UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

ENERGY CONSERVATION OPPORTUNITIES AT THE DEFENCE FORCES MEMORIAL HOSPITAL

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Research Project submitted in Partial Fulfilment of the Requirement for the Award of the Degree of Master of Science in Energy Management of the University of Nairobi

June, 2021

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SUPERVISORS DECLARATION

We confirm that the above student carried out this research project under our supervision as University supervisors.

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DECLARATION OF ORIGINALITY

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DEDICATION

I dedicate this project to my wife, children and mum for their tireless support and encouragement during my entire period of study.

ACKNOWLEDGEMENT

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Finally, to my parents, I thank them for teaching me the importance of aiming high at all times.

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LIST OF SYMBOLS AND ABBREVIATIONS

Accom	Accomodation
A	Amperes
A_F	Area of floor (m^2)
Church AC	Anglican Church
BTU	British Thermal Unit
COP	Coefficient of Performance
Cpls	Corporals
CBA	Cost Benefit Analysis
I	Current (A)
I_{fl}	Current at Full Load (A)
DFMTS	Defence Forces Medical Training School
DFMH	Defence Forces Memorial Hospital
^0C	Degrees Centigrade
ρ_f	Density of flue gases (kg/m^3)
ρ_w	Density of water (kg/m^3)
Dept	Department
EER	Energy Efficiency Ratio
ft	Foot or feet
GJ	Gigajoule
GWh	Gigawatt-hour
Hz	Hertz
hp	Horsepower
Hr	Hour
A_f	Incinerator Chimney Cross-sectional Area (m^2)
P_i	Input Power
ICU	Intensive Care Unit
J	Joules
K	Kelvin
$Kshs$	Kenya Shillings
kg	Kilogram
kg/s	Kilograms per second
kJ	Kilojoule
kJ/s	Kilojoules per second
kW	Kilowatt
kWh	Kilowatt-hour
KPLC	Kenya Power and Lighting Company
LPG	Liquefied Petroleum Gas
L	Litres
L/s	Litres per second
Lm	Lumens

Lm_{pf}	Lumens per fixture
Lx_{rl}	Lux Level required
$\dot{m}_f$	Mass flow rate of flue gas *(kg/s)*
$\dot{m}_w$	Mass flow rate of water *(kg/s)*
MOPC	Medical Out Patient Clinic
MJ	Megajoule
m	Metres
m^3/s	Metres cubed per second
m^2	Metres squared
Offrs	Officers
ORs	Other Ranks
OPD	Out Patient Department
P_o	Output Power
PBP	Payback Period
%	Percent
π	Pi (3.142)
Psi	Pounds Per Square Inch
P	Power *(W, kW)*
PF or pf	Power Factor
PF_{fl}	Power Factor at Full Load
p	Pressure (N/m^2)
ROI	Return on Investment
Church RC	Roman Catholic Church
Sgts	Sergeants
c_f	Specific Heat Capacity of flue gas *(J/kgK)*
c_w	Specific Heat Capacity of water *(J/kgK)*
T	Temperature *(K)*
T_{in}	Temperature at inlet *(K)*
T_{out}	Temperature at outlet *(K)*
T_{cold}	Temperature of refrigerant - lowest *(K)*
T_{hot}	Temperature of refrigerant - highest *(K)*
v	Velocity *(m/s)*
V	Volts
v	Volume (m^3)
v_f	Volume of flue gases (m^3)
v_w	Volume of water (m^3)
WOs	Warrant Officers
W	Watts

ABSTRACT

A study on energy conservation measures was conducted at the Defence Forces Memorial Hospital (DFMH) to identify opportunities which would cut down on the overall energy cost. This was guided by evaluation of energy cost distribution among the utilities in use. The biggest cost at 68 % of the total energy cost was out of electricity, 16 % diesel and 16 % LPG in 2017; 66 % electricity, 17 % diesel and 17 % LPG in 2018; 72 % electricity, 21 % LPG and 7 % diesel in 2019.

The study narrowed down on the energy sources, lighting, water heating systems and incinerator, refrigeration and air conditioning, electrical motors and generator and laundry equipment. The main objective of the project was to perform a level II energy audit of the hospital which entailed reviewing energy bills, determining energy losses in the lighting system, assessing energy losses in water heating system and incinerator, evaluating refrigeration and air conditioning overall efficiency, evaluating electrical motors and generator performance efficiency, determining the power losses of the laundry equipment, identifying energy saving opportunities in the areas of focus and performing a cost-benefit analysis for identified energy saving opportunities.

The method of executing the research project involved audit planning, general data acquisition, equipment testing and measurements, analysis of raw data and recommendations on energy conservation opportunities. The economic tools for determining the financial savings included the following: Capital Investment, Annual Financial Saving, PBP and ROI where possible while for the energy conservation opportunities, energy consumption technique was applied. The analysis identified that; in lighting, replacing all the 918 Fluorescent tubes with LED lights would result to payback periods of averagely less than 1 year, in the water heating system, the boiler was found to be underutilized with an output of 366.34 kJ/s and its current usage was 51.04 kJ/s. Instant showers were found to be consuming 187,447.5 kWh per year. The waste heat energy in the incinerator was found to be 490.42 kJ/s. For the HVAC system, one of the equipment was oversized at 4.6 kW, hence replacing it with the correct size would save the hospital Kshs 290,152.80 per year with a payback period of 1 year 11 months. It was also found that laundry and boiler feed water pumps motors had operating efficiencies below 75 % and would require regular maintenance and servicing. It was also notable that the same machines had low power factors which required appropriate measures to improve, example by insertion of capacitors for power improvement. The generator performance efficiency was 34.4 %. Power failure of the utility company (KPLC) costed the DFMH a loss of Kshs 130,489.60 (17 %) per year. In the laundry, the washer extractors and dryers consumed 608 kWh and 816 kWh per day respectively. If replaced with more efficient machines, financial savings of Kshs 1,527,120 and Kshs 3,406,495.70 per year for washer extractors and dryers respectively would be realized, with payback periods of 3 years 3 months and 2 years 6 months respectively.

For the power quality, the maximum Total Harmonic Distortion (THD) was found to be 2.17 % which is within the recommendation of < 5 % according to IEEE Std 519-1998.

CHAPTER ONE

1.0 Introduction

Conservation of energy and its efficient use are actions intended to reduce energy consumption without sacrifice of productivity or increase of costs. These actions have the capability of scaling down capital investments required in providing extra energy supply and reducing its whole resource use. Important factors to consider in energy efficiency and conservation are; high prices of energy, uncertainty of supply, harmful impacts on environment and health, and exhaustion of resources of energy [1].

Minimizing energy costs for any consumer is a desirable component of saving on money. The main objective of energy management is to minimize on energy costs which form part of the three major expenses of an organization, i.e. labour, raw materials and energy. This means that any judicious control of energy bills can lead to tremendous cost savings to an organization. Energy consumers with huge energy bills or those who have large fraction of their operating costs being dominated by energy bills, have a strong motivation to introduce energy conservation measures which help in cost-control. Saving initiatives on energy expenses can save a customer or an organization approximately between 10 % to 20 % on power bills, while investment cost programs with typical payback period of two years or less can save an organization/facility an additional 20 - 30 %. Therefore, in most cases energy cost control programs lead to reduction on energy bills and also reduction on emission of environmental pollutants [2]. Adoption of appropriate sources of energy after an effective energy audit, catalyzes accomplishment of Sustainable Development Goals (SDG) numbers 7 and 13.

In most countries, Hospital facilities are huge consumers of energy. The escalating costs of energy due to economic inflation and environmental concerns caused by increased emission of greenhouse gases make the reasonable use of energy and the energy conservation measures more important. Great need to tame energy consumption must be considered in both the industries and the building sectors. The latter has attracted significant interest in large scale, country wide, and in small scale like residential houses, commercial buildings and hospital facilities.

Hospital facilities due to their operational nature use large amounts of energy hence the possibilities of saving energy can be extensive. Most of the hospital facilities are long-standing and exhibit a lot of similarities in the building construction and in the other facilities as well as services since they use same codes and practices for building.

In the past, energy efficiency experts have concentrated on energy use in industrial processes thereby neglecting other key areas like hospitals. This situation has resulted in high-energy bill in hospitals and consequently high operating costs hence increased cost of accessing health services. According to the Kenya government big four agenda for the period 2017 - 2022, universal health provision is one of the agenda and with high costs of energy it could be a challenge to attain this.

The Defence Forces Memorial Hospital (DFMH) is a Kenya Defence Forces (KDF) referral hospital founded in 1970 based in Nairobi and situated off Mbagathi Road located approximately 10 km from the city centre. The hospital has eight wards each with an average bed capacity of 20. DFMH is one of the major hospitals in Kenya which offers medical services to the KDF personnel and their immediate families.

Electrical energy from the grid is the major component of energy used in both lighting and powering of the medical machines and equipment in the facility [8]. The other energy sources used are diesel and Liquid Petroleum Gas (LPG). The diesel is used to power Diesel Power Generator set for emergency power generation in case of grid power failure, the hot water boiler and in the incinerator. The LPG is used for cooking in the facility kitchens.

Preliminary evaluation showed that the major energy consuming areas were the lighting systems, laundry equipment, laboratory machinery, and catering units. Not only does the high consumption increase the institutions fiscal budget but also contributes negatively towards the environment.

An energy audit was conducted to analyze the current usage hence created a baseline for an Energy Management System (EMS) as well it identified the significant practices that could improve energy consumption (energy conservation opportunities - ECOs). The audit criteria used involved investigation of energy consumption behavior, the number of energy consuming appliances, equipment, machinery, and activities that could improve energy efficiency. The breakdowns of the energy consumptions for the three years were highlighted in Table 1.1 and represented by Figures 1.1, 1.2 & 1.3.

Table 1.1: Energy Sources at Defence Forces Memorial Hospital

Year	2017		2018		2019	
Sources of Energy	**Annual Consumption**	**Energy used (GJ)**	**Annual Consumption**	**Energy used (GJ)**	**Annual Consumption**	**Energy used (GJ)**
Electricity	966,910.00 kWh	3,480.88	968,695.00 kWh	3,487.30	951,573.00 kWh	3,425.66
Diesel	54,570 Ltrs	2,128.23	60,508.00 Ltrs	2,566.51	19,860.00 Ltrs	774.54
LPG	48,000 kgs	2,191.20	48,000 kgs	2,191.20	48,000 kgs	2,191.20
Total		**7,800.31**		**8,245.01**		**6,391.40**

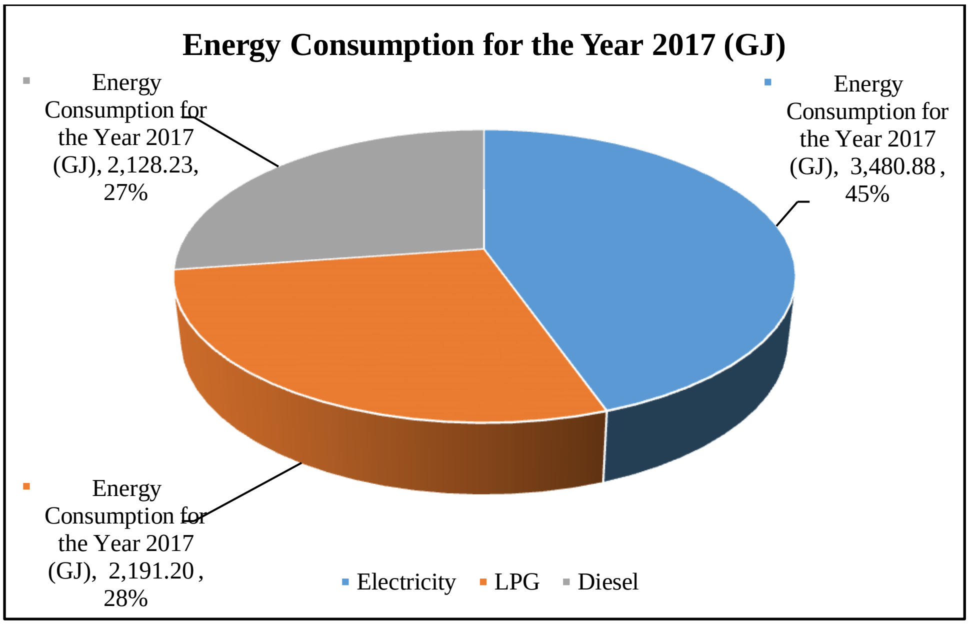

Figure 1.1: The Facility Energy breakdown for year 2017

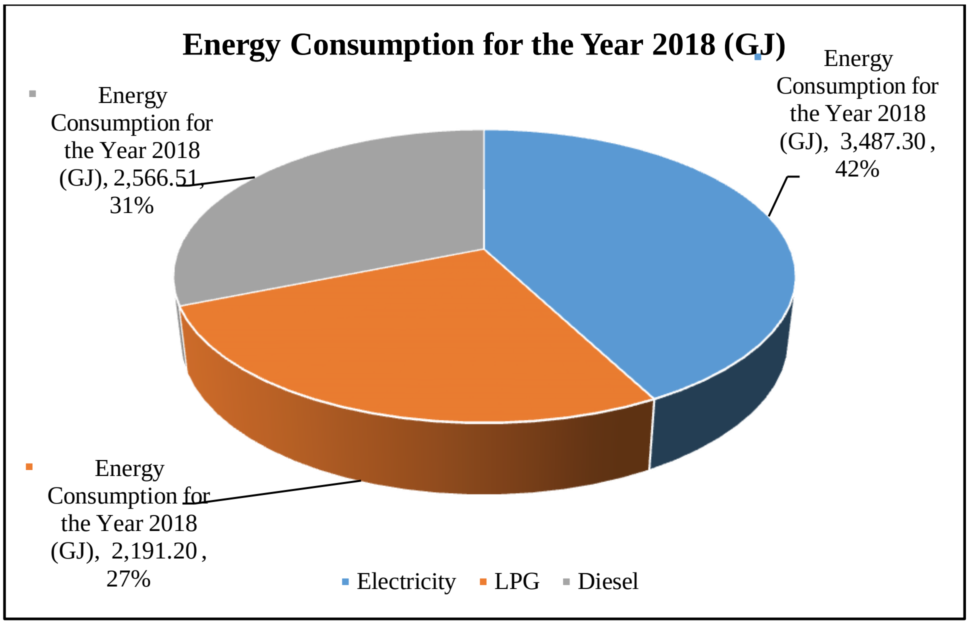

Figure 1.2: The Facility Energy breakdown for year 2018

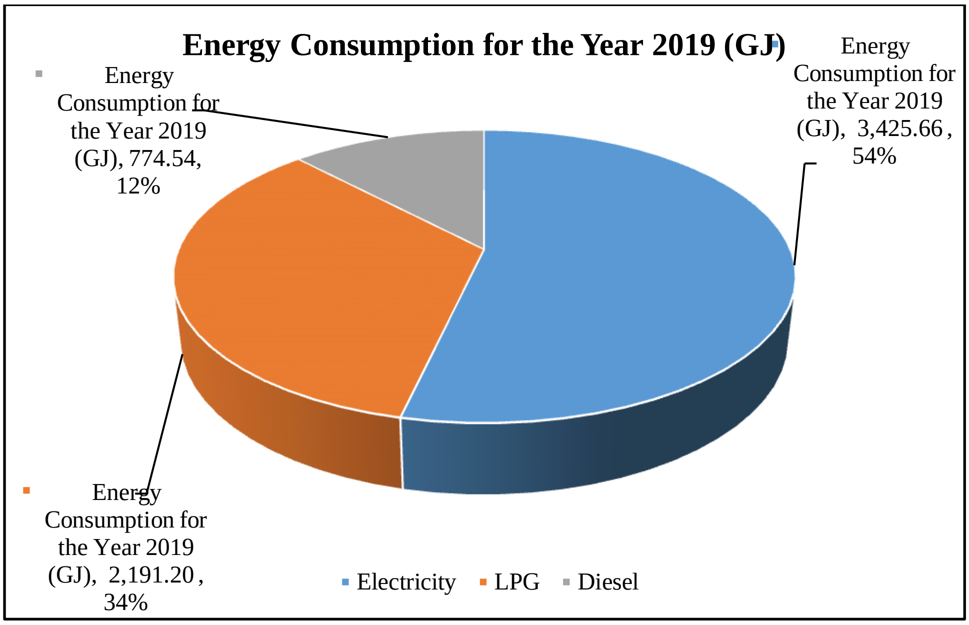

Figure 1.3: The Facility Energy breakdown for year 2019

From the breakdown, it could be seen that the primary energy consumption was distributed into electricity, at 966,910 kWh, equivalent to 3,480.88 GJ, making up 45 % of the total energy, LPG at 48,000 kgs, equivalent to 2,191.20 GJ, making up 28 % and Diesel at 54,570 Litres, equivalent to 2,128.23 GJ making up 27 % in the year

2017. The breakdowns of the energy costs for the three years were highlighted in the Figures 1.4, 1.5 & 1.6.

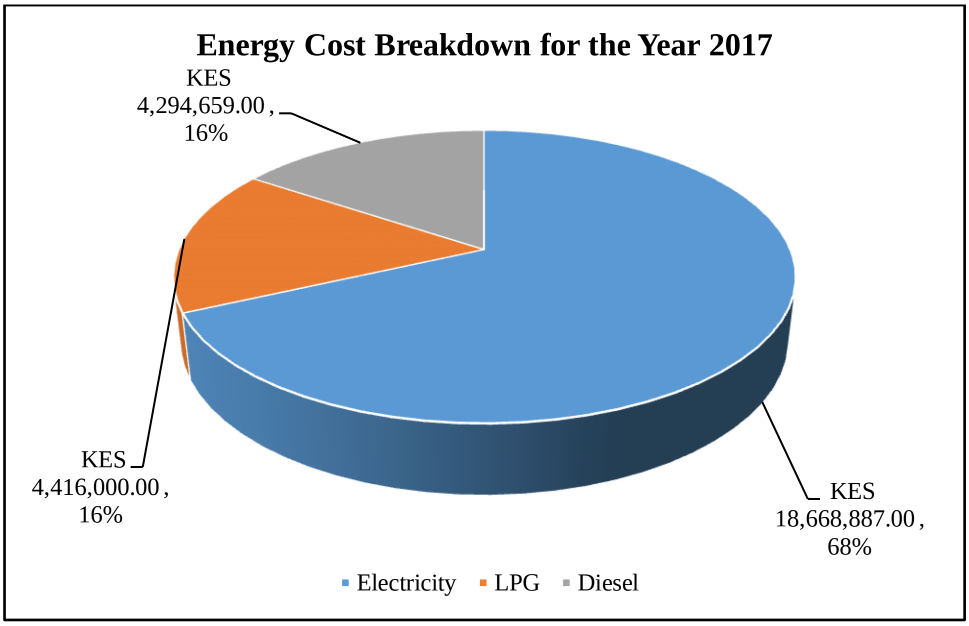

Figure 1.4: Facility Energy cost breakdown for the Year 2017

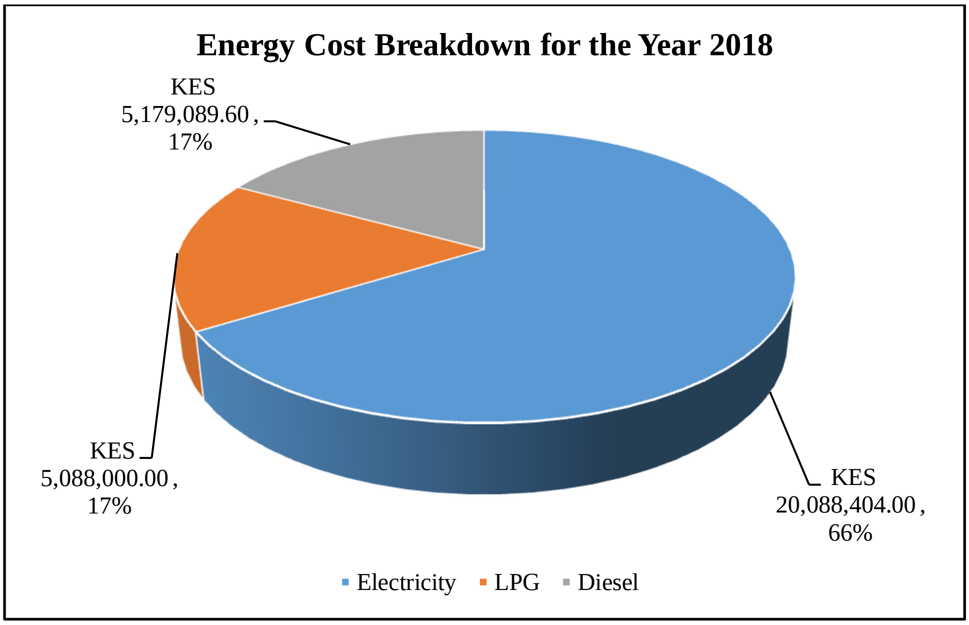

Figure 1.5: Facility Energy cost breakdown for the Year 2018

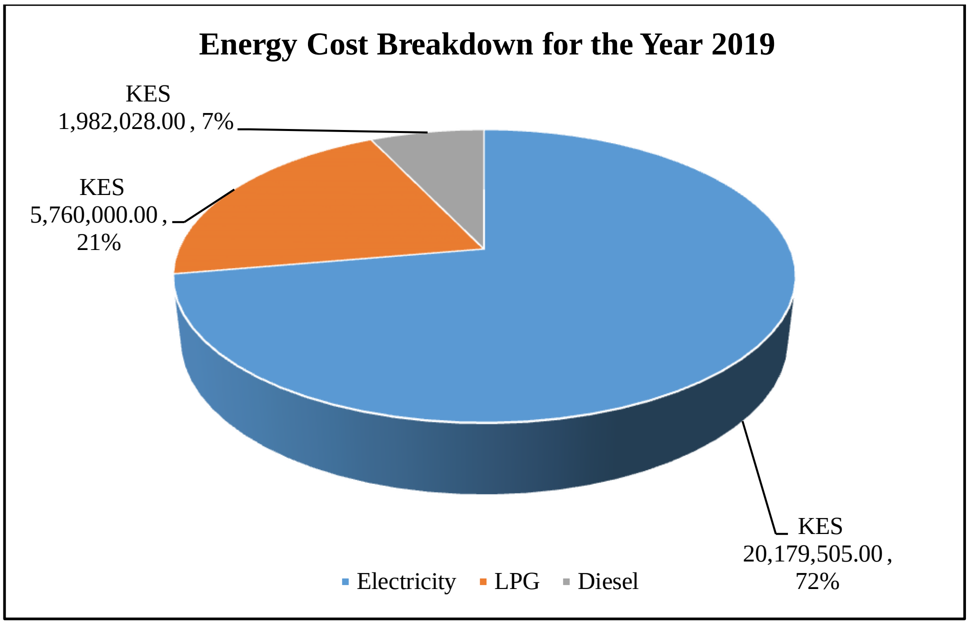

Figure 1.6: Facility Energy cost breakdown for the Year 2019

The energy cost breakdown showed that for the year 2017 electricity cost was Kshs 18,668,887.00 making up 68 % of the total cost of energy, cost of LPG was Kshs 4,416,000.00 making up 16 % of the total cost of energy and the cost of Diesel was Kshs 4,416,000.00 making up the remaining 16 %.

