ASSESSMENT OF ENERGY EFFICIENCY AND MANAGEMENT IN WATER SUPPLY – A CASE STUDY OF MZUZU WATER SUPPLY

MSc. INFRASTRUCTURE DEVELOPMENT AND MANAGEMENT THESIS

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MSc. Infrastructure Development and Management Thesis

By

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BSc. (Mechanical Engineering)-University of Malawi

Submitted to the Department of Mechanical Engineering, Faculty of Engineering, in partial fulfilment of the requirements for the degree of Master of Infrastructure Development and Management

University of Malawi

The Polytechnic

March 2017

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DECLARATION

I declare that this research entitled 'Assessment of Energy Efficiency and Management in Water Supply – A Case Study of Mzuzu Water Supply' is my own work. It is submitted in partial fulfilment of the requirements for the Master of Science Degree in Infrastructure Development and Management at the Polytechnic, University of Malawi. It has not been submitted for any other degree to any university or any learning institution for examination or any academic achievement.

SIGNATURE :

DATE :

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CERTIFICATE OF APPROVAL

The undersigned certify that they have read and approve for examination by the University of Malawi, Polytechnic this thesis entitled 'Assessment of Energy Efficiency and Management in Water Supply – A Case Study of Mzuzu Water Supply'.

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Signature : ________________________________

Date : ________________________________

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DEDICATION

I dedicate this dissertation to God Almighty, my entire family and management and staff at Northern Region Water Board.

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ABSTRACT

Energy is prime mover of all economic sectors. Therefore, efficient use of energy in the water sector would contribute to sustainable development. There are many social, economic and environmental benefits that can be realised once efforts towards effective energy management and energy efficiency measures are promoted. Developing countries have lagged behind in the implementation of energy efficiency and management measures hence missing the potential benefits of executing such projects. Malawi is one of the countries that has not fully utilised the opportunities in energy efficiency and management in the water utilities. This thesis has assessed energy efficiency and management in water supply system and is accomplished by investigating the existing level of energy efficiency and management practices in Mzuzu water supply as a case study. There are four methods which were used to come up with research findings; firstly, a survey was carried out using a structured questionnaire which was randomly distributed across the study area. Secondly, an energy audit was carried out in Mzuzu water supply system. Thirdly, energy Monitoring and Targeting (M&T) techniques were employed and used to establish existing relationship of energy consumed and water produced so that mathematical models can be established. Fourthly, Pumping System Assessment Tool (PSAT), was used to assess the efficiency of Mzuzu water supply pumping system. The outcome of the survey and energy audit expose that energy is poorly managed in water supply system due to lack of management commitment as evidenced by unavailability of energy policies, energy efficiency knowledge gap and insufficient funds to roll out implementation of energy efficiency measures. The audit captures correct power demand estimate, power factor correction and utilisation of changes in tariff by ESCOM in a 24-hour operational period as some of the areas where significant potential energy cost savings can be realised. Energy M&T techniques establish existing proven relationship between energy and water in the three pumping stations. PSAT analysis identifies low efficiency pumping systems and their associated energy savings potential in the study area. PSAT also show failed pumping system design in some of the pumping stations. The Plan-Do-Check-Act management model is recommended for continued energy savings and management gains.

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CONTENTS

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LIST OF FIGURES

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LIST OF TABLES

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ACRONYMS AND ABBREVIATIONS

ANSI	:	American National Standards Institute
ASME	:	American Society of Mechanical Engineers
BEP	:	Best Efficiency Point
CIPEC	:	Canadian Industry Program for Energy Conservation
CMMS	:	Computerized Maintenance Management Systems
CUSUM	:	Cumulative Sum Control Chart
EE	:	Energy Efficiency
EIA	:	Environmental Impact Assessment
EMS	:	Environmental Management Systems
ESCOM	:	Electricity Supply Corporation of Malawi
HI	:	Hydraulic Institute
KVA	:	Kilovolt-Ampere
KW	:	Kilowatt
KWh	:	Kilo Watt-hour
LCC	:	Life Cycle Costing
M&T	:	Monitoring and Targeting
MERA	:	Malawi Energy Regulatory Authority
MWK	:	Malawi Kwacha
MWSS	:	Mzuzu Water Supply System
NRW	:	Non-Revenue Water
NRWB	:	Northern Region Water Board
PSAT	:	Pumping System Assessment Tool
SCADA	:	Supervisory Control and Data Acquisition
SPRU	:	Science Policy Research Unit
TDH	:	Total Dynamic Head
UNEP	:	United Nations Environmental Programme
UNICEF	:	United Nations Children's Emergency Fund
UNIDO	:	United Nations Industrial Development Organization
UN-Water	:	United Nations Water

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US$	:	United States Dollars
USEPA	:	United States Environmental Protection Agency
VFD	:	Variable Frequency Drive
WHO	:	World Health Organization
WSS	:	Water Supply System

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CHAPTER 1

INTRODUCTION

1.1 Background: Global and Local Context

Globally, various resources are needed to facilitate human development. Water and energy are among the top on the list. These resources are vital for nations' social and economic development as well as environmental sustainability. Energy requires large amounts of water for various processes and in some cases energy is harnessed from moving water or waterfall; while also energy is paramount in pumping, treatment, and distribution of water and for collection, treatment, and discharge of wastewater. This relationship is commonly known as the energy-water nexus, or the water-energy nexus. This means that any attempt to save water saves energy and vice-versa (Copeland, 2014). Energy is universally significant for the creation of wealth and improvement of social welfare and environment. Energy keeps the transport sector on the move, provides industrial motive and process power, lights and heats up our homes, powers the electrical equipment in homes and hospital, powers machinery to supply essential services to society and the list would go on.

Energy is a scarce and expensive resource, and therefore it contributes significantly to the cost of production of goods and services. Energy is the key element that must be managed to insure a company's profitability (Turner, 2005). Furthermore, many countries, including Malawi, are in energy deficit situation. As such, energy supplying companies tie their tariff structure to energy use behaviour of their customers by charging lower rates for low load demands and surcharges for high load demands. Despite these incentives and disincentives, many companies continue to bear the avoidable costs of energy mismanagement because they do not know where to start to improve the way they utilise energy. Improved energy efficiency and management would reduce energy costs. Energy efficiency is a measure of energy used for delivering a given service and improving energy efficiency means getting more from the energy that we use (EEDO, 2012). On the other hand, energy management is the strategy of adjusting and optimising energy using systems and procedures so as to reduce energy requirements per unit output. The objective of energy management is to achieve and maintain load requirement, minimise the cost of energy and environmental effects (Lamba & Sanghi, 2015). Energy efficiency and energy management facilitate systematic approach to improving use of energy at a facility level.

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Water utility plants are amongst high energy intensive industries at national level. Energy studies show that about 2 to 3% of the energy consumption in the world is used for pumping and water treatment for urban and industrial purposes. Furthermore, the same study indicates that energy consumption could be reduced by about 25% in most of water systems all over the world through performance improvements in the energy (Watergy, 2009). Energy efficiency and management improvements are possible when an energy audit in a facility is carried out which seeks to determine where, when, why and how energy is being used. A better understanding of the facilities that consume energy is necessary for a successful energy audit and this can be accomplished through plant surveys and system measurements. Studies outline 3 types of energy audits namely; preliminary, general and detailed energy audits. Preliminary energy audit (walk-through) is the simplest and quickest type which focusses on major energy consumers in a facility, a general energy audit expands the preliminary audit by collecting more detailed information of a facility in operation over a defined period of time, and a detailed energy audit is more advanced to general energy audit, it provides a dynamic model of energy use characteristics of a facility (Singh, M., Singh, G., & Singh, H., 2012). A preliminary energy audit is preferred because of its simplicity but also it fits well where resources for energy studies are limited. Typical energy audits may involve collecting and analysing existing power consumption and water production from utility bill analysis and production figures. Electrical system audit includes motor efficiency, power factor corrections, variable frequency drives and lighting systems and controls; process system audit sometimes referred to as housekeeping involves process redesigns, optimization and planning to remove bottlenecks and improve flow materials and information; and mechanical system audit include pumps, filters, heating and ventilation systems and associated controls (US.EPA., 2016).

Water and wastewater utility energy consumption is generally in the order of 30 to 60% of a city's energy bill (U.S. EIA, 2015). These facilities require significant energy to power pumps, aeration systems, and other equipment and systems operating almost 24 hours a day; this poses a great challenge to a community with limited energy supply. There are many factors that can affect the way energy is utilised and managed at a water supply facility. Energy usage can vary based on water source, age of the facilities, treatment type, storage capacity, topography, and system size, which encompasses volume produced and service area (U.S.EPA., 2013). This means that different water supply systems (WSSs) have different energy requirements and these

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call for separate energy assessment for each WSS. It is stated that energy represents the largest controllable cost of providing water or wastewater services to the public and that most facilities were designed and built when energy costs were not a major concern (U.S.EPA., 2008). This research has undertaken an energy efficiency and management assessment at Northern Region Water Board (NRWB), a government parastatal that is responsible for supplying potable water to urban and peri-urban areas in the northern region of Malawi.

1.2 Malawi Context

Water problems in Malawi are exacerbated by limited availability of energy. Malawi has a total installed capacity of electricity generation as at March 2015 of 430 MW of which about 80% (351.8MW) is contributed by Electricity Supply of Malawi (ESCOM) and the remainder is from private sector against projected demand of 700 MW (Taulo, Gondwe, & Sebitosi, 2015). This energy gap calls for optimal energy utilisation to minimise wastage. Many industries are affected by insufficient power supply in Malawi and this is detrimental to the development of the country. Any attempts to save energy in Malawi would lessen the gap that exists and that would boost multiple social and economic gains. According to studies done at Mzuzu University, energy savings are economically viable in Malawi (Krishnakumar & Dhungel, 2013).

Northern Region Water Board is wholly owned by the Government of Malawi under the Water Works Act (No. 17 of 1995). NRWB is governed by both internal and external policies and regulations which include; Water Works Act (1995), Water Resources Management Act (2013), Sanitation Policy (2008), National Water Policy (2005). According to its Strategic Business Plan (SBP) 2015-2020, NRWB saves a population of 277,412 with 79% coverage and 35,565 customers. Furthermore, the same SBP indicates that NRWB has an asset value of 8.3 billion kwacha (MWK) and 2.7 billion MWK as revenues with 340 employees. NRWB efforts to achieve its mandate to adequately supply potable water to its customers is constrained by a number of challenges such as insufficient energy supply and related energy costs. This means that any proven way to gain energy savings would lessen financial burden and improve water supply to customers.

Mzuzu water supply system (MWSS) is in Mzuzu city in the Northern Region of Malawi. It is the largest water supply for NRWB with a daily production of about 18,000m^3 and an average

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Non- Revenue Water (NRW) of 38% largely due to commercial losses (NRWB, 2015). The average energy intensity for the whole system is 0.37KW/m^3. MWSS had a 38% contribution to the NRWB total expenditure of which 13% was due to energy cost (NRWB, 2015). With escalating prices of different materials for water treatment and supply, any effort to identify cost-effective opportunities for energy efficiency is imperative in order to reduce financial challenges and also sustain environment. This research is not only motivated to fulfil the academic requirements but also by the desire to contribute towards operational cost reduction efforts through improvements in the energy utilization in MWSS.

1.3 Problem statement

MWS strives to supply potable water to water users in urban and peri-urban areas of Mzuzu city. On average, MWS connects 90 new customers per month. Each new water connection (NWC) is associated with an increase in water production which ultimately demands for more energy use and related supplies. Currently, NWC and water supply are limited by water treatment and pumping capacity, and insufficient funds to procure chemicals and associated plumbing materials as well as meet operational costs. While costs of chemicals and plumbing materials are fixed, the operational costs could be reduced through improved efficiency and management. Currently, energy costs are at 13% of operational costs. The focus of this research, therefore, is to systematically identify energy savings opportunities in MWS since NRWB has limited information on energy efficiency and management. The absence of energy studies makes it difficult to know which operational units or processes within MWS are the major energy users and which of these are operating at low or high efficiency. This research conduct energy studies in MWS to bridge energy information gap that exists. The absence of energy studies makes it difficult to know which operational units or processes within Mzuzu plant are the major energy users, hence the need for energy audit which will enable prioritization of energy saving opportunities, identification of corrective measures and associated financial benefits.

1.4 Main objectives

The main objective of this research project is to assess energy efficiency and management in MWS.

1.4.1 Specific objectives

The specific objectives are to;

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a. Audit energy in MWS system;
b. Assess potential energy savings in MWS; and
c. Develop energy utilization model in MWS system.

1.5 Research Questions

In order to achieve the aims of this thesis work, the under listed research questions will be addressed:

a. What energy consumption processes are in MWS?
b. What are levels of energy saving potential and opportunities in MWS?
c. How best could energy use be optimized in MWS?

1.6 Significance of research

The study has identified energy management gaps in MWS through survey and energy audit. The gaps, if implemented, will be instrumental in designing, implementing and sustaining energy efficiency improvements in NRWB. The findings will contribute to operational efficiency of the NRWB and ensure reliability in water supply services. The results from this study will motivate other WSSs and other industries in Malawi to carry out their energy management studies in their respective systems so that the benefits are felt at a broader scale and this will ultimately lessen the energy gap in Malawi. Furthermore, this study is contributing towards implementation of industrial energy efficiency as articulated by the United Nations Sustainable Energy for all (SE4All, 2015); a programme that Government of Malawi will implement in the near future.

1.7 Ethical issues

As a way of handling ethical issues emanating from this study, a number of measures were considered in carrying out this research work. This study applied voluntary participation to avoid coercing participants in this research. Also, research participants were fully informed about the procedures and risks involved and were asked for consent to participate. Furthermore, there was guarantee of privacy through confidentiality and anonymity. Considering also that the research was done largely at a work place, efforts were done that all information gets to participants with equal treatment. Introductory part of the questionnaire (Appendix 1) dealt with ethical issues.

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1.8 Summary of the Chapter and Structure of the Thesis

This section outlines the summary of the rest of the chapters.

Chapter 2 is a summary of literature of background information from journal articles, books and internet resources. It contains information on related studies done locally and regionally. It also contains a review of relevant theory on WSSs and energy management.

Chapter 3 deals with methodology. It outlines the research design, data collection approached and data analysis techniques.

Chapter 4 provides information on existing plant installations in MWS. It depicts layout of pumping system and pictorial views, it also tabulates available historical and current data on existing plant installations.

Chapter 5 outlines results and discussions. The results come from the survey, energy audit, Pumping System Assessment Tool (PSAT) and energy Monitoring & Targeting (M&T) techniques.

Chapter 6 summarises energy saving opportunities emanating from available literature, survey, energy audit carried out, energy M&T techniques and PSAT as applied in MWS.

Chapter 7 provides conclusion and recommendations. This summarizes the study and provides areas that need further action.

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CHAPTER 2

LITERATURE REVIEW

In this chapter, literature review has been done from the various sources to explore the subject within the search terms 'energy efficiency (EE) and energy management'. The subject area is wide and complex. Therefore, for the purpose of this research, the literature search was confined only to those that directly or indirectly affect the WSSs. The schematic below was developed to guide the theory, academic arguments and context of the study so as to inform methodology and data analysis.

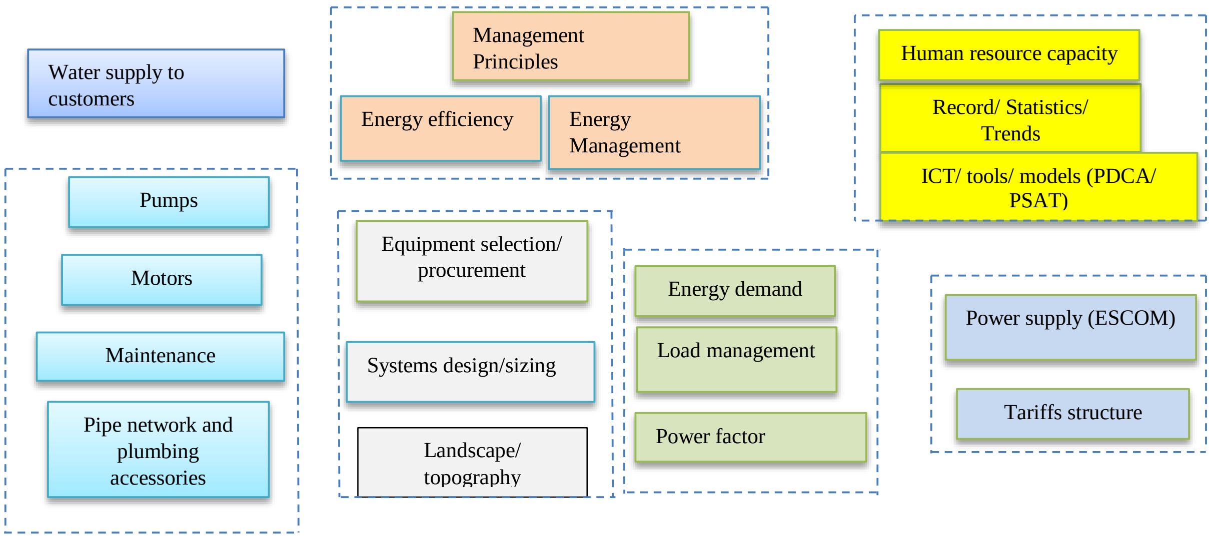

Figure 1: Scope of literature survey

Figure 1 shows how the review has been clustered. Energy efficiency and management are part and parcel of good management practice. Implementation of EE and management will require qualified and right number of personnel and appropriate tools in order to keep records, statistics and trends of energy utilisation and intensities which are key prerequisite for an effective EE and management system. In addition, Electricity Supply Corporation of Malawi (ESCOM) set tariffs structure from time to time to manage load and peak demand as incentives to consumers to manage their loads and demands as part of good energy management practice.

Pumps and their corresponding motors are the largest energy users in WSSs. Therefore issues of sizing, design, quality procurement and maintenance are very important. Landscape and topography may affect pumping heads and appropriate design will be necessary to ensure gravity is used to the systems advantage wherever possible. Demand for water ultimately

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determines the quantity of water to be supplied and energy demand. All these interrelated issues will be discussed in subsequent sections.

2.1 Water Supply Systems (WSSs)

Water supply systems are nearly found in many parts of the world with huge volumes of literature associated with these systems. The availability of water resources in a given location is key to implementation of WSSs. There are various challenges to the availability of water resources due to multiplicity of uses and these threats must be set within the much broader contexts of changes in the economic, social and political landscapes (UN-WATER, 2012). Water constitutes a worldwide challenge for the 21st century, both in terms of the management of available water resources and the provision of access to drinking water and sanitation for the world's population (UNESCO, 2009). The increasing world population, industrialization, social and economic needs of the people are some of the factors that contribute to water challenges. As a way of addressing global water issues, UN-Water Task Force was formed with an overarching objective to contribute to public information and informed decision-making in water and related sectors, it also aims to support international and national decision makers and advance the implementation of international agreed goals and targets on water and sanitation (UNESCO, 2009). A number of local and global policies are available that guide use of WSSs and sources to address some of these challenges. Table 1 depicts the situation of water resources in the world.

