resistance from the first group of loads, but once the water reaches boiling point, the appliance switches off. The amount of energy delivered to the water is independent of the voltage applied. However, should the voltage fall, the water will simply be heated for a longer period until the desired temperature is reached. The duration is therefore dependent on power delivery. The authors note that by integrating consumer demand over a given time period, the behaviour of a number of such loads over a longer period of time resembles a

constant power load [41].

Another significant contribution by the authors relates to the concept of modelling domestic loads as constant current sinks [41]. The authors' proposal is based on result sets from a vast amount of accumulated load data in South Africa. It is noted that many heavy load consumer appliances, such as geysers, stoves and heaters, have large resistive heating components with a resultant power factor approaching unity. The particular model of representing loads as currents at unity power factor is considered valid since the results indicate consistency with observed operation of real loads [38].

2.3.2.2 Statistical description of loads

A statistical description of domestic loads, specifically in the form of a probabilistic representation, is required to portray the non-deterministic characteristics of these loads in a more precise manner [38].

As outcomes of load-specific research, a range of probabilistic functions has been derived for a multiplicity of domestic loads. As shown in Figure 2-5, a histogram provides the means to graphically represent probability as frequency of occurrence on the y-axis of measured and normalized consumer load currents, depicted on the x-axis, measured during representative time intervals. A probability function, and more specifically its derivative in the form of a pdf, can be used to describe the distribution of these currents through a best-fit procedure.

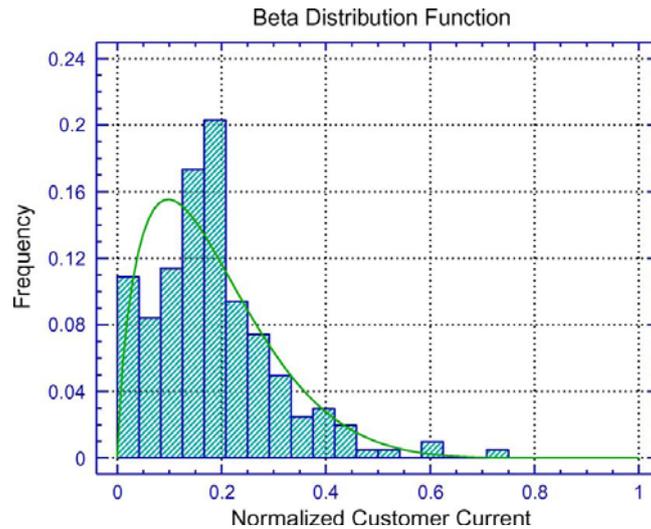


Figure 2-5: Beta probability density function fitted to histogram outline [41]

The cited research concludes that the Beta pdf was found to be the most appropriate statistical expression to represent domestic load current data [41]. As noted by Herman and Gaunt, since *"domestic electrical loads cannot be negative (and) cannot exceed the circuit breaker rated tripping current"*, the Beta pdf was found to be the best mathematical function to describe the load current given these constraints [41]. The Beta pdf is likewise limited *"to a finite base in the same way that the load currents are confined between 0 and the circuit breaker limit."* [42]. A Beta distribution caters for the description of an asymmetrical or skewed distribution [38].

The Beta pdf is parameterized by two constants, α and β , which provide the shape of the curve. The Beta pdf as documented by Herman and Kritzinger is given in Equation (2-1) [42].

$$f(x) = x^{\alpha-1}(1-x)^{\beta-1}/B(\alpha, \beta) \quad 0 < x < 1 \quad (2-1)$$

$$B(\alpha, \beta) = \int_0^1 u^{\alpha-1}(1-u)^{\beta-1} du$$

where

$f(x)$ gives the probability density on the y-axis,

α, β are constant values obtained from acquired statistical data for various consumer classes [38],

x is normalized customer current constrained between 0 and 1
and

u is the variable (probability on the x-axis) over which to integrate from 0 to 1.

According to Equation (2-1), the probability of an observation between two points on the x-axis, 0 and 1, is equal to the area (integral) under the curve between these two points.

The skewness of the Beta pdf will vary in accordance with whether the load is restricted by a low circuit breaker dimensioning, resulting in either a left-skewed or right-skewed distribution [36]. Figure 2-6 illustrates the variable skewness and the inclusion of a circuit breaker scaling value c [38].

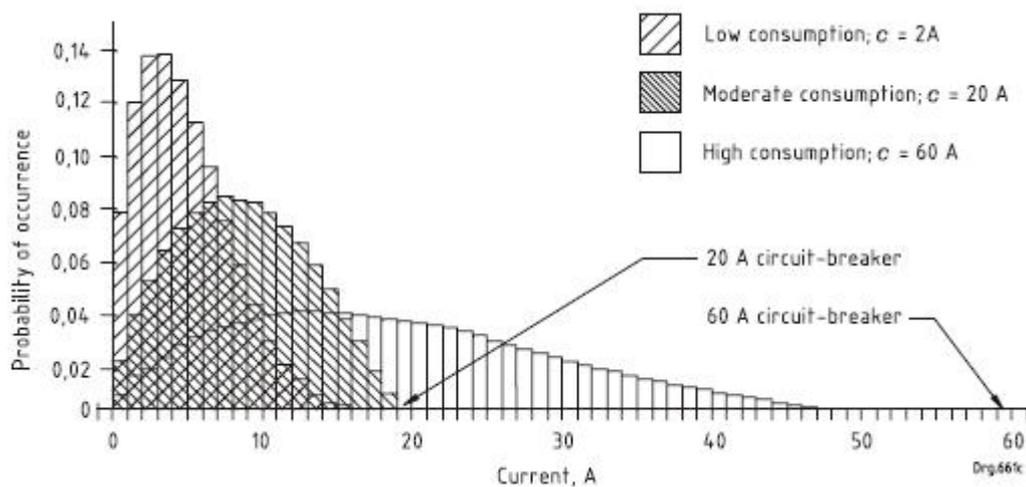


Figure 2-6: Examples of differently skewed load distributions [38]

2.4 Residential power distribution

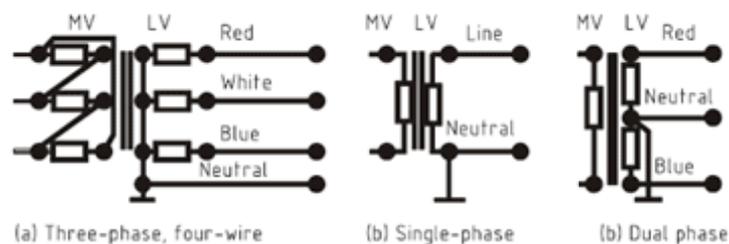
Eskom, the South African utility company, is responsible for the distribution of electricity either directly to customers or via municipalities. In the latter case, municipalities purchase electricity in bulk from Eskom for resale to consumers. Increasingly, South African

residential consumers make use of pre-paid electricity meters which are installed in homes. Electricity is purchased from vendors in the form of a coded coupon. The code must be entered into the pre-paid meter which displays the amount of available electricity.

In South Africa, standard voltage supplied to residential consumers is regulated in accordance with Government Notice (no R103 of 26 January 1996) as an amendment to Regulation 9 of the Electricity Act (no 41 of 1987). The statutory voltage is determined as $230\text{ V} \pm 10\%$ or 253 V maximum and 207 V minimum at the point of supply [44].

For a residence a low-voltage (LV) distribution topology is valid as indicated in Figure 2-7, which can be differentiated into three distribution systems, namely:

- A three-phase, four wire topology.
- A single-phase topology.
- A dual or bi-phase topology [38].



MV = Medium Voltage; LV = Low Voltage

Figure 2-7: Arrangement of conductors and transformers for the three types of LV distribution systems [38]

The live wire entering a house is split by means of a distribution board into several separate circuits placed in parallel, for distributed use in the house [43]. The distribution board contains a main protection switch and circuit breaker switches. Each circuit contains a circuit breaker where the wire and circuit breaker size is determined based on the current demands for each circuit, to provide protection for the designated parts of the electrical system. The alternating current (AC) circuit provides the power to each electrical outlet or plug connection point in the home. Each outlet thus serves as an AC source for the appliances

connected to the circuit.

2.5 Interactive web technology for the end-user

In view of the reality of influencing behaviour and attitudes, the end-user has occupied a conceptually central role during the research and development process of the web application. Considerable time was spent in giving due consideration to current trends in improving user experiences on the web and evaluating available and appropriate technologies. This section provides a review of some of these technology options.

The degree to which an application will embrace emerging technologies largely determines its advocacy and success. In this regard, the effectiveness of the web application is entirely dependent on the type of technology, accessibility, data integrity and more recently, interactivity. Interactive applications have gained prominence with the ubiquitous presence of smartphones and software applications, commonly referred to as "apps". There has been a rapid expansion of innovative open-source third party apps developed for smartphones, ranging from information management tools such as dashboards to information-sourcing platforms [48].

The term dashboard originates from the dashboard in a motor vehicle where a driver can monitor major functions at a glance. The term is now commonly integrated into management information systems to monitor for example sales, revenue and key trends. A dashboard has become "*(a)n easy to read, often single page, real-time user interface, showing a graphical presentation of the current status (snapshot) and historical trends of an organization's key performance indicators (KPIs) to enable instantaneous and informed decisions to be made at a glance.*" [49].

Research on residential energy optimization from a smartgrid perspective [50], notes the efforts in recent years to develop residential energy management systems to intelligently manage residential energy consumption and raise awareness about consumption. This has given rise to the development of both commercial projects such as Microsoft's System Hohm,

and freely available energy monitoring tools such as Google's PowerMeter [51]. Nevertheless, the GoogleMeter service was retired in September 2011 and similarly Microsoft's Hohm has been halted [51]. A number of conjectures are put forward as to why the big Internet companies' online energy monitoring tools have failed [52]. One reason considers the market for home energy management to be still too immature and that the online energy tools were prematurely introduced. A survey conducted by the American Consumer Electronics Association (CEA) established that end-users were unaware of emerging energy management systems despite cost concerns related to their energy consumption [53]. The CEA found that 64 percent of consumers were unaware of electricity management programmes and 66 percent of consumers were not familiar with the smartgrid [52]. Furthermore, one of the largest and most aggressive smart metering programmes in America set their initial rollout of phase one only for 2012 [52].

However, in comparison with the American market, there is a far greater financial incentive for South Africans to utilise energy saving tools. According to a September 2012 report by the United States Energy Information Administration (EIA), the nominal US residential electricity price is expected to average 11.91 cents per kilowatt-hour (kWh) during 2012 with an increase of 0.9 percent in 2013 over the average 2012 price. When measured in real terms, the cost of residential electricity in the US decreases by an annual average of 0.8 percent in both 2012 and 2013 [54]. In terms of disposable income, an average American household spends far less on electricity compared to a South African household. Forecasts indicate that due to a drop in natural gas prices in America, households will subsequently have the benefit of a higher average annual disposable income. For gas-powered electricity generators, lower gas prices yield lower retail electricity prices thereby directly reducing energy costs of households and businesses [55].

To date there is no market research available from the Human Sciences Research Council (HSRC) in South Africa on how the South African market may respond to the introduction of smart metering technology or online energy metering tools. In February 2012, the European Utilities Telecom Council (EUTC) and Eskom held a conference on the Smart Grid in Africa in view of planning for the development and deployment of smart metering [56]. Eskom's acting General Manager for research, technology and development noted that the commercial

viability of smart metering still needs to be demonstrated since it is key to be able to deploy and interface with existing systems [57].

The web technology options considered to achieve a successful user-experience firstly had to meet requirements determined from a development point of view. These considerations included the selection of an appropriate format, where possible making use of robust open-source solutions, as well as ease of development, deployment, maintenance and extendibility. Some of the key requirements of the application were to be dynamic and database-driven and provide fundamental data visualization in the form of "at-a-glance" information, akin to a dashboard application. Perhaps most important, has been the matter of catering for a South African end-user, implying an honest review of what can be most effectively accomplished, yet presented and communicated in the simplest way.

South Africa's diverse demographic make-up poses a challenge in identifying the target market and the average end-user with whom to engage during the design process. Due to the definite tiers of literacy in the population, ranging from highly sophisticated to very rudimentary, the application is required to be as simplistic, minimalist and intuitive as possible. It is not a given that even a very literate and intelligent user is adequately informed with regards to energy consumption or energy efficiency. The task of employing appropriate technology in the most effective way to establish access for the user to energy efficiency know-how and to guide and empower the user to make sensible decisions, required a balancing act. For this reason the design favoured graphic content and intuitive navigation.

The remaining section of this literature review examines some of the most optimal ways which were considered and choices made to achieve a design that meets the set criteria.

2.5.1 Effective design for the end-user

According to an expert on User Experience Design, three essential aspects are required when designing for an end-user, i.e. Content Strategy, Interaction Design and Visual Design [58].

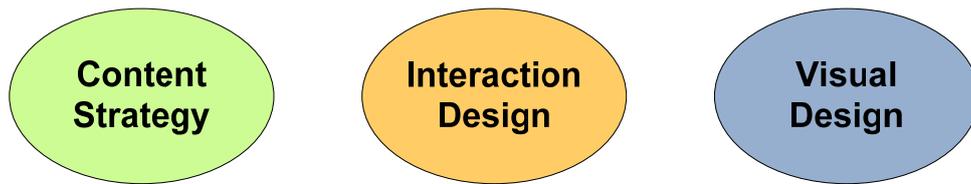


Figure 2-8: Three key components of end-user design

A number of principles have been identified to adhere to for effective user interface design. These were originally developed by Molich and Nielsen [59] and since distilled by Nielsen to a set of "Usability Heuristics" [60]. The following four have been considered most significant for the application that was developed:

- *Conformation between the system and "the real world"*: The system design should adopt familiar conventions with which the user can relate. The presentation and ordering of information should appear natural and logical. The design and terminology should be user-oriented as opposed to system-oriented.
- *Consistency and standards*: Ambiguity should be avoided so that users do not have to wonder about the meanings of different words, situations or actions.
- *Enhance visibility*: Promote visibility in favour of reliance on the user's ability to recall objects, actions and selections. Dialogue and program flow should demonstrate a sense of continuity. Instructions for system-use should be easily perceptible and retrievable as needed.
- *Clear and minimalist design*: Evaluate and convey what information is essential and relevant, since a focus on one particular area or dialogue inadvertently reduces the relative visibility of other areas.

In further support of the principle of user-oriented design, Brooks makes the case for "more is less". "A (software) system may deliberately provide fewer features than it is capable of. If a system is too complicated to use, many of its features will go unused because no one has the time to learn how to use them" [61]. Simplicity and clarity lead to good design. A user-friendly system should demonstrate conceptual integrity which can only be accomplished through separation of architecture from implementation [61]. Defining the system is an iterative process since it is not always initially apparent what questions must be answered

[61]. Software systems therefore require careful planning during the design activity.

Content strategist and author of "Content Strategy for the Web", Halvorson, defines content strategy as "*plan(ning) for the creation, delivery, and governance of content ... that supports business objectives and meets users' goals.*" [62]. Content strategy relies on the discerning use of words, phrases and graphics to produce unambiguous content to underwrite a user experience that is rewarding and not frustrating.

The following section gives a brief literature overview of some of the technology options and type of client-server arrangement that were considered to ensure data integrity and reliable, dynamic data exchange.

2.5.2 Technology options for dynamic client-server data exchange

During the relative short history of the Internet, the static display of data has given way to server-side technologies to drive dynamic and flexible data exchange. Classic client-server side technology is based on a request from the client (web-browser) to the server and a response which is returned. Each separate request requires the reloading of a HyperText Markup Language (HTML) page or a browser "refresh".

A sequential communication process takes place, i.e. the web server communicates with an application server, which in turn communicates with a database server, as outlined in Figure 2-9. The final results are returned to the user through the web server.

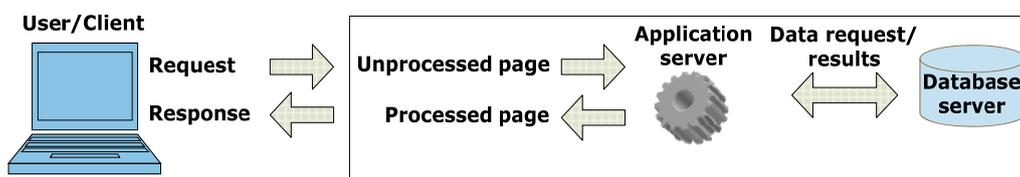


Figure 2-9: Classic client-server side technology

The combination of Apache, MySQL and PHP constitute a popular and well-supported open-source solution for creating dynamic web pages, as shown in Figure 2-10. This combination or stack is commonly referred to as "AMP" [63].

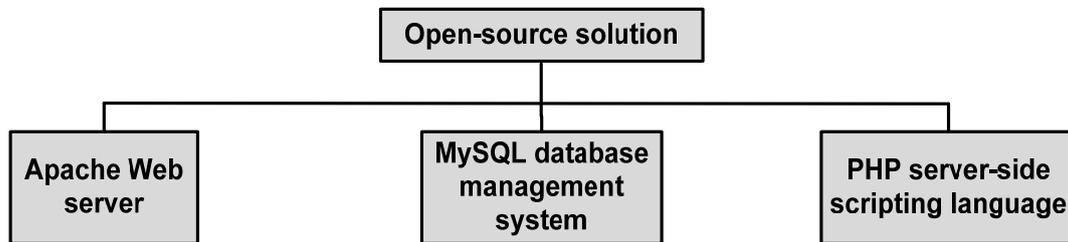


Figure 2-10: Open-source solution to create dynamic web pages

Open-source means that both MySQL and PHP are free to use or even modify [64]. The Apache web server was developed by the Apache Software Foundation and has the advantage of also being open-source/free of charge and works on every platform [65].

PHP is an acronym for *Hypertext Preprocessor* and is an open-source, general-purpose server-side scripting language predominantly utilised for the development of web applications [66]. During its development, the PHP parser was rewritten and renamed as the Zend scripting engine [67]. Subsequently Zend has expanded to create the Zend Framework, which is an open-source, object oriented web application framework for PHP 5 [68], as well as a line of PHP products including a PHP Integrated Development Environment (IDE) called Zend Studio [69].

A scripting language is interpreted when the program is executed at runtime, as opposed to being compiled by a compiler. Server-side indicates that the code resides, is interpreted and processed on the server and a result, in the form of HTML, is sent to the web browser [64]. PHP can manipulate data, usually in a database, on the server.

2.5.2.1 Rich Internet Application

In recent years, the stage has been set for what is termed RIAs, or Rich Internet Applications. An RIA offers a more seamless data exchange process as well as a user experience that offers much more in terms of interactivity compared to page-based HTML counterparts. The chosen platform for development of the application is in the form of an RIA to be deployed as a web application using the Flex framework. The option also exists to migrate to a desktop application which the user can install. Flex has been around since 2004 with version 4 released in 2010 and version 4.5 soon after [63]. The Flex framework is used to create Flash content.

Although a client-side scripting language such as JavaScript allows for development of an interactive user experience, Ullman discusses the case for and against Flash [63]. The first issue is "*Why should you use Flash to develop your RIA, instead of HTML and JavaScript, the most logical alternative?*" Considerations, such as the ease and speed with which a complex level of interactivity can be achieved as well as cross browser scripting support/compatibility issues, were taken into account. Although a Flash Player plug-in (downloaded for free) is required by the user to play Flash content, the adoption rate is high and if a user's computer does not have a current enough version of the player, he/she will be prompted to upgrade. The Adobe Flash Player software was originally created by Macromedia and has since been developed and distributed by Adobe Systems. The software is used for viewing multimedia [70]. With regard to future deployment alternatives, Flash content is, however, not supported on all mobile devices. To date, Apple is famously resistant meaning that iPod, iPhone and iPad users cannot view Flash content, which is probably the most negative aspect.

The advent of HTML5 offers a supported standard to build web applications in the foreseeable future making it another contender for web application development. The new HTML5 specifications are focussed on rich media support, graphical tools, visual presentation and enhancements to JavaScript. However, many of the new HTML5 elements are not supported in older web browsers [71]. In a Questions and Answers-(Q&A) blog article [72], the Adobe Flex Developer team commented on the future of Flex in comparison

with HTML5 as follows:

- There will be continued development, support and release of the Flex Software Development Kit (SDK), but as an open-source project under the Apache Software Foundation, to which Adobe will actively contribute.
- Flex currently has, and is expected to continue to have for a number of years to come, several advantages over HTML5, in particular:
 - Consistent feature-level performance across various platforms.
 - A programming model and component set which considerably enhances productivity when building complex application user interfaces.
- In 3 to 5 years from now, HTML5 technology should support the cases where Flex is currently at the forefront and may then become the preferred choice for enterprise development.

It was decided to develop the application using the Flex SDK, which is available for free. Flash Builder is Adobe's IDE for creating Flex 4 applications. It is based on the popular open-source Eclipse IDE. Although Flex Builder is a commercial product requiring a license, Adobe offers free copies of Adobe Flash Builder 4 Standard to registered students, faculties and staff of eligible educational institutions.

Development of applications in Flex utilises two languages, namely MXML and ActionScript. MXML is based on an Extensible Markup Language (XML) language and is used for the layout of user interface components and for declaring non-visual aspects of the application. Both HTML and XML are tag-based, but the difference is that HTML was created to display information, whereas XML was created to structure, store and transport information. In XML the developer creates the tags. Like HTML, MXML provides tags, although a much richer tag set in comparison to HTML. Furthermore, MXML can be extended with custom components. ActionScript is a scripting language developed by Adobe and has similar syntax and semantics as the JavaScript scripting language [73].

Two types of user interface components are supported by MXML, namely containers and controls. Controls are for example buttons, list boxes and text fields, whereas containers are

rectangular regions of the screen's real estate which contain the controls, for example a canvas.

The Flex framework can be fully integrated with PHP as the server-side scripting language and a MySQL database. PHP provides data exchange between the Flash client and the MySQL database. In a Flex application, client-side processing and server-side processing is handled by separating client code from server code. Flex is an event-driven technology and a user action or a program event can trigger access to a data service such as PHP. Code generation features in Flash Builder caters for the creation of strongly typed Flex data services, made possible by Zend Studio's PHP code introspection capabilities. For example, a user clicking a button control in an application is a user action event whereby client-side code calls a web service. The application user interface is compiled into a binary SWF file that is sent to the client as depicted in Figure 2-11.

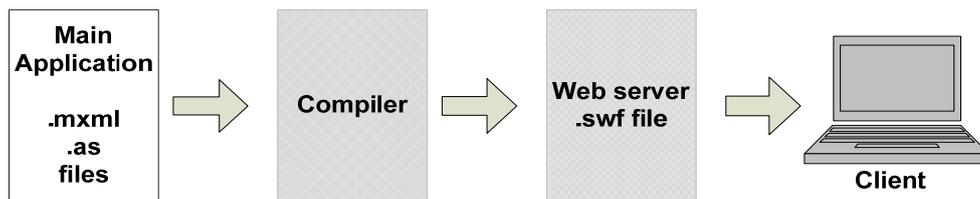


Figure 2-11: Basic constituents of a Flex application

Within the Adobe Flash environment, a SWF (pronounced "swif") file is the format used for ActionScript (.as files), vector graphics and multimedia. SWF files originated with the FutureWave Software company, then moved to Macromedia and is currently controlled by Adobe. Web animation with vector graphics is mostly accomplished using SWF format [74].

When the application makes a request to a data service the SWF file is not recompiled and no page refresh is required. The remote service (for example PHP), returns only data and Flex binds the returned data to the GUI components in the client application. The result data is therefore available to use as dynamic content in the application [75].

There are a number of architecture frameworks available to use for Flex applications,

supporting a Model, View, Controller (MVC) structure. With an addition of a Services component, software architect, Berkovitz, summarizes the MVCS framework as follows [76]:

- The Model denotes semantic data.
- The View is responsible for interaction and presentation.
- The Controller is responsible for actions.
- Services are reserved for communication.

Adobe consultant, Daraedt, discusses three architectural frameworks as possible alternatives to employ in the development of a Flex application [77]:

- The Flex native MVC framework (no third party framework)
- Cairngorm
- PureMVC

The native Flex framework uses decoupled, reusable view components. The application root tag constitutes the main application container which fulfils the role of both model and controller. This framework is only suggested for relatively simple applications and Daraedt is of the opinion that the Flex framework alone does not provide an optimal toolset to create the architectural separation between the Model, View and Controller [77].

One of the key components of an RIA relates to the inclusion of graphics. Computer graphics relate to image data. There are commonly three formats used for web graphics: Graphics Interchange Format (GIF), Joint Photographic Experts Group (JPEG) and Portable Network Graphics (PNG). These formats provide good compression which reduces the size of the graphic file [78]. Flex supports embedding JPEG, GIF and PNG files [79]. Flex also supports the Scalable Vector Graphics (SVG) and Flash XML Graphics (FXG) formats, although the use of SVG has been deprecated since Flex 4, with a shift in favour of FXG as the future markup for graphics.

Adobe created FXG for the Flash platform, as a specification for an XML-based graphics file format to describe two-dimensional vector graphics [80]. Images in computer graphics are

represented using vector graphics, whose building blocks are points, lines and polygons which can be described with mathematical equations [81].

2.5.2.1 Relational database

Several types of database models exist, including hierarchical models and the Relational Model, which is most widely used. The Relational Model was conceived in 1969 and one of the branches of mathematics on which the model is based, is set theory, from where the term "relation" is also derived [82]. The Relational Model determines how data is stored as relations in a relational database, which a user in turn perceives as tables. A relation consists of tuples, which are sequences or ordered lists of elements (records) and attributes (fields) [61], [82]. Another description explains a tuple to represent an object with accompanying information about the object. As shown in Figure 2-12, a relation is defined as a set of tuples that have the same attributes.

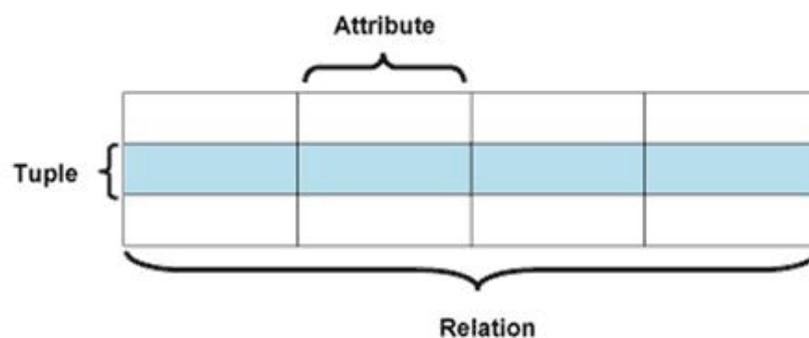


Figure 2-12: Relational database record represented as a tuple and attribute (adapted from [83])

A relation represents a table organized into rows and columns [84]. Tables are the main structures in the database and a table should be subject-specific. Each instance of a table is uniquely represented by a record.

Two keys, namely a Primary Key (PK) and a Foreign Key (FK), are used in a relational database. The PK uniquely identifies each record within a table and every table in a database should have a PK attribute. If it is determined that a relationship exists between two tables, the association is formally established by inserting a copy of the PK that belongs to the first

table into the second table, where it becomes a FK. A FK ensures relationship-level integrity by associating correct records with each other [82].

Between a pair of tables, it is possible to distinguish amongst three different types of associations, namely one-to-one, one-to-many and many-to-many. Of special interest are the latter two relationships, i.e. one-to-many and many-to-many. In order to accommodate either of these relationships, a linking table must first be established. A linking table is defined by taking a copy of the PK of each table in the relationship and using them to form the structure of the new table. The advantage of a linking table is that it accomplishes the association of any number of records from the two tables in the relationship.

The Relational Model forms the basis for database products known as Relational Database Management Systems (RDBMS). Relational databases involve more thought during the design and programming, but offer an improvement in terms of reliability and data integrity. Furthermore, relational databases are more searchable and allow for concurrent users [64].

Normalization is the process of optimising table structures and in order to efficiently organise data in a database. Firstly, normalization eliminates the creation of redundant data. Redundant data is duplicated data, i.e. when the same data is stored in more than one table. Secondly, normalization promotes relational integrity by only storing related data in a table. Normalization therefore supports both optimal and logical storage in a database [85].

