APPLICATION OF DMAIC TO IMPROVE ENERGY CONSUMPTION IN A COMMERCIAL BUILDING

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A thesis submitted to the Faculty of Engineering and the Built Environment,

Durban University of Technology, for the fulfilment of the requirement for Master of Engineering in Industrial Engineering

March 2021

Acknowledgements

My sincere gratitude to the following persons for their contributions and guidance:

- Jehovah Almighty God, “the only one who gives ability to be successful”, without him nothing will be done.
- My supervisor Professor Ian Joseph Lazarus, for mentoring my study with patience and expertise leadership.
- My co-supervisor Dr Oludolapo Akanni Olanrewaju, for academic perception and relevant support.
- My beloved wife for her moral support.
- My pastor and Apostle Benjamin Lokola for his advice and encouragement.
- My friend and colleague Jean Claude Baraka for his advice during this study.

Declaration

I hereby declare that the work which is being presented in this thesis entitled "improving energy usage in commercial building using Six Sigma DMAIC" for the award of the Degree of Master of Technology in Industrial Engineering, Durban University of Technology is an authentic record of my own work under the supervision of Prof. Ian Lazarus, Professor in the Department of Physics and Dr. Oludolapo Akanni Olanrewaju, Senior Lecturer in the Department of Industrial Engineering, Durban University of Technology.

This work has been submitted with the verification and authorization of my supervisors.

Publications

Submitted papers:

- Conference paper: 30 June 2020, status: Accepted and published.

Kanyinda, K., Lazarus I J**.,** Olanrewaju, O.A., *Influence of six sigma DMAIC to reduce time wasting of line supervisor in production manufacturing*, International Conference of Industrial Engineering and Engineering management (IEEE), 14-17 Dec. 2020. **URL: WWW.IEEM.ORG**

- Conference paper: 30 July 2020, status: Accepted

Kanyinda, K., Olanrewaju O.A., *A3 Problem Solving: A Case of Assembly Line Downtime*, 2nd African International Conference on Industrial Engineering and Operations Management. Harare, Zimbabwe, December 08-10, 2020. http://ieomsociety.org/harare2020/

- Journal paper: 30 July 2020, status: Pending

Kanyinda, K., Lazarus I J., Olanrewaju O.A. *Improving energy usage in commercial building using six sigma DMAIC*, *South* African Journal of Industrial Engineering, July 2020. Saije.journals.ac.za

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Abbreviations

CO_2:	Carbon dioxide
CT:	Current Transformer
DMAIC:	Define Measure Analyse Improve control
DOE:	Department of Energy
DUT:	Durban University of Technology.
EE:	Energy Efficiency
EES:	Energy Efficiency Strategy
EnMS:	Energy Management System
EG:	eGauge
NEES:	National Energy Efficiency Strategy.
NERSA:	National Energy Regulation of South Africa
OECD:	Organization for Economic Co-operation and Development
IEA:	International Energy Agency
EnM:	Energy Management
KPI:	Key Performance Indicator
kW:	Kilowatt
kWh:	Kilowatt hour
Eskom:	Electricity Supply Commission
HVAIC:	Heat, Ventilation, Air-Con
kVA:	Kilovolt ampere
LSS:	Lean Six Sigma
PDCA:	Plan-Do-Check Act
SS:	Six Sigma
SEU:	Significant Energy User
SCC:	Statistical Control Chart

SPC: Statistical Process Control

SPSS: Statistical Package for Social Sciences

WEEA: World Economy Efficiency Association

Abstract

Improving energy use in a commercial building has become the subject of great importance in organizations worldwide. Improving energy usage refers to the efforts to reduce energy consumption. Reducing energy consumption in commercial buildings can be accomplished through continuous supervision using appropriate managerial techniques. Commercial companies are required to use energy more efficiently and participate in energy improvement.

This study seeks to improve electrical energy consumption in commercial buildings by Analysing the electrical data consumption and identifying the factors that contribute to high consumption using Six Sigma DMAIC (Define-Measure-Analyse-Improve-Control) problem solving methodology. A case study was used to validate the DMAIC framework. Two years of electrical consumption data of a case study done from January 2018 to December 2019 was collected and analysed. The study revealed an average increment in energy consumption of 3.9 %. The outcomes using statistical Pareto chart showed that the boiler is the highest significant energy user in the building with 38.3% due; followed by the kitchen with 24.2 %, followed by DB A and lifts with 20,1 % and the rest with 17.37 %. After the campaign of DMAIC, there was a reduction of 6 % in boiler consumption which was 2.3 % reduction of total consumption of the month for the building.

Therefore, the study successfully demonstrates how Six Sigma DMAIC methodology can be applied to improve electrical consumption in a commercial building and reduce its related costs.

Key words: Commercial building, Six Sigma DMAIC, Electrical consumption, energy usage.

Chapter One: Introduction

1.1 Electrical energy crisis

The study to improve electrical energy use in buildings has become important within the commercial building environment. Organizations have been seeking the use of alternative sources of energy due to the increased electricity costs and demands. Due to the effect of this energy demand on the economy and the growth in population, there is need for continuous improvement and energy management implementation that could assist businesses reduce their electrical energy consumption and energy costs. Energy management and monitoring are the most important elements to ensure continuous improvement in energy usage. Rathore (2011) argues that the energy crisis of 1973 forced the world to look for an alternative arrangement to assure energy sufficiency, hence the focus is to improve energy usage. A number of governmental and non-governmental institutions are developing different but reliable energy policies, new professions of energy engineering and new energy management approaches to respond to current energy crises (Ahuja and Tatsutani, 2009). Energy has been an important resource in the development of any organization, but the capability of the organization is measured by its performance.

One of the Key Performance Indicators (KPIs) for net profit margins in organizations is the financial indicator. However, the best way for organizations to increase net profit is to reduce their costs, which will lead to better production. This can be achieved through continuous improvements in the organization’s operations. Recently, the cost of energy has significantly influenced the performance of an organization. Pîrlog and Balint (2016) define KPI as a measurement of how well the industrial process accomplishes the operational activity in an organization, which is critical for the current and future success of that organization. It is possible to determine the energy performance of a commercial building through a calculation model by assessing the electrical energy use from energy meters and hence evaluate the costs. Recently, researchers are deviating from calculating energy demand for analysing the real energy consumption of buildings. One of the motives is that it becomes difficult to predict the building energy use without standardized models of calculation. For measured and analysed data, there is a need for current management of energy usage in buildings.

Management is the effective use of available resources of the organization with the least cost, leading to reducing or eliminating wastage. One of the management approaches that provides the framework for continuous improvement in an organization is the six sigma (SS) approach called DMAIC problem-solving. DMAIC is the acronym of Define-Measure-Analyse-Improve-Control (Gejdoš, 2015). According to Starbird (2002), this approach is used in the quality management methodology with the objective to solve problems, improve quality, increase profitability, and provide customer satisfaction. The approach can also provide a breakthrough in strategies and disciplined methods for use in gathering data and statistical methods of analysis, to identify the sources of errors and ways of eliminating these errors. The study will explain how the DMAIC methodology can improve process activities in each of its five stages.

It is also very important to have correct and reliable measured data. Recently, the innovations in technology have made things easier for energy managers to measure and calculate energy consumption and evaluate the performance of an organization's resources for improvement. One of the tools used is called: “eGauge” monitoring meter. This modern device for energy-data collection is a system that automatically records and measures energy consumption at regular intervals such as every 15-minutes, 30-minutes, hour(s), day(s), month(s) even year(s). Detailed data of energy consumption at intervals make it possible to identify patterns of energy wastage. The improvement of energy presents many benefits, but despite the technological advantage and benefits offered, some organizations are still not aware of the need to improve their energy consumption.

1.2 Problem statement

Considering the increase of electrical energy consumption and energy prices globally due to the increased demand, there is a growing interest in improving energy usage in organizations. In 2005, the South African National Energy

Efficiency Strategy (NEES) adopted the Energy Efficiency Strategy (EES), which established a set of compulsory measures to help Eskom reduce pressure on the grid and reach its target. In response, all economic sectors including small and large business companies are required to use energy more efficiently and participate in energy improvement at all stages of the energy usage. The Electricity Supply Commission (Eskom), a South African state-owned electricity supplier company has confronted and is still confronting a critical supply shortage and has recently indicated the need for an additional tariff hike over the next three years. Eskom's (2018/2019) budget made provision for the construction of more fired power stations. The greater the electricity consumption, the more the price increases, and the greater the need for reducing energy consumption, improving energy use, and implementing energy efficiency practices. With prices showing no sign of decreasing according to the National Energy Regulator of South Africa (2018), there is an existing agreement acknowledging that energy efficiency implementation (EEI) has significant potential across all sectors of the national economy.

According to Pérez-Lombard, Ortiz and Velázquez (2013), efforts have been carried out in recent years to investigate the issues related to Energy Efficiency (EE). Kebede, Kagochi and Jolly (2010) believe that economic and population growth in South Africa is the driving force behind the increased demand, as formerly disadvantaged homes and residential areas are being electrified. The National Energy Regulator of South Africa (NERSA) approved a 13.87 % average price increase which was implemented on 1 April 2019 for Eskom direct (Eskom, 2018/2019), resulting in consumers first needing to their reduce electricity demand and to reduce their electricity bills to avoid an exorbitant electricity bill. All the public and private sectors in South Africa are confronted with this problem.

1.3 Energy efficiency and energy management

1.3.1 Energy efficiency from global and national perspectives

Different disciplines have defined energy efficiency (EE) depending on their fields of work. Pérez-Lombard, Ortiz and Velázquez (2013) explain that EE is widely used in different fields with different meanings, including amongst others engineering, economy, sociology, and medicine. It is connected to other terms such as efficacy, effectiveness, savings, and performance. Being efficient is to accomplish something with the least amount of time and effort. According to the European Commission, efficiency means “doing more with less” as described in the Green Paper, energy efficiency of the European Union (DeCanio, 1998). In general, energy efficiency refers to using less energy to produce the same amount of energy or useful output.

$$EE = \frac{Useful\ output\ of\ process}{Energy\ input\ into\ a\ process}$$

Energy efficiency also means a strategic energy management system (EnMs) to optimize energy use. It can mean the ability to avoid waste energy or the ability to do things well which will be explained in the second chapter of this study. Improving energy use in buildings is an efficient use of energy (reducing energy consumption) that consists of a minimum amount of energy required to provide products or services which will minimize costs and maximize earnings. Ahuja and Tatsutani, (2009) argue again that EE can be exclusively important in fast developing countries as a way to manage rapid demand growth, ease supply constraints and allow energy production and distribution infrastructure to ‘catch up’. Using less energy in the building can mean lower electricity bills which implies more money saved.

In the national context, South African energy relies largely on local coal reserves for its driving force, and the country is facing significant problems, the most vital is not only supply and demand issues due to the shortage from the national grid but also from the price increase. To stimulate the participation of both public and private sectors in energy efficiency improvement, the South African government has initiated incentives like tax-rebates for companies, including the commercial sector to demonstrate energy efficiency and savings. The savings allow for a tax deduction of 95c/kWh saved on energy consumption, Gejdoš (2015). In response, all economic sectors including small and large businesses are required to use energy more efficiently and participate in energy improvement at all the stages of energy usage.

The commercial sector including higher education institutions as well as financial, public, retail, business, wholesale, hospitality, entertainment, information and communication services are required to participate in energy efficiency improvement. The commercial sector is among the largest sectors of higher power consumption; it is third only to industry and residential sectors. According to Statistics South Africa (2018), the commercial sector uses about 11 % of total national energy as illustrated in Figure 1.1

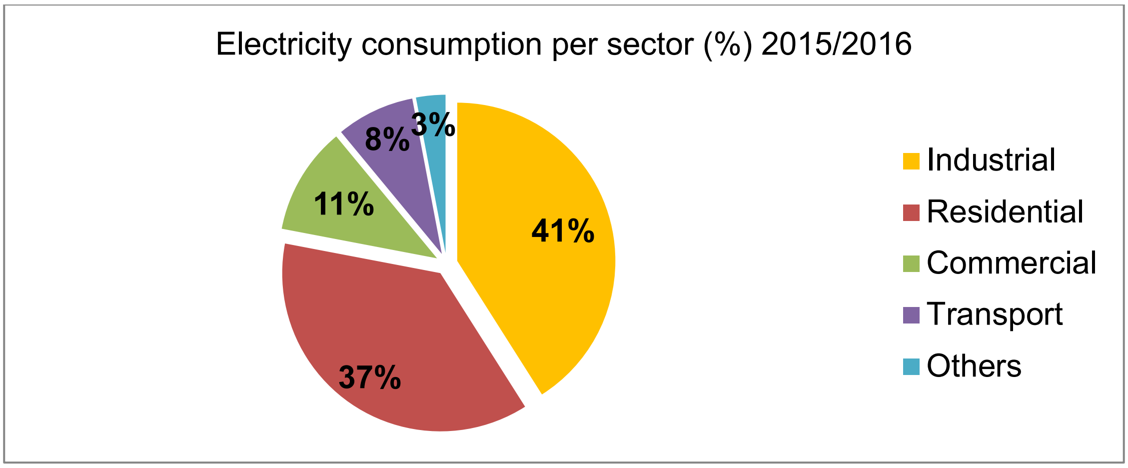


Figure 1.1 Consumption per sector in percentage. Eskom website, 2018)

Although Figure 1.1 only shows the consumption percentage per key sector of the South African economy, it serves as a reminder that improving energy usage and managing energy resources is crucial to the development of a nation.

Schnapp (2012), includes energy savings (reduction in energy consumption) and reduced energy costs (both for final users and for utilities) in list of possible benefits that EE presents. Despite the benefits listed above, DeCanio (1993) believes that “investments in energy efficiency have a low priority”. The authors further argued that such lack of interest from the public and private sectors on energy efficiency improvement is mostly due to the traditionally low cost of energy.

There are many elements to ensure energy efficiency in the building; the most important is energy management. Naidoo (2014) argues that “most energy efficiency in industry is achieved through changes in how energy is managed in an industrial facility, rather than through installation of new technologies”. Besides the South African government’s attempts to reduce and optimize electrical energy consumption through the implementation of energy efficiency strategy, energy management is one of the most affordable and quickest options to produce results. In the article "*The future of energy supply: challenges and opportunities"*, Armaroli (2007) states that "the 21st century will be largely defined by the way we face and resolve the energy crisis".

1.3.2 Energy management

Since the cost of energy has become a significant factor in the performance of the organization, the management of energy resources also becomes very important. Management of energy implies application of available resources more effectively with efficiency and minimum cost by reducing or even eliminating wastage, argues Rathore (2011). For Doty and Turner (2004), energy management may be defined as the judicious use of energy to accomplish prescribed objectives. For private organizations, these objectives are generally to assure maximized profits and enhance competitive advantage. Many organizations do not emphasize EE or energy improvement as the main objective of their business because energy does not produce revenue, but in contrast, they select or identify the main areas that are most advantageous. As the costs of energy have increased gradually in recent years, reducing operational expenses within an organization, for instance, has arisen as the main objective in government and private sectors.

Only in recent years, organizations have started to realize that energy usage can be among the core activities of the organization, because if managed well the organization can save money and enhance the organization's financial performance. In other words, this means that in reducing and managing energy usage more efficiently, organizations can reduce their operating costs and improve the profit. The idea is supported by Rathore (2013:141-145) who argues that the: "need to conserve energy, particularly in industry and commerce is strongly felt as the energy cost takes up substantial share in the overall cost structure of energy operation, hence it calls for management of energy or management of the resources". One of the management approaches that provides a framework for continuous improvement in an organization is the six sigma (SS) approach called DMAIC. It is an acronym for Define-Measure-Analyse-Improve-Control.

1.4 Why DMAIC

DMAIC is a Six Sigma simple tool for performance improvement according to Pyzdek (2003). It is a common and well-known methodology developed from the Lean Six Sigma (LSS) approach for the execution of projects (Sunder, 2016). This methodology was designed to solve a problem in the existing process or product and/or service offering to regain control. Its main purpose is to guide the project team from the beginning (define phase) to maintaining the results (control phase) and reducing process variation. In line with this research, variation can be anything that can increase energy consumption and high cost of electricity. The approach emphasizes statistical data analysis, fact-based decision making and guides a structured exploration of reasons leading to the problem. Rathore (2011) explains that the energy management is “the process of monitoring, controlling, and conserving energy in building” for instance and the steps involved during that process is like those used for DMAIC. These steps are metering energy consumption, data collection, finding areas of opportunity for improvement, tackle the problem, and follow up with data from the meter to see if the effort of energy saving worked out.

Six Sigma was invented by engineer Bill Smith at Motorola in the 1980s to address the company’s chronic problems of meeting customer expectations in a cost-effective manner. The discovery was motivated by the high cost of poor quality discovered at Motorola like many other companies at that time. It was as high as 15 % to 20 % of the sales revenue, consequently, a large portion of the product failed to meet customer requirements which led to scrap, rework and other services. Within improvement projects, quality problems were systematically analysed at the front end of the process and continued throughout the manufacturing process using four phases (Measure, Analyses, Improve, and Control). Statistically, Six Sigma refers to a process in which the range between the mean of a process quality measurement and the nearest specification limit is at least six times the standard deviation (6σ) of the process.

In the book, *Quality management for organizations using Lean six sigma techniques*, Jones (2014) states that DMAIC focuses on eliminating unproductive steps, developing and applying new metrics and using technology to drive improvement. Six Sigma has a strategic component aimed at not only developing employees' commitment to it but also actively involving a higher level of management. Objective evidence showed that Six Sigma through the DMAIC approach can help firms achieve significant performance improvement. The benefits of Six Sigma include cost reduction (increase profit), customer satisfaction, and (3) sales revenue growth Pande et al. (2000).

Six Sigma DMAIC has the ability to help an organization make more money by improving customer value and efficiency. Energy, like quality and environment, is deeply affected by many external factors including human factors, the increase of electricity and fuel prices, the rising needs for smarter equipment and technology for its sustainability and maintenance. For organizations to remain competitive in the market today, energy has emerged as one of the key sectors that require continuous improvement tools such as the Six Sigma DMAIC procedure. During the DMAIC process, eGauge was proposed as useful instrument to evaluate how the energy has been used, this instrument offers customer the ability to daily read separate consumption on boilers, lights, kitchen and others depending on business specification. Such development gives DMAIC as a Six Sigma approach more validity to analyse the daily collected result and assess areas in desperate need for enhancement and additional maintenance.

1.5 Aim and Objectives

The aim of this study is the application of Six Sigma's DMAIC (Define, Measure, Analyze, Improve and Control) to analyse electrical data consumption and identify factors or areas of opportunity that contribute to high electrical energy usage, this will result in reducing electricity consumption and cost savings.

Information on the energy usage arrangements is vital to informing the way forward for any energy management program. To effectively reach the above aim, the specific objectives were to create an information base from which the energy management plan could be established, and those specific objectives are to:

- Investigate the larger energy resources and quantify the energy consumption.
- Evaluate the energy consumption performances of each energy user.
- Identify significant energy users and identify the causes of high energy consumption.
- Establish and implement energy-saving measures that will minimize energy consumption in a commercial building.

1.6 Research Questions

1. What energy users in commercial building consume more energy?
2. What are the causes of high energy consumption?
3. Which energy-saving measures will minimize energy consumption in a commercial building?

1.7 Significance of the study

The study is investigating a commercial building in Durban, South Africa with the purpose of improving the building's energy consumption with the application of Six Sigma DMAIC methodology. Six Sigma uses the very formal DMAIC process, which breaks down a specific project into phases says Zugelder (2012). Electrical energy consumption data was collected on a six-storey commercial building in Durban, South Africa with the purpose of achieving these study objectives. The outcomes of research assisted in developing a before and after scenario to highlight cost and consumption improvement. The study findings will also be used as a model for energy waste reduction not only to commercial sectors but as well as other sectors such as the industrial and residential sectors.

1.8 Additional theoretical terms

It is necessary to understand the terminology used in relation to electrical energy consumption.

eGauge: is an energy monitoring system for residential and commercial applications (Egauge.net 2019). According to the same eGauge website, “eGauge monitors electricity on every circuit with precision and accuracy. It can also measure the power of individual circuits in its electricity panel using sensors called current transformers (CTs)”. Furthermore, the “meter also displays energy data on its webpage in real-time, watching as the graph changes every second, revealing potential problems that could never have been discovered with a simple utility bill”.

Electricity tariff: is considered as non-fuel cost. According to ema.gov.sg (2019), the electricity tariff includes power generation cost (this cost includes manpower, maintenance costs as well as the capital costs of the stations); grid charge (cost associated to the transportation of electricity through the power grid; market support services (MSS) fee (cost of billing and meter reading); and power system operation and market administration fees (cost of operating the power system and administering the wholesale electricity market).

Behavioural Change: is a change in energy-consuming activity originated by, and under control of, a person or organization or changing driving habits, it affects energy efficiency. An example of behavioural change is adjusting the thermostat setting of boilers.

Boiler: A device for generating steam for power, processing, or heating purposes or for producing hot water for heating purposes or hot water supply.

Commercial: Commercial refers to non-manufacturing business establishments, including hotels, motels, restaurants, wholesale businesses, retail stores, and health, social, and educational institutions. But in line with utility, commercial is categorised as service as all users whose demand or annual use go above specified limit.

Commercial Building: A building with more than 50 percent of its floor space used for commercial activities. A commercial building comprises, but are not limited to, stores, offices, Educational institutions, churches, museums, hospitals, clinics, warehouses, and jails. Government buildings are included but for buildings on sites with restricted access.

Distribution board: supply panel that divides an **electrical** power feed into subsidiary circuits. It is a portion of an electric system that is dedicated to delivering electric energy to an end-user.

Efficacy: A system of measurement used to compare light output to energy consumption. Efficacy is measured in lumens per watt.

Energy: The capacity for doing work as measured by the capability of doing work (potential energy). Energy has several forms; electrical energy is usually measured in kilowatt-hours (kWh) (Stanner,1996).

Energy Efficiency: Two different concepts of energy efficiency are discussed, a technical and specific concept. In the technical concept, increases in EE take place when either energy inputs are reduced for a given level of service or there are increased or enhanced services for a given amount of energy inputs. In a more specific concept, energy efficiency is to use the same fewer resources to produce the same results (energy inputs are used to provide goods or services).

Peak Demand: The maximum load during a specified period.

1.9 Dissertation layout

Chapter Two discusses the literature review on energy management (EM), energy efficiency (EE) and DMAIC problem-solving. Chapter Three presents the study methodology using DMAIC and detailing its impacts. The research findings are presented in Chapter Four. In Chapter Five, the research findings are discussed focusing on the application of the Six Sigma DMAIC tools for the improvement of energy use in a commercial building. Finally, the summary, conclusions and recommendations are presented based on the interpretation of data provided in Chapter Five.

1.10 Conclusion

Poorly managed and improper control of electrical energy usage may significantly increase the amount of wasted energy in a building. The efficient use of electrical energy depends on the proper technique or approach being accepted as having an enormous ability to both reduce energy wastage and generate cost savings. DMAIC has been embraced as having an enormous potential to both reduce energy wastage and generate cost savings. Electrical energy use and issues related to electrical energy improvement have been discussed in this chapter.

This chapter has also illustrated the study’s aim and objectives for energy consumption improvement.

Chapter Two: Literature review

2.1 Introduction

The chapter offers the theoretical outline of three major concepts of improvement of the energy usage found in this study namely: energy management, energy efficiency (EE), and DMAIC methodology. The first two concepts have a strong connection and with matching meaning which is to accomplish energy improvement. An overview of the literature related to improvement of energy use in commercial buildings using six sigma DMAIC approach has raised two issues: energy improvement through energy management and the importance of energy improvement in the commercial sector through DMAIC. This chapter also reviews the literature on tools to analyse and interpret the electrical data consumption for improvement; the review is to gain a detailed understanding of Six Sigma DMAIC approach. The cross-cutting in this energy improvement topic was to identify the factors that contribute to the increase in electricity consumption.