Table 1: Water balances

Water Occurrence	**Volume**	**Amount of water**	
	10^3Gm^3	**% water**	**% of fresh water**
World oceans	1300000	97	
Salt lakes/seas	100	0.008	
Polar ice	28500	2.14	77.6
Atmospheric water	12	0.001	0.035
Water in organisms	1	0.000	0.003
Fresh lakes	123	0.009	0.335
Water courses	1	0.000	0.003
Unsaturated zone	65	0.005	0.18
Saturated zone	800	0.60	21.8
Total fresh water	36700	2.77	100
Total water	1337000	100	

Source: Holy, 1992.

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From Table 1, freshwater resources which are desirable in WSSs are unevenly distributed, with much of the water located far from human populations. Polar ice contains about 77.6% of the world's freshwater but these are concentrated in Greenland and Antarctica which is far from human habitation and are not readily accessible for human use. Also, most freshwater lakes are located at high altitudes, with nearly 50% of the world's lakes in Canada alone. Many lakes, especially those in arid regions, become salty through evaporation, which concentrates the inflowing salts. Moreover, many of the world's largest river basins run through thinly populated regions. Furthermore, agricultural water use accounts for about 75% of total global consumption, mainly through crop irrigation, while industrial use accounts for about 20%, and the remaining 5% is used for domestic purposes (UNEP, 2002). Good water conservation practices are a must for sustenance of these water resources globally. This would involve ultimate utilisation of processes that use large amounts of water such as energy generation and use.

Water supply systems abstract raw water from groundwater, lakes, rivers, rainwater harvesting or fog collection and desalination as shown by the hydrological cycle in Figure 2.

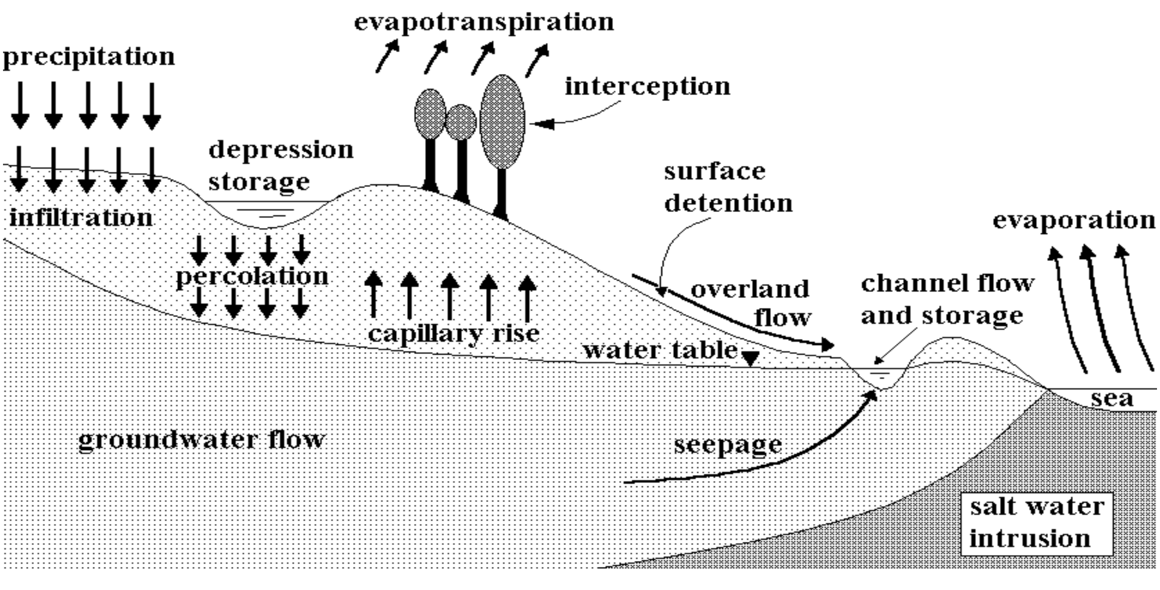

Figure 2: The hydrological cycle *(Laat and Savenije, 1992).*

The hydrological cycle begins with the evaporation of water from the surface of the river, ocean or sea and transpiration from vegetative cover. The rising moist air cools and water vapour condenses to form clouds. Water is then deposited on the earth's surface as rain, snow, hail etc. in a process called precipitation and is collected in various forms as water sources.

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Each of the water sources in the cycle has different energy requirements for treatment.

Raw water[1] requires treatment to make it potable based on Malawi Bureau of Standards and World Health Organisation (MBS, 2005; WHO, 2011). The generalized water treatment process is shown on Figure 3.

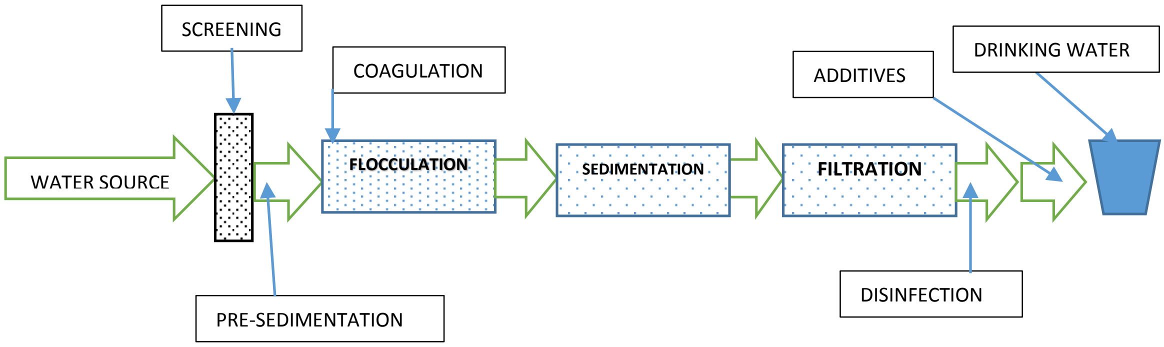

Figure 3: Generalised water treatment process *(Hickey, 2008)*.

As depicted in Figure 3, there are various water treatment processes. The choice of the process depends on the scale of the plant and quality of water. Hickey (2008), outlines eight major steps in water treatment process. The steps are:

Step 1: Screening - Water passes through a series of screens designed to remove debris such as twigs, leaves, paper, stones, and other foreign matter. Screens are frequently removed for cleaning or are back-washed from high-pressure pumps to prevent clogging. Strainers in boreholes and other systems using foot valves act as screens.

Step 2: Pre-sedimentation - While the water moves slowly through each reservoir, much of the sand and silt settles to the bottom. Treatment lines and basins are shut down periodically during times of minimum domestic consumption for cleaning. This applies to the portions of the physical plant described in Steps 2 through 8.

Step 3: Coagulation - A coagulant, aluminium sulphate, is added to the water as it flows to sedimentation basins. Coagulants aid in the removal of suspended particles in the water by causing them to consolidate and settle.

Step 4: Flocculation - The water is gently stirred with large paddles to distribute the coagulant. This takes approximately 25 minutes.

[1] Raw water is untreated water

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Step 5: Sedimentation - The water flows into sedimentation basins where particles settle to the bottom. After about 4 hours, roughly 85 percent of the suspended material settles out.

Step 6: Filtration - Water at the top of the basins flow to large gravity filters, traveling through layers of small pieces of hard coal, sand, and gravel. The filters help remove smaller particles from the water.

Step 7: Disinfection - This may be accomplished by these methods:

Chlorine is added to kill bacteria and viruses. Ammonia also is added. The chlorine and ammonia combine to form chloramines compounds.

Step 8: Additives - Depending on the quality of the water at this point, the following additives may be injected into the water stream to accomplish the stated benefits:

Fluoride is added to reduce tooth decay. Calcium hydroxide is added to reduce corrosion in the pipes and equipment of the distribution system.

After treatment, water is considered potable or suitable for drinking and is delivered through the pipes either through pumping or gravitates to various consumers.

Some water treatment systems extract their raw water through pumping to the treatment plant while others are gravity fed from the source. Also, some WSSs extract their raw water covering longer distances with high pumping heads while others have low pumping heads. The rate of wear and tear in a pump increase with age and this reduce pump performance and ultimately increase maintenance and energy costs. Also, desalination is an energy intensive process while also underground water sources require more energy due to increased pumping head as compared to surface water source. These variables in water treatment systems are a clear indication that each WSS require specific energy improvement studies for unique solutions. Studies indicate that in WSSs about 90% of energy is used for pumping as depicted in Figure 4 (Bunn & Reynolds, 2009; EPRI, 2002; Grundfos, 2004). This is supported and as noted from above, water sources are far from where the population is located and pumping is the main technique of conveying volumes of water needed from one point to the other.

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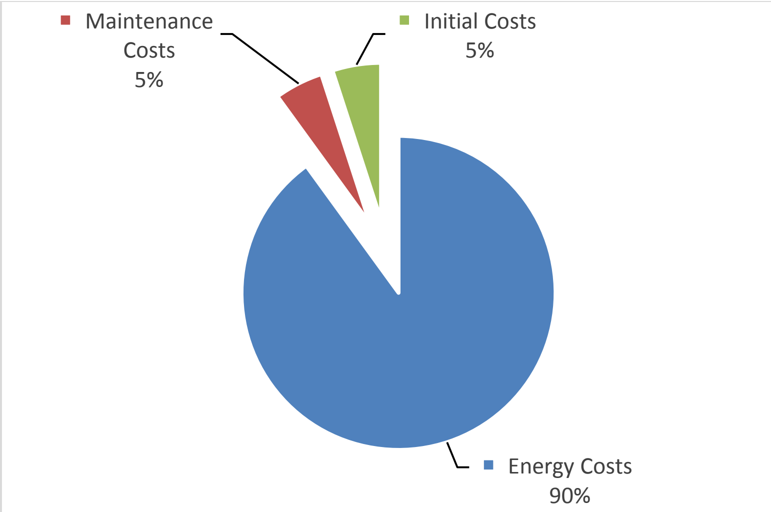

Figure 4: Typical life cycle costs of a pumping system *(Grundfos, 2004).*

2.2 Energy Efficiency and Management

2.2.1 Energy Efficiency

Energy efficiency is understood differently in national and international literature as well as in various scientific disciplines. It is a way of managing and restraining the growth in energy consumption. Something is more energy efficient if it delivers more services for the same energy input, or the same services for less energy input (IEA, 2017). Energy efficiency describes the ratio between the benefit gained and the energy used (Irrek & Thomas, 2008). For electricity, power factor which is the ratio between real power and apparent power defines how a system utilises power supplied and this has an effect on energy demand charges. The overall EE of WSS can be indicated by electricity use per unit of water delivered to end users (KWh/m^3) (Liu, Ouedraogo, Manghee, & Danilenko, 2012). This is commonly termed as energy/electricity intensity or specific energy. There is evidence that EE improvements are possible; at Emfuleni in South Africa they realised 14 million KWh/year energy savings with 12000 tonnes GHG emissions avoided with a payback of less than 3 months, at Pune in India 3.8 million KWh/year energy savings with 38,000 tonnes/year CO_2 emissions avoided was achieved (Barry, 2007). The case studies in South Africa and India are a proof that even in MWS energy savings are possible.

2.2.2 Energy Management

Energy management is defined as ‘the judicious and effective use of energy to maximize profits (minimize costs) and enhance competitive positions’ (EMANZ, 2016). Globally, WSSs through

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pumping account for approximately 25% of the energy consumed by pumping units, and for about 20% to 60% of the total electricity usage in many industrial, water, and wastewater treatment facilities (Ferman, 2008; Europump & Hydraulic Institute, 2001). The studies indicate that by optimising pumping units, the scope for savings for an average system amount to 10% of the current pumping cost (Water Research Centre, 1985). These percentages provide measurable opportunity for energy savings in any WSS.

Energy accounts for about one third of the operating budget for drinking water and wastewater systems (Ferreira & Castanheira, 2005; U.S.EPA., 2008). Many companies, organizations and municipalities are spending large amounts of their revenue on purchasing energy for their production processes, industrial and household services.

There are many and varied reasons for energy inefficiencies in water treatment and supply systems. For instance, a report sites that energy efficiency challenges are due to sector governance issues, knowledge gaps and financing hurdles (Liu, Ouedraogo, Manghee, & Danilenko, 2012). Inefficiencies in water systems may be due to old and outdated equipment, aged pipes, wrong maintenance and replacement policy, complexity in the supply network, lack of cross information between various departments that manage operations and absence of correct measuring and monitoring of main parameters that regulate the system (Moreira, 2012). It is also reported that electrical energy expenditure depends on the specific character of the area, specific character of water supply source, the treatment technology used, and the means by which the water is transported to the consumer (Constantin & Smaranda, 2005). While all the reasons given above correctly represent issues that affect many water treatment and supply systems, each WSS has unique reasons that are pertinent to it and hence the need to evaluate each system separately to establish baseline data. It would be interesting to establish the reasons for energy inefficiencies in NRWB and devise solutions to address the challenges.

Many energy management practices have been studied, explored and practiced and many savings have been realized. For savings in energy management to be realized, a better understanding of sources of energy inefficiencies are needed. This can be achieved by an assessment of WSS through energy audits. An energy audit is envisioned to assess how much energy is consumed and identify measures that can be taken to utilize energy more efficiently without affecting the quality of the processes (U.S.EPA., 2008). It is paramount to establish the

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energy balance[2] in the WSS~~;~~ this involves comparing the energy input into the system against the energy transferred into the fluid. Understanding where energy is being consumed is critical to focusing resources where the greatest savings potential exist. Furthermore, different systems have unique opportunities to reduce energy use or cost depending on system specific changes and available opportunities within the power provider's rate schedules (Coleman, et al., 2009). For example, the sole energy provider in Malawi, ESCOM, has 265% on peak and off pick charge difference (ESCOM, 2016), this implies that by avoiding pumping during on peak hours, energy costs would be reduced considerably based on this tariff structure. Pumping stations energy bill and demand profiles, readings from pressures, flow rates, voltages and amperage are essential for a successful energy management strategy.

There are significant gains that can be realized such as reduced energy use and associated costs, and greenhouse gas emissions once EE measures and renewable energy sources are employed. Furthermore, literature reveals that EE coupled with a change in process technology can result in even more benefits including increased treatment efficiency, potential for increased treatment capacity, and better capability to meet permissible standards. For example, throttling a fixed speed pump wastes energy, also, a pump with a variable speed drive will be more expensive than a fixed speed pump and its average efficiency over the range of operation may not be as high as that of a fixed speed pump, which can spend most of its time running at its design duty (Johnson, Ratnayaka, & Brandt, 2009). In other words, the cost of the pump should not be the only variable in the procurement process in order to achieve better energy management practices. It is also established that there is a strong correlation between the reliability[3] of pumps and their efficiency; i.e. pumps that operate close to their best efficiency point tend to perform more reliably and with greater availability[4] (Dubris, 2001). This revelation indicates that a proper water facility design is a source of energy savings.

The following areas have been identified as critical in achieving improvement in energy use;

i. Load shifting;
ii. Use of variable frequency drive (VFD);
iii. Use of high efficiency motors;

[2] Energy balance from the 1st law of thermodynamics, energy cannot be created or destroyed but can transform from one form to another.
[3] Reliability is a measure of how long the item performs its intended function.
[4] Availability is a measure of the percentage of time the equipment is in an operable state.

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iv. Process optimization and Supervisory Control and Data Acquisition (SCADA) systems;
v. Water leakage control;
vi. Power factor correction;
vii. Proper pumping system design;
viii. Proper maintenance works of pumps and motors; and
ix. Efficient usage of water.

Water and wastewater facilities can often achieve a 20 to 30 percent reduction in energy use through energy efficiency upgrades and operational measures (Leiby & Burke, 2011).

2.3 Energy consumption reduction strategies

The characteristics of WSS determine the strategies that can be employed to reduce energy consumption. According to Tsutiya (2001), there are various steps as outlined below that can be employed to any particular system with an aim of reducing the overall costs.

2.3.1 Reduction of cost without reduction in electrical energy consumption

a. Without additional investment (administrative actions)
   i. Suitability of the demand;
   ii. Changes in tariffs;
   iii. Leakage detection; and
   iv. Measurement errors.
b. With additional investment (operational actions)
   i. Changes in voltage;
   ii. Capacity factor improvement; and
   iii. Power factor correction.

2.3.2 Reduction of cost with reduction in electrical energy consumption

a. Reduction of the total head (reduction in head loss)
b. Reduction in the total supplied water
   i. Leakage control; and
   ii. Rational use of water.
c. Enhancement in the efficiency of the pumping systems
   i. Motor efficiency; and
   ii. Pump efficiency.

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2.3.3 Reduction of cost by changing the operational system

a. Changes in the pump-tank system;
b. Usage of variable speed drives; and
c. Changes in operational procedures.
d. Reduction of cost by automation of the WSS
e. Reduction of cost by generating electrical energy with independent systems.

From the literature, it is observed that water resources and quality are dwindling because of population, human activity and climate change. These challenges have made water treatment and transmission energy intensive. We also learn that WSSs have varying energy requirements and that pumping dominates energy requirements in WSSs. There is clear evidence from literature that energy consumption in WSSs can be reduced considerably through proper energy management practices. The reduction in energy consumption can be a great remedy to a country such as Malawi where energy supply is insufficient. Malawi has not benefited much on available energy efficiency measures due to energy efficiency information gap that exists. It is from this background that this study has been initiated so that benefits associated with energy savings are fully utilised.

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CHAPTER 3

METHODOLOGY

This is a positivistic research with an applied, quantitative and deductive approach. It is also exploratory because the research involves a case study. The following methods were employed:

3.1 The Survey

The study employed the use of a structured questionnaire due to explorative nature of the study to gather more data related to energy policies, energy efficiency and management practice in the study area. The survey targeted NRWB employees in Technical Department in Mzuzu, Ekwendeni, NkhataBay, Chintheche, Mzimba, Rumphi, Chilumba, Karonga, Songwe and Chitipa WSSs located across the Northern Region of Malawi. Employees in Technical Department are involved in day-to-day usage of energy and hence their likelihood to have the knowledge on energy efficiency and management. Although Technical Department was targeted, employees from other departments were also involved because of their contribution to energy efficiency and management decisions from design, procurement, usage and disposal of energy related assets.

The development of the questionnaire was based on the lessons from other studies (Sorrell, et al., 2000; Thollander & Ottoson, 2008); as well as personal experience in managing WSSs. The questionnaire tries to establish energy management practices in the study area, perception on energy saving opportunities, barriers and driving forces to energy efficiency improvement.

3.2 Energy Audit and ASME EA-2-2009 – Energy Assessment for Pumping Systems

A preliminary energy audit was done at MWSS. The energy assessment of MWSS was based on the standard ASME/ANSI EA-2-2009 which provided the requirements to be performed during the assessment of the pumping systems. The standard is applicable because about 90% of energy costs in WSSs globally are through pumping (Grundfos, 2004; Reinbold & Hart, 2011). There are three levels of pump system assessment that EA-2-2009 state and are shown in Table 2 (ASME EA-2-2009, 2009).