In order to describe the normalization process, the founder of the relational database model designed a sequence of numbered rules, referred to as normal forms [85]. First Normal Form (1NF) is the first and most basic form of normalization whereas Fifth Normal Form (5NF) exhibits the uppermost level. In practical applications, 1NF to 3NF are most common and sufficient. A database in 1NF ensures a single value per column. For example, a table which allocated 1 field for a person's initials and surname would not be in 1NF, since two pieces of information are stored in the particular field [85].

Being 1NF compliant is a prerequisite to be 2NF compliant, and every database column in a table which is not a key, should relate only to the PK. If multiple records in a table have the same value for a column, the database is not in 2NF. In order to be in 2NF, FKs must be used to signify relationships between tables [85]. In conclusion, a database in 2NF (and by implication in 1NF), with mutually independent non-key columns, will automatically be in 3NF [85].

The database, that was designed and created for the web application, is based on a relational model and compliant to 3NF. Numerous instances of linking tables were employed to provide the required functionality and to preserve data integrity.

Structured Query Language or SQL, was developed in order to query a relational database [82]. In terms of providing database access in the form of a standard query language, SQL is most commonly used. MySQL is an open-source database management system and is developed, distributed and supported by the Oracle Corporation [86]. The SQL part of MySQL refers to "*Structured Query Language*". MySQL consists of several components including the MySQL server, *mysqld*, to run and manage databases and *mysql* as the MySQL client or interface, to provide a gateway to the server [64]. MySQL databases are relational.

2.6 Software modelling and the UML standard

Modelling plays a central role in software engineering. The Unified Modelling Language (UML) was created as a standard language to visualize, specify, describe and document a software system. The UML was developed as a notation to document a software design and not a design method per se [87].

2.6.1 UML diagrams

There are a number of different diagrams that comprise the UML, each with a specific function. As part of the software development process, the following UML diagrams were used to describe the software:

- *Use case diagrams*, which present the system's primary functionality and describe the interactions between the system and its users (human or non-human).
- *Activity diagrams*, which are a graphic form of pseudocode, and describe the flow of activities.
- *Sequence diagrams*, to illustrate message sequencing by emphasizing the flow of control between objects within the system [87].

As described by Hunt, the way in which a system or subsystem is used, are explained with use case diagrams [87]. Actors are any elements, i.e. humans, other computers or other role players, which interact with the system. Use case diagrams fulfil a significant role for illustrating the functionality of the overall system by providing a contextual framework for the system's definition. Sequence diagrams can be effectively employed in combination with use case diagrams to demonstrate the succession of interactions that take place between the actors and the system [87].

Apart from representing a user, an actor can also represent *the role* played by the user at a specific point in time. In this regard, a use case is more aptly defined to be a descriptor of the interaction between a user and the system for a specific reason. The collection of all the use cases defines the system's overall functionality. In order to accurately define the use cases it is necessary to identify the actors as role players. Towards that end, the practice of storyboarding is particularly helpful in describing system operation [87]. Storyboards are visual aids to plan the sequencing of actions and events in a similar fashion as to how a story unfolds.

Hunt cites a list of questions to aid the identification of use cases [87]. Of special significance for the web application are the following three questions:

- "*What are the main tasks of each actor?*"
- "*Will the actor have to read/write/change any of the system information?*"
- "*What use cases will create, store, change, remove or read system information?*"

Having identified the use cases, it is required to identify the actions taken or steps performed within each use case. The use case naming convention makes use of verbs whereby a name is determined by the action described, for example, "Login" explains the use case procedure of how a user should log into the system with a username and password.

As part of documenting the software, use was made of a free trial version of *UML for ActionScript and Flex* (UML4AS). UML4AS is a UML editor that employs technology to support code generation and reverse engineering. According to Chikofsky and Cross, redocumentation is the most dated and basic example of reverse engineering and involves a process of either creating or revising a semantically equivalent representation of a software system [88]. Since redocumentation is aimed at a human user it is typically accomplished by means of different views to portray data flow, structures or flow of control. In the case of UML4AS, it is promoted as a developer friendly tool to model and synchronize code in .as and .mxml files. According to the developers of UML4AS, UML modelling tools can be cumbersome and induce an overhead to the development flow [89]. In this regard, UML4AS proposes to enhance developers' productivity through intelligent modelling tools as follows:

- Integration with Eclipse based IDEs and minimum overhead.
- Simple navigation from code to class diagrams and functional diagrams, for example use case diagrams and activity diagrams.

2.6.2 The Unified Process

The Unified Process is an engineered design process framework that was developed as a complement to the UML [87]. The process consists of four phases as shown in Figure 2-13:

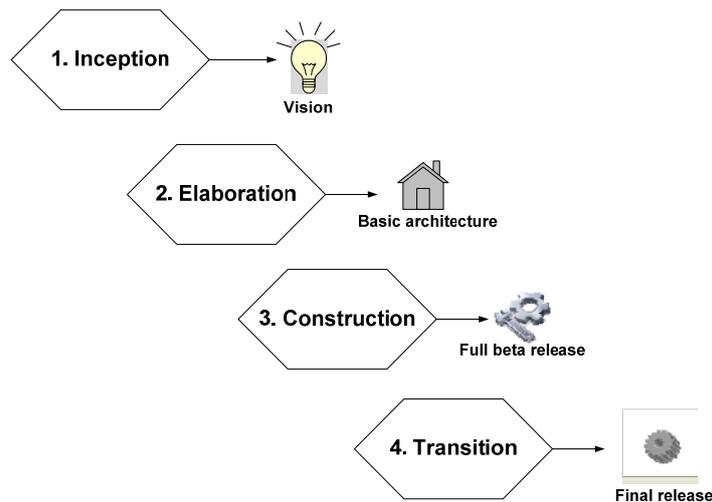


Figure 2-13: Achievements for each phase of the Unified Process [87]

The main achievement of the elaboration phase is the basic architecture of the software. Software architecture is likened to a skeletal construct "*on which the muscles (functionality) and skin (user interface) of the system*" are placed [87]. In Flex 4, the term "skins" is used to describe all the visual elements of a component. Skins can be applied to components by using Cascading Style Sheets (CSS) or MXML [90].

A completed construction phase is the result of the implementation process, offering a fully functional product that constitutes the software, design and models [87]. The final product, ready for beta testing, may not be without defects [87]. The construction phase is usually the largest phase with the most iterations and focuses on both the design and implementation of the bulk of the system. To ensure a successful outcome for this phase, the critical outcomes of the project should be monitored and it is in fact quite normal for additional use cases to still be identified during construction [87].

As depicted in Figure 2-14, the Unified Process advocates that a software design task should rely on an iterative and incremental approach.

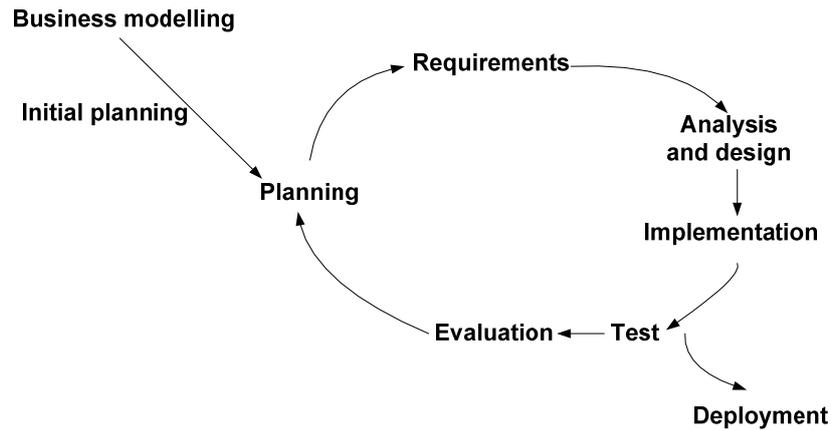


Figure 2-14: Unified Process' incremental and iterative approach to software development [87]

One of the key elements of the Unified Process is reliance on use cases, since use cases help to identify who uses the system and towards what end. This aspect is referred to as the top-level functionality [76], [87]. In this regard, use cases aid the identification of the basic system requirements. Use cases are employed in the Unified Process to ensure that the evolving design remains relevant and aligned with the user's requirements. A designer depends on the use cases to distinguish what must be done within a specific iteration. The Unified Process is designed to provide flexibility in order to be adapted to different situations, types of projects and techniques [87]. Hunt reiterates that "*it is a framework that encourages you to adapt it to your own needs.*" [87].

2.6.3 Agile Modelling

Agile Modelling is considered a simplified version of the Unified Process and resembles more closely a way of thinking than a way of doing. Essentially, Agile Modelling means to "*do just enough design and modelling for what is needed at the time and expect to come back and change, review, refactor and add more detail, later on, to appropriate areas of the model.*" [87]. One of the suggestions given on how to fill in the details at a later date is to reverse engineer the code. Hunt also supplies a more succinct definition for Agile Modelling, namely that it "*aims to model just enough and no more.*" By its very nature, a software model should not be as detailed as the software itself, since it is simply an abstraction. Nevertheless, modelling a complex software system may demand multiple client and server architectures

and technologies, multiple editions of the software as well as years of person time [87].

Only documentation essential to support the tasks are needed, since only "enough" models need to be developed [87]. Documentation evolves with the development of a software system, from that which is required during the creation process, to what is needed once the system is complete and enters the support phase. UML4AS supports agile development flow.

3 RELATIONAL DATABASE AND SOFTWARE DEVELOPMENT

3.1 Introduction

This chapter discusses the design and development of the main relational database and web application as highlighted in Figure 3-1.

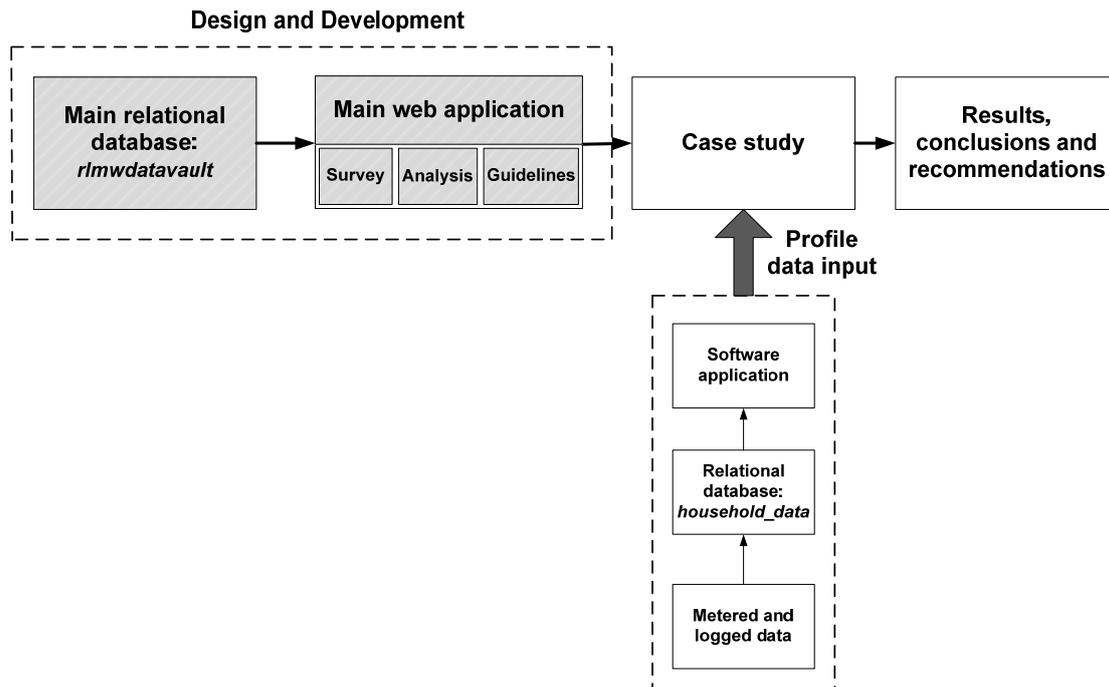


Figure 3-1: Components of the research project: database and main web application

This chapter covers the following sections:

- An overview of the application's development according to the phases and milestones that form part of the Unified Process.
- The design and development of the relational database.
- The development of the Graphical User Interface (GUI).

The first section provides an overview of the implementation of the three essential design aspects, namely Content Strategy, Interaction Design and Visual Design based on the functional and structural requirements of the application.

In the second section, a detailed discussion is provided on the development of a relational SQL database to ensure dynamic-driven content for the web application. The formal relations are set out diagrammatically to illustrate the database structure and attention is given to the use of linking tables. The current database structure is evaluated in terms of its advantages and shortcomings.

The third section of this chapter outlines the software development and focuses on specific elements of the GUI such as data visualization.

3.2 Overview of the development of the web application

At the time of commencing this research project, the author had no prior knowledge of the programming languages to build an RIA, SQL database query language or the PHP scripting language. Since this research project had to be completed within a designated timeframe, Agile Modelling was adopted as the most realistic development philosophy and the web application was developed using the Unified Process as a guideline. The main achievement of each phase of the Unified Process is shown in Figure 3-3 and these have been taken into consideration as it relates to the overall development of the web application.

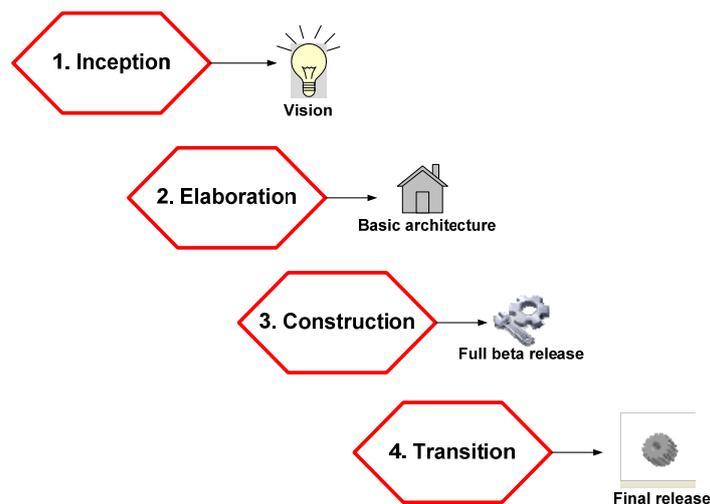


Figure 3-2: Implementation of the 4 phases of the Unified Process [87]

The implementation of the inception phase results in the concept or vision of what the particular web application should accomplish, as indicated in Figure 3-3.

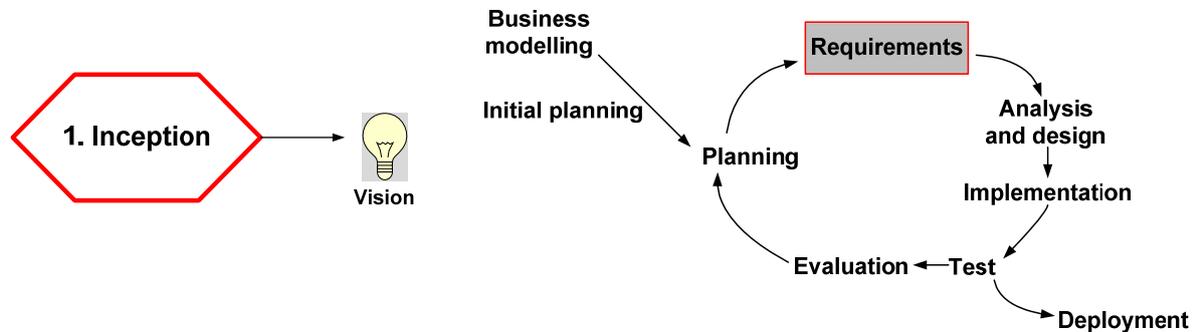


Figure 3-3: The Unified Process: determining requirements as part of the inception phase [87]

Since the web application is dynamic and database-driven, the requirements determined during the inception phase of the development process, involved both the database and the software application GUI.

Storyboarding and formal descriptions were used to narrate the vision of what the web application should provide. The following concepts encapsulate the envisioned functionality and user experience:

- Organisation of data in a database in order to provide dynamic data which is optimized to convey only necessary information.
- The concept of spaces and venues whereby the user can create a model of his/her residence.
- Create an application requiring minimal data input through typing on the part of the user.
- An interactive experience whereby the user can utilise functionality such as drag-and-drop and selection from dropdown boxes rather than typing.
- Inclusion of graphics and generic icons to represent unambiguous content.
- An appliance audit or survey procedure whereby the user can identify appliances per venue and populate each venue with a list of appropriate appliances.
- The concept of grouping appliances according to logical functional categories, for

example laundry.

- A hierarchical navigational layout within which the user can create a project, access venues and appliances.
- Analyse installed capacity and view consumption by means of data visualization within a dashboard framework.
- Access energy efficiency guidelines organised into a logical categorical framework.

3.2.1 Functional requirements

The application is designed in a hierarchical form to create a residential energy management project by integrating three components, namely a survey section, an analysis section as well as a guideline section. The functionality associated with each section can be summarised as follows:

- *The survey section:*
 - The user first "builds" his/her house by selecting venues or areas and adds these to the house.
 - The user conducts an audit of his/her house by placing appropriate electrical appliances in each venue/area.
- *The analysis section:*
 - The user can view installed capacity per venue/area or for the entire house.
 - The user selects an appliance and assigns a daily usage profile to it by determining when, and for how long, certain appliances are in use. The user can thereby characterize and create a load profile per appliance based on appliance-specific usage.
 - The user views a resultant daily usage profile generated from the accumulated usage profiles of a number of appliances.
 - The user views predicted consumption over a certain period, for example one day, based on a daily usage profile.
 - Provides a cost analysis by combining the time of appliance operation depicted in the usage profile with a Time Of Use (TOU) tariff structure, whereby price determination is based on peak versus off-peak usage.
 - Raise awareness of the cost benefits of appliance scheduling.

- *The guideline section:*
 - Associated with each generic appliance, for example a kettle, is a list of guidelines for efficient use. By exposure to the guidelines, a user can be educated on practices to improve energy efficiency.

Based on the functionality, the development of the application was divided into two phases with the overall design shown in Figure 3-4. Phase 1 has been completed and so has the conceptualization of Phase 2.

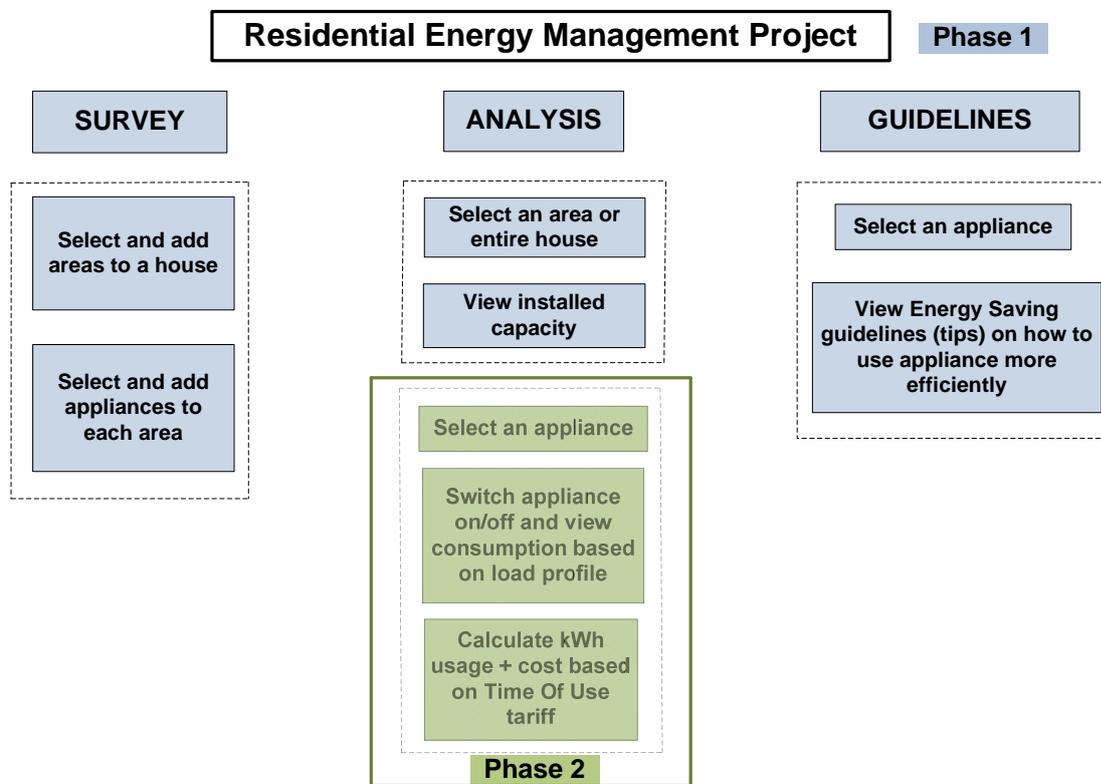


Figure 3-4: Summary of key user-defined tasks in the web application

Phase 2 of the web application involves the following functionality:

- The user selects an appliance and assigns a daily usage profile to it by determining the times during the day when the appliance is in use. The user can thereby characterize and create a load profile per appliance based on appliance-specific usage.
- The user views a resultant daily usage profile generated from the accumulated usage

profiles of a number of appliances.

- The user views predicted consumption over a certain period, for example one day, based on a daily usage profile.
- Provides a cost analysis by combining the time of appliance operation depicted in the usage profile with a Time Of Use (TOU) tariff structure, whereby price determination is based on peak versus off-peak usage.

As set out in Table 3-1, specific user tasks and outcomes were identified, as they relate to the functionality, including tasks associated with login and registration procedures.

Table 3-1: User defined tasks and outcomes

Task	Outcome
Register or log in	Authenticated user
Create or access a project	One or more saved projects per user
Survey	Area and appliance inventories
Analyse	View of installed capacity, usage profiles, predicted consumption, costs
View guidelines	Educated on improved energy efficiency

In order to establish the appropriate platform for Phase 2, the data input from the case study was seen as a necessary component in terms of contributing load profile information for use in the web application. As one of the outcomes from the case study, the development platform has been set in place in order to commence the implementation of Phase 2.

Following the inception phase, an analysis of the functional requirements led to the analysis and design of the application to implement the set requirements.

3.2.2 Analysis and design

The elaboration phase of the Unified Process mostly involves the analysis and design component as illustrated in Figure 3-5.

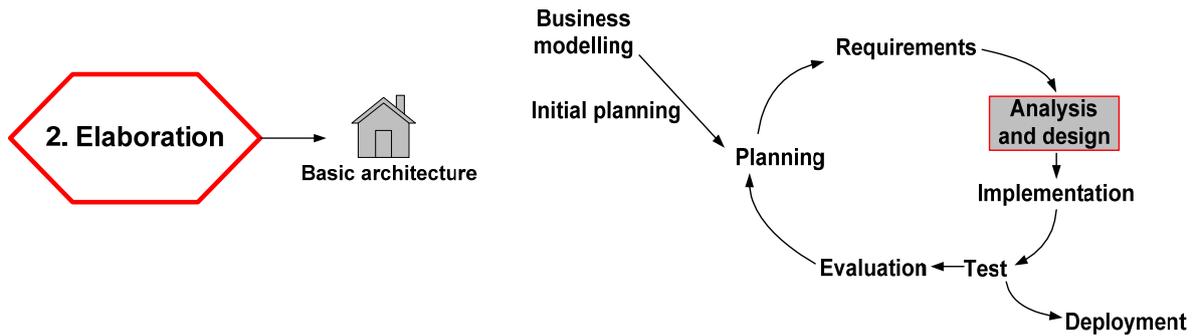


Figure 3-5: The Unified Process: Analysis and design as part of the Elaboration phase [87]

It is important to revisit the following aspects pertaining to the application’s structural and functional requirements:

- What type of experience will be effective and appropriate for a user with a reasonable level of computer literacy?
- In what format should the content be presented in order to realise a successful user experience?
- What is the most optimal way to convey the desired information?
- What type of technology can provide a dynamic, interactive user experience?
- What type of data storage will be most appropriate to ensure flexibility and data integrity?

3.2.3 Implementation

The construction phase of the Unified Process primarily entails the implementation part of the development process as illustrated in Figure 3-6.

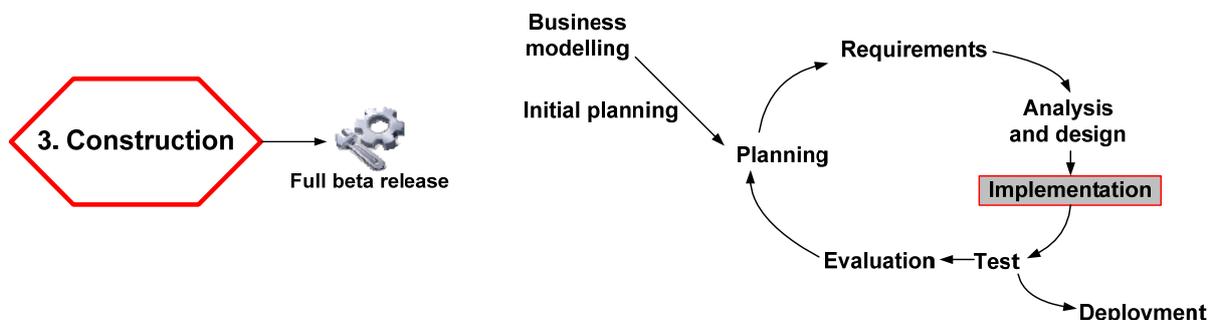


Figure 3-6: The Unified Process: Implementation as part of the Construction phase [87]

During the development of the application, the primary focus has been on implementing the four usability heuristics mentioned in 2.5.1 as they apply to the three key components for effective end-user design as shown in Figure 3-7.

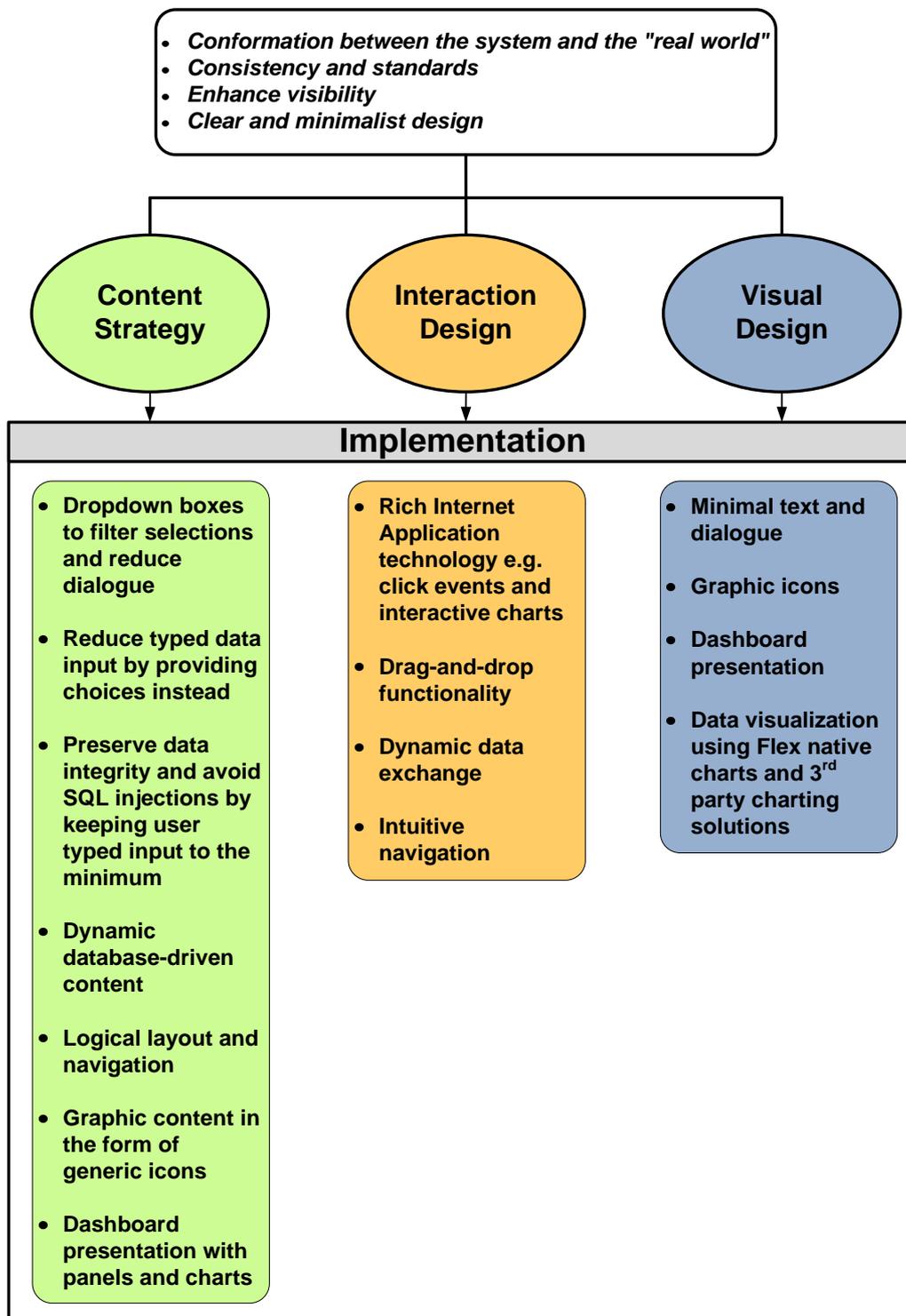


Figure 3-7: Implementation of three key components of end-user design

As can be seen from the diagrammatic presentation in Figure 3-7, a number of aspects are repeated since the content is presented largely in a graphic format with integrated interactivity.