The planned method of the review of the literature adopted by the researcher includes two steps. The first step defines the main concepts identified in the previous paragraph of this chapter. The second step identifies the content of concepts and data used to determine whether an article should be related to DMAIC literature or not. The study used Google Scholar as the primary search database and books, published academic papers and published government reports were taken to consideration.

There are many materials in relation to the improvement of energy globally and in South Africa and there is also a wide range of literature on the application of Six Sigma DMAIC in industries nationally and globally, but there are a few similar studies on commercial buildings using DMAIC methodology as an approach for energy improvement in South Africa.

2.2 Achieving energy improvement using energy management.

The term energy management (EM) was defined in Chapter One according to Capehart, Turner & Kennedy (2006) as the “judicious and effective use of energy to maximize profits (minimize costs) and enhance competitive positions”. EM can be also a careful way of managing energy to reduce consumption and increase profits. It involves strategies to monitor and control energy usage and procedures to reduce energy requirements. The authors further explained that companies were becoming more efficient in their use of energy, and that could be shown in their data, this comes as no surprise for those involved in energy management. Some managers did not pull out all possible savings from economizing but are looking for other approaches to become more competitive. Other organizations began to realise that their managers were leaving lots of money on the table when they do not initiate a good energy management plan. Energy management requires detailed insight into energy consumption, analysis, controlling of the related risks, and identification of opportunities.

The South African Alternative Energy Association (SAAEA) (2015) defined energy management as a practice of making informed decisions, based on structural insights into energy consumption and its impact on an organization. Energy management requires permanent and detailed insight into energy consumption, analysis of the related risks, translation into risk management and identification of opportunities. All of these must be in line with corporate strategy. The author still argues that with good energy management, an organization makes a positive and conscious decision on the management of its energy consumption. This is the strategy of controlling, adjusting, monitoring, and optimizing energy consumption using systems and procedures to reduce energy requirements or total costs. All these must be in line with the organization's strategy to reduce costs by using a system and standard procedure (The strategy must be established based on organization strategy).

The aim of the research was to identify factors that contribute to high electrical energy usage to minimize energy cost without compromising customer satisfaction. Since the commercial sector is diverse, what is required by effective energy management depends on many different factors, for example, the organization size and type of business. To monitor the energy management program for large energy users such as commercial buildings involves the installation of a complete information management system or data collection system such as a smart meter that can collect and identify the energy consumption, savings and continuous opportunities for improvement to meet the organization's financial constraints. According to Cruz-Cázares, Bayona-Sáez, and García-Marco, (2013) "You can't manage what you can't measure". In energy management terms means that "You can't manage energy, if you don't measure it"; unless there is a positive understanding of energy consumption at individual buildings or departmental levels, there is no valid way of identifying energy-saving opportunities. In order to estimate the consumption of every resource, it was important to emphasize load measurement because it is this activity that allows for the finding of detailed energy data. It was also important to prioritize resources according to their contribution to the total energy cost, in such a way that those that are energy intensive can be addressed first.

Govender (2005) explained that experience has shown that a 1 to 2 % reduction in consumption can be reached after meters are installed just by letting users know that they are being monitored, and up to a 5 % reduction in total reduction can occur when users then become practical in better handling the use of their energy. Metering is a crucial part of data achievement. Some technical reports on the different types of meters and schematic diagram for the building required for energy management can be found in Figure 4.1. A well-designed metering system frequently yields surprising results and frequently identifies considerable savings. Through proper monitoring, recording and analysis, the use of meters can lead to corrective actions that produce the desired result of reducing energy cost.

2.2.1 Energy management policy

Long ago, energy efficiency had been regarded as a technical aspect of equipment, systems, and buildings; until recently, energy efficiency became energy management which emerged as a distinct field of interest. Energy management is now a discipline on its own, independent of the many technical areas to which efficiency applies. On the other hand, the investigation will not be accomplished only on equipment but also by the behaviour and overall attitude of the energy users of the building.

Government, non-government organizations and institutions are working to find a response to the energy crisis by creating new energy policies and new approaches to improve energy efficiency worldwide. The idea is supported by Govender (2005:12) who argued that the World Energy Efficiency Association (WEEA) was founded in 1993 as a private, non-profit organization composed of a developed and developing country, institutions and individuals charged with increasing energy efficiency. It was also established to facilitate communications among these institutions with an interest in energy efficiency by assisting developing countries including South Africa in accessing information on energy efficiency.

In South Africa, there were various academic studies on energy management in different institutions. One of the examples was the work accomplished by Calmeyer at the University of Pretoria (1999:111). Through this work, the systematic model to energy management was delivered, well-defined, structured, and linked to the energy policy and energy strategy. The author went further to define the energy policy as an official statement that can be made by a government, an individual through which the course of action is being adopted with respect to energy. The energy policy defined the pathway of the EM plan and is specific to each organization. An energy policy stated what an institution intends doing about energy management and the goals they hope to achieve. He added that energy policy should not be confused with energy strategy. The policy defines what the institution intends doing regarding energy whereas the strategy determines how it will be accomplished.

2.2.2 Energy management strategies

There is a growing urgency to face up to the challenge of sustainable energy globally. Many countries support energy services that promote social, environmental, and economic aims on sustainable improvement. To accomplish such aims, a complete energy strategy that provides for the needs of an organization desires to be developed. There are the technical (technology) and non-technical opportunities or best practices for energy savings which exist within the building, mining, and manufacturing sectors. The table 2.1 gives the overview of previous literature of energy management strategies in different industries related to their scope.

Table 2.1 Previous papers with energy management strategies and scope of study

Previously published review papers on EMS	***Characteristic of Management***				**Range of study**	
	Strategic model	Supporting technical model	Supporting behaviour model	Manufacturing performance	Sectoral	Process
Olatomiwa et al. (2016)	x			x		
Zhang et al. (2012)	x	x			x	
Iris and Lam (2019)	x					
Zhang, Yan, and Du. (2015).	x				x	
Govender (2014)	x	x	X			
Rozali (2014)			X	x		x
Dhiraj & Deepak (2014)	x			x	x	x
Zhang, (2009)	x			x		
Petersen et al, 2007	x		X			
Govender (2005)	x	x				
Ke (2008)	x		X		x	
Kane Jr et al., 2003	X					
Calmeyer (1999)	x		X		x	

DMAIC problem solving framework provides a step-by-step guideline for implementing electrical energy management. This continual improvement framework ensures that the buildings continually improve the EMS implementation procedure and, consequently, electrical energy performance and organizational culture. The study undertaken by Razali (2014) claimed that many companies worldwide continue to achieve improvements in business performance using the Six Sigma approach. His study pursued to evaluate the factors that contribute to high electrical energy consumption in the Faculty of Computer and Mathematical Sciences. The electrical consumption was analysed using DMAIC.

The non-technical opportunities tend to turn around issues such as behavioural change arising from increased awareness, training, accountability, and information systems. The strategy recognizes that energy management best practice will play a vital role in achieving the national target. Nationally, the Department of Mine and Energy (DME) has commenced an initiative to develop and roll-out an energy management training and awareness programme to be implemented within the industry and mining sectors (Department of Mineral and Energy Pretoria, 2005). The staff does not only influence the functioning of the building but also influences energy consumption through EE information received. If more information is given to staff and all building users, they can make better decisions and their behaviours can change. Darby (2006) argues that by enabling final consumers to make better-informed decisions, a reasonable amount of information should be provided; while Petersen et al. (2007) explained that students, supplied with information on environmental consequences of resource use can decrease electricity usage. For Iris and Lam (2019), The operational strategies cover methods that focus on energy aware planning of operations in ports. The energy-aware planning aims to reduce energy consumption of equipment, reduce the processing time of operations, operate the equipment in non-peak hours, and optimize operations considering energy prices. Olatomiwa et al. (2019) argue that the behavior is one of influencing factors in the Energy management strategies. According to Weber (1997), energy consumption belongs to the realm of technology but energy conservation to the realm of society. This statement was connected to idee of Zhang et al. (2012) that presented an energy management strategy for a commercial building in a supermarket application and also established some objectives which include reduce the electricity bill, maintain a balance between the power of peak and off-peak periods to reduce the CO_2 emissions, and ensure energy availability during load shedding, and reduce the electricity bill and the CO_2 emissions of commercial buildings such as supermarkets by using photovoltaic (PV) and storage systems. The study used the energy management supervision strategy based on the rules of the electricity bill to accomplish the objectives. It was shown in his study that with the help of simulations and comparisons, the energy bill cost and the CO_2 emissions could be reduced.

For Imes and Hollister (2015) in “Energy management system and method”, the energy management systems took a passive role to residential energy management. For example, when consumers lack energy awareness and typically left with having to evaluate a monthly bill to determine how much energy was consumed and consumers lack transparency into what the leading causes of energy consumption are at their residences. Some utility companies are providing energy display only technologies that will allow consumers to see what the current price of energy may be, the case of smart meter. Smart metering (eGauge) was continuously monitoring the energy consumption with a view to gaining a better understanding of the energy consumption and transportation stages. It improves the decision-making phase in future, and positively influence the energy behavior of final users and managers (energy awareness). Since smart metering permits the real-time visualization of consumed energy, users can better understand their own energy behavior. In this case, there is the advantage of reducing energy waste and encourages users to change underperforming behaviours.

2.3 Importance of energy efficiency in the commercial sector

As stated in section 1.3, EE has different definitions depending on the field of work. It links to efficacy, effectiveness, savings or performance of energy users. these three terms are important to this study. Technically, efficiency was defined in section 1.3 as the energy output divided by the energy input and expressed as a percentage. According to the European Commission, efficiency means “doing more with less” as described in the Green Paper, energy efficiency of the European Union (EU), DeCanio (1998). Generally, this definition is applicable to many fields including business. This definition has caught the attention of the researcher. For this study, EE refers to using less energy to produce the same amount of energy, this can also mean that it is the ability to avoid wastage of energy consumption that can produce the desired result. In this regard, EE becomes the basis for determining, measuring, monitoring, and controlling energy consumption in the processes.

Energy efficiency improvements are, however, often influenced by many factors but for the purpose of this study, two factors will receive attention: technological and non-technological factors. Sorrell (2015) described technological developments and the adoption of technologies as efficient methods and processes that have significant impacts on reducing total energy consumption. Non-technological factors which have an impact on energy efficiency are often introduced through standards, which generally promote the adaptation of more efficient equipment, appliances and methods (Sorrell 2015). Van der Waal (2014) claimed that the rising cost of electricity in South Africa and the increased demand on the grid, have stimulated large commercial businesses to implement energy-efficient initiatives and technologies. The introduction of NEES by the national government to achieve a target of 15 % by 2015, has promoted EE and sustainable practices among businesses. Van der Vaal went further to argue that energy efficiency can become a culture in South Africa if large commercial businesses invest in initiatives that positively influence the perception of energy-consumers and encourage the adoption of sustainable practices. Cutting down the consumption according to Van der Waal is investing in efficient motors, water heating systems, proper building management, and regular maintenance. A study performed by (Didden, 2005) has shown that replacing conventional motors by Variable Speed Drive (VSD) compressors is good but requires improvements in some cases. In these cases, the savings are decreased or even eliminated by process downtime duration due to the VSD tripping on voltage depressions because of short circuits in the grid. Gupta (1999) completed a study analysing some initiatives of EE and environmental improvements in Indian micro, small and medium enterprises (MSMEs); it was believed that a technocratic top-down approach for energy efficiency improvement was not comprehensive.

(Maistry, 2012) conducted a case study at the Metropolitan University of Gauteng to examine the implementation of EE in the context of green or sustainable campus movement. The study focused on energy efficiency and demand-side management (DSM) where the first technique, which deals with energy conservation and efficiency to save energy, focused on the behaviour of consumers. The second technique is demand or load response program to shift and reschedule the energy consumption. This second technique is related to technology-based action.

The study on energy audit of the Howard College Campus of the University of KwaZulu-Natal (Govender, 2005) focused on establishing a base for energy conservation opportunities to be realized for electricity cost savings at the University of KwaZulu-Natal. The Industrial Energy Management Training Course (2015) listed characteristics for companies that are effectively doing energy management. Among the characteristics are:

1) To display a broad awareness of the benefits of energy efficiency throughout the organization.
2) To collect and analyse information to manage their energy use.
3) To have an energy management plan (short term and long term).
4) To integrate the task of managing energy into the overall management structure of the organization.
5) To provide leadership for energy management through a "champion" or group of committed staff — an energy management team — and, perhaps have top-down commitment expressed in the form of an energy policy.

2.4 Six Sigma DMAIC

2.4.1 Six Sigma DMAIC history

Six Sigma is linked to many statistics tools, such as factor analysis, statistical control chart and Pareto charts. People who use Six Sigma can benefit from applying those tools and techniques without the aid of statistical experts. Thus, Six Sigma is a systematic method to help organizations to investigate critical problems and find out solutions to be implemented continuously.

Six Sigma has played an instrumental role in quality control regulations since its early days as Motorola's control method says Seow et al. (2004). Between the years of 1987 and 1997, Motorola Incorporation's implementation of the idea of Six Sigma led to the company saving over USD 140 billion (Chang et al. 2013) becoming an international benchmark for quality control. Six Sigma is a management philosophy developed by Motorola in 1986 by Billy Smith, it requires setting extremely high objectives, collecting data, and analysing results to reduce defects in products and services (Atanas et al., 2016). The Six Sigma success story in Motorola has proved its ability to improve quality while reducing operating costs and increased customer satisfaction (Harry and Schroeder, 2000). Six Sigma has also been proven to be rare in its ability to improve both process and product quality (Zugelder, 2012). Today, Six Sigma DMAIC is used in many industrial sectors state Atanas et al. (2016). Since its first acknowledgement, Zugelder (2012) believed that Six Sigma DMAIC has demonstrated its fluency in many other sectors such as service delivery and healthcare. Recent years, however, have seen an increased interest for Six Sigma DMAIC in the energy sector. The power supply quality problem is becoming more and more important for customers and manufacturers, argue Gupta, et al. (2011) and Tianrui and Sen (2012). Poor power supply increases risk, the cost of doing business, and hence, in general, ruins a business explain Hsu, Chen, and Yang (2013). Therefore, this study used the Six Sigma control method with the DMAIC framework to reduce the energy consumption over time in order to enhance the power supply efficiency in a commercial building in Durban. For Jones (2014), the main ideas of Six Sigma (SS) thinking are important. He advised that the mindset of Six Sigma should be that Six Sigma takes a business problem, converts it to an engineering problem that uses statistics, then develops an engineering solution, and finally converts that to a business solution. Figure 2.1 explains how SS takes a business problem to a business solution.

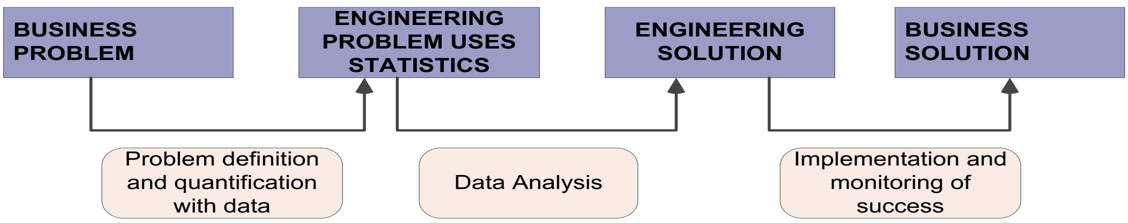


Figure 2.1 Role of industrial systems engineering thinking and methods.

2.4.2 Energy improvement using Six Sigma DMAIC

According to Kane Jr et al. (2003), Six Sigma with its structured problem-solving approach, its strong focus on statistics and proven method for controlling improvements long after they are made is ideally suited to help drive energy efficiency excellence. DuPont Corporation established a goal in September 1999 to hold total global energy use flat from 1990 to 2010. Six Sigma has been involved in identifying and realizing energy efficiency improvements, in pursuit of the goal and will also ensure that the achieved gains continue well into the future (Kane Jr et al., 2003). Using Six Sigma tools to analyse energy conversion processes such as steam boiler, turbine generator, central refrigeration, or when applied to energy utilization processes such as manufacturing process heating and refining, both applications of SS have led the authors to achieve remarkable sustained energy saving averaging over $250,000 per year at DuPont (Kane Jr et al., 2003). Furthermore, Kaushik et al. (2008) applied six sigma methodologies in the thermal power plant seeking energy conservation leading to control costs, maintenance of high levels of safety and quality, and save energy.

McIlroy and Silverstein (2001) explained that Northrop Grumman implemented Lean Six Sigma in an Aerospace Company. They integrated a problem-solving process developed at GE with the Lean Thinking methods and Kaizen events. They used Six Sigma's strategy and methods within their product teams, not as a separate package. Their proper process integrated Workout, Kaizen and DMAIC into the Six Sigma Breakthrough Trial. They used subject matter experts and a Black Belt on their project team and completed a four to five day Define/Measure phase, then performed the Measure, Analyze and Improve phases of roughly thirty days each. The final activities included a post-Trial phase as the Control, Integrate and Realize phase. They used the Lean improvements "to change some things that are obvious and save the Six Sigma tools for the High Fruit – the harder problems". They also used Six Sigma tools to legalise (authorize) proposed solutions statistically prior to implementing the solutions.

In Chapter One of this study, it was said that the original mission of Six Sigma's DMAIC methodology is variation reduction, for this study, variation is anything that could influence the increase of energy consumption. As stated by de Mast and Lokkerbol (2012), Six Sigma and its DMAIC are built on perceptions from the quality engineering ground, incorporating ideas from statistical quality control, total quality management, and Taguchi's quality control. Generally, it has been used like quality improvement, efficiency improvement and cost reduction. Li et al. (2008) conducted a study and successfully implemented the DMAIC approach to improve the capability of the solder paste printing process by reducing thickness variations from a nominal value.

A study presented by Goyal showed how Lean Six Sigma was implemented in a company that converted paper documents to electronic copies (Goyal, 2002), The company first improved the inconsistency of the product quality through the application of Six Sigma quality tools. They used a DMAIC improvement process. Firstly, they performed a Define and Measure of the problem by using brainstorming to identify over 30 problems, and finitized the problems into two categories, then prioritized the problems using a weighted voting consensus system. A second brainstorming session further defined the problems (problem = customer desire – current). Then, collected data to measure the problem. The second phase achieved was the Analysis phase. They flowcharted the process and identified the value-added and non-value-added activities. Principles of Lean manufacturing were introduced during the Analysis phase including zero waiting time, zero inventory, scheduling using pull techniques, reducing batch sizes, line balancing and cutting actual process times. With the data collected, it took the group only a few minutes to draw a Pareto Diagram of delays and concluded that three vital reasons causing 70 % of the delay was non-processing (waiting). They performed an Idea Generation phase to develop an implementation plan. They performed a pilot test of the new process, and then implemented the change and checked the result. To control the processes, they implemented control charts (a Six Sigma technique) and standard operating procedures (a Lean tool). The Lean Six Sigma implementation reduced the error rate by 98 % when converting paper documents to electronic copies, increased productivity over 50 %, reduced costs, improved quality, and improved the ability to handle peaks of input data within customer specified turnaround limits (Goyal, 2002).

2.5 Similarities, differences, and preferences of concepts

From the different studies above, it can be concluded that for successful improvement of energy use, the following are required:

- energy management
- energy efficiency
- DMAIC methodology

The above-mentioned points do not constitute a comprehensive list to ensure success but are a common thread in the studies analysed above. The likenesses of energy management, energy efficiency and DMAIC problem-solving in the energy improvement journey used by this literature review is their pursuit to efficient use of the energy and the cost-effective savings.

Authors of different studies discussed in this chapter agreed on the similarities of the concepts and they have demonstrated that efficient use of energy can be achieved by technological progress and by a change in behaviour. DMAIC, as a process, is one of the methodologies capable of tackling the problem using technical and non-technical approaches to improve energy use in different sectors of the economy (Van der Waal, 2014), these improvements can be measured.

The DMAIC methodology has shown a wider application in different industries and how the engineering, manufacturing, mining, commercial and services organizations can achieve competitive advantages, efficient decision making, and problem-solving capabilities within a business context. Therefore, adopting the DMAIC procedure turns out to be an effective method in improving energy. DMAIC approach is favoured over other approaches because, the energy-saving portions are clearly defined and are subject to normally recognized measurement or verification approaches (statistical tools), to legalise (authorize) proposed solutions statistically prior to implementing them.

Gaps: There is little interest locally in DMAIC process improvement, even studies globally have demonstrated initiatives of organizations to improve energy use in different sectors of the economy, mainly in the manufacturing industry predominantly with the technical approach. But such initiatives require a general perspective necessary for comprehensively addressing the problem. A drawback of DMAIC exists in an internal team. It is too comfortable for the internal team with current practices, the team sometimes can miss clear opportunities for improvement. Another disadvantage when collecting data with internal lacking experience is identifying multiple resources of reducing energy. Therefore, the best way to perform data collection is to initially have an outside team come in and give an internal energy team the bridges of where to start reducing energy.

2.6 Conclusion

This chapter has covered all three energy concepts (energy management, energy efficiency and DMAIC problem-solving) of the study regarding energy improvement. Through various studies, it has been seen that these concepts have the common objective which is the efficient use of energy. These concepts have been reviewed to achieve the study objectives.

The highlight of this literature review is the fact that Six Sigma DMAIC has proven to be a very useful tool for improving electrical energy consumption and cost reduction for the business process. Its application into energy improvement in recent years has proven equally beneficial. Key data can be collected, through establishing energy frameworks to identify scenarios for energy reduction. Once the electrical energy consumption profiles for commercial buildings have been established, additional helpful interventions from technological opportunities can be also identified.

Chapter Three: Methodology

3.1 Introduction

One of the main methodologies within Six Sigma is the DMAIC problem solving. This data driven approach focuses on reducing variation. It follows the structure Define-Measure-Analyze- Improve-Control. The study started by first identifying an appropriate building that needs to be studied. The building identification characteristics involved the one with improvement possibility associated with higher energy consumption and cost. Also, the research investigated electrical Switch and DB installations; floors, rooms and appliances used in building. After a building satisfying all of the above specifications was determined and relevant permissions granted, a process mapping, a building drawing and schematic diagram was drafted in order to map out the building wiring procedure and specifications. Figure 3.2 illustrates the studied commercial building, electrical supply flow chart and their respective distribution boards. The voice of customer (VOC) was well defined; the team, the current process mapping, the building drawing, and schematic diagram were well identified. The first step ensured that processes around the building was well defined.

The second step consisted of data collection and measure. The procedure used to collect electrical data is a smart device called eGauge system which permits its users to view historical and live data for the lifetime of the hardware. The retrieved data were presented in a spreadsheet form and subjected to further analysis sing Microsoft excel and SPSS version 25.0 in third step.

The outcomes were presented as descriptive statistics in the form of graphs and other figures. The results was compared to previous data (historical data) to confirm the potential causes for improvement of the process.

3.2 DMAIC Process

The methodology follows the rigorous pattern defined as Define, Measure, Analyse, Design, and Control to improve energy consumption within a commercial building. This methodology leads the project team from the beginning of the plan (Define) to sustaining the results (Control). The main concept that needs to be understood is that Six Sigma is a performance target that applies to a single representative which is critical-to-quality (CTQ), argued Zugelder (2012), the CTQ in this study is the requirement of the customer which is to identify factors that influence the increase of the energy consumption to reduce energy price. Figure 3.1 describes the key processes for each step of the DMAIC closed-loop process. DMAIC problem-solving approach is a useful and effective method for continuous process improvement. Its purpose is to improve an existing business process by eliminating unproductive steps, often focusing on measurements, statistical tools and techniques to reach sustainable solutions and also apply technology for continuous improvement. The resulting solutions will reduce or eliminate the problem and improve the performance of the organization.