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Table 2: Pump System Assessment levels *(ASME EA-2-2009, 2009)*

Activity	**Assessment Level**		
	1	2	3
Prescreening opportunities	Required	N/A	N/A
Walk through	Optional	Required	Required
Identify system with potential saving opportunities	Required	Required	Required
Evaluate systems with potential saving opportunities	Optional	Required	Required
Snapshot type measurement of flow, head and power data	Optional	Required	N/A
Measurement/data logging of systems with flow conditions that vary over time	N/A	N/A	Required

The primary objectives of Level 1 assessment was to pre-screen the pump systems in MWS, this can also be termed as preliminary energy audit as it seeks to determine which systems have the greatest opportunity for energy savings. Those systems with the greatest opportunity were further assessed with the activities of Level 2 assessment and analysed further. The Level 1 assessment was executed on all of the pump systems in MWS. Applying simple worksheets, most basic information was gathered for further analysis. The primary objective of a Level 2 assessment was to gather operational data for existing pumping systems either by retrieving stored data or measuring with portable measuring devices, such as flow meters, voltmeter, ammeters, wattmeter, and power factor meters. The collected data was for a defined period of time and was representative of normal operation. The information from a Level 2 assessment was used to determine an estimate of the potential energy savings of the system.

3.3 Pumping System Assessment Tool

The Pumping System Assessment Tool (PSAT), a free online software tool to help industrial users assess the efficiency of pumping system operations (PSAT, 2008), was used. PSAT and the specialist training program were established to help in identifying pump system energy efficiency improvement opportunities, primarily in industrial plants (Casada, 2007). The US Department of Energy's (DOE) Industrial Technologies Program contracted with the Oak Ridge National Laboratory to develop PSAT, and the related training program in 2000

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(Towsley, 2010). The tool uses achievable pump performance data from Hydraulic Institute standards and motor performance data from the Motor Master+ database to calculate potential energy and associated cost savings. The tool also enables users to save and retrieve log files, default values, and system curves for sharing analyses with other users (Casada, 2007). The tool was used to assess energy efficiency in MWS pumping stations to evaluate both component and system performance.

3.4 Energy Monitoring and Targeting (M&T)

Energy M&T, is a management technique which emanates from the concept that energy can be treated as a controllable resource and that energy saving opportunities can be identified by analyzing data and taking actions as a result of such an analysis (CIPEC, 2002; Ferreira & Castanheira, 2005). The aim of M&T was to optimize energy use without affecting the intended processes. Energy M&T was used in MWS and specifically pumping units. The following steps were used in this energy efficiency technique;

a. Energy Audit (Preliminary). Site analysis and identification of main energy consumers – Pre-screening opportunities and walk through as presented in ASME/ANSI EA-2-2009 Table 2;
b. Identification of other variables (production, turbidity, weather, schedule, Non-revenue water (NRW), power factor etc.);
c. Data gathering – Extracting existing production and energy consumption data. Measure any required data at regular intervals;
d. Define the baseline – Using spreadsheets and SPSS determine specific energy consumption, perform bivariate correlation analysis, CUSUM and design of a basic models using all variables;
e. Monitor variations – difference between data measured and baseline;
f. Identify causes – whether positive (to be repeated) or negative (to be eliminated);
g. Set targets – to use baseline to identify realistic and attainable targets; and
h. Monitor results – to ensure projected targets are reached and sustainable.

CUSUM plots and steps e, f, g and h were not performed owing to insufficient data and time.

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CHAPTER 4

CASE STUDY-MZUZU WATER SUPPLY

This chapter aims at describing the case study WSS in detail so that the pumping subsystems and energy demand could be appreciated when the analysis is done in Chapter 5. Furthermore, it provides the visual perspective of the scope, pipe network and topography.

4.1 Profile of Northern Region Water Board (NRWB)

Northern Region Water Board is one of the five water boards in Malawi located to the North of Malawi with its headquarters in Mzuzu city. Mzuzu city is located at -11.47 latitude and 34.02 longitude at an elevation of 1275 metres above sea level.

4.2 Mzuzu Water Supply System

Mzuzu water supply system delivers potable water to the residents of Mzuzu city and surrounding areas. The main source of raw water for MWS is Lunyangwa Dam. The dam has an active estimated storage volume of 4.13 million m^3 (Lahmeyer International, 1991).

Raw water from Lunyangwa dam gravitates to the treatment plant by design to reduce energy usage, a fraction of raw water is pumped from three bridges and old intake chamber to the treatment plant as auxiliary sources to minimize dam draw-down. The treated water is then pumped to three directions; MBC, Katawa and Government Booster Stations. At MBC, potable water is pumped to Signal Hill and Lusangazi reservoirs where it is gravitated for consumption. At Katawa, treated water is pumped to Lunyangwa and Nkhorongo reservoirs for use. At Lunyangwa reservoirs, water is pumped to an elevated tank which feeds the higher areas as depicted in Figure 5 (Metaferia, 2008) and topographic map in Figure 6. Table 3 shows a summary of Mzuzu pumping station operating conditions.

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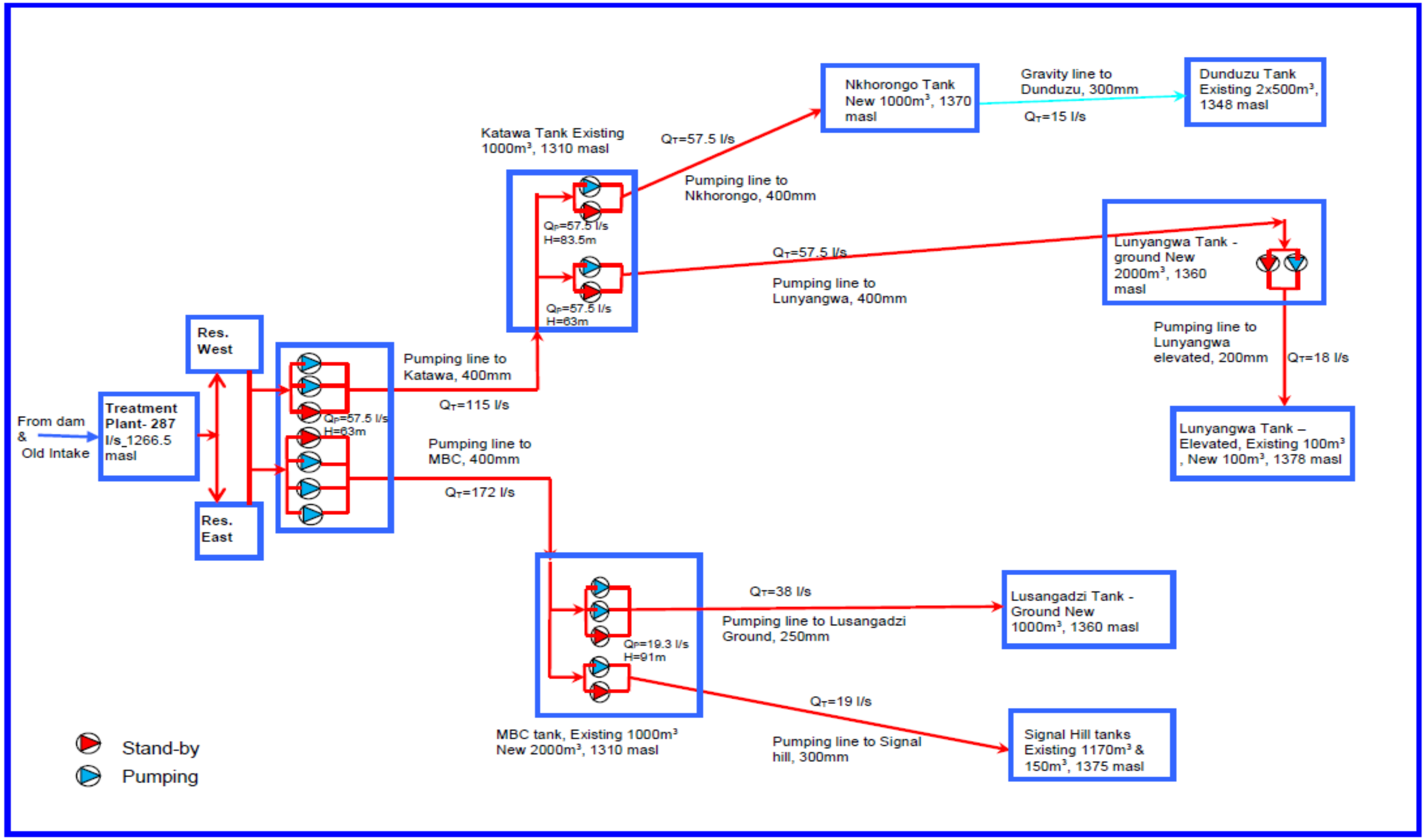

Figure 5: Schematic Layout of Mzuzu Water Supply Pumping System

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Figure 6: Mzuzu Water Supply Pumping System Topographic Map

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Table 3 Summarised Mzuzu pumping station operating conditions

Item	**Description**	**Location**	**Year installed**	**Motor rating (KW)**	**Capacity (l/s)**	**Pumping efficiency (%)**	**State of impeller**	**State of casing**	**Remarks**
1	Submersible Pump	Main plant	2015	27/37.7	96	No flow meter	Good	Good	Throttled
2	MBC Feeders	Main plant	2010	55	57.5	76	Worn out	Good	Frequent breakdowns
3	Government Feeders	Main plant	1994	55	50	87	Worn out	Worn out	Frequent breakdowns
4	Katawa Feeders	Main plant	2010	55	57.5	77	Good	Good	
5	Backwash pumps	Main plant	1994	22	250	61.2	Good	Good	Operate 3 hrs a day
6	Signal Hill Feeder	MBC Station	2010	30	19	91	Good	Good	Inadequate capacity
7	Lusangazi Feeder	MBC Station	2010	30	19	71	Good	Good	Inadequate capacity
8	Lunyangwa Feeder	Katawa	2013	55	57.5	87	Good	Good	Upgraded
9	Nkhorongo Feeder	Katawa	2010	75	57.5	76	Good	Good	

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From Table 3, Government Feeders and Backwash pumps are already above 10 years in service which is recommended for replacement. Motor size range from 22 to 75 kW with total installed capacity of 620 KW. This means that if all the motors run at the same time it would result in 620 kW-hours of energy units. This is a situation that needs to be avoided if maximum demand is to be managed.

4.3 Pumping Station Operating Conditions

There are three main pumping stations under study in MWSS and these are; Main plant, MBC and Katawa Booster stations, each of these stations use centrifugal pumps.

4.3.1 Main Treatment Plant

4.3.1.1 Submersible Pumps

There are two submersible pumps each driven by a 4 pole motor rated 27KW and 37.5KW respectively. These pumps were installed as result of erratic rains received during the years preceding 2015 which significantly led to reduced dam levels to sustain continuous operation. The pumps were earmarked to push raw water from the abandoned old intake and three bridges streams. It was discovered during audit that these two pumps were excessively throttled during the 6 months in operation due to insufficient raw water from the sources. Also, it was observed that during the months the pumps were not in operation i.e. October 2015 to March 2016, the energy consumption dropped significantly (Figure 7). These pumps have no flow meter and they also use common ESCOM meter for the whole plant for electricity consumption.

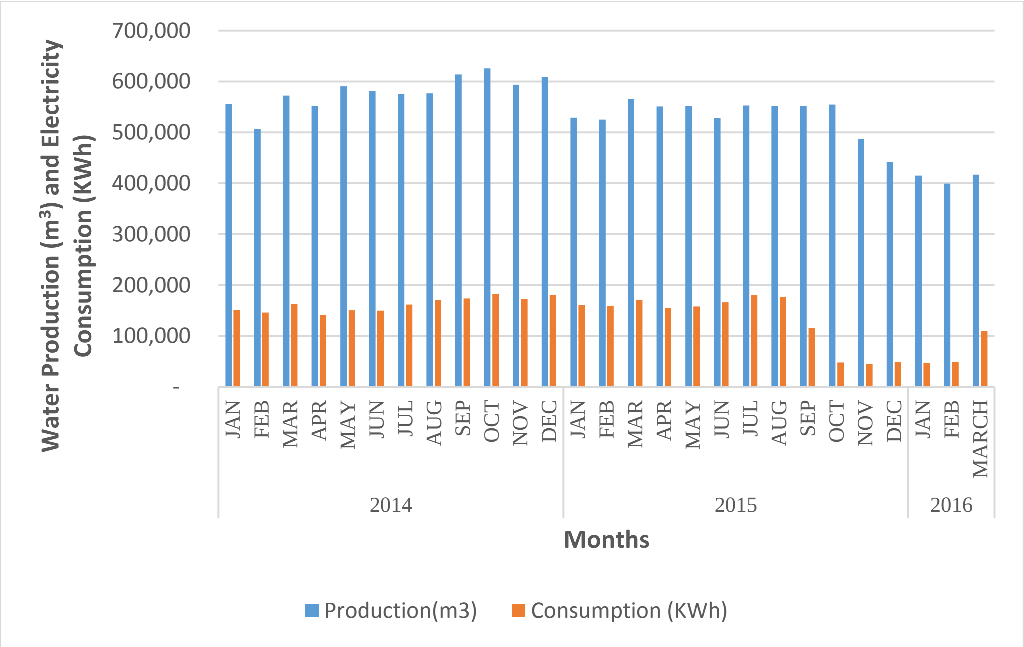

Figure 7: Main Plant Water Production and Energy Consumption Trends

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4.3.1.2 MBC Feeder Pumps

The second station is where four surface horizontal pumps, KSB model ETA 100-250, are installed. Three pumps are operated at a time and one on standby. Frequent breakdowns on these pumps were noticed. Impellers were worn out and holes were seen in some cases as seen in Figure 8. These could be some of the attributes to 76% pumping efficiency as shown on Table 3. As the efficiency of the pumps drop, more energy is consumed to balance up the losses.

Figure 8: MBC Feeder Impeller.

4.3.1.3 Govt. Feeder Pumps

The third station is where 2 surface horizontal split casing pumps, SPP model HSRB 4, are installed. One pump is operated at a time and one on standby. The records indicate frequent breakdowns for the past decade, moreover, the spares for the sets were discovered very scarce locally. Although the pump sets were planned for abandonment in 2009, they are still operational. These pumps are in wear-out phase in the bath-tub curve which is characterised by frequent breakdowns due to fatigue and this draws more energy for operation.

4.3.1.4 Katawa Feeder Pumps

The fourth station is where 3 surface horizontal pumps, KSB model ETA 125-50/2, are installed. Two pumps are operated at a time and one on standby.

4.3.1.5 Backwash Pumps

The fifth station is where 2 low pressure surface horizontal pumps, type AM35A, are installed. One pump is operated at a time and one on standby. These pumps have no flowmeter and they are operated for total sum of 3 hrs (20 minutes for each of the 9 filters) in a day.

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4.3.1.6 Air Blowers

In addition to the pumps, there is a set of air blowers coupled to a 2 pole motor each rated 30KW, drawing 18.8 A, with a working pressure of 17KPa. One blower is operated for 45 minutes daily and one on standby, these are used for air blowing during the treatment process.

4.3.2 MBC Booster Station

4.3.2.1 Signal Feeder Pumps

The first pumping set at this station is where 2 surface horizontal pumps, KSB model ETA 65-250, are installed. One pump is operated at a time and one on standby. The audit revealed inadequate capacity on these pumps in relation to water demand hence the continued use of Government Feeders which also feed the same location but were planned for abandonment as earlier indicated.

4.3.2.2 Lusangazi Feeder Pumps

The second pumping set at MBC Booster station is where 3 surface horizontal pumps, KSB model ETA 65-250, are installed. Two pumps are operated at a time and one on standby. The 71% pump efficiency and inadequate capacity shown in Table 3 could be attributed to wrong pump design and poor demand estimate as presented in results and discussions. Also, the transmission line is a 250mm PVC pipe as shown on Figure 4, this size for an 8.45km line is small hence it attracts more head losses.

4.3.3 Katawa Booster Station

4.3.3.1 Lunyangwa Feeder Pumps

The first pumping set at Katawa Booster station is where 2 surface horizontal pumps, KSB model ETA 125-50/2, are installed. One pump is operated at a time and one on standby. Although the pumps indicate an efficiency of 87% in Table 3, they were upgraded in 2013.

4.3.3.2 Nkhorongo Feeder Pumps

The second pumping set at Katawa Booster station is where 2 surface horizontal pumps, KSB model ETA 80-250, are installed. One pump is operated at a time and one on standby.

4.3.4 Flow Meters

Flow meters used in Mzuzu water supply pumping stations are WP-Dynamic type and are ideal for the measurement of high, relatively constant flow rates. They can measure water of temperatures up to 130°C, and are found in sizes DN 40 to DN 300mm. The installed sizes are DN 200mm and DN250mm. These meters have patented hydro dynamically balanced rotor with high overload capacity. They require unrestricted straight pipe in front of the flow meter 3 x DN to be installed. They are suited because they are maintainable by replacing parts. Average readings were taken for each pump set or combination to arrive at the flow rates. Figure 9 shows pumping station flow meter.

Figure 9: Pumping station flow meter.

4.3.5 Energy Consumption Meter

The main electricity meter was installed by the Electricity Supply of Malawi (ESCOM) and is used for billing the pumping station's energy consumption. ESCOM meters are located at the step-down transformer. These are the same meters that NRWB use to check their energy consumption as well as power factor of the pump stations. The installed meters are INHEMETER. During normal pumping operations, daily energy consumption is recorded every 6am. Main energy meter is shown in Figure 10.

Figure 10: Energy consumption meter.

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CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 The Survey

Figures 11-14 show the results of the response rate of 82 out of 100 questionnaires that were administered during the study. One hundred questionnaires were administered to members of staff of NRWB. A response rate of 82% was attained. This demonstrates the importance and interest the respondents had in the issues of energy management and energy efficiency. Further analysis of the respondents was done based on gender, educational qualification, the department where they belong and the position they were holding within NRWB.

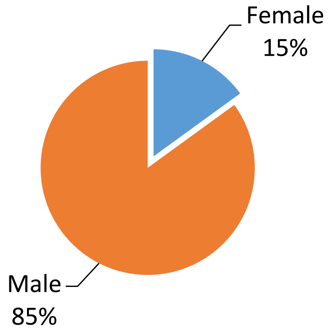

Figure 11: Gender distribution of respondents

As it can be shown in figure 11, there were comparatively more males than females. This is lower than national average of 30% for non-agriculture wage employment (NSO, 2013), but probably not unusual for technical organizations like NRWB. However, the results will not necessarily be affected by such since issues of energy management and energy efficiency cut across gender boundaries.

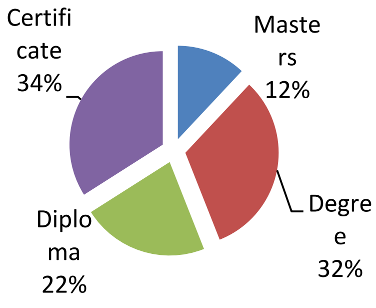

Figure 12: Qualification of respondents

The results in Figure12 show that 66% of the respondents possessed diploma and above. Therefore, it would be expected that such respondents were capable of understanding contents

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of the questionnaire and interpretation of results and probably some knowledge on energy, EE and energy management. Level of education is also critical in assimilation of new knowledge and implementation of energy management and energy efficiency projects.