1.1 Problem Statement

Energy cost in Kenya has been on the rise over the past years due to increased cost of fossil fuel, unreliable hydropower due to climate change and ever-increasing energy demand due to increasing population and industrialization. Hospitals in Kenya majorly use energy in boiler systems, lighting, refrigeration, laundry, cooking and in powering other hospital machinery which run throughout.

According to a study conducted by the Energy Regulatory Commission/Ecocare in the year 2013 on Energy Performance, hospitals are ranked in the same category as other high-energy consumption industries like cement, metal and allied, paper and others [3]. This makes hospitals a priority area for energy efficiency improvement. Preliminary study of energy bills for the Defence Forces Memorial Hospital whose occupancy is between 100 to 150 people per day indicated that average electricity bill alone was approximately 1.5 million Kenya shillings per month. This was an indication of high overall energy bills comparing it with similar facilities. For instance, an energy audit carried out at Chengalputtu Medical College Hospital Buildings in India whose occupancy was 600 people per day identified an equivalent electricity bill of approximately 1.3 million Kenya shillings per month [6]. This necessitated the need to identify possible energy saving opportunities at the Defence Forces Memorial Hospital.

1.2 Research Objectives

1.2.1 Main Objective

The main objective of the project was to perform a level II energy audit of the hospital.

1.2.2 Specific Objective

The specific objectives were:

i) To review energy bills to establish trends in energy consumption and cost.

ii) To determine energy losses in the lighting system.

iii) To assess energy losses in water heating system and incinerator.

iv) To evaluate refrigeration and air conditioning overall efficiency and preset operation temperature.

v) To assess and evaluate electrical motors and generator performance efficiency.

vi) To determine the power losses of the laundry equipment.

vii) To identify energy saving opportunities in the areas of focus.

viii) Perform a cost-benefit analysis for identified energy saving opportunities.

1.3 Research Questions

i) What is the energy cost for the Defence Forces Memorial Hospital?

ii) What are the main energy consuming utilities at the Defence Forces Memorial Hospital?

iii) What are the energy losses in lighting at the Defence Forces Memorial Hospital?

iv) What are the energy losses in water heating system and incinerator at the Defence Forces Memorial Hospital?

v) What are the energy losses in refrigeration and air conditioning system at the Defence Forces Memorial Hospital?

vi) What are the performance efficiencies of the available electrical motors and generators at the Defence Forces Memorial Hospital?

vii) What are the power losses of the laundry equipment at the Defence Forces Memorial Hospital?

viii) What are the quantifiable energy conservation opportunities at the Defence Forces Memorial Hospital?

ix) What are the cost benefits of the energy saving opportunities?

1.4 Justification of the Study

Just like processing industries and manufacturing plants, hospitals consume a huge amount of energy each day to support life saving machines and other basic operations. Many hospitals in Kenya spend millions on energy bills every month hence there is a direct need to come up with a viable means of reducing their energy consumption and cost without compromising on service delivery.

In most buildings, the three items which normally top the list in operation expenses are always the energy (which entails electrical and thermal), labor and raw materials used. If one were to relate to the manageability of the price or potential cost savings in every of the above elements, energy would consistently emerge at the highest in ranking, hence energy management function accounts for a strategic space of reducing value. Energy Audit can aid in understanding a lot regarding the use of energy and fuels in buildings, and aid to identify the areas of waste occurrence and wherever improvement opportunity exists.

The Energy Audit would provide a positive orientation to the reduction of energy value, preventive maintenance and quality control programs that are important for production and utility activities. Such a program can aid in keeping attention on differences which occur within the energy prices, availability and reliability of energy supply, make a decision on suitable energy mix, pinpoint energy conservation skills, retrofit for energy conservation equipment etc.

The primary objective of Energy Audit is to outline means of reducing consumption of energy per unit of product output or to reduce operational prices. Energy Audit offers a “Bench-mark” (point of reference) to manage energy in the building and also gives the foundation for preparation of a more effective energy use within a facility.

The results of the energy audit at DFMH can be replicated across other facilities in the health sector to ensure that energy is used judiciously and effectively to minimise cost as well as reduce environmental impacts.

1.5 Scope of the Study

The research assessed the past and current energy consumption at the Defence Forces Memorial Hospital. The study was limited to the health facility only in order to identify the available possible energy conservation opportunities in the following main areas:

- Energy Sources
- Lighting.
- Water heating systems and incinerator.
- Refrigeration and Air conditioning.
- Electrical motors and generator.
- Laundry equipment.

The study involved analysis of energy (electrical power) bills for thirty six months (2017 – 2019) for the Defence Forces Memorial Hospital.

An energy audit was conducted and analyzed the current usage hence created a baseline for an Energy Management System (EMS) as well as identified the significant practices that could improve energy consumption (energy conservation opportunities - ECOs). The audit criteria used involved investigation of energy consumption behavior, the number of Energy consuming appliances, equipment, machinery, and buildings activities that could improve energy efficiency.

The scope of this energy audit was summarized into the following sub areas:

i) Audit planning
ii) General data acquisition
iii) Equipment testing and measurements
iv) Analysis of raw data
v) Recommendations on energy conservation opportunities.

1.6 Report Organization

This report consists of five chapters as explained herein: chapter one provides the introduction and the background theory in the study of energy conservation opportunities at the Defence Forces Memorial Hospital. This involves understanding of the current energy utilization in the facility. The objectives of the research project, scope, justification for conducting the research and the research contribution are also highlighted.

Chapter two covers theoritical aspect of an ideal energy audit, majorly covering the seven steps of an energy audit.

Chapter three highlights the method used in the research, formulae adequate for addressing the specific objectives and sources of data crucial for accomplishment of the project.

Chapter four presents the results and analysis of the results to achieve the research projects objectives.

Chapter five provides the conclusion and the recommendations for further research.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

Energy audit is the process of inspecting, assessing or surveying the current energy consumption and analysing the energy flows in order to come up with the possible energy conservation opportunities in a building. It may include a process or system to reduce the amount of *energy* input into the system without negatively affecting the output [2].

2.1 Overview of the Energy Cost Control Program in Energy Management

Energy management is the keen attention given in effecting structural, technical and behavioural actions in an economical and environmentally friendly manner with the objective of improving the energy performance of an organization and maintaining the achieved enhancements. It ensures that a corporation regularly passes through the cycle of creating policy, coming up with actions, implementing actions and checking results, reviewing progress and updating policy and objectives as required [2,9].

Energy Cost Control (ECC) programs are designed to reduce energy consumption and emissions of environmental pollutants. One of the initial steps of an efficient energy value management program is an Energy Audit (EA). An EA entails inspection, survey, and analysis of energy flows in a facility to determine conservation and optimization measures that would reduce energy usage and cost. However, an EA alone is not effective in reducing energy use or cost. The implementation of the identified opportunities is the only sure way of attaining energy efficiency [2].

Constant monitoring and periodic auditing would help realize the benefits of the conservation measures and identify areas for further enhancement to maintain energy savings. An Energy Management System (EMS) would be crucial in monitoring, controlling, and optimizing the performance of the energy-intensive systems and processes. It would promote energy awareness among staff and improve participation while enhancing the knowledge of energy consumption, and pinpointing opportunities for improvement.

The top management in the institution/facility should be good role models in energy cost control. This would help in the coordination of these programs and ensuring the involvement of all employees in implementing the energy-saving initiatives. Regular meetings need to be held to review the accomplished tasks and their impacts on energy usage and cost savings. This would help in the verification of the results and effectiveness of the measures taken before a follow-up audit is done. An award system should be established for recognition of employees or departments that stand out as big energy savers. Publicizing such successful implementation results would motivate other employees to put their best foot forward in optimizing energy use so as to receive recognition for their contributions. The above efforts would lead to sustainable energy cost control programs.

2.2 Types of Energy Audits

There are several energy audits as discussed in the following sub-sections.

2.2.1 Industrial Audits

Industrial energy audit involves complex assessment of industrial facilities. Most industrial buildings have tremendous complex equipment which requires complex analysis for a proper audit to be accomplished. Some of the common industrial equipment include: huge chillers, boilers, ventilating fans, water heaters, coolers and freezers, and broad lighting systems. Equipment found in industrial audits can also be found in commercial audits. Small hybrid generation systems are usually found in both commercial and industrial facilities [2].

The availability of extremely specialized equipment found in industrial processes differentiates the industrial audit with commercial audit, otherwise without the specialized equipment both commercial and industrial audit are the same. The scope of an industrial audit is wide thus causing a great challenge to industrial organizations. This leads most organizations seeking specialized services from consulting energy audit firms to examine their processes and recommend operational and equipment changes that result in greater energy productivity [2].

2.2.2 Commercial Audits

Comprehensive commercial energy audits are almost similar to industrial energy audits. The range of commercial audits is between simple audits conducted in small offices to fairly complicated audits conducted in big office buildings or huge shopping centres. The likely differences between commercial audits and industrial audits are highlighted in the following discussion [2].

Commercial energy audits entail extensive consideration of the overall building envelope structures and substantial amounts of specialized energy consuming equipment at the facility. Buildings with offices, large shopping centres and big malls have intricate building envelopes that need to be scrutinized and assessed. Materials used in building, levels of insulation, constructions of doors and windows, skylights, and other envelope features must be put into consideration in order to identify possible viable Energy Conservation Opportunities.

Commercial facilities also have large energy consuming equipment, like big chillers, huge HVAC systems, cookers and various office equipment like; workstations and photocopy machines. Considerable amount of the equipment found in commercial facilities is the same as that found in producing or industrial facilities. Potential Energy Conservation Opportunities would consider energy efficient equipment, re-use of waste water, or changes in operations to utilize less costly energy.

2.2.3 Residential Audits

Energy audits for any large buildings are at times same as commercial audits, whereas audits of single-family houses are averagely simple. Most residential energy audits emphasis on parameters like: the thermal envelope, electrical appliances like the heater, air conditioner and any "plug loads" [2].

In order to conduct an effective residential energy audit, the auditor should first obtain past energy bills and analyse them to determine any power consumption trends or anomalies. When conducting the energy audit, examination of the facility design is done to ascertain the quality of insulation, the conditions of windows and doors seals, and the reliability of the ducts. Inspection of heating, ventilation and air conditioning systems is carried out by recording equipment model numbers, age, size and efficiencies. During the post-audit analysis, identification and evaluation of potential ECOs such as addition of insulation, redesigning of window panes, insulation of doors, and changing to higher efficient HVAC systems can be adopted.

In conclusion of the audit, the auditor computes costs, benefits and Simple Payback Periods and presents them for implementation [2].

2.3 Levels of Energy Audits

According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), energy audits levels have been categorized into three levels. These three levels build on each other depending on its complexity. Increase in audit complexity leads to an increased thoroughness of facility assessment, data complexity and detailed final audit report [4].

2.3.1 Level I: This type of audit is also referred to as general audit. It is the simplest form of energy audit. It encompasses the energy wastage which can be pointed out from a glance. This audit can be accomplished during walk through surveys to the facility. In a level I audit measurements are not mandatory. Most energy conservation measures from this level of energy audit are no-cost or low cost. Activities in this level of audit include an assessment of energy bills and a brief site inspection of your building [4].

2.3.2 Level II: This level of energy audit involves in-depth analysis of prices of energy, amount of energy usage, building structure design and a refined survey of energy use in a facility/building. Engineering analysis also forms a basis in determining the no-cost and low cost energy conservation opportunities. Level II audits can be used to provide recommendations for potential capital intensive energy conservation opportunities [4].

2.3.3 Level III: This is a comprehensive level of energy audit and involves a detailed analysis of capital intensive modification audits or investment grade audits. It provides concrete suggestion and financial analysis using complex Engineering derivations to determine the energy conservation measures of major capital investments. A level III audit comprises of Level I and Level II activities and also involves monitoring, data collection and engineering analysis [4].

2.4 Determining the Level of Energy Audit

In selecting the appropriate level of energy audit the following factors are put into considerations: the projects goals and available budget. For facilities where there is no capital intensive improvement plan or budget, a Level I audit is the most preferred and could give results that make the cost of the audit worthwhile. Facilities that have never been audited should consider a Level II or Level III audit due to the complexities of systems and wide potential energy savings opportunities.

Though Level II and Level III audits are more expensive and complex. They are good options if there are defined energy efficiency goals which have never been implemented or when there are plans for major renovation or system upgrade. Preliminary feasibility study should be done before the initiation of a Level II and Level III audits in order to determine the scope of the ECOs and to ensure that the energy audit is profitable [4].

2.5 Components of Energy Audit

Energy audits start by collection of data regarding the facility’s operation and considering also the past records of the utility energy bills. When the data is fully collected it is then analysed using various tools of analysis in order to portray a picture of the facility’s energy uses, possible areas of energy wastage and also to guide the energy auditor in identifying the areas to examine for achievement of reduced energy costs. In order to minimize the areas of wastage and losses changes which are referred to as energy conservation measures are identified and examined to determine their benefits and their cost benefits/effectiveness. The energy conservation opportunities are assessed according to their prices and benefits/savings and an economic comparison is created to rank them among several options.

To accomplish an energy audit, an energy plan is developed and specific ECOs which have been identified are chosen for implementation and therefore the method of energy saving is achieved [2].

2.6 The General Procedure for the Energy Audit

Generally, an energy audit follows the steps indicated in Table 2.1. The steps involve the planning, awareness programs, data collection, cost benefit analysis and reporting. [6].

Table 2.1: General Procedure for the Energy Audit [6]

NO.	PLAN OF ACTION	PURPOSE/RESULTS
1	• Planning/organizing • Walk surveys • Interviews with relevant staff	• Organizing resources and establishing an energy policy, energy policy statement and energy audit proposal. • Organize audit tools and time plan. • Data collection • Familiarization tour. • Observation & assessment of current energy utilization.
2	• Brief meetings and awareness program.	• Cooperation enhancement. • Distribution of questionnaires in different departments • Creating awareness and orientation
3	• Basic data collection, Process Flow Diagram & Energy Utility Diagram	• Analysis of historic data, collection of baseline data. • Preparation of flow charts for process. • Diagram for all service utilities system (Example: Single line power distribution diagram, water, compressed air & steam distribution.) • Design, operating data and schedule of operation • Trend for annual electrical energy utilization and Annual Energy Bill sourced from user manual, log sheets, machine nameplates and interviews.
4	• Conducting of survey and monitoring.	• Measuring of Insulation and Lighting survey to be done using portable instruments to acquire more and accurate data.
5	• Examining of energy consumption	• Balance of Energy and Material & analysis of energy loss/waste.
6	• Identifying and developing Energy Conservation opportunities (ECOs).	• Identifying and consolidating Energy Conservation opportunities. • Consider, improve and refine ideas. • Evaluate the past ideas recommended by personnel of the facility. • Evaluate the past ideas recommended by energy auditor, if any. • Use brainstorming and value analysis techniques • Get in touch with dealers for new/efficient equipment or technology.
7	• Cost benefit analysis.	• Evaluate technical viability, economic feasibility and prioritize Energy Conservation options for application. • Rank by low, medium and long term opportunities.
8	• Report & Presentation.	• Documentation, Report Presentation.

2.7 Technical Steps for Energy Management

The most important function in effective and efficient management of energy is to set up methods of routinely evaluating performance of energy and identifying its conservation opportunities by adopting technical, behavioral and managerial aspects.

Energy management takes various ways which could involve capital intensive implementations like equipping new and more efficient systems to simpler activities like preventive maintenance which ensure efficient operations. It is also important to comprehend the current utilization and the available opportunities for reducing the present usage.

The Seven Steps for energy management were used for analysis in this audit and provided a methodical approach. These steps are divided into two distinct stages as outlined herein [12].

Phase 1: Understanding Present Usage

Phase one of the energy management process involves the first four steps, the main purpose of these steps is to gain control and understanding of the current energy utilization, energy cost, past and current variability and the physical distribution of energy in the facility. Energy utilization at this phase involves evaluating energy usage from the purchase point towards the utilization point.

Step 1: Understand energy costs

The first step in finding the most appropriate energy management method is understanding the Cost of energy which is dependent on several factors i.e. demand, energy, time-of- utilization and the power factor. It is easier to evaluate the consumption of thermal fuels than electricity because they are sold by mass and volume.

In this step the DFMH energy bills for electricity, LPG and diesel consumption were analyzed for a duration of the current past three-year period as shown in Tables 4.1 to 4.14 and Figures 4.1 to 4.13.

Step 2: Compare yourself

The facility is compared in terms of energy parameters internally and externally.

i. External comparisons involve comparing and analyzing the energy consumption levels of the facility with other identical facilities, industries or sites

   External comparisons help in setting energy targets and creating realistic saving prospects.

ii. Internal Comparisons involve comparing the energy use within the facility itself, this may include comparing consumption of different months in the past two or three years or comparing energy consumption on different sites or building in a multi-site operation.

Step 3: Understand when energy is used

Electricity cost is dependent of the time of utilization and the demand. Keeping a demand profile helps in determining the rate of electricity use over a given duration. Demand profile is an important energy management tool for the electricity bill

Step 4: Understand where energy is used

Energy should be treated like any other product. Developing an inventory for all the available electrical ad thermal loads enables one to focus on the biggest and highly priced consumers.

Phase 2: Identify Savings Opportunities

The second phase entails step 5 to step 7 and is done to identify the energy saving opportunities in a accost effective sequence. In this audit it involved concentration on the low cost measures before considering utilizing resources in acquiring new machineries.

Step 5: Match usage to requirement

This involves matching what you actually utilize to what is required. The key consideration here is the duration and magnitude of utilization.

Step 6: Maximize system efficiencies.

Matching appropriately the energy need and usage helps to assure that the components of the system are matching the need and they are operating most efficiently. The most important considerations in this step include: checking on the effect of performance conditions, maintenance and the technology of the equipment.

Step 7: Optimize the energy supply.

This step looks to identifying the best energy source or sources available. This may consist of different options such as heat recovery mechanisms, alternative fuels or energy sources, considerably bigger measures including a co-generation or combined heat and power (CHP) system.

2.8 Energy Bill Analysis

To perform energy audit accurately, it is necessary to have an understanding of the rate structure applied in billing the energy use. The clarity of the basis of the costs would help in controlling the cost of the energy consumed. Electrical consumption may consist of a client charge, energy charge, demand charge, power factor charge, and alternative miscellaneous charges. Billing system in Kenya is cost reflective.

The reading of maximum power in kW that a consumer demands during a month determines the electrical demand charge. The utility company averages the power reading over intervals from a quarter of an hour to at least one hour such that very short variations do not adversely have an effect on the customer's energy bills [5].

In Kenya, the billing structure by Kenya Power and Lighting Company is as outlined in Table 2.2.