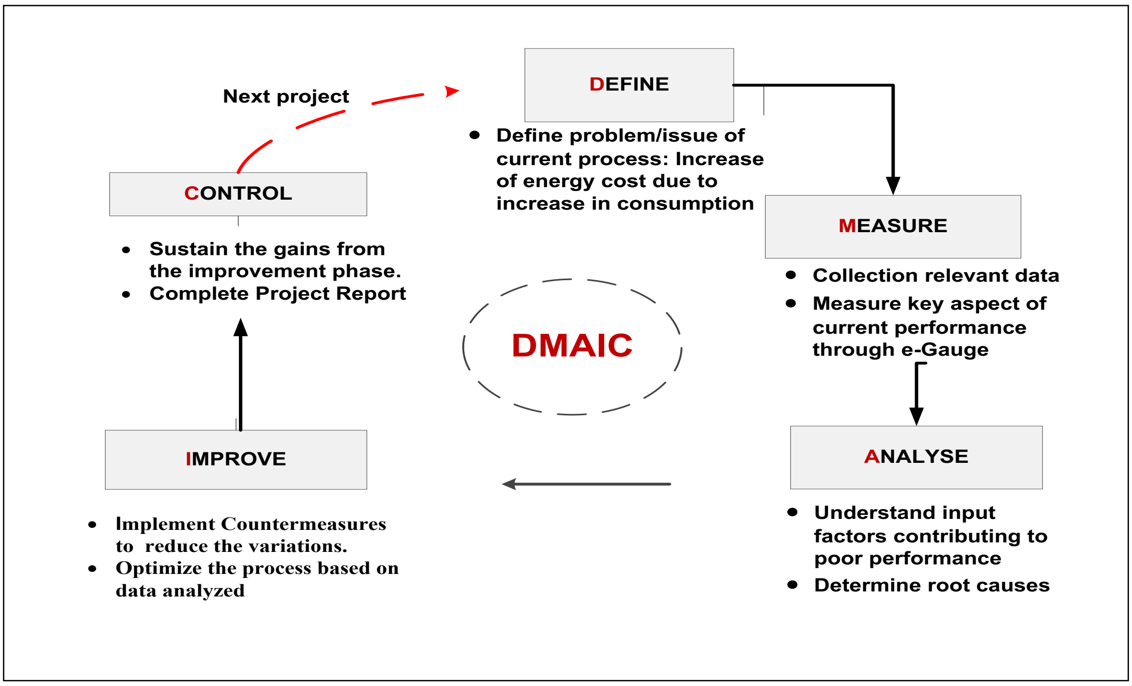


Figure 3.1 DMAIC process closed loop

3.2.1 Define step

This step starts with the identification of a problem that requires the solutions and ends with a clear understanding of the scope of the problem and management support. The define step ensures that the problem goes through the DMAIC process and it is linked to company priorities. To identify the problem, the project team met with a maintenance manager, electrical engineer, general manager, and industrial engineer at the building. The aim of the meeting was how to reduce their monthly cost of electricity. The problem statement was the monthly cost that was increasing due to the increase in electrical consumption and the goal is to improve its usage.

Section 1.3.1 explained the energy crisis in South Africa and mentioned all energy sectors which contribute to the national economy. The commercial sector alone consumes 11 % of total national energy. A commercial building in the city of Durban, South Africa, was chosen for this study. After a discussion on the problem statement in the meeting, management was asked a series of questions (interview) to establish if the plan of the building exists to understand the electrical layout to locate the SEU, to know where to install the eGauge meter to produce the required data for analysis and to determine the daily energy consumption. The drawing of the building was unavailable; therefore, it was necessary to walk through the building to draft a temporary drawing to determine the right location of SEUs and electrical layout and locate a place for installation of the eGauge meter. The common areas of energy users found in building were the kitchen, offices, one clinic, apartments, restaurant, and beauty salon. These areas have different energy users such as air conditioners, boilers, televisions, computers, clinic machines, elevators, lights, and kitchen appliances. Some of the energy users do not have direct circuit breakers, but combined circuit breakers. For example, air conditioners, clinic machines and lights do not have individual circuit breakers but are fed from the plugs.

During the walkthrough the building, it was found that the electricity supplier, one municipality breaker feeds two parts of the building, the first part of the building is at east side which has six floors. These six floors are fed from the distribution board called Void DB and each floor has mini distribution boards (DB) that feed all the apartments on that level. The second part of the building is at the west side and has four floors. These floors are fed from the DB A and each floor has a distribution board (DB) that feeds all the apartments of the respective floors on the west side. All electrical distribution boards in the building were located, and a building sketch was drafted for better understanding. Figure 3.2 shows the building sketch and the location of the DB. It was then important to identify how the energy flows from the supplier, Eskom to the end-users. The supplier feeds the power (energy) from its transformer through the municipality breaker to the building breaker then to the energy user breakers. The capacity of energy depends on customer demand. Figure 3.2 shows how the power flows from the supplier to the end-user.

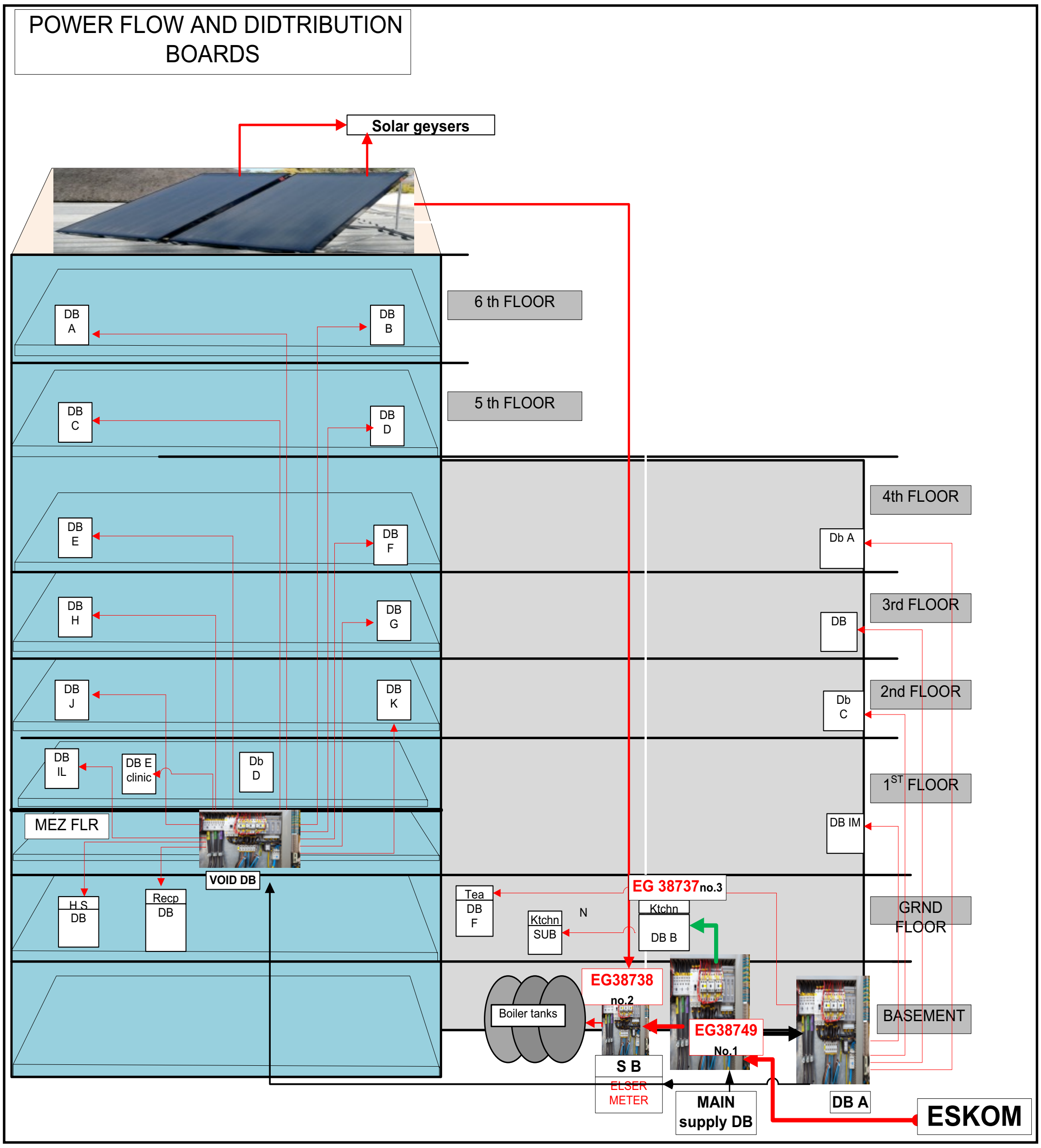


Figure 3.2 Building sketch and DB locations

It is also important to find out the strategic points for installing eGauge devices before data collection.

3.2.2 Measure step

This step consists of measuring the electrical consumption data collected for the building. The historical data collected from supplier bills and actual data collected from SEUS through the eGauge smart meter to help monitor the consumption.

3.2.2.1 Baseline

To determine the historical data of electrical consumption in the building and its associated costs for the building, the researcher gathered electricity bills from the supplier for a one-year period. The electricity bills for the recent year, 2018 was recorded on a monthly basis for reliable data and the monthly cost for energy consumed was recorded. They both consumed energy and the cost charts were constructed for future comparison after improvement. The electrical consumption in kWh versus years was constructed to establish a baseline that could help the study as a reference or standard for comparison for future performance. In the baseline, the study focussed on details of energy used and rand spent (cost): the energy consumed, the energy demand and the period, for example, the monthly energy consumption, the cost or charge of energy used supplied by national energy supplier, Eskom with electricity bills from the supplier.

The historical data provided by the electricity supplier (Eskom) through the electricity bills, no consumption details of individual SEU of the building was provided. Therefore, the eGauge system was needed recover data from each SEU. The historical data of energy consumption and energy costs are presented in Figure 4.2 and 4.3 in chapter four below. Three smart eGauge meters were installed.

3.2.2.2 eGauge installation

eGauge is a smart meter that reads and measures current transformers as many times as possible, calculates power, stores data, and displays the information. Data stored were calculated in a given period (seconds, minutes, hour(s), day(s), month(s), or year(s). According to Dittawit and Aagesen (2015), eGauge is a revolutionary smart meter which gives consumers more choices and real-time information. Information and communication technology are tightly integrated for better management. According to Energy Savings for Schools Program Colorado (2018), eGauge is an electricity monitor with an easy-to-use web-based portal to view electricity use in a building in real-time and overtime. The installation of this smart meter-reading device is highly recommended. Figure 3.3 describes the eGauge device.

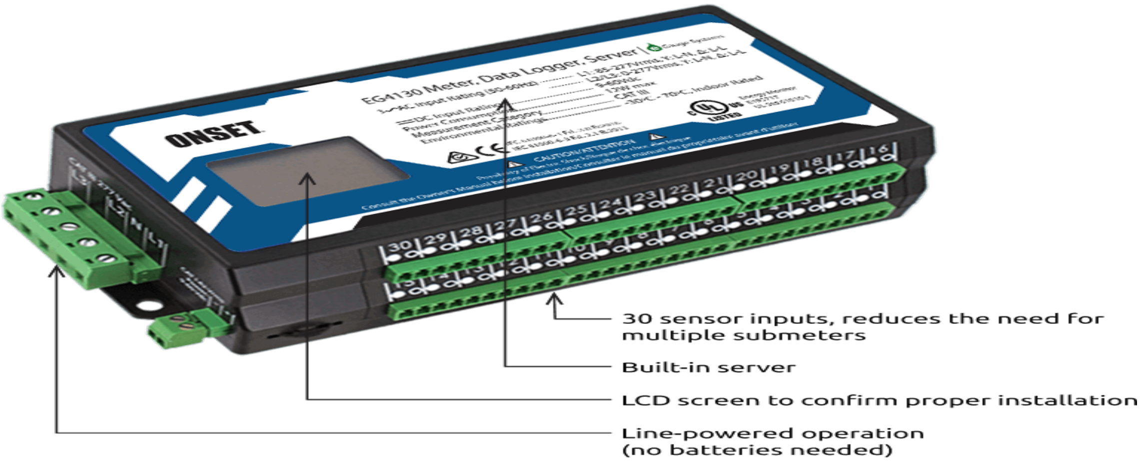


Figure 3.3 eGauge components

This vital instrument is installed with a direct connection to the electrical panel, so one can immediately be connected to the distributed electrical wiring. The first eGauge or number one (no. 1) is connected to the main supplier breaker in the main distribution board. There is a guideline to be followed with the installation of the eGauge and associated current transformers (CTs). The eGauge has a potential transformer configuration (Woodall et al.) that informs the device of any potential-transformers (PTs) that may be installed and has also different CTs according to their capacities. In this study, the installed eGauge in the building is 30 CTs input used in different strategic areas in the building.

According to the Energy Savings for Schools Program Colorado (2018), in order to properly install an eGauge, it is critical to understand a key concept called a “phase”. An electrical system phase represents one line of power. Usually, electrical panels have multiple phases powering the breakers within it, for example, a 120/240VAC panel has 2 distinct phases, and the breakers in that panel are either powered by Phase A or Phase B. When measuring power, a current on Phase A must be multiplied by the voltage of Phase A to correctly calculate power for a circuit. The phase of the electrical system connects with each available voltage terminal position.

Figure 3.4 Power connectors

Figure 3.5 Current transformers (CT's)

Below is the example of three-phase installation measuring power coming from a power utility (grid) as installed in this building. CT1 is on leg L1, so they must be multiplied by L1; CT2 is on leg L2, so it must be multiplied by L2 and CT3 is on L3 so it must be multiplied by L3. The first voltage-tap (L1) and the first grid CT1 are required to measure the power flowing on phase 1, L2 and CT2 measure the power flowing on phase 2, then the third voltage-tap (L3) and a third Grid CT3 is required to measure power flow on phase 3.

Table 3.1 Three-phase installation

Pin	Phase	Leg
1	Phase A Main CT	L1
2	Phase B Main CT	L2
3	Phase C Main CT	L3

Wiring the 5-position plug is as follows:

Black wire: pin labelled L_1 to breaker for phase L_1.

White wire: pin labelled N to Neutral.

Red wire: pin labelled L_2 to breaker for phase L_2.

Blue wire: pin labelled L_3 to breaker for phase L_3 (3-phase installations only).

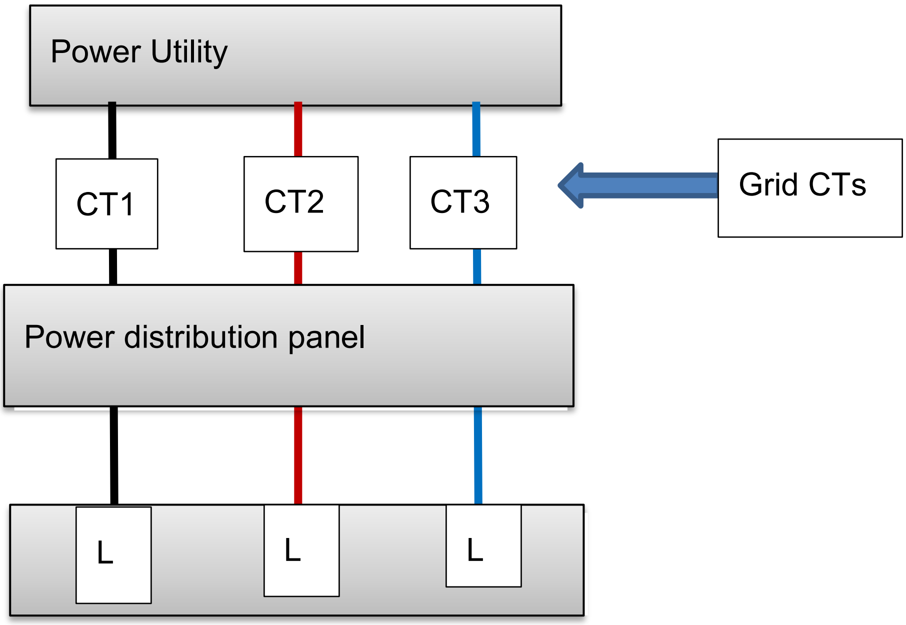


Figure 3.6 Standard three-phase installation

In order to connect the AC voltage, the user needs to first determine its electrical service type. Secondly, connect the eGauge "N" terminal to the neutral bus bar of the electrical panel using NEC compliant conductor. Thirdly, connect applicable lines L_1, L_2, and L3 to a breaker or fuse block using an NEC compliant conductor. Finally, make sure that each line is connected to its respective voltage phase in the panel.

3.2.2.3 Collection of actual data

The eGauge meter reads current transformers as many times as possible, calculates power, stores the data, and creates a user interface to display the information. The user interface is a webpage, so there is no additional software to install or download. The data deposited can be exported to an Excel spreadsheet. the eGauge has inputs and outputs that are connected to circuit breakers of energy users such as kitchen, main supply, and many more. The device can measure separately, yet collectively segment all the building for higher consumption such as the boiler, the common kitchen, the light and plugs. The data collected from an eGauge meter are recorded hourly, daily, weekly even monthly depending on the customer's needs. The device also allows the real-time values access, long-term reports, an interactive graphical interface, and many other tools (eGauge.net, 2016).

The eGauge in Figure 3.3 provides 12 positions for the CT plugs. The silk-screened numbers indicate which CT should be connected to which pair of pins. Pins that are to receive the black wire of the CTs are marked with a circle with a black interior, but pins for the white wires are marked with a circle with a white interior.

Table 3.2 describes power connectors of eGauge, and their description rated for measurement performed in the building installation. According to the eGauge website, "Pin L1 serves three purposes: it powers the device, the voltage on the line is measured to calculate power used/generated on phase L1, and model EG301x devices carries the power-line signal for communicating with the Home Plug AV wall-plug adapter. The pin must be wired to the building's power supply with a voltage in the range from 85–277Vrms (to neutral). In contrast, pins L2 and L3 are used purely as voltage-taps so power used/generated on phases L2 and L3 can be calculated. Wiring these pins is necessary only if there are CTs measuring current(s) on L2/L3. The voltage on these lines can be 0-277Vrms (Vac or Vdc). The input impedance for L2 and L3 is approximately 950kΩ at 60Hz. By connecting L2 or L3 to a DC-voltage, it becomes possible to monitor, for example, the voltage on a battery backup".

Table 3.2 eGauge power connector

Pin	Name	Description
1	L1	Wire to phase 1 of building supply
2	N	Wire to building's Neutral.
3	L2	Wire to Phase 2 of building supply for split- and three-phase installs.
4		Unused. Leave unconnected.
5	L3	Wire to Phase 3 of building supply for three-phase installs.
6	P	Records the power calculated from one or more current/voltage-pairs.
7	I	Records the current measured by one of the connected CTs

The power components define which currents and voltages are to be combined to calculate a register's power figure. In our example, the power component for the Main Service is as follows:

Equation 1: $P = CT_1L_1 + CT_2L_2 + CT_3L_3$

The Main Service power is calculated as the product of the current measured by CT_1 and the voltage measured on line L_1 (for example, black leg) plus the current measured by CT_2 and the voltage measured on line L_2 (for example, red leg), plus the current measured by CT_3 and the voltage measured on line L_3 (for example, blue leg). The power coming from the three legs of the three-phase power feed from the utility are combined into a single register.

It is possible to record the three legs in separate registers, the total power for the main supplier:

Equation 2 = Main P: main supplier red [L_1] + main supplier white [L_2] + main supplier blue [L_3].

Main supply: Main supply L1 + Main supply L2 + Main supply L3

Boiler Total: Boiler element 1+ Boiler element 1B + Boiler element 2 + Boiler element 3.

Kitchen total: Kitchen main L1 + Kitchen main L2 + Kitchen main L3

After the performance of all the components or energy users have been measured in the unit of time (month, days or hours), the next step is to analyse them in order to determine the cause of the increase in consumption.

3.2.3 Data analysis step

This step consisted to understand the input factors contributing to poor performance and identify the cause-and-effects relations. It commences with analysis data measured in previous step using eGauge device. The data obtained however from eGauge were exported to Microsoft Excel in the form of a spreadsheet and are subjected to analysis using Microsoft Excel and SPSS version 25.0. The results were presented here as descriptive statistics in the form of graphs, tables, charts and histograms in order to analyse the performance. The data collected from eGauge for each energy user such as boiler, kitchen, lights and plugs were evaluated during a period to compare their performance. The total consumption of each EU was given and the statistic tool such as a Pareto bar chart was used to determine the most significant energy users that influences the variation in consumption or cost.

After identifying the SEU's, a fish-bone diagram was constructed to visualize the potential causes to find out the root cause of the problem. As the name indicates, the fishbone resembles the side view of the skeleton of a fish. The head represented the problem, which is the high consumption of the boiler. The different lines attached to fishbone spine like ribs are called individual causes or categories. Each category influencing the consumption was added to the diagram by brainstorming the reasons for bad data issue. (e.g. How could category like equipment affect the electrical consumption?). The sub-causes could be added as well to identify why each cause happens.

3.2.4 Improve step

This is the stage of optimizing the process and implement the countermeasure or looking at the other ways of improving electrical consumption and saving money. The resource or equipment that consume the most was identified and cause of variation were determined in previous step, now a new way of solving this problem by reducing variation or temperature.

The control chart was used from individual values of electrical consumption versus the time to identify how energy was consumed during that period. A typical control chart contains a center line that represents the average. In this case it is the average value of consumption values ($\bar{X} = X_1\ X_2\ X_3 \ldots Xn/N$), where N is the number of observations. The other two horizontal lines, called the upper control limit (UCL) and the lower control limit (LCL), are also shown on the chart. These control limits are chosen to determine if the process is in control. The variation on consumption is identified within or outside the control limits.

For the improvement, awareness campaign for energy conservation in the building was launched (e.g. switching off electrical energy users when not in use). Verification of the mean or average consumption either decreased or stayed the same after the campaign scenario. The improvement or saving in kWh and in rand is made by subtracting the consumption before the campaign from after the campaign.

3.2.5 Control step.

The final change is determined and the closing performance and all related changes are documented. Rigorous follow-up and corrective action with comprehensive documentation can increase the possibility that the gains are sustained. This phase includes the control of the improvement. It is the process of managing and sustaining the gains achieved in the improvement phase. As said in the beginning that DMAIC is a continuous improvement approach, to manage the new improvement. Management needs to continuously carry out the same steps of this project, communicate with energy users in terms of energy awareness campaign , change the policy in terms of control of energy user's temperature set up. Also the improved control limits resulting from previous phase need to be maintained in this phase. Some tools used in step are, I-MR chart, control plan, visual management and verification of financial savings. Refer to Table 3.3 to see the summary of the five DMAIC steps and its objectives.

Table 3.3 Summary of five phases of DMAIC

Steps	Objectives
Define	Define current processes, energy components and energy savings goals used
Measure	Measure the data collected, it allows for the understanding of the current process. Understanding of data derived from meter readings, or data recording devices. Establish performance value and improvement opportunity.
Analysis	Analyze of the data measured to determine the major cause of the problems by using statistical tools.
Improve	Choose cheap ways to save electrical. Consumption before and after the campaign.
Control	Use tools to sustain the gains achieved in previous phase: Awareness, maintain control limits, monitoring improvement, verify financial savings.