Much attention was given to content strategy due to the objective of engaging with, and educating the user within a minimalist design framework. In order to create meaningful content in the most effective manner, it was decided to lean more towards visual data in the form of a graphic drag-and-drop environment.

3.3 Database structure and relations

As part of the project work, a relational database was integrated with the application to provide the dynamic client-server data exchange functionality. This section discusses this database structure and its relations as illustrated in Figure 3-8.

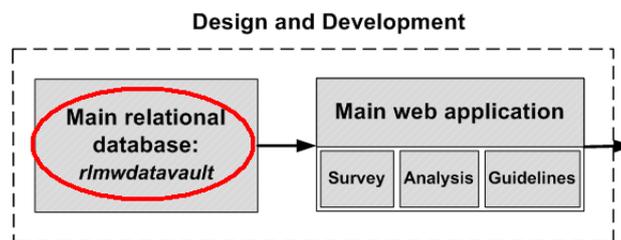


Figure 3-8: Design and development of the main relational database

SQL Queries pertaining to aspects that render key functionality are also included in this section. The database structure was designed on the basis that end-users of electricity is confined to a consumer class, such as the residential class, where electric usage is distinguished by subdividing usage into end-use categories, as incorporated by Willis [16].

The two platforms which were used during the development and testing of the application have been Microsoft Windows and the UNIX/Linux platform. The stacks which were

respectively used are WAMP (Windows, Apache, MySQL and PHP) and LAMP (Linux, Apache, MySQL and PHP). The development work was done using the most recent stable versions at the time of commencing development, namely PHP 5.3.0 and MySQL 5.1.36.

MySQL Community Edition is a freely downloadable version of the MySQL open-source database and includes MySQL Workbench for visual modelling, SQL development and administration [91]. MySQL Workbench consists of a comprehensive visual tool-set for database architects, developers, and administrators to accomplish 3 main tasks: design, development and administration. The design tool-set allows for the visual design and modelling of databases and also enables an existing database to be reverse engineered. The specific action is referred to as the creation of an Enhanced Entity-Relationship (EER) model from an existing database. The development tools are visual tools for creating, executing, and optimizing SQL queries. The administration tools are a dedicated tool-set for server configuration and user administration [92].

The database consists of more than 50 tables of which 27 tables were reserved for common household appliances. The list of household appliances is, however, not comprehensive. Due to the size of the database and practical considerations, a combination of MySQL Workbench's design tools for modelling, Microsoft Office Visio 2007 Database Model Diagram and phpMyAdmin version 3.2.0.1 were used to document the structure and content of the database for the purposes of inclusion in this thesis document. An EER model is based on the Enhanced-Entity (ER) model used in database design and is a conceptual or high-level model to describe a database. According to the ER model, each table record is an entity and a record can have one or more relationships with other table records or entities, thereby establishing entity-relationships [84]. The 27 tables dedicated to common household appliances are shown in Figure 3-9.



Figure 3-9: MySQL Workbench rendition of collapsed EER model of appliance tables

3.3.1 One-to-many relationship

A one-to-many relationship exists between each appliance table and the *loadclasses* table, since one record in the *loadclasses* table is associated with many records in each appliance table. The SQL query to illustrate this relationship is given in Listing 3-1.

```
SELECT L.Designation as Load_class, A.Brand
FROM dishwashers A
LEFT JOIN loadclasses L on A.loadclassesID= L.ID
```

Listing 3-1: SQL query to illustrate one-to-many relationship between an appliance table and the *loadclasses* table

The above query yields the following result set, as shown in Table 3-2.

Table 3-2: Result set for SQL query in Listing 3-1

Load_class	Brand
Dishwashers	Bosch
Dishwashers	Bosch
Dishwashers	Bosch
Dishwashers	Siemens
Dishwashers	Siemens
Dishwashers	Samsung

ID is the Primary Key (PK) in the *loadclasses* table and becomes a Foreign Key (FK) as *LoadClassesID* in each of the appliance tables. This one-to-many relationship is depicted in Figure 3-10. For practical reasons, only six appliance tables were included to illustrate the one-to-many relationship. The same relationship holds for each of the remaining 21 appliance tables not shown.

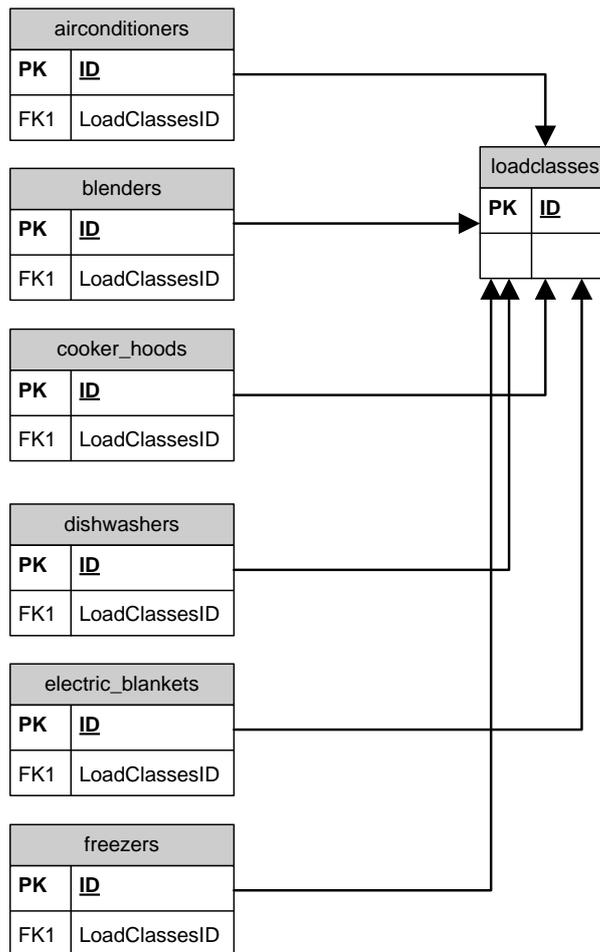


Figure 3-10: Microsoft Visio diagram indicating one-to-many relationship between an appliance table and the *loadclasses* table

Figure 3-11 shows the structure of the *loadclasses* table, while Table 3-3 lists the content of the ID and Designation fields.



Figure 3-11: MySQL Workbench EER model of the *loadclasses* table structure

Table 3-3: Content of the ID and Designation fields of the *loadclasses* table

ID	Designation
1	Airconditioners
2	Blenders
3	Dishwashers
4	Electric blankets
5	Geysers
6	Hand mixers
7	Hobs
8	Hotplates
9	Kettles
10	Lights
11	Microwaves
12	Ovens
13	Pumps
14	Refrigerators
15	Solar geysers
16	Stand heaters
17	Stand mixers
18	Steamers
19	Stoves
20	Toasters
21	Tumble driers
22	Underfloor heating
23	Washing machines
24	Towel warmers
25	Cooker hoods_Extractors
26	Freezers
27	TVs

Functional classes were identified to depict end-use categories, similar to those identified by Willis [16]. As designed into the database table structure, each appliance is not only linked to a specific *loadclass*, but also to a specific *functionalclass*. The *functionalclass* indicates the main functional category that each appliance is assigned to. Each *loadclass* is assigned to one specific *functionalclass* and each *functionalclass* can contain many *loadclasses*. This association is therefore also an example of a one-to-many relationship. As previously mentioned in section 2.5.2.1, a number of linking tables were created to ensure the resolution of one-to-many and many-to-many relationships. Shown in Figure 3-12 is the diagrammatic representation of the resolution of the one-to-many relationship by means of a linking table.

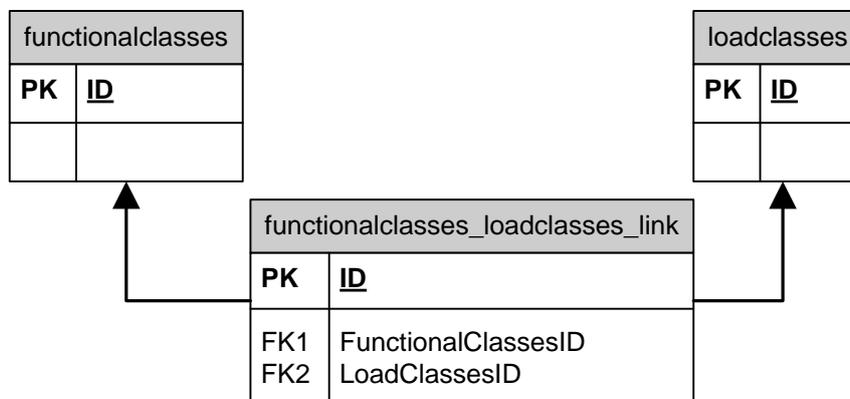


Figure 3-12: Use of a linking table to resolve a one-to-many relationship

The structures of both the *functionalclasses* table and the *functionalclasses_loadclasses_link* table are shown in Figure 3-13 and in Table 3-4, the content of the ID, Designation and Description fields of the *functionalclasses* table are given.

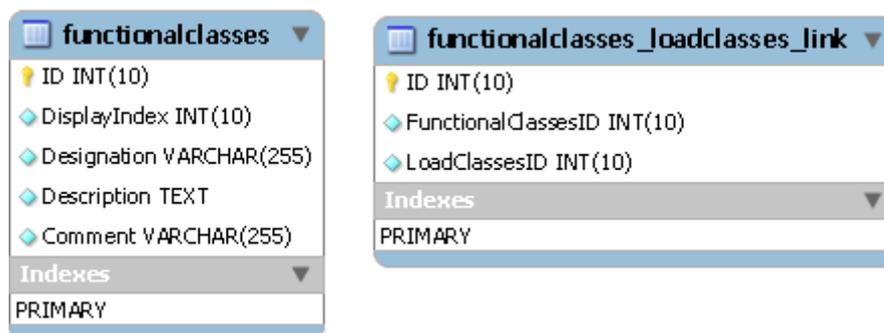


Figure 3-13: MySQL Workbench EER model to show structures of the *functionalclasses* and *functionalclasses_loadclasses_link* tables

Table 3-4: Content of the ID, Designation and Description fields of the *functionalclasses* table

ID	Designation	Description
1	Cooking	Includes stoves, hotplates, steamers, microwaves, ...
2	Food Preparation	Includes toasters, mixers, blenders etc.
3	Water heating	Includes kettles, urns, geysers, solar water heaters...
4	Refrigeration and Freezing	Includes refrigerators, freezers and combination r...
5	Laundry	Includes washing machines, tumble driers, irons, ...
6	Cleaning	Includes dishwashers, vacuum cleaners etc.
7	Lighting	Includes light fittings (indoors and outdoors), la...
8	Entertainment	Includes TVs, DVD players, audio systems etc.
9	Heating, ventilation and cooling	Includes air conditioners, heaters, fans, underflo...
10	Recreation	Includes swimming pool pump.
11	IT Infrastructure	Includes printers, laptops and other computers.
12	Telecommunication	Includes telephones and other communication devices...

In order to produce only relevant information to the user, linking tables and SQL queries, for example, queries utilising join operations to find commonality (intersection) on key values, yield the desired filtered results.

A linking table contains only identification numbers or IDs. To demonstrate the one-to-many relationship, namely that a number of *loadclasses* belong to every *functionalclass*, a MySQL query can be used that involves the *functionalclasses_loadclasses_link* table along with the original tables referenced by the linking table. To retrieve a useful result for a request such as, "show all appliances that belong to each *functionalclass*", a query involving the particular linking table with two LEFT JOINS are required, as given in Listing 3-2.

```
SELECT L.Designation as Appliance_name, F.Designation as Category
FROM functionalclasses_loadclasses_link A
LEFT JOIN functionalclasses F on A.FunctionalClassesID = F.ID
LEFT JOIN loadclasses L on A.LoadClassesID = L.ID
ORDER BY F.Designation ASC
```

Listing 3-2: SQL query to retrieve result set for "show all appliances that belong to each *functionalclass*"

The query in Listing 3-2 yields the following result set, as shown in Table 3-5:

Table 3-5: Result set for SQL query in Listing 3-2.

Appliance_name	Category
Dishwashers	Cleaning
Hobs	Cooking
Hotplates	Cooking
Microwaves	Cooking
Ovens	Cooking
Steamers	Cooking
Stoves	Cooking
TVs	Entertainment
Blenders	Food Preparation
Hand mixers	Food Preparation
Stand mixers	Food Preparation
Toasters	Food Preparation
Airconditioners	Heating, ventilation and cooling
Electric blankets	Heating, ventilation and cooling
Stand heaters	Heating, ventilation and cooling
Underfloor heating	Heating, ventilation and cooling
Towel warmers	Heating, ventilation and cooling
Cooker hoods_Extractors	Heating, ventilation and cooling
Tumble driers	Laundry
Washing machines	Laundry
Lights	Lighting
Pumps	Recreation
Refrigerators	Refrigeration and Freezing
Freezers	Refrigeration and Freezing
Geysers	Water heating
Kettles	Water heating
Solar geysers	Water heating

3.3.2 Many-to-many relationship

Similarly, each area is associated with a number of *functionalclasses* and in turn a particular *functionalclass* can be associated with many areas. This association is therefore an example of a many-to-many relationship. Shown in Figure 3-14 is the diagrammatic representation of the resolution of the many-to-many relationship by means of a linking table.

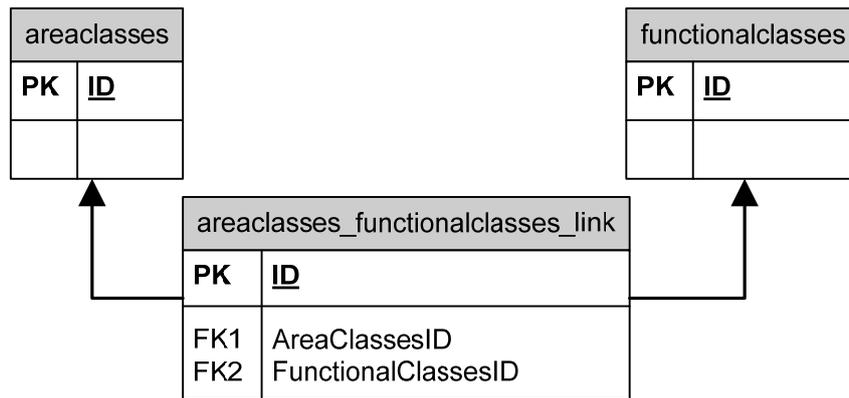


Figure 3-14: Use of a linking table to resolve a many-to-many relationship

The structures of both the *areaclasses* table and the *areaclasses_functionalclasses_link* table are shown in Figure 3-15. In Table 3-6, the content of the ID, Designation and Description fields of the *areaclasses* table are given. Only those descriptions deemed necessary were included in the database table.

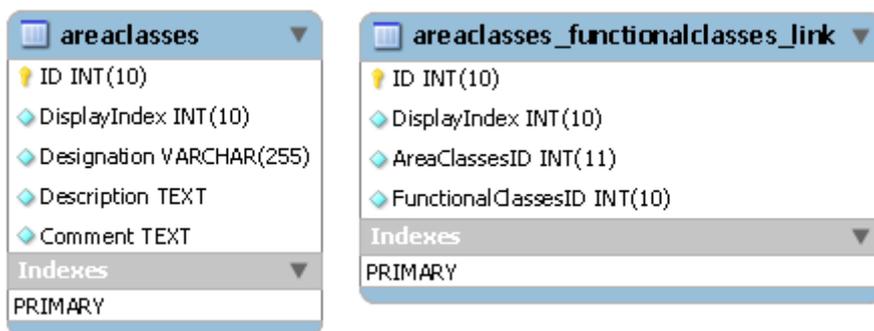


Figure 3-15: MySQL Workbench EER model of the structures of the *areaclasses* and *areaclasses_functionalclasses_link* tables

Table 3-6: Content of the ID, Designation and Description fields of the *areaclasses* table

ID	Designation	Description
1	Kitchen	
2	Scullery	Area for dishwasher, washing machine, tumble-drier...
3	Living Area	Areas such as a lounge, sitting room or TV room.
4	Passage	Any connecting areas and stairways.
5	Dining room	

ID	Designation	Description
6	Bedroom	
7	Study	
8	Bathroom	
9	Store room	
10	Garage	
11	Patio	
12	Swimming pool	Swimming pool pump and light.
13	Outside area	Includes driveway.
14	Roof space	Area between the roof of the house and the ceiling...
15	Loft	Area in the roof that can serve as a room.

To further illustrate the many-to-many relationship, the SQL query for a request such as, "show all areas and the *functionalclasses* associated with each area", is given in Listing 3-3. The expected result for this query is provided in Table 3-7, showing 25 of the records retrieved.

```
SELECT L.Designation as Area, F.Designation as Category
FROM areaclasses_functionalclasses_link A
LEFT JOIN functionalclasses F on A.FunctionalClassesID = F.ID
LEFT JOIN areaclasses L on A.AreaClassesID = L.ID
ORDER BY L.Designation ASC
```

Listing 3-3: SQL query to retrieve result set for "show all areas and the *functionalclasses* associated with each area"

Table 3-7: Partial result set for the query in Listing 3-3

Area	Category
Bedroom	Water heating
Bedroom	Lighting
Bedroom	Entertainment
Bedroom	Heating, ventilation and cooling
Dining room	Lighting

Area	Category
Dining room	Entertainment
Dining room	Heating, ventilation and cooling
Garage	Water heating
Garage	Refrigeration and Freezing
Garage	Laundry
Garage	Cleaning
Garage	Lighting
Garage	Heating, ventilation and cooling
Kitchen	Cooking
Kitchen	Food Preparation
Kitchen	Water heating
Kitchen	Refrigeration and Freezing
Kitchen	Laundry
Kitchen	Cleaning
Kitchen	Lighting
Kitchen	Entertainment
Kitchen	Heating, ventilation and cooling
Living Area	Lighting
Living Area	Entertainment
Living Area	Heating, ventilation and cooling

3.3.3 Queries for more complex application-specific requirements

It was also necessary to cater for a more involved intersection scenario on the premise that only certain functions are associated with certain areas or venues and accordingly, only those appliances or *loadclasses* which are grouped within certain *functionalclasses*. Practically, it simply means that under normal circumstances, a user will not have a washing machine in a dining room or a microwave in a bathroom. Therefore, a *functionalclass* such as laundry is associated with areas such as a kitchen, scullery, garage or bathroom. The application caters for the general case, where cooking is normally associated with a kitchen. However, the exceptional case, where all activities including cooking, takes place in a single room, is in fact not unusual considering the South African context where a significant number of people live in single-room dwellings or shacks. Furthermore, households who live in one-room or bachelor apartments will experience constraints based on limited space.

As portrayed in Figure 3-16, thinking in sets, allows for a diagrammatic illustration by means of a Venn diagram [39], [82] of a 3-way intersection of *functionalclasses*, *loadclasses* and *areaclasses*.

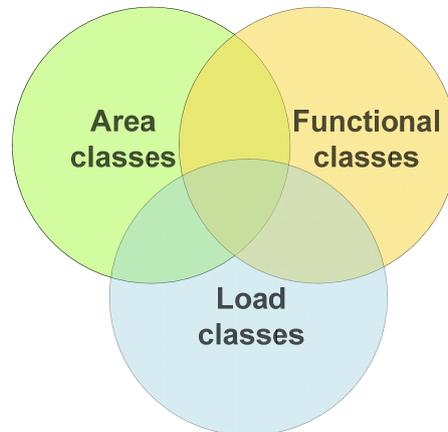


Figure 3-16: Venn diagram to illustrate 3-way intersection

The need for such an intersection arose from the requirement that the web application should provide the user with a selection of appropriate appliances per venue or area. In order to facilitate the selection process, the user must first choose an area in his or her home (for example the kitchen), to populate with appropriate appliances. The second choice that the user must make would be to select a *functionalclass* (for example cooking) from a list of *functionalclasses* associated with the particular area or room. Based on the second choice of *functionalclass* (for example cooking), the user can choose a variety of appliances, such as a microwave. Based on this choice, a list of available microwave models is retrieved from which the user can choose.

The paraphrased query for the cited example would be, "I would like to place appliances in my kitchen, starting with all cooking appliances, and of all the appliances associated with cooking, I would like to start with microwaves". The MySQL query that facilitates such a 3-way intersection, uses three INNER JOIN statements as well as a conditional WHERE statement and GROUP BY statement as shown in Listing 3-4.

```

SELECT t.Designation
FROM LoadClasses t
INNER JOIN areaclasses_loadclasses_link r ON r.LoadClassesID = t.ID
INNER JOIN areaclasses_functionalclasses_link m ON m.AreaClassesID = r.AreaClassesID
INNER JOIN functionalclasses_loadclasses_link p ON p.LoadClassesID = r.LoadClassesID
WHERE p.FunctionalClassesID = $itemID
AND r.AreaClassesID = $areaID
GROUP BY t.Designation

```

Listing 3-4: SQL query to facilitate 3-way join between *areaclasses*, *functionalclasses* and *loadclasses* based on a user's choices

Alternatively, the query to retrieve all load types associated with each area is shown here in Listing 3-5.

```

SELECT Ar.Designation, M.Designation
FROM areaclasses_loadclasses_link B
LEFT JOIN areaclasses Ar ON B.AreaClassesID = Ar.ID
LEFT JOIN loadclasses M ON B.LoadClassesID = M.ID
AND EXISTS (
SELECT F.Designation, L.Designation
FROM functionalclasses_loadclasses_link A
LEFT JOIN FunctionalClasses F ON A.FunctionalClassesID = F.ID
LEFT JOIN LoadClasses L ON A.LoadClassesID = L.ID)

```

Listing 3-5: SQL query to retrieve all load types associated with each area

Apart from the association (relationship) between a *loadclass* with an end-use category (*functionalclass*), most *loadclasses* (as opposed to individual appliance models) are associated with one or more energy efficiency guideline categories, each in turn containing a

number of guidelines. For example, a *loadclass* such as Refrigerators has certain guideline categories and guidelines associated with each category. The query to retrieve all guideline categories and guidelines associated with Refrigerators is shown here in Listing 3-6:

```
SELECT A.Designation AS Category, F.Designation AS Guideline
FROM guidelinecontent F
LEFT JOIN guidelinecategories A ON A.ID = F.GuidelineCategoriesID
WHERE F.LoadClassesID = 14
ORDER BY F.GuidelineCategoriesID ASC
```

Listing 3-6: SQL query to retrieve all guideline categories and guidelines associated with Refrigerators

The result set for the above query is summarized in Table 3-8.

Table 3-8: Result set for SQL query in Listing 3-6

Category	Guideline
Efficiency	Refrigerators and freezers are always in use, acco...
Efficiency	Refrigerators with the freezer at either the botto...
Efficiency	Through-the-door icemakers and water dispensers ar...
Efficiency	Match and choose your refrigerator based on the ne...
Efficiency	In a single door unit, it is essential that the se...
Location	If possible, place your refrigerator or freezer in...
Location	Chest freezers should be defrosted once or twice a...
Maintenance	Regularly check the rubber seals around the door o...
Maintenance	Regularly defrost manual-defrost refrigerators and...
Maintenance	Keep condenser coils/panels, usually found at the ...
Maintenance	Allow enough space around the refrigerator for air...
Usage	Energy is lost every time you open the refrigerato...
Usage	Use smaller cabinets for storing frequently used i...
Usage	Freezers will have to work harder if more than one...
Usage	Cover liquids and wrap foods stored in the refrige...
Usage	Switch on the energy saving switch if there is one...
Usage	Empty out, clean, and switch off the refrigerator ...

The implementation of the guideline section is discussed in further detail in 3.4.1.3.

3.3.4 Advantages and shortcomings

Being 1NF, 2NF and 3NF compliant, the current database structure offers the following advantages:

- Elimination of data redundancy.
- Ensuring the resolution of one-to-many and many-to-many relationships through the use of linking tables.

The obvious shortcomings are mostly related to the content since ongoing research is required to ensure the existence of an up-to-date database. Such a database would be populated with the most current household appliance models and their electrical ratings. Every electrical appliance should carry a label stating its power consumption in watt, although in some cases the current and voltage requirements are stated instead.

It would be apparent to consider appliances which are both commonly available and most popular, in terms of being purchased most frequently. The main method of research has been the Internet. Market research may be required to analyse sales statistics to obtain information on the most popular appliance brands and models sold. On the other hand, many households may have older appliance models which are no longer listed on Internet sales catalogues, so it becomes an intricate task to produce comprehensive content. It might be helpful to introduce one or two additional categories: a chronological category to cater for older and newer models and/or, a hierarchical category to distinguish between more advanced and more basic, less expensive models.

During the Internet research process, a further challenge has been the fact that there is not a standard set of information available per appliance. Relevant information had to be gleaned from marketing catalogues on a range of websites and all appliance specifications are not equally detailed. For example, some sites provide nameplate ratings in watt for appliances whereas others do not. Should it be required to do an in-store survey of the major household

appliance outlets which South African consumers frequent, such as *Game* or *DionWired*, it would be both a time-consuming and costly exercise. Nevertheless, to ensure the validity of information on household appliances the database content should be managed and reviewed on a regular basis.

3.4 The Graphical User Interface (GUI)

In parallel with the development of the relational database, the main web application was designed and developed. This section discusses this development process as illustrated in Figure 3-17.

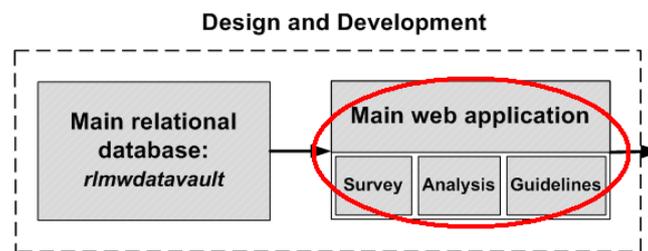


Figure 3-17: Design and development of the main web application

Two environments or platforms are required during a software development process, namely the development environment and the deployment environment. The web application was developed on a Windows Operating System (OS) running a WAMP server. In using the Unified Process as guide for the development of the particular web application, the achievements of the elaboration and construction phases are discussed.

3.4.1 Elaboration and construction phases

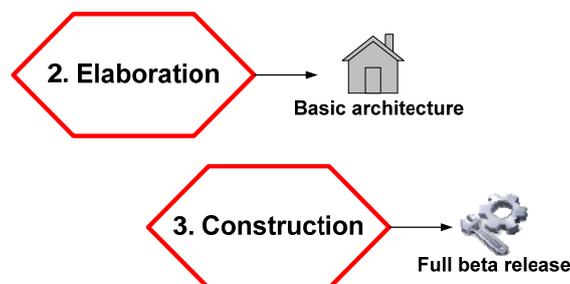


Figure 3-18: The Elaboration and Construction phases of the Unified Process [87]

The main achievement of the elaboration phase is the basic architecture of the software. The milestone of the construction phase is a beta-release functional product deemed ready for testing. As noted in section 2.6, the construction phase is usually the largest phase with the most iterations and focuses on the design and implementation of the majority of the system.