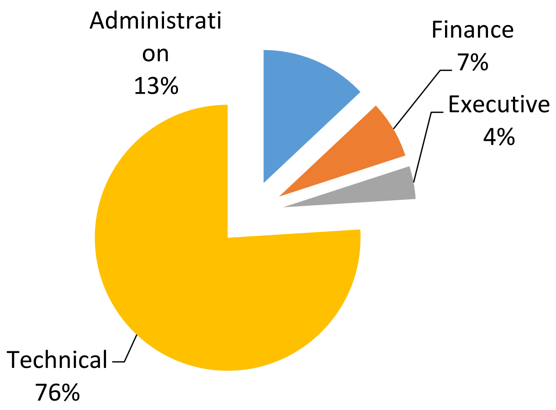

Figure 13: Level of education of respondents

The results in Figure 13 indicate that Technical Services Department dominated in the participation of the survey contributing three quarters of the respondents. This was expected as planned in the methodology but could also mean that the water industry is highly technical in nature.

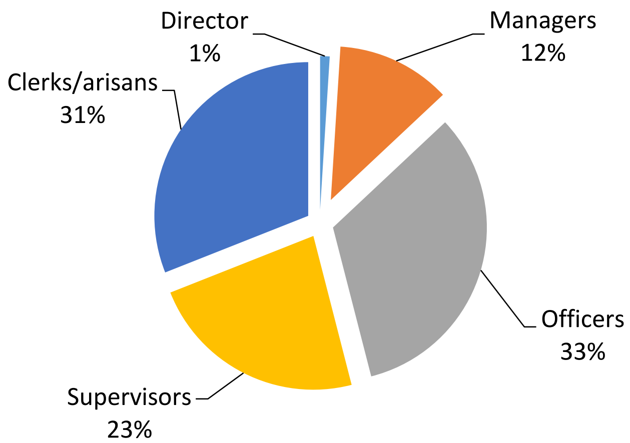

Figure 14: Distribution of positions held by respondents

The results shown in Figure 14 indicate that the survey cut across all the levels of employees hence their opinions are also diverse and inclusive. The numbers are also representative of pyramidal structured organization like NRWB (13% senior management, 23% supervisory roles and 64% the rest).

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5.1.1 Energy Policy

Figure 15 shows the results of energy management practices in the study area from the perspective of the respondents. Respondents of the survey were asked to rank availability, commitment, integration, and awareness of energy policy in the study area.

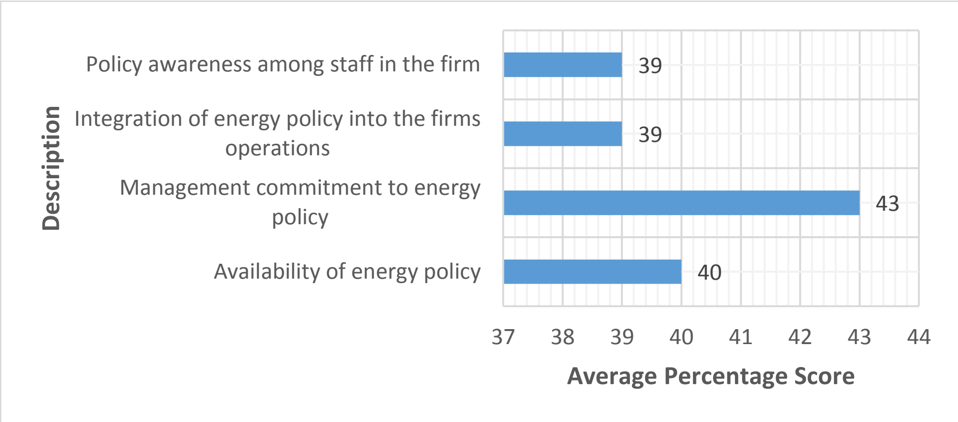

Figure 15: Average score (from questionnaire) percentage of the respondent rating of energy policy

From the results, a 40% rating indicate that there is informal energy policy; 43% indicate that management has interest but not committed to energy management; 39% show that there is no energy policy integration into the firms operation; and 39% indicate that there is no energy policy awareness amongst members of staff. The results from the perception of respondents imply that management commitment on EE improvements is inadequate. Management commitment to EE is one of the most critical factors for effective and sustained EE improvements and without a general governance framework or institutional environment that demands good performance, specific EE efforts at the utility level are unsustainable (Liu, Ouedraogo, Manghee, & Danilenko, 2012; Thollander & Ottoson, 2008).

5.1.2 Information Sources

Figure 16 shows scaled results of EE opportunities information sources in the study area from the perspective of the respondents. Respondents of the survey were asked to rank the effectiveness of some official and unofficial information sources with regard to EE in NRWB.

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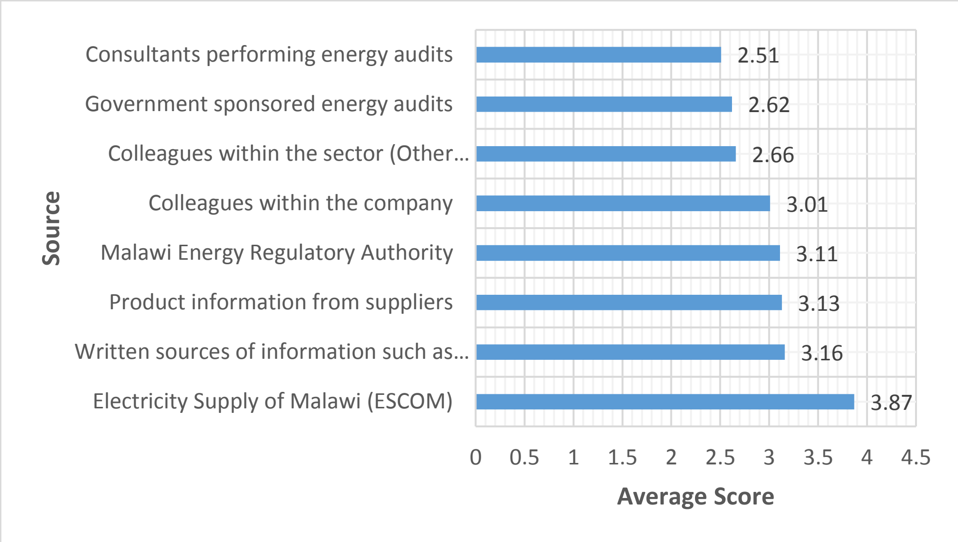

Figure 16: Scaled results (from questionnaire) of EE opportunities information sources.

The results show that information from ESCOM was ranked as the best source. This is in line with EE and management studies done in Ghana (Apeaning, 2012). ESCOM as a public sole electricity utility company in Malawi is well positioned in the energy market to promote industrial EE in Malawi because of their strong energy ties with consumers and the technical familiarity with customer equipment. Written sources of information such as journals came second and information from suppliers of equipment was ranked third as the most effective source of information. Demographics indicated that 66% of the respondents hold diploma and above, this explains why written sources such as journals came the second. Many scholars approve journals as having worth of information compiled from different research works. Water supply systems in Malawi and in particular MWS, procure most of its water supply plant and equipment from abroad and product information from the suppliers is critical for decision making. Information from Malawi Energy Regulatory Authority (MERA) was ranked the fourth. MERA is an energy regulatory body for both energy producers and consumers and their information is pertinent towards EE. The ranking may indicate that MERA has not adequately disseminated information on energy management to its stakeholders such as NRWB. For a successful implementation of water supply EE and management, there is need to access relevant information on energy. The credibility and source of the information is as important as the worth of the information.

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5.1.3 Energy Consuming Processes

Figure 17 shows scaled results of six common energy consuming processes in MWSS. The survey ranked these processes from 1 (lowest consuming) to 5 (highest consuming) process.

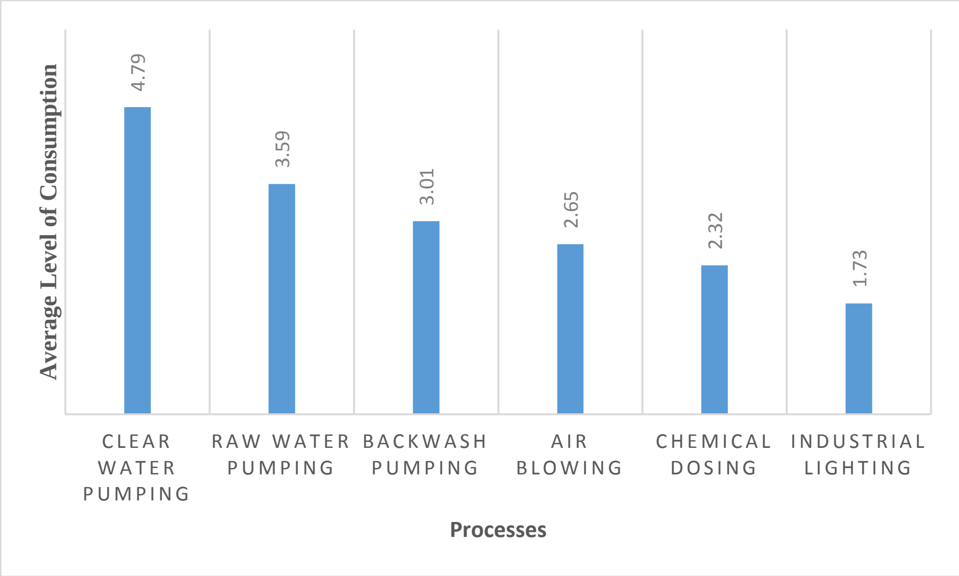

Figure 17: Scaled results (from questionnaire) on respondents' perception of energy consuming processes.

The results from the perception of respondents show that clear water pumping consumes more energy than the rest in NRWB. This agrees with the studies which indicate that about 85% of energy consumption in WSSs is through pumping globally (Grundfos, 2004; Reinbold & Hart, 2011). The results entail that in WSS, EE measures should be concentrated on pumping equipment so that considerable savings can be realised.

5.1.4 Energy efficiency measures

Figure 18 shows the average score rating of EE technology and measures assessed by the various respondents using a scale of 1 (not implemented) to 5 (extensively implemented.

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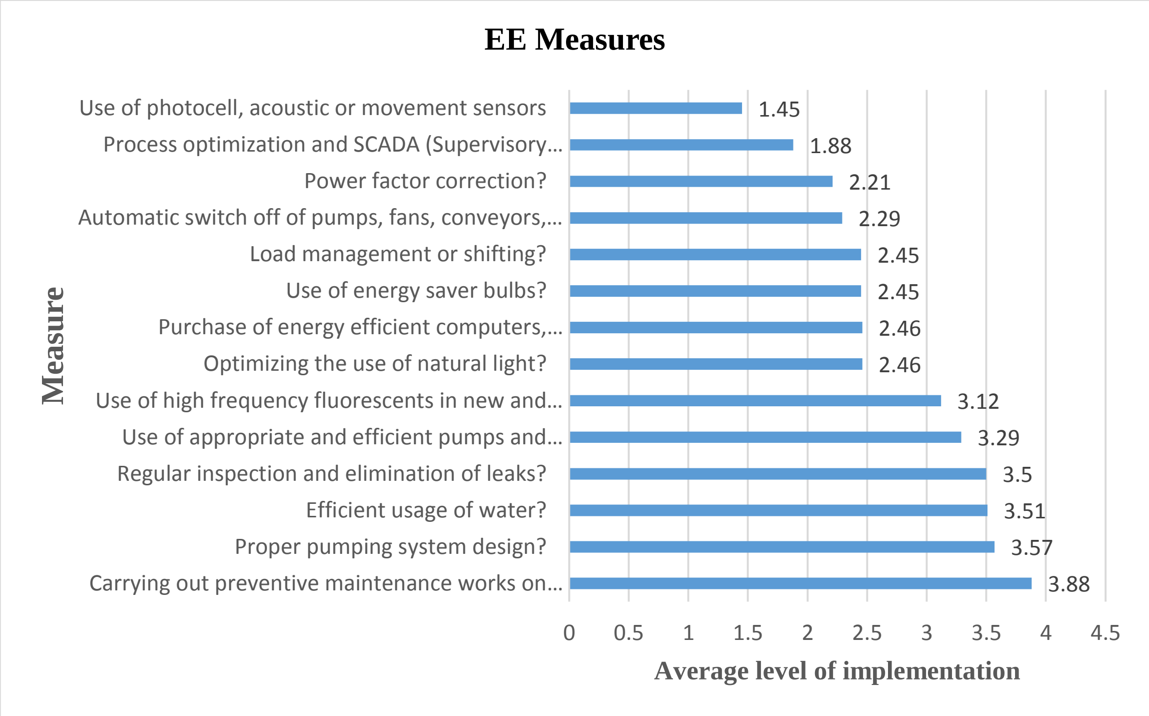

Figure 18: Scaled results (from questionnaire) of EE measures.

The results show that carrying out preventive maintenance works was best implemented in the study area seconded by proper pumping system design. These are widely known measures and commonly practised in many industries hence most of the respondents were familiar with them. The demographics in Figure 13 also indicate that 76% of the respondents were from technical services department and these are responsible for carrying out preventive maintenance as well as pumping system design. This may have contributed to the high rating of these two measures. This seems to be in line with EE studies done in Kenya (Tiony, 2012).

Literature reveals that large energy saving potentials exist in WSSs. The results show that the study area has not implemented most of energy efficiency measures, this could be attributed to lack of management commitment as discussed under section 5.1.1 and an assessment of the barriers will help to further explain this finding. Power factor correction is widely used in energy savings yet the study reveals that the study area had not implemented power factor correction; this can be attributed to lack of funds or ignorance of the benefits. The avoidance of idle operation of pumps, blowers and other electrical equipment is another effective means of reducing electricity consumption. There was no indication in the study area that there was existence of automatic switching off systems to put off idle equipment. Measures used to reduce energy consumption by lighting systems includes; replacement of tungsten filament lamps with energy saver bulbs, optimization of daylight and replacement of 38mm fluorescents with 26mm, etc. It was revealed through the study that none of the areas studied had light control systems

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to automatically switch lights on and off when needed. The implementation of energy saver bulbs in the study area is attributed to efforts by the Malawian government and ESCOM in the promotion of energy saver bulbs in the country and this seem to be in line with similar studies done in Ghana (Apeaning, 2012). Optimising the use of natural light was ranked the fifth, the measure doesn't attract any investment but sensitisation and behavioural change. The use of appropriate and efficient pumps and motors is largely implemented in the study area though not targeting energy savings. The inspection and elimination of water leaks in pumps, tanks and distribution line is extensively implemented though not also targeting energy savings due to lack of knowledge. Most respondents indicated that preventive maintenance work was extensively implemented yet the energy audit found that most of the works were reactive maintenance due to various reasons.

5.1.5 Barriers to energy efficiency improvement

Figure 19 shows the average score rating of 22 barriers to EE improvement assessed by the various respondents using a scale of 1 to 5; 1 for not important, 2 for rarely important, 3 for sometimes important, 4 for important and 5 for very important.

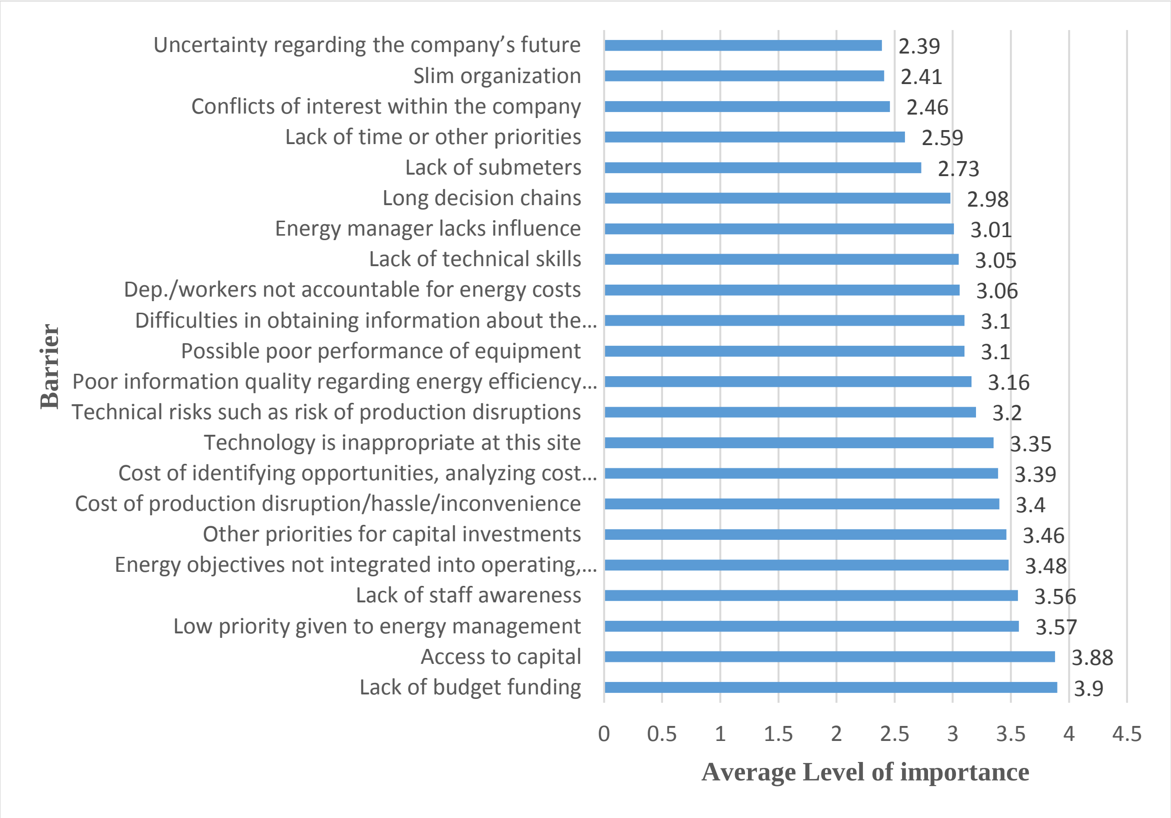

Figure 19: Scaled results (from questionnaire) of barriers to EE improvement.

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The results indicate that lack of budget funding and access to capital were considered as the most important barriers followed by low priority given to energy management and then lack of staff awareness. This also seems to be in line with similar studies done in Ghana (Apeaning, 2012). Many developing countries, including Malawi, fail to access funds for industrial EE; this can be attributed to lack of knowledge on funding opportunities available, insufficient technical capacity to accurately evaluate the benefits of EE investments, and lack of commitment demonstrated by lack of budget allocation of funds into EE measures. One study states that barriers to EE differ depending on the type of industrial production, country and industry specific conditions (Sorrell, et al., 2000). In NRWB, the study discovered that many projects have been undertaken for the past decade which targeted increasing plant capacity, reticulation and reservoirs without covering energy management. This study will raise awareness and create an opportunity for NRWB to implement EE measures because of multiple benefits that are presented in the report.

5.1.6 Driving forces for EE improvement

Figure 20 shows the average score rating of 18 driving forces to EE improvement as assessed by the various respondents using a scale of 1 to 5; 1 for not important, 2 for rarely important, 3 for sometimes important, 4 for important and 5 for very important.