3.3 Conclusion

In this chapter, a detailed account of how data were collected from the commercial building being studied and steps the researcher intends to take in order to analyse the data and interpret the results are presented. The obtained results were reported as the mean ± Standard deviation (σ). The data obtained is subjected to further analysis with SPSS version 25.0. The outcomes were presented as descriptive statistics in the form of graphs, charts, tables and presentations. In Chapter four, the obtained data will be interpreted to give a result for the study.

Chapter Four: Results and Discussion

4.1 Introduction

This chapter gives a detailed analysis of the outcomes of data collected using eGauge in the building studied. This section describes and illustrates DMAIC was used to find out the factors that contribute to increase of electricity bill for the building. Three eGauge systems were installed in the building with the aim of collecting the building's daily energy consumption. The recorded data were measured in kilowatt and were exported to an Excel spreadsheet. In order to reach the study's objectives, the data obtained were subjected to analysis using quality tools and techniques. The use of these tools and techniques was guided by a main structured improvement method known as Define-Measure-Analyse-Improve Control (DMAIC). Figure 4.1 is the schematic diagram of the building describing: the electricity supplier sources, SEU, transformers and building distribution boards (DB).

The national electricity supplier "ESKOM" feeds to its transformer, the transformer in turn feeds the building's main distribution board where eGauge number one is installed to collect the total building consumption or total power fed to the building. The building's main DB feeds the sub-DBs on each floor through DB A and VOID DB. The significant energy users involve kitchens appliances, computers, boilers, air-conditioners, lights, lifts, and cold-rooms.

4.2 Define step.

It is the first stage in the DMAIC approach. Its purpose is to clearly understand and identify the business problem, project goal, potential resources or SEUs, target, and project charter as shown in the Project Charter in Figure 4.1. A team comprising of building manager, technician or electrician and researcher. Through a questionnaire (in a meeting with management), the study described the problem, but at this stage the root cause and solution to the variation were not included. The Table 4.2 gives questions and answers of problem description.

Table 4.1 Project charter

Background	Increase Of Energy Usage
Objective	To identify SEU and Improve energy usage
Scope	Electrical energy
Sponsor	University
Project Target	3 % savings
Project constraints	Cost of electricity increase to high
Team	Electrician, Maintenance manager, Researcher
Process Flow	Building diagram/drawing/Distribution Boards
Resources	Kitchen equipment, boilers, plugs

Table 4.2 Questionnaire to identify problem.

Questions	Answers
What is the problem/ issue that customer complaining?	It is the monthly increase of electrical consumption (variation)
What is wrong with variation?	Electrical consumption increase
Where and when variation been noticed? (graphic)	Figure 4.2 (historical data)
Where is location of variation?	Energy distribution (Fig.4.4 and Fig.4.5). Performance record
What type of variation?	Water temperature set too high
When the increase start happening?	More than a year ago
What is financial impact to the organization?	More electrical consumption Increases as variation increases
What is the trend of Increase? Bad/worse	Increase with increase in T°
Is there object varying the same with variation?	Dependent on variation

The schematic diagram of Figure 4.1 is the map to help understand and identify the boundaries of SEU and the key process to customers. The diagram also helps to identify key input factors that deliver the output response and informs where the data collection start point should be. The purpose of the customer requirement was to understand the prospects and needs and transform such into measurable

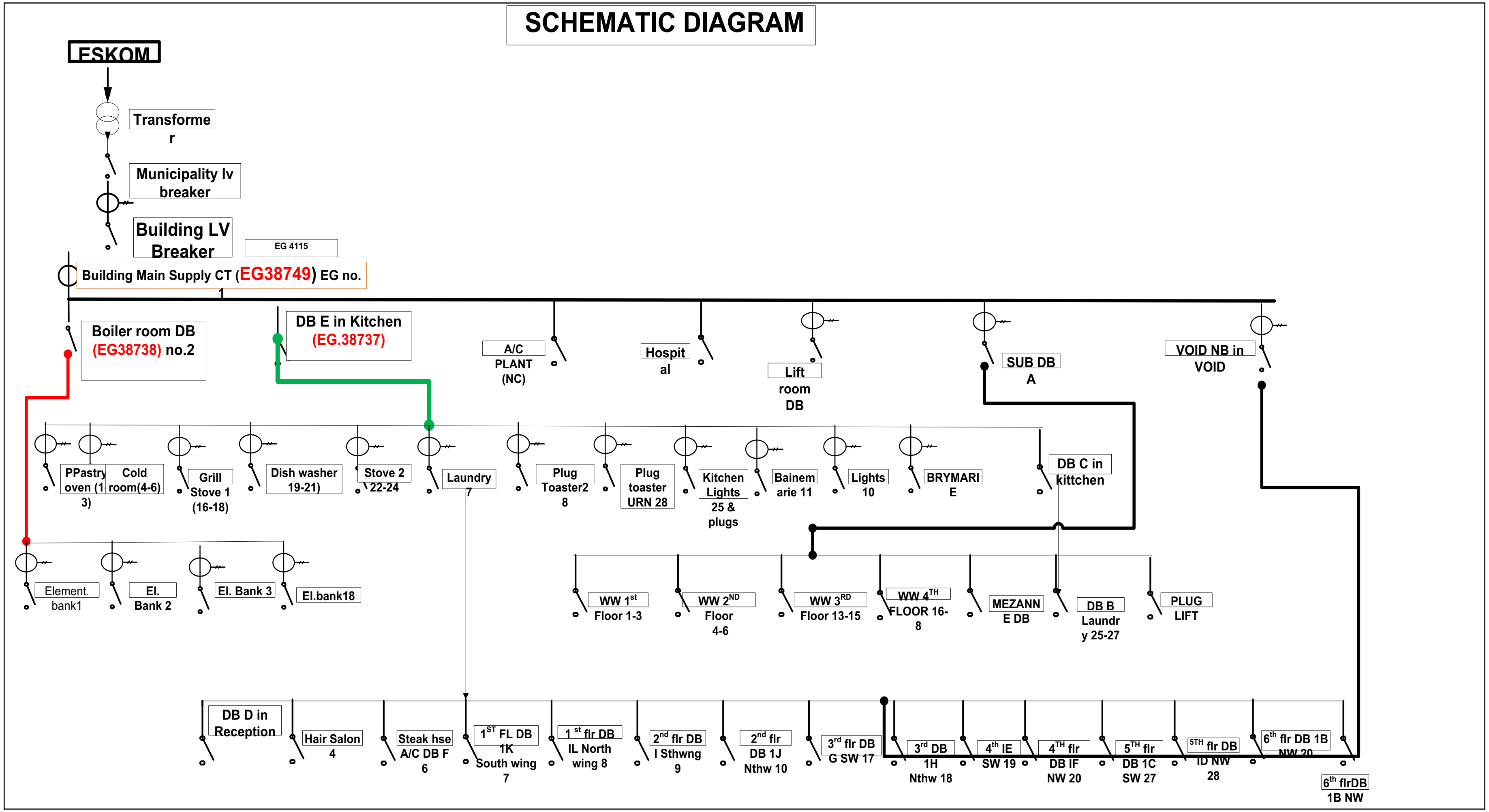


Figure 4.1 Flow diagram

and valuable features to ensure the focus on reducing electricity consumption. Briefly, this starting phase focuses on defining and identifying the goal of the study (requirements) which is to optimize both the consumption of energy use and its cost by eliminating energy wastage using the Six Sigma methodology DMAIC. In this step, the process mapping was used before getting started to describe the flow and a smart meter (EG) was used to measure and determine the actual power consumption and to gain an understanding of significant energy users (SEUs) or major appliances that consume more energy. Three eGauge systems were installed in the building with the aim of collecting the building's daily energy consumption.

4.3 Measure step

In this step, potential sources for variation in the process is identified through the process mapping and process data aspect. The potential cause in this step is the identification of the SEU that consumes the most energy among energy users. After the collection of data, the recorded information was measured in kilowatts (kWh) and recorded on an Excel spreadsheet. The outcomes were presented as descriptive statistics in the form of graphs, cross- tabulations and other figures for the quantitative data. The historical data of the building issued by energy supplier Eskom was used to construct the "**baseline**" which was the current state of electricity consumption for years 2017 and 2018 for verification of future performance. The Pareto chart was constructed to measure the performance of each SEU to identify the SEU. A fishbone diagram was also constructed to identify the possible causes for non-conformity or cause of increase of energy usage.

The building being studied was connected to three eGauge systems. As described in Table 4.3, eGauge number 1 (EG no. 1) is connected to the main supply current transformer (CT) which was from the income supply cable that reads all the incoming energy from the supplier. The second system (EG no. 2) is connected to the boiler room DB that reads only the power that fed to the two boilers with two elements each. While the last eGauge system (EG no. 3) is connected to the kitchen to read only energy fed to the kitchen equipment. All three eGauge systems are linked to the Ethernet. Data were generated and exported to the Excel spreadsheet hourly, daily, weekly, and monthly.

Table 4.3 eGauges connections

eGauges	Area Connected	Energy Users (Eu's)
No. 1	Main supply	All Equipment
No. 2	Boiler	Elements 1, 1B, 2, 3
No. 3	Kitchen	1 cold-room, 1 dishwasher, 2 stoves, 2 pastry ovens, 2 toasters, 1 extractor fan, 2 bain-maries, 2 washing machines, 2 dryers, kitchen lights, DB A

In line with Table 4.3, from eGauge number 1 to eGauge number 3, the first eGauge records the total consumption of the building; it is denoted as "Main total". As said previously, it was installed at the incoming cable that feeds all the building DBs. Its consumption is equal to the total energy supplied by Eskom, the national power supplier. eGauge number 2 is connected to boiler DBs and each boiler has two elements each to heat the water to distribute to the building. It makes four elements in total for two boilers. The last eGauge number 3 recorded the kitchen consumption. The illustration of different energy users connected to eGauge number two and number three is in the Appendix section (Figure A and Figure B). The kitchen, for example, had 10 energy users/equipment: Cold room (fridge), pastry oven, stoves, dishwashers, washing machines, toasters, bain-maries, extractor fans and kitchen lights including plugs for small boilers. This is explained in detail later in this chapter.

4.3.1 Baseline

Figure 4.2 describes the current state of electricity consumption for years 2017 and 2018. The historical data of the building issued by energy supplier Eskom will serve to construct the "**baseline**" for verification of future performance. Twelve months of the electricity bill of the building was constructed. The result shows that the consumption during 2018 was higher except for February and March 2017 where energy consumption was unavailable which helps the company to evaluate energy performance and identify opportunities to save energy.

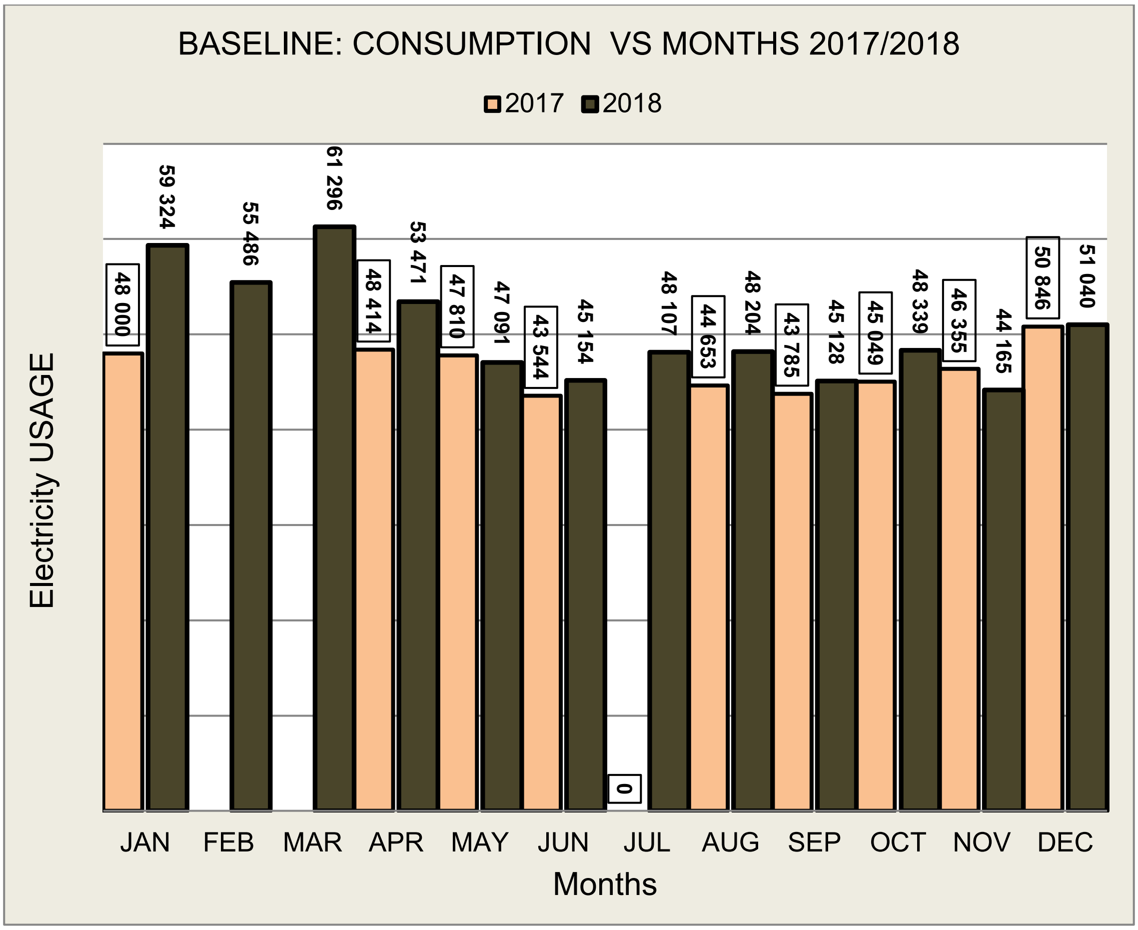


Figure 4.2 Baseline bar chart of 2017 and 2018 electrical usage

Based on the bar graph in Figure 4.2, the consumption during the second year (2018) was higher than the previous year except for November where consumption was lower than 2017. For year 2017, the consumption of February and March was unavailable. From September to April, the electrical consumption is high compared to consumption from June to August which is the wintertime, and this period is grouped as a peak time. During peak time, electricity is charged differently from electricity supplier Eskom (more than double). Table 4.2 provides the amount in rand spent on consumption of each month. Generally, the pricing of electrical consumption varies according to the sector. For the commercial sector, the charge depends on demand: the high demand season and low demand season. In this study, the high demand season starts from June to August and low demand season starts from September to May. During high demand season, the electrical consumption costs almost more than double compared to standard season. The table below illustrate the electricity consumption for June 2017, where electrical consumption was 43543.78 kWh and the costs were 43550.2 rand, the local currency.

Table 4.4 Details of June 2017 charge from the supplier, Eskom

	Consumption (kWh)	Cost/kWh	Amount (R)
Energy - Standard	21885.88	0.8385	18351.90
Energy - Peak	6919.80	2.6019	18004.63
Energy - Off-peak	14738.10	0.4881	7193.67
TOTAL	43543.78	3.9285	43550.2

The bar graph in Figure 4.3 shows the rand electricity expense versus electricity consumed for years 2017 and 2018.

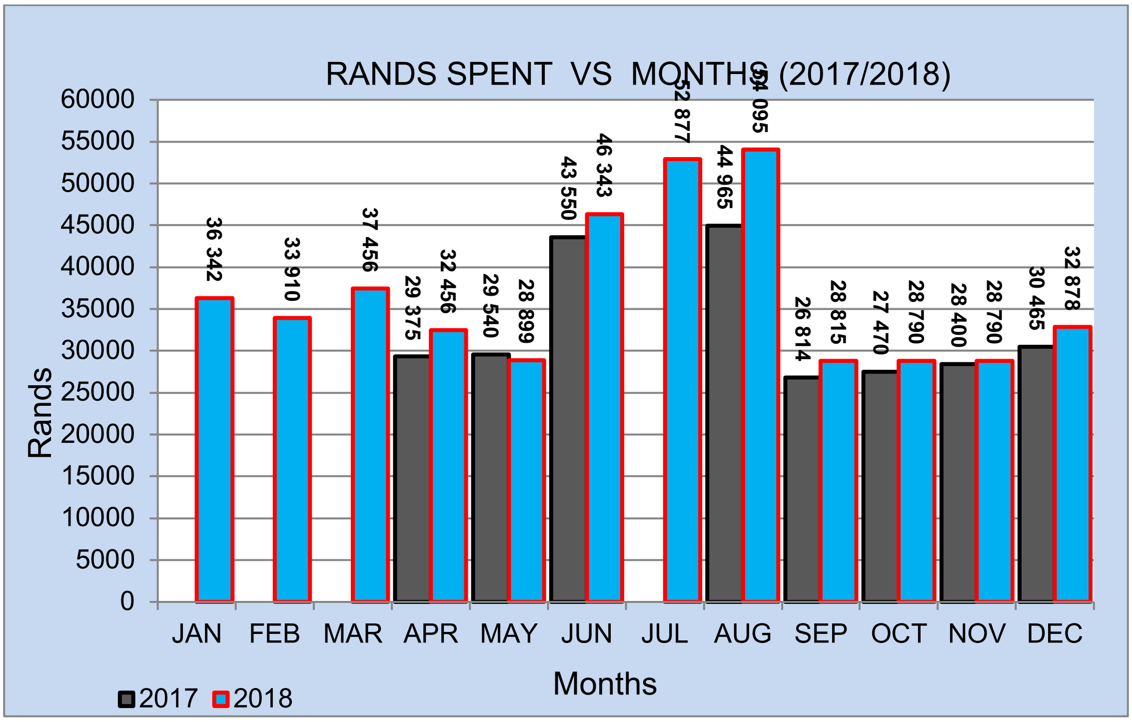


Figure 4.3 Monthly electrical bar chart cost for the building

4.3.2 eGauge data collections

4.3.2.1 Significant energy user's performance

The example of data recorded from October 2018 to February 2019 describes five main areas of the building in Figure 4.4. These five different areas were connected directly to the three eGauges. Figure 4.5 describes the performance of every area evaluated in percentage. The energy consumption shows that the boiler is the area that uses the most electricity energy with 38 % of the total consumption of the building. The kitchen comes in second using 24.2 % of the total consumption of the building followed by void DB with 21 %, then DB A with 21 % and the lifts were last with 3 %.

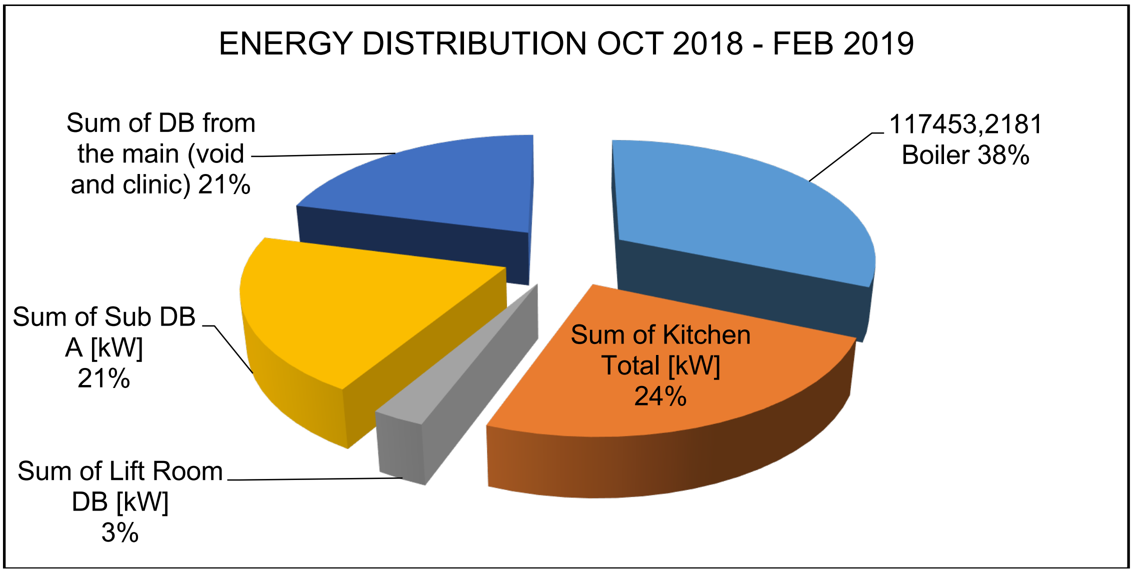


Figure 4.4 Energy distribution

Table 4.3 describes the recent energy consumption in kilowatt-hour (kWh) for 29 days collected from three different eGauges, their proportion in percentage, and their costs in rand (R) spent for each kilowatt used at the temperature. At that time, the boiler was running at 52 degree Celsius (52 ˚C).

Table 4.5 Energy consumption of three eGauges (1/06/2019 – 29/06/2019)

	eGauge No. 1	**eGauge No. 2 (Boiler)**	**eGauge No. 3 (Kitchen)**	**Rest (Db A and Lift, Void and Clinic)**
kWh	42189.7	16171.7	10196.9	15821.1
%	100	38,33	24,2	37,47
COST (R)	48464.71	18577	11713.5	18174,21

The eGauge number one was connected to the main incoming cable from the supplier and recorded a consumption of 42189.7 kWh, that represents the total consumption of the building for estimated cost of 48464.71 rand (R), the local currency. The eGauge number two was connected to the boiler and had recorded 16171.7 kWh of consumption which is 38.33 % of the total consumption with an estimated cost of R18577. The eGauge number two contains four elements (Boiler element 1, Boiler element 1B, Boiler element 2, and Boiler element 3). eGauge number three was connected to kitchen activities; it recorded 10196.9 kWh, which was 24.2 % of the total kitchen consumption and the estimated cost is R11713.5. REST is consumption eGauge no. 1 subtracted from eGauge no. 2 plus the consumption of eGauge no. 3. It means the total consumption of the building subtracted by boiler consumption and kitchen. The total of the rest of SEU used was 37 % of the total consumption of the building. The west side of the building was fed by DB A and the east side was fed from Void DB, both from the main DB as described in Figure 4.1. Some equipment in the building that were not connected individually to eGauge include computers, air conditioners, clinic machines and personal electrical devices. They did not have individual breakers in DB but were combined to the unique breaker labelled as a plug. These plugs fed sub-DB on different floors of the building, their total consumptions were the summation of individual consumptions in DB A for the building at the west-side and Void at the East-side. The study realized the first specific objective of identifying significant energy users (SEU) by conducting the energy audit in the previous part of this study. Figure 4.5 (Pareto chart) describes how process improvement was realized from the area with the highest energy consumption to the lowest one.

4.3.2.2 Pareto Chart

Pareto is a useful six sigma tool that leads to specific focus points and targets the most important aspects that can affect the energy consumption argument (Montgomery, D.C. and Woodall, W.H., 2008). Pareto identifies and rates the influencing parameters or problem areas that will have the biggest payoff to focus on. By observing Figure 4.5, the problems which caused the energy consumption to increase are plotted on the x-axis and the energy consumptions which were the consequences of the causes are plotted on the y-axis. The green diagonal line represents the cumulative percentage of energy consumption of areas. The Pareto Chart classified the problems according to the degree of importance; the boiler is identified as the first problem causing the increase in energy consumption with 38.3 % of the total consumption of the entire building. Followed by the kitchen in second position with 24.2 %. This makes a total of 62 % of the energy consumed. The total of cumulative percentage of boiler, kitchen and DB A and Lifts raised to 82%.