3.4.1.1 Application framework and structure

Flex employs a model-view design pattern where user interface (UI) components form the view. The native Flex framework uses decoupled, reusable view components where the main application container acts both as a controller and a model. In view of time constraints to acquire additional skills to master a framework such as Cairngorm which, according to Daraedt [77], is poorly documented, it was decided to utilise the Flex native framework.

A user interface in Flex is structured by means of MXML containers and controls on the principle that data needs to be contained and controlled. A container provides a hierarchical structure for organizing and laying out the user interface. A container is a rectangular region such as an area with a horizontal layout (HGroup), an area with a vertical layout (VGroup), canvas or panel. Within a container, other containers or controls can be arranged so that a parent container can contain children, i.e. more containers and controls, specifying their layout [75], [93].

Flex applications support a clear separation between the client-side and the server-side. There is no direct communication between a Flex user interface component and a server-side data source such as a database table. The intermediary is a data access component which connects to a remote service that in turn interacts with the server-side data source [75]. The data access component retrieves data based on a call-and-respond model with an event-handler and call responder.

Flex accesses data services in one of the following three ways [75]:

- As a remote object.
- As an HTTP (REST-style) service.

- As a web service (SOAP).

The three data access components that use remote procedure calls to interact with a server environment are therefore: RemoteObject, HTTPService and WebService components. REST refers to Representational State Transfer and is an architectural style, whereas SOAP refers to Simple Object Access Protocol. SOAP web services are software modules with methods, commonly called operations [75].

For the particular web application, both the HTTPService data access component and RemoteObject component were used. The HTTPService can be used with any kind of server-side technology. In conjunction with PHP and a SQL DBMS, the component displays the results of a database query in an application. The HTTPService's send() method makes the call to the relevant PHP page [75].

Service calls in Flex are asynchronous, which implies that the client application does not have to wait for returned data and is not blocked waiting for the data to be retrieved or updated [75]. Data from a service call is stored in a CallResponder associated with the service call. UI components use data binding to retrieve the returned data from the CallResponder [75]. Data binding in Flex allows a UI component to be updated dynamically.

Flex applications are event-driven as UI components respond to events. A user action or a program event can trigger access to a service by means of generating a service call. An event initiated by a user is for example when the user clicks a button or selects an item from a drop-down box. The click event or selection event triggers a service call. An event initiated by the program is for example a creationComplete event, whereby a list component in the user interface is seemingly automatically populated with data from the database upon loading of the component. No action by the user is required to instantiate the data population of the list. Event handlers are ActionScript code that defines how the component should respond to the event [93].

For the particular application, an external CSS file or stylesheet was used to apply styles to various components in the application.

3.4.1.2 Navigation

Intuitive navigation was identified as one of the key aspects to promote simplicity. Navigation was designed around the user tasks listed in Table 3-1, namely:

- Registration or login
- Project creation/access
- Survey
- Analysis
- Guidelines

In Flex, either navigator containers or view states can be used to facilitate navigation. In terms of available navigator containers, a tabbed interface requires, for example, the use of a TabNavigator container. The developer's choice between using view states or navigator containers depends on the application requirements and UI design. View states provide a way to change an application's appearance and/or content in response to user actions [63]. View states also promote the re-use of components.

For the particular web application, use was made of ViewStack navigator containers with NavigatorContent components. It is possible to incorporate browser history integration by setting the historyManagementEnabled attribute of the ViewStack to true, which is noted as one of the main reasons to use a ViewStack [94]. Other web architectures store session data on the server and synchronize client access to the data with cookies. Cookies are variables generated by the server and returned by the client on each new page request by the user [95]. The advantage of cookies is that it relieves the client of the need to manage data persistently. However, two of the disadvantages are firstly user scalability issues, because each time a new user visits the application, additional server memory is required, and secondly, the fact that a user can disable cookies, thereby rendering the solution ineffective [95].

Navigation is handled by setting the selectedIndex attribute of the ViewStack to a numeric value starting at 0. In addition to the ViewStack, a LinkBar control was used to control the active child of a ViewStack container [96], as well as a dropdown-style MenuBar as shown in Figure 3-19.

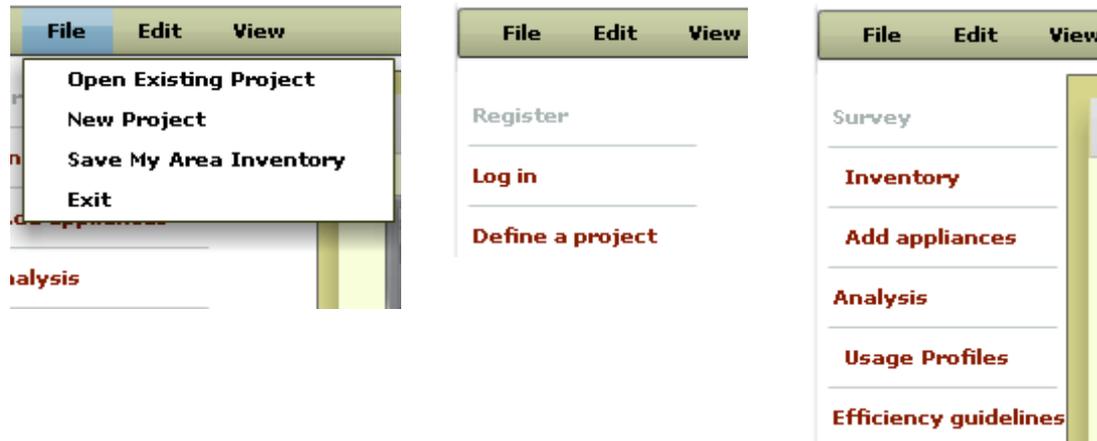


Figure 3-19: Example of a MenuBar (top) and LinkBar (left) navigation controls

3.4.1.3 Data-driven UI components

List controls and hierarchical data used in tree controls as well as menu-based controls, are examples of data-driven UI components. Data-driven, or data-centric controls depend on data retrieved from a remote database server. Numerous instances of list controls were implemented in the application in the form of datagrids, dropdown boxes and drag-enabled lists of icons. The latter is described more fully in the context of interactivity in the next section.

A tree control is a hierarchical structure consisting of branches and leaf nodes. The tiered categorical organization of the web application's Energy Efficiency Guideline section was well-suited for implementing a tree structure as shown in Figure 3-20 and Figure 3-21.

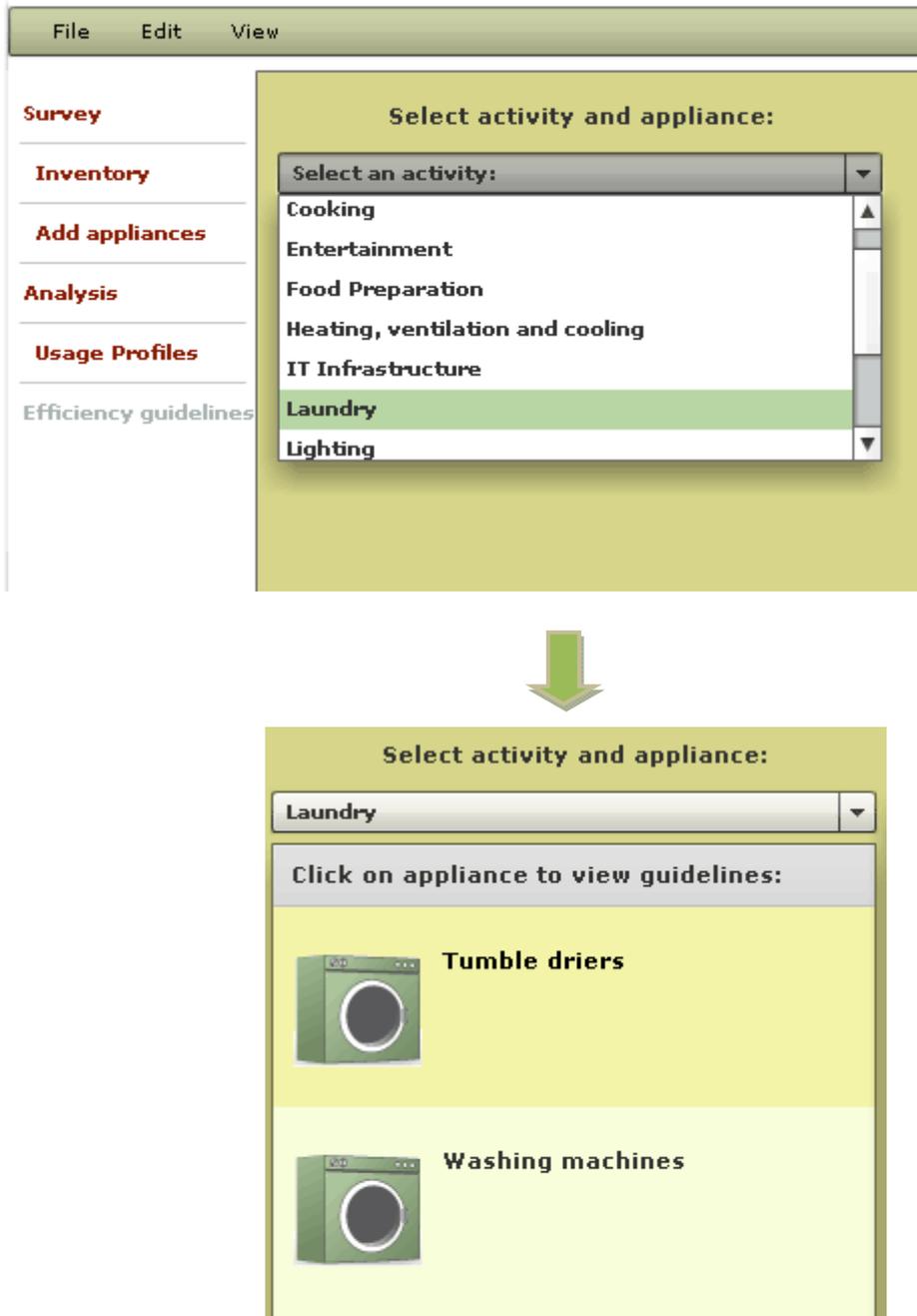


Figure 3-20: Category or *functionalclass* selection, followed by appliance selection

Upon making a selection, the user can view the guidelines per selected appliance in a hierarchical tree structure as illustrated in Figure 3-21.

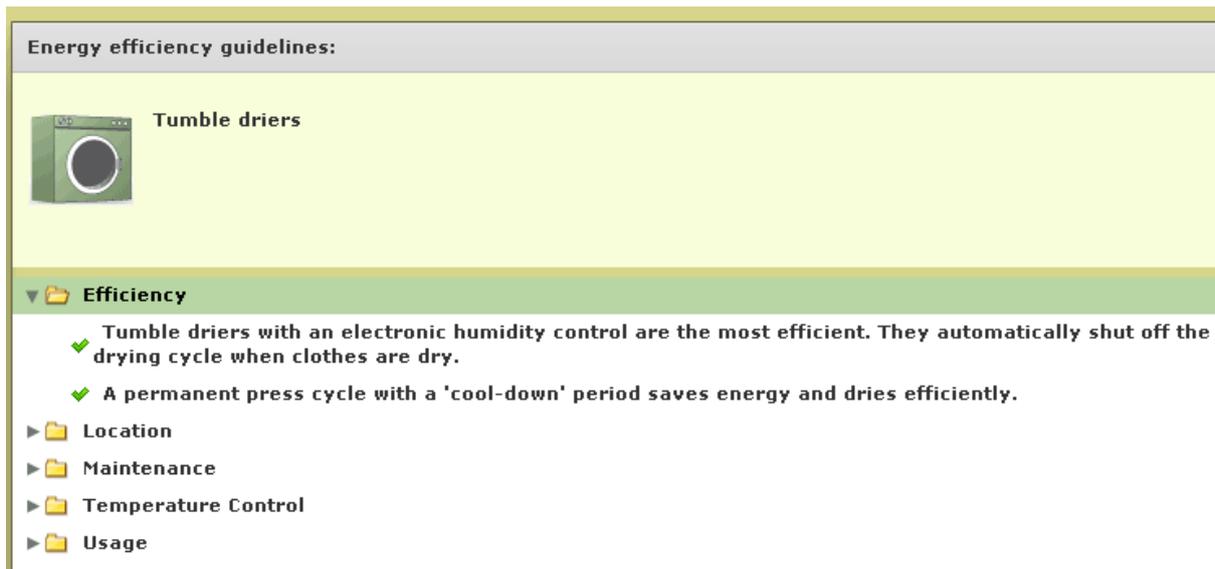


Figure 3-21: Tree structure to implement guideline categories and associated guidelines per selected appliance

3.4.1.4 Interactivity

As explained in 3.4.1.1, Flex is an event-driven framework where events are handled asynchronously. The client application does not have to wait while a request is processed and a result retrieved and dispatched. Two main features of the developed web application provide the desired interactivity, namely:

- The intrinsic event-driven features of the application.
- The drag-and-drop interactive features.

The desired interaction between a user and the application is accomplished in a Flex application by using a container as a drop target and setting the `dragEnabled` attribute of the source, or item to be dragged, such as a list item, to `true`. Drag-and-drop events can then be triggered to result in certain changes or actions taken by appropriate event handlers.

3.4.1.5 CRUD functionality

CRUD is an acronym used to denote the following tasks: create (or insert), read (or retrieve), update and delete. The PHP server together with the Zend Action Message Format (AMF)

library, provide the necessary functionality for a dynamic, database-driven application. AMF is used to serialize data between the client application and the data service [75].

When initially accessing services implemented in PHP, Flash Builder determines whether the supported version of the Zend Framework is installed. If the latter is not found, the developer is prompted to install the Framework and upon acceptance, Flash Builder installs a minimal version [75]. The Zend Framework, which contains the ZendAMF library, is installed in the web server's document root folder. In the case of the WAMP server, the root folder of the Apache web server is the www folder. Flash Builder creates two configuration files: `amf_config.ini` and `gateway.php` for Flex projects that access PHP services [75]. Flash Builder facilitates the generation of a sample service or prototype that provides CRUD functionality based on a database table structure. Data services are placed in a services directory.

An `HTTPService` component is used to both send and respond: it sends a HyperText Transfer Protocol (HTTP) GET or POST request and then includes the data from the HTTP response in a client application.

3.4.1.6 Data visualization

In view of the objective to develop an application with dashboard features, it was important to use the most suitable charting controls. Key Performance Indicators (KPIs) that are displayed in a dashboard are typically presented in the form of graphs or gauges.

Flex has a built-in component library of data-driven UI components which include several charting controls. Of the available controls, the Flex native pie chart and column chart were used in the web application. However, to include more complex data visualization, a comprehensive investigation was conducted to identify suitable third party charting solutions for evaluation. The data source and delivery format dictated the type of chart to use. The following charts were evaluated: Steema's TeeCharts, amCharts, FusionCharts, AnyChart and AnyChart Stock component (AnyStock). From these, AnyStock charts were considered

to be the most appropriate charting solution to incorporate into the web application. AnyChart partners include Adobe, Oracle and Microsoft and some notable customers include Oracle, Microsoft, Ford, VolksWagen, JPMorgan, General Electric, Schlumberger, Lockheed Martin 3M and Reuters [97]. In addition, online support for AnyChart and AnyStock has been excellent. AnyChart and AnyStock charting solutions are, however, not free but watermarked free trial versions are available and were used.

The AnyChart Stock component can use comma separated values (.csv) formatted data as data source. Using an external data source in favour of an embedded source is preferable, since it caters for the use of large data sets [98]. To this end, a server-side script (such as PHP) can be used in combination with an SQL query to access a database and generate dynamic external source data. In that case, the Uniform Resource Locator (url) is provided in the application as the dynamic data source url or path to the script. The external server script is then used to access dynamic data.

Flex native charts can have, amongst others, an XML file or HTTPService as data source or data provider for the chart data. Provided in Figure 3-22 to Figure 3-24, are examples of Flex native pie and column charts that were implemented in the web application's dashboard to visualize KPIs such as the installed capacity per area, given in percentage and in watt, as well as total installed capacity, given in percentage and in watt.

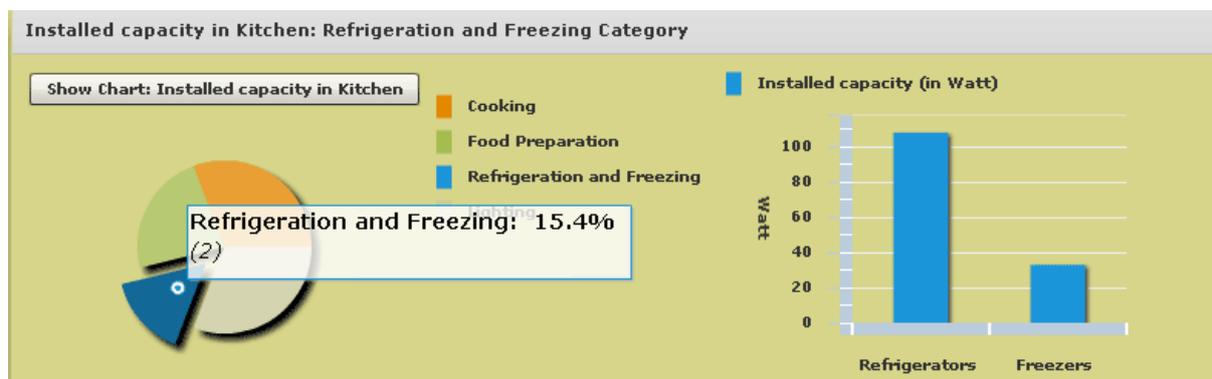


Figure 3-22: Example of interactive data visualization using Flex native pie and column charts: installed capacity per venue

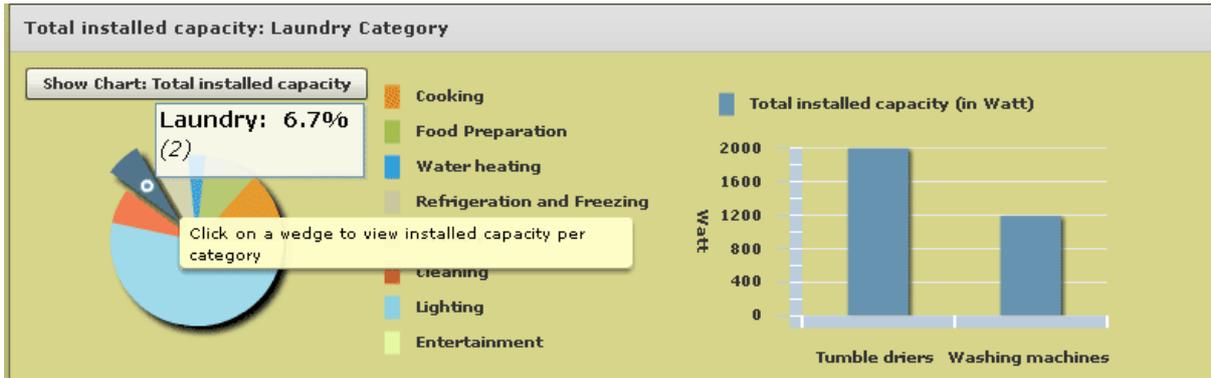


Figure 3-23: Example of interactive data visualization using Flex native charts: total installed capacity



Figure 3-24: Example of interactive data visualization using Flex native charts: total installed capacity (cont.)

3.4.1.7 Graphics

Information graphics specialists were consulted and were responsible for the conceptualization and design of the visual data artwork in the form of vector-based icons. A first basic set of high quality graphic symbols/icons were developed to represent clear, and where possible, generic, data such as electrical appliances. The inclusion of such expertise was considered invaluable in establishing a minimalist GUI where a graphic picture can replace the proverbial thousand words.

A combination of FXG and SVG formats were used in the web application. It is possible to

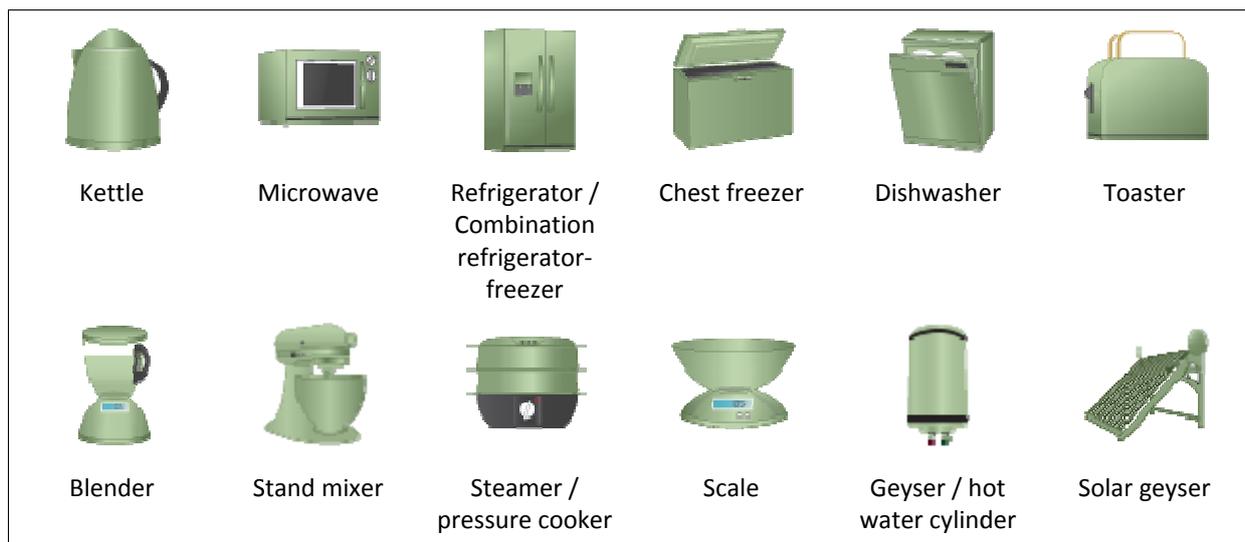
convert SVG to FXG using graphic software such as Adobe Photoshop or Illustrator CS5 (or later versions) by opening the SVG file and exporting it as an FXG file. Icons for both venues and appliances/equipment were designed.

The icons shown in Figure 3-25 were used in the web application to depict generic venues or areas commonly associated with a residence.



Figure 3-25: Icons to represent some generic venues or areas associated with a residence

Figure 3-26 shows examples of the generic household appliance icons.



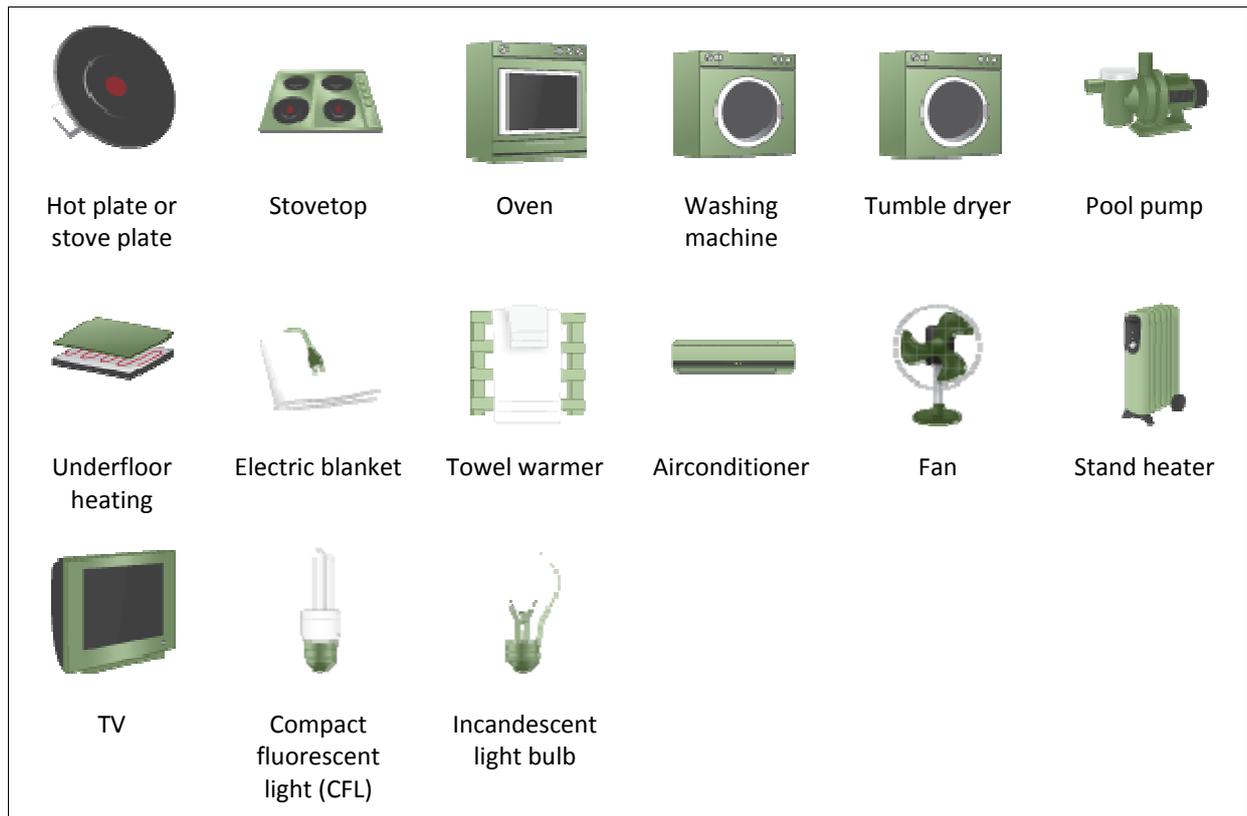


Figure 3-26: Icons to represent generic household appliances and equipment

3.4.2 Transition phase

As indicated in Figure 3-27, the beta release version precedes the final release version. According to the Unified Process, the end of the construction phase is followed by the final stage, namely the transition phase.

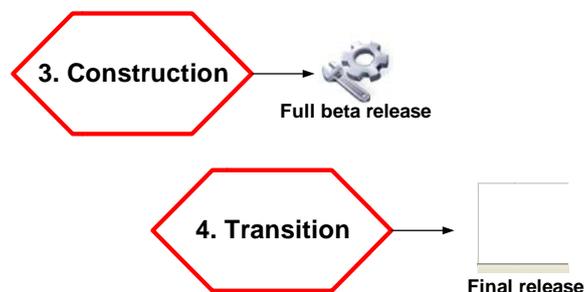


Figure 3-27: Construction and transition phases of the Unified Process [87]

In preparation of the successful completion of the construction phase and in anticipation of a successful transition phase, a suitable testing environment had to be set up as a preliminary requirement to facilitate beta testing. The Flex/Flash Builder development process concludes with the deployment of a release version. As noted in section 3.4.1, the development environment was a Windows OS whereas the deployment environment is an Ubuntu Linux server.

It was therefore necessary to set up a local Ubuntu server to test the deployment of the application locally. As described in 3.4.2.2 and in APPENDIX B, a virtual Ubuntu LAMP guest was set up on a Windows Vista host and Webmin installed in order to emulate a suitable testing environment. The next step will be to utilise the load profile data input from the case study to complete Phase 2, as noted in Figure 3-4. Once both phases of the application are complete, a beta release version of the application can be deployed and tested on the remote Ubuntu server.

3.4.2.1 Documentation: UML diagrams

A combination of use case diagrams, activity diagrams as well as sequencing diagrams have been used to describe the web application. Use was also made of UML4AS, specifically a class diagram model. UML4AS re-engineers ActionScript code and is designed to integrate with Flex. The core functionality of the web application is described with a use case diagram depicting the user as actor and a number of use cases as shown in Figure 3-28.