Table 2.2: Approved Electricity Tariffs for 2018/19 [12]

Code	Customer Type (Code Name)	Energy Limit kWh/month	Charge Method	Unit	Approved Non Fuel Charge Rates
DC-L	Domestic - Lifeline	0-10	Energy	KShs/ kWh	12.00
DC-O	Domestic -	>11	Energy	KShs/kWh	15.80
SC	Small Commercial	0 – 15,000	Energy	KShs/ kWh	15.60
CI1	Comm./Industrial	>15,000	Energy	KShs/ kWh	12.00
			Demand	KShs/ kVA	800
CI2	Comm./Industrial	No Limit	Energy	KShs/ kWh	10.90
			Demand	KShs/ kVA	520
CI3	Comm./Industrial	No Limit	Energy	KShs/ kWh	10.50
			Demand	KShs/ kVA	270
CI4	Comm./Industrial	No Limit	Energy	KShs/ kWh	10.30
			Demand	KShs/ kVA	220
CI5	Comm./Industrial	No Limit	Energy	KShs/ kWh	10.10
			Demand	KShs/kVA	220
SL	Street Lighting	No Limit	Energy	KShs/kWh	7.50

The components of a KPLC energy bill comprise of fixed components and variable components.

i. Fixed Components include:

ERC levy, REP levy, Fuel Energy Cost, WARMA levy and Inflation Adjustment.

ii. Variable Components include:

Foreign Exchange Rate Fluctuation Adjustment (FERFA) and VAT.

2.9 Implementation Schedule and Continuous Energy Monitoring

For effective implementation, a thoughtful approach needs to be considered in order to prudently build the capacity in line with the energy management goals. Therefore, there is need to develop a communication plan for accurate dissemination of information and awareness creation on the goals, extra training to boost staff capacity, staff involvement and regular progress monitoring. The incorporation of the plans below would greatly promote energy conservation in the entire medical facility:

i) Getting support of the administration.
ii) Forming an energy team and appointing a conservation site champion.
iii) Training the energy team and the employees on retrofit energy conservation measures.
iv) Reporting to the administration on the success of the simple measures.

2.10 Energy Consumption in Other Institutional Hospitals

In similar energy audits performed in two hospital facilities namely; Chengalpattu Medical College Hospital Buldings, India [6] and George Town Public Hospital, Guyana [16] with bed capacities of 600 and 450 respectively, the annual electricity consumption per person was estimated to be 2,374 kWh and 12,623 kWh. The DFMH had an annual electricity consumption of approximately 5,947 kWh per person.

2.11 Results of Previous Energy Audit at DFMH

The previous energy audit done by the facility technical personnel had not been fully implemented. It was therefore against this shortcoming that this audit was done.

2.11.1 Recommendations of Previous Audit

a) Laundry/Water heating systems

i) Installation of solar water heaters.
ii) Switching off of idle machines

b) Lighting Systems

i) Utilization of LED lamps.
ii) Installation of solar PV panels for lighting.

c) HVAC/Motors and Drives Systems

i) Scheduled maintenance of all HVAC systems.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter focuses on the procedures and tools used for carrying out the energy audit at the Defence Forces Memorial Hospital.

3.1 Data Collection and Analysis

3.1.1 Primary Data

Primary data was sourced from walk through observations, power bills, direct measurements using measuring instruments, nameplates, flow diagrams etc. Data collection for the audit was through: oral interviews, direct instrument measurement, historic data, Energy bills, national regulations and standards and facility design.

Data which was utilized for Energy Audit at the DFMH was as follows:

1. **Power bill for all the facility for the last thirty-six months (2017-2019)**: This data gave critical details on the real and reactive power consumed as well as power factor surcharges. The data also was used to determine whether the institution was being billed using the appropriate tariff or not.
2. **Equipment inventory:** The nameplate of motors and generators were used to determine the respective efficiency, power factor, power rating, operating hours and permissible loading.
3. **The amount, frequency, and time of loading of machines and systems in place:**

   This information was significant in determining the power demand during peak and off-peak periods thus suitable when recommending alternative and affordable energy sources.
4. **Technical diagrams such as process and wiring diagrams**: These helped the energy auditor to understand the processes involved hence establishing whether there is energy wastage and its source.
5. **Fuel consumption:** To ensure energy efficiency and conservation, it is vital to know the type of fuel consumed by the various equipment in the facility. For instance, the specific type of fuel and the amount used in the kitchen boiler or backup generators.

6. **The maintenance costs of electrical consuming equipment within the hospital:**

   Analysis of this information was important in determining energy saving opportunities, for instance, need for fuel switching or equipment replacement to minimize energy cost.

7. **Luminance levels at different times of the day for all the lighting systems in the hospital:** This helped moderate the energy usage of the light bulbs. For instance, through the utilization of natural lighting during the day.

8. **Level of emission of environmental pollutants from the processes and the systems used within the facility:** Greenhouse gases like carbon dioxide are the main pollutants, which can be present in exhaust fumes from the catering department.

3.1.2 Secondary Data

Secondary data was obtained from statistical evaluations. Data was analyzed by use of qualitative and quantitative methods of data analysis.

Analysis of the collected data was done to pinpoint huge consumers of energy, in energy consumption by all utilities at DFMH. This was done through measurement and quantification. From the obtained data, the monthly power consumption (kWh) by DFMH was established.

The tools used for analysis of data are as outlined below:

a) Analysis of Energy Sources

i) Electricity as a Source of Energy [13]

The analysis of the electrical energy was determined using Equation 3.1:

$$Total\ Electrical\ Energy\ (GJ) = \frac{Total\ Electricity\ (kWh) \times 3.6}{1000} \tag{3.1}$$

ii) Diesel as a Source of Energy [14]

The tools which were used for the analysis of the Diesel energy were:

$$Total\ Diesel\ Energy\ (GJ) = \frac{Total\ Diesel\ (Litres) \times 39}{1000} \tag{3.2}$$

$$Total\ Diesel\ Energy\ (kWh) = \frac{Total\ Diesel\ (GJ) \times 1000}{3.6} \tag{3.3}$$

iii) LPG as a Source of Energy [13]

The tools which were used for the analysis of the LPG energy were:

$$Total\ LPG\ Energy\ (GJ) = \frac{Total\ LPG\ (kg) \times 45.65}{1000} \tag{3.4}$$

$$Total\ LPG\ Energy\ (kWh) = \frac{Total\ LPG\ (GJ) \times 1000}{3.6} \tag{3.5}$$

b) Lighting Systems Analysis [7], [9], [10], [19]

The tools which were used for the analysis of the lighting systems were:

i) Power consumption parameters of lighting systems

Power consumption parameters for different lighting systems was determined using Equations 3.6 and 3.7.

$$Power\ rating = voltage\ rating \times current\ rating \times power\ factor$$

$$= V \times I \times Cos\Theta \tag{3.6}$$

$$Power\ consumption = power\ rating \times operating\ time \tag{3.7}$$

$$Total\ Power\ Rating = (light\ rating + choke\ rating) \times no.of\ lamps \tag{3.8}$$

$$Required\ Lumens = required\ lux\ level \times area\ of\ floor$$

$$= Lx_{rl} \times A_F \tag{3.9}$$

$$No.of\ Lamps = \frac{Required\ Lumens}{Lumen\ per\ fixture \times utilization\ factor \times lamp\ lumen\ depreciation}$$

$$= \frac{Lx_{rl} \times A_F}{Lm_{pf} \times UF \times LLD} \tag{3.10}$$

$$Energy\ Saving = (Existing\ Total\ Rating - Total\ Rating\ of\ proposed\ lamps) \times Number\ of\ hours \tag{3.11}$$

$$Annual\ Financial\ Saving = Cost\ of\ electricity \times Energy\ Saving \tag{3.12}$$

$$Capital\ Investments\ (Kshs) = Total\ cost\ of\ fixtures$$

$$= cost\ of\ one\ fixture \times number\ of\ fixtures \tag{3.13}$$

The power consumption of any electrical appliance depends on the power rating and the usage time. The larger the power rating in the electrical appliance, the more power is consumed every second. The longer the usage time, the more electrical power is consumed.

The appropriate energy conservation opportunities were identified and were ranked according to the power /energy consumption saving and the payback period.

c) Water Heating Systems and Incinerator

i) Boiler [9], [20]

Power Consumption of the Boiler

This was determined by use of Equation 3.7.

$$Mass\ of\ hot\ water\ required\ = density\ of\ hot\ water \times volume\ of\ hot\ water$$
$$= \rho_w \times v_w \tag{3.14}$$

$$Heat\ Energy\ required\ to\ raise\ water\ temperature$$
$$= mass\ of\ hot\ water\ required$$
$$\times\ specific\ heat\ capacity\ of\ water \times temperature\ rise\ of\ water$$
$$= \dot{m}_w \times c_w \times (T_{out} - T_{in}) \tag{3.15}$$

ii) Instant Showers [9]

Power Consumption of the Instant Showers

This was also determined using of Equation 3.7.

iii) Incinerator [9], [20]

$$Waste\ Heat\ Energy$$
$$= mass\ flow\ rate\ of\ flue\ gas$$
$$\times\ specific\ heat\ capacity\ of\ flue\ gas$$
$$\times\ temperature\ drop\ of\ flue\ gas$$

$$= \dot{m}_f \times c_f \times (T_{in} - T_{out}) \tag{3.16}$$

$$Mass\ flow\ rate\ of\ flue\ gas =$$
$$density\ of\ flue\ gas \times chimney\ cross\ sectional\ area \times velocity\ of\ flue\ gas$$
$$= \rho_f \times A_f \times v_f \tag{3.17}$$

d) Heating, Ventilation and Air Conditioning Systems Analysis [9], [13], [21], [22]

The following tools were used for the analysis of the HVAC systems:

i) Equation 3.7.

ii) Coefficient of Performance (COP)

Coefficient of Performance (COP),

$$COP = \frac{T_{cold}}{(T_{hot} - T_{cold})} \tag{3.18}$$

iii) Energy Efficiency Ratio (EER)

Room air conditioner's energy efficiency ratio (EER)

$$EER = 3.41 \times COP \tag{3.19}$$

e) Electrical Motors and Generators [7], [9], [22]

The following mathematical tools were used for the analysis of the Electrical Motors and Generator systems in determination of their operating efficiencies:

Equations 3.6 and 3.7 were used. And also;

$$Rated\ Input\ Power = Apparent\ Power \times Power\ Factor$$

$$Rated\ Input\ Power = kVA \times pf \tag{3.20}$$

$$Rated\ Input\ Energy = Rated\ Input\ Power \times operational\ time \tag{3.21}$$

$$Efficiency = \frac{Output\ Power}{Input\ Power} \times 100 = \frac{P_o}{P_i} \times 100 \tag{3.22}$$

$$Full\ Load\ Power\ Factor = \frac{Input\ Power}{Voltage \times Full\ Load\ Current}$$

$$PF_{fl} = \frac{P_i}{V \times I_{fl}} \tag{3.23}$$

f) Laundry Equipment [9]

Power consumptions of the laundry machines were determined using Equation 3.7.

g) Cost Benefit Analysis

i) Payback Period (PBP) [2]

The ranking of the energy conservation measures was done by calculating the payback period (PBP) of various systems as shown in Equation 3.24.

$$Payback\ Period\ (PBP) = \frac{Capital\ Investment}{Annual\ Financial\ Saving} \tag{3.24}$$

ii) Return on Investment (RoI) [2]

The determination of the rate of return on investment was done using Equation 3.25.

$$Return\ on\ Investment = \frac{Annual\ Financial\ Savings}{Total\ amount\ of\ investment} = \frac{1}{PBP} \tag{3.25}$$

3.2 Audit Data Requirement and Source

Some of the data required for energy audit and respective sources are shown in Table 3.1.

Table 3.1: Data Requirement and Source

Data	Source(s)
System layouts	Layout drawings
Operating hours	Hospital work schedule
Applicable tariff	Electricity bill
Measuring data for technical audit	Measuring instruments such as lux meter, flue gas analyzer, infrared thermometers, and demand & power analyzers.
Appliance unit efficiencies and parameters	User manual and nameplate information during both walk and technical audits

3.3 Audit Procedure

The audit procedure involved the following steps:

i. A walk through audit to determine the glaring energy conservation opportunities.

ii. A physical survey of the hospital to develop an appreciation of the scope of work, and understand the various energy utilities.

iii. A review of the electrical energy bills for the hospital, usage of other energy sources such as automotive diesel and LPG.

iv. Interviews with various staff regarding modes of operation.

v. Technical and financial analysis to determine opportunities for energy efficiency and

vi. Compiling of the energy audit report.

3.4 Tools and Equipment

There were various tools and equipment that were used during the data collection process at DFMH. The summary of the tools and equipment is highlighted in Table 3.2.

Table 3.2: Instruments used for the Audit

<table>
<tr><th>Tool</th><th>Measurement Output</th><th colspan="2">Range and Specifications</th><th>Accuracy</th></tr>
<tr><td rowspan="5">PEL 103 Power Analyzer</td><td rowspan="5">Power Factor, Voltage, Current, kW, Electricity Consumption</td><td>Voltage (Vrms)</td><td>0.01V</td><td>±0.1%</td></tr>
<tr><td>Current (Arms)</td><td>0.001-10A</td><td>±0.1%</td></tr>
<tr><td>Power (W)</td><td>0.1-1KW</td><td>±1.5%</td></tr>
<tr><td>Power Factor</td><td>0.01</td><td>±0.03%</td></tr>
<tr><td>Harmonics</td><td></td><td></td></tr>
<tr><td rowspan="2">EXTECH Lux meter</td><td rowspan="2">Model LT300</td><td>Lux</td><td>40.00, 400.0, 4000, 40.00k, 400.0kLux</td><td>± (5% Rdg + 0.5% Full Scale)</td></tr>
<tr><td>Foot candle (Fc)</td><td>40.00, 400.0, 4000, 40.00k, 400.0kFc</td><td>± (5% Rdg + 0.5% Full Scale)</td></tr>
<tr><td rowspan="2">Fluke 117 clamp ampere meter</td><td rowspan="2">Spot measurement of AC current</td><td>Voltage (Vrms)</td><td>0.01V</td><td>±0.1%</td></tr>
<tr><td>Current (Arms)</td><td>0.001-10A</td><td>±0.1%</td></tr>
<tr><td>Infrared Thermometer</td><td>IR700-Digital Infra Red</td><td>Temperatures</td><td>-50°C to 700°C</td><td>± 1.5% or ± 1.5°C</td></tr>
<tr><td>Tape Measure</td><td>Linear distances</td><td colspan="2"></td><td></td></tr>
<tr><td>Safety Equipment</td><td>Safety of the Audit personnel</td><td colspan="2"></td><td></td></tr>
<tr><td>Cameras</td><td>Pictures of units and processes</td><td colspan="2"></td><td></td></tr>
</table>

3.5 Scope of the Energy Audit

The energy audit emphasized on both equipment and the facility energy consuming systems.

3.5.1 Energy Sources

The audit on the energy sources entailed:

- Electricity as a source of energy
- Diesel as a source of energy

- LPG as a source of energy

3.5.2 Lighting Systems

The audit on the lighting systems involved the following activities:

- Measurement of light intensity
- Determination of lumen depreciation
- Determination of lamp types and characteristics
- Identification of various lighting controls
- Identification of energy conservation opportunities for lighting systems.

3.5.3 Water heating systems and Incinerator

The following were considered:

- Boiler system
- Instant showers
- Incinerator
- Available energy saving measures.

3.5.4 Air Conditioning Systems

In determining the energy conservation measures for air conditioning systems, the following parameters were considered:

- Identification of HVAC basics, estimation of loading and determination of their efficiencies
- Consideration of the piping arrangement
- Identification of the energy conservation measures.

3.5.5 Electrical Motors and Generator

For all electrical motors and generator, the factors which were considered were:

- Motor operating characteristics and their efficiencies
- Diesel generator
- Available energy saving measures.

3.5.6 Laundry Equipment

For laundry equipment, the following were considered:

- Washer extractors
- Drying machines

- Other laundry equipment
- Available energy saving measures.

3.5.7 Actions adopted in this audit

i) Visual checkup and data collection.
ii) Assessment on the general design and layout of the facility, equipment and quantification.
iii) Measurement of energy consumption and other parameters for identification of the current use of energy. This helped to understand the current energy situation.
iv) Detailed calculations, analysis and assumptions.
v) Data validation.
vi) Identification of the profitable energy saving opportunities.

3.6 Conclusion

The research identified, listed and evaluated the power consuming equipment and systems. Detailed description on the equipment, model, hours of operation per day, all parameter ratings etc. were entered into a data sheet. Energy saving calculations, estimated cost incurred and the recommendations on energy saving opportunities were determined. Ranking of the energy saving measures was done according to simple payback time, rate of return on investment and efficiencies.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Energy Sources at DFMH

Electricity, Diesel and LPG were the sources of energy used at the Defence Forces Memorial Hospital. Electricity was used for powering hospital equipment, diesel was used for the boiler, incinerator and standby generator, while LPG was used for cooking purposes.

4.1.1 Electricity as a Source of Energy

Electricity was the main source of energy at the Defence Forces Memorial Hospital. Tables 4.1, 4.2 and 4.3 show the electricity consumption for the years 2017, 2018 and 2019, respectively.

Table 4.1: Electricity Consumption for Year 2017

Period (Months)	High Rate (kWh)	Low Rate (kWh)	Demand (kVA)	Demand (kW)	PF	Electricity Cost (Kshs)
Jan-17	43314	37191	236	232	0.98	1,500,408
Feb-17	41733	34592	248	244	0.98	1,483,812
Mar-17	45101	37767	237	233	0.98	1,549,984
Apr-17	40093	37480	246	242	0.98	1,505,852
May-17	43284	37216	240	235	0.98	1,500,500
Jun-17	41603	35232	238	232	0.97	1,397,050
Jul-17	46835	40347	240	236	0.98	1,633,644
Aug-17	48146	38163	242	237	0.98	1,751,555
Sep-17	44241	35320	217	215	0.99	1,497,986
Oct-17	45043	37852	239	237	0.99	1,608,069
Nov-17	44231	34966	242	240	0.99	1,623,426
Dec-17	43531	33629	239	236	0.98	1,616,601

Table 4.2: Electricity Consumption for Year 2018

Period (Months)	High Rate (kWh)	Low Rate (kWh)	Demand (kVA)	Demand (kW)	PF	Electricity Cost (Kshs)
Jan-18	50315	30230	232	229	0.98	1,609,381
Feb-18	46566	28178	228	225	0.99	1,580,475
Mar-18	51487	31306	241	238	0.99	1,797,181
Apr-18	46770	31599	237	234	0.99	1,754,307
May-18	43531	33629	239	236	0.99	1,615,601
Jun-18	41603	35232	238	232	0.97	1,397,049
Jul-18	56805	34483	261	257	0.98	1,937,797
Aug-18	58531	31786	244	241	0.99	1,811,788
Sep-18	49977	33035	236	233	0.99	1,669,286
Oct-18	54255	29932	240	237	0.99	1,696,137
Nov-18	48652	27474	229	226	0.99	1,550,116
Dec-18	42776	30543	216	214	0.99	1,669,286

Table 4.3: Electricity Consumption for Year 2019

Period (Months)	High Rate (kWh)	Low Rate (kWh)	Demand (kVA)	Demand (kW)	PF	Electricity Cost (Kshs)
Jan-19	47634	27016	226	223	0.99	1,540,563
Feb-19	42481	24266	225	222	0.99	1,421,005
Mar-19	47880	29236	220	217	0.99	1,590,670
Apr-19	49889	27890	224	220	0.98	1,607,466
May-19	50014	28372	223	219	0.98	1,713,914
Jun-19	47634	27016	226	223	0.99	1,540,563
Jul-19	55946	31196	237	233	0.98	1,881,202
Aug-19	51457	32906	248	243	0.98	1,827,431
Sep-19	52550	32564	255	249	0.98	1,800,000
Oct-19	55497	28091	248	243	0.98	1,808,581
Nov-19	53244	30679	243	238	0.98	1,764,577
Dec-19	49299	28816	239	235	0.98	1,683,533

In order to understand the current Energy use for the DFMH, electricity bills for the three years (2017-2019) were analyzed comprehensively as shown in Tables 4.4, 4.5, 4.6, 4.7 and represented in Figures 4.1 to 4.7.

To get some of the important parameters, the following mathematical tools were used:

Total Usage kWh

This is the total electricity consumption in kilowatt-hour (kWh) and is given by the sum of high rate kWh and low rate kWh, i.e.,

$$Total\ Usage\ (kWh) = High\ Rate\ (kWh) + Low\ Rate\ (kWh) \tag{4.1}$$

For example, in January 2017, High Rate consumption was 43314 kWh and Low Rate consumption was 37191 kWh.

Hence,

$$\text{Total Usage kWh for January 2017} = 43314 + 37191$$
$$= 80505\ kWh$$

Similar analysis was done for all the other months of the three years considered for the energy audit and were as shown in Tables 4.4, 4.5 and 4.6.

Electricity Energy Equivalent (Joules)

This is the electrical energy in kilowatt-hour (kWh) converted into joules (J), kilo-joules (kJ), mega-joules (MJ) or giga-joules (GJ) and was determined using Equation 3.1.