According to pareto principle or rule, Pareto analysis is recognised as the 80/20 rule because it is built on the idea that 80 percent of a project's gain can come from doing 20 percent of the work or 80 percent of problems may be caused by as few as 20 percent. The Pareto Principle is not a law but an observation that most things in life are not distributed evenly (Brooks,2014).

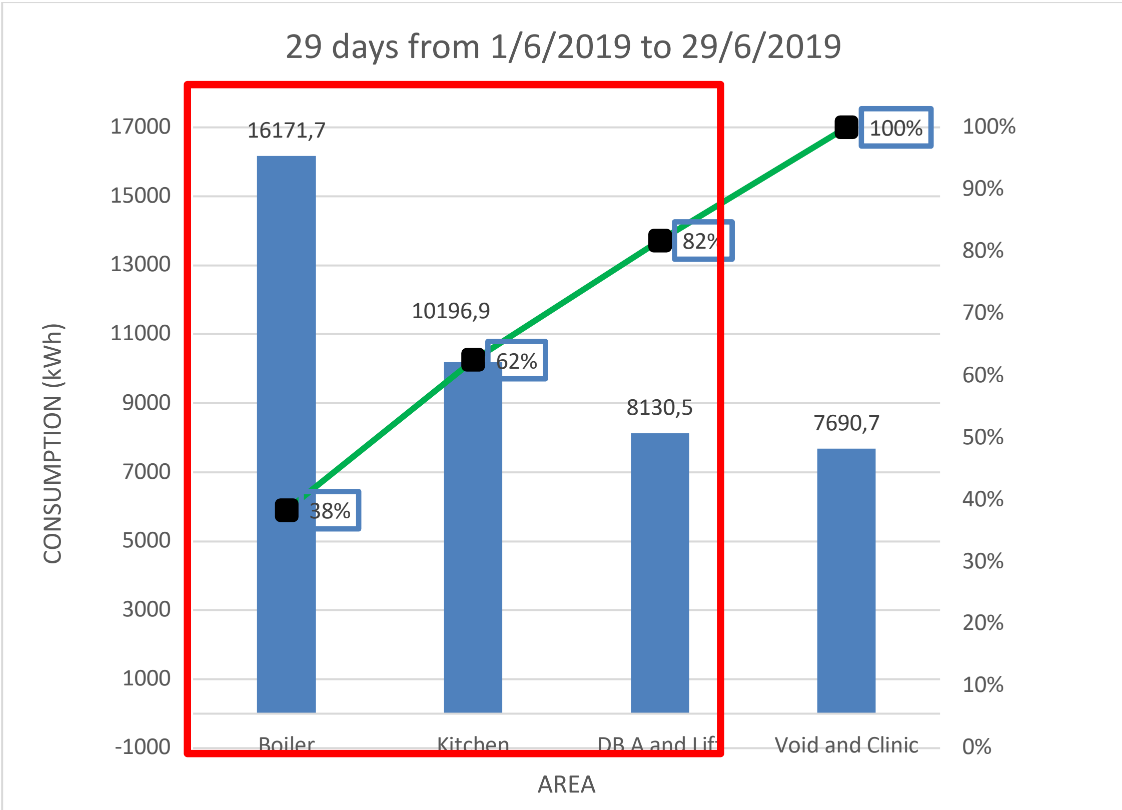


Figure 4.5 Pareto chart of energy users

There are main benefits of using a Pareto analysis in this study: The first is that pareto analysis categorized problems found in the process so that leaders could identify its different types such as in Figure 4.5. Another benefit is that the pareto analysis is a simple method for prioritizing problems so that you can identify which problems have the greatest effect on the result of a situation. In this context , the process improvement of SEUs (Boiler, Kitchen, DB A and Lift, Void and Clinic) could not be done simultaneously, but it was important to start improving one SEU after another as identified figure 4.5 due to the handling of a large amount of data at the time. From figure 4.5, it was necessary to focus first on boiler as cause, rather than spreading the effort over on all problem at the same time, followed by the kitchen then the DB_A and Lifts for the simple reason that the process improvement must start with the area which had the highest consumption such as described in the Pareto chart.

By following Pareto principle (the 80/20 Rule), the three first areas of problems ((Boiler, Kitchen, DB A and Lift) should be included in improvement process of this study , but only the boiler was found. contrast, had not been respected . The first reason is that the Pareto analysis does not only shows you the most important problem to solve, but it also gives you a score showing how severe the problem is. It is the reason why more importance or priority was given to the boiler as an example of how the process improvement was carried out. The same procedure of improvement could be carried on with the rest of areas (Kitchen and DB A and Lift) to be improved, but the improvement of boiler had significant impact. Second reason of not including the three remaining areas in the improvement process in study is due to the time constraint of due project and large handling of data, the areas such DB_A, Kitchen and lift was planned for future study.

4.3.2.3 Boiler Room Performance

The building had a boiler room, which had two boilers; each boiler has two elements to heat the water; that makes four elements in total as indicated in Table 4.4 as boiler element 1, boiler element 2, boiler element 3 and boiler element 1B. The consumption of each element is in kWh and percentage proportionally for each of its element. The total energy of the boilers is the summation of energy for each element: Boiler total = Boiler element 1+ Boiler element 1B+ Boiler element 2 + Boiler element 3.

Table 4.6 Components

Boilers Elements	Consumption (Kwh)	Percentage
1	3384.94	20.93
2	4626.03	28.61
3	4507.45	27.87
1B	3653.27	22.59
Total	16171.69	100%

The above table reflects that elements 2 and 3 are consuming more energy than elements 1 and 1B. The cause can be attributed to the maintenance of the boiler elements. The boiler receives the water, not at the ambient temperature, but at the preheated temperature by the solar geysers placed on the roof of the building.

4.3.3 Solar system

The solar heating water system placed at the roof of the building was not effective to heat water at the required temperature for the entire building, for example, customers and tenants needed water at plus or minus forty degrees Celsius for the household work. In contrast, the solar system could not reach that requirement, the solar geyser placed on the roof of the building worked independently of the electricity system. The water enters the geyser system inlet at an average temperature of +- 24 degrees, is heated in the system and got out at an average temperature of ± 37 degrees during the daytime, then was fed to the boiler reservoir or the boilers. The temperature needed was still high, therefore, the water needed heating again in the boiler. The reading collected from the meter is only the electrical consumption, therefore, this study abstained from including the solar system used to feed the boiler. Before improvement begins, the investigation must question the huge increase in energy consumption of the boiler and identify the real causes using the quality tool called "Cause-and-effect diagram" or "Fish Bone diagram".

4.4 Analysis step

In the Analysis step, the objective is to use the data from the Measure step, begin to determine or identify the cause-and-effect relationships in the process and to understand the different sources of variability. The potential causes of the defects in the Analysis step can quantify problems, customer issues or waste and inefficiency that motivated analysing data collected from the previous step to help an organization to develop a better understanding of current energy usages and implement an energy management plan. When an energy-saving opportunity is identified, the cost can be calculated. The results can be useful for developing energy-saving goals and an action plan. During this stage, statistical tools such as normal control charts, histogram, regression, and many more are used to analyse data being collected. This statistical tool provides objectives and means of controlling quality in any transformation process even in the providing of services. Oakland (2003) argues that the attention to many aspects of a company's operations from data recording to the control chart plotting are required for the successful introduction of a good management system and implementation of statistical process control (SPC).

In this study, each SEU presented in pareto chart should be analysed to determine the cause-and-effect relationship to understand their source of variation. Due to the high cost of additional equipment such as eGauges which needed to be installed at different areas in the building, only one SEU, namely the boiler was used. The inclusion of other SEU like the kitchen, DBA and lift can be included for future research.

4.4.1 Cause and effect diagram of boiler

The cause and effect or fishbone diagram in this study examined the boiler area by organizing potential causes into smaller categories or showing the relationships between contributing factors. Based on the data collected for boiler elements shown in Table 4.6, two boiler elements have low consumption (20.93 % and 22.59 %) (Element 1 and Element 1B), but other two are slightly higher (28.3% and 27.87%) than the first two, and the reason the boiler was unnecessarily consuming the energy and increasing cost was not confirmed. However, according to Figure 4.5 of Pareto, the boiler is the SEU that consumes the most energy in the building. To track the reasons or causes of variance, the fishbone diagram was constructed.

The areas of problems were identified as "People", "Equipment", "Method", "Materials" and 'Environment'. Under "People", one problem was identified as the behaviour of employees on how to save energy. The similar idea was explained by Petersen et al. (2007) who reported that students who are supplied with information on environmental consequences of resource use can decrease electricity use. Other problems identified under "People" were skills of people, experiences of users and the usage number. More people use hot water which increases electricity use. "Method" included the problem of expertise (technological devices) used. The timing of an automatic on or off sensor and the setting of the temperature devices helped the building manager to control the water temperature in the boiler. Often the unnecessary higher set up of temperature can waste energy.

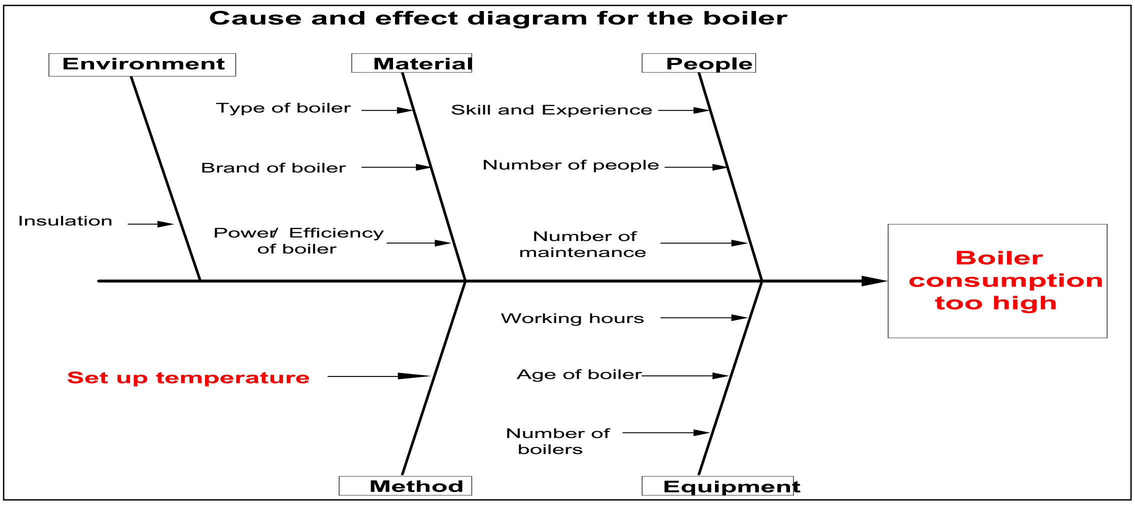


Figure 4.6 Cause and effect diagram for boiler

Under "Material‟, the problem is the type of material used for the boiler (for example, isolation material), the age of boiler and the brand of boiler, power of the boiler and elements used, but all these problems mentioned were not the cause. Sometimes, a quality brand can be expensive but can save energy. The frequency of maintenance can help to find out the cause problem, for example, when elements lose power in the boiler, but this was not the case. It is a must for the boiler to be serviced such as getting boiler elements, pipes insulated and checked in order to maintain its performance. The high consumption of electricity also depends on "Equipment‟ or "Machine".

The following factors need to be taken into account: how many boilers, the age of the boilers and its components, and how many hours and days have the boilers been used for this study, the problems identified lie in the "Method" used to manage the temperature of water in the boiler. The set-up temperature and on and off timing of the boiler.

4.4.2 Hypothesis statements

Table 4.7 Hypothesis statement

Potential Cause	Hypothesis Statement	True/False
Boiler set up of temperature	Temperature set too high can contribute to total consumption of energy	True

4.4.3 Boiler temperature setup

The manual digital dial device was set up for the boilers to allow setting the output temperature of the water. The recommended output of water depended on time (or season) and especially on customer satisfaction, which means that the temperature setting could be changed according to the season or weather (summer or winter, sunny or cloudy day). Customers wanted an adequate temperature of water for its residents at any time. The boiler had been set at minimum and maximum temperatures to heat water to allow the boiler to work at best efficiency. The higher the temperature is set, the quicker the boiler will be able to heat the water. Therefore, the bills also increase, and the boiler's efficiency could decrease.

The readjustment of temperature to heat the water of the building depended on customer requirements (season and daily weather); therefore, this readjustment could happen one or more times daily due to the complaints of water users. As an example, when two out of a hundred water users complain of the water in the shower being cold, the temperature is readjusted up; the same happens during cold weather. In contrast when the weather is warm, the set temperature remained unchanged. That was where the problem of waste started. The study had collected data according to different temperatures set to heat water for different dates. The table 4.6 describes the data collected at different set temperatures during 35 days from 3 May to 7 June 2019. The reason why temperatures are not in order (straight from 52 degrees to 60 degrees) is that the maintenance manager set up the boiler to accommodate daily weather during these 35 days.

Table 4.8 Boiler consumption with temperature variation

No.	Temperature	Date	kWh	Consumption/Week
1	54 °C	5/3/2019	470.01	3645.72
2		5/4/2019	608.39	
3		5/5/2019	530.4	
4		5/6/2019	536.92	
5		5/7/2019	499.45	
6		5/8/2019	496.45	
7		5/9/2019	504.1	
8	53 °C	5/10/2019	512.66	3517.81
9		5/11/2019	517.03	
10		5/12/2019	509.95	
11		5/13/2019	506.86	
12		5/14/2019	498.68	
13		5/15/2019	509.73	
14		5/16/2019	462.9	
15	52 °C	5/17/2019	431.2	3427.6
16		5/18/2019	423.2	
17		5/19/2019	413.7	
18		5/20/2019	568.5	
19		5/21/2019	472.2	
20		5/22/2019	576.3	
21		5/23/2019	542.5	
22	57 °C	5/24/2019	516.6	3835.75
23		5/25/2019	524.1	
24		5/26/2019	530.2	
25		5/27/2019	570.35	
26		5/28/2019	575.5	
27		5/29/2019	543	
28		5/30/2019	576	
29	58 °C	6/1/2019	547	4098.2
30		6/2/2019	607	

31		6/3/2019	604.5	
32		6/4/2019	571.8	
33		6/5/2019	537.2	
34		6/6/2019	618.7	
35		6/7/2019	612	
Total			**18525.1**	**18525.08**

This means that it was not important to set minimum temperatures when the weather was too cold.

In Table 4.6, column 1 describes a number of days of recording, column 2 represents the temperature in degree Celsius set for that day, column 3 includes the dates of recording, column 4 comprises the daily consumption in kWh and column 5 represents the total weekly consumption in kWh. Figure 4.7 describes the graph of consumption from 17 May to 23 May 2019. The set temperature for the boiler was 52 ˚C and the total consumption recorded for all seven days was 3427.6 kWh. At this temperature, complaints that water was cold were registered from customers.

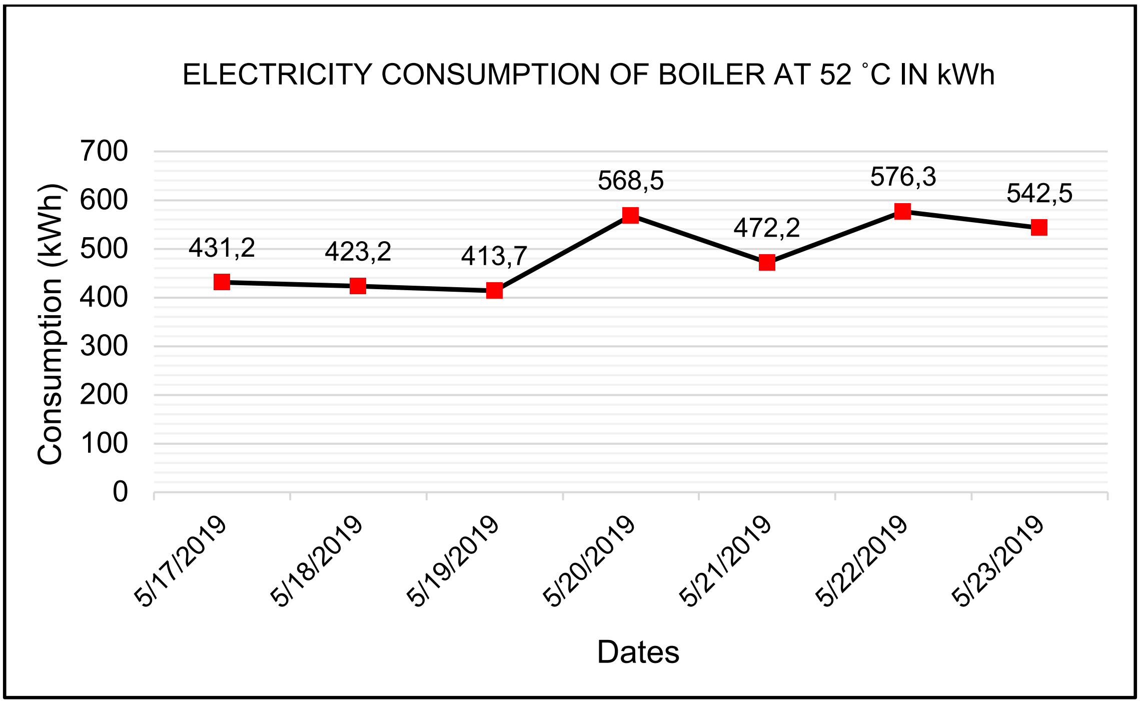


Figure 4.7 Boiler consumption boiler at 52 ˚C

Figure 4.8 illustrates the consumption from 10 May to 26 May 2019, the set temperature for the boiler was 53 ˚C and the total consumption recorded for all seven days was 3517.8 kWh. At this temperature, the consumption is slightly higher than at the previous temperature of 52 ˚C. During this period, complaints that water was cold were registered from residents as well.

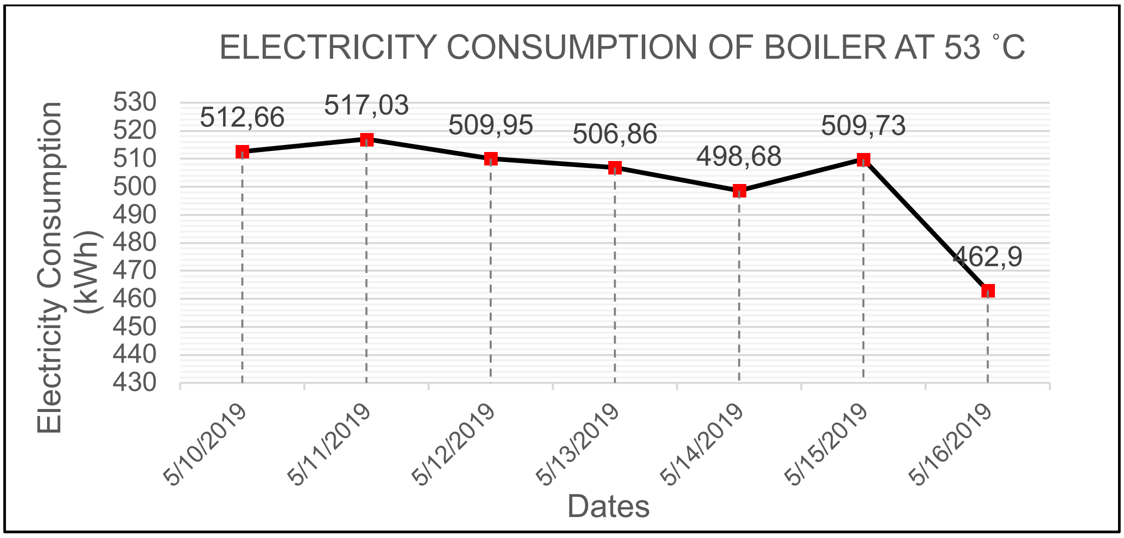


Figure 4.8 Graph of the boiler at 53 °C

Figure 4.9 describes consumption of boiler s for seven days from 3 May to 9 May 2019. The boiler was set at the temperature of 56 °C and the total consumption for the boiler had increased to 3645.7 kwh. Compared to two previous temperatures of 52 °C and 53 °C, *few complaints from customers were recorded*. The management was not satisfied to keep the water at this temperature. Based on the graph below, the highest consumption recorded was 608.39 kWh on 4 May 2019.

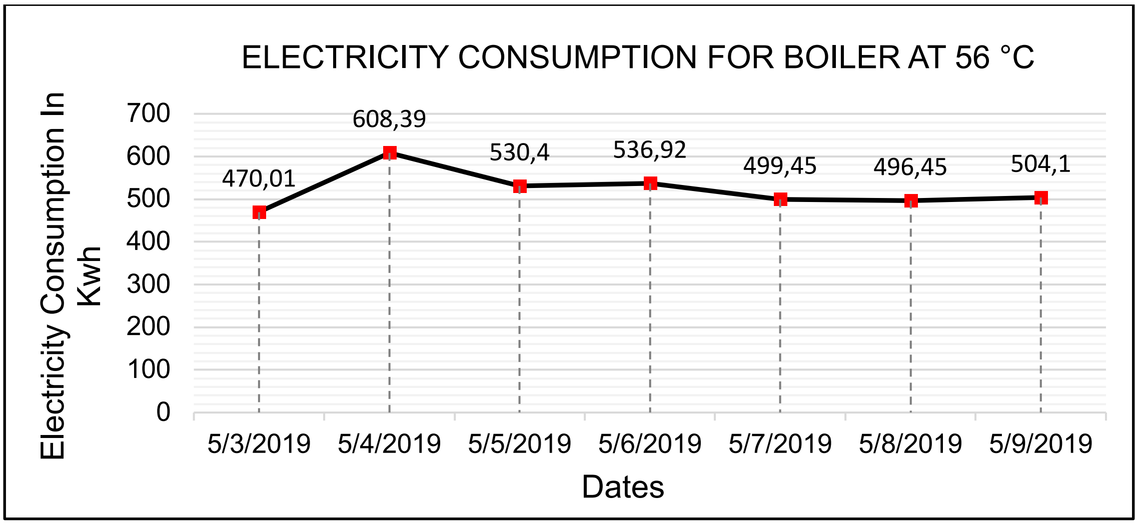


Figure 4.9 Boiler consumption boiler at 56 °C

Figure 4.10 describes consumption of boilers for seven days from 22 May to 28 May 2019 set at the temperature of 57 °C and the total consumption for the boiler had increased to 3835.75 kWh. Compared to three previous temperatures of 52 °C, 53 ºC, and 56 °C. At 57 °C no complaints from residents were recorded.