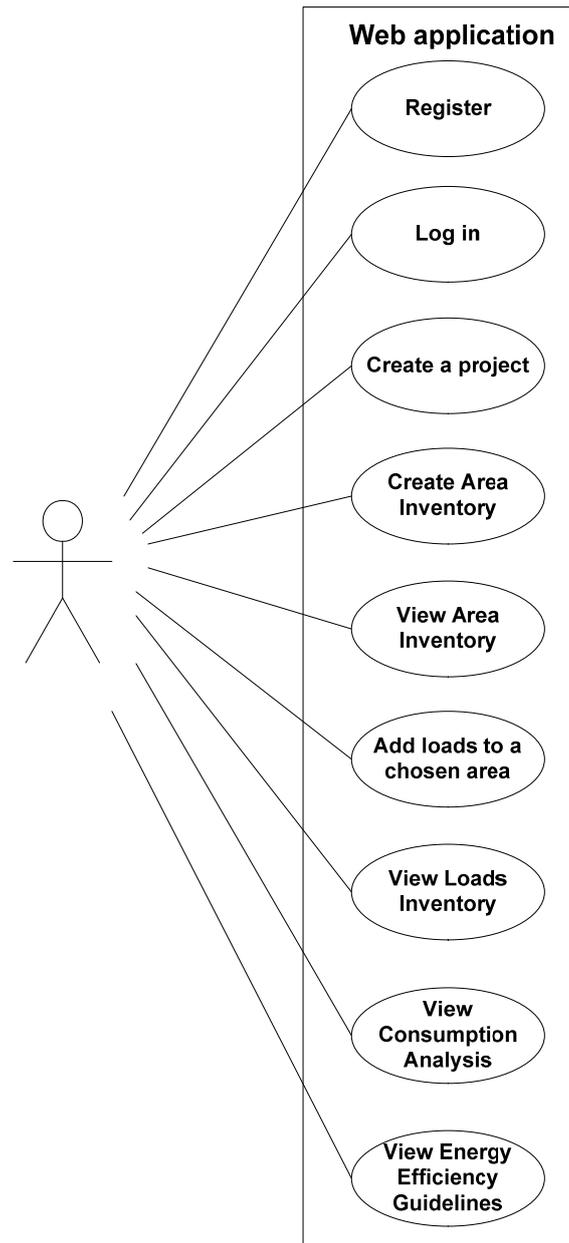


Figure 3-28: Use case diagram depicting the user as actor and a number of use cases

Activity diagrams are used to illustrate how a particular operation is performed and the purpose of an activity diagram is similar to pseudocode. Illustrated in Figure 3-29 is an example of three activity diagrams which describe the procedures of user registration, user login and creation of a project by a user. Actions are identified as round-cornered rectangles and the name of the action or other description of it may appear in the symbol. The abbreviation "act" refers to activity. A detailed UML4AS class diagram of the web application is given in Figure 3-30, showing attributes and operations.

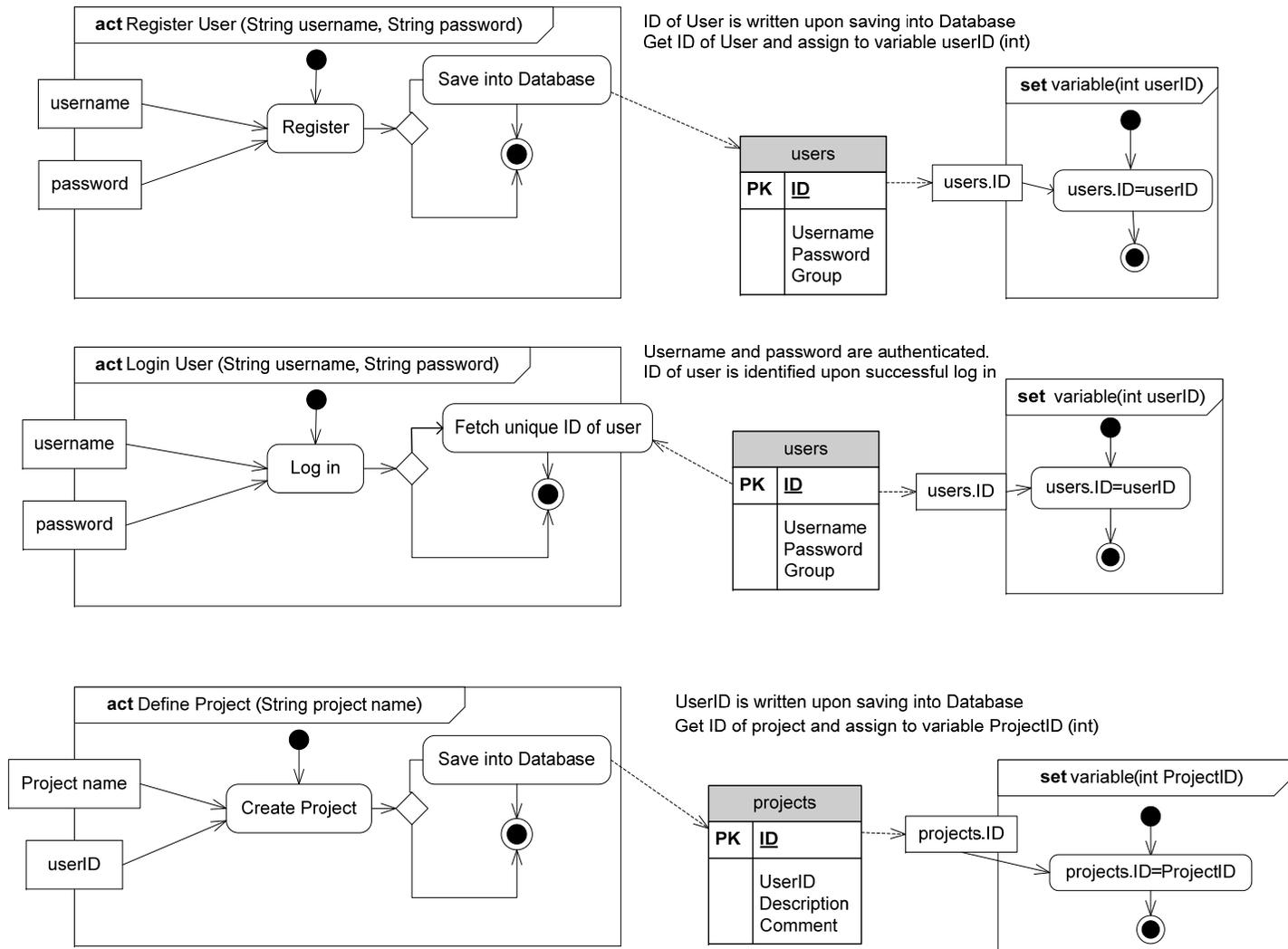


Figure 3-29: Activity diagrams to illustrate user registration, login and project creation



Figure 3-30: A UML4AS-reverse engineered class diagram

3.4.2.2 Setting up the testing environment

Ubuntu's version 11.10 (*Oneiric Ocelot*), LAMP server was set up as a virtual server (guest) on a Windows Vista host, using Oracle's VirtualBox [99]. VirtualBox is a free open-source virtualization product that runs on various hosts, including Windows and Linux, and supports numerous guest operating systems. Based on the deployment directives provided in [100], [101] and [102], a deployment manual was compiled which summarizes the necessary sequence of steps to be performed to successfully deploy the web application. The manual is included in APPENDIX B.

4 CASE STUDY

4.1 Overview

The case study was conducted at a residence in Uniepark, a residential suburb in Stellenbosch. Stellenbosch is a town in the Western Cape province of South Africa. As part of the case study, electrical supply to the residence and electrical loads in the residence were monitored and logged and the results processed and modelled.

The overall objective of the case study was not merely to collect data for one specific household with a set of specific appliances, but rather to investigate an appropriate methodology to generate appliance load profiles through measurement. Generally load studies depict supply measurements, but do not necessarily include appliance-specific load profiles. By generating accurate load profiles as part of a strategy to predict household consumption, the case study was performed in support of the main research of developing an application for residential end-users to improve energy efficiency.

As set out in section 1.4, the case study was conducted to achieve the following objectives:

- To investigate and substantiate the residential energy consumption context.
- To log not only supply, but also collect specific usage data for a number of electric household appliances.
- To establish an overall methodology to log appliance usage in a typical middle income residence.
- To establish a methodology for processing the logged data in a meaningful way with the view to obtain usage profile and duty cycle data that is compatible with the software application.
- To determine a strategy to correlate electrical supply metered data with appliance usage log data and produce a visual display that incorporates both sets of data.
- To present the outcomes of processed log data visually in the form of generated load profiles for a number of appliances.
- Utilise the household case study as a test case scenario for the web application in terms of a user-defined project.

In view of the overall project, this chapter provides a description of how the case study component contributed data input in the form of metered and processed data as indicated in Figure 4-1.

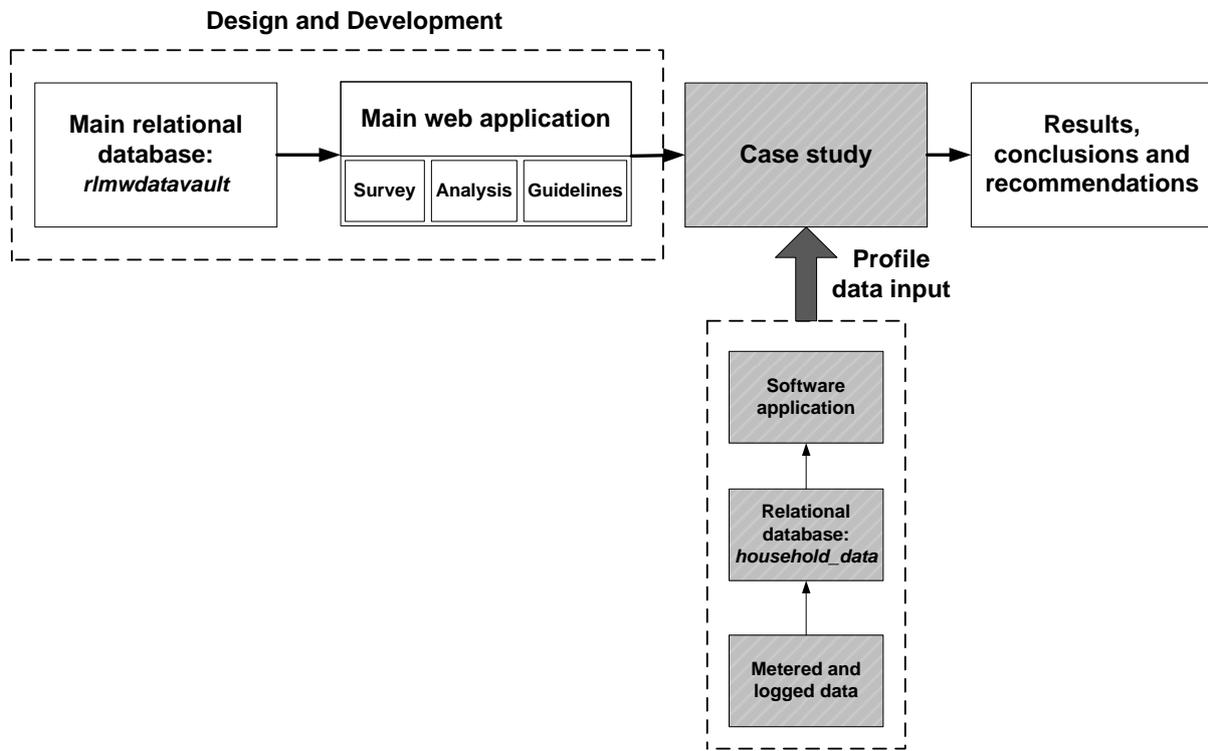


Figure 4-1: Case study component of the research project

It was necessary to create a means to store and process the metered and logged data. For this purpose, a separate MySQL database, *household_data*, was designed to store the metered and logged data from the residence. Section 4.2.3 which documents the metered results, provides details on the database structure. The metering and logging of the residence was commenced at the end of January 2012 and was still being continued at the time of submission.

The visual display requirements of load profiles necessitated the development of a supporting software application integrated with the database to control and manage the selection and display of load profiles of the logged appliances. In addition, the need to visually compare logged supply and usage data to establish correlation between the two data sets also required data visualization in the form of charts in a software GUI.

4.1.1 Description of residence parameters

The following parameters apply to the residence in this case study:

- The residence is located in the suburb Uniepark, in the Stellenbosch municipal area.
- The Stellenbosch Municipality purchases electricity from Eskom and resells it to consumers.
- A pre-paid electricity meter is installed in the residence.
- The household falls into a middle income category.
- The household consists of four members, namely two adults and two children.
- A single-phase low-voltage (LV) topology is applicable.

The residence is built as a single structure but consists of a main section and a separate apartment. The main residence consists of the following venues (areas) as listed in Table 4-1:

Table 4-1: Venues/areas of the main residence

Venue/Area	Count	Venue/Area	Count
Bedroom	3	TV room/ Living area	1
Bathroom	2	Lounge	1
Kitchen	1	Scullery	1
Open-plan dining area	1	Study	2
Passage	1	Patio	1
Swimming pool	1	Double garage	1

An appliance audit per venue was conducted for the main residence to include the appliances that were logged. The results from the appliance audit are listed in 4.2.1.2.

4.1.2 Stellenbosch Municipality

In an effort to reduce the electrical load, the Stellenbosch Municipality introduced an incentive to switch geysers off and on by means of an installed device, in the homes of consumers within targeted suburbs. Uniepark was included in the targeted list of suburbs. Included in APPENDIX C is documentation provided by the Stellenbosch Municipality

which accompanied the drive to market and install the devices. The device was installed in the residence and connected to the geyser in September 2012. This fact will be taken into consideration when interpreting the logged geyser data.

The replacement of all Eskom's residential tariffs in favour of an Inclining Block Tariff (IBT) structure has been endorsed by NERSA. This action has been motivated as a protective measure for domestic users with a lower usage against steep cost escalation. The subsequent IBT roll-out by Eskom has been implemented in two phases and commenced on the 1st of April 2010 with implementation for residential customers with conventionally metered supply [33]. Secondly, implementation for pre-paid electricity commenced a year later since the retail prepayment system required modification in order to accommodate the new tariff structure. Included in APPENDIX C, the IBT structure is provided as applied by the Stellenbosch Municipality for residential consumers. Additionally, a list of household municipal electricity tariffs for 2012/13 is provided, considered appropriate by NERSA.

As part of the case study, costs of electricity that was purchased from a number of different vendors in Stellenbosch were documented over a period of approximately 7 months during 2012. The costs are included in APPENDIX C.

As mentioned in section 1.2.2, NERSA sets guidelines on an annual basis that determine a percentage for municipal electricity tariff increases. During July 2012, NERSA made available a list of 33 municipalities who had requested additional increases over and above the set guidelines [13]. Eskom's submission for price increases over the next five years has been lodged with the South African Local Government Association (SALGA) and the National Treasury. Increased prices will be implemented early in 2013 which will subsequently serve as the basis for local authorities' mid-year increases.

4.2 Methodology

The methodology that was followed can be summarised by means of the following steps:

- An appliance audit was conducted of the residence.

- Electrical supply to the residence was logged and the data was stored and processed.
- A number of electrical appliances in the household were logged using data loggers to record usage in terms of ON/OFF events.
- A database was designed and developed to store the supply and appliance log data.
- A software application was developed to access the database data and process and display the results in the form of load profiles.

4.2.1 Appliance audit

An appliance audit was conducted per area/venue for the main residence and the audit results were utilised for two purposes, namely:

- To implement a test case scenario for the main web application by creating a user-defined project consisting of an area inventory and loads inventory.
- To identify and record a list of household appliances whose usage could be logged by means of data loggers.

4.2.1.1 Implementation results from the main web application

As part of testing the main web application, the following area and loads inventories were created for the residence and stored in the *rlmwdatavault* database, given respectively as Table 4-2 and Table 4-3. The appliance audit for the web application is not representative of all household appliances in the residence for two reasons, namely:

- Only appliances represented as tables in the *rlmwdatavault* database were included.
- Only appliances for which graphic icons exist were included since an appliance icon is used by the user as the drag-source during the creation of a loads inventory by means of drag-and-drop interactivity.

Table 4-2: Area inventory of the case study residence

AreaClassesID	Designation	AreaClassesID	Designation
6	Bedroom 1	3	Lounge
6	Bedroom 2	4	Passage

AreaClassesID	Designation	AreaClassesID	Designation
6	Bedroom 3	7	Study 1
8	Bathroom 1	7	Study 2
8	Bathroom 2	11	Patio
1	Kitchen	12	Swimming pool
2	Scullery	10	Garage
5	Dining room		
3	TV room		

Table 4-3: Load inventory per area/venue of the case study residence

AreaInventoryID	LoadClassesID	Designation
1	10	Light
1	10	Light
2	10	Light
2	16	Heater
3	10	Light
3	16	Heater
4	10	Light
5	10	Light
6	11	Microwave
6	12	Oven
6	14	Refrigerator
6	5	Electric Geyser
6	9	Kettle
6	20	Toaster
6	2	Blender
6	6	Hand mixer
6	10	Light
6	18	Steamer
6	10	Light
7	10	Light
7	10	Light
7	3	Dishwasher

AreaInventoryID	LoadClassesID	Designation
7	21	Tumble Dryer
7	23	Washing Machine
8	10	Light
9	27	TV
9	10	Light
9	1	Airconditioner
10	10	Light
11	10	Light
11	10	Light
12	10	Light
12	10	Light
12	16	Heater
13	10	Light
14	10	Light
15	13	Swimming pool pump
16	10	Light

Results from the main web application’s analysis section are included as Figure 4-2 to Figure 4-4, notably results in terms of installed capacity per venue and per category for the entire house.

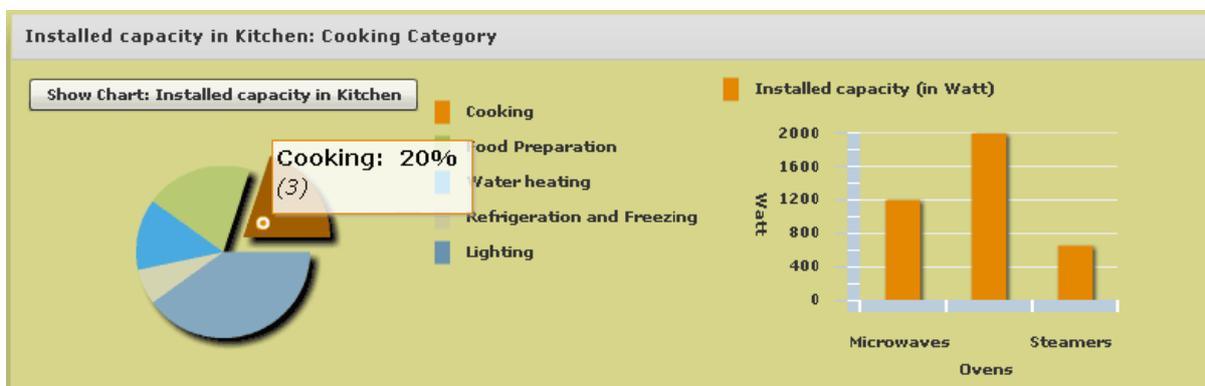


Figure 4-2: Installed capacity in kitchen

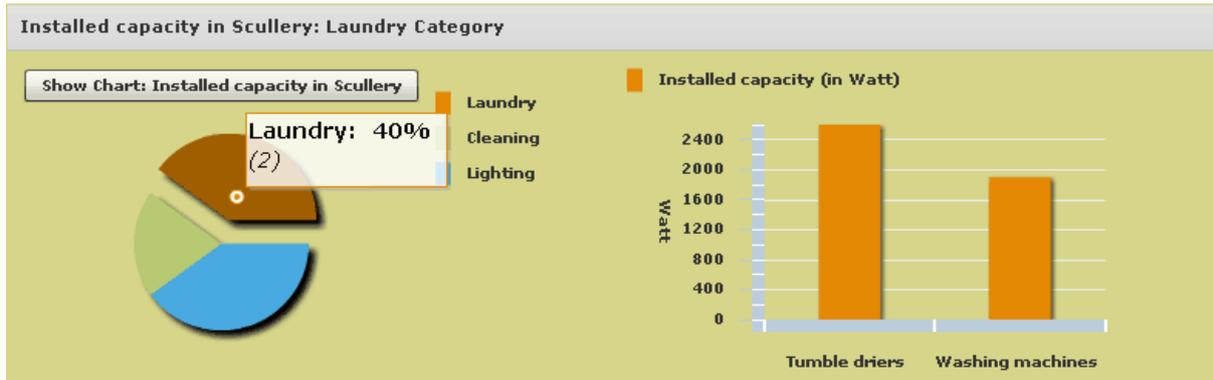


Figure 4-3: Installed capacity in scullery

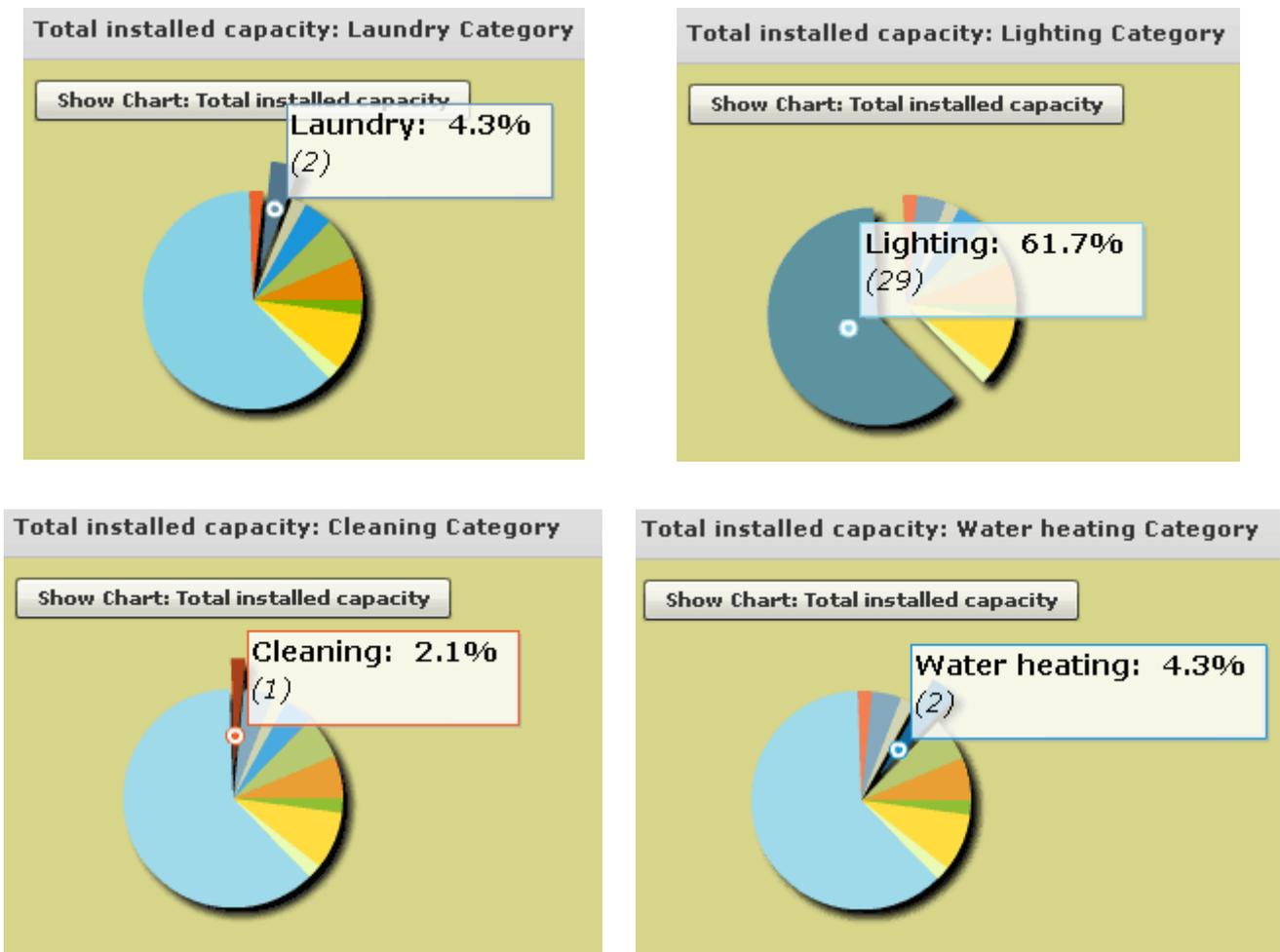


Figure 4-4: Total installed capacity for a number of categories

The breakdown of installed capacity provides insight into the contribution made by various functional categories to the overall household load composition. The next step will be to

enable the user to define and generate a usage profile whereby the user can view for example a usage profile for a typical day as certain appliances are switched on and off at various times during the day.

The conceptualization of Phase 2 of the web application as given in Figure 3-4, involves the following aspects:

- Enable the user to select an appliance and assign a daily usage profile to it by determining the times during the day when the appliance is in use. The user can thereby characterize and create a load profile based on appliance-specific usage.
- Enable the user to view a resultant daily usage profile generated from the accumulated usage profiles of a number of appliances.
- Enable the user to view predicted consumption over a certain period, for example a day, based on a daily usage profile.
- Provide cost analysis by combining the time of appliance operation depicted in the usage profile with a Time Of Use (TOU) tariff structure, whereby price determination is based on peak versus off-peak usage.

Phase 2 is dependent on the finalization of load profiles similar to those as generated by the logging process and documented in section 4.2.3 of this chapter. The case study input in terms of generated load profiles, will be used as the point of departure in the conceptualization depicted in Figure 4-5, where the user can define a usage profile per appliance.

Select an area in your home:

Bathroom 2 Kitchen

Scullery Dining room

Create a usage profile. When, and for how long, is the Kettle used?

 **Kettle**

Switch ON at:

For how long?

ON
 OFF

My Kettle profile

Switched ON at:

Value (Watt)

Profile name

Figure 4-5: Conceptualization of user-defined appliance profile

4.2.1.2 Audit results for logged appliances

An appliance audit per venue was conducted for the main residence to include only those appliances that were logged by means of data logging equipment. Table 4-4 includes the list of logged appliances and equipment resulting from the audit.

Table 4-4: Audit of logged appliances per venue

Venue/Area	Appliance	Count	Venue/Area	Appliance	Count
Kitchen	Kettle	1	Scullery	Dishwasher	1
	Microwave/Convection oven	1		Washing machine	1
	Refrigerator and freezer	1		Tumble drier	1
	Oven	1		Lights	1
	Lights	9 (6 in working order)	TV room	TV	1
Swimming pool	Pump	1		Lights	1
Main residence	Geyser	1	Study	Stand heater	1

Detail of the nameplate ratings of the appliances are provided in section 4.2.2.2.

4.2.2 Electrical power supply and appliance event logging

As shown in Figure 4-6, this section provides detail on the data recorded in terms of the power supplied to the residence and the usage data of individual household equipment and appliances which were logged as ON/OFF events by means of data loggers.

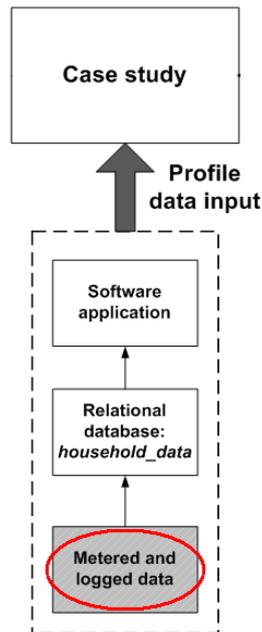


Figure 4-6: Process of collecting power consumption metered data and appliance-logged data

Recording log data over a specific time period is the first step towards implementing temporal modelling of usage and consumption. Temporal modelling depicts usage or consumption over time and resembles a load composition audit. Both the PowerSight data and the ON/OFF logged event data were exported in .csv format and imported into a MySQL database, *household_data*.

4.2.2.1 Supply measurements using PowerSight

A PowerSight instrument along with PowerSight Manager software were used for recording and analysing the total electric power supplied to the residence. The PS 2500 unit was used for data collection.