The results indicate that 'long term energy strategy' is ranked as the most important driver seconded by 'Environmental Management Systems (EMS)' which was closely followed by 'threats of rising energy prices'. This also seems to be in line with similar studies done in Ghana but with slight difference in ranking (Apeaning, 2012). Although, 'Environmental Management Systems (EMS)' and 'Environmental Company Profile' were ranked in the second and sixth position respectively, these external drivers are very important for improving EE, especially with companies that compete on an international market with stringent environmental concerns. Water supply systems are key to environmental concerns and are supposed to comply with all international water quality standards such as World Health Organisation (WHO). The fourth and fifth ranked drivers are market related with the ultimate purpose of improving the profitability of the company. Respondents also ranked 'Energy efficiency requirements by Malawian government' as the eighth most important driver even though there are no specific stringent laws or standards with regard to energy use in Malawian government. Energy tax is also another effective driver used world-wide by governments to promote EE in companies, but

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in this survey, it was ranked in the twelfth position. The result of this low ranking can be attributed to the fact that energy prices are subsidized and controlled by the government as such lack competitive pricing or taxes to influence EE improvement. Energy efficiency improvement for a particular firm can be driven by either internal or external forces or a combination of both. The study of driving force for implementing EE forms a basis for decision makers to formulate strategies that can be employed to enhance implementation of EE measures and technologies.

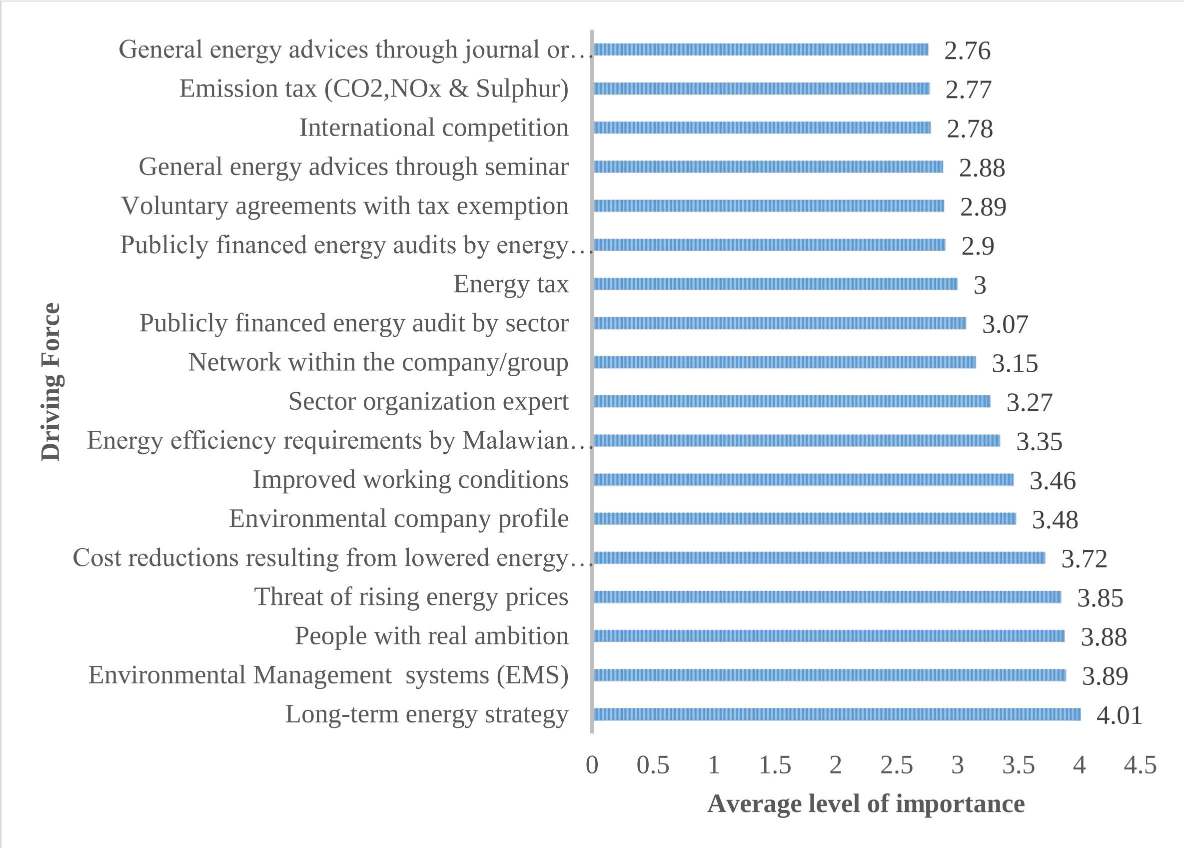

Figure 20: Ranked results (from questionnaire) of driving forces to EE improvement.

5.1 Energy Monitoring and Targeting

5.1.1 Introduction

In this section, historical data as well as snapshot measurement data for the year 2014-2015 and 2015-2016 are analysed and discussed.

5.1.2 Total Electricity Consumption and Production at the Mzuzu Main Plant

Figure 21 shows total production and energy consumption for the period 2014-2016, with electrical consumption in kilowatt—hours (kWh) and corresponding flow rate in cubic meters (m^3).

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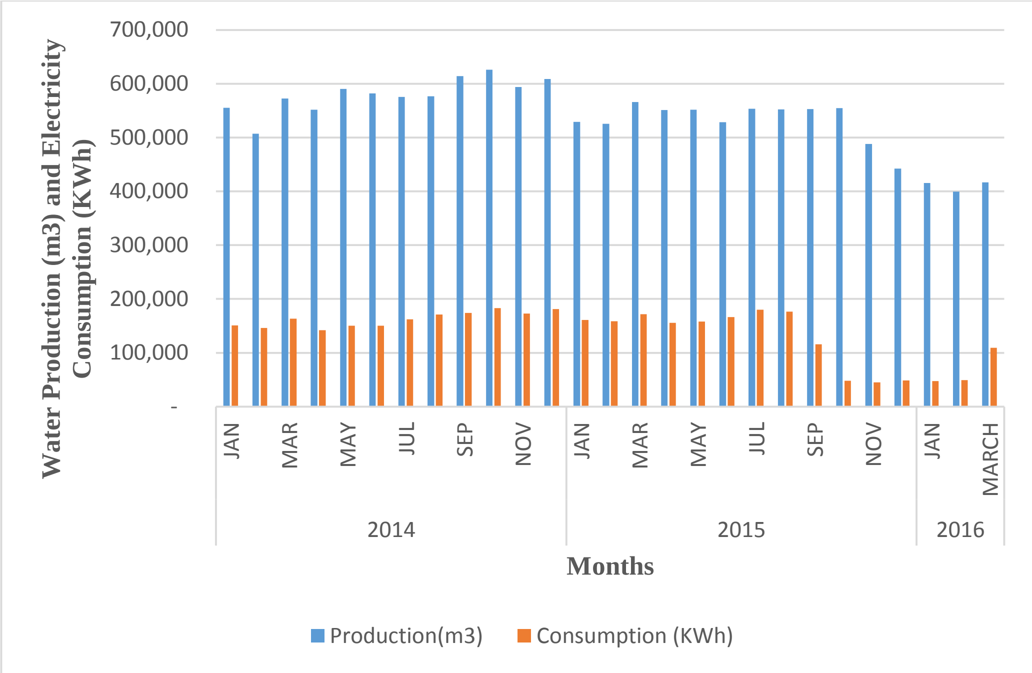

Figure 21: Main Plant Water Production and Energy Consumption

The results show a steady energy consumption pattern except for 2015 in the months of September, October, November and December. In these months, the study discovered that submersible pumps were switched off owing to reduced flows in the water sources, the energy consumption also reduced during the same months. It is still not certain whether this huge drop could be attributed to only switching off of submersible pumps which together have total installed capacity of 65KW against a total installed capacity of 385KW at the main plant. The other attribute to sharp drop of energy consumption could be malfunctioning of energy meter during this period, in the month of January 2016, ESCOM changed its energy meter indicating that it had a problem.

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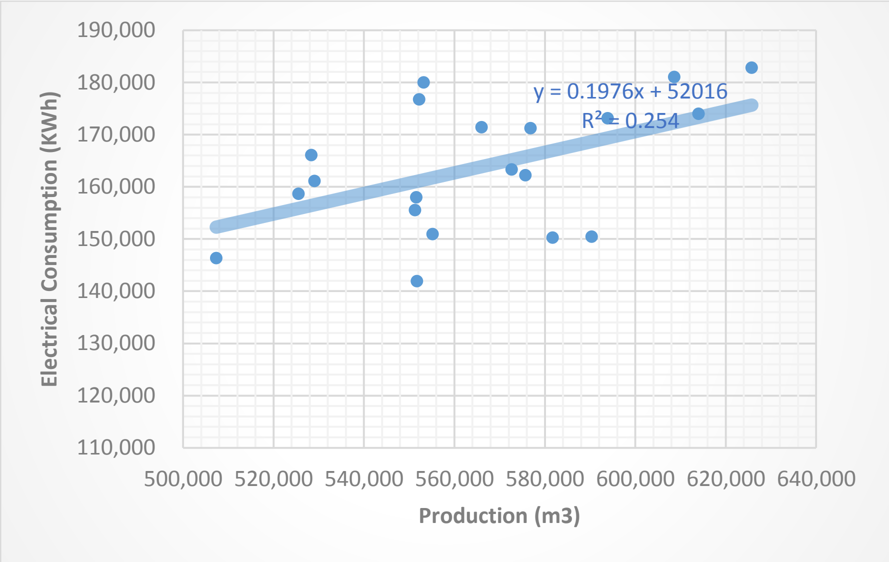

Figure 22: Specific Energy Consumption for Mzuzu Main Plant

Figure 22 shows specific energy consumption for the same period 2014-2015 for Mzuzu Main Plant. The results show that there is a positive relationship between variables. The trends indicate that electricity consumption increases with an increase in production. The Y – intercept of 52,016KWh from the equation is very critical in ascertaining the cost of other energy consumers when there is no production. It was noted that at the main plant there are blowers, backwash and submersible pumps which also share common energy consumption meter but do not directly contribute to the volume produced. From the equation, the relationship has a coefficient of determination, $r^2 = 0.254$, and $r = 0.504$, this means that only 25.4% of the total variation in the energy cost can be explained by the variation in production. The other 74.6% of the variation are due to other factors. Testing the significance of the correlation coefficient, for $r = 0.504$, $n = 20$, critical values obtained in tables, refer Appendix 2, for a 2 tailed is ±2.104, test value (t) = $r\sqrt{\{(n-2)/(1-r^2)\}} = 2.47$, the test value falls in the critical region The correlation coefficient suggests a weak relationship between the power consumed and the volume produced. This is expected because of the submersible pumps, blowers, and backwash pumps which consume significant amount of energy but are not metered separately since they do not directly contribute to production output.

5.1.3 Total Electricity Consumption and Production at MBC Booster Station

Figure 23shows water production and energy consumption for the period 2015-2016, with electrical consumption in kilowatt—hours (kWh), and corresponding flow rate in cubic meters (m^3).

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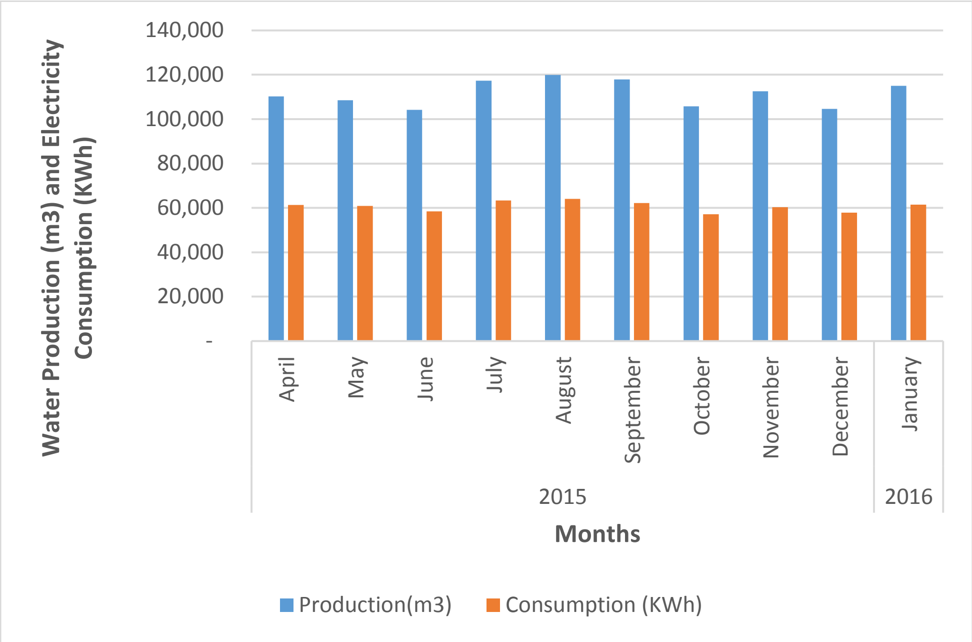

Figure 23: MBC Booster Station Water Production and Energy Consumption

The results show a steady energy consumption pattern for the months under review with almost double the energy intensity compared to the Main Plant. The difference in energy intensity could be attributed to comparative higher heads at MBC station than Main Plant even though production is also lower.

Figure 24 shows specific energy consumption for the same period 2015-2016 for MBC Booster Station.

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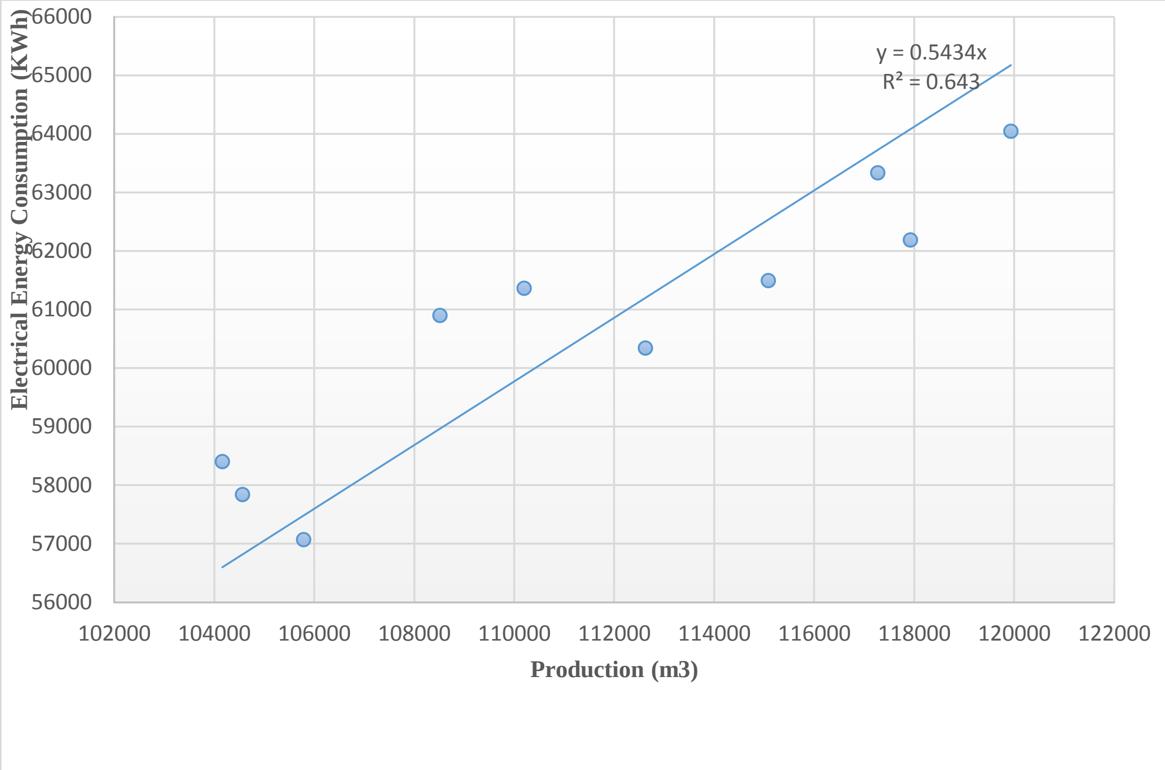

Figure 24: Specific Energy Consumption for MBC Booster Station

The results show that there is a positive relationship between variables. The trend indicates that electricity consumption increases with an increase in production. There is no Y – intercept in the equation, this is expected as there are no other considerable energy consumers to contribute when pumping has stopped except the lighting whose value is negligible. There is a relative increase in the gradient comparing with the main plant. This is true because the booster station is conveying volumes of water to distant places with high head losses. From the equation, the relationship has a coefficient of determination, $r^2 = 0.643$, and 'r' = 0.80, the 'r' value which is closer to unity indicate a strong relationship in the variables, also, 64.3% of the total variation in the energy cost can be explained by the variation in production.. The other 35.7% of the variation is due to other factors. Testing the significance of the correlation coefficient, for r = 0.8, n = 10, critical values obtained in tables, refer Appendix 2, for a 2 tailed is ±2.306, test value (t) = $r\sqrt{(n-2)/(1-r^2)}$ = 3.77, the test value falls in the critical region. It can be concluded that there is a significant relationship between volume produced and electrical consumption. We can use the equation to predict future energy cost as a result of increased volume of production.

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5.1.4 Total Electricity Consumption and Production at Katawa Booster Station

Figure 25 shows total production and energy consumption for the period 2015-2016, with electrical consumption in kilowatt—hours (kWh) and corresponding flow rate in cubic meters (m^3).

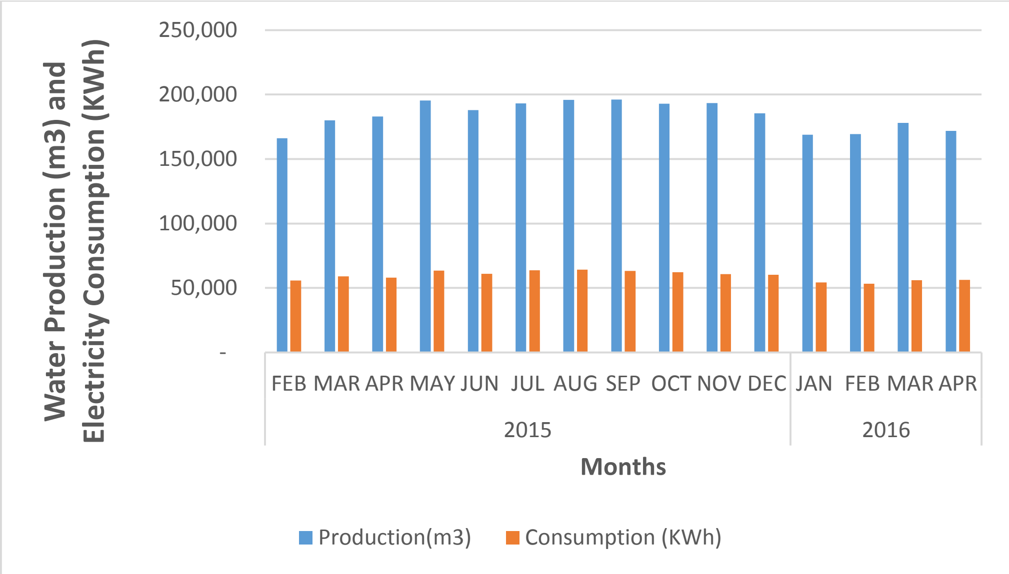

Figure 25: Katawa Booster Station Water Production and Energy Consumption

The results show a steady energy consumption pattern for the months under review with an energy intensity of above that of the main plant and lower to that of MBC Booster with the same reasoning but also with improved system efficiency as will be noticed in the following correlation and regression analysis.