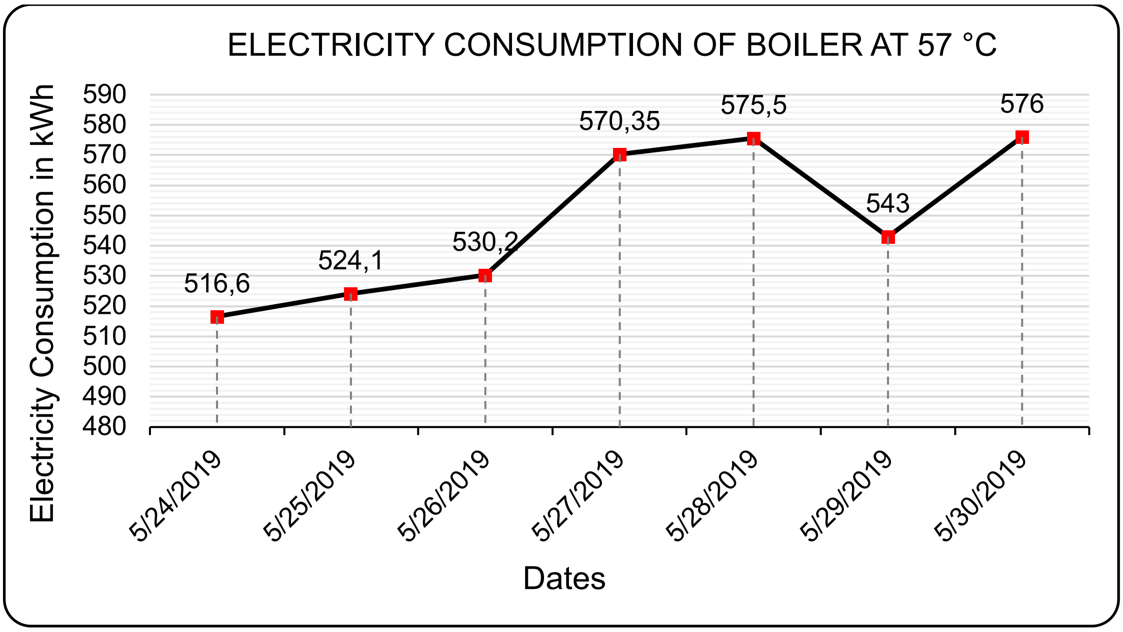


Figure 4.10 Boiler consumption at 57 °C

After adjusting the boiler temperature to accommodate customers' requests, the maximum temperature reached 57 °C, and no complaints were recorded for that time. This was beginning of wintertime in South Africa. Surprisingly, the building policy had a maximum target of sixty degrees for the warmer seasons and sixty-two degrees Celsius for the cold period such as wintertime. The consequence of increasing the temperature is that the higher the temperature is set, the more the consumption increases. Figure 4.11 demonstrated that, at boiler temperature set at fifty-eight degree Celsius (58 °C), the consumption escalated to 4098.2 kWh for 7 days (1 June to 7 June 2019), more than previous set temperatures.

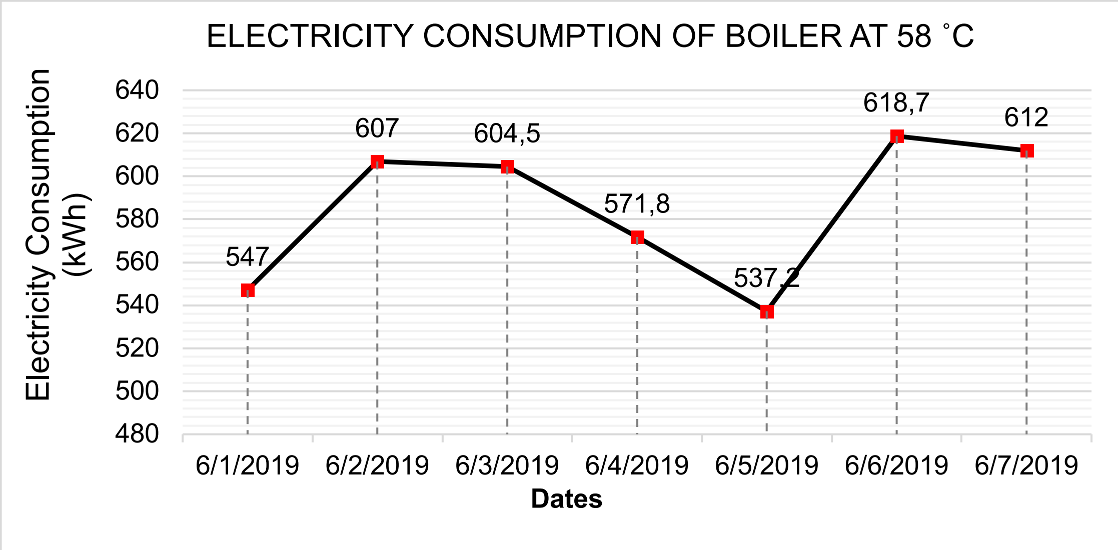


Figure 4.11 Boiler consumption at 58 °C

Two temperature settings, 57 ˚C and 58 ˚C satisfied customers. More analysis was done to establish what boiler temperature should be maintained, the lowest acceptable consumption in kilowatt, and the minimum cost that could satisfy the customer during this time. This is called the optimal point which will be discussed further in the Analysis step.

Table 4.9 describes the variation of electricity consumption of the boiler against the adjustment of the temperature for 35 days of the study. Column 1 of this table represents the dates of the temperature adjustment, for example, from 17 May to 23 May 2019, the boiler ran at the temperature of fifty-two degree Celsius (52 ˚C). Column 2 is the temperature adjusted. Column 3 represents variation or the difference of the previous temperature and actual temperature. Column 4 is the consumption recorded for that period, and the last column is the consumption difference between the actual weekly consumption and previous weekly consumption.

Table 4.9 Temperature against electrical consumption

Temperature (˚c)	Date Of Adjustment	Temperature Variation (Δt)	Consumption/Week (kWh)	Consumption Variation
52	17 to 23 May, 2019	0 °C	3427.2	0
53	10 to 16 May, 2019	1 °C	3645.8	218.2
56	3 to 9 May, 2019	3 °C	3748.02	102.22
57	24 to 30 May, 2019	1 °C	3835.75	87.73
58	1 to 7 May, 20 19	1 °C	4098.2	262.45

If T_1 = 52 °C; T_2 =53 °C; T_3 = 56 °C; T_4=57 °C and T_5 = 58 °C and T_6 = 60 °C

ΔT = Variation of temperature

T_a = Actual temperature

T_p = Previous temperature

$\Delta T = Ta - Tp$

Examples:

$\Delta T_2 = T_2 - T_1$ = 53 °C – 52 °C = 1 °C

$\Delta T_3 = T_3 - T_2$ = 56 °C – 53 °C = 3 °C

$\Delta T_4 = T_4 - T_3$ = 57 °C – 56 °C = 1 °C

$\Delta T_5 = T_5 - T_4$= 58 °C – 57 °C = 1 °C

$\Delta T_6 = T_6 - T_5$= 60 °C – 58 °C = 2 °C

The graph in Figure 4.12 illustrates the change of electrical consumption relatively with change of temperature. As said, at temperature (T_1), the daily consumption for the boiler only was 3427.6 kWh; at the temperature (T_2), daily consumption for the boiler only was 3517.81 kWh, and at temperature (T_3), the consumption was 3748.02 kWh. At this temperature, few complaints were recorded for bathing in cold water. With (T_4), the customers were satisfied, and no complaints was registered. There is no reason to increase the temperatures to 58 °C and to 60 °C.

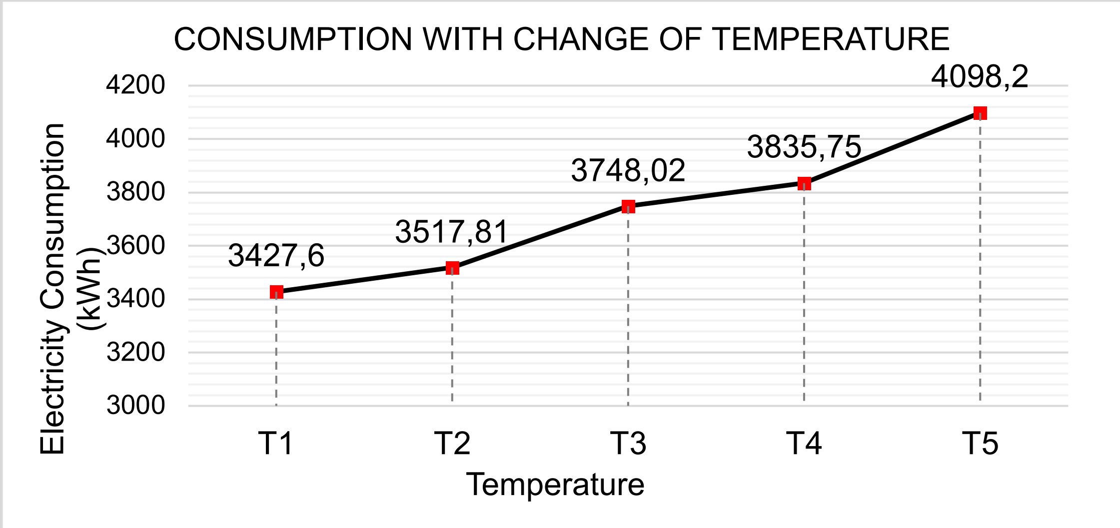


Figure 4.12 Temperature variation

The graph in Figure 4.12 illustrates that electricity consumption is increasing gradually in function with the increase of set temperature of the boiler. It means that for an increase of one degree Celsius in the boiler temperature, there was an increase proportionally in electricity consumption as well. For examples from T1=52 to T2=53 degrees, the consumption increased from 3427.6 to 3517.81 kWh, the same with T3 or 56 degrees to T4 or 57 degrees, the consumption had increased from 3748.02 kWh to 3835.75 kWh. Following from Figure 4.14, the curve increases as the temperature increases. There was a correlation between the temperature setting of the boiler and electrical energy variation.

4.4.4 Auto off /on timing

The table 4.10 describes stoppage time data collected with eGauge for just seven days for the month June 2019. The device was set to go off for five hours per day to save electricity. During the first three hours from six to eight o'clock, the water starts cooling down and becoming cold, after these three hours of stoppage, the water temperature dropped significantly and, the tenants started to complaining.

When the device kicked on to allow the boiler to heat again the water, the consumption was doubling because water went too cold. Hence, no saving of electricity. The option of having device to stop water for many hours without calibrating the temperature or consumption was excluded.

Table 4.10 Boiler data and stoppage time

	JUNE							
TIME	1st	2nd	3rd	4th	5th	6th	7th	TOTAL
0:00	15.1	20	14.5	17.6	14.2	16.4	16.7	114.5
1:00	16.1	14.5	18.4	14.5	15.1	15.1	21.1	114.8
2:00	20.1	17.6	18.6	18.7	14.9	15.6	17.1	122.6
3:00	16	16.1	13.9	16.1	18.1	13.6	14.5	108.3
4:00	19.1	18.6	16.1	17.6	13.8	16.1	18	119.3
5:00	21.1	28.5	15.7	24.1	23.6	17	22.2	152.2
6:00	0	0	0	0	0	0	0	0
7:00	0	0	0	0	0	0	0	0
8:00	0	0	0	0	0	0	0	0
9:00	3.1	52.1	51.7	50.3	52.1	51.7	50.3	311.3
10:00	48.3	49.2	49.7	52.2	52.5	53.1	51.9	356.9
11:00	50.9	51.8	52.1	51.7	52	53.2	52.1	363.8
12:00	51.2	52.2	52.4	52	50.9	52.9	52.1	363.7
13:00	42.7	47.3	46.4	51.9	39.2	52.5	51.9	331.9
14:00	41.6	41.6	42.2	43	40.1	45.5	48.4	302.4
15:00	37.2	41.4	42	36.2	36.2	40.2	40.9	274.1
16:00	24.9	18.9	27.3	21.3	12.1	34	21	159.5
17:00	0	0	0	0	0	0	0	0
18:00	0	0	0	0	0	0	0	0
19:00	37.7	43.3	49.4	37.7	43.3	49.4	51	311.8
20:00	48.9	35.4	44.4	17.3	16	39.2	34.2	235.4
21:00	20.2	25.8	19	16.1	13	17.5	17.1	128.7
22:00	17.2	13.5	15.2	17.5	15	21.1	16.1	115.6
23:00	15.6	19.2	15.5	16	15.1	14.6	15.4	111.4
Total	547	607	604.5	571.8	537.8	618.7	612	4098.2

After recording the data, the next step is to identify saving opportunities in the data collected.

4.4.5 Boiler temperatures variation and audit

Determining the influence of the variation temperature set of the boilers using monthly consumption records, (Maistry) determined how the boiler timer influences the increase of electricity. Both analyses will permit the study to come up with proposals for improvements.

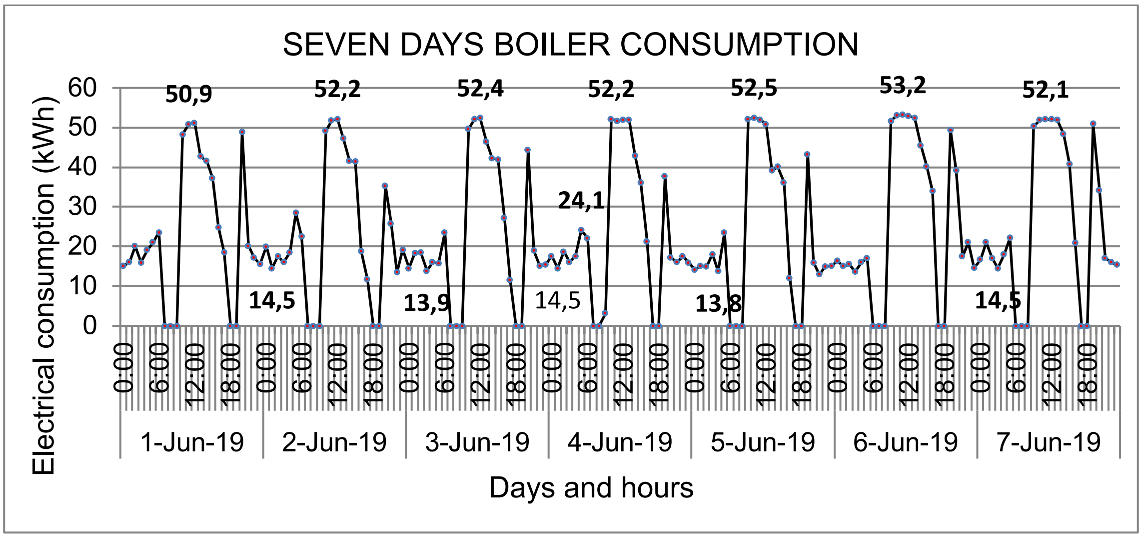


Figure 4.13 Seven days of boiler

The boiler was not heating water through all twenty-four hours a day, but it had an automatic device that was switched on and off for electrical power for three hours in the morning (from 6:00 to 9:00) and two hours in the evening (from 18:00 to 20:00). During these times, the boiler could not consume electricity; the number of kWh consumed was 0kWh, but the water temperature dropped to minimum degree Celsius. Graph 4.13 revealed that from 18:00 am to 20:00 there was a consistent increase in energy consumption. The sum of all four elements of boilers showed the highest energy consumption rate. The research first identified hours with the highest and the lowest consumption rate in kWh per total energy user. The next step included analysing the months where the consumption occurred the most or the least during that particular hour.

4.4.6 Control chart

The **control chart** is **used** to study how a process or activity changes over time. Data were plotted in time order, the control chart was constructed by compiling consumption data collected for the boiler during this period in time order. Control chart always have central line or average $\overline{x} = x_1 + x_2 + x3 \ldots x_n /N$ that provides a average of data consumption. The upper control limit (UCL) is 3σ above the average and lower control limit (LCL) is at 3σ below the average.

The control charts here were used in this case by compiling the data in table 4.8 of boiler consumption with temperature variation. Figure 4.14 shows two graphs, the individual chart on top and moving chart in bottom. The centred red horizontal lines for both figures represent the averages or estimated series of value x_i of energy consumed from 03 May 2019 to 06 June 2019 divided by number of observation (N). where for individual chart, the average ($\overline{x}$) is 529.3 kWh and Moving Range chart is 35.2 kWh. The two dashed lines represent the upper control limit (UCL) which is the highest value of energy consumption (and lower control limit (LCL), the green zigzag line in the middle is the performance or variation of electrical consumption of the boiler.

The I-MR is really two charts in one. At the top of the graph is an Individuals (I) chart, which plots the values of each individual observation, and The bottom part of the graph is a Moving Range (MR) chart, which plots process variation as calculated from the ranges of two or more successive observations.

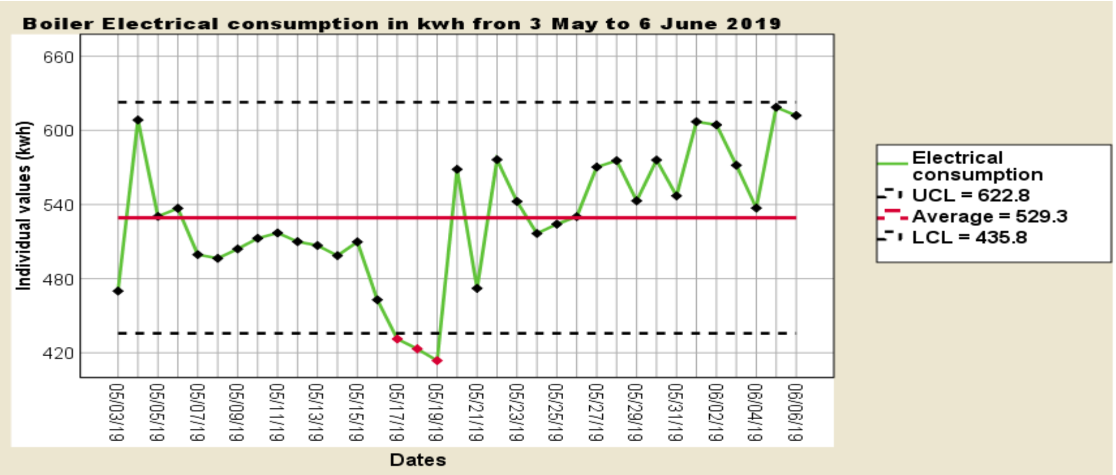
Individual-Chart Limits: The lower and upper control limits for the individual charts are calculated using the formulas UCL = $\overline{x} + 3\sigma$ and LCL = $\overline{x} - 3\sigma$ and σ standard sigma or standard deviation normally set to 3.

Moving Range-Chart Limits: The lower and upper control limits for the Moving Range chart are calculated using the formula $\hat{\sigma}$ LCL = R − 3σ and UCL = R + 3σ.

These two charts are used here because the Individual-X chart and Moving Range because these charts are used to monitor individual values and the variation of a process based on samples taken from a process over time (hours, shifts, days, weeks, months, etc.). Individual-X and Moving Range charts are a set of control charts for variable data (Woodall et al. 2004). The Figure 4.14 describes the statistical control chart (SCC) constructed with electricity consumption data recorded for 35 days or number of observations (from 3 May to 6 June 2019.

For this study, both individual and moving control charts are elaborated with help of SPSS 25 software by analysing data of energy consumed at certain period.

The control chart was elaborated using IBM SPSS software that is used to analyse and solve complex business and research problems through a user-friendly interface..



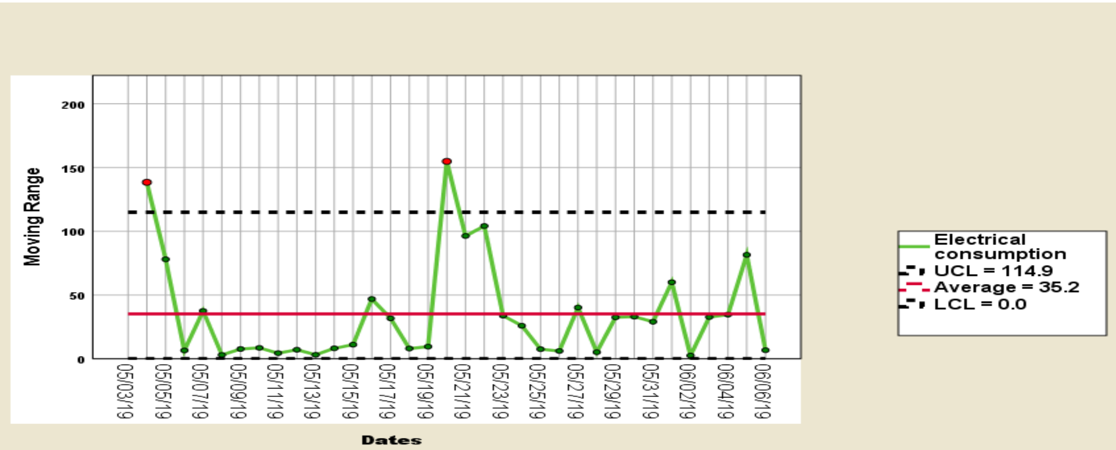


Figure 4.14 I-MR Chart of Electrical consumption from 1st May to 6th June 2019

Based on the I-MR value chart in figure 4.14, from 17, 18 and 19 May 2019, the consumption was very low due to the eGauge stoppage for maintenance. During these days, the performance line shows out of control. This means that the three points were behind the lower control limit (LCL). The next step was to analyse the relevant data by removing all the out-of-control limit points (these three points).

The next step is to ignore the out-of-control points (points outside the dashed lines in the individual value chart. The result is Figure 4.15.

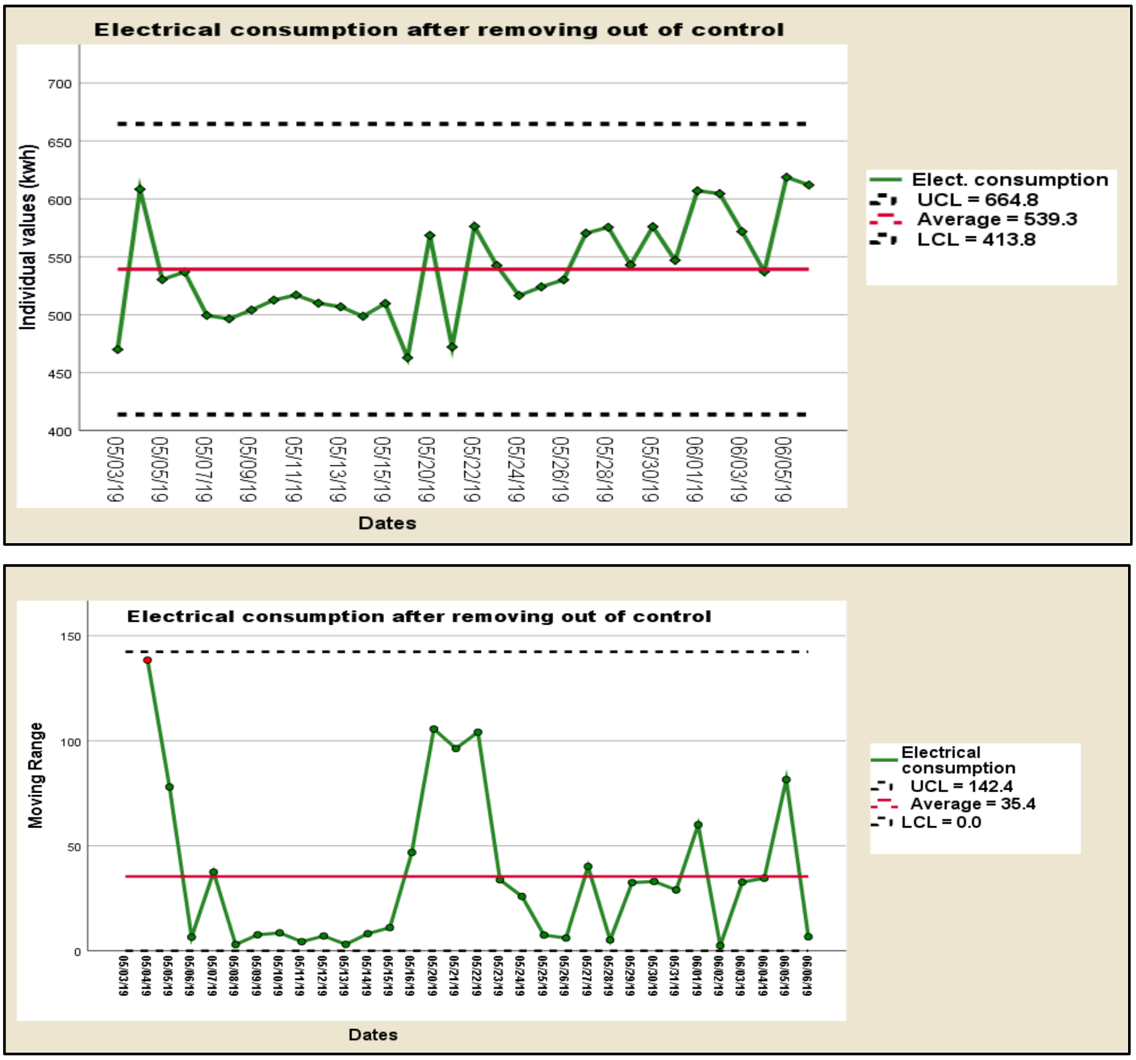


Figure 4.15 From 3 May to 7 June 2019 Consumption (removing maintenance days).