Figure 4-7: Connection of the PS 2500 PowerSight unit in the residence

To measure true power in a single-phase circuit, the V_a must be attached to the live or hot circuit and V_n to the neutral circuit [103]. A current transformer must then be clamped around the hot cable as shown in Figure 4-7. The PowerSight unit finds the instantaneous product of the voltage and current and sums these over complete cycles in order to report true rms power.

In AC power circuits, the following three types of power measurements are typically made:

- The true power, measured in W, of the circuit is the actual power consumed.
- The apparent power, measured in voltamperes (VA), is the product of the rms voltage and the rms current.
- The reactive power, measured in var, is the power which is temporarily used but returned during a cycle.

Communication with the PS 2500 unit can be established via a Bluetooth connection. A USB (universal serial bus) Bluetooth device (USB-to-Bluetooth) was installed on the laptop used to connect to the unit.

The time frame over which readings are calculated is called the logging period. One record of

measurements is created and stored in PowerSight at the end of each logging period. In agreement with a suitably short sampling method described by Willis, the logging period was set for 5 minutes [16]. The data log resides in the PowerSight unit and PowerSight Manager is required to retrieve this information and store it into the computer. Each record of the data log contains the time and date, maximum, minimum, and the average of for example true power as indicated in Figure 4-8.

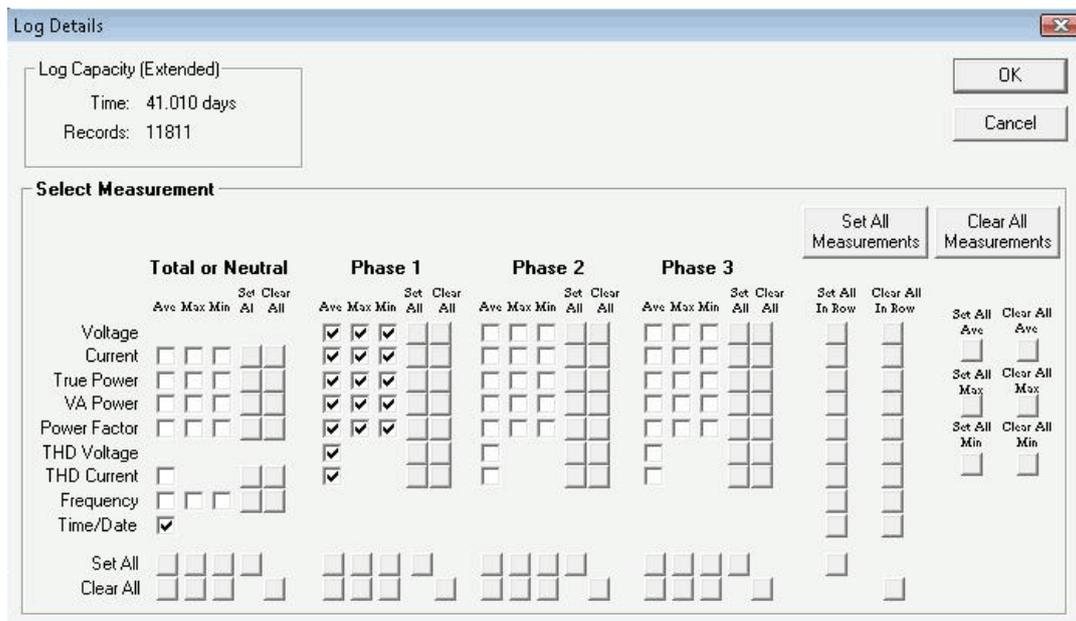


Figure 4-8: PowerSight selection options for single-phase

Analyzing a data log using PowerSight Manager allows for a graphical analysis of the data. A previously saved data log can be viewed. Upon selecting a data log to view, a "Primary Choice" must be made to select the measurement type. All measurement views provide a temporal display and the primary choices are listed in Table 4-5.

Table 4-5: PowerSight Manager primary measurement choices

Voltage	Current	A Voltage/Current pair
VA Power	True Power	Power Factor
Energy	Harmonic Distortion	Frequency

Following the "Primary Choice", a "Secondary Choice" must then be made. For the case

study, the selection of true power for a single phase was applicable. When a "Total" value has meaning, it will automatically be displayed, for instance, true power in each phase and the total power over time.

It is also possible to generate a PowerSight Manager report for inclusion into a Microsoft Word document as shown in Figure 4-9:

PowerSight Manager Report

Friday, June 01, 2012

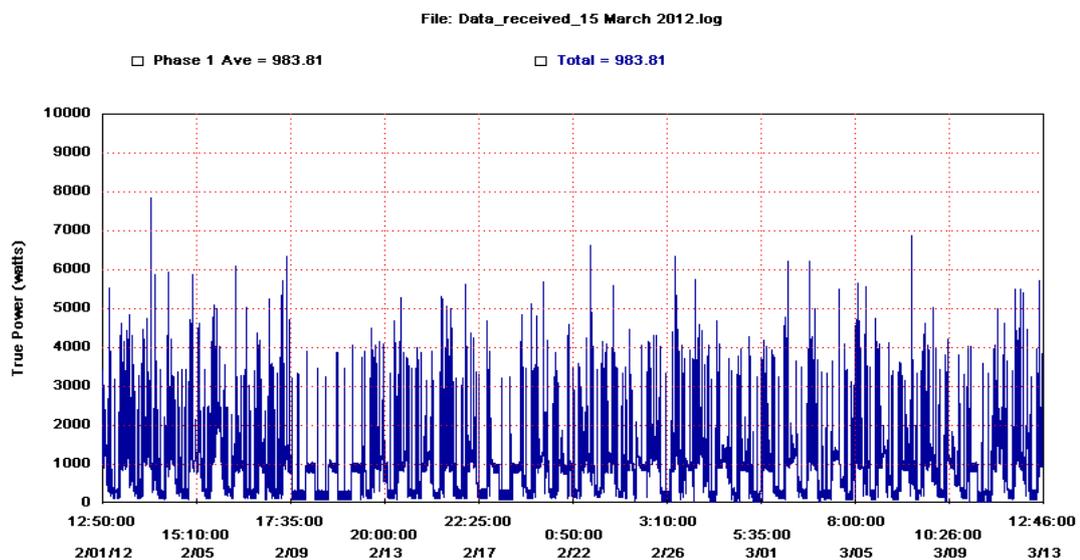


Figure 4-9: PowerSight Manager report

4.2.2.2 Appliance logging

Data collection can be effectively performed using data loggers aligned with the requirements of a particular load survey. Some of the main features of data loggers implemented by Herman and Gaunt [41] included the following:

- Averaging of samples over a predetermined interval and subsequent sample storage.
- Short sampling interval of 5 minutes.
- All collected data is uniquely identified by means of a timestamp and logger label. In addition, the data log format enables export into spreadsheet software such as Microsoft Excel.

As part of this case study, data loggers were used to log ON/OFF usage events for a number of household appliances and equipment. HOBOWare software was used to set up the data loggers for deployment and to read out the data. Communication is established via a USB interface cable to a computer's USB port. A logger needs to be launched by firstly verifying that the clock on the computer housing the software which will launch the device, is correctly set. The software makes provision for a description in order to uniquely identify each logger. The sampling interval can be set and the device can be launched by means of a "Button Start" by pressing a reset button for approximately 5 seconds. Once launched and logging, the logger's operational status can be verified.

In order to retrieve data recorded by a logger, the logging device must be connected to the computer running the HOBOWare software. The data can then be read out from the logger to the computer, allowing the user to view the plotted data within the HOBOWare interface or save the data in a file. A graph can also be copied in bitmap format for pasting into other programs and documents such as a Word document. The data file can be exported in .csv format and imported into Microsoft Excel.

As indicated in 4.2.1.2, a load survey was conducted of household appliances and equipment and certain appliances were elected to be logged. Appliances such as the kettle, microwave, refrigerator/freezer, washing machine, tumble dryer, dishwasher, TV and stand heater were logged via plug-in loggers. In order to log equipment without an electric plug outlet, some logging devices were connected directly via the circuits in the distribution board, for example the oven, the main geyser and some lights, as shown in Figure 4-10. Due to space constraints in connecting some loggers in this manner, not all lights were logged.



Figure 4-10: Data loggers for equipment with direct connections to the household circuit

The stove stop operates with gas and an additional geyser was not measured since it is very rarely switched on, i.e. only on occasion when guests are accommodated in a separate apartment. This geyser is also not wired through the main distribution board, but is separately connected via a switch. The swimming pool pump was directly logged via a small distribution board situated adjacent to the swimming pool. Depicted in Table 4-6 is a list of the household appliances and equipment which were logged along with their nameplate or measured ratings in watt.

Table 4-6: List of logged household appliances/equipment and power ratings

	Household appliance/ Load description	Power rating (W)	Brand and/or model	Additional information
1	Washing machine	1 900 W	Mercury	Maximum capacity 5 kg
2	Tumble drier	2 500 - 2 700 W	Bosch Er-NrWTA 2000 ZA/02	15 A
3	Dishwasher	2 300 W	LG	
4	Kettle	2 520 - 3 000 W	Russell Hobbs Model: 3067-10	Maximum capacity 1.7 litres
6	Microwave / Convection oven	Maximum* 1 550 W	LG SolarDOM	
7	Oven element	Measured and calculated: 2000 W		
8	Refrigerator and freezer	220 W	Siemens KA 58 NA 70	Side by side No frost Fridge/Freezer

9	Geyser element	Measured and calculated: 3000 W		
10	Stand ,heater	2 200 W	Bauer 14 Fin oil heater	
11	TV	128 W	Samsung Plasma Display Panel	
12	Swimming pool pump	Measured and calculated: 533.6 W	ESPA	
13	Lights: 2 fluorescent tubes (scullery)	36 W / tube	Philips Lifemax TLD 36W/33-640 G9 Cool White 79 lm/W	Lamp voltage = 103 V, Lamp current = 0.44 A ¹
	Lights: 9 halogen downlights of which 6 in working order (kitchen)	Label: 50 W 6 x 50 W = 300 W **Measured and calculated: 253 W	Measured and calculated: 40 W per light	12 V

¹Depends on function selected, for example Defrost/Convection/Grill/Microwave.

** Also measured and calculated as per Table 4-7.

As indicated in Table 4-6, the average power output of some household equipment was calculated through measurement, namely:

- The main geysers element.
- The oven element.
- The swimming pool pump.
- One light circuit that supplies lights in the kitchen and scullery area.

A clamp meter was used to measure I_{rms} for each of the listed equipment during operation and with V_{rms} taken as 230V (based on PowerSight measurements). The geysers element, oven element and halogen downlights are assumed to be purely resistive loads and the average power absorbed by each of these loads was calculated using $P_{ave} = V_{rms}I_{rms}$ as indicated in Table 4-7. The average power absorbed by the swimming pool pump is calculated as the product of the rms load voltage, V_{rms} , the rms load current, I_{rms} , and a power factor of 0.8.

¹ Based on data sheet information [Online] Available:
http://download.p4c.philips.com/14bt/3/323102/tl-d_standard_colours_323102_ffs_aen.pdf

Table 4-7: Measured I_{rms} values for selected equipment and calculated P_{ave} values

Load description	Measured value of I_{rms} (A)	Calculated value of P_{ave} (W)
Main geyser element	13 A	2990 \approx 3 000 W
Oven element	9 A	2070 \approx 2 000 W
Swimming pool pump	2.9 A	2.9 A \times 230 V \times 0.8 = 533.6 W
Light circuit: 6 halogen downlights in kitchen	1.1 A \div 6 = 0.18 A	41.4 \approx 40 W per light

Fluorescent lamps are known for their contribution of harmonics [16]. In order to correctly calculate the average power, the fundamental current component (assuming a sinusoidal load voltage) and the phase shift of the fundamental current component in respect to the voltage, should be measured. However, using a true rms power meter the true power can be measured and as indicated in Table 4-5, the PowerSight instrument can measure harmonic distortion.

For reference purposes and to augment this list of household appliances with said power ratings, a list of common household appliances per category, along with the average wattage or power rating per appliance, are included in Table 4-8 [46]. The categories given in Table 3-4 are quite similar to those assigned to the *functionalclasses* in the database structure.

Table 4-8: Power rating of electric household appliances (adapted from [46])

Appliance	Average wattage (W)	Appliance	Average wattage (W)
Food preparation		Laundry	
Coffeemaker	1 200	Clothes dryer	4 850
Dishwasher	1 200	Washing machine (automatic)	510
Electric frying pan	515	Water heater	2475
Mixer	1 200	Comfort conditioning	
Microwave oven	1 450	Air conditioning (room)	860
Oven	12 200	Fan (circulating)	88
Toaster	1 150	Heater (portable)	1320
Health and beauty		Home entertainment	
Hair dryer	600	Radio	70

Shaver	15	TV	145 - 240
Houseware			
Vacuum cleaner	630		

4.2.2.3 Appliance duty cycles

Unlike appliances such as lights, toasters and kettles, a number of appliances' operation exhibit cyclic on and off patterns over time. These cycles are referred to as duty cycles and are features of appliances that typically have some kind of temperature control system or some other embedded controller. Appliances that have duty cycles are for example hot water geysers, air conditioning units, heaters, refrigerators and freezers as well as dishwashers and washing machines. Most of these appliances have, as part of their control system, a thermostat to control temperature. For example, in the case of an air conditioning unit, during the hottest part of the day the unit will remain on for longer and off for shorter periods in order to achieve and maintain a required set ambient temperature [16].

As depicted in Figure 4-11, it is important to differentiate between an appliance duty cycle, which is intrinsically part of some appliances, and a usage cycle initiated by a user. For example, when a user switches an appliance such as a washing machine, on at 06:15 on a weekday morning in summer, the user has initiated a usage cycle. If that is the usual time that the user uses the appliance on a weekday in summer, a usage pattern or profile can be identified for the particular appliance. On the other hand, once the washing machine is switched on and depending on its setting, the appliance itself runs through an appliance-specific pattern of on and off cycles of variable duration. These duty cycles will vary based on the washing machine's washing, rinsing or spinning cycles.

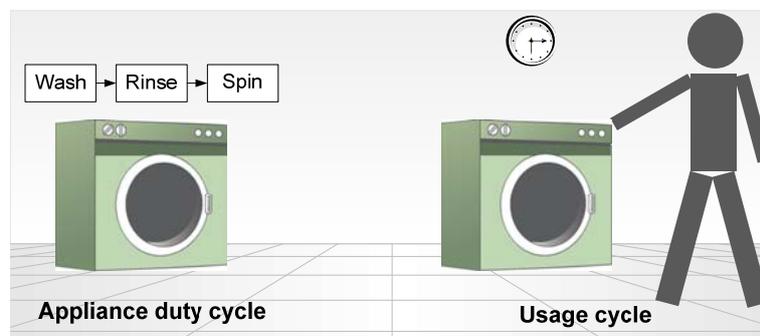


Figure 4-11: Appliance duty cycle versus usage cycle

Analysis of a load profile of an appliance such as a washing machine, whose operation is controlled by means of controller, requires awareness and knowledge of appliance settings and approximate duration, in order to distinguish between usage cycles initiated by the user and the intrinsic duty cycle.

4.2.3 Processed data results

It was necessary to create the means to firstly store the PowerSight and event logged data and secondly, to process and display the results. A MySQL database, *household_data*, was designed to store the logged data results. A software application was developed to process and display the results. This section briefly describes respectively the development of the database and the supporting software application, as indicated by Figure 4-12.

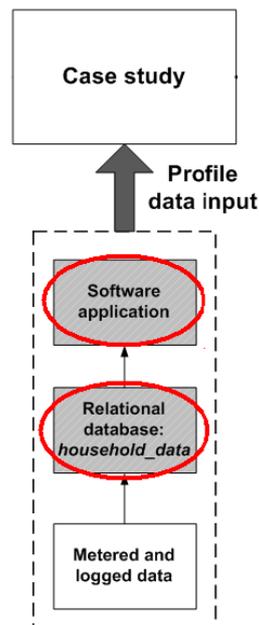


Figure 4-12: Design and development of the *household_data* database and supporting software application

The data in .csv format files were imported by means of SQL queries into the database. The MySQL Workbench design tool-set was used to provide an EER model of the database shown here in Figure 4-13.

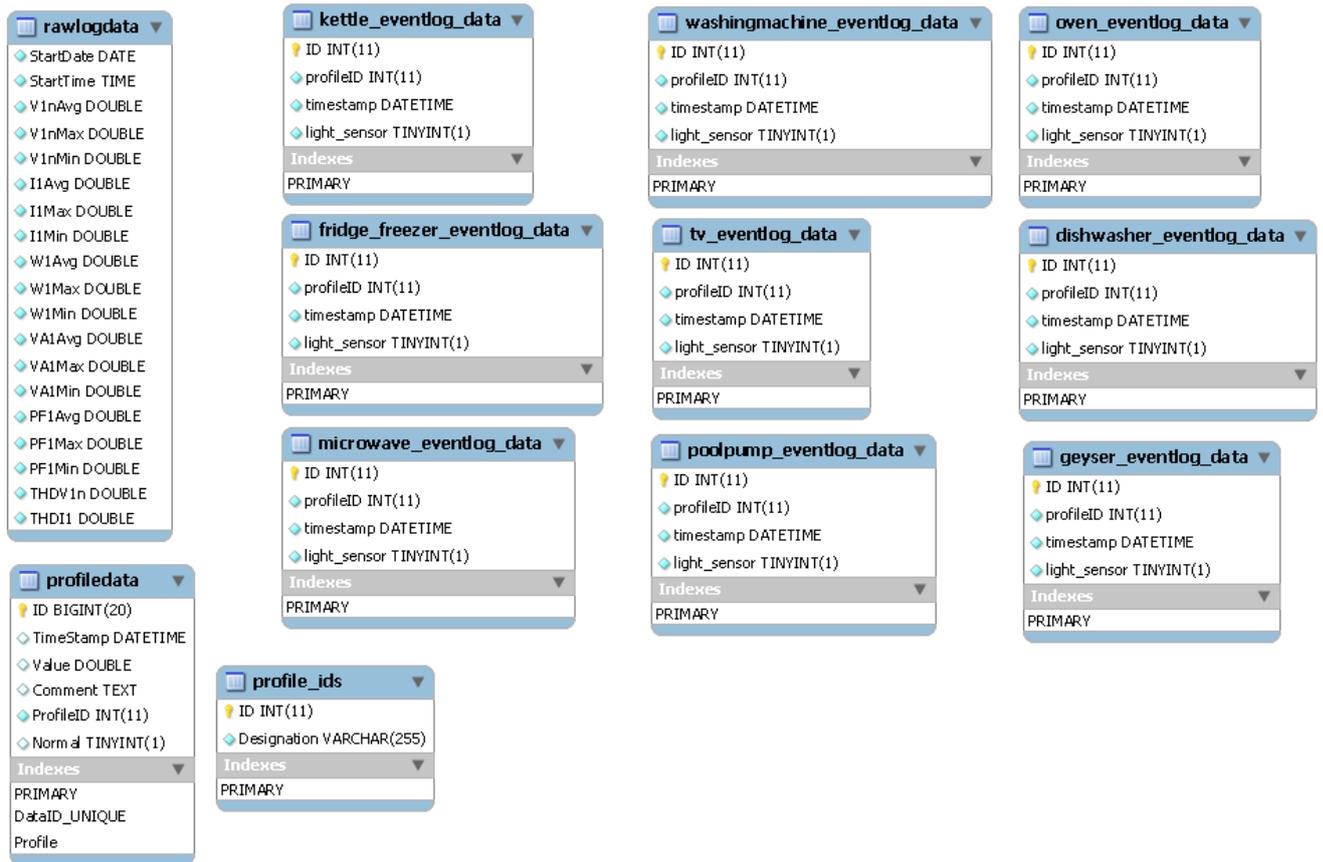


Figure 4-13: MySQL Workbench EER model of the household_data database

The table *rawlogdata* was created for storage of the PowerSight metered results. From there, the relevant data such as true (average) power was extracted by means of an SQL query into another table *profiledata* for use in data visualization charts. The flow diagram in Figure 4-14 describes the sequence of steps performed in collecting, storing and processing the case study data.

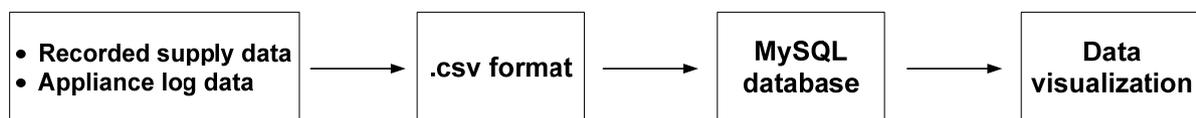


Figure 4-14: Data storage and processing flow diagram

In order to establish a software application to process the results, a web interface was developed by means of the Flex framework and AnyStock charts, integrated with the MySQL

database. The reasons for once again using the combination of Flex, MySQL, PHP and AnyStock are three-fold:

- To be able to re-use components from the main web application such as display layout containers, graphic icons and a navigation framework.
- To generate accurate load profiles in a suitable format and of high visual quality.
- To investigate the most appropriate way to present load profiles as part of establishing the framework for Phase 2 of the main web application.

Having designed and developed a GUI based on some of the same principles as the main web application, a generic PHP script with SQL queries was written to access the PowerSight metered data from the database as well as the selected appliance log data. The PHP script is used as a dynamic data source for the AnyStock chart.

The AnyStock charting solution was used for the following reasons:

- A PHP script can serve as a dynamic data source for the chart.
- The AnyChart Stock component caters for the use of large data sets.
- Easy integration of the dynamic database-driven data into the GUI.
- Offers functionality to window a variety of timeframes, whether short or long, by selecting and adjusting the time of year and/or time of day window.

Data visualization was implemented using an AnyStock chart. The graphs are shown in Figure 4-15 to Figure 4-17. However, since not all the appliances in the residence were logged, it can only be verified that the indicated appliances made a contribution to the overall power consumption. The more appliances that are selected and included in the chart area, the more difficult it becomes to view a large window due to overlapping caused by the simultaneous operation of appliances. Figure 4-15 illustrates data visualization using AnyStock of the ON/OFF events for a number of appliances, but the window focuses on the geyser and fridge/freezer. Figure 4-16 shows the duty cycle of a single appliance (the geyser) as intermittent shorter and longer ON times against the overall metered true power. A timer switch controls the operation of the swimming pool pump, as is evident from Figure 4-17.

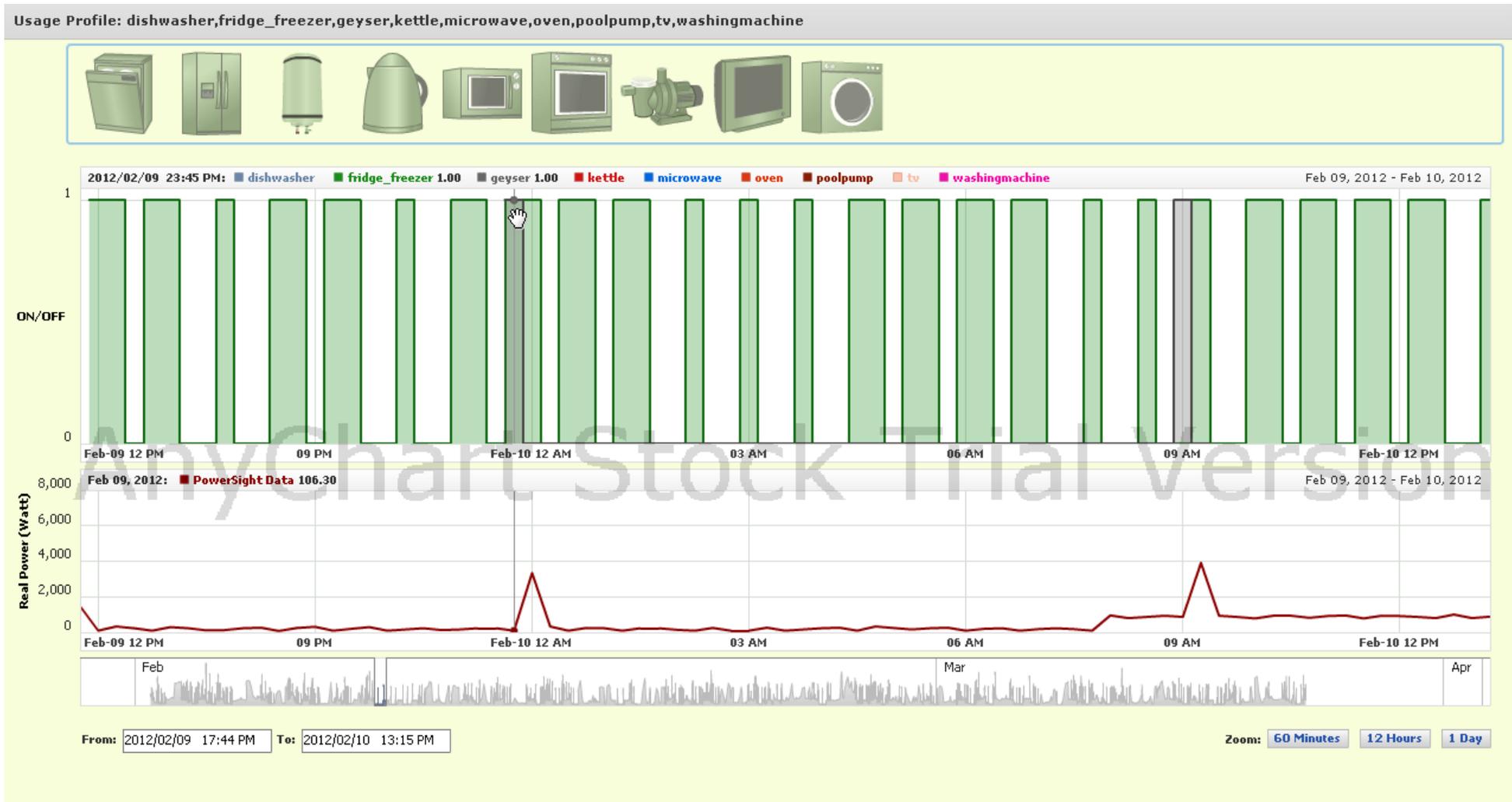


Figure 4-15: Data visualization of PowerSight metered data together with logged event data using AnyStock chart

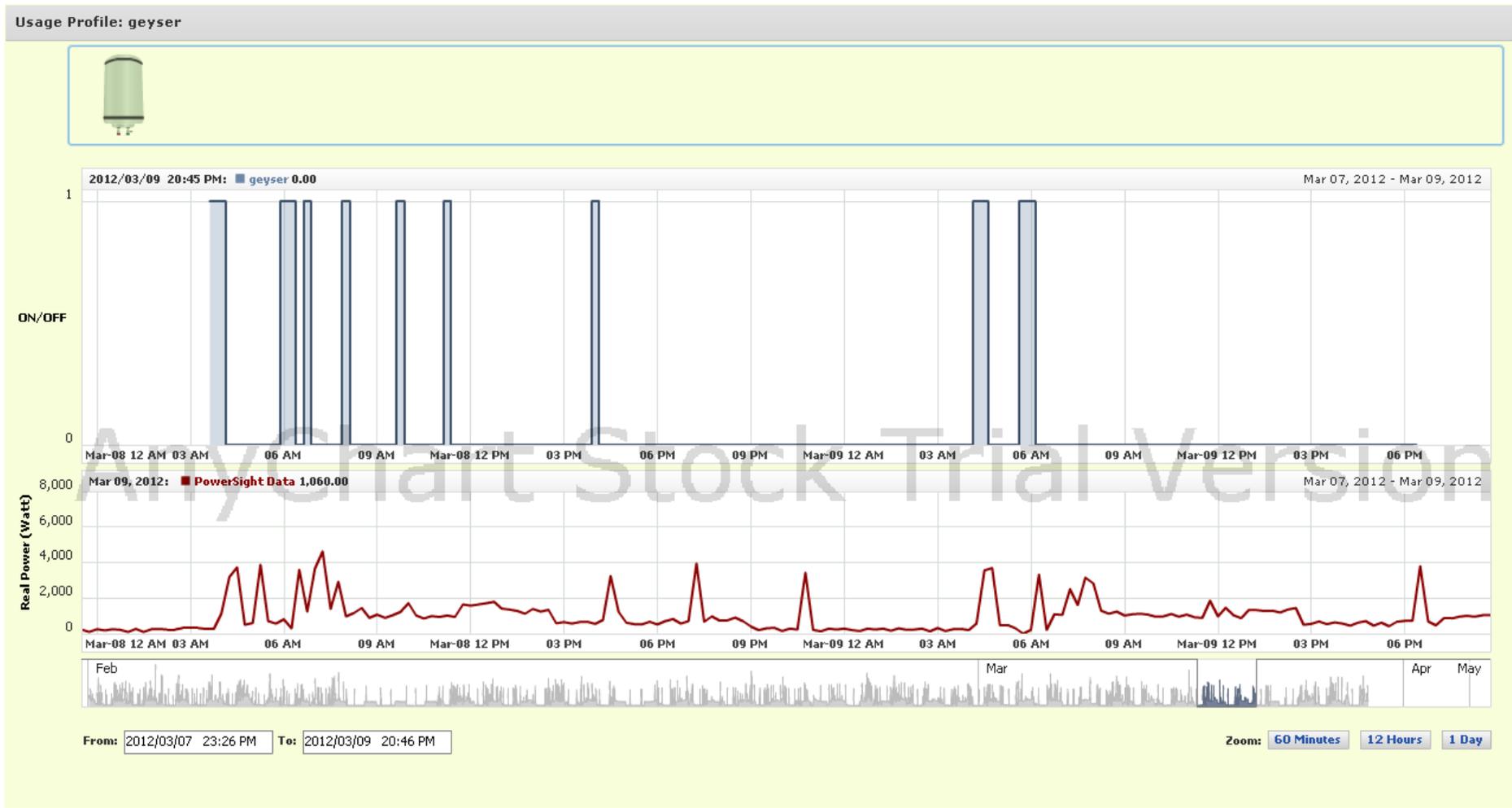


Figure 4-16: AnyStock data visualization of true power plus geyser logged event data