Figure 26 shows specific energy consumption for the same period 2015-2016 for Katawa Booster Station.

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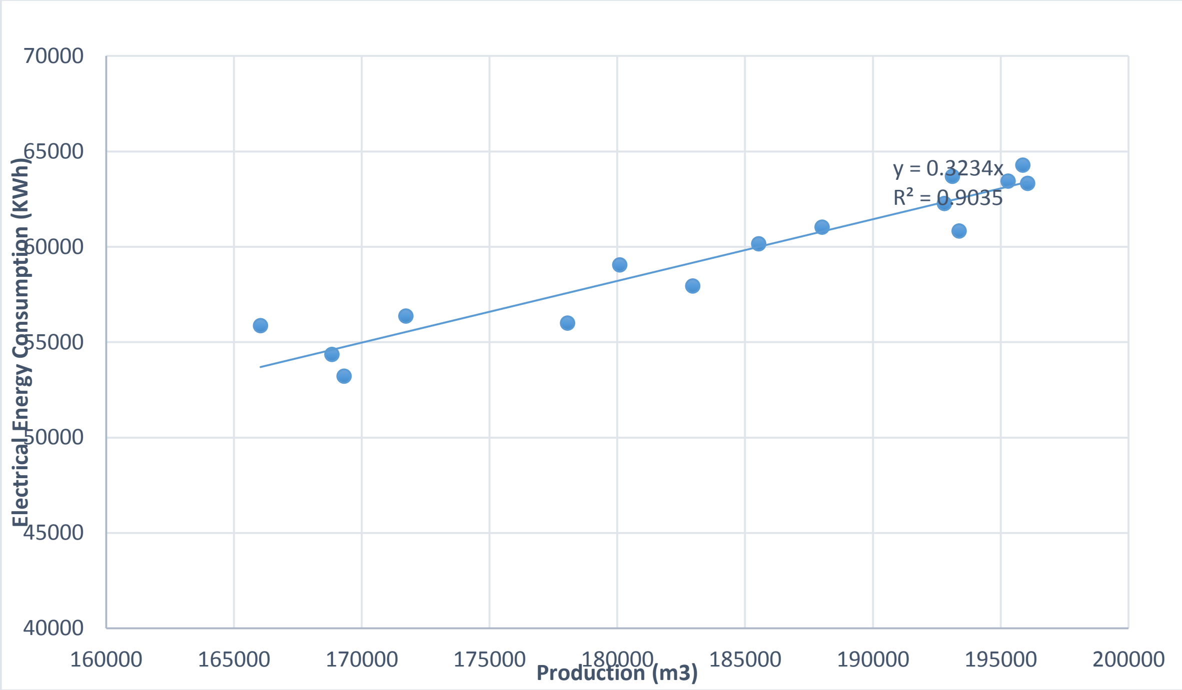

Figure 26: Specific energy consumption for Katawa Booster Station

The trend indicates that electricity consumption increases with an increase in production. There is no Y – intercept in the equation, this is expected as there are no other considerable energy consumers at the station to contribute when pumping has stopped except the lighting whose value is negligible. There is a relative increase in the gradient comparing with the main plant but also a decrease compared to MBC. From the equation, the relationship has a coefficient of determination, r^2 = 0.9035, and 'r' = 0.951, the 'r' value which is closer to unity indicate a strong relationship in the variables, also, 90.35% of the total variation in the energy cost can be explained by the variation in production, the other 9.65% of the variation is due to other factors. Testing the significance of the correlation coefficient, for r = 0.951, n = 15, critical values obtained in tables, refer Appendix 2, for a 2 tailed is ±2.16, test value (t) = $r\sqrt{(n-2)/(1-r^2)}$ = 3.77, the test value falls in the critical region. It can be concluded that there is a significant relationship between volume produced and electrical consumption. We can use the equation to predict future energy cost as a result of increased volume of production at this station.

5.1.5 Energy model for the three stations

Energy models are based on historical energy data. A good model quality should have a year of consistent energy data (ASHRAE, 2002). The WSS under study had no previous study to act as baseline, hence the need to first establish one as benchmark. Simple mathematical baseline models were employed from the three stations under study. These models are critical and can

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be of great importance in interpreting recent energy use, as a purpose-specific problem solving aid; verify energy savings, as a legally binding accounting instrument; substantiate success stories for management, as a performance metric; and also to motivate behaviour from co-workers, as a control signal (Hilliard & Jamieson, 2014).

i. **Mzuzu Main plant**

A mathematical energy model emanating from the regression line as a result of historical data relationship of energy and production at the main plant (refer figure 22) was;

$$y = 0.1976x + 52016;$$

where 'y' represents a dependent variable, electrical energy consumption in KWh and 'x' represents an independent variable, production in m^3 for the station.

ii. **MBC Booster**

A mathematical energy model emanating from the regression line as a result of historical data relationship of energy and production at MBC Booster station (refer figure 24) was;

$$y = 0.5434x;$$

where 'y' represents a dependent variable, electrical energy consumption in KWh and 'x' represents an independent variable, production in m^3 for the station.

iii. **Katawa Booster**

A mathematical energy model emanating from the regression line as a result of historical data relationship of energy and production at Katawa Booster station (refer figure 26) was;

$$y = 0.3234x;$$

where 'y' represents a dependent variable, electrical energy consumption in KWh and 'x' represents an independent variable, production in m^3 for the station.

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5.2 PSAT Analysis

Table 4 shows a summary of PSAT results from the three stations under study. Figure 27 shows PSAT analysis for MBC Feeders and is representative of other stations.

Table 4: Summary of PSAT results for Main Plant, MBC and Katawa

	Description	**Pump Efficiency (%)**		**Optimisation Rating[5] (%)**		**Off peak tariff**	**Annual Savings**	**Remarks**
		Designed	**Actual**	**Condition A[6]**	**Condition B[7]**	**US$/KWh**	**potential**	
1	MBC Feeders	78	55.3	69.2	98.3	0.028	12,600	
2	Govt. Feeders	-	67.9	87.2	100.3	0.028	1,700	No design data
3	Katawa Feeders	76	52.1	67.4	103.7	0.028	8,800	
4	Backwash pumps	-	65.2	72.9	90.4	0.028	1,500	No design data
5	Signal Feeder	75	49.7	64.7	71.83	0.028	2,600	
6	Lusangazi Feeder	75	44.3	57.6	93.7	0.028	6,200	
7	Lunyangwa Feeder	77	63.4	80.6	93.2	0.028	2,600	
8	Nkhorongo Feeder	79	48.4	59.9	81.2	0.028	7,400	

[5] Optimization rating is the measure of the overall rating of the existing pumping system efficiency relative to the optimal motor and pump expressed as a percentage (PSAT, 2008).
[6] Condition A is the existing installation actual analysis
[7] Condition B is the existing installation designed analysis

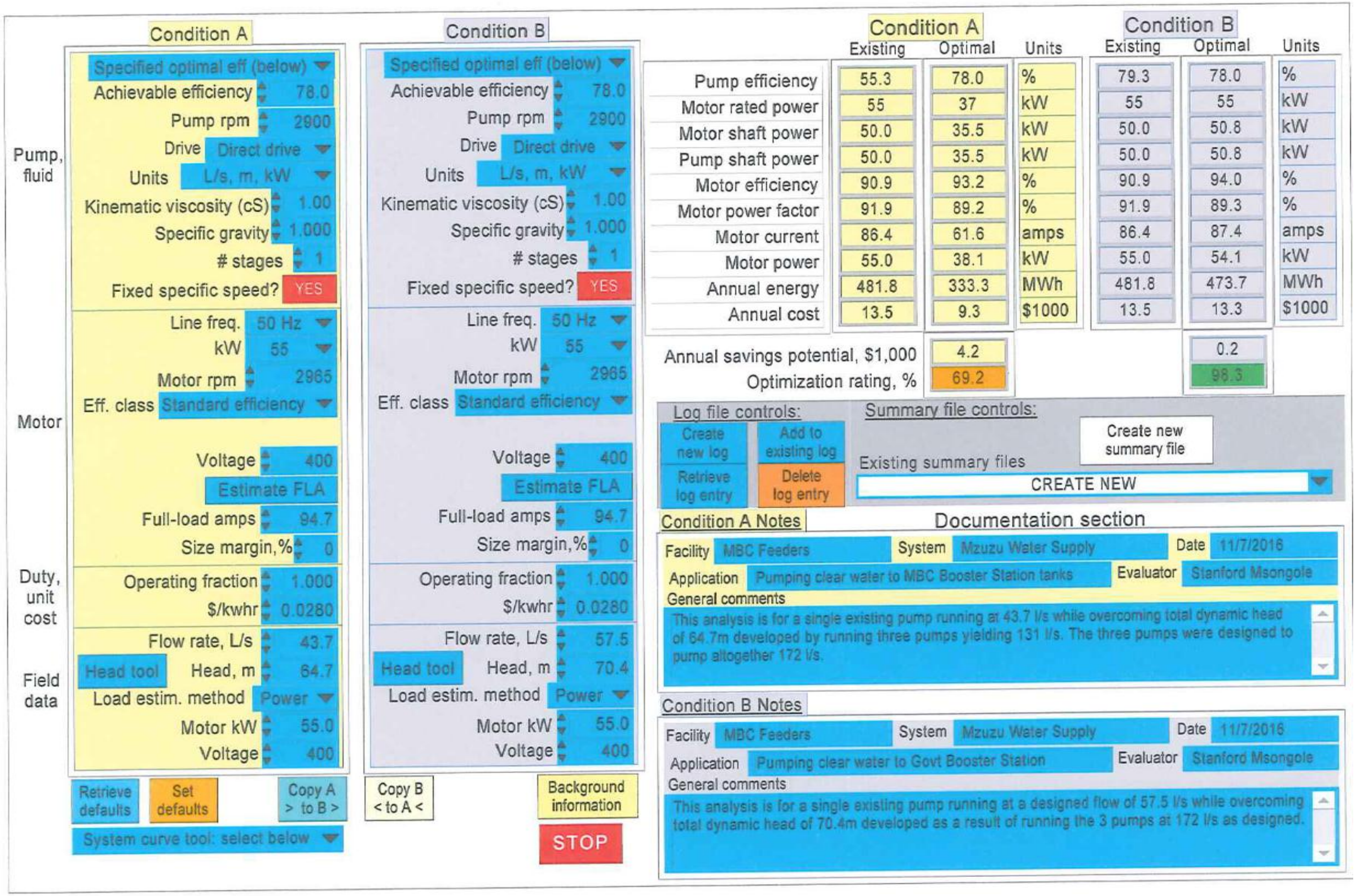

Figure 27: MBC Feeder PSAT Analysis

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5.3.1 MBC Feeders

Table 4 shows a summary of PSAT results for all pumping stations under study. Figure 27 depicts PSAT analysis results for MBC Feeders and is demonstrative of other pumping stations analysed. Condition 'A' shows an average pumping efficiency. The pump was designed to operate at 78% efficiency while pumping at 57.5 l/s (Metaferia, 2008). However, at the time of the study, the analysed results showed a rate of 43.75 l/s and this represents an operating efficiency of 55.3%. The results show that the current flow output should optimally use a 37 KW motor and not a 55KW motor as shown in the analysis. The analysis identifies an off peak saving potential of US$4,200 annually for a single pump, and this translates to US$12,600 annually for the three pumps in operation if they were to operate optimally. Condition 'B' analysis indicate that the pumps were designed to operate under optimal conditions as also viewed on MBC Feeder pump curve in Appendix 3 for a total dynamic head of 70.4m at a designed flow rate of 57.5 l/s but there are other factors owing to the average rating. The loss of efficiency on MBC Feeders could be attributed to poor maintenance strategies as captured during survey and audit where maintenance policy and plans were not available and this is also evident on the condition of the impellers, refer Figure 8, and possible wrong pumping configuration for the three pumps running at the station. These also could be some of the contributing factors to a weak correlation between energy consumed (KWh) and production (m^3) at the Main Plant.

5.3.2 Government Feeders

PSAT results in Table 4 indicates an above average optimisation rating for condition 'A', the analysed yield was at 43.5 l/s and this represents an operating efficiency of 67.9% from the analysis. The analysis identifies an off peak saving potential of US$1,700 annually for a single pump, if it were to operate optimally. Condition 'B' at 50 l/s flow output indicates a fully optimised pumping system. The loss of efficiency on Government Feeders could be attributed to poor maintenance strategies and age and these could be contributing factors to a weak correlation between energy consumed (KWh) and production (m^3) at the Main Plant. The pump sets were planned for abandonment owing to system review (Metaferia, 2008).

5.3.3 Katawa Feeders

From Table 4, PSAT results for Katawa Feeders depict a slightly above average optimisation rating for Condition 'A' with an average pumping efficiency. The pump was designed to

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operate at 76% efficiency while pumping at 57.5 l/s (Metaferia, 2008) but at the time of the study, the analysed yield was at 44.3 l/s and this represents an operating efficiency of 52.1% from the analysis. From the analysis and based on the existing operating conditions, the pump should optimally use a 37 KW motor and not a 55KW motor. The analysis identifies a saving potential of US$4,400 annually for a single pump, and this translates to US$8,800 annually for the two pumps in operation if they were to operate optimally. PSAT analysis for condition 'B' indicates that the pumps were designed to operate under optimal conditions as also viewed on Katawa Feeder pump curve in Appendix 4 for a total dynamic head of 72.8m at a designed flow rate of 57.5 l/s. The loss of efficiency on Katawa Feeders could be attributed to poor maintenance strategies as captured during survey and audit where maintenance policy and plans were not available and possible wrong pumping configuration for the two pumps running at the station. These also could be some of the contributing factors to a weak correlation between energy consumed (KWh) and production (m^3) at the Main Plant.

5.3.4 Backwash pumps

From Table 4, Condition 'A' for Backwash pump indicates an above average optimisation rating with a slightly above average pump efficiency. The designed flow output is 250 l/s and the pumps have been operational since their installation in 1994, but at the time of study, the analysed yield was at 153 l/s and this represents an operating efficiency of 65.2% from the analysis. The analysis indicates that the existing operating conditions should optimally use a 15 KW motor and not a 22KW motor. The analysis identifies an off peak saving potential of US$1,500 annually for a single pump, if it were to operate optimally. Condition 'B' indicates that the pumps were optimally designed. The loss of efficiency on Backwash pumps could be attributed to poor maintenance strategies and age and these could be contributing factors to a weak correlation between energy consumed (KWh) and production (m^3) at the Main Plant.

5.3.5 Signal Hill Feeders

From a summary of PSAT results in Table 4, for Signal Hill Feeders, Condition 'A' shows average optimisation rating and low pump efficiency. The pump was designed to operate at 75% efficiency while pumping at 19 l/s (Metaferia, 2008) but at the time of the study, the analysed yield was at 17.3 l/s and this represents an operating efficiency of 49.7% from the analysis. The pump from the analysis should optimally use an 18.5 KW motor and not a 30KW motor. The analysis identifies an off peak saving potential of US$2,600 annually for a single

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pump if it were to operate optimally. Condition ‘B’ gave a 71.83% optimization rating, the analysis give a 22 KW rating motor as opposed to a 30 KW .This rating indicates that the pumps were initially not designed optimally according to the available operating conditions, the Signal Hill Feeder pump curve in Appendix 5 for a total dynamic head of 80.1m and a designed flow output of 19 l/s also agree. The loss of efficiency on Signal Hill Feeders could be attributed to wrong design of pumps running at the station which may have happened as a result of poor demand estimate. These are some of the contributing factors to increased operational cost at the station and this contributes to the relationship that exits between energy consumed (KWh) and production (m^3) at MBC Booster Station.

5.3.6 Lusangazi Feeders

From a summary of PSAT results in Table 4, for Lusangazi Feeders, Condition ‘A’ shows an average optimisation rating and a low pumping efficiency. The pump was designed to operate at 75% efficiency while pumping at 19 l/s (Metaferia, 2008) but at the time of the study, the analysed yield was at 13.5 l/s and this represents an operating efficiency of 44.3% from the analysis. The pump from the analysis should optimally use an 18.5 KW motor and not a 30KW motor. The analysis identifies an off peak saving potential of US$3,100 annually for a single pump, and this translates to US$6,200 annually for the two pumps in operation if they were to operate optimally. Condition ‘B’ analysis gave a 93.7% optimization rating, a 26 KW rating motor as opposed to a 30 KW. This rating indicates that the pumps were initially not designed for full optimization according to the available operating conditions. The pump curve in Appendix 5 for a designed flow output of 19 l/s and a developed total dynamic head of 105m has a duty point outside the curve. The loss of efficiency on Lusangazi Feeders could be attributed to wrong design due to poor demand estimate, wrong pumping configuration for the two pumps running at the station and poor maintenance strategies for the existing pumps running at the station. These are some of the contributing factors to increased operational cost at the station and this contributes to the relationship that exits between energy consumed (KWh) and production (m^3) at MBC Booster Station.

5.3.7 Lunyangwa Feeders

From a summary of PSAT results in Table 4, for Lunyangwa Feeders, Condition ‘A’ shows an above average optimisation rating and pumping efficiency. The pump was designed to operate at 77% efficiency while pumping at 57.5 l/s (Metaferia, 2008) but at the time of the study, the

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analysed yield was at 50 l/s and this represents an operating efficiency of 63.4% from the analysis. The existing pumping conditions should optimally use a 45 KW motor and not a 55KW motor as shown in the analysis. Also, the analysis identifies an off peak saving potential of US$2,600 annually for a single pump if it were to operate optimally. PSAT analysis for condition ‘B’ gave 73.5 % pump efficiency as opposed to 77% on the design. The pump curve in Appendix 4 indicates that the pump is suited for the designed conditions of 57.5 l/s and a developed total dynamic head of 66.4m. The loss of efficiency on Lunyangwa Feeders could be attributed to design error. These are some of the contributing factors to increased operational cost at the station and this contributes to the relationship that exits between energy consumed (KWh) and production (m^3) at Katawa Booster Station.

5.3.8 Nkhorongo Feeders

From a summary of PSAT results in Table 4, for Nkhorongo Feeders, Condition ‘A’ shows an average optimisation rating and low pumping efficiency. The pump was designed to operate at 79% efficiency while pumping at 57.5 l/s (Metaferia, 2008) but at the time of the study, the analysed yield was at 43.5 l/s and this represents an operating efficiency of 48.4% from the analysis. The existing conditions should optimally use a 45 KW motor and not a 75KW motor as shown in the analysis. The analysis identifies a saving potential of US$7,400 annually for a single pump if it were to operate optimally. PSAT analysis for condition ‘B’ gave a 66.2 % pump efficiency as opposed to 79% on the design. The pump curve in Appendix 6 indicates that at a designed condition of 57.5 l/s and a developed total dynamic head of 80.8m, the duty point is slightly outside the curve. These indicate that the design of Nkhorongo Feeders was compromised and present a wide margin for improvement according to the available operating conditions. The loss of efficiency on Nkhorongo Feeders could be attributed to wrong design and poor maintenance strategies for the existing pumps running at the station. These are some of the contributing factors to increased operational cost at the station and this contributes to the relationship that exits between energy consumed (KWh) and production (m^3) at Katawa Booster Station.