After removing the three points of out of control from the graph in Figure 4.14, Figure 4.15 shows that the process is in control (no special external causes). All the data are between the control limits.

There are two patterns in the performance line:

1. The first pattern of the performance line at the left of the graph is below the average red line (central line) from 5 May until 16 May 2019. This was explicable due to the low boiler temperature set to heat water. Electrical consumption was low from 5 May until 19 May 2019 because the temperature set to boil water was low.
2. The second pattern started from 27 May until 6 June 2019 due to the increase of set temperature to heat the water. The performance line was above the

average line (or central line). However, from 19 May until 26 May 2019, the consumption performance was on the average line.

Therefore, the two patterns of the electrical consumption should be compared, the below central line and the above central line after removing the three days of maintenance by constructing a histogram that provides the visual representation of data distribution. The first group of 16 points on the left side below the central line from 4 May to 21 May 2019 was taken, and the second group of 16 points above central line from 22 to 6 June 2019 was also taken to construct two different histograms.

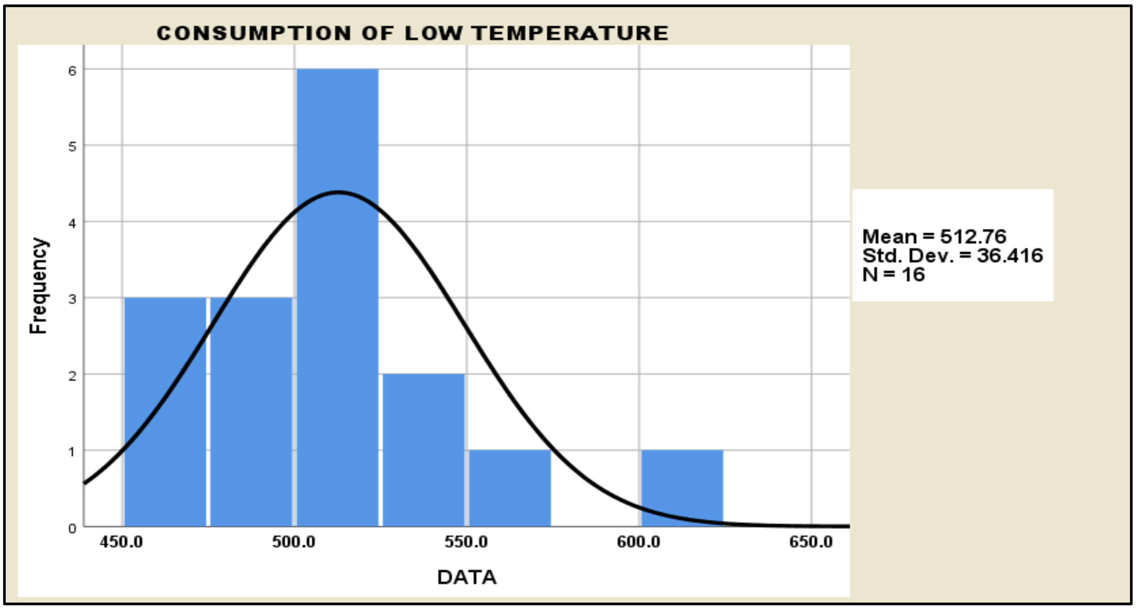


Figure 4.16 Consumption before removing out of control point.

This is proved that the temperature increase influences the energy consumption. Figure 4.17 shows the average electricity consumption was at 512.76 kWh for lower temperature.

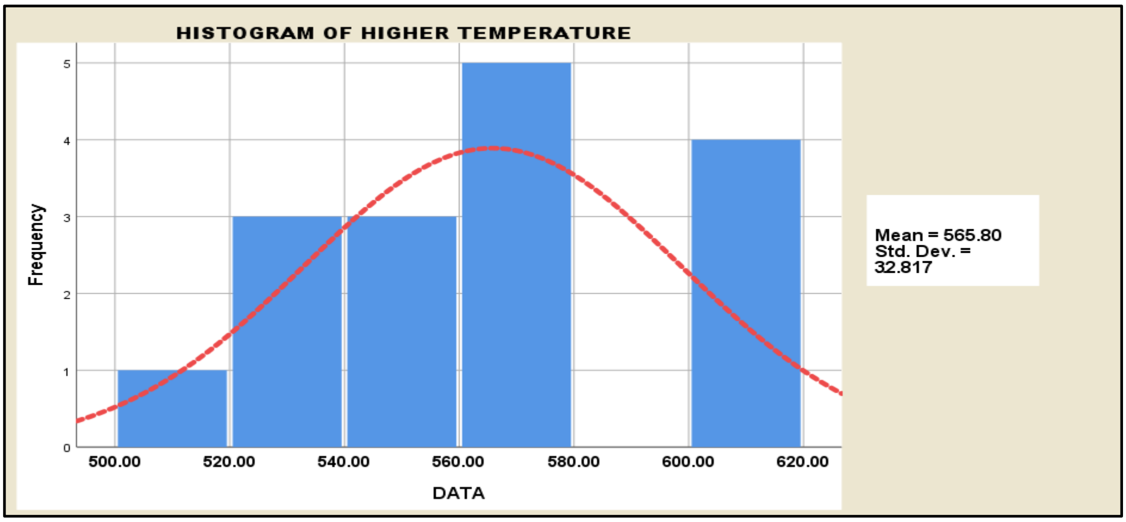


Figure 4.17 Consumption from 17th to 7th June

For the second histogram, the average increased to 565.8 kWh. The average consumption of 512.76 kWh was obtained when using lower temperatures (from 52 °C to 56 °C) and the average consumption of 565.8 kWh was obtained when using higher temperatures (56 °C to 58 °C). Both 56 °C and 58 °C satisfied residents' requirements, but it is important to decide which of the two will fulfil the requirement of cost-effectiveness. Based on figures 4.16 and 4.17, we can recognise that the electrical consumption increased at least 10 % from the beginning of the study (from 512.76 – 565.8 kWh). Thus, the objective of this project was to identify factors that influenced the increase in electricity use and reduce consumption by 3 % every month by the end of 2019.

Table 4.11 Electrical consumption for 22 May to 28 May 2019

Date	T °C	(Kwh) /Week	Rands	Complaints
5 June – 12 June 19	58	4098.2	4098 x 2.6019 = R10663.1	No
22 May – 28 May 19	57	3835.75	3835.75 x 2.6019 =R9980.2	No
Savings	1	4098.2 – 3835.75 = 262.45	262.45 x 2,6019 = R 682.9/week	

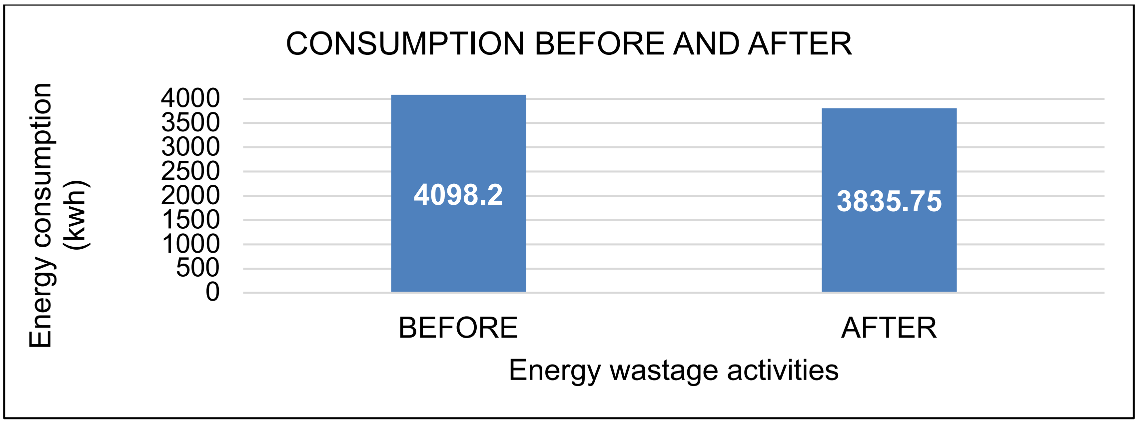


Figure 4.18 Energy wastage

No complaint was recorded for both 57 °C and 58 °C temperatures, but with 58 °C, consumption and cost were higher with no complaint from customers as well. Every week, the building wasted an average 262.45 kWh, approximately 37.5kWh/day. The building wasted 1124.8 kWh or R2926.6 over 30 days. The total electrical consumption for 30 days collected data from 1 June to 30 June 2019 was 15882.9. Therefore, the second option is advantageous for a company with lower cost. More saving can be achieved when strict policies are put in place to ensure the average temperature with lower electrical consumption.

Table 4.12 Electrical consumption for 30 days.

Consumption	**kWh**	**Rands (R)**
Actual consumption for 30 days	15882.9	41325.5
Wasted energy for 30 days	30 x 37.5 kWh = 1125	2927.13
Actual saving (wasted energy) in percentage	1125/15883= 7%	

Normality test: In the agreement with (Helsel and Hirsch 2002), the normal probability plot is a graphical technique for assessing whether a data set is approximately normally distributed. Figures 4.18 and 4.19 will test the normality of both distributions of data for low and high temperature.

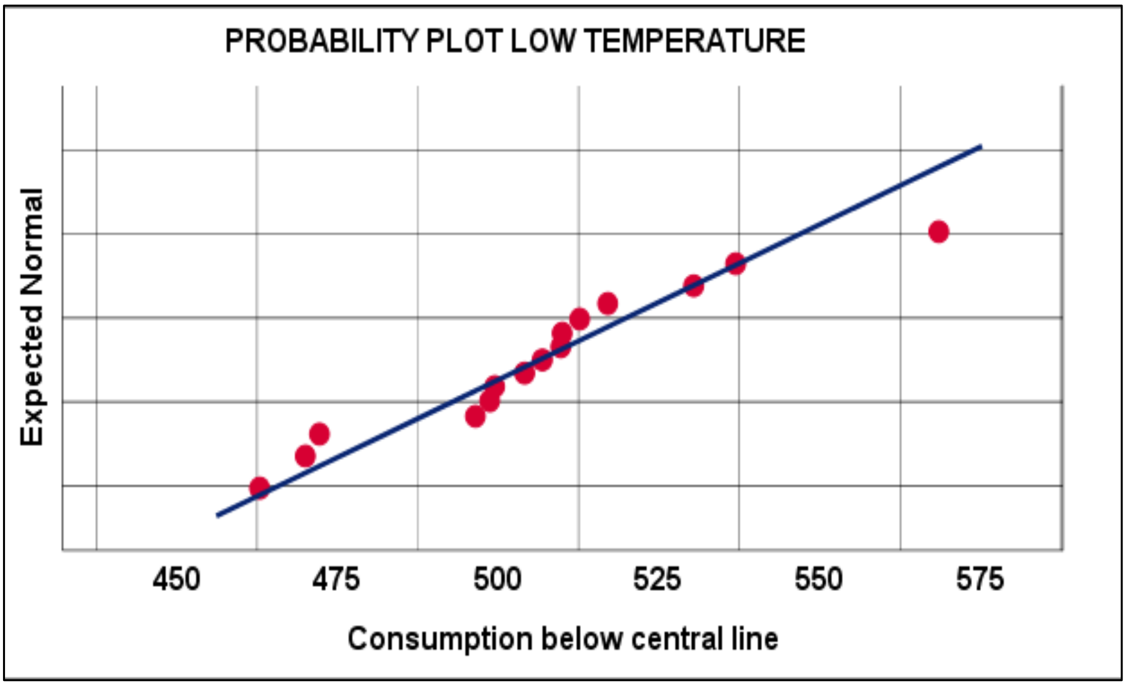


Figure 4.19 Normal probability plot of electrical consumption at low temperature

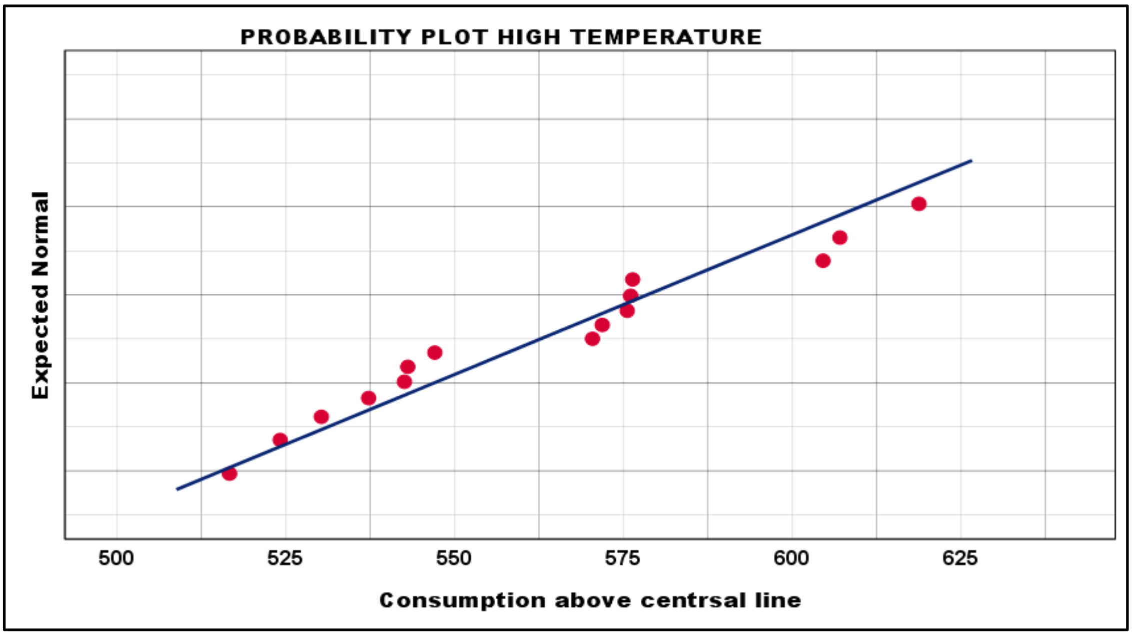


Figure 4.20 Normal probability plot of electrical consumption at high temperature

Table 4.13 Descriptive statistics

	Mean	Std Deviation	P
Performance below central line	15	26.9103	0.054
Performance above central line	15	32.81675	0.054

p-value (p) = 0.054

The normal probability plot is a graphical technique for assessing whether a data set is approximately normally distributed (Helsel and Hirsch 2002). The probability plots in Figures 4.19 and 4.20 show most of the points lying on a straight line. The proposed method in Figures 4.19 and 4.20 suggests once the plot is lying at the straight line presented, the data achieved is normal. The probability of rejecting the null hypothesis (H0) is true for the level of significance (α). It means that, if calculated p-value is less than the chosen level of significance, then the null hypothesis (H0) is rejected.

The estimated p-value for given data set of the study:

H0: The distribution is normal ($p > 0.05$)

H1: The distribution is not normal ($p < 0.05$)

This proved that there is enough evidence to conclude that the distribution is normal. Besides, both p-values (p) = 0.054 are greater than α=0.05, thus proves the data is normally distributed.

4.5 Improvement step

In the two previous stages, Measure and Analyse stages, the research was focused on determining the factors that impacted the performance of the system and identifying potential sources of waste and interpreting the data obtained. According to the results from the previous steps, the major cause of a power increase was due to the increase in the boiler temperature set up. This step consisted of thinking about specifics in the process to have the desired impact on the performance of energy delivery. The campaign to improve electrical consumption was organized to create not only awareness but also to set a proper boiler temperature to heat water to accommodate everyone (staff, employees and residents) who use hot water in the building and revise the timing of the device used to stop the boiler from heating water at an unnecessary time. A meeting was set up with the maintenance manager on 4 July 2019 from 13. 30 to 14.00 in that regard. During that meeting, two suggestions were made:

A. **Awareness**: The objectives of that campaign to create awareness among staff and residents by means of a questionnaire. After two hours of talk involving staff, the first idea was to give a sample questionnaire to all energy users to create awareness of the impact of saving electricity. The objective of the questionnaire was to find out knowledge of energy savings.

B. **Temperature variation**: The second point of discussion in the campaign was to decide on the appropriate water temperature to satisfy hot water users during different periods. After evaluation of the results in the analysis step, Figure 4.12 describes increment in temperature increase, this has brought a significant increase in electrical consumption and relatively increased total cost in electricity demand.

The acceptable temperature for that period was 57 °C. At this temperature, all customers were happy with the hot water. The satisfaction of customers is one of the DMAIC problem-solving objectives. The consumption was 3835.75 kWh at the temperature of 57 °C, and at 58 °C, the consumption was 4098.2 kwh. The average unnecessary increase in temperature from 57 °C to 58 °C was 262.45 kWh for just for one week. The price per kWh according to the supplier is R1.0326. According to demand season given by energy supplier Eskom, from May to August, the high demand season (HDS) or peak period; the cost of electricity was R2.6019/kWh compared to R0.8385/kWh for a standard period and R0.4881/kWh for off period. The price increase for consumption 3835.75 kWh to 4098.2 was 262.45 kWh x R2.6019 = R682.9 per month. It was said (building policy) that the minimum and maximum operating temperature is 60 °C and minimum operational temperature for the boiler is 52 °C to 56 °C for summer but 52 °C to 60 °C for winter (from May to September). The maximum temperature collected in this study was 58 °C, but the study has shown that the appropriate or acceptable temperature during this period of winter is 57 °C not 60 °C. Table 4.10 below gives the summary description of the price for different periods.

Table 4.14 Electricity price of different periods

Status	Cost
Off Peak	R0.4881/kWh
Standard Period	R0.8385/kWh
Peak Period or High demand Season	R2.6019/kWh

Table 4.12 described the weekly consumptions variation related to change in temperature from the Table 4.5. This table 4.9 includes control upper and lower limits of consumption and the average daily consumption. In this table, from temperature of 52 degree to 57 degree, the consumption has increased until reaching optimal point of 3835,75 kwH for a week and average daily consumption of 547,9 kwH, it the point where customer was satisfied. The 5th raw in table 4.9 shows the optimal point (optimal temperature) but the 6th in red show the waste of electricity. The study found that, the wastage of electrical energy with a boiler temperature set to heat the water at 58 ˚C upwards.

Table 4.15 Temperature variation and control limits

No of week	***Temperature variation***	***Weekly Consumption***	***Upper Limit***	***Average***	***Lower Limit***	***Std deviation***
1	52 °C	3427.6	576.3	489.65	413.7	
2	53 °C	3517.81	517.03	502.544	462	18,366
3	54 °C	3645.72	558,39	520.817	463.01	44.59
4	56 °C	Data not collected				
5	57 °C	3835.75	603	547.9	492	25
6	58 °C	4098.2	682	585.45	489.2	33.24

Table 4.16 Savings in rand and percentage

	Maximum T °C	**Consumption (Kwh)/Week**	**Cost /Week (R)**	**Customer Satisfaction**
Before	58	4098.2	10663.1	Yes
After	57	3835.75	9980.2	Yes
Saving	1	262.45	682.9	
% Saving		6.4 %	6.4 %	

Figure 4.21 shows the Individual and Moving Range control charts for before improvement (before the decision to maintain the appropriate temperature of 57, the maximum temperature was 58 °C) and after improvement (after the decision, the maximum temperature was 57 °C). Based on this, it can be concluded that the control limit of the average electrical consumption or the Mean of the chart of 57 °C is lower than the Mean of the chart of 58 °C (547.9 < 585.5) for individual value. In average, the average % reduction was:

Percentage reduction $= \frac{Mean\ before - Mean\ after}{Mean\ after}$ x 100

$= \frac{585.5-547.9}{585.5}$ x 100

= 6.42 or 6%

As described in Table 4.12, the electrical consumption at 57 ˚C is also lower than the electrical consumption at 58 ˚C (3835.75 kwh < 4098.2 kWh). The variation in consumption is 6.42 % (4098.2 kWh – 3835.75 / 4098.2) = 6.42 %.

Therefore 6,42% is the improvement for boiler only. However, the boiler had 38,3% of the whole building consumption, then 6.42 % improvement of the boiler represented 2.4% improvement of total consumption of the building.