For example, in February 2017, Total Usage kWh was 76325 kWh, hence,

$$\text{Electricity Energy Equivalent (GJ) for February 2017} = \frac{76325 \times 3.6}{1000}$$
$$= 275\ GJ$$

The electricity energy equivalent (GJ) for the 36 months of consideration in the energy audit were done and were as shown in Tables 4.4, 4.5 and 4.6

Table 4.4: Electricity Bill Analysis for Year 2017

Period (Months)	Total Usage (kWh)	Equivalent (GJ)	Demand (kVA)	Demand (kW)	PF	Electricity Cost (Kshs)	Unit Electricity Cost (Kshs)
Jan-17	80,505	290	236	232	0.98	1,500,408	18.64
Feb-17	76,325	275	248	244	0.98	1,483,812	19.44
Mar-17	82,868	298	237	233	0.98	1,549,984	18.70
Apr-17	77,573	279	246	242	0.98	1,505,852	19.41
May-17	80,500	290	240	235	0.98	1,500,500	18.64
Jun-17	76,835	277	238	232	0.97	1,397,050	18.18
Jul-17	87,182	314	240	236	0.98	1,633,644	18.74
Aug-17	86,309	311	242	237	0.98	1,751,555	20.29
Sep-17	79,561	286	217	215	0.99	1,497,986	18.83
Oct-17	82,895	298	239	237	0.99	1,608,069	19.40
Nov-17	79,197	285	242	240	0.99	1,623,426	20.50
Dec-17	77,160	278	239	236	0.98	1,616,601	20.95
Total	**966,910**	**3,481**	**2,864**	**2,819**	**11.81**	**18,668,887**	**231.73**
Average per month	**80,575.83**	**290**	**238.67**	**234.92**	**0.98**	**1,555,740.55**	**19.31**

Figure 4.1 was a representation of the annual electricity consumption trend with an avarage consumption of 80,575 kWh per month for the year 2017. Figure 4.2 represented the power factor behavior for the facility for the same period.

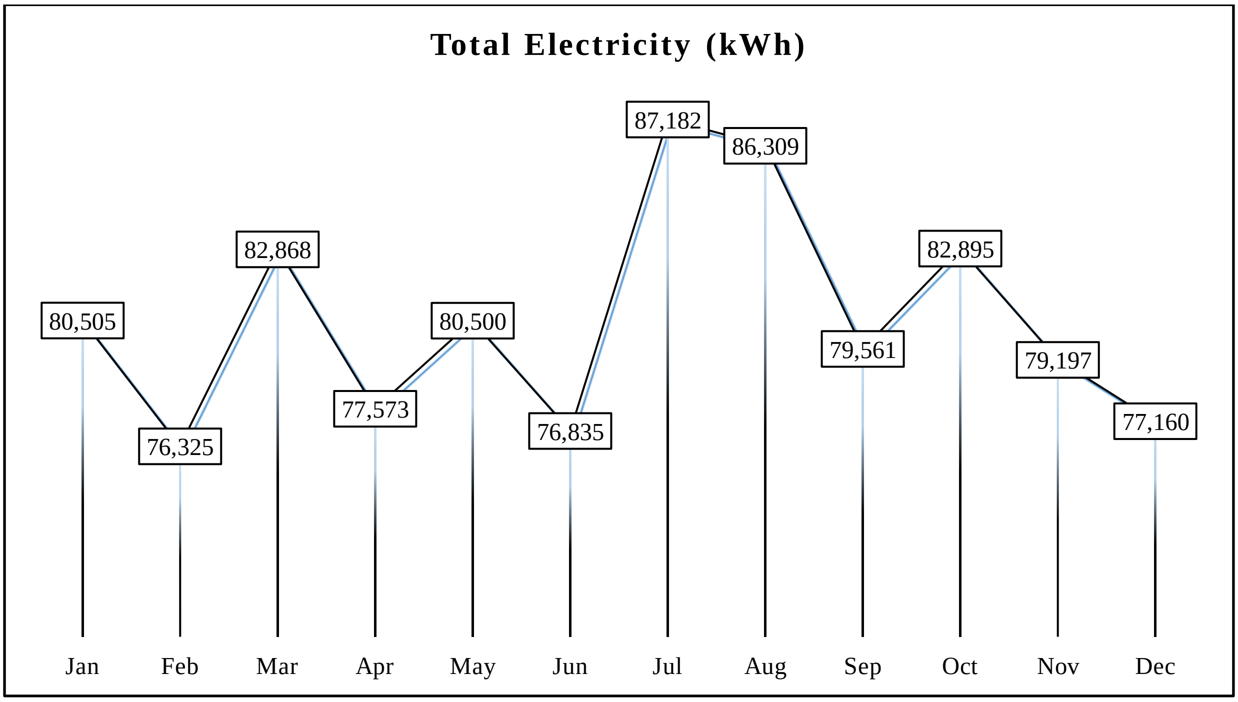

Figure 4.1: Electricity Consumption Trend for Year 2017

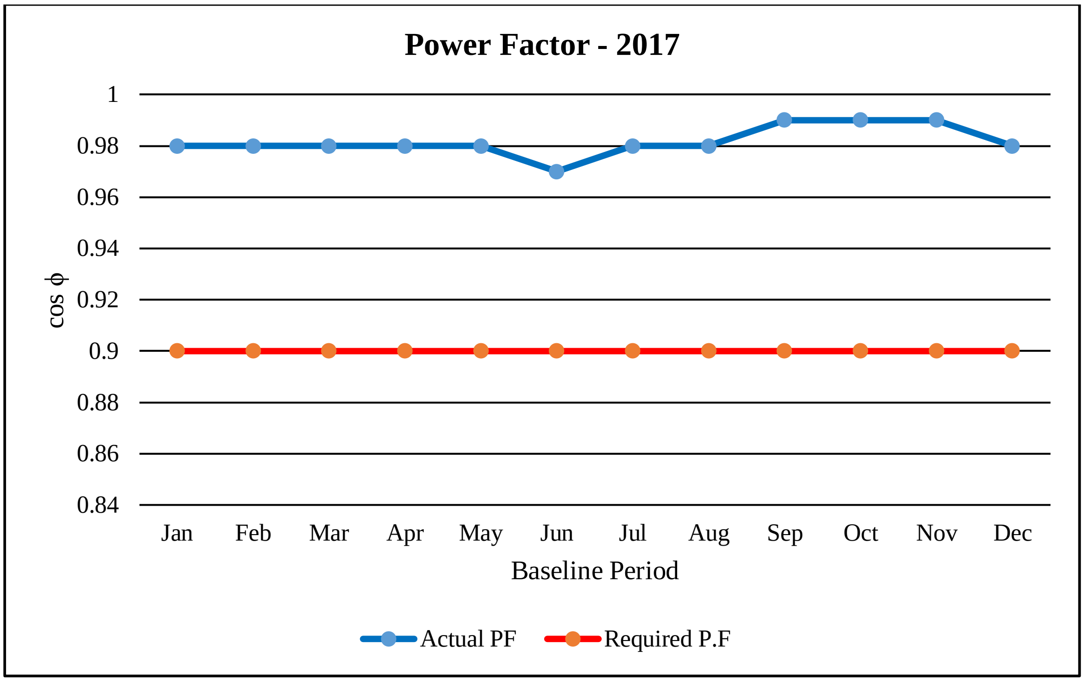

Figure 4.2: Power Factor Trend for Year 2017

Similar electricity bill analysis for the period between January 2018 and December 2019 was shown in Tables 4.5 and 4.6 and their subsequent electricity consumption trends and power factor characteristics represented in Figures 4.3 to 4.6. The average power factor of DFMH was 0.98. This factor was above the statutory requirement of 0.9 and within the allowed range by the energy regulators. This power factor was regarded as good power factor. The reason for the improved (good) PF could be attributed to the insertion of static capacitors for power factor correction purposes in the system as was recommended in a previous audit done in 2013. The average monthly total usage/consumptions for 2018 and 2019 were approximately 80,724 kWh and 79,297 kWh respectively as represented in Tables 4.5, 4.6 and Figures 4.3 and 4.5.

Table 4.5: Electricity Bill Analysis for Year 2018

Period (Months)	Total Usage (kWh)	Equivalent (GJ)	Demand (kVA)	Demand (kW)	PF	Electricity Cost (Kshs)	Unit Electricity Cost (Kshs)
Jan-18	80,545	290	232	229	0.98	1,609,381	19.98
Feb-18	74,744	269	228	225	0.99	1,580,475	21.15
Mar-18	82,793	298	241	238	0.99	1,797,181	21.71
Apr-18	78,369	282	237	234	0.99	1,754,307	22.39
May-18	77,160	278	239	236	0.99	1,615,601	20.94
Jun-18	76,835	277	238	232	0.97	1,397,049	18.18
Jul-18	91,288	329	261	257	0.98	1,937,797	21.23
Aug-18	90,317	325	244	241	0.99	1,811,788	20.06
Sep-18	83,012	299	236	233	0.99	1,669,286	20.11
Oct-18	84,187	303	240	237	0.99	1,696,137	20.15
Nov-18	76,126	274	229	226	0.99	1,550,116	20.36
Dec-18	73,319	264	216	214	0.99	1,669,286	22.77
Total	**968,695**	**3,487**	**2,841**	**2,802**	**11.84**	**20,088,404**	**249.01**
Average per month	**80,724.58**	**291**	**236.75**	**233.50**	**0.99**	**1,674,033.67**	**20.75**

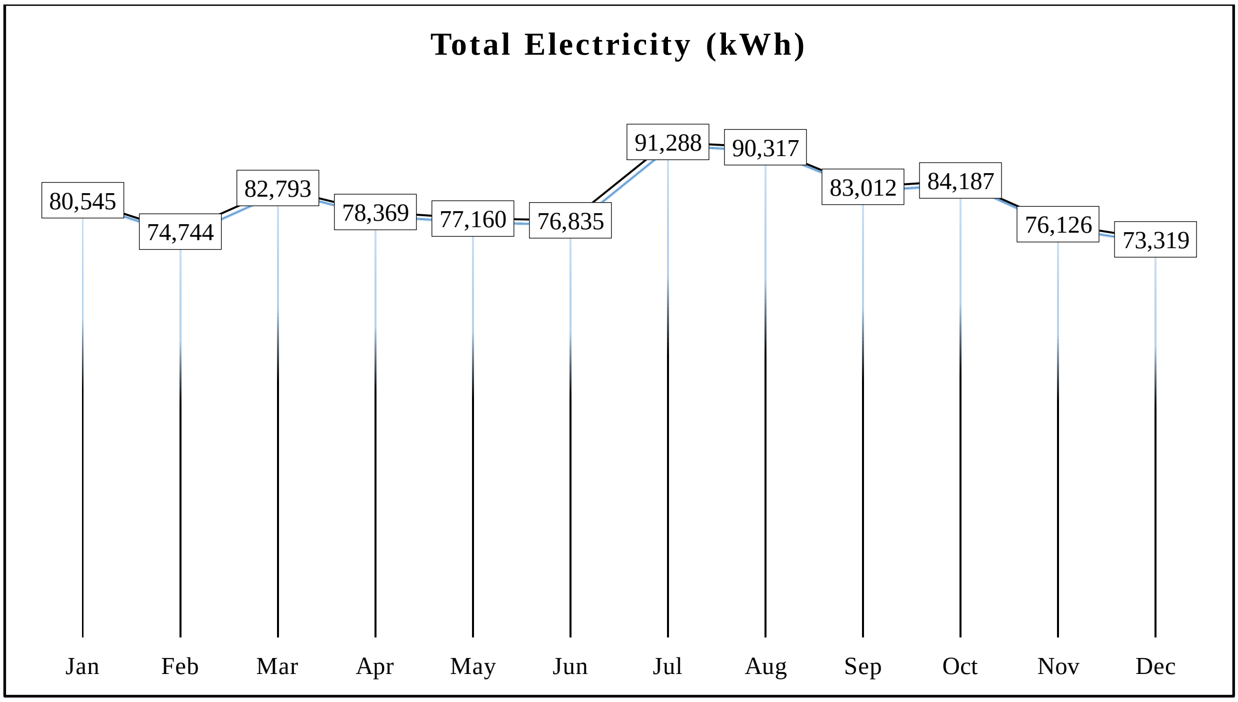

Figure 4.3: Electricity Consumption Trend for Year 2018

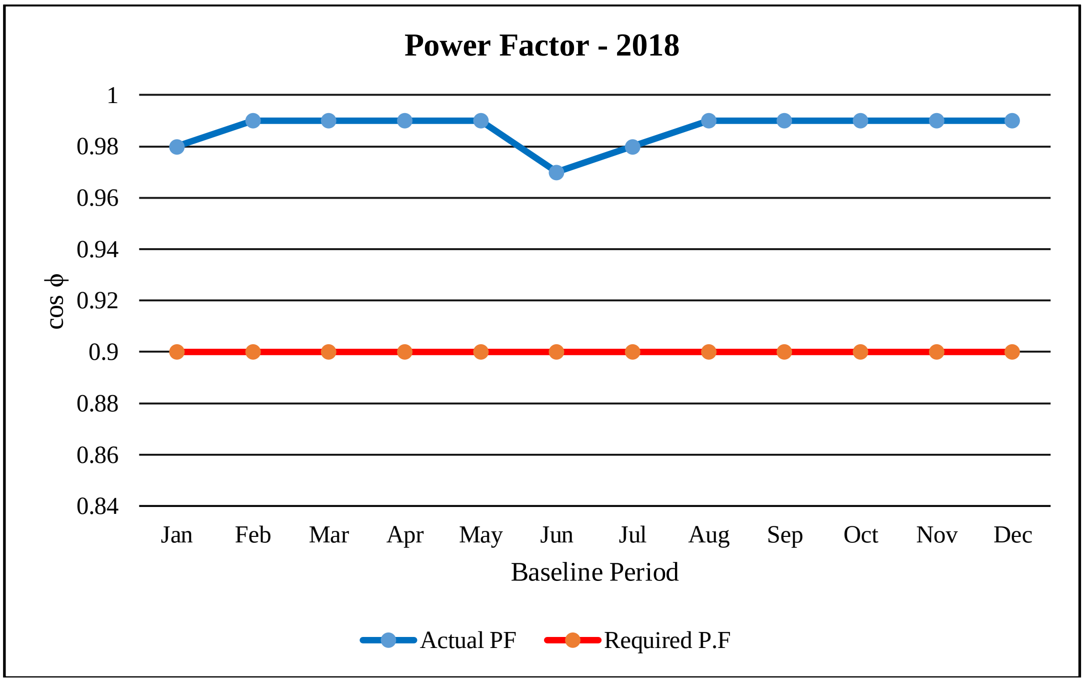

Figure 4.4: Power Factor Trend for Year 2018

Table 4.6: Electricity Bill Analysis for Year 2019

Period (Months)	Total Usage (kWh)	Equivalent (GJ)	Demand (kVA)	Demand (kW)	PF	Electricity Cost (Kshs)	Unit Electricity Cost (Kshs)
Jan-19	74,650	269	226	223	0.99	1,540,563	20.64
Feb-19	66,747	240	225	222	0.99	1,421,005	21.29
Mar-19	77,116	278	220	217	0.99	1,590,670	20.63
Apr-19	77,779	280	224	220	0.98	1,607,466	20.67
May-19	78,386	282	223	219	0.98	1,713,914	21.87
Jun-19	74,650	269	226	223	0.99	1,540,563	20.64
Jul-19	87,142	314	237	233	0.98	1,881,202	21.59
Aug-19	84,363	304	248	243	0.98	1,827,431	21.66
Sep-19	85,114	306	255	249	0.98	1,800,000	21.15
Oct-19	83,588	301	248	243	0.98	1,808,581	21.64
Nov-19	83,923	302	243	238	0.98	1,764,577	21.03
Dec-19	78,115	281	239	235	0.98	1,683,533	21.55
Total	**951,573**	**3,426**	**2,814**	**2,765**	**11.79**	**20,179,505**	**254.34**
Average per month	**79,297.75**	**285**	**234.50**	**230.42**	**0.98**	**1,681,625.42**	**21.19**

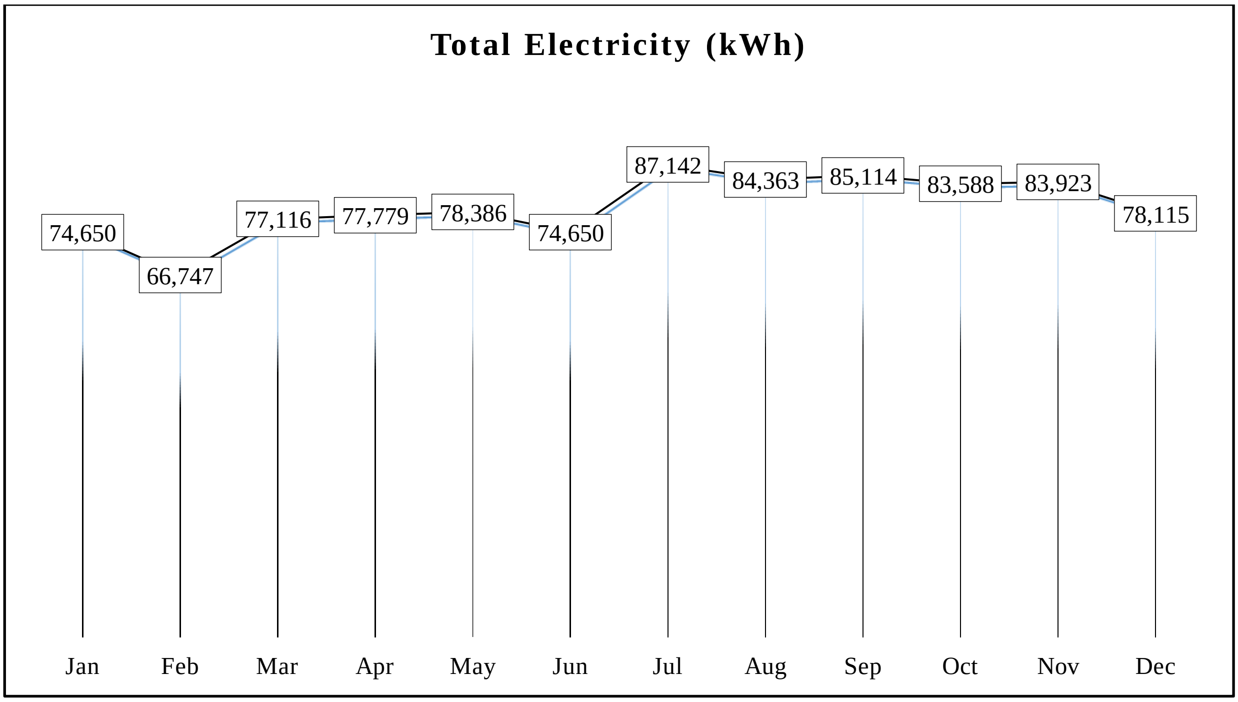

Figure 4.5: Electricity Consumption Trend for Year 2019

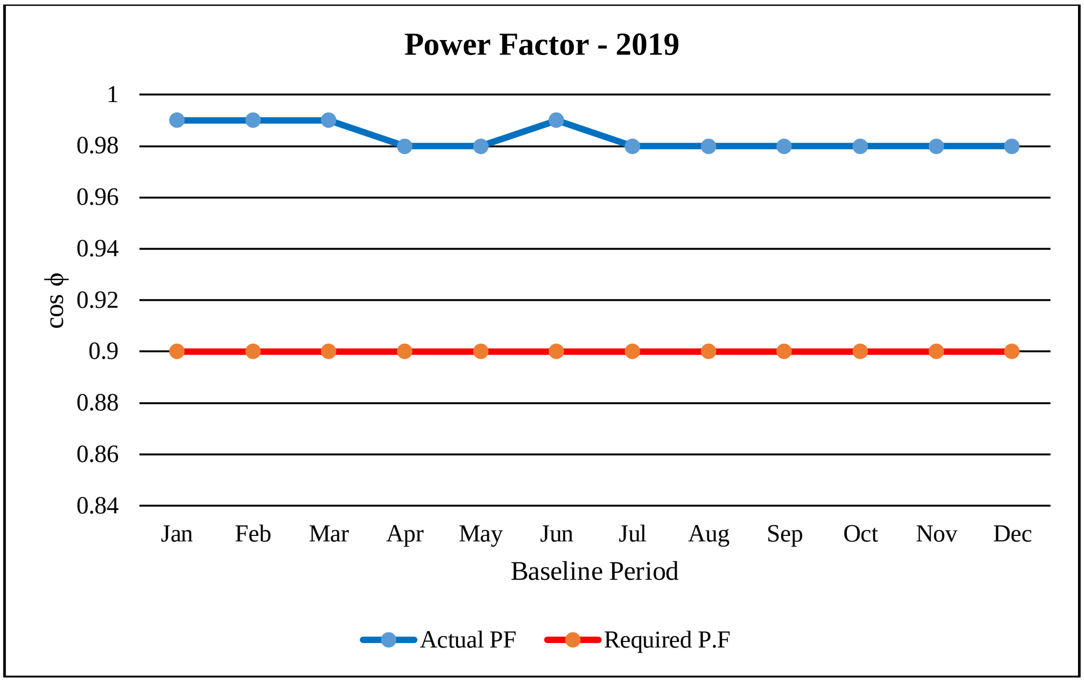

Figure 4.6: Power Factor Trend for Year 2019

Table 4.7 represented the summary of the electricity bill analysis for the years 2017 to 2019 and Figure 4.7 showed the respective electricity consumption trend for the same period.