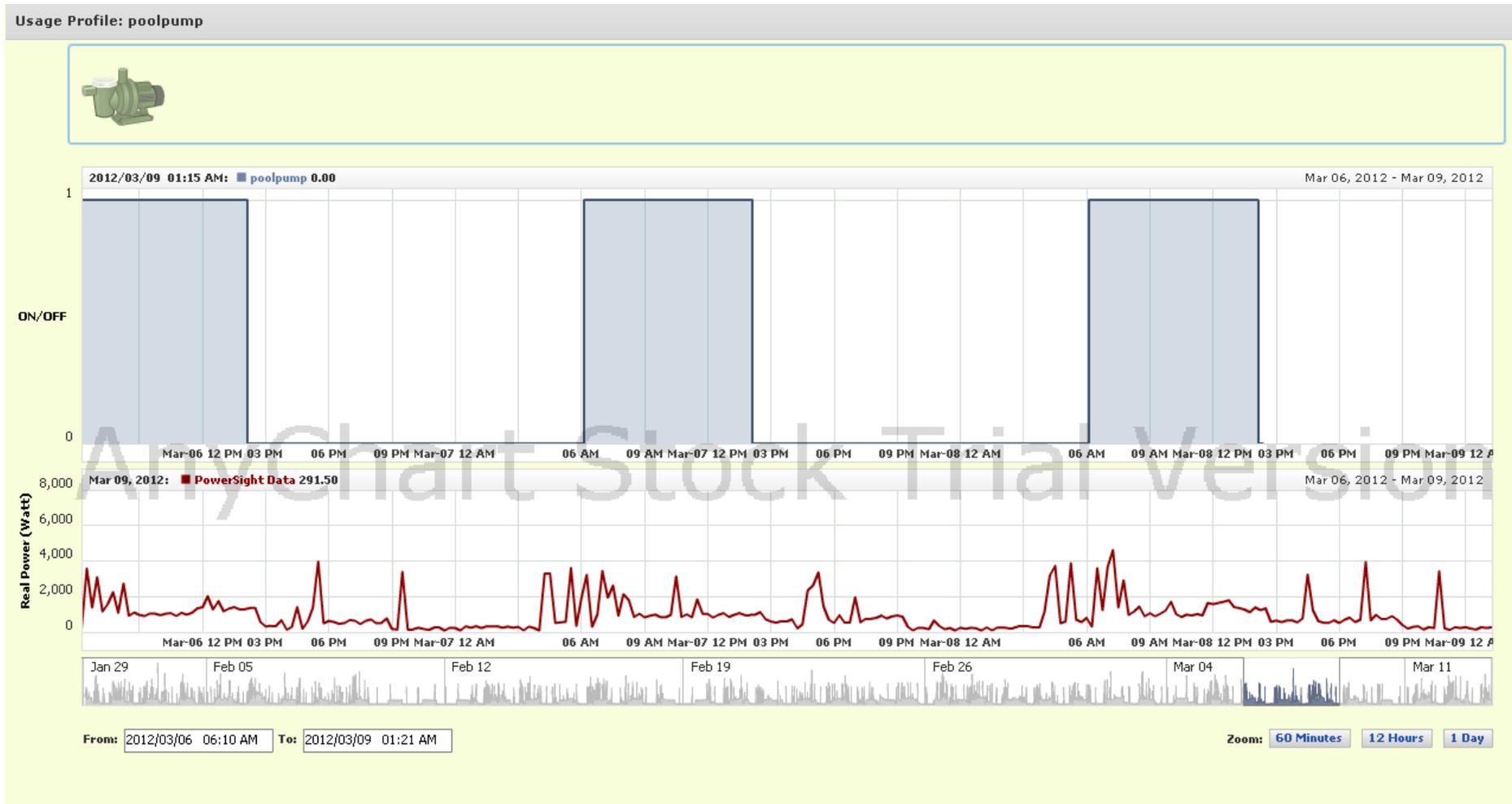


Figure 4-17: AnyStock data visualization of true power plus poolpump logged event data

4.2.4 Data cycle

The data cycle shown in Figure 4-18 illustrates how per load logged data can be used in a manner that is of statistical interest.

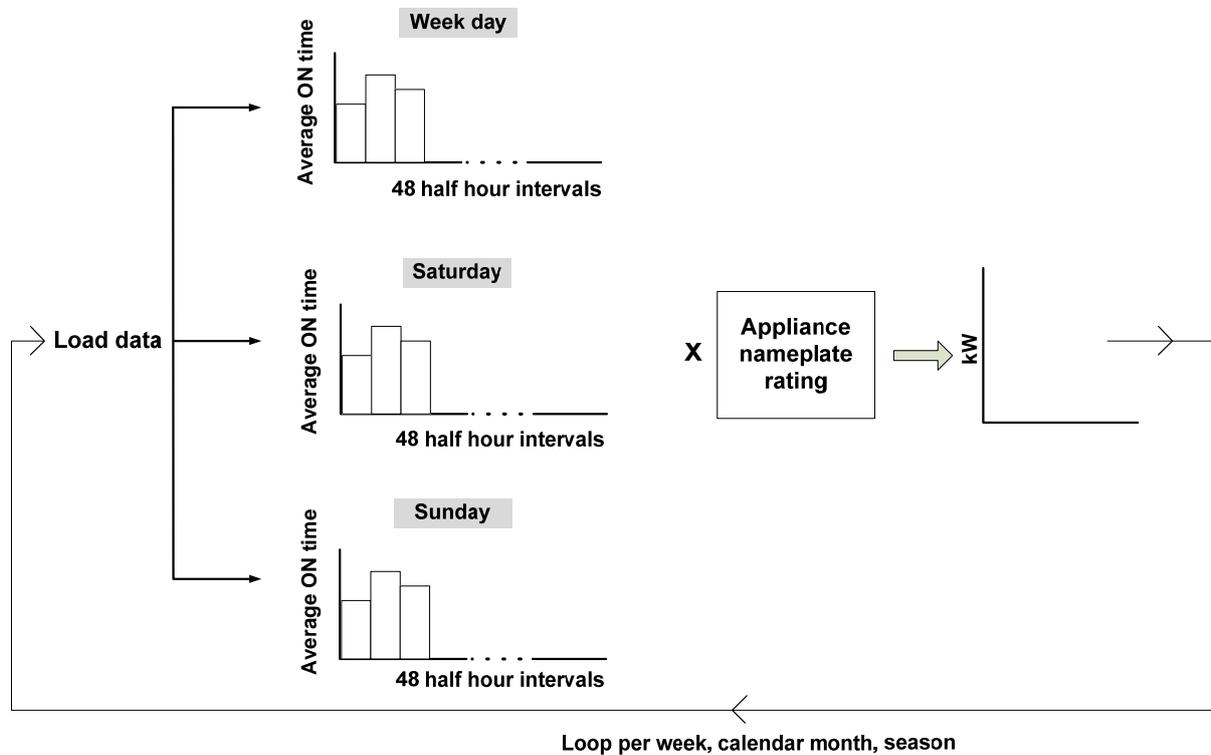


Figure 4-18: Per load logged data cycle

Household appliance usage exhibits a week day usage pattern that generally differs from a weekend day usage pattern. By differentiating between respectively a week day, a Saturday and a Sunday, the logged data for a number of different loads can be processed for a particular day, consisting of 48 half hour intervals, to determine the fraction or percentage of time that each load is in use. To generate consumption data per load in kW format, the appliance name plate rating can be used to multiply with the fraction or percentage of time that the appliance is in use during a particular day. This process can be repeated for each load over an extended period for example a week, calendar month or season.

To date, the first stage has been completed in that logged events have been stored for a

number of household appliances.

4.3 Case study results

In terms of the case study objectives, the following results were achieved through the methodology that was followed:

- Successful investigation of the residential energy consumption context.
- Recording of both supply measurements and the collection of specific usage data for a number of household appliances.
- Establishment of an overall methodology to log appliance usage in a typical middle income residence.
- A data processing methodology to process recorded data in a meaningful way.
- A strategy to correlate supply measurements with logged appliance usage data by producing a visual display to incorporate both sets of data.
- "At-a-glance" visual presentation of the outcomes of processed logged data in the form of generated load profiles for a number of appliances.
- Preliminary analysis of the correlation between true power and usage of, either individual, or a combination of, appliances by selecting and focussing on a windowed timeframe.
- Generating load profiles for a number of appliances by means of the processed logged data.

A few problems were experienced during the logging process. Firstly the available version of the HOBOWare software (version 2.2.0) was not compatible with either operating system on two different laptops which the author had access to, respectively Windows Vista and Windows 7 Ultimate. In order to circumvent this problem a virtual licensed version of Windows XP was installed as a guest operating system on the Windows 7 laptop by means of Oracle's VirtualBox. The virtual XP operating system could not be installed on the Vista laptop since it was already used for the virtual Ubuntu server.

Another problem which was encountered was that of synchronization. As indicated in section

4.2.3, one of the objectives was to establish some correlation between the total power supply as per the recorded PowerSight data, and the separately logged events of loads which contribute to the overall consumption. The PowerSight software and Bluetooth USB device were installed on the Windows Vista laptop. The clocks of the two operating systems, the Vista laptop and the virtual XP laptop, were initially not the same and it was an oversight on the part of the researcher to not verify that. Subsequently, a non-ideal solution was to adjust the timestamps of the PowerSight metered data accordingly.

The degree to which the logging process was experienced as intrusive/invasive should be considered within the context of a particular household. Since the logged data formed a necessary component of the research case study, the loggers were not deemed intrusive.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Overview

Energy security has become a focus area in the energy debate, both globally and locally. Energy Efficiency (EE) has been identified as the simplest option to make a positive contribution to energy security, offering benefits to both energy suppliers and consumers alike. The project work is motivated on the premise that in the case of South African residential end-users, not only do many already experience fuel poverty, but the expected future price increase of electricity will place most household budgets under pressure. In further support of the promotion of EE is the need for South Africans, as part of the global population, to participate in efforts to mitigate negative climatic impacts and respond to the need to improve sustainability. Active participation by consumers to improve EE requires some form of intervention to educate and raise awareness.

The literature review included an overview of energy efficiency in more general terms and subsequently shed light on the South African context. Drawing on demographic data, the review provided insight into some of the challenges and complexities in addressing the residential electric energy load and introducing EE intervention measures. The challenge to accurately forecast demand stems from the fact that in estimating end-use energy consumption, the forecaster must take cognisance of the fact that consumer behaviour is intrinsically non-deterministic and sporadic and therefore end-use is stochastic. However, despite the application of smart metering to improve load curve modelling, probabilistic modelling remains an indispensable tool for distribution network planning and operation [104].

The literature review also highlighted a number of technology options which were considered for the development of an interactive, dynamic web application. The review provided an in-depth look at the best approach to develop an effective end-user design. These aspects served as the point of departure in implementing both the user interface and the relational database to drive the dynamic web content.

A case study was conducted of a middle-income residential household to augment data input in the form of load profiles. The household also served as a test case for the web application in terms of a user-defined project.

As set out in Figure 5-1, this chapter concludes with a summary of the outcomes for the project in terms of the overall results, conclusions and recommendations for further work.

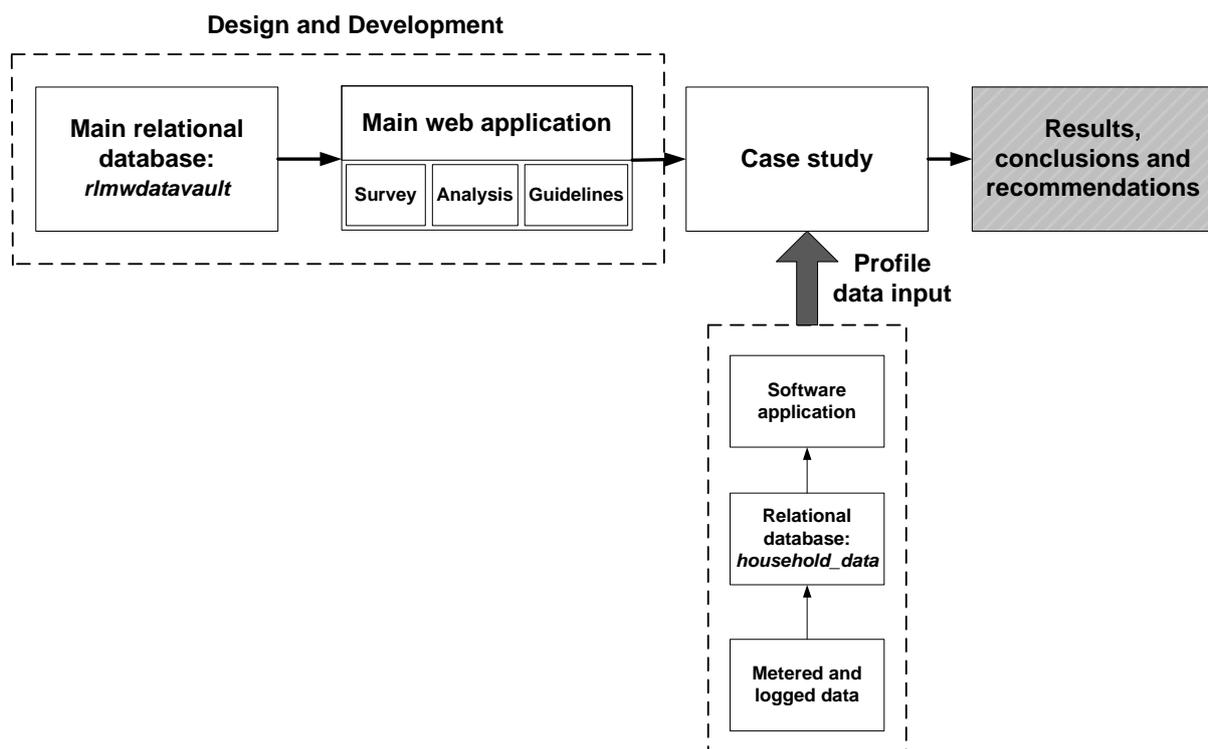


Figure 5-1: Outcomes of the research project: results, conclusions and recommendations

5.2 Results and conclusions

In view of the original research objectives provided in section 1.4, the research work documented in this thesis has covered the following aspects:

- A project overview and motivation for the research objectives of the study.
- A comprehensive literature review which included:
 - End-use energy efficiency as it applies to residential end-users with special focus on South African residents.

- Reference to the residential electric energy load and household energy profiles.
- Interactive web technology options for end-users and dynamic client-server data exchange technology.
- The development of the relational database which provides the dynamic-driven content for the web application.
- The development of the software framework and key aspects of the web application such as the GUI and data visualization.
- The conducting of a case study.

As one of the main research objectives, the web application has been developed as a tool to both educate and empower residential end-users to promote and improve EE. The project work has been of an investigative nature in terms of investigating which technology options to pursue in order to provide fairly complex functionality in the simplest, most intuitive fashion. It was decided to evaluate Flex/Flash technology to develop an RIA as the means to present the application and achieve the desired dynamic interactivity.

Based on functionality, the development of the application was divided into two phases of which Phase 1 has been completed as well as the conceptualization of Phase 2 and the first steps towards its implementation. Phase 2 of the web application involves the functionality described in section 3.2.1 and has been dependent on results from a feasibility investigation of how to best generate and include user-defined load profiles. The feasibility investigation was performed during the processing of case study data. The profiles are necessary to enable a user to make informed decisions about consumption and improve energy efficiency. Upon completion of the beta version of the application, it should be released for review by a selected focus group.

The following evaluation highlights the outcomes achieved and identifies selected areas for recommended further work:

- *The survey section:* The user can conduct a load survey or appliance audit of his/her house by creating both area and loads inventories.

- *The analysis section:*
 - The functionality associated with the analysis section that involves a breakdown of installed capacity based on the user's loads inventory is complete. The breakdown can be shown per area or for the entire residence.
 - The analysis component to generate load usage profiles in order for the user to predict consumption and associated costs has been conceptualized by means of the case study.
 - Based on the processing of appliance usage data from the case study, the platform has been designed and suitable data visualization has been investigated and tested to visually present a load profile based on appliance-specific usage.
 - Once fully implemented, this portion of the analysis section will enable the user to view a resultant daily usage profile generated from the accumulated usage profiles of a number of appliances.
- *The guideline section:* Associated with each generic appliance, for example a kettle, is a list of guidelines for efficient use. The guidelines have been presented in a categorized structure and by exposure to the guidelines, a user can be educated on practices to improve energy efficiency.

The case study has provided insight into the power consumption and appliance usage of a residential middle-income household. The main goal of the case study was not to merely collect data for a specific household with a set of specific appliances, but to investigate and establish an appropriate methodology to generate appliance load profiles through measurement. The case study aimed to collect so-called grassroots level data in the form of appliance-specific load profiles. In this regard, the case study was conducted in support of the main research work to develop an application for residential end-users as a means to improve energy efficiency. By producing accurate load profiles, the case study has established a methodology to provide and augment necessary data input. The completion of the main web application was dependent on this data input since appliance profiling is required for a user to analyse and predict consumption. The creation of the profiles also enabled the investigation of how best to include and present the profile data in a web application.

Nonetheless, the logging process was not without impediments. Only preliminary steps have been taken to statistically interpret and process the metered and logged results in a meaningful manner. The following section provides a number of recommendations with regards to statistical modelling which can still be undertaken.

5.3 Recommendations

The recommendations that are provided relate to the following areas:

- The relational database as source of dynamic content for the main web application.
- The main web application.
- Improvement of the process of recording supply measurements and log data, which formed part of the case study;
- The matter of statistical residential load modelling.

5.3.1 Database

As evaluated in section 3.3.4, the listed shortcomings should be addressed. The obvious limitations concerning the database are mostly related to the content, with specific suggestions provided in 3.3.4. Currently the list of tables dedicated to common household appliances are not comprehensive, for example, there are no tables for vacuum cleaners, clothing irons, hair driers, DVD players or TV game consoles. Ongoing research is required to ensure the existence of an up-to-date database.

5.3.2 Web application

The load profile data input from the case study must be utilised to complete the functionality associated with Phase 2, as listed in section 3.2.1 and notably:

- To enable the user to view predicted consumption over a certain period, for example one day, based on a daily usage profile.
- Provide cost analysis by combining the time of operation depicted in the usage profile with a Time Of Use (TOU) tariff structure, whereby the user can implement appliance scheduling.

The incorporation of appliance duty cycles into the relevant usage profiles will introduce a level of increased complexity and the challenge of presenting the information in an uncomplicated way will require careful planning.

In view of the main objective of the application of improving energy efficiency through promotion of energy efficient habits and changed behaviour, this key outcome can only be evaluated once the web application is complete. A beta release version can then be rolled out to a focus group to receive appropriate feedback. The end-user's ability to make informed decisions to improve energy efficiency would be based on aspects such as the following:

- Implementation of usage guidelines to reduce consumption and cost.
- A better understanding of the cost benefits of appliance scheduling in terms of a Time Of Use (TOU) tariff structure.
- Replacing energy *inefficient* appliances with more efficient models.

In order to provide a comprehensive list of appliances from which a user can create a loads inventory, additional icons will be required to augment the current list in accordance with the addition of further database tables for appliances. These icons should be specified and designed, preferably by the same graphic artists, in order to produce the same appearance and quality and thereby guarantee continuity.

In terms of a few general remarks, it is envisioned that this type of application could add educational value in a learning environment such as an Expo, where the drive is often towards exposing learners and young adults to sustainable practices such as energy efficiency and scientific progress. The possibility also exists to incorporate an incentivised list of vendors per geographic location in South Africa who stock, for example, various EnergyStar-rated appliances [105]. Finally, it would seem worthwhile to investigate the possibility of migrating the application in the form of a mobile app to the mobile platform in addition to the web platform. Alternatively, or additionally, it would be worth exploring the possibility to incorporate the application with technology employed in smart metering so that it can interface with smart systems that are being developed.

5.3.3 Collecting metered data

Depending on the data collection procedure, it is advisable to have one dedicated laptop, Bluetooth enabled, on which to install the necessary metering software, being PowerSight Manager and HOBOWare. As a fairly obvious, but nonetheless preliminary step, it is important to verify the versions of the software and hardware requirements to avoid compatibility issues. By ensuring the correct clock setting on the designated laptop, preferably automatic update via the Internet, it is possible to synchronize the metered data to the logged events. Only synchronized data is of any value to verify a correlation between true power and appliance usage.

5.3.4 Statistical residential load modelling

In order to create statistically meaningful data results, it would be necessary to complete a data cycle as shown in Figure 4-18. Additionally, it will be useful to present and analyse the metered and logged data in terms of statistical measures to view, for instance, the variance between the different loads. Only preliminary research on the Beta pdf has been conducted at the time of submission of this thesis. Further work can be explored and developed around the statistical representation of the logged data in terms of a Beta pdf.

In conclusion, it could be useful to investigate the possibility of applying an econometric modelling approach to direct metering information, as alluded to in [106]. The cited paper is titled, "*Estimating End-Use Demand: A Bayesian Approach*" [107]. From a statistical viewpoint, Bayes' theorem defines conditional probability as it applies to two events, where the probability of an event A, depends on a second event B [39], leading to the concept of conditional demand. Although Econometrics is a field of study that applies mathematics and statistical methods to economic data, research demonstrates that it is possible to model annual household energy demand by means of an econometric strategy [106].

The AnyStock component, which was the charting solution of choice for the main web application and the case study GUI, includes a set of 30 technical and mathematical indicators as financial forecasting is done by means of these indicators. In terms of data

visualization, no substantial investigation has yet been conducted as to whether any of these might be useful in energy demand analysis.

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APPENDIX A

A.1 Statistical results from Stats SA

A.1.1 Results from National Community Survey 2007 and Census 2011 General Household Survey

Table A-1: Summary of totals: Census 2011 General Household Survey results percentage children per household, aged 17 years and younger [29]

Household size	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Total	4.50%	8.80%	12.6%	16.5%	14.5%	11.7%	8.70%	6.60%	4.50%	5.40%	1.90%	1.30%	0.70%	0.80%	0.20%	0.30%	0.20%	0.20%
Household size	19	20	21	22	23	24	25	26	TOTAL									
Total	0.10%	0.00%	0.10%	0.10%	0.00%	-	-	0.10%	100%									

Table A-2: National Community Survey 2007 and Census 2011 General Household Survey results for household type [22], [29]

Percentage distribution of households by type of main dwelling

	Census 2001	CS 2007
House or brick structure on a separate stand or yard	55,7	59,3
Traditional dwelling/hut/structure made of traditional materials	14,8	11,7
Flat in block of flats	5,3	4,8
Town/cluster/semi-detached house (simplex: duplex: triplex)	2,9	2,7
House/flat/room in back yard	3,7	2,9
Informal dwelling/shack		
in backyard	4,1	4,7
NOT in back yard e.g. in an informal/squatter settlement	12,3	9,7
Room/flatlet not in back yard but on a shared property	1,1	0,9
Caravan or tent	0,3	0,1
Private ship/boat	-	0,0
Workers' hostel(room)	-	2,9
Other	-	0,3
Total	100,0	100,0

Percentage distribution of main dwelling type: General Household Survey 2011	
Dwelling/house or brick/concrete block structure on a separate stand or yard or on farm.	69.10%
Traditional dwelling/hut/structure made of traditional materials	12.60%
Flat or apartment in a block of flats	2.80%
Cluster house in complex	0.30%
Town house (semi-detached house in complex)	0.70%
Semi-detached house	1.40%
Dwelling/house/flat/room in backyard	1.80%
Informal dwelling/shack in backyard	2.90%
Informal dwelling/shack not in backyard; e.g. in an informal/squatter settlement or on farm	5.10%
Room/flatlet on a property or a larger dwelling servants' quarters/granny flat	1.00%
Caravan/tent	0.00%
Other (specify)	0.10%
Unspecified	2.20%
Total	100.00%

Table A-3: National Community Survey 2007 and Census 2011 General Household Survey results for fuel type used for lighting in households [22], [29]

Percentage distribution of households by type of energy/fuel used for lighting

	Census 2001	CS 2007
Electricity	69,7	80,1
Gas	0,2	0,2
Paraffin	6,8	5,3
Candles	22,7	13,7
Solar	0,2	0,2
Other	0,3	0,5
Total	100,0	100,0

Percentage distribution lighting fuel type: General Household Survey 2011	
Electricity from mains	86.80%
Electricity from generator	0.10%
Gas	0.00%
Paraffin	2.20%
Wood	0.10%
Coal	0.00%
Candles	9.30%
Animal dung	0.00%
Solar energy	0.10%
Other; specify	1.20%
None	0.10%
Total	100.00%

Table A-4: National Community Survey 2007 and Census 2011 General Household Survey results for fuel type used for heating in households [22], [29]

Percentage distribution of households by type of energy/fuel used for heating

	Census 2001	CS 2007
Electricity	49,0	58,7
Gas	1,1	1,0
Paraffin	14,6	13,0
Wood	24,6	20,2
Coal	6,6	3,9
Animal dung	0,7	0,2
Solar	0,2	0,1
Other	3,1	2,8
Total	100,0	100,0

Percentage distribution heating fuel type: General Household Survey 2011

Electricity from mains	40.60%
Electricity from generator	0.00%
Gas	2.00%
Paraffin	10.20%
Wood	22.70%
Coal	2.70%
Candles	0.00%
Animal dung	0.20%
Solar energy	0.00%
Other; specify	0.90%
None	18.60%
Unspecified	2.00%
Total	100.00%

Table A-5: National Community Survey 2007 and Census 2011 General Household Survey results for fuel type used for cooking in households [22], [29]

Percentage distribution of households by type of energy/fuel used for cooking

	Census 2001	CS 2007
Electricity	51,4	66,4
Gas	2,5	2,0
Paraffin	21,4	14,8
Wood	20,5	15,2
Coal	2,8	1,2
Animal dung	1,0	0,2
Solar	0,2	0,0
Other	0,2	0,1
Total	100,0	100,0

Percentage distribution cooking fuel type: General Household Survey 2011

Electricity from mains	70.90%
Electricity from generator	0.00%
Gas	2.00%
Paraffin	4.70%
Wood	17.80%
Coal	1.10%
Candles	0.00%
Animal dung	0.30%
Solar energy	0.00%
Other (specify)	1.20%
None	0.10%
Unspecified	1.90%
Total	100.00%

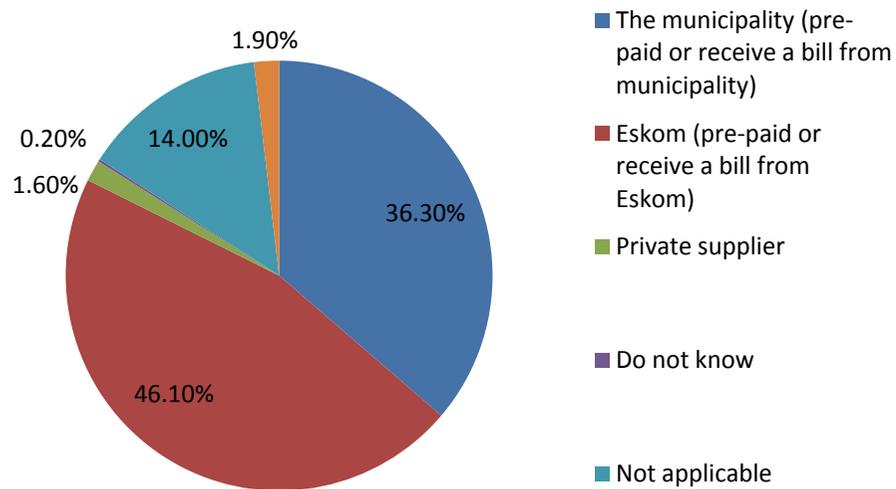


Figure A-1: Census 2011 electricity supply results from General Household Survey (adapted from [29])

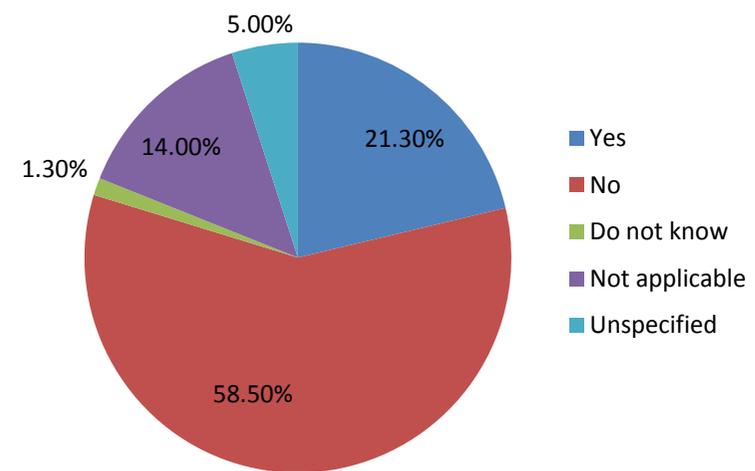


Figure A-2: Census 2011 free electricity results from General Household Survey (adapted from [29])

Table A-6: Census 2011 Internet access results from General Household Survey [29]

Census 2011 General Household Survey Results	Internet connection in the household		Internet for students at a school/university/college		Internet in a library or community hall/centre	
	Yes	8.70%	Yes	5.80%	Yes	3.30%
No	89.30%	No	92.20%	No	94.80%	
Unspecified	2.00%	Unspecified	2.00%	Unspecified	2.00%	
	Internet Café 2 km or less from the household		Internet at place of work			
Yes	4.10%	Yes	15.40%			
No	93.90%	No	82.60%			
Unspecified	2.00%	Unspecified	2.00%			

APPENDIX B

B.1 Manual to deploy a Flex and PHP application developed in Flash Builder to an Ubuntu server

For this project, the remote server is an Ubuntu Linux server. To emulate a suitable testing environment, a virtual Ubuntu LAMP host was set up and Webmin installed. Webmin is a web-based interface for Unix system administration [108]. A new directory (folder) was created in var/www.