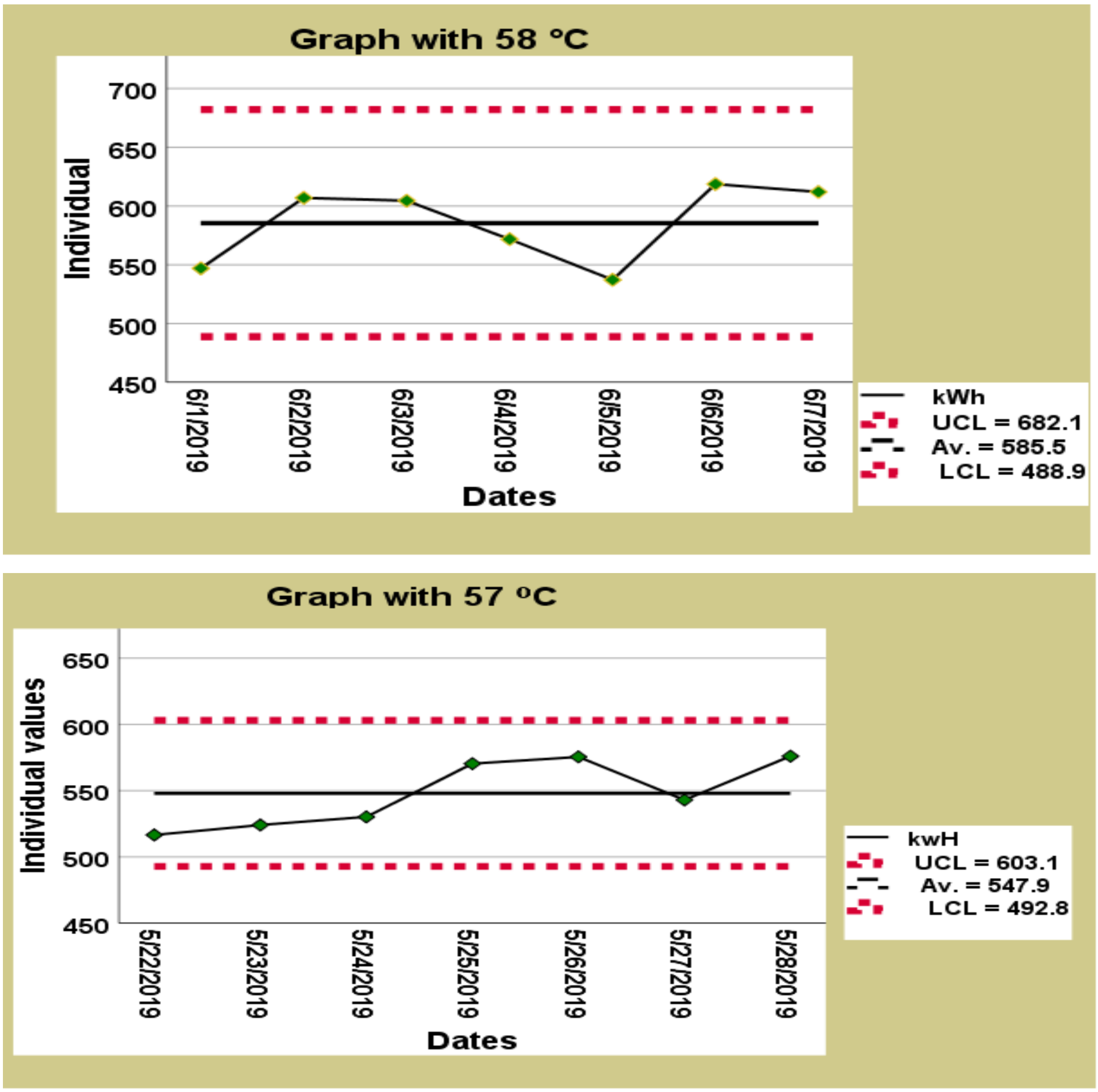


Figure 4.21 Control limits and averages of improvement

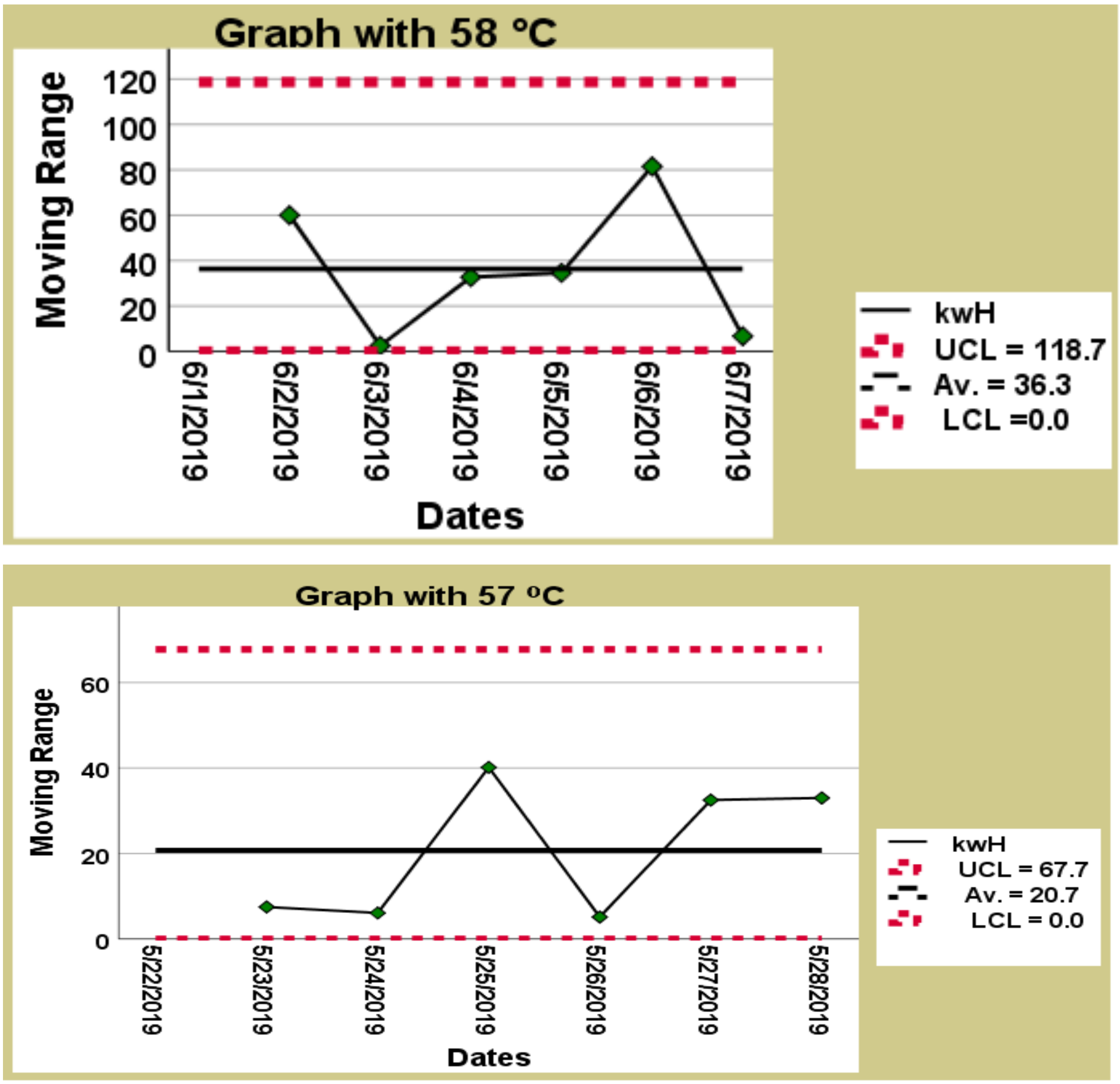


Figure 4.22 Before improvement and after improvement

4.6 Control step

This step ensured that the process is stable. Figure 4.22 and 4.23 show the before and after graphs campaign for electricity usage. The average consumption in graph with 58 °C (before campaign of DMAIC) is 585.5 kWh higher than the after campaign of DMAIC in the second graph (547.9 kWh) due to the reduction of the boiler temperature. Relatively, the costs have also decreased. The building management can adopt the policy of keeping the lower temperature that satisfies users to keep the cost lower. This temperature can be maintained or reduced if the building policy of monitoring the data from the eGauge and communicating with the building's users is followed. The goal of this step is to maintain the gains achieved in this study. Some tools that were deployed with a view to sustain the gains achieved at the improvement phase were:

- Monitor water temperature in different areas of the building.
- Audit electricity usage daily, checking on daily use metrics.
- Monthly communication to customer and users with data provided by eGauge
- Monthly cost of electricity consumption should not exceed that of consumption from the previous.
- Introduce an automatic system by management to cut boiler power down when limited temperature is exceeding 57 degree. It means that the range of temperature, from 52 ˚C to 56 ˚C, in summer and from 52 ˚C to 57 ˚C) in winter, should be respected.

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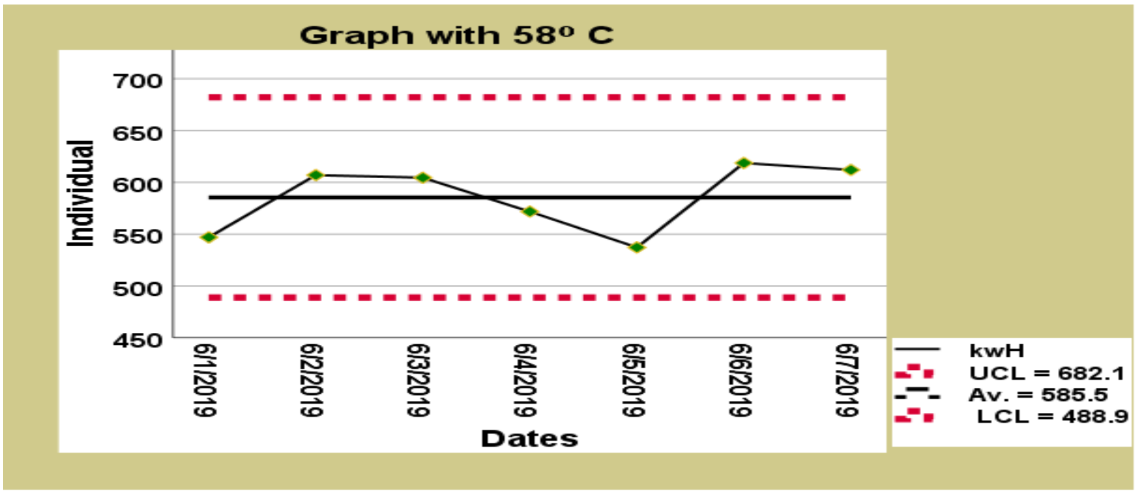

Figure 4.23 Energy usage before improvement

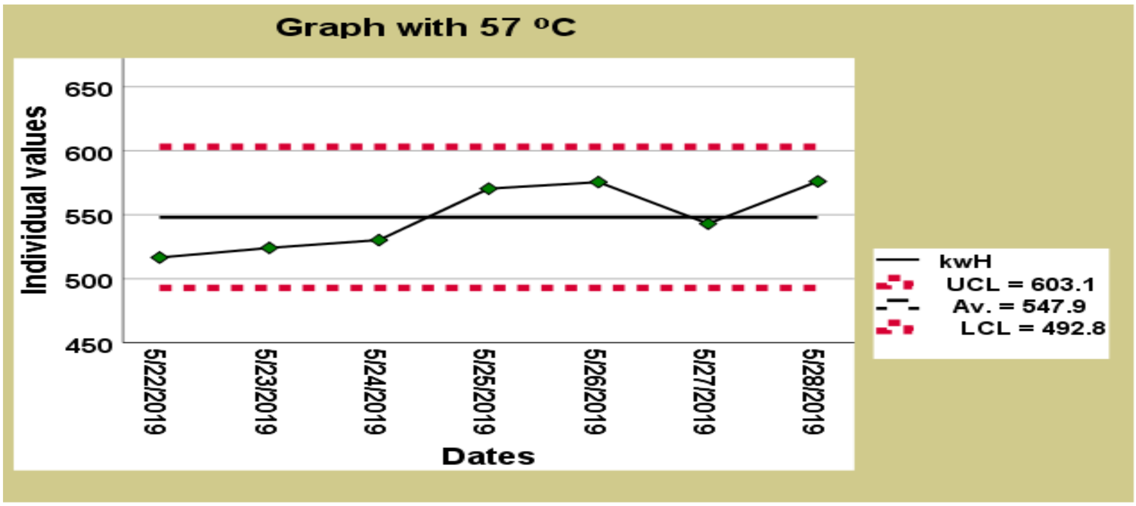

Figure 4.24 Energy usage after improvement

Table 4.17 Saving in Rand after improvement

Electrical Consumption/week	**T °C**	**Average consumption**	**Peak period**	**Cost (R)/Week (Average x peak period)**
4098.2	58	585.5	2.60	10663.1
3835.75	57	547.9	2.60	9980.2
262.45	1	37.6		682.9

Based on the data at this time, the usage should be lower than 3835.75 kwH or at an average of 547.9 kwH per week. Let's say we set the average at 547.9 kwH, the total consumption is 3835.75 kwH or R9980.2. By practicing energy saving, we can save up to 37.6 kwH in average or 262.45 electrical consumption per week or R682.9 per week or R2731.6 per month. The cost to implement the system (automatic shutdown) is much smaller in South Africa than saving of one year obtained.

Secondly, based on average weekly usage, there is savings of 6.4 % in consumption of the boiler only which led to cost saving of the total electrical consumption and the cost of electrical consumption of the building.

Chapter Five: Conclusion and Future Research Work

5.1 Conclusion

This study used the Six-Sigma DMAIC problem solving method to improve electrical energy consumption in commercial building. Starting by setting the goal of the study, identification of the problem as monthly increase of electrical energy consumption, this study wanted to improve the electrical energy consumption in commercial building in first step. In the second step of measurement, all consumption (historical and actual) in kwH were gathered. Using quality analysis methods to determine SEUs performance, the result indicated the following: Boiler had 38%, Kitchen 24%, DB A and Lifts 21% and others 19%. Using cause- and -effect in analysis step of the framework to identify the key factors affecting the energy consumption, the source of variations was identified through data aspect.

Through the improvement strategy by using control method and awareness, 6.4 % was reduced only for boiler which was the 2,4% of total consumption of the building. After implementation of control step of DMAIC, tracking and monitoring data from eGauge SEUs was so important. The methods and analyses presented in this study led to the conclusion that quality management tools used in DMAIC problem solving were useful in energy improvement. They helped to find the source of the problems, eliminating them and even to avoid them in future.

5.2 Recommendations

Improving energy use in buildings means improving the electrical energy used by electrical devices and this energy is measured in kilowatt-hours (kWh). The total amount of electricity used by electrical devices can be continuously supervised, controlled, and reduced using appropriate managerial techniques for commercial buildings. Improving energy usage may also reduce expenses on electrical bills. The following are some recommendations to reduce electrical usage:

- Pursue the consumption reduction measurement; set energy consumption target (control limits and averages); provide training on energy improvement role players.
- Dynamic management of critical period of consumption (busy periods, peak period) by using behavioral approach that provides alerts to the management to control the consumption.
- Daily commitment by managers and employees.
- This study focused mainly on improving the electrical consumption of equipment within the constraints of existing commercial practices and procedures. Additional efforts could be made into the possible energy savings from modifying the process parameters themselves. For example, in the context of the boiler room methods, this would involve modifying the time and temperatures required for boiler usage within the specific environment.

Fore future research, the following are recommended:

- Findings of the study show opportunities for electricity reduction. Most notable is the electricity savings potential through improving consumption of hot water boiler and kitchen. It is important that functioning management requires to install more submeters in building for equipment to allow monitoring energy consumption or energy performance for the equipment. By installing more submeters, it will allow to explain the efficiency or performance of the sub-metered equipment for better energy improvement.
- Implementing energy surveys pre- and post- awareness campaigns to monitor improvements through information provision or awareness creation.

Appendix

Appendix 1. Boiler elements

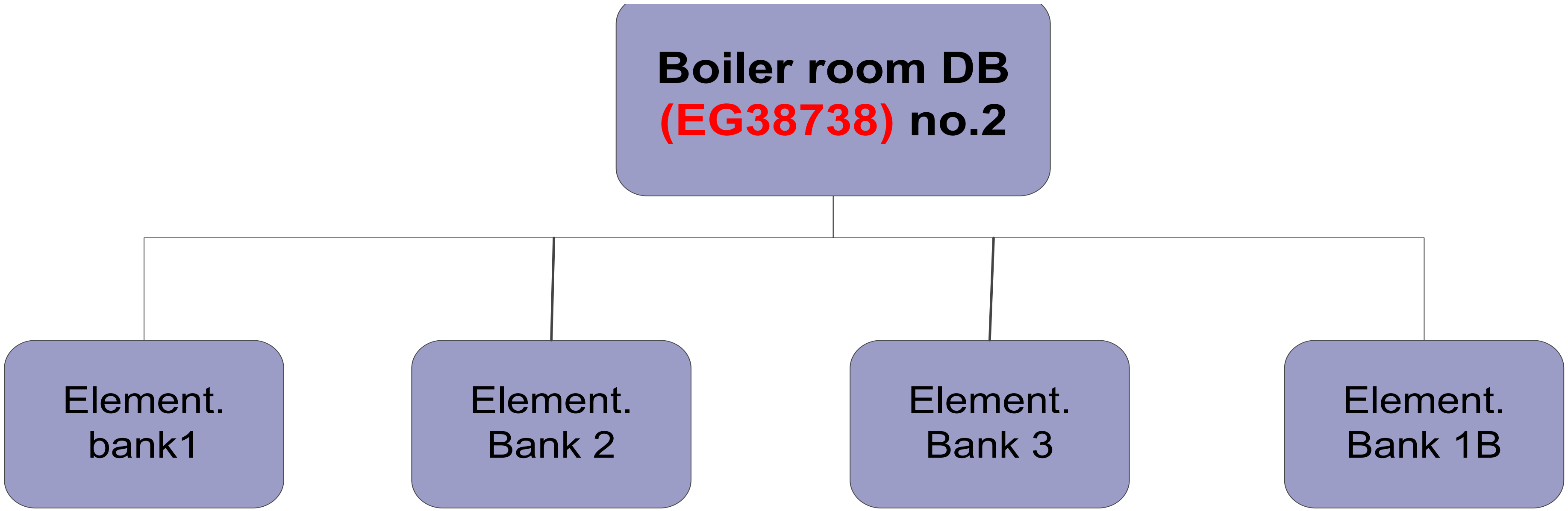

Figure A1. Boiler elements

Appendix 2. Kitchen components

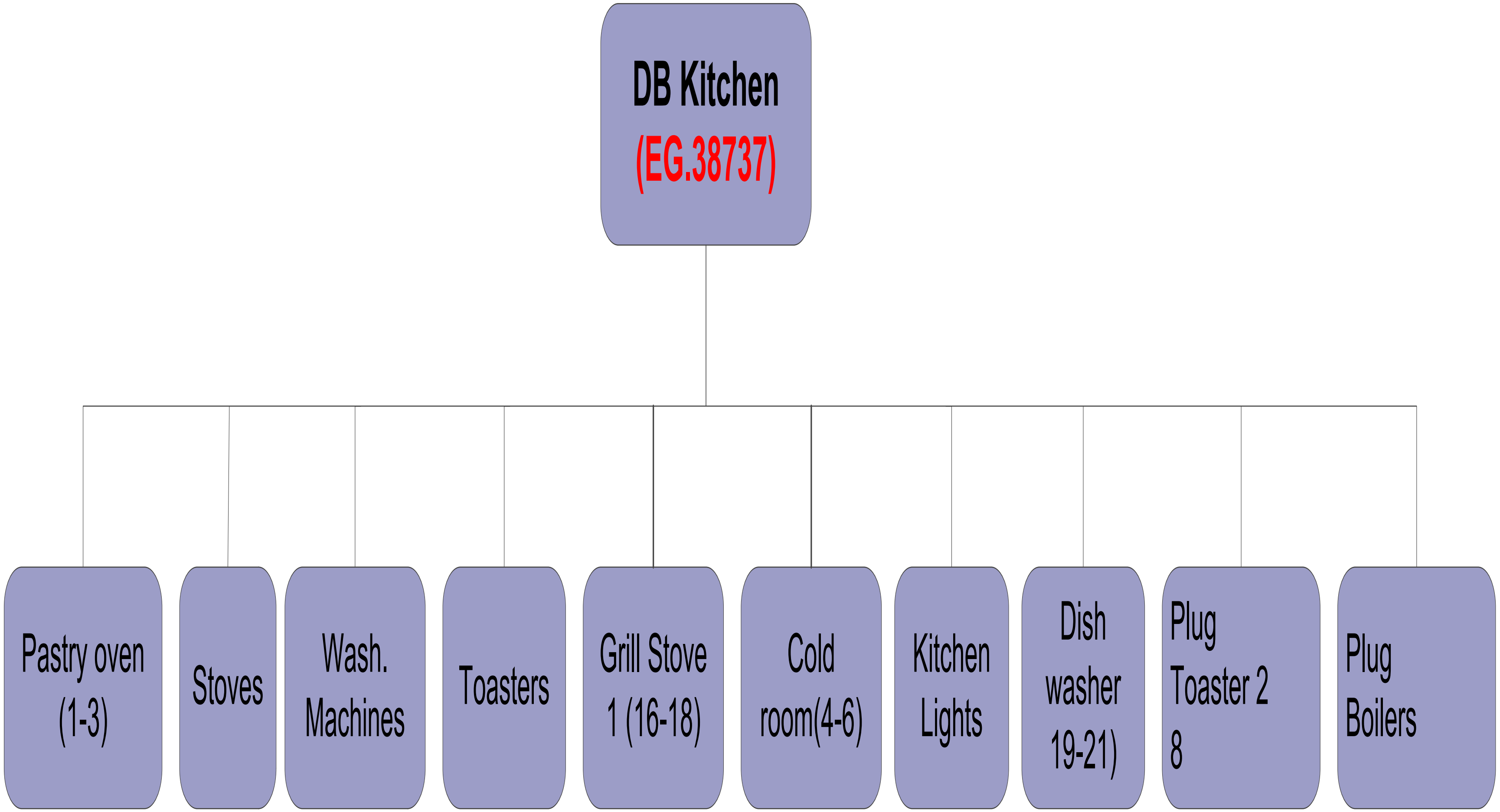

Figure A2. Kitchen energy user

Appendix 3. Questionnaire

Electrical energy improvement and control questionnaire

I am master student from DUT, and I am conducting a questionnaire to find out about energy consumption in …. ………….....................as part of my research on the energy efficiency. If you could take a few minutes to complete the questionnaire, we would be very grateful. Thank you for your time.

1. General Information

- Please tick the answer to the question below.

First Name [ ]

Last Name [ ]

Address. [ ]

Post code [ ]

Email [ ]

- Would you like someone to contact you regarding your responses on this survey? In particular, we may be able to help you benefit from local schemes for home energy efficiency.

○ Yes

○ No

If yes, email address: [ ]

- Please tick which age groups live in your home (tick all that apply)

☐ Under 16 years

- ☐ 17 - 25 years old
- ☐ 26 - 60 years old
- ☐ 61- 70 years old
- ☐ 70+ years old

- What is your highest completed academic qualification?

- ☐ Below Matric
- ☐ Matric
- ☐ Three-year diploma
- ☐ Three-year degree
- ☐ Four-year diploma (e.g. BTech degree) Four-year degree (e.g. Honours degree)
- ☐ Master's degree
- ☐ Doctorate

- Have you ever heard of energy saving in building?

☐ Yes ☐ No

- Do have any sign of energy efficiency or energy saving in your office (E.g.: Switch light off computers and light when leaving the office)

☐ Yes ☐ No

- Who do you think is responsible for energy saving in building?

☐ Manager ☐ Staff ☐ Tenant ☐ All above

- Are you aware of energy cost yearly of the building?

☐ Yes ☐ No

- Name 2 ways you can save energy that would cost nothing.

A. ____

B. ____

- How often do you turn the heating down or off when you go out for a few hours or when you go to bed at night?

○ Almost always

○ Very often

○ Not very often

○ Never

2. Management

- What heating controls have you (or envisage) use in the building? (tick all that apply)

☐ Heating programmer

☐ Radiator valves

☐ Room thermostat

☐ Storage heater controls

☐ No heating controls

☐ Don't know

- How often do you proceed in data collection for measurement?

☐ Daily

☐ Weekly

☐ After 2 weeks

☐ Monthly

☐ None

- How often do you give feedback of electricity consumption to the energy team?

- [ ] Daily
- [ ] Weekly
- [ ] After 2 weeks
- [ ] Monthly
- [ ] None

- Do you communicate with staff member regarding energy saving matters (educating and training opportunities)?

- [ ] Yes   - [ ] No

- What new improvements would you ideally need to make in for the building to make it more energy efficient?

- [ ] Solar photovoltaic
- [ ] Underfloor heating
- [ ] Wall insulation
- [ ] Thermostatic radiator valves
- [ ] New boiler
- [ ] Internal wall insulation
- [ ] New radiators
- [ ] New thermostat

- Lowering set point of boiler (even by 1ºC) to gain further savings

3. Energy Users

3.1 Boiler:

- Do you turn hot water off when shaving?

☐ Yes ☐ No

- Turn hot water off when washing hands?

☐ Yes ☐ No

- How long do you take shower?

☐ 20 Minutes

☐ 25 Minutes

☐ 30 Minutes

☐ Longer than above

☐ Shorter than above

- Who is responsible for adjusting or check operation of high and low limit control setting?

☐ Manager

☐ Team Leader

☐ Owner

☐ Installer

☐ Maintenance manager

3.2. Lighting

- Turn off the light when not used?

☐ Yes ☐ No

- Choose high efficiency lights

☐ LED

☐ Florescent

- [ ] **Incandescent**
- [ ] All above
- [ ] None

3.3 Others Equipment

- What equipment can be switched off at night?

- [ ] Lights
- [ ] Air Conditioners
- [ ] Boiler
- [ ] Computers
- [ ] All the above

- How often do shutdown your computers after work?

- [ ] Yes   - [ ] No

- Do you turn hot water off when shaving?

- [ ] Yes   - [ ] No

- Do use electricity usage monitor?

- [ ] Yes   - [ ] No

- what do you think is more important, technology, awareness or behaviour?

- [ ] Technology
- [ ] Awareness
- [ ] Behavior
- [ ] All the above

- Thank you for completing this energy improvement questionnaire. Any further comments?

Data protection: The information provided in this survey will be used by researcher to help make your buildings more energy efficient. However, it will not be shared with anyone else in a way that enables your responses to be identified.

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