Table 4.7: Electricity Bill Analysis Summary for Years 2017 to 2019

Month	Electricity Consumption (GJ) - 2017	Electricity Consumption (GJ) - 2018	Electricity Consumption (GJ) - 2019
January	290	290	269
February	275	269	240
March	298	298	278
April	279	282	280
May	290	278	282
June	277	277	269
July	314	329	314
August	311	325	304
September	286	299	306
October	298	303	301
November	285	274	302
December	278	264	281

February consistently remained as the the minimum electricity consuming month for the three year study with an average electricity consumption of 261.3 GJ and July as the highest electricity consuming month with an average consumption of 319 GJ. The difference (energy saving) between the highest and the lowest energy consumption levels represented an 18.1 % saving. Figure 4.7 represented the energy consumption characteristics between 2017 and 2019. The behavioural response of energy consumption for the period was almost the same, that was, a rise in consumption of electricity for a particular month was reflected in all the years and vice versa.

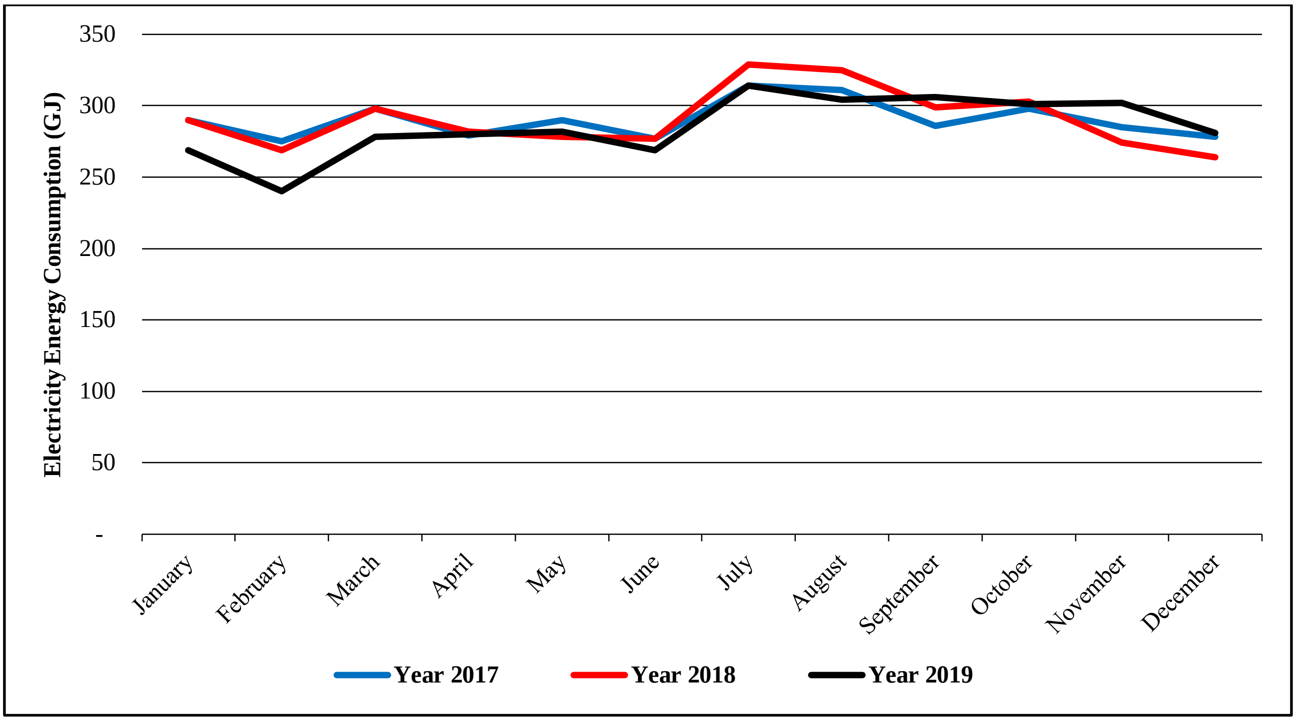

Figure 4.7: Electricity Bill Analysis for Years 2017 to 2019

In summary from the three-year electricity bills analysis, the following issues were noted:

a) The electricity consumption in 2017 ranged between 76,325 kWh to 87,182 kWh (i.e. 10,857 kWh range) and was more stable than in 2018 and 2019, which had 17,969 kWh and 20,395 kWh ranges, respectively.

b) The electricity bills (energy costs) in 2017 and 2018 were increasing progressively but there was a slight drop in 2019 which could be enhanced. This could be attributed to the tariff changes by the energy and petroleum regulatory authority implemented in October 2018 which reduced the total consumption cost from Ksh 21.85771 per kWh to Ksh 15.08171 per kWh a cost drop of approximately 30 %.

c) There was almost similar increase in consumption in February and June.

d) Peak energy consumption for the three years was in July. This could be attributed to the regular use of room heaters to manage the temperatures during the cold season of July. The hospital also recorded the highest occupancy of outpatients and inpatients in the same month.

4.1.2 Diesel as a Source of Energy

Diesel was another source of energy used at the Defence Forces Memorial Hospital. Table 4.8, 4.9 and 4.10 showed the consumption of diesel and its yearly costs in the boiler, generator and incinerator for the years 2017, 2018 and 2019.

Diesel consumptions for the three years (2017-2019) were analyzed using the following mathematical tools:

Diesel Energy Equivalent (Joules and Watt-hour) [14]

This is the diesel energy content in joules (J), kilo-joules (kJ), mega-joules (MJ) or giga-joules (GJ) and watt-hour (Wh), kilowatt-hour (kWh), megawatt-hour (MWh) or gigawatt-hour (GWh). They were determined by Equations 3.2 and 3.3.

For example, in August 2018, Diesel Usage in litres was 5710 litres, hence,

$$\text{Diesel Energy Equivalent (GJ) for August 2018} = \frac{5710 \times 39}{1000}$$

$$= 223\ GJ$$

Similarly, using Equation 3.3 the total diesel energy was determined as shown.

$$\text{Total Diesel Energy (kWh)} = \frac{223 \times 1000}{3.6}$$

$$= 61{,}858\ kWh$$

Table 4.8: Diesel Consumption for Year 2017

	Quantity (litres) in the Year 2017			
Date	**Boiler**	**Generator**	**Incinerator**	**Total**
January	3750	1100	400	**5250**
February	3750	300	350	**4400**
March	3750	1400	450	**5600**
April	3750	1380	600	**5730**
May	1900	520	350	**2770**
June	2200	350	350	**2900**
July	3300	-------	400	**3700**
August	3700	650	300	**4650**
September	3720	1000	300	**5020**
October	4030	800	400	**5230**
November	3600	500	600	**4700**
December	3720	1000	800	**5520**
	Cost of Diesel per litre - Kshs 78.70			

Table 4.9: Diesel Consumption for Year 2018

Date	Quantity (litres) in the Year 2018			
	Boiler	Generator	Incinerator	Total
January	4030	1100	450	**5580**
February	3640	600	310	**4550**
March	4030	1000	400	**5430**
April	4500	1300	350	**6150**
May	4600	1200	600	**6400**
June	4030	900	800	**5730**
July	4098	500	600	**5198**
August	3640	1470	600	**5710**
September	3360	800	600	**4760**
October	3500	700	800	**5000**
November	4500	900	600	**6000**
December	4500	500	300	**5300**
	Cost of Diesel per litre - Kshs 78.70			

Table 4.10: Diesel Consumption for Year 2019

Date	Quantity (litres) in the Year 2019			
	Boiler	Generator	Incinerator	Total
January	1000	500	310	**1810**
February	-------	800	350	**1150**
March	-------	400	400	**800**
April	-------	300	400	**700**
May	-------	400	450	**850**
June	-------	200	400	**600**
July	-------	800	400	**1200**
August	1700	1500	200	**3400**
September	-------	200	200	**400**
October	-------	800	350	**1150**
November	2400	400	500	**3300**
December	3000	1000	500	**4500**
	Cost of Diesel per litre - Kshs 99.80			

Using Equation 3.3, the diesel energy equivalent (GJ) for the thirty-six months' duration in consideration was done and indicated as shown in Tables 4.11, 4.12 and 4.13. The consumption trends for the three years under study were represented in Figures 4.8, 4.9 and 4.10.

Table 4.11: Diesel Consumption Analysis for Year 2017

Month	Usage (Litres)	Equivalent (GJ)	Equivalent (kWh)	Cost (Kshs)	Total Energy Cost (KSh)
January	5,250	205	56,875	78.70	413,175.00
February	4,400	172	47,667	78.70	346,280.00
March	5,600	218	60,667	78.70	440,720.00
April	5,730	223	62,075	78.70	450,951.00
May	2,770	108	30,008	78.70	217,999.00
June	2,900	113	31,417	78.70	228,230.00
July	3,700	144	40,083	78.70	291,190.00
August	4,650	181	50,375	78.70	365,955.00
September	4,120	161	44,633	78.70	324,244.00
October	5,230	204	56,658	78.70	411,601.00
November	4,700	183	50,917	78.70	369,890.00
December	5,520	215	59,800	78.70	434,424.00
Total	**54,570.00**	**2,128**	**591,175**	**944.40**	**4,294,659.00**
Average	**4,547.50**	**174**	**49,265**	**78.70**	**357,888.25**

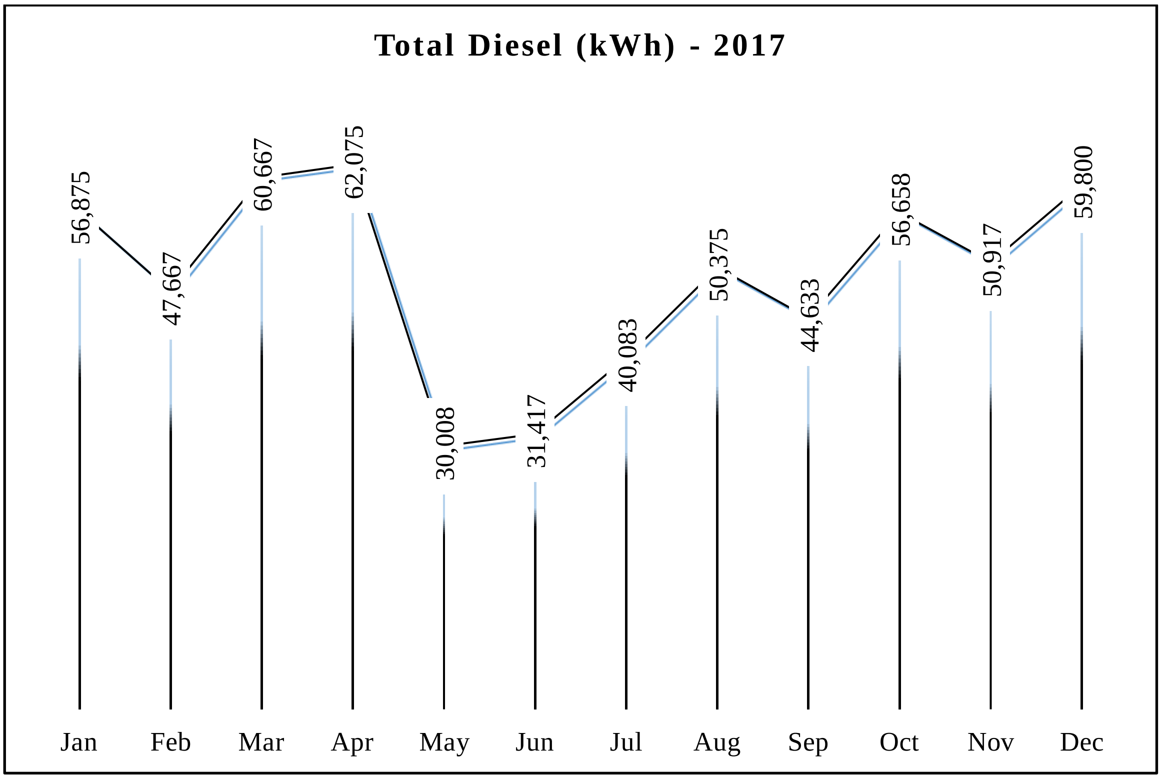

Figure 4.8: Diesel Consumption Trend for Year 2017

Table 4.12: Diesel Consumption Analysis for Year 2018

Month	Usage (Litres)	Equivalent (GJ)	Equivalent (kWh)	Cost (Kshs)	Total Energy Cost (KSh)
January	5,580	218	60,450	78.70	439,146.00
February	4,550	177	49,292	78.70	358,085.00
March	5,430	212	58,825	78.70	427,341.00
April	6,150	240	66,625	78.70	484,005.00
May	6,400	250	69,333	78.70	503,680.00
June	5,730	223	62,075	78.70	450,951.00
July	5,198	203	56,312	78.70	409,082.60
August	5,710	223	61,858	78.70	449,377.00
September	4,760	186	51,567	78.70	374,612.00
October	5,000	195	54,167	78.70	393,500.00
November	6,000	234	65,000	78.70	472,200.00
December	5,300	207	57,417	78.70	417,110.00
Total	**62,208**	**2,567**	**712,920**	**944.40**	**4,895,769.60**
Average	**5,184.00**	**215**	**59,410**	**78.70**	**407,980.80**

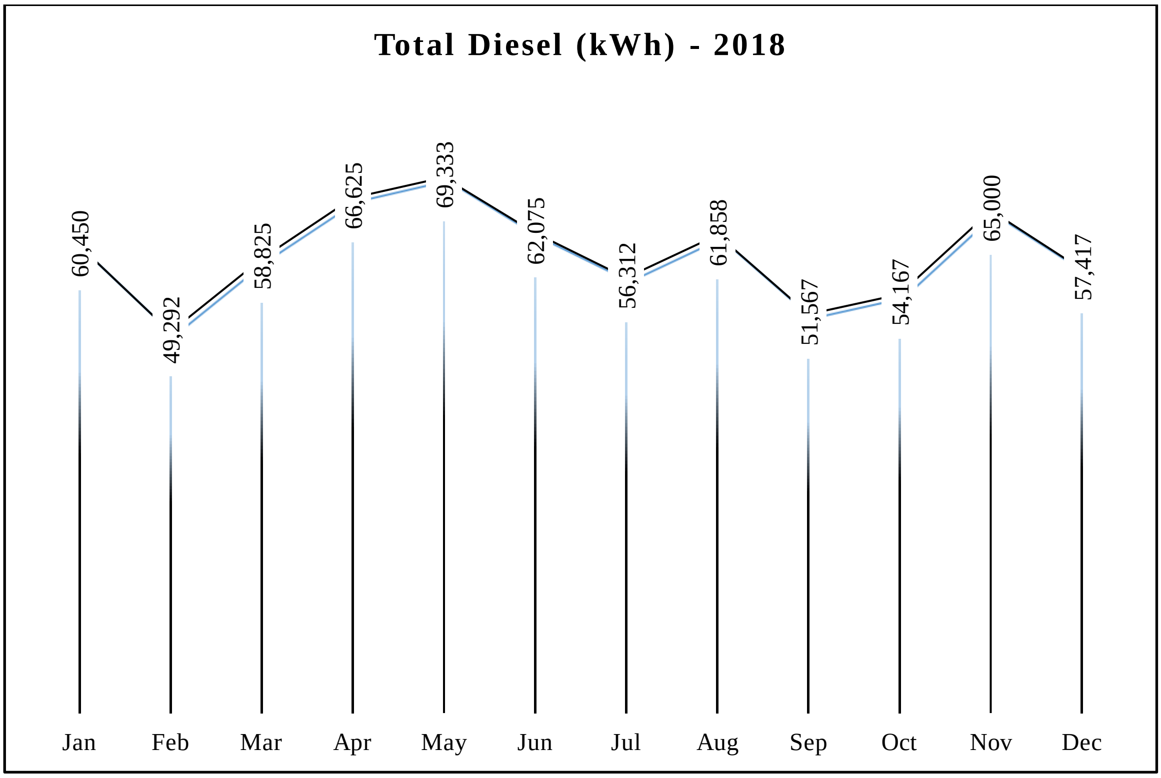

Figure 4.9: Diesel Consumption Trend for Year 2018

Table 4.13: Diesel Consumption Analysis for Year 2019

Month	Usage (Litres)	Equivalent (GJ)	Equivalent (kWh)	Cost (Kshs)	Total Energy Cost (KSh)
January	1,810	71	16,608	99.80	180,638.00
February	1,150	45	12,458	99.80	114,770.00
March	800	31	8,667	99.80	79,840.00
April	700	27	7,583	99.80	69,860.00
May	850	33	9,208	99.80	84,830.00
June	600	23	6,500	99.80	59,880.00
July	1,200	47	13,000	99.80	119,760.00
August	3,400	133	36,833	99.80	339,320.00
September	400	16	4,333	99.80	39,920.00
October	1,150	45	12,458	99.80	114,770.00
November	3,300	129	35,750	99.80	329,340.00
December	4,500	176	48,750	99.80	449,100.00
Total	**19,860**	**775**	**215,150**	**1,197.60**	**1,982,028.00**
Average	**1,655.00**	**54**	**17,929**	**99.80**	**165,169.00**

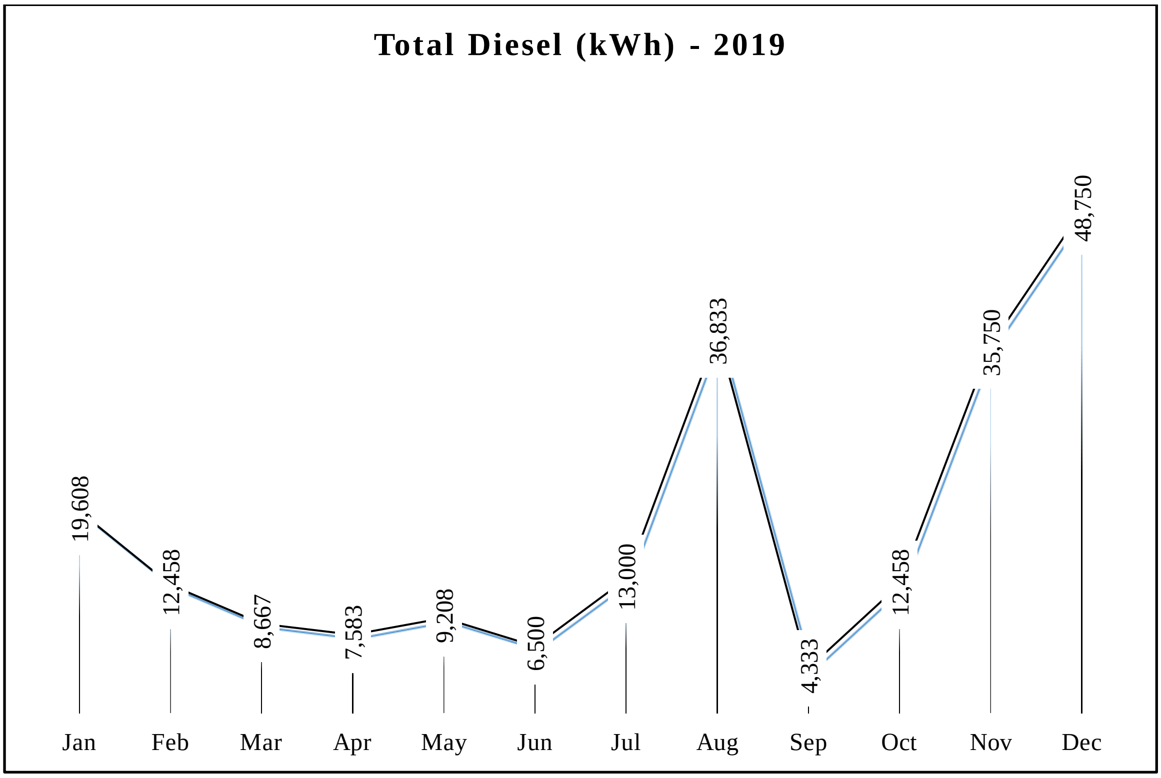

Figure 4.10: Diesel Consumption Trend for Year 2019

Table 4.14: Diesel Consumption Analysis Summary for Years 2017 to 2019

Month	Diesel Consumption (Litres) - 2017	Diesel Consumption (Litres) - 2018	Diesel Consumption (Litres) - 2019
January	5,250	5,580	1,810
February	4,400	4,550	1,150
March	5,600	5,430	800
April	5,730	6,150	700
May	2,770	6,400	850
June	2,900	5,730	600
July	3,700	5,198	1,200
August	4,650	5,710	3,400
September	5,020	4,760	400
October	5,230	5,000	1,150
November	4,700	6,000	3,300
December	5,520	5,300	4,500

From the three-year overall diesel consumption trend the monthly average amount of diesel consumption in 2017 and 2018 increased progressively from 4,547.5 litres to 5,484 litres, an increment of 936.5 litres. In 2019 the diesel consumption dropped significantly to an average monthly consumption of 1,655 litres which was a 69.8 % drop, this could be associated with the lack of diesel fuel supply due to the boiler breakdown in 2019 but resumed operation in November 2019. It was also noticeable that consumption of diesel for the boiler in November and December in 2019 was lower (2,400 L and 3,000 L respectively) compared to 2017 (3,600 L and 3,720 L) and 2018 (4,500 L) during the same period. This could be due to the preventive maintanance and servicing done to the boiler before its resumption to operation.