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CHAPTER 6

ENERGY SAVING OPPORTUNITIES AND MANAGEMENT

6.1 Introduction

The existing literature indicates that a 10 to 30 percent energy savings per measure with a payback period of 1- to 5-years is practical for most of the commonly applied technical measures to address energy efficiency (U.S.EPA., 2008; Liu, Ouedraogo, Manghee, & Danilenko, 2012). Sound energy saving opportunities depend on conditions of facilities, technologies used, effective energy prices, and other factors affecting the technical and financial performances of individual WSSs (Liu, Ouedraogo, Manghee, & Danilenko, 2012). The characteristics of WSS determine the strategies that can be employed to reduce energy consumption.

In this chapter, some steps on major energy cost saving opportunities for MWS are analysed as outlined by (Tsutiya, 2001). The savings are identified from available literature, energy audit carried out, energy M&T techniques as well as Pumping System Assessment Tool (PSAT) as applied in MWSS.

6.2 Cost reduction without any change in electrical energy consumption

6.2.1 Energy savings with no additional investment (administrative actions)

6.2.1.1 Correct demand estimate

Table 5 shows declared and actual electricity demand in the study area from energy M&T and audit.

Table 5: Declared and actual electricity demand for Mzuzu water supply.

Station	**Declared (KVA)**	**Actual (KVA)**	**Remarks**
Main Plant	380	218.78	Lowest was at 106.43KVA
MBC Station	56	121.22	Under declared
Katawa Station	180	141.67	Over declared

The findings indicate over and under declared electricity demand. For Mzuzu Main Plant, lowest average actual demand of 106.43 KVA was for six months when the submersible pumps were not in operation, this is also in agreement with water production and electricity consumption data for the same period as indicated in Figure 7. The Board is charged and

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penalised as a result of these anomalies. These charges are established to reserve capacity from the power grid for the user and the charge is applied to the monthly utility bill often independent of the energy charges. A correct declaration of electricity demand would save such charges which are sometimes exorbitant because they act as punishment.

Table 6 shows an extract from ESCOM current tariffs which were effected on 6th February, 2016 and applicable to MWS system.

Table 6: Extract from ESCOM Current Tariffs *(ESCOM, 2016)*.

Tariff Code	**Description**	**Type of Charge per month**	**Existing Rate (MWK)**	**% Change**	**New Rate (MWK)**
ET9	Maximum Demand - Low Voltage Supply (Large power for industrial users, supplied at three phase supply and metered at 400 Volts)	Fixed Charge per Month	26,000.00	7.5%	27,950.00
		On peak Unit Charge per KWh	73.00	7.5%	78.48
		Off peak Unit charge per KWh	20.00	7.5%	21.50
		Capacity Charge per KVA based on the customers annual declared demand	3,076.25	7.5%	3,306.97
		Demand Charge per KVA based on actual monthly demand	4,978.04	7.5%	5,351.39

From Table 5 and 6 the following potential energy savings are identified;

Katawa Booster

The station declared 180 KVA but the average actual demand in the year July 2015 to June 2016 was 141.67KVA, re-declaring to 150 KVA would save in a year;

Saving = (12*30KVA*MWK3, 306.97/KVA) = **MWK1, 190,509.20, i.e. US$ 1,630**.
This saving, at the time of the study, could be utilised by connecting about 19 customers in the system and this would bring multiple benefits.

Mzuzu Main Plant

The station had a demand of 106.43KVA for six months in the year under study. This amounts to energy saving potential of;

Saving = (6* (380-106.43) KVA * MWK3306.97 / KVA) = **MWK5,428,126.70 i.e. US$7,436**.
The saving is quite significant and could be used to procure a complete pump set for MBC Feeders at the material time of the study. This is a direct saving in energy cost for the over declared stations which does not require any investment.

6.2.1.2 Changes in tariffs

ESCOM changes in tariff during a 24 hr period in a day provide opportunity for energy savings. Table 7 depicts revised ESCOM changes in tariff during a 24-hr period.

Table 7: ESCOM revised changes in tariff on a 24-hr period *(ESCOM, 2016)*.

Days	**Time of the day**			**ESCOM charge in Malawi Kwacha per KWh**	
	00:00 – 7:00	12:00 - 17:00	20:00 – 24:00	**Off peak**	**On peak**
Monday-Friday	Off peak	Off peak	Off peak	21.50	78.48
Saturday	The whole day is off peak				
Sunday					
Public Holiday					

There is a 265% difference in energy tariff between on and off peak hours of the day. Any reduction of pumping hours during on peak tariff would yield instant energy saving potential by the same 265% change in tariff. Mzuzu water supply from the energy audit, operate 24 hours in most of the pumping stations under study which would make application of this energy cost saving opportunity a challenge. The plant and reservoir installation at the time of study had low capacities to halt pumping in relation to available water demand. A possible future review on the designs should consider this significant energy cost saving potential.

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6.2.1.3 Measurement errors

There are misleading production and energy consumption data captured during energy M&T which result into wrong calculation and energy pricing. A correct measurement gives a true reflection of energy cost. From the month of May, 2016, MBC Booster Station developed measurement errors and ESCOM was averaging the consumption. This could be a source of saving to both parties.

6.2.2 Energy savings with additional investment (operational actions)

6.2.2.1 Power factor correction

Power factor is the ratio of the true power capacity of the circuit (measured in KW) to the power the utility actually needs to provide (measured in volt-amperes, VA). Consumers with low power factor require greater generation capacity than what is actually used. The three major pumping stations under study (Main plant, MBC and Katawa) had all power factor ranging from 0.84 to 0.86 with no power factor correction units. A recent communication from ESCOM introduced a penalty to any station with a power factor below 0.90 from January, 2016. The power factor surcharge is meant to encourage the business embrace energy efficiency and Demand Side Management measures (ESCOM, 2016). An improvement of power factor to at least 0.99 would yield multiple benefits including prolonged lifespan of the equipment due to efficient use and reduced energy cost. A perfectly corrected power factor would also reduce energy loss through increased heat losses. The ESCOM Demand Charge per KVA based on actual monthly demand reading would relatively drop as a result of power factor correction. The Demand Charge is one of the highest charges pegged at MWK5, 351.39/KVA at the time of the study, refer Table 6.

6.3 Reduction of cost with reduction in electrical energy consumption

6.3.1 Water Demand Management (WDM)

Water energy nexus and also energy M&T analysis which was done in the earlier section identify that energy consumed by a water system is proportional to water production. This entails that reducing water production will reduce energy consumption and vice versa. Mzuzu water supply at the time of the study had a non- revenue water averaging 37%. The percentage exceeds the set target of 25%. Any reduction in any of the physical losses even though it

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requires significant capital investment would save energy i.e. reduction in pumping hrs, sustaining developed pressures so that water reaches targeted area. The strategies to be employed would involve leakage control and rational use of water.

6.3.2 Improving the efficiency of the pumping systems (pump and motor efficiency)

The two submersible pumps operating at the Main Plant are overrated and waste a lot of energy in operation. The pumps were excessively throttled during the six months in operation. Whenever a valve is not fully open it imparts losses to the system and is a source of energy wastage. Corrective measures to improve efficiency would be installing a new pump suited to the prevailing operating conditions or install VFD. The measures would save such existing energy loss. PSAT results in Table 4 show optimisation rating and annual energy saving potential, improving pump and motor efficiency in Mzuzu water supply would potentially save US$43,400 annually on energy costs as shown in PSAT analysis on off peak tariff rate.

6.4 Reduction of cost by changing the operational system

6.4.1 Usage of Variable Speed/Frequency Drive (VSD/VFD)

These are motor controllers that drive an electric motor by varying the frequency and voltage supplied to the electric motor. These drives improve efficiency by matching the pump to operate near its best efficiency point (BEP). From PSAT analysis and operating curves of the installed pumps in the appendices, none of the pumps are operating near BEP but also all the pumps are operating on Fixed Speed Drive (FSD). Installing VFD can lead to significant energy savings in MWS System. Their ability to match flow with demand decreases the number of times a pump is switched on and this reduces surge on the system (Coleman, et al., 2009).

6.5 Reduction of cost by automation of Mzuzu water supply system

6.5.1 SCADA systems are common in automation of water supply systems

The savings emanate from optimising the treatment and pumping operations by automatic adjustment of speed drives, pump sequencing, backwash initiation and duration. SCADA system also provides an efficient way of monitoring energy use and demand peaks so that operators can easily visualise what is happening and implement necessary measures and decisions to manage energy consumption and demand. A customised SCADA system can

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include energy providers' rate schedule so that power costs are shown so that they can influence good decisions from the plant operators.

6.6 Reduction of cost by generating electrical energy with independent systems (i.e. solar/wind energy)

ESCOM is a sole provider of electricity in Malawi, this monopoly disadvantages energy consumers who have no alternative in terms of comparison on energy pricing, quality, and availability. Moreover, with impacts of climate change eminent on water sources necessary for generation of electricity puts business environment for energy consumers and in particular NRWB at a high risk. Solar and wind being renewable energy would provide this alternative and reduce the aforementioned risks to manageable levels upon successful investment appraisals for viability.

6.7 Energy management

Sustaining energy savings in Mzuzu water supply demands a culture of continuous improvement. The Plan-Do-Check-Act (PDCA) model is pertinent in coming up with MWS management guidelines. The PDCA model is applicable because it facilitates an organizational culture of continuous improvement. The model is a circular evolving process that focuses on continual improvement over time as indicated in Figure 28 (U.S.EPA., 2011).

6.7.1 Applying the Plan-Do-Check-Act in Mzuzu water supply system

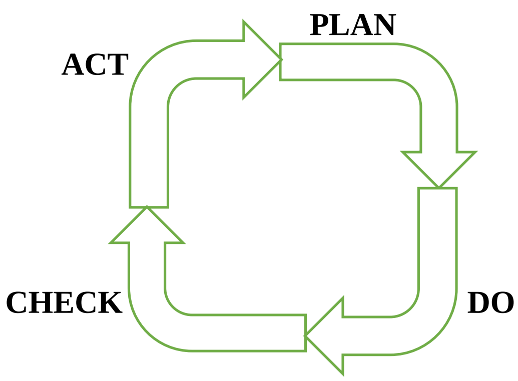

Figure 28: Plan-Do-Check-Act management approach

Figure 28 and Table 8 show an energy management approach that was applied during the research to enable the process of continuous energy improvements (U.S.EPA., 2013). The survey from the respondent's perspective already identified gaps on non-existence of energy policy, low management commitment and staff awareness on energy issues. NRWB need to establish an energy policy and overall energy improvement goals as stipulated in NRWB strategic business plan for 2015 – 2020. The study through energy audits, energy M&T and PSAT have some energy baseline data for MWSS which need to be promoted and sustained. Energy saving potential opportunities identified in the study need to be evaluated and prioritized. The results need to be monitored, reviewed and communicated effectively to every employee for their involvement.

Table 8: Steps for Designing, Implementing, and Sustaining Energy Efficiency Improvements in Water and Wastewater Facilities. Source: US.EPA, 2013.

Plan	**Step 1. Get Ready**
	Establish the facility's energy policy and overall energy improvement goals. Secure and maintain management commitment, involvement and visibility. Choose an energy "fence line" Establish energy improvement program leadership. Secure and maintain employee and management buy-in.
	Step 2. Assess Current Energy Baseline Status
	Establish a baseline and benchmark facilities. Perform an energy audit. Identify activities and operations that consume the most energy or are inefficient
	Step 3. Establish an Energy Vision and Priorities for Improvement
	Identify, evaluate, and prioritize potential energy improvement projects and activities
	Step 4. Identify Energy Objectives and Targets
	Establish energy objectives and targets for priority improvement areas. Define performance indicators
Do	**Step 5. Implement Energy Improvement Programs and Build a Management System to Support Them**
	Develop action plans to implement energy improvements Get top management's commitment and approval Develop management system "operating controls" to support energy improvements Begin implementation once approvals and systems are in place
Check	**Step 6. Monitor and Measure Results of the Energy Improvement Management Program**
	Review what the facility currently monitors and measures to track energy use. Determine what else the facility needs to monitor and measure its priority energy improvement operations. Develop a plan for maintaining the efficiency of energy equipment Review the facility's progress toward energy targets.

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	Take corrective action or make adjustment when the facility is not progressing toward its energy goals. Monitor/reassess compliance status.
Act	**Step 7. Maintain the Energy Improvement Program**
	Continually align energy goals with business/operation goals Apply lessons learned Expand involvement of management and staff Communicate success

The results from the survey can be linked to PSAT results and energy savings outlined. Failure to have correct demand estimate is due to low commitment from management on EE and management as well as lack of knowledge on potential energy savings. There is no extra investment needed and one would assume management grabbing this energy saving potential. The survey results in figure 15 rated proper pumping system design as highly implemented in the study area yet application of changes in tariff are challenged by insufficient pump and reservoir capacity to utilise the potential savings. This is basically pumping system design failure which is contrary to survey findings. Similarly, PSAT results in Table 4 show inefficient pumping system for Signal, Lusangazi and Nkhorongo Feeders yet the survey results from the perception of respondents rated highly proper pump system design implementation in the study area. It was important to use all the methods in this study for conclusive findings and recommendations. The measures that require investment such as power factor correction, use of variable speed drives and automation were poorly rated yet they have potential energy savings, this also seem to be in line with similar studies done in Kenya (Tiony, 2012).

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CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

The assessment of EE and management in MWSS was accomplished through the survey, energy audit, PSAT, and energy M&T techniques. The survey provided an overview of energy management from the perspective of respondents in the study area. The energy audit dealt with actual EE and management practices in the study area. PSAT calculated designed and actual energy efficiencies on the three pumping stations. The tool also established energy savings potential in the pumping stations. Energy M&T established water production and energy consumption relationships in the three pumping stations under study. From the study, the following conclusions were derived;

a. NRWB has not implemented most of EE measures; this could be attributed to lack of knowledge on the available EE measures, insufficient funds for implementation, and low management commitment as evidenced by unavailability of energy policy. ESCOM, a sole electricity supplier and MERA, an energy regulator, are expected from the study, to provide adequate information on EE measures and where necessary provide incentives to those who manage their energy well and also penalize those who worst energy.
b. Long term energy strategy, environmental management system, people with real ambition, threat of rising energy cost, and cost reductions resulting from lower energy use were some of highly ranked driving forces for EE improvement in the study area.
c. There is significant loss of pump efficiency in almost all pumping stations under study as observed from the PSAT results which show a remarkable difference between the designed and actual pump efficiencies.
d. Potentially, MWS through improved motor and pump efficiency can save US$ 43,400 annually on energy cost for an off peak tariff for Main Plant, MBC and Katawa pumping stations. This saving translates to 500 new water connections at the material time of the study with resultant effects of increased access to potable water in the supply areas and increased sales volume. A 265% energy saving potential can be realized in MWSS for each reduction in pumping during the on peak tariff though pumping and reservoir capacity pose a challenge to this opportunity. Annually, about US$ 10,000 energy reduction without investment can be realized through correct demand estimate in MWSS.

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e. Energy consumption in MWS is proportional to production. The test values for Mzuzu Main Plant, MBC and Katawa Stations fall in the critical regions with correlation coefficient, R, of 0.50, 0.80 and 0.95 respectively. The weak correlation at the Main Plant is due to submersible pumps which are not metered but share the same energy meter. The mathematical energy models emanating from Main Plant, MBC and Katawa Station can be used as baseline models for interpretation of energy use, monitoring variations, identifying causes, setting targets and monitoring results in MWSS.

7.2 Recommendations

The following recommendations were arrived at for possible implementation and further studies:

7.2.1 From the study

a. There is need to have maintenance and energy policy with senior management commitment for its implementation and diverse membership from different sections of the organization. Management should support planning and budgeting of energy improvement activities and extra effort is needed towards capacity building both in human resource and facilities.
b. There is need for companywide awareness and training in EE and management. Information on EE measures and benefits should be available to management and all employees.
c. There is an urgent need to review all pumping system designs in order to utilise available energy savings potential.
d. There is need to improve process instrumentation such as flowmeters so that accurate data is captured. This would improve the strength of the correlation between water produced and energy consumed so that the generated energy mathematical models could be generalized for future energy demands.
e. The Plan-Do-Check-Act energy management model need to be practised in MWS for continued benefit on energy saving opportunities.

7.2.2 For further research

a. Energy efficiency and management should involve both technical and economic appraisals. Further studies will be required to appraise each of the options on energy savings separately in order to compare capital costs, cost savings, energy reduction, payback time, and operational impacts on MWSS.

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b. The quality of electrical power supply from the provider (ESCOM) is not within the scope of this assessment. A further study is recommended to establish the power quality effects on EE.

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APPENDICES

Appendix 1: Questionnaire

The Polytechnic, Faculty of
Engineering, P/Bag 303, Chichiri.
Blantyre

Questionnaire for thesis work on assessment of energy efficiency and management in water supply – a case study of Mzuzu Water Supply.

Introduction

The researcher, Stanford Msongole, is a student registered with University of Malawi, The Polytechnic, pursuing Master of Science Degree in Infrastructure Development and Management. The research is being conducted as a requirement by the University to award MSc Degree to the student. Privacy, confidentiality and anonymity of participants will be safeguarded in the course of conducting the research. Furthermore, data will be collected and reported in a way that will not cause any form of embarrassment, stress, discomfort, pain and harm to the participants.

Instruction

Please read the questions carefully. Cross the appropriate square brackets or fill in the requested information/data. Please choose the best answer which reflects what is happening in your organization, Return the completed questionnaire by email to stanfordmsongole@yahoo.co.uk or through courier services to be paid for by the researcher upon delivery of the mail. The physical address to which the completed questionnaire should be sent is; Stanford Msongole, Northern Region Water Board, Kawiluwilu House, P/Bag 94, Mzuzu, Malawi.

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1. Interviewee personal details

Name of company……………………………………………………………………......

Job title……………………………………………………………………………...

Name of person (Optional)……………………………………………………........

Gender: Male [ ] Female [ ]

Qualification: Certificate [ ] Diploma [ ] Undergraduate Degree [ ] Masters or above [ ]

Email address (Optional)……………………………………………………………….

Office/ Mobile Phone (Optional)……………………………………………………….

Address…………………………………………………………………………………

2. Demographics

Which department do you work in?	**Which is your current position in the organization?**
☐ Executive	☐ Director
☐ Technical Services	☐ Manager
☐ Finance	☐ Officer
☐ Administration	☐ Supervisor
☐ Other (please indicate):	☐ Clerical/Artisan
	☐ Other (please indicate):

3. Commitment

a . Does your company have an explicit/implicit energy policy?
No policy [ ] Informal policy [ ] Incomplete policy [ ] Complete, formal, well communicated policy [ ]

b. If yes, is the top management of your firm full committed to the energy policy?
No interest [ ] Interest but no commitment [ ] some commitment, but could do better [ ] Full commitment [ ]

c. If yes, is the energy policy fully integrated into your firms operations?
No [ ] informal integration [ ] Partial formal integration [ ] Full formal integration [ ]

d. If yes, what is the level of the policy awareness among staff in the firm?

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Not at all [ ] informally and infrequently [ ] informally but regularly [ ] Formal ongoing awareness programs [ ]

4. Information sources

On a scale of 1 to 5, 1 for less used and 5 for excellently used. How useful do you consider the following sources to be as regards information on energy efficiency measures?