Prior to commencing with the steps, it is helpful to understand the distinction made between absolute paths and relative paths (either document-relative or root-relative) [109]. An absolute path gives the entire URL starting with "*http://*" or "*https://*", which are respectively abbreviations for HyperText Transfer Protocol (HTTP) and HyperText Transfer Protocol Secure (HTTPS) [65]. These protocols determine the set of communication rules between the client or browser and the web server. HTTPS is a secure version of HTTP - an encrypted HTTP channel which encrypts all the information being exchanged in order to secure the transfer of confidential or sensitive information [65], [60]. The difference between document relative and root relative differentiates between the points of reference. The reference is either the document itself or the web root directory.

B.1.1 The development side in Flash builder

- Ensure all paths in the main .mxml file are relative (not absolute):

Examples of absolute paths:
<pre> <s:HTTPService id="deleteFlatFileService" url="http://localhost/HouseholdEnergyUsage/services/csv/deleteFlatFile.php" /> <s:HTTPService id="checkValidDataService" url="http://localhost/HouseholdEnergyUsage/services/AnyStock.php" method="POST" resultFormat="e4x" result="checkValidDataService_resultHandler(event)" /> Protected function giveID(stockgraph:AnyChartStock,appliance_name:String):void { var str:String=''; if(stockgraph==AnyChartStock_graph){ str=" </pre>

```

http://localhost/HouseholdEnergyUsage/services/AnyStock_ROC.php?string="
+ appliance_name;
    }
    else if(stockgraph==AnyChartStock_graph2){
        str="
http://localhost/HouseholdEnergyUsage/services/db.php?string=" +
appliance_name;
    }
    stockgraph.xmlFile=str;
}

```

Examples of relative paths:

```

<s:HTTPService id="deleteFlatFileService"
url="services/csv/deleteFlatFile.php"/>

<s:HTTPService id="checkValidDataService" url="services/AnyStock.php"
method="POST" resultFormat="e4x"
result="checkValidDataService_resultHandler(event)"/>

protected function
giveID(stockgraph:AnyChartStock,appliance_name:String):void
{
    var str:String='';
    if(stockgraph==AnyChartStock_graph){
        str="services/AnyStock_ROC.php?string=" + appliance_name
    }
    else if(stockgraph==AnyChartStock_graph2){
        str="services/uit_db.php?string=" + appliance_name;
    }
    stockgraph.xmlFile=str;
}

```

- In Flash Builder’s package explorer view, locate the services package that contain the .php files and locate the _Super_...Service.as ActionScript file. Make the necessary change in the .as file to reflect the appropriate location (new relative path) of the gateway.php file on the remote server. For example:

On development side:	For deployment side:
_serviceControl.endpoint = "gateway.php";	_serviceControl.endpoint = "/HouseholdEnergyUsage/gateway.php";

- In Flash Builder, export a Release Build, by navigating to Project → Export Release Build. Typically, a new folder is created with the same name, for example "HouseholdEnergyUsage" within wamp/www/HouseholdEnergyUsage. Inside this newly created folder are the files to be copied into var/www on the remote Ubuntu server using a tool such as WinSCP. WinSCP is a free, open-source file transfer client for Windows to support protocols such as Secure File Transfer Protocol (SFTP), Secure Copy Protocol (SCP) and File Transfer Protocol (FTP). The main function of WinSCP is file transfer between a local and a remote computer and offers scripting

and basic file manager functionality [110].

- Check to see whether the web root folder name (for example "HouseholdEnergyUsage") on WAMP is similar when compared to LAMP (on the remote Ubuntu server). For example:

```
<?php header("Content-Type:text/xml");
require_once('connection_household_data.php');//connection info
$name = $_REQUEST['string'];

$csvArray = explode(",", $name);

$dir = $_SERVER['DOCUMENT_ROOT'].'HouseholdEnergyUsage/services/';
$dir_csv =
$_SERVER['DOCUMENT_ROOT'].'HouseholdEnergyUsage/services/csv/';
```

Make the necessary changes in the .php files if the root folder has a different name.

B.1.2 The deployment side: setting up the Ubuntu server

- Using WinSCP: copy from wamp/www/HouseholdEnergyUsage/HouseholdEnergyUsage, where this last folder is the Release Build, into the Ubuntu server's var/www/HouseholdEnergyUsage.
- The Zend Framework needs to be installed on the remote server. Using WinSCP, copy the ZendFramework folder from the development side, for example in www/HouseholdEnergyUsage, into var/www/HouseholdEnergyUsage on the Ubuntu deployment side.
- Locate the amf_config.ini file and make the following changes to it:

On development side:

```
[zend]
;set the absolute location path of webroot directory, example:
;Windows: C:\apache\www
;MAC/UNIX: /user/apache/www
webroot =C:/wamp/www/HouseholdEnergyUsage

;set the absolute location path of zend installation directory, example:
;Windows: C:\apache\PHPFrameworks\ZendFramework\library
;MAC/UNIX: /user/apache/PHPFrameworks/ZendFramework/library
;zend_path =

[zendamf]
amf.production = false
amf.directories[]=bin-debug/services
```

For deployment side:

```
[zend]
;set the absolute location path of webroot directory, example:
;Windows: C:\apache\www
;MAC/UNIX: /user/apache/www
webroot =/var/www

;set the absolute location path of zend installation directory, example:
```

```
;Windows: C:\apache\PHPFrameworks\ZendFramework\library
;MAC/UNIX: /user/apache/PHPFrameworks/ZendFramework/library
zend_path = /var/www/HouseholdEnergyUsage/ZendFramework/library
```

```
[zendamf]
amf.production = true
amf.directories[] = /var/www/HouseholdEnergyUsage/services
```

- Copy the services folder that contain the .php files, into
var/www/HouseHoldEnergyUsage.
- Change the database connection information in the relevant .php files. For example:

On development side:

```
<?php
//connection info

define("DATABASE_SERVER", "localhost");
define("DATABASE_USERNAME", "root");
define("DATABASE_PASSWORD", "");
define("DATABASE_NAME", "household_data");

$dbc = mysqli_connect(DATABASE_SERVER, DATABASE_USERNAME,
DATABASE_PASSWORD, DATABASE_NAME);
?>
```

For deployment side:

```
<?php
//connection info

define("DATABASE_SERVER", "127.0.0.1");
define("DATABASE_USERNAME", "katriendp");
define("DATABASE_PASSWORD", "katriendp");
define("DATABASE_NAME", "household_data");
//define("DATABASE_PORT", "3306");

$dbc = mysqli_connect(DATABASE_SERVER, DATABASE_USERNAME,
DATABASE_PASSWORD, DATABASE_NAME);

?>
```

- If a .php file uses a MySQL query such as "SELECT INTO OUTFILE..." to write a .csv file to a directory (folder) on the remote Ubuntu server, ensure that:
 - mysql is the owner of the directory (for example csv) into which the file is saved as shown in Figure B-1.

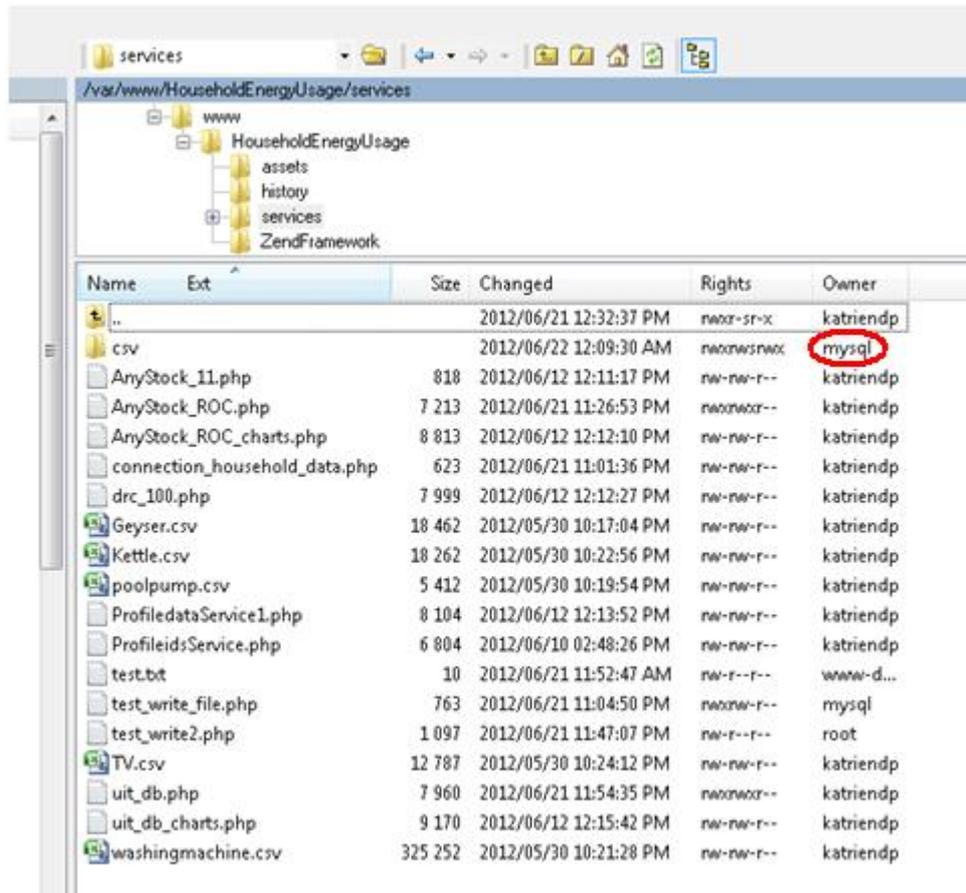


Figure B-1: Mysql ownership of the directory to which files are written

Right click on the directory (for example csv) and select Properties to open up the window shown in Figure B-2. The octal number *777 allows full access. It is important to change the permissions to appropriately limit access and guarantee a secure directory.

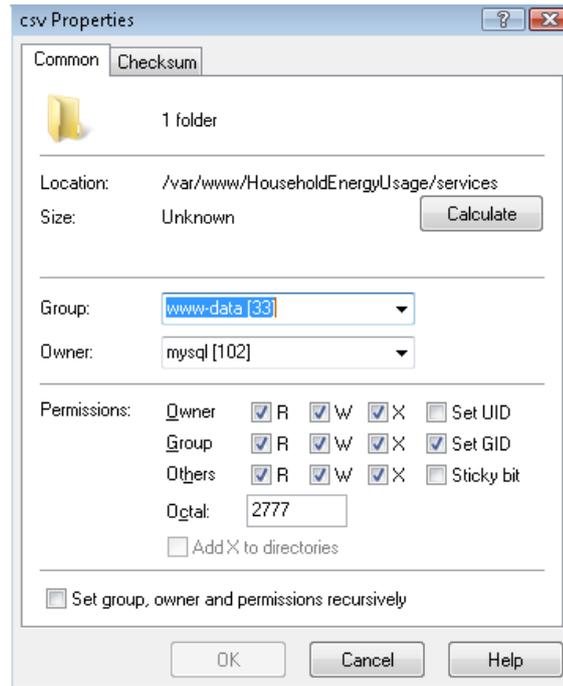


Figure B-2: Permission settings of the directory to which files are written

- The permissions of the .php file itself, which executes the MySQL query using the "SELECT INTO OUTFILE..." statement, can also be set separately.

- Similarly, permissions of the services directory can be set as shown in Figure B-3 and Figure B-4:

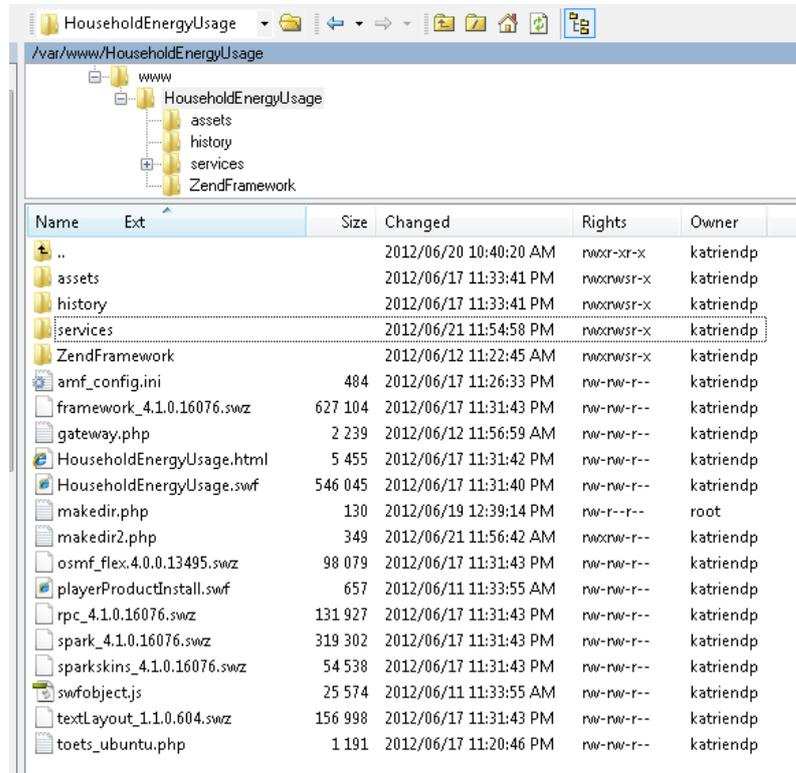


Figure B-3: Permissions of the services directory

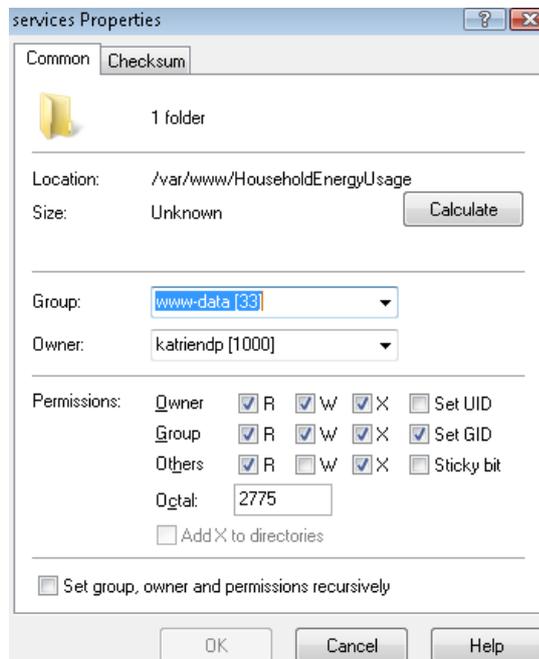


Figure B-4: Permissions of the services directory (cont.)

- Add the relevant directory path by adding the following lines to root→
etc→apparmor.d→user.sbin.mysql :

```
/var/www/HouseholdEnergyUsage/services/ r,  
/var/www/HouseholdEnergyUsage/services/** rw,
```

- A .php file that contains the MySQL statement "SELECT INTO
OUTFILE... " to write to a directory (for example csv), must have the
following highlighted forward slash as part of the relative path to the
directory:

```
$dir_csv =  
$_SERVER[ 'DOCUMENT_ROOT' ] . '/'HouseholdEnergyUsage/services/csv/';
```

APPENDIX C

C.1 Stellenbosch Municipal documentation



Figure C-1: Documentation supplied by Stellenbosch Municipality



Figure C-2: Installed device to switch geyser on and off

STELLENBOSCH MUNICIPALITY	
ELECTRICITY TARIFFS FOR THE PERIOD 1 JULY 2011 TO 30 JUNE 2012 Applicable to services rendered from 1 July 2011.	
	Application 2011/2012 (excl VAT)
Domestic Lifeline (registered indigent consumers)	
Fixed Charge per month	0
Energy Rate (c/kWh) (<= 50kWh)	63
Energy Rate (c/kWh) (51 - 350kWh)	72
Energy Rate (c/kWh) (351 - 600kWh)	98
Energy Rate (c/kWh) (> 600kWh)	114
Domestic Pre-Paid Lifeline (registered indigent consumers)	
Fixed Charge per month	0
Energy Rate (c/kWh) (<= 50kWh)	63
Energy Rate (c/kWh) (51 - 350kWh)	72
Energy Rate (c/kWh) (351 - 600kWh)	98
Energy Rate (c/kWh) (> 600kWh)	114
Domestic Regular	
Fixed Charge per month (Rand)	65
Energy Rate (c/kWh) (<= 50kWh)	63
Energy Rate (c/kWh) (51 - 350kWh)	72
Energy Rate (c/kWh) (351 - 600kWh)	98
Energy Rate (c/kWh) (> 600kWh)	114
Domestic Pre-Paid Regular	
Fixed Charge per month (Rand)	65
Energy Rate (c/kWh) (<= 50kWh)	63
Energy Rate (c/kWh) (51 - 350kWh)	72
Energy Rate (c/kWh) (351 - 600kWh)	98
Energy Rate (c/kWh) (> 600kWh)	114

Figure C-3: Stellenbosch Municipality electricity tariffs for the period 1 July 2011 – 30 June 2012 [111]

STELLENBOSCH MUNICIPALITY					
ELECTRICITY TARIFFS: APPLICABLE TO ALL CUSTOMERS SUPPLIED BY THE STELLENBOSCH MUNICIPALITY					
TARIFFS APPLICABLE TO SERVICES RENDERED FROM 1 JULY 2012					
				2011/2012	2012/2013
1. DOMESTIC					
Life Line PP (For qualifying indigent customers and receiving the first 60 units free per month)	Block 1	0 - 50 kWh	c/kWh	n/a	n/a
	Block 2	51 -350 kWh	c/kWh	72.00	103.50
	Block 3	351 -600 kWh	c/kWh	98.00	118.50
	Block 4	601 - 99999 kWh	c/kWh	114.00	133.50
Regular PP (Using Prepaid Meters AND Less than 600kWh per month average previous Financial Year: 60 Ampere single and 3 - phase maximum)	Block 1	0 - 50kWh	c/kWh	63.00	69.50
	Block 2	51 -350 kWh	c/kWh	90.00	103.50
	Block 3	351 -600 kWh	c/kWh	107.00	118.50
	Block 4	601 - 99999 kWh	c/kWh	118.00	133.50
Regular (Using Credit Meters OR Prepaid Meters with more than 600kWh per month average previous Financial Year: 60 Ampere single and 3 - phase maximum)	Fixed Charge		R/month	R 65.00	R 80.00
	Block 1	0 - 50kWh	c/kWh	63.00	69.50
	Block 2	51 -350 kWh	c/kWh	72.00	85.50
	Block 3	351 -600 kWh	c/kWh	98.00	112.50
	Block 4	601 - 99999 kWh	c/kWh	114.00	132.50

Figure C-4: Stellenbosch Municipality electricity tariffs from 1 July 2012 [112]

C.2 Pre-paid electricity costs

Figure C-5 shows a record of costs associated with pre-paid electricity purchased from a number of different vendors in Stellenbosch for a period of approximately 7 months during 2012. Costs exclude 14% Value Added Tax (VAT) and additional service charges which ranged from 4,5% to 28,5% of the electricity amount.

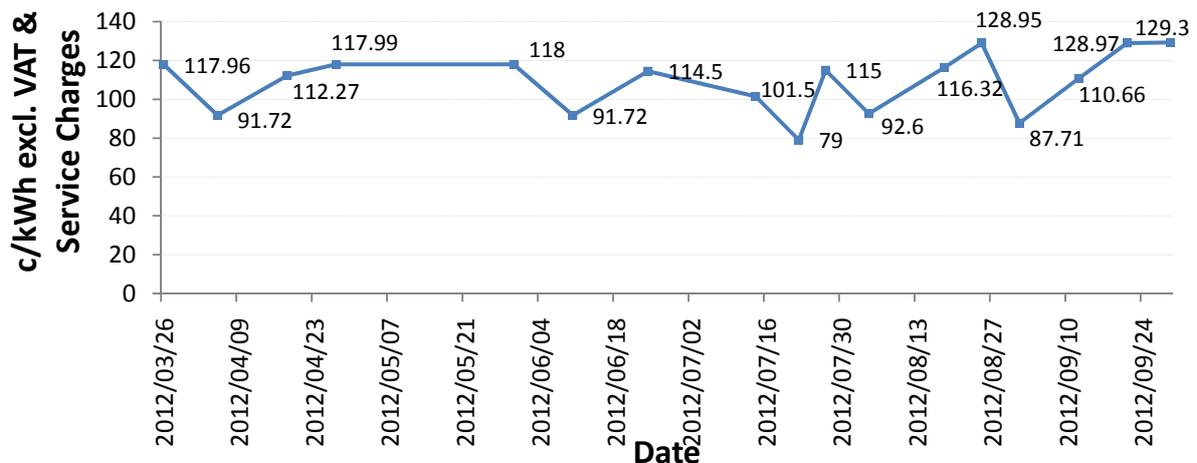


Figure C-5: Electricity costs (c/kWh) over a period of 7 months

According to NERSA, acceptable household municipal electricity tariffs for 2012/13 are as follows [13]:

Table C-1: The 2012/13 municipal residential tariff structure as prescribed by NERSA [13]

0-50 kWh	51-350 kWh	351-600 kWh	More than 600 kWh
61-66 c/kWh	77-82 c/kWh	104-109 c/kWh	124-129 c/kWh

C.3 Time of Use (TOU) pricing scheme

Shown in Figure C-6, a TOU pricing scheme for residential tariffs is proposed for suburban residential consumers [33]. As indicated, the scheme will be implemented in a phased approach once advanced metering infrastructure is in place.

Non-Local Authority & Local Authority Residential Tariffs *continued...*

HOMEFLEX

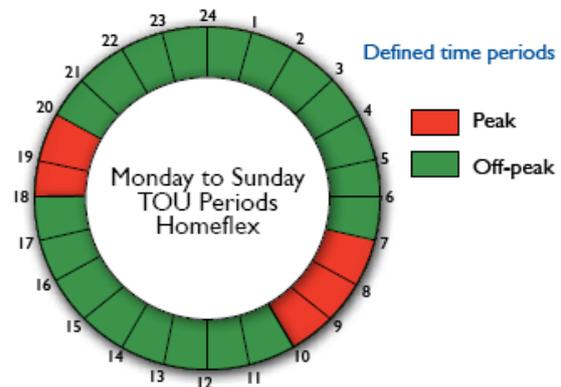
A TOU electricity tariff suitable for medium-to-high usage residential customers in urban areas with an NMD of up to 100 kVA and has the following charges:

- seasonally and time-of-use differentiated c/kWh active energy charge
- a R/day network access charge based on the NMD of the supply
- a R/day service charge based on the NMD of the supply
- a c/kWh environmental levy charge, applied to the total active energy supplied in the month

This tariff will be implemented initially on a voluntary basis to 10 000 suburban residential customers in selected areas, together with advanced metering infrastructure (smart metering technology). Homeflex will be marketed to suburban residential customers in a phased approach, once the advanced metering infrastructure (meter, communications and systems) is in place.

The Homeflex tariff is made up of a range of tariffs, as follows:

Homepower 1	dual-phase 32 kVA (80 A per phase) three-phase 25 kVA (40 A per phase)
Homepower 2	dual-phase 64 kVA (150 A per phase) three-phase 50 kVA (80 A per phase)
Homepower 3	dual-phase 100 kVA (225 A per phase) three-phase 100 kVA (150 A per phase)
Homepower 4	single-phase 16 kVA (80 A per phase)



HOMEFLEX Non-Local Authority Rates

		Service charge (R/day)		Network access charge (R/day)		Peak energy charge (c/kWh)		Off peak energy charge (c/kWh)		Environmental levy charge (c/kWh)	
		VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.
Homeflex 1	High demand	R2.96	R 3.37	R 3.68	R 4.20	174.87	199.35	55.10	62.81	2.00	2.28
	Low demand					65.86	75.08	43.89	50.03	2.00	2.28
Homeflex 2	High demand	R2.96	R 3.37	R 7.95	R 9.06	174.87	199.35	55.10	62.81	2.00	2.28
	Low demand					65.86	75.08	43.89	50.03	2.00	2.28
Homeflex 3	High demand	R2.96	R 3.37	R16.00	R 18.24	174.87	199.35	55.10	62.81	2.00	2.28
	Low demand					65.86	75.08	43.89	50.03	2.00	2.28
Homeflex 4	High demand	R2.96	R 3.37	R 1.88	R 2.14	174.87	199.35	55.10	62.81	2.00	2.28
	Low demand					65.86	75.08	43.89	50.03	2.00	2.28

Figure C-6: Eskom’s proposed TOU pricing scheme for residential consumers