For the boiler, diesel generator and the incinerator for year 2017, 2018 and 2019. Figures 4.11 - 4.13 showed the representations of the diesel consumption trends.

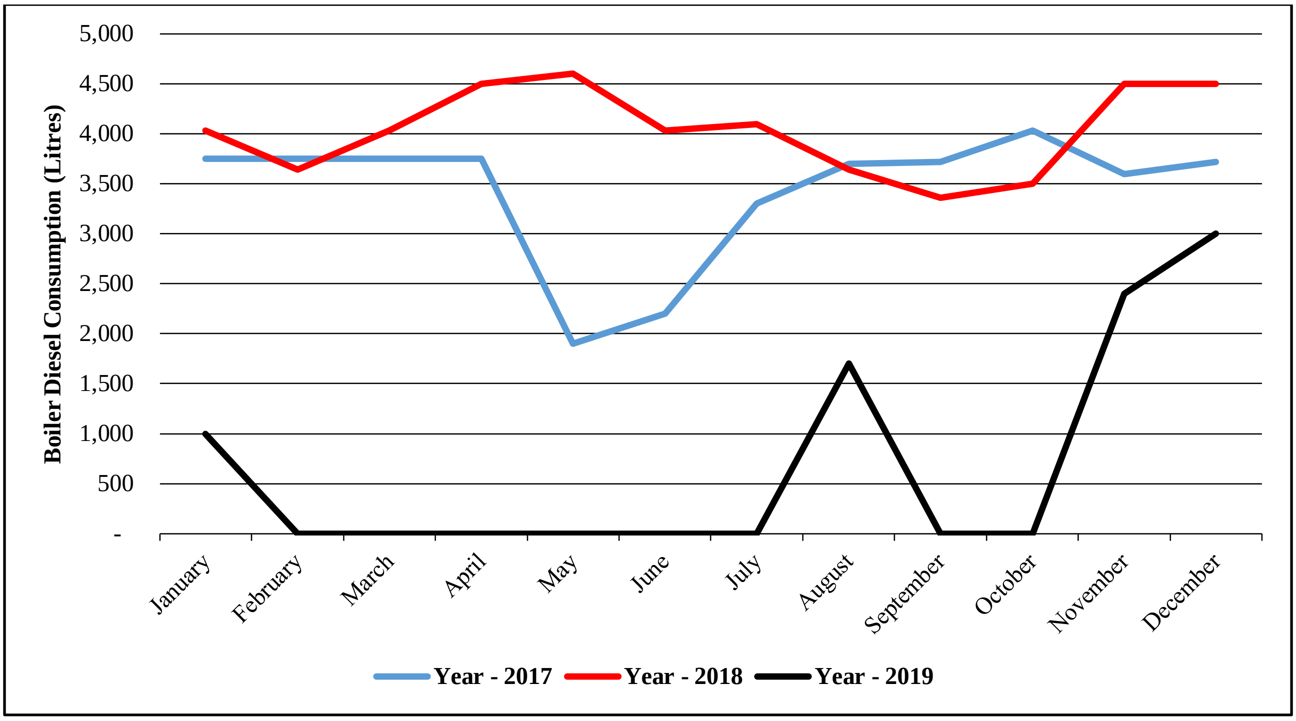

Figure 4.11: Boiler Diesel Consumption Analysis for Years 2017 to 2019

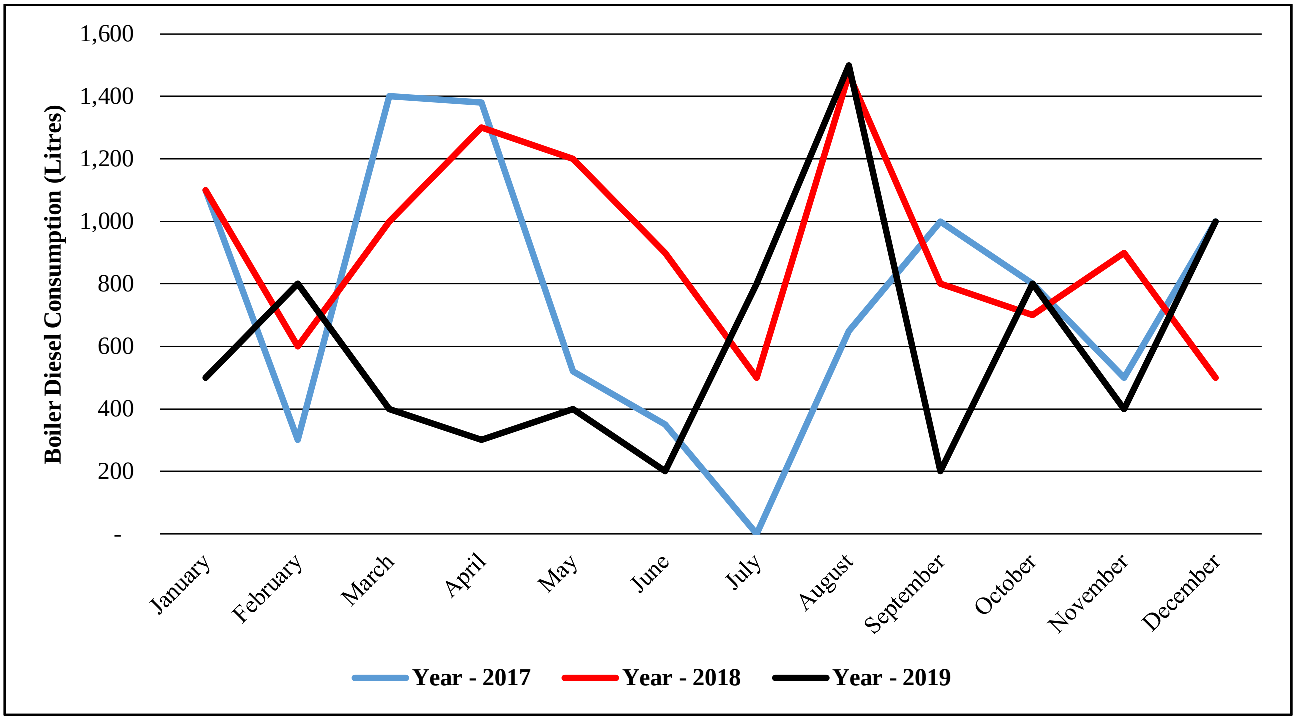

Figure 4.12: Generator Diesel Consumption Analysis for Years 2017 to 2019

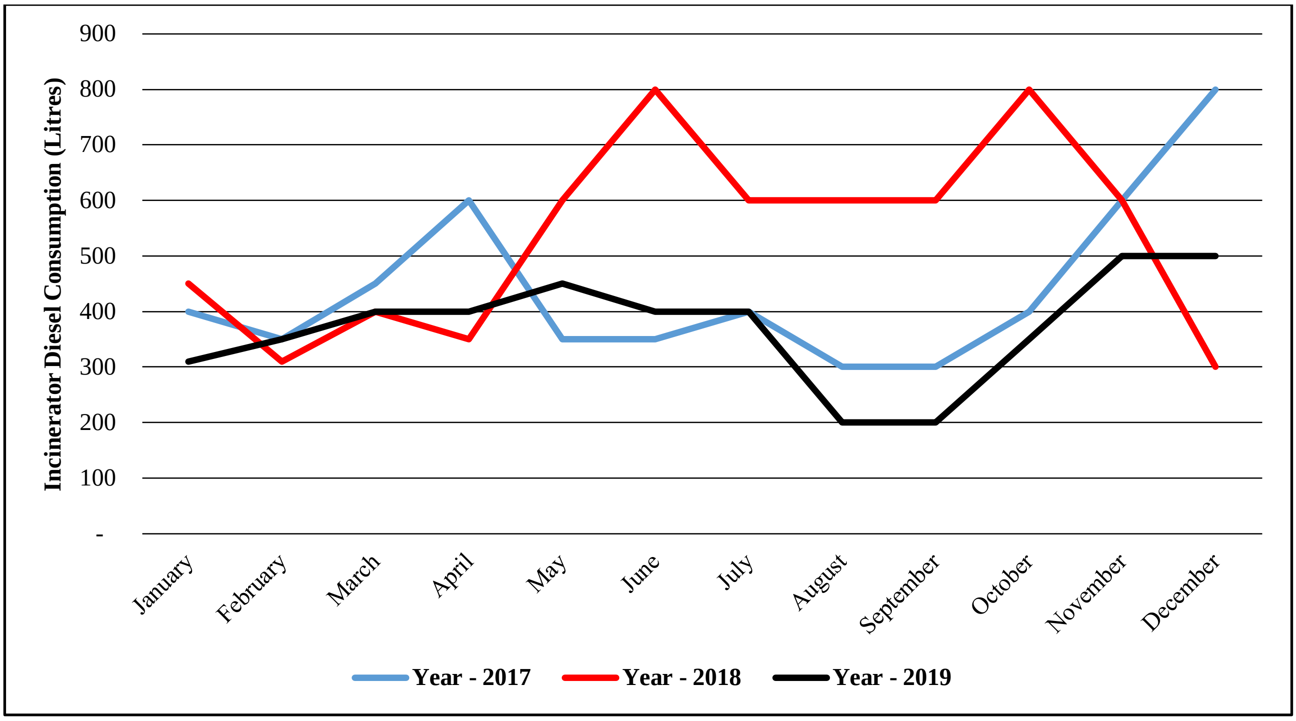

Figure 4.13: Incinerator Diesel Consumption Analysis for Years 2017 to 2019

4.1.3 LPG as a Source of Energy

LPG consumption for the facility showed a constant trend in each of the two kitchens of the DFMH, which included: the main hospital, Officers' mess and WOs/Sgts' mess. In summary, the monthly LPG consumptions for the two kitchens were as follows:

i) The main hospital kitchen consumed approximately 3000 kgs per month throughout the three-year period.

ii) The Officers' and WOs/Sgts' messes kitchens had a constant monthly consumption of 1000 kgs of LPG throughout the three-year period of study.

Therefore, the total monthly LPG consumption for DFMH was 4000 kgs throughout the three-year duration. The recommended LPG costs per kg in 2017, 2018 and 2019 were Kshs 92, Kshs 106 and Kshs 120 respectively and the average total energy costs for the same duration were Kshs 4,416,000, Kshs 5,088,000 and Kshs 5,760,000 respectively.

LPG Energy Equivalent (Joules and Watt-hour) [13]

This is the LPG energy content in joules (J), kilo-joules (kJ), mega-joules (MJ) or giga-joules (GJ) and watt-hour (Wh), kilowatt-hour (kWh), megawatt-hour (MWh) or gigawatt-hour (GWh). They were determined by Equations 3.4 and 3.5.

The LPG Usage in kgs was 48,000 kgs per year, hence, for the three years, the energy equivalent was calculated as,

$$Total\ LPG\ Energy\ (GJ) = \frac{Total\ LPG\ (kg) \times 45.65}{1000}$$

$$\text{Total LPG Energy (GJ)} = \frac{48000\ \times 3\ \times 45.65}{1000}$$

$$= 6{,}573.60\ GJ$$

$$Total\ LPG\ Energy\ (kWh) = \frac{Total\ LPG\ (GJ) \times 1000}{3.6}$$

$$\text{Total LPG Energy (kWh)} = \frac{6{,}573 \times 1000}{3.6}$$

$$= 1{,}825{,}833.33\ kWh$$

$$\text{Annual Total LPG Energy (kWh)} = \frac{1{,}825{,}833.33}{3}$$

$$= 608{,}611.11\ kWh\ per\ year$$

The LPG consumption did not vary with facility occupancy which was variable; this aspect caused interest in monitoring the actual utilization of the LPG. Possible energy conservation measures would be to regulate the gas pressure or to motivate the kitchen staff to switch off burners when cooking was done (behavioral aspect of energy management).

The LPG system had no gas consumption meters from the tanks to the kitchens to monitor the consumptions, but it had two gauges installed on each tank. The gauges were pressure gauge and percentage volume gauge.

The system needs to have LPG gas meters between the tanks and kitchens to monitor the consumptions of gas.

4.2 Preliminary Energy Assessment

During the preliminary assessment of the facility glaring energy conservation opportunities were identified by considering the nameplate specifications of individual accessories.

4.3 Lighting System

DFMH used eight types of lights and a total number of 1,013 lights as summarized in Table 4.15. A detailed information about all the lighting systems in the hospital was as shown in Appendix A1.

The nameplates gave limited information on the specifications of the lighting systems. In order to determine the rated necessary parameters for the lightings, further mathematical calculations were done.

Table 4.15: Lighting Systems Summary

Total Number of Lamps	
5ft Single Fluorescent tubes (58W)	60
4ft Single Fluorescent tubes (36W)	812
2ft Single Fluorescent tubes (18W)	46
4ft LED tubes (18W)	45
Energy Saver bulbs (7W)	26
Incandescent Bulb (60W)	6
Mercury Bulb (60W)	2
LED Floodlight (250W)	16
Total	**1,013**

4.3.1 Determination of Power consumption of lighting systems

The tools which were used for the analysis of the lighting systems were:

i) Power consumption Parameters of lighting systems

Power consumption for different lighting systems was determined using Equations 3.6 to 3.13.

Operating time was estimated to be twelve hours based on equal day equal night conditions in Kenya and the working schedule of the health facility.

Required lumens, number of lamps, energy saved, annual savings in Kenya shillings, capital investments and pay back period were calculated and tabulated as shown in Table 4.16 to enable in the determination of the appropriate possible ECOs.

For example:

Considering OPD department with a floor area of 200 m^2, 40 pieces of 4ft fluorescent tube operating for 24 hours a day and rated at 240 V, 36 W and 10 W choke rating, Equation 3.8 was used to determine the total power.

$$Total\ Power\ Rating\ = (light\ rating + choke\ rating) \times no.of\ lamps$$
$$= (36\ W + 10\ W) \times 40$$
$$= 1{,}840\ W$$

Equation 3.9 was used to determine the required lumens for the aforementioned OPD department as:

$$Required\ Lumens\ = required\ lux\ level\ \times area$$
$$= Lx_{rl}\ \times A_F$$
$$= 150\ \times 200$$
$$= 30{,}000\ lm$$

In order to determine the number of lamps required Equation 3.10 was applied.

$$No.of\ Lamps$$
$$= \frac{Required\ Lumens}{Lumen\ per\ fixture \times utilization\ factor \times lamp\ lumen\ depreciation}$$

$$= \frac{Lx_{rl}\ \times A_F}{Lm_{pf} \times UF \times LLD}$$
$$= \frac{150 \times 200}{1980 \times 0.85 \times 0.9}$$
$$= 20\ lamps$$

Similarly, to determine the energy saving, annual financial saving and capital investment Equations 3.11, 3.12 and 3.13 were used respectively.

$$Energy\ Saving\ \ = \ (Existing\ Total\ Rating - Total\ Rating\ of\ proposed\ lamps)\ \times$$
$$Number\ of\ hours$$
$$= \ (1840 - 356.51) \times 7200$$
$$= \ 10{,}681{,}128\ Wh$$
$$= \ 10{,}681.16\ kWh$$

$$Annual\ Financial\ Savings\ (Kshs) = 21.21 \times 10{,}681.16$$
$$= Kshs\ 226{,}547.30$$

$$Capital\ Investments\ (Kshs) = Total\ cost\ of\ fixtures$$
$$= cost\ of\ one\ fixture\ \times number\ of\ fixtures$$
$$= 1500\ \times 20$$
$$= Kshs\ 30{,}000$$

ii) Cost Benefit Analysis

The cost benefit analysis was determined using Equations 3.24 and 3.25 respetively.

For example:

Considering OPD department with a floor area of 200 m^2, 40 pieces of 4ft fluorescent tube operating for 24 hours a day and rated at 240 V, 36 W and 10 W choke rating:

$$Payback\ Period\ (PBP) = \frac{Capital\ Investment}{Annual\ Saving}$$

$$Payback\ Period\ (PBP) = \frac{30{,}000}{226{,}547.30}$$

$$= 0.131\ years$$

$$Return\ on\ Investment = \frac{Annual\ Financial\ Savings}{Total\ amount\ of\ investment} = \frac{1}{PBP}$$

$$Return\ on\ Investment\ (ROI) = \frac{1}{0.131}$$

$$= 7.63$$

It was noted that the facility continued to use discharge lamps especially fluorescent lamps despite being inductive loads and their power factor being low. Low PF increased reactive power hence making the facility to be surcharged by the utility company. Some disadvantages associated with fluorescent lighting were as follows: As fluorescent lights heat up more voltage was required to heat them up to operate, the mercury and phosphorus inside fluorescent bulbs is hazardous**,** frequent switching results in early failure, light is omni-directional (wastage), emit ultraviolet light (not eye friendly), audible humming (noise pollution) and disposal of fluorescent tubes pose an environmental threat due to their composition of phosphor and toxic mercury.

The optimization of lighting systems could lead to sizeable energy-efficiency improvements. There were many low-cost and no-cost measures available to reduce lighting costs resulting in significant savings.

An off-line excel calculator was developed to help in the determination of the various lighting system parameters as tabulated in Table 4.16. The table represents the technical and economic analysis of the DFMH facility considering independent units.

Table 4.16: Lighting Systems Analysis

Room/Area	Hours of Operation (hrs)	Area (m^2)	Rating of the Existing Lights (W)	Rating of Choke (W)	Existing number of Fixtures	Existing Light Lumens (lm)	Existing Rating of Lights (W)	Total Existing Rating of Lights (W)	Required Lux Levels (Lx)	Required Lumens (lm)
Elgon Ward	5400	442	58	10	1	5200	68.00	2,966.00	100	44200
	5400	442	36	10	63	3250	2,898.00	2,966.00	100	44200
Buna Ward	5400	277	58	10	8	5200	544.00	998.00	100	27700
	5400	277	36	10	5	3250	230.00	998.00	100	27700
	5400	277	18	10	8	1350	224.00	998.00	100	27700
Sorsbie Ward	5400	264	58	10	8	5200	544.00	830.00	100	26400
	5400	264	36	10	5	3250	230.00	830.00	100	26400
	5400	264	18	10	2	1350	56.00	830.00	100	26400
Malkaloni Ward	5400	270	58	10	8	5200	544.00	802.00	100	27000
	5400	270	36	10	5	3250	230.00	802.00	100	27000
	5400	270	18	10	1	1350	28.00	802.00	100	27000
Modogashi Ward	5400	277	58	10	8	5200	544.00	830.00	100	27700
	5400	277	36	10	5	3250	230.00	830.00	100	27700
	5400	277	18	10	2	1350	56.00	830.00	100	27700
Maternity Ward	7200	256	58	10	6	5200	408.00	814.00	100	25600
	7200	256	36	10	7	3250	322.00	814.00	100	25600
	7200	256	18	10	3	1350	84.00	814.00	100	25600
Newborn Unit Ward	7200	208	36	10	18	3250	828.00	828.00	100	20800

Table 4.16: Lighting Systems Analysis Contd...

Room/Area	Lumens of Proposed Lighting Fixtures (lm)	Rating per fixture (W)	New Number of Fixtures	Total Rating of Proposed Fixtures (W)	Projected Energy Savings (kWh)	Cost of Electricity Kshs/kWh)	Total Cost of Fixtures (Capital Investments) (Kshs)	Projected Annual Financial Savings (Kshs)	Payback Period (Years)	Return on Investment (ROI)
Elgon Ward	2420	22	24	525.25	13,180.04	21.21	42,975.21	279,548.57	0.154	6.505
	1980	18	30	525.25	13,180.04	21.21	35,016.84	279,548.57	0.125	7.983
Buna Ward	2420	22	15	329.17	3,611.66	21.21	26,932.43	76,603.31	0.352	2.844
	1980	18	19	329.17	3,611.66	21.21	21,944.94	76,603.31	0.286	3.491
	990	9	37	329.17	3,611.66	21.21	29,259.92	76,603.31	0.382	2.618
Sorsbie Ward	2420	22	15	313.73	2,787.88	21.21	21,390.37	59,130.98	0.362	2.764
	1980	18	18	313.73	2,787.88	21.21	26,143.79	59,130.98	0.442	2.262
	990	9	35	313.73	2,787.88	21.21	52,287.58	59,130.98	0.884	1.131
Malkaloni Ward	2420	22	15	320.86	2,598.18	21.21	21,876.52	55,107.39	0.397	2.519
	1980	18	18	320.86	2,598.18	21.21	26,737.97	55,107.39	0.485	2.061
	990	9	36	320.86	2,598.18	21.21	53,475.94	55,107.39	0.970	1.031
Modogashi Ward	2420	22	15	329.17	2,704.46	21.21	22,443.69	57,361.59	0.391	2.556
	1980	18	19	329.17	2,704.46	21.21	27,431.17	57,361.59	0.478	2.091
	990	9	37	329.17	2,704.46	21.21	54,862.35	57,361.59	0.956	1.046
Maternity Ward	2420	22	14	304.22	3,670.43	21.21	20,742.18	77,849.73	0.266	3.753
	1980	18	17	304.22	3,670.43	21.21	25,351.55	77,849.73	0.326	3.071
	990	9	34	304.22	3,670.43	21.21	50,703.11	77,849.73	0.651	1.535
Newborn Unit	1980	18	14	247.18	4,181.92	21.21	20,598.14	88,698.54	0.232	4.306

Table 4.16: Lighting Systems Analysis Contd...