Source	**Scale**				
	1	**2**	**3**	**4**	**5**
Colleagues within the company					
Colleagues within the sector (Other Water Boards)					
Written sources of information such as journals					
Electricity Supply of Malawi (ESCOM)					
Product information from suppliers					
Consultants performing energy audits					
Government sponsored energy audits					
Malawi Energy Regulatory Authority					

5. On a scale of 1 to 5 where 1 is low energy consumption and 5 is the maximum energy consumption, how much do each of the following processes contribute to energy consumption in your company?

Process	**Scale**				
	1	**2**	**3**	**4**	**5**
Industrial Lighting					
Raw water pumping					
Chemical dosing					
Backwash pumping					
Air blowing					
Clear water pumping					

Others

Please highlight any other energy consumption process which you have but are not indicated above:

……………………………………………………………………………………………………

……………………………………………………………………………………………………

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6. The following table list some common measures for reducing energy consumption. Please indicate the extent to which your company has implemented each measure by assigning it a number on a scale from 1 (not implemented) to 5 (extensively implemented).

Measure	**Scale**				
	1	**2**	**3**	**4**	**5**
Use of energy saver bulbs?					
Use of high frequency fluorescents in new and replacement fittings?					
Use of photocell, acoustic or movement sensors					
Purchase of energy efficient computers, photocopiers and other office equipment?					
Optimizing the use of natural light?					
Use of appropriate and efficient pumps and motors or variable speed drives?					
Power factor correction?					
Load management or shifting?					
Process optimization and SCADA (Supervisory Control and Data Acquisition) systems?					
Automatic switch off of pumps, fans, conveyors, air conditioner and other equipment when not required?					
Proper pumping system design?					
Regular inspection and elimination of leaks?					
Efficient usage of water?					
Carrying out preventive maintenance works on pumps and motors?					

Others

Please highlight any other major energy efficiency measures that you have implemented but which are not indicated above:

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7. **Barrier to energy efficiency improvement**

Studies by researchers identify energy efficiency measures which are cost-efficient but which are not implemented. According to the aggregated experience in your company on a scale of 1 to 5, 1 for not important, 2 for rarely important, 3 for sometimes important, 4 for important and 5 for very important, how do you value the following factors impact on the implementation of cost-effective energy efficiency measures at your company?

Factor	**Rating**				
	1	**2**	**3**	**4**	**5**
Technology is inappropriate at this site					
Cost of production disruption/hassle/inconvenience					
Cost of identifying opportunities, analyzing cost effectiveness and tendering					
Possible poor performance of equipment					
Access to capital					
Slim organization					
Lack of budget funding					
Other priorities for capital investments					
Technical risks such as risk of production disruptions					
Uncertainty regarding the company’s future					
Poor information quality regarding energy efficiency opportunities					
Difficulties in obtaining information about the energy consumption of purchased equipment					
Lack of time or other priorities					
Lack of technical skills					
Lack of staff awareness					
Dep./workers not accountable for energy costs					
Energy objectives not integrated into operating, maintenance or purchasing procedures					
Low priority given to energy management					
Energy manager lacks influence					
Conflicts of interest within the company					
Lack of sub meters					
Long decision chains					

Do you have any further comments on barriers to energy efficiency improvement?

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8. **Driving forces for energy efficiency improvement**

Successful industrial energy management is characterized by a number of factors, external as well as internal. According to the aggregated experience in your company, on a scale of 1 to 5, 1 for not important, 2 for rarely important, 3 for sometimes important, 4 for important and 5 for very important, how do you value the following factors impact on the implementation of cost-effective energy efficiency measures at your company?

Factor	**Rating**				
	1	**2**	**3**	**4**	**5**
People with real ambition					
Long-term energy strategy					
Environmental Management systems (EMS)					
Environmental company profile					
Improved working conditions					
Cost reductions resulting from lowered energy use					
Network within the company/group					
Threat of rising energy prices					
International competition					
Energy tax					
Emission tax (CO2,NOx & Sulphur)					
General energy advices through seminar					
General energy advices through journal or booklet					
Voluntary agreements with tax exemption					
Energy efficiency requirements by Malawian government					
Publicly financed energy audits by energy consultant					
Publicly financed energy audit by sector					
Sector organization expert					

Do you have any further comments on driving forces for energy efficiency improvement?

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Thank you very much for completing this questionnaire.

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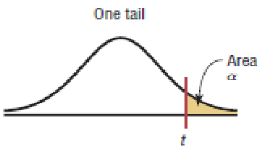
Appendix 2: The *t* Distribution

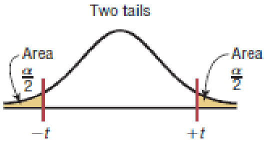
Table F The *t* Distribution

	Confidence intervals	80%	90%	95%	98%	99%
	One tail, α	0.10	0.05	0.025	0.01	0.005
d.f.	Two tails, α	0.20	0.10	0.05	0.02	0.01
1		3.078	6.314	12.706	31.821	63.657
2		1.886	2.920	4.303	6.965	9.925
3		1.638	2.353	3.182	4.541	5.841
4		1.533	2.132	2.776	3.747	4.604
5		1.476	2.015	2.571	3.365	4.032
6		1.440	1.943	2.447	3.143	3.707
7		1.415	1.895	2.365	2.998	3.499
8		1.397	1.860	2.306	2.896	3.355
9		1.383	1.833	2.262	2.821	3.250
10		1.372	1.812	2.228	2.764	3.169
11		1.363	1.796	2.201	2.718	3.106
12		1.356	1.782	2.179	2.681	3.055
13		1.350	1.771	2.160	2.650	3.012
14		1.345	1.761	2.145	2.624	2.977
15		1.341	1.753	2.131	2.602	2.947
16		1.337	1.746	2.120	2.583	2.921
17		1.333	1.740	2.110	2.567	2.898
18		1.330	1.734	2.101	2.552	2.878
19		1.328	1.729	2.093	2.539	2.861
20		1.325	1.725	2.086	2.528	2.845
21		1.323	1.721	2.080	2.518	2.831
22		1.321	1.717	2.074	2.508	2.819
23		1.319	1.714	2.069	2.500	2.807
24		1.318	1.711	2.064	2.492	2.797
25		1.316	1.708	2.060	2.485	2.787
26		1.315	1.706	2.056	2.479	2.779
27		1.314	1.703	2.052	2.473	2.771
28		1.313	1.701	2.048	2.467	2.763
29		1.311	1.699	2.045	2.462	2.756
30		1.310	1.697	2.042	2.457	2.750
32		1.309	1.694	2.037	2.449	2.738
34		1.307	1.691	2.032	2.441	2.728
36		1.306	1.688	2.028	2.434	2.719
38		1.304	1.686	2.024	2.429	2.712
40		1.303	1.684	2.021	2.423	2.704
45		1.301	1.679	2.014	2.412	2.690
50		1.299	1.676	2.009	2.403	2.678
55		1.297	1.673	2.004	2.396	2.668
60		1.296	1.671	2.000	2.390	2.660
65		1.295	1.669	1.997	2.385	2.654
70		1.294	1.667	1.994	2.381	2.648
75		1.293	1.665	1.992	2.377	2.643
80		1.292	1.664	1.990	2.374	2.639
90		1.291	1.662	1.987	2.368	2.632
100		1.290	1.660	1.984	2.364	2.626
500		1.283	1.648	1.965	2.334	2.586
1000		1.282	1.646	1.962	2.330	2.581
(z) ∞		1.282[a]	1.645[b]	1.960	2.326[c]	2.576[d]

[a]This value has been rounded to 1.28 in the textbook.
[b]This value has been rounded to 1.65 in the textbook.
[c]This value has been rounded to 2.33 in the textbook.
[d]This value has been rounded to 2.58 in the textbook.

Source: Adapted from W. H. Beyer, *Handbook of Tables for Probability and Statistics,* 2nd ed., CRC Press, Boca Raton, Fla., 1986. Reprinted with permission.





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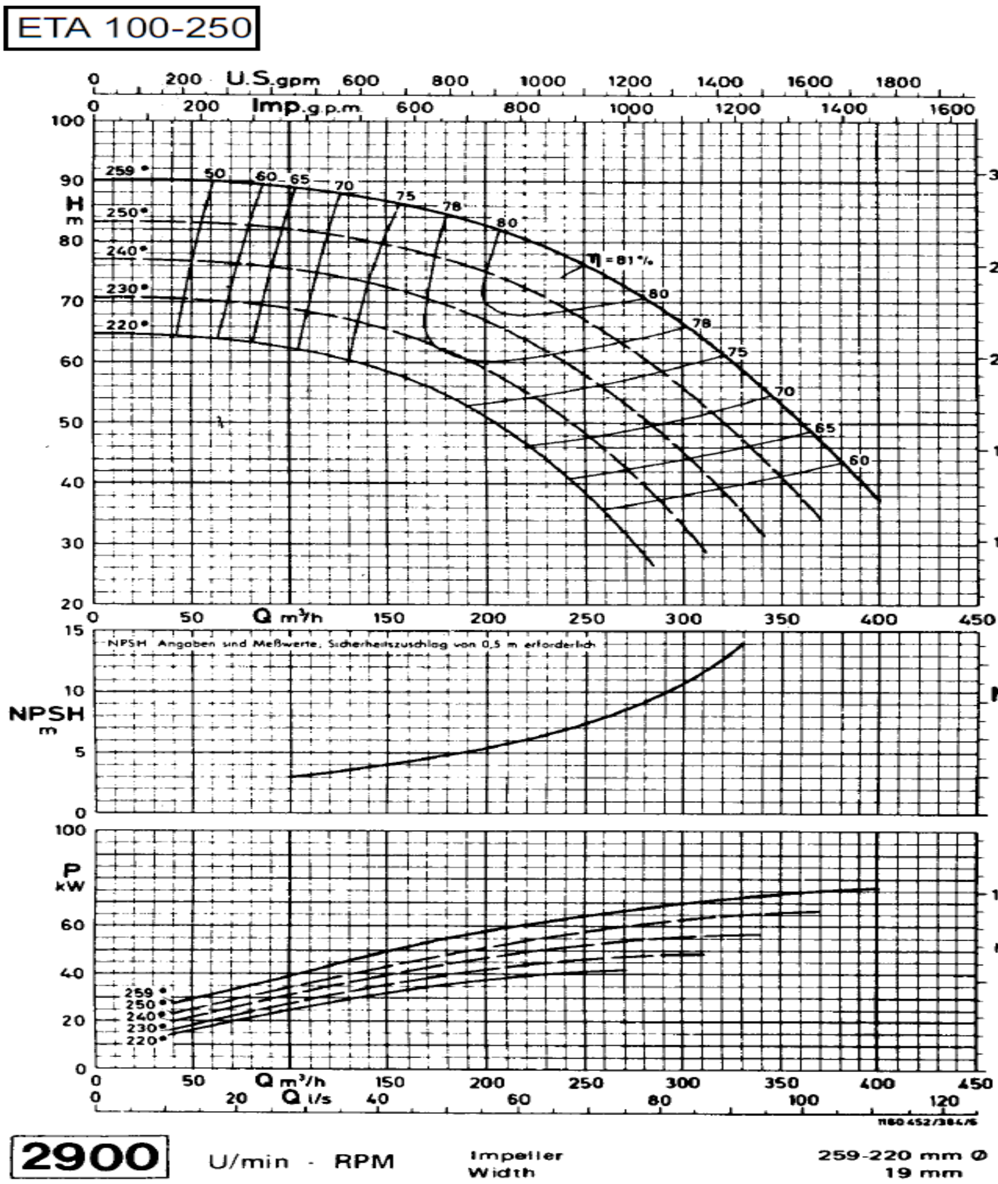
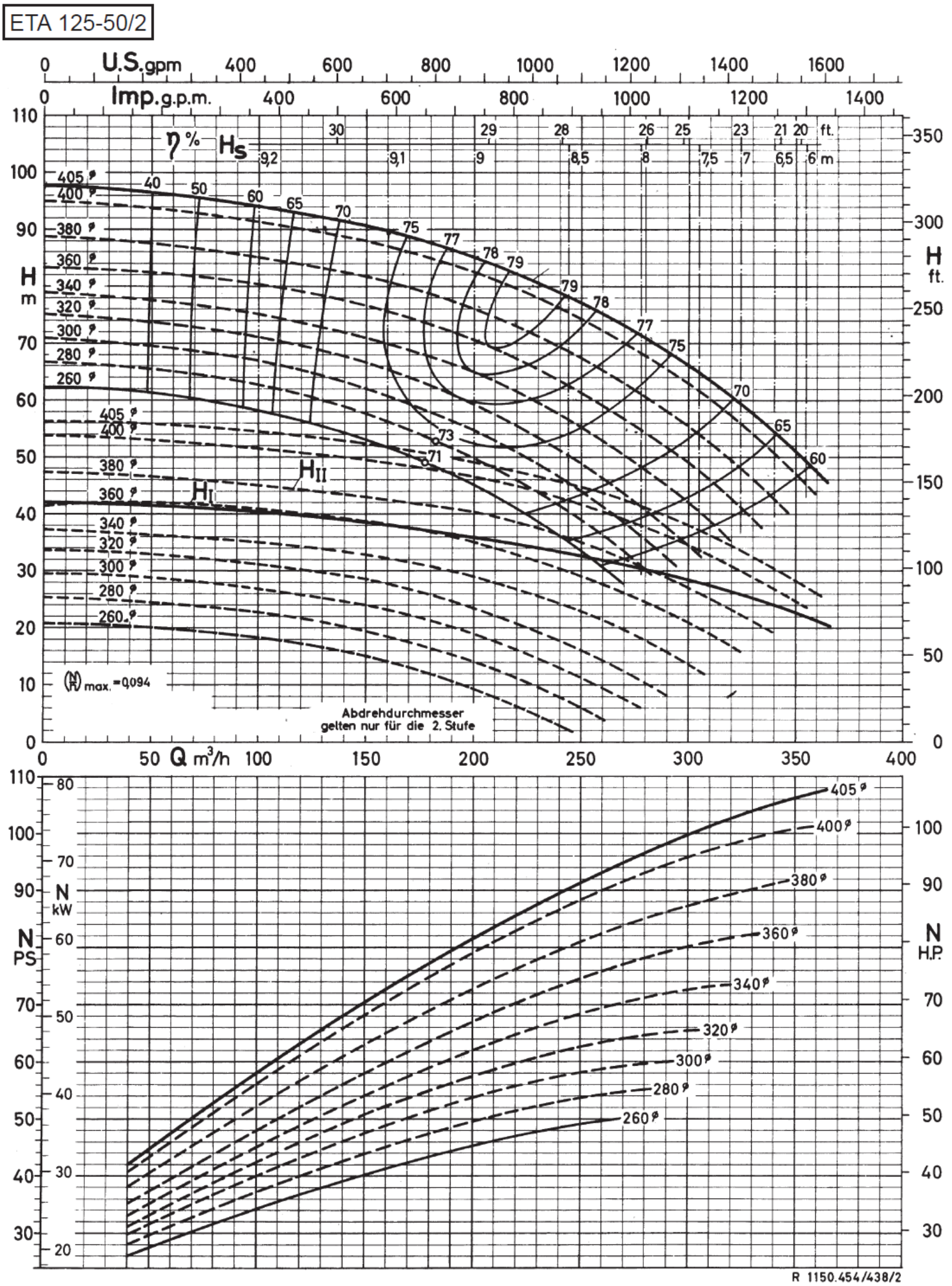
Appendix 3: MBC Feeder Pump Curve



Appendix 4: Katawa and Lunyangwa Feeder Pump Curve



Impeller 1st	330 mm Ø	Impeller outlet width 1st	22 mm
Impeller 2nd	405-260 mm Ø	Impeller outlet width 2nd	16 mm

1460 R.P.M.

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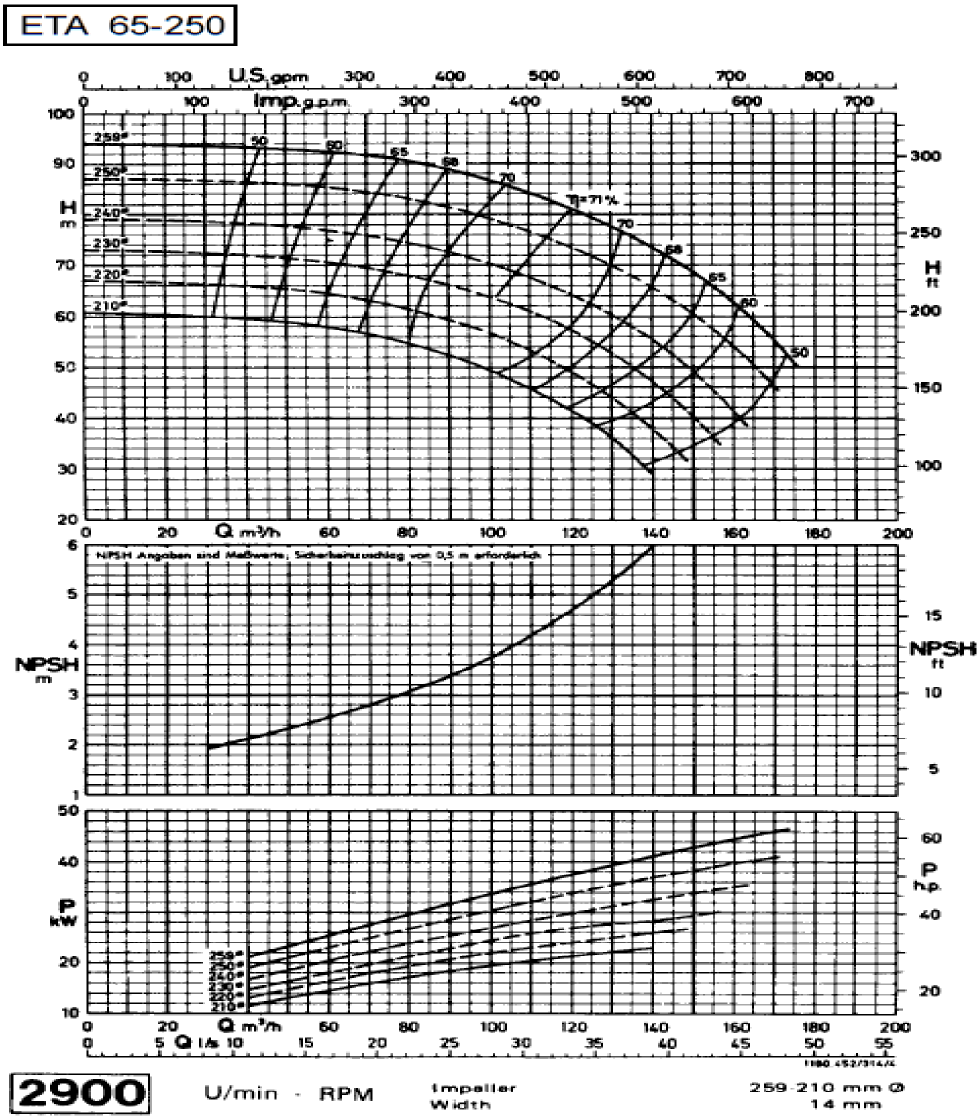
Appendix 5: Signal Hill and Lusangazi Feeder Pump Curve



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Appendix 6: Nkhorongo Feeder Pump Curve