Room/Area	Hours of Operation (hrs)	Area (m^2)	Rating of the Existing Lights (W)	Rating of Choke (W)	Existing number of Fixtures	Existing Light Lumens (lm)	Existing Rating of Lights (W)	Total Existing Rating of Lights (W)	Required Lux Levels (Lx)	Required Lumens (lm)
Inpatient Pharmacy	3600	20	36	10	3	3250	138.00	138.00	100	2000
Radiology Department	5400	564	36	10	73	3250	3,358.00	3,718.00	40	22560
	5400	564	60		6	800	360.00	3,718.00	40	22560
Physiotherapy Dept	3600	167	36	10	17	3250	782.00	782.00	40	6,680.00
MOPC Clinic Department	3600	90	36	10	10	3250	460.00	460.00	100	9,000.00
CCC Department	3600	132	58	10	5	5200	340.00	460.00	100	13,200.00
	3600	132	36	10	2	3250	92.00	460.00	100	13,200.00
	3600	132	18	10	1	1350	28.00	460.00	100	13,200.00
OPD Department	7200	200	36	10	40	3250	1,840.00	1,840.00	150	30,000.00
ICU Department	7200	215	36	10	18	3250	828.00	828.00	500	107,500.00
Renal Department	3600	138	36	10	3	3250	138.00	698.00	500	69,000.00
	3600	138	18	10	20	1350	560.00	698.00	500	69,000.00
Theatre Department	7200	178	36	10	56	3250	2,576.00	2,576.00	500	89,000.00
Laboratory Department	7200	170	36	10	41	3250	1,886.00	1,886.00	500	85,000.00
Outpatient Pharmacy	7200	63	36	10	5	3250	230.00	230.00	100	6,300.00
	3600	111	58	10	12	5200	816.00	1,000.00	100	11,100.00
New OPD Clinics	3600	111	36	10	4	3250	184.00	1,000.00	100	11,100.00
Dental Department	3600	78	36	10	17	3250	782.00	782.00	500	39,000.00
Drug Store Department	3600	297	36	10	24	3250	1,104.00	1,104.00	100	29,700.00

Table 4.16: Lighting Systems Analysis Contd...

Room/Area	Lumens of Proposed Lighting Fixtures (lm)	Rating per fixture (W)	New Number of Fixtures	Total Rating of Proposed Fixtures (W)	Projected Energy Savings (kWh)	Cost of Electricity Kshs/kWh)	Total Cost of Fixtures (Capital Investments) (Kshs)	Projected Annual Financial Savings (Kshs)	Payback Period (Years)	Return on Investment (ROI)
Inpatient Pharm	1980	18	2	23.77	411.24	21.21	1,980.59	8,722.37	0.227	4.404
Radiology Department	1980	18	15	268.09	18,629.50	21.21	22,341.06	395,131.68	0.057	17.686
	990	9	30	268.09	18,629.50	21.21	44,682.12	395,131.68	0.113	8.843
Physiotherapy	1980	18	5	79.38	2,529.42	21.21	6,615.17	53,649.10	0.123	8.110
MOPC Clinic	1980	18	6	106.95	1,270.97	21.21	8,912.66	26,957.34	0.331	3.025
CCC Department	2420	22	8	156.86	1,091.29	21.21	10,695.19	23,146.35	0.462	2.164
	1980	18	9	156.86	1,091.29	21.21	13,071.90	23,146.35	0.565	1.771
	990	9	18	156.86	1,091.29	21.21	26,143.79	23,146.35	1.129	0.885
OPD Dept	1980	18	20	356.51	10,681.16	21.21	29,708.85	226,547.30	0.131	7.626
ICU Department	1980	18	71	1,277.48	(3,236.26)	21.21	106,456.72	(68,641.10)	-1.551	-0.645
Renal Department	1980	18	46	819.96	(439.07)	21.21	68,330.36	(9,312.71)	-7.337	-0.136
	990	9	92	819.96	(439.07)	21.21	136,660.72	(9,312.71)	-14.675	-0.068
Theatre Dept	1980	18	59	1,057.64	10,932.23	21.21	88,136.26	231,872.53	0.380	2.631
Laboratory Dept	1980	18	57	1,010.10	6,306.47	21.21	84,175.08	133,760.29	0.629	1.589
Outpatient Pharm	1980	18	5	74.87	1,116.96	21.21	6,238.86	23,690.78	0.263	3.797
	2420	22	6	131.91	3,125.13	21.21	8,993.68	66,284.09	0.136	7.370
New OPD Clinics	1980	18	8	131.907308	3,125.13	21.21	10992.2757	66,284.09	0.166	6.030
Dental Dept	1980	18	26	463.46	1,146.75	21.21	38,621.51	24,322.58	1.588	0.630
Drug Store Dept	1980	18	20	352.94	2,703.81	21.21	29,411.76	57,347.85	0.513	1.950

Table 4.16: Lighting Systems Analysis Contd...

Room/Area	Hours of Operation (hrs)	Area (m^2)	Rating of the Existing Lights (W)	Rating of Choke (W)	Existing number of Fixtures	Existing Light Lumens (lm)	Existing Rating of Lights (W)	Total Existing Rating of Lights (W)	Required Lux Levels (Lx)	Required Lumens (lm)
Biomedical Department	3600	76	36	10	7	3250	322.00	322.00	100	7,600.00
Eye Unit Department	3600	24	36	10	4	3250	184.00	184.00	100	2,400.00
Farewell Home	7200	131	36	10	24	3250	1,104.00	1,132.00	100	13,100.00
	7200	131	18	10	1	1350	28.00	1,132.00	100	13,100.00
Officers' Mess	7200	395	36	10	23	3250	1,058.00	1,086.00	200	79,000.00
	7200	395	18	10	1	1350	28.00	1,086.00	200	79,000.00
WOs' & Sgts' Mess	5400	334	36	10	13	3250	598.00	598.00	200	66,800.00
WOs' & Sgts' Canteen	5400	93	36	10	2	3250	92.00	148.00	200	18,600.00
	5400	93	18	10	2	1350	56.00	148.00	200	18,600.00
Cpls' & ORS' Mess	5400	134	36	10	15	3250	690.00	690.00	200	26,800.00
Main Cook House	5400	144	36	10	12	3250	552.00	552.00	500	72,000.00
Church RC	7200	209	36	10	17	3250	782.00	782.00	300	62,700.00
Church AC	7200	330	36	10	17	3250	782.00	782.00	300	99,000.00
Mosque	7200	166	36	10	17	3250	782.00	782.00	300	49,800.00
DFMTS School	3600	112	36	10	36	3250	1,656.00	1,656.00	300	33,600.00
Camp Admin Wing	7200	140	36	10	14	3250	644.00	644.00	500	70,000.00
ORS Single Accom Blocks	5400	328	36	10	144	3250	6,624.00	6,960.00	300	98,400.00
	5400	328	18	10	12	1350	336.00	6,960.00	300	98,400.00

Table 4.16: Lighting Systems Analysis Contd...

Room/Area	Lumens of Proposed Lighting Fixtures (lm)	Rating per fixture (W)	New Number of Fixtures	Total Rating of Proposed Fixtures (W)	Projected Energy Savings (kWh)	Cost of Electricity Kshs/kWh)	Total Cost of Fixtures (Capital Investments) (Kshs)	Projected Annual Financial Savings (Kshs)	Payback Period (Years)	Return on Investment (ROI)
Biomedical	1980	18	6	90.31	834.07	21.21	7,526.24	17,690.55	0.425	2.351
Eye Unit Dept	1980	18	2	28.52	559.73	21.21	2,376.71	11,871.79	0.200	4.995
Farewell Home	1980	18	9	155.67	7,029.54	21.21	12,972.87	149,096.64	0.087	11.493
	990	9	18	155.67	7,029.54	21.21	25,945.73	149,096.64	0.174	5.746
Officers' Mess	1980	18	53	938.80	1,059.84	21.21	78,233.31	22,479.24	3.480	0.287
	990	9	105	938.80	1,059.84	21.21	156,466.63	22,479.24	6.960	0.144
WOs' & Sgts' Mess	1980	18	45	793.82	(1,057.43)	21.21	66,151.71	(22,428.11)	-2.949	-0.339
WOs' & Sgts' Canteen	1980	18	13	221.03	(394.38)	21.21	18,419.49	(8,364.86)	-2.202	-0.454
	990	9	25	221.03	(394.38)	21.21	36,838.98	(8,364.86)	-4.404	-0.227
Cpls' & ORS' Mess	1980	18	18	318.48	2,006.21	21.21	26,539.91	42,551.80	0.624	1.603
Main Cook House	1980	18	48	855.61	(1,639.52)	21.21	71,301.25	(34,774.24)	-2.050	-0.488
Church RC	1980	18	42	745.10	265.69	21.21	62,091.50	5,635.37	11.018	0.091
Church AC	1980	18	66	1,176.47	(2,840.19)	21.21	98,039.22	(60,240.39)	-1.627	-0.614
Mosque	1980	18	33	591.80	1,369.44	21.21	49,316.70	29,045.77	1.698	0.589
DFMTS School	1980	18	23	399.29	4,524.17	21.21	33,273.92	95,957.58	0.347	2.884
Camp Admin Wing	1980	18	47	831.85	(1,352.50)	21.21	69,320.66	(28,686.63)	-2.416	-0.414
ORS Single Accom Blocks	1980	18	65	1,169.34	31,269.56	21.21	97,445.04	663,227.40	0.147	6.806
	990	9	130	1,169.34	31,269.56	21.21	194,890.08	663,227.40	0.294	3.403

Table 4.16: Lighting Systems Analysis Contd...

Room/Area	Hours of Operation (hrs)	Area (m^2)	Rating of the Existing Lights (W)	Rating of Choke (W)	Existing number of Fixtures	Existing Light Lumens (lm)	Existing Rating of Lights (W)	Total Existing Rating of Lights (W)	Required Lux Levels (Lx)	Required Lumens (lm)
Laundry	3600	168	36	10	6	3250	276	360	300	50,400.00
	3600	168	18	10	3	1350	84	360	300	50,400.00
Security Lights	3600		58	10	14	5200	952.00	952.00	50	-
	3600		36	10	40	3250	1,840.00	1,840.00	50	-
	3600		60		2	800	120.00	120.00	50	-

Table 4.16: Lighting Systems Analysis Contd...

Room/Area	Lumens of Proposed Lighting Fixtures (lm)	Rating per fixture (W)	New Number of Fixtures	Total Rating of Proposed Fixtures (W)	Projected Energy Savings (kWh)	Cost of Electricity Kshs/kWh)	Total Cost of Fixtures (Capital Investments) (Kshs)	Projected Annual Financial Savings (Kshs)	Payback Period (Years)	Return on Investment (ROI)
Laundry	1980	18	34	598.930481	(860.15)	21.21	49,910.87344	(18,243.78)	-2.736	-0.366
	990	9	67	598.930481	(860.15)	21.21	99,821.74688	(18,243.78)	-5.472	-0.183
Security Lights	2420	22	14	308.00	2,318.40	21.21	21,000.00	49,173.26	0.427	2.342
	1980	18	40	720.00	4,032.00	21.21	60,000.00	85,518.72	0.702	1.425
	990	9	2	18.00	367.20	21.21	3,000.00	7,788.31	0.385	2.596
Total					**242,023.67**			**5,133,321.96**		

4.3.2 Discussions

In order to achieve easy derivation of various necessary parameters, an off-line excel calculator was developed to help in the determination of the inserted parameters like Required Lumens, Number of fixtures, Projected Energy Saving, Projected Annual Financial Saving, Payback Period and Return on Investment as tabulated in Table 4.16.

4.3.3 Suggested ECOs for Lighting Systems

During the walk through survey on lighting systems several energy conservation opportunities were identified and outlined below:

i) Minimize Use of Artificial Lighting Sources

This could be achieved by:

- Improving Natural Day Lighting Through Building Design or Retrofitting. For instance, optimizing the size of the windows.
- Using lighter colors for ceilings, walls, floors and furniture so that the light is reflected more effectively within the space.
- Rearranging rooms to achieve the most effective lighting conditions.
- Skylighting windows, roofing sheet for natural lighting and improving the energy efficiency in lighting systems.

The lighting systems accounted for a sizeable energy costs in the building audited. Optimum use of natural sunlight would therefore save the facility on their energy expenses. The optimum use of daylight would help reduce the need for electric lighting during the day hence save on energy cost. The lighting systems which were identified to operate for 24 hours included nurse stations, high dependency units, intensive care units and theatre rooms. The reason for their dependence on lighting through out the clock was due to their sensitivity and the nature of operations taking place in them which was considered as delicate and crucial. Similarly, facilities like the general wards, some staff offices and the catering unit were identified as possible 12 hour operators.

ii) Replacing T-12 Tubes with T-8 Tubes

T-12 lamps have high maintenance and energy costs due to high-energy consumption, poor efficiency, low lamp life, high lumen depreciation and poor color rendering index. Replacing them with T-8 tubes averagely doubles the efficiency hence saving on energy input.

iii) Replacing Magnetic Ballasts with Electronic Ballasts

Ballasts regulate the amount of electricity required to start a lighting fixture and maintain a steady light output. Electronic ballasts save 12 - 25 % of electricity use compared to magnetic ballast. Additionally, T8 lights with electronic ballasts use between 32 % and 40 % less electricity than T12 lights fitted with electromagnetic ballasts.

iv) Replacing Compact Fluorescent Lamps (CFLs) with LED Lamps.

Use of Light Emitting Diode (LED) bulbs offer significant prospects for progress, especially for smart control. LED bulbs are a sustainable alternative solution to achieve energy savings objectives in residential, service sector buildings, or infrastructure units. They provide great energy efficiency, have a long lifetime, possess excellent color rendering, are environmentally friendly and have smart management capability.

v) Install Motion Sensitive Light Switches.

Lighting controls provide users with the desired convenience and flexibility levels while supporting active energy savings and cost reduction by switching lights off when not needed.

These controls include:

Timers to turn off lights after a certain period has elapsed. These are suitable in areas where the typical time spent on an activity is well defined.

Occupancy and motion sensors. These sensors detect movement hence determine when a space is unoccupied in order to turn off lights. They are well suited in places where time spent on an activity is undefined.

Programmable clocks for use to controlling the switching of lights either on or off at preset times.

The use of wireless remote control systems and devices for simple and economical retrofitting of existing applications.

According to previous researches the payback period for lighting control systems is averagely less than two years [15]. Many lighting efficiency opportunities, such as turning lights off manually or automatically when not needed, can also be implemented without any capital outlay or redesigning of lighting systems.

Besides energy and cost savings, retrofitting lighting systems also come with other benefits like lower maintenance costs and increase opportunities to make adjustments based on needs. Additionally, they eradicate the frequency beat and flickering normally associated with migraine and eyestrain thus improve visual comfort and improve color rendering.

vi) Embrace energy saving culture

This is a behavioral method of managing energy i.e. encourage all people using the facility to switch off lights when not in use.

4.4 Water Heating System and Incinerator

4.4.1 Boiler System

The hospital had a fire tube hot water boiler which was used to heat water for bathing in the wards. Its specifications were as shown in Table 4.17. The boiler system took in approximately 5000 litres of water daily and heated it from room temperature of 20 ^{0}C to 55 ^{0}C at 4 psi in 4 hours. More water was recycled within the system to maintain it at a desired temperature of application. Water left boiler reservoir to utility point at 55 ^{0}C and 4 psi, and returned at approximately 30 ^{0}C.

The burner motor which operated the fuel pump that helped the nozzles to atomise the fuel, used electrical energy and it ran as long as the boiler was on as well as the boiler feed water pump. The hot water from the calorifier was also boosted by a pump which also used electrical energy. It ran for only 20 minutes during the 4 hours operation of the boiler. Diesel was burnt during combustion in the boiler to provide heat energy for heating the water.

Water transport lines of about 37 feet were partially lagged and lost heat energy on the exposed portions of the line. The boiler ran for about 4 hours daily and two blowdowns were done per day. Feed water also coming to the boiler was not dosed.

Table 4.17: Boiler Specifications.

Boiler Type	Model	Boiler Description	Output (Btus/hr)	Max Working Pressure (Psi)	Burner Motor Rating (Hp)	Boiler Feed Water Pump Rating (Hp)	Calorifier Ciculation Pump Rating (Hp)	Electrical Supply	Feed Water Temperature (^{0}C)
Fire Tube Boiler	Nu-Way	Hot Water boiler	1,250,000	300	1	2	5.5	415V/50Hz	20

4.4.1.1 Determination of Rated Power Consumption for Boiler

From preliminary information obtained from the machine nameplates the following parameters were determined by mathematical analysis:

The rated power consumptions of the burner motor and calorifier ciculation pump were calculated using Equation 3.7.

Thus;

For the burner motor rated at 415V, 1 hp and running for 4 hrs per day

$$Power\ consumed = power\ rating\ \times operational\ time$$

$$= 1 \times 0.7457 \times 4 = 2.9828\ kWh\ per\ day$$

The power consumptions were done and indicated in Table 4.18.

4.4.1.2 Determination of Energy Required to Heat Water in the Boiler

This was determined using Equations 3.14 and 3.15 as shown below.

$$Volume\ of\ hot\ water\ requirements\ = 5000\ Litres/4\ hours$$

$$= \frac{5000\ Litres}{4 \times 60 \times 60} = 0.3472\ L/s$$

$$= 0.0003472\ m^3/s$$

$$Mass\ of\ hot\ water\ required\ = density\ of\ hot\ water\ \times volume\ of\ hot\ water$$

$$= 1000 \times 0.0003472$$

$$= 0.3472\ kg/s$$

$$To\ raise\ water\ temperature\ from\ 20\ ^0C\ to\ 55\ ^0C, Heat\ Energy\ required$$

$$= 0.3472 \times 4.2 \times (55 - 20)$$

$$= 51.04\ kJ/s$$

From the three-year boiler diesel consumption trend the amount of diesel consumption in 2017 and 2018 had increased progressively from 41,170 litres to 44,828 litres, an increment of 3,658 litres, which was about 8.9 % increase. Between

2018 and 2019, a drastic drop on annual consumption was realized with a drop of 36,728 litres of diesel which was an 81.9 % drop. This was associated with the lack of diesel fuel supply in 2019 but resumed operation in November 2019.

Table 4.18: Boiler Systems Analysis.

Boiler Type	Model	Boiler Description	Output (Btus/hr)	Max Working Pressure (Psi)	Burner Motor (kWh per day)	Boiler Feed Water Pump Motor (kWh per day)	Calorifier Ciculation Pump (kWh per day)	Electrical Supply	Feed Water Temp (^{0}C)
Fire Tube Boiler	Nu-Way	Hot Water boiler	1,250,000	300	2.9828	5.9656	1.3671	415V/50Hz	20

4.4.1.3 Discussions

The boiler output was 1,250,000 Btu/hr which was 366.34 kJ/s. Its current consumption for heating water was 51.04 kJ/s, an indication that the boiler was being under utilized. The boiler electrical energy consumption was 10.32 kWh per day.

4.4.1.4 Suggested ECOs for the Boiler

The following measures were identified as possible energy conservation opportunities:

i. The boiler feed water should be dosed to reduce formation of scales and sludge.
ii. Consider exclusive solar water heating system with boiler system as a back-up.
iii. Number of blowdowns should be reduced to minimize heat loss.
iv. All hot water lines should be lagged to maintain the heated water temperatures high for longer.

4.4.2 Instant Showers

DFMH used two types of instant showers and had a total number of 82 instant showers as summarized in Table 4.19. A detailed information about all the instant showers in the hospital was as shown in Appendix A2.

The nameplates gave limited information on the specifications of the instant showers. In order to determine the rated necessary parameters for the instant showers further mathematical calculations were done.

Table 4.19: Instant Showers Summary

Total Number of Instant Showers	
Lorenzetti (4600-5500 W)	75
Horizon (5400 W)	7
Total	**82**

4.4.2.1 Determination of Power consumption for the Instant Showers

The tools which were used for the analysis of the instant showers were:

i) **Power consumption Parameters of Instant Showers**

Power consumption for instant showers was determined using Equation 3.7 as shown below.

Total operating time for all the instant showers per day was 123 hours. For 82 instant showers, each will operate for 1.5 hours per day on average.

Power Consumption of the Instant Showers

$$Power\ consumed = power\ rating \times operational\ time \times no.of\ showers$$

For Lorenzetti (4600-5500 W) ≈ 5050 W, number of instant showers was 75.

$$Power\ consumed = 5050 \times 1.5 \times 75$$
$$= 568.13\ kWh$$

For Horizon (5400 W), number of instant showers was 7.

$$Power\ consumed = 5400 \times 1.5 \times 7$$
$$= 56.70\ kWh$$

Therefore,

$$Total\ Power\ consumed = 568.125 + 56.70$$
$$= 624.83\ kWh\ per\ day$$
$$= 187{,}447.5\ kWh\ per\ year$$

Cost of this energy from the utility company (KPLC) would be:

$$Cost\ of\ energy = 187{,}447.5 \times 21.206$$
$$= Kshs\ 3{,}975{,}011.70 \text{ per year}$$

4.4.2.2 Determination of Diesel Energy Equivalence, Cost and Savings

Diesel energy equivalence for the energy consumed by instant showers was determined using Equations 3.2 and 3.3 as shown below.

$$Total\ Diesel\ Energy\ (kWh) = \frac{Total\ Diesel\ (GJ) \times 1000}{3.6}$$

Therefore;

$$Total\ Diesel\ Energy\ (GJ) = \frac{Total\ Diesel\ (kWh) \times 3.6}{1000}$$

$$Total\ Diesel\ Energy\ (GJ) = \frac{187{,}447.5\ \times 3.6}{1000}$$

$$= 674.81\ GJ\ per\ year$$

$$Total\ Diesel\ Energy\ (GJ) = \frac{Total\ Diesel\ (Litres) \times 39}{1000}$$

Therefore;

$$Total\ Diesel\ Energy\ (Litres) = \frac{Total\ Diesel\ (GJ) \times 1000}{39}$$

$$Total\ Diesel\ Energy\ (Litres) = \frac{674.81 \times 1000}{39}$$

$$= 17{,}302.82\ litres\ per\ year$$

$$Cost\ of\ Diesel\ energy = 17{,}302.82 \times 99.80$$

$$= Kshs\ 1{,}726{,}821.44 \text{ per year}$$

If diesel was to be used to produce the same energy which the instant showers consumed to heat water, then there would be savings in terms of energy consumption costs.

$$Savings\ in\ energy\ cost = Kshs\ (3{,}975{,}011.70 - 1{,}726{,}821.44)$$

$$= Kshs\ 2{,}248{,}190.26 \text{ per year}$$

4.4.2.3 Modification of the Boiler Piping System to replace Instant Showers

This would involve installation of the hot water piping systems and all the necessary accessories from the boiler to all the areas which required hot water within the facility. This would be at an estimated cost of Kshs 5,500,000 as the capital investment.

Hence the cost benefit analysis was done using Equations 3.24 and 3.25 respectively as follows;

$$Payback\ Period\ (PBP) = \frac{Capital\ Investment}{Annual\ Financial\ Saving}$$

$$Payback\ Period\ (PBP) = \frac{5{,}500{,}000.00}{2{,}248{,}190.26}$$

$$Payback\ Period\ (PBP) = 2.45\ years$$

$$Return\ on\ Investment = \frac{Annual\ Financial\ Savings}{Total\ amount\ of\ investment} = \frac{1}{PBP}$$

$$Return\ on\ Investment\ (ROI) = \frac{1}{2.45}$$

$$= 0.408$$

Power consumptions were calculated and tabulated as shown in Table 4.20 to enable in the determination of the appropriate possible ECOs.

Table 4.20: Instant Showers Analysis

No.	Instant Shower Model	Quantity	Voltage (V)	Current (A)	Rating (kW)	Frequency (Hz)	Operating Hours per day	kWh per day
1.	Lorenzetti	75	220-240	20.9-22.8	4.6-5.5	50/60	1.5	568.13
2.	Horizon	7	240	30	5.4	50	1.5	56.70
	Total							**624.83**

4.4.2.4 Discussions

Total power consumption of the instant showers in a year was 187,447.5 kWh, which translated to Kshs 3,975,011.70 per year. This same energy could be provided by use of diesel fuel in the boiler at a cost of Kshs 1,726,821.44 per year, resulting into a saving of Kshs 2,248,190.26.

Modifying the boiler piping systems so as to be able to provide the required hot water would cost Kshs 5,500,000 being the investment capital. This would result to a pay back period of 2 years 6 months and a return on investment of 0.408.

4.4.2.5 ECOs for Instant Showers

Eliminate completely the showers and use hot water from the boiler by modifying the boiler piping systems so as to be able to provide the required hot water for bathing in the bathrooms.

4.4.3 Incinerator System

Waste heat refers to release of fluid streams from a system at temperatures above ambient. Waste heat recovery aims at recovering part of this energy from process fluid streams and reused within the process with an aim of improving proces efficiency. The hospital had an incinerator which was used to burn all medical wastes in the hospital. The incinerator system had three components; Primary burner rated 0.25 kW, Secondary burner rated 0.125 kW and blower rated 3.7 kW as shown in the Table 4.21.

Electrical energy was used to run the blower and the burners' fuel pumps. Diesel was burnt during combustion in the incinerator to produce fire to burn waste hospital products.

Table 4.21: Incinerator Specifications

No.	Equipment Name	Model	Voltage (V)	Current (A)	Rating (kW)	Frequency (Hz)
1.	Primary Burner	Bentone	220-240	1.7	0.25	50
2.	Secondary Burner	Hanning	230	0.95	0.125	50
3.	Blower	Locally assembled	220-240/380-415	12.9/7.4	3.7	50

The quantity of diesel consumed annually in 2017, 2018 and 2019 was 5,300, 6,410 and 4,460 litres respectively despite the constant waste loading and same operating hours. This was an indicator that there was a wastage in the fuel consumption of the incinerator.

The incinerator had a burning rate of 75 kg of waste per hour and burned for three hours per day on average and in six days of a week. The burner was electrically fired and diesel was used as fuel. The incinerator was well insulated and used electric heaters and diesel fuel to burn medical waste. It burned 5,390 liters of diesel annually with a stack temperature of 600 ^{0}C.

The medical waste being burnt was not normally weighed before burning.

Waste heat recoverable from the incinerator could be used to heat the facility’s hot water demand, providing a potential energy saving for the organisation. This would reduce the diesel usage in the hot water boiler thus costs.

4.4.3.1 Determination of Rated PF and Rated Power Consumption for Incinerator

The power factor and power consumption of the incinerator equipment were determined by Equations 3.6 and 3.7 based on the preliminary information obtained from the incinerator. Therefore,

For the Primary burner rated at 240 V, 1.7 A and 0.25 kW

$$Power\ Factor\ (pf) = \frac{P}{VI}$$

$$= \frac{250}{240 \times 1.7} = 0.61$$

$$Power\ consumption = power\ rating \times operational\ time$$

$$= 0.25\ kW \times 3\ hrs = 0.75\ kWh\ per\ day$$

4.4.3.2 Waste Heat Energy

This was determined by use of Equations 3.16 and 3.17 as shown below:

$$Waste\ Heat\ Energy$$

$$= mass\ flow\ rate\ of\ flue\ gas$$

$$\times\ specific\ heat\ capacity\ of\ flue\ gas$$

$$\times\ temperature\ drop\ of\ flue\ gas$$

$$= \dot{m}_f \times c_f \times (T_{in} - T_{out})$$

$$Mass\ flow\ rate\ of\ flue\ gas =$$

$$density\ of\ flue\ gas \times chimney\ cross\ sectional\ area \times velocity\ of\ flue\ gas$$

$$= \rho_f \times A_f \times v_f$$

$$= 0.405 \times \left(\frac{\pi}{4} \times 0.6 \times 0.6\right) \times 11.7$$

$$= 1.35\ kg/s$$

$$Waste\ Heat\ Energy = 1.35 \times 1.214 \times (600 - 300)$$

$$= 490.42\ kJ/s$$

4.4.3.3 Determination of Diesel Savings

If waste heat from the incinerator was to be captured and used to heat water, the boiler would not run for 3 hours. Therefore waste heat recovery would save boiler energy bills as follows:

In 2017 $= \frac{3hrs}{6hrs} \times 41170\ litres \times Kshs\ 78.70 = Kshs\ 1{,}620{,}039.50$

In 2018 $= \frac{3hrs}{6hrs} \times 48428\ litres \times Kshs\ 78.70 = Kshs\ 1{,}905{,}641.80$

In 2019 $= \frac{3hrs}{6hrs} \times 8100\ litres \times Kshs\ 99.80 = Kshs\ 404{,}190$

Total savings in 2017, 2018 and 2019

$$= 1{,}620{,}039.50 + 1{,}905{,}641.80 + 404{,}190$$

$$= Kshs\ 3{,}929{,}871.30$$

Averagely Kshs 1,309,957.10 savings per year.

4.4.3.4 Modification of the Incinerator

This would entail installation of a heat exchanger (economizer) to capture waste heat and also the piping system to the wards. This would be at an estimated cost of Kshs 1,700,000 as the capital investment.

Hence the cost benefit analysis was evaluated using Equations 3.24 and 3.25 respectively as follows;

$$Payback\ Period\ (PBP) = \frac{Capital\ Investment}{Annual\ Financial\ Saving}$$

$$Payback\ Period\ (PBP) = \frac{1{,}700{,}000}{1{,}309{,}957.10}$$

$$Payback\ Period\ (PBP) = 1.3\ years$$

$$Return\ on\ Investment = \frac{Annual\ Financial\ Savings}{Total\ amount\ of\ investment} = \frac{1}{PBP}$$

$$Return\ on\ Investment\ (RoI) = \frac{1}{1.3}$$

$$= 0.769$$

For the available incinerator equipment, the power factor and power consumption were calculated and tabulated in Table 4.22.

From the three-year incinerator diesel consumption trend, the amount of diesel consumption in 2017 and 2018 had increased progressively from 5,300 litres to 6,410 litres, an increment of 1,110 litres (20.9 % increase). Between 2018 and 2019, a drastic drop on annual consumption was realized with a drop of 1,950 litres of diesel which was a 33.4 % drop. This drastic drop could be attributed to poor record keeping and unaccountablity of the employees concerned. This project recommended compulsory weighing of wastes before being incinerated and poper recording of diesel consumed to determine the actual diesel consumption per each kilogram of waste burnt. This initiative would create accountability of all staff working at the incinerator.

Table 4.22: Incinerator System Analysis

No.	Equipment Name	Model	Voltage (V)	Current (A)	Rating (kW)	Frequency (Hz)	P.F.	Operating Hours per day	kWh per day
1.	Primary Burner	Bentone	220-240	1.7	0.25	50	0.61	3	0.75
2.	Secondary Burner	Hanning	230	0.95	0.125	50	0.57	3	0.375
3.	Blower Motor	Locally assembled	220-240 / 380-415	12.9/7.4	3.7	50	0.69	3	11.1

4.4.3.5 Discussions

From the boiler analysis in 4.4.1.2, energy required to heat bathing water for patients of 5,000 litres from 20 ^{0}C to 55 ^{0}C was 51.04 kJ/s.

The waste heat energy from incinerator was approximately 490 kJ/s against hot water energy requirements of 51.04 kJ/s, therefore waste heat energy would fully meet energy required to heat water for use at the Defence Forces Memorial Hospital.

Hence, for 3 hours when the incinerator was running, waste energy from the incinerator chimney could be recovered by use of an economizer and this would translate to 100 % diesel savings for 3 hours when the incinerator was running, which would give a saving of Kshs 1,309,957.10 per year.

To capture this waste heat energy from the incinerator, an economizer would have to be incorporated at an investment capital cost of Kshs 1,700,000. This would give a pay back period of 1 year 4 months and a return on investment of 0.769.

4.4.3.6 Suggested ECOs for the Incinerator

The incinerator was evaluated and the following measure was identified as possible energy conservation opportunity:
A heat recovery unit should be installed on the incinerator exhaust to be used to preheat water for various uses in the hospital facility especially laundry processes and bathing water for patients..

4.5 HVAC Systems

For this study, the refrigeration equipment in Mashujaa Farewell Home, which was the hospital mortuary was considered. DFMH mortuary had 4 chambers, each with an independent refrigeration system as summarized in Table 4.23. A detailed information about all the HVAC systems in the hospital mortuary was as shown in Appendix A3.

Table 4.23: HVAC Systems Summary

Total Number of Air Conditioners		
Model	**Type**	**Quantity**
Bitzer	2GES-2-40S	3
Bitzer	2DES-3-40S	1
Total		**4**

4.5.1 Determination of Rated Power Consumption for HVAC Systems

From preliminary information obtained from the machine nameplates the following parameters were determined by mathematical analysis:

Determination of the HVAC systems power consumption was achieved by use of Equation 3.7.

Thus;

For the three refrigeration systems of type 2GES-2-40S rated at 400 V, 2.7 kW and running for 24 hrs per day.

$$Power\ consumed = power\ rating \times operational\ time$$

$$= 2.7\ kW \times 24\ hrs \times 3 = 194.4\ kWh\ per\ day$$

For the HVAC systems, the power consumptions were done and indicated in Table 4.24.

4.5.2 Determination of Refrigeration Efficiency

Refrigeration efficiency is measured in terms of the Coefficient of Performance (COP) - the ratio of cooling energy supplied to the amount of electrical energy used. The coefficient of performance or COP of a heat pump, refrigerator or air conditioning system is a ratio of useful heating or cooling provided to work required. Higher COPs equate to lower operating costs.

This was determined using Equation 3.18 as shown below:

$$COP = \frac{T_{cold}}{(T_{hot} - T_{cold})}$$

$$Tcold = -10\ °C = 263K$$

$$T_{hot} = 45\ °C = 318\ K$$

Therefore,

$$COP = \frac{263}{(318 - 263)}$$

$$= 4.78$$

4.5.3 Determination of Air Conditioning Efficiency

The efficiency of a room air conditioner operating at a specific outdoor temperature is measured by air conditioner’s energy efficiency ratio (EER). A higher EER indicates a higher efficient system. The EER energy-efficiency rating indicates the number of BTUs removed per hour or “pulled out” for each watt of power drawn by the system. Generally, an EER of 12 or above is considered energy efficient.

EER was determined using Equation 3.19 as follows:

$$EER = 3.41 \times COP$$

$$EER = 3.41 \times 4.78$$

$$EER = 16.3$$

Table 4.24: HVAC Systems Analysis

Equipment	Quantity	Specs	Rating (kW)	Evaporator outside temp.	Condenser outside temp.	Operating Hours (Daily)	Consumption per day (kWh)	COP	EER	Condition
Bitzer 2GES-2-40S	3	400V, 50Hz, 5.0A	2.7	-10^0C	45^0C	24	194.4	4.78	16.3	Leakages, Cladding
Bitzer 2DES-3-40S	1	400V, 50Hz, 8.6A	4.6	-10^0C	45^0C	24	110.4	4.78	16.3	Leakages, Cladding

4.5.4 Determination of Electrical Energy Savings

If the refrigeration system Bitzer 2DES-3-40S which had a rating of 4.6 kW was replaced with Bitzer 2GES-2-40S which had a rating of 2.6 kW, the objective of cooling would still be achieved. This replacement would yield an energy saving as follows:

$$Energy\ savings = (4.6 - 2.7)\ kW \times 24\ hrs\ = 45.6\ kWh\ per\ day$$

$$= 45.6 \times 300 = 13{,}680\ kWh\ per\ year$$

Cost of this energy saved from the utility company (KPLC) would be:

$$= Kshs\ (13{,}680 \times 21.21)$$

$$= Kshs\ 290{,}152.80$$

Kshs 290,152.80 savings per year.

4.5.5 Replacement of Refrigeration System

This would involve purchase and installation of Bitzer 2GES-2-40S Refrigeration System to replace the current Bitzer 2DES-3-40S Refrigeration System at an estimated cost of Kshs 550,000 as the capital investment.

Hence the cost benefit analysis was done using Equations 3.24 and 3.25 respectively as follows;

$$Payback\ Period\ (PBP) = \frac{Capital\ Investment}{Annual\ Financial\ Saving}$$

$$Payback\ Period\ (PBP) = \frac{550{,}000}{290{,}152.8}$$

$$Payback\ Period\ (PBP) = 1.9\ years$$

$$Return\ on\ Investment\ = \frac{Annual\ Financial\ Savings}{Total\ amount\ of\ investment} = \frac{1}{PBP}$$

$$Return\ on\ Investment\ (ROI)\ = \frac{1}{1.9}$$

$$= 0.526$$

4.5.6 Discussions

The efficiency of the air conditioning system was good as its EER was 16.3 which was more than 12. The 4 cold chambers in the hospital mortuary were equal in sizes and cooled by 4 independent refrigeration systems, 3 of which were Bitzer 2GES-2-40S type (2.7 kW) and one was Bitzer 2DES-3-40S type (4.6 kW). The Bitzer 2DES-3-40S refrigeration system consumed more energy than the other three, yet the Bitzer 2GES-2-40S type could still perform the same task. If the Bitzer 2DES-3-40S were to be replaced with Bitzer 2GES-2-40S, the hospital would realise a saving of Kshs 290,152.80 per year. The replacement would be at an estimated cost of Kshs 550,000 as the capital investment, resulting to a pay back period of 1 year 11months and a return on investment of 0.526.

4.5.7 Suggested ECOs for the HVAC Systems

The HVAC Systems were evaluated according to the machine nameplates and the following measures were identified as possible energy conservation opportunities:

Theoretically Proper maintenance of HVAC systems was estimated to save up to 10 % of space air-conditioning energy usage. This could be achieved through measures such as:

i. Replacing the Bitzer 2DES-3-40S Refrigeration System with Bitzer 2GES-2-40S Refrigeration System.
ii. Eliminating the leakages of the refrigerant and cladding the parts with worn out claddings.
iii. Cleaning distribution systems (fans, filters and air ducts) quarterly.
iv. Maintaining and regularly tuning all HVAC equipment and sensors.
v. Upgrading or replacing with more energy efficient HVAC systems
vi. Applying demand management and HVAC optimization steps. This can lead to significant cost savings by enabling a downsizing of existing

HVAC systems. Downsizing HVAC systems can also lead to significant co-benefits such as increased water savings, as HVAC systems are responsible for up to 30 % of water use in institutional buildings.

4.6 Electrical Motors and Generators

The hospital had five motors which ran various water pumps in the facility. Due to accessibility, the study covered only three pumps, one for the laundry, one for purification machine for the renal dialysis and the other one for boiler feed water. Their specifications were as indicated in the Table 4.25.

Table 4.25: Electrical Motors Specifications and Location

Location	Equipment Name	Model	Equipment Description	Voltage (V)	Current (A)	Rating (kW)	Frequency (Hz)
Laundry	Water pump	Pedrollo	Air cooled	240	5.8	0.75	50
Renal Dialysis Machine	Water pump	Grundfos	Air cooled	240	3.65	0.75	50-60
Boiler Feed Water	Water pump	Catco	Air cooled	415	3.39	1.5	50

The hospital had also one standby three phase generator which used diesel and had specifications as shown in Table 4.26. The diesel generator was only used as a backup power source in case of the grid power failure.

Table 4.26: Generator Specifications.

Generator Name	Type	Size (kVA)	Voltage (V)	Current (A)	Frequency (Hz)	P.F.	RPM
Stamford AC Generator	HCI634H1 3 Phase	750	415	1043.4	50	0.8	1500

4.6.1 Determination of Rated Power Factor (PF) and Consumption for Electrical Motors

From preliminary information obtained from the machine nameplates the following parameters were determined by mathematical analysis:

Power factor and power consumption of the electrical motors were determined using Equations 3.6 and 3.7.

Thus;

For the Pedrollo air cooled water pump rated at 240 V, 5.8 A and 0.75 kW

$$Power\ Factor\ (pf) = \frac{P}{VI}$$

$$= \frac{750}{240 \times 5.8} = 0.54$$

$$Power\ consumed = power\ rating \times operational\ time$$

$$= 0.75\ kW \times 96hrs = 72\ kWh\ per\ week$$

For all available electrical motors, the rated power factors and power consumptions at rated levels were computed and tabulated in Table 4.27.

Table 4.27: Electrical Motors Analysis

Room No.	**Equipment Name**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (kW)**	**Frequency (Hz)**	**PF**	**Operating Hours/week**	**kWh per week**
Laundry	Water pump	Pedrollo	240	5.8	075	50	0.54	96	72
Renal Dialysis Machine	Water pump	Grundfos	240	3.65	0.75	50	0.87	70	52.5
Boiler Feed Water	Water pump	Catco	415	3.39	1.5	50	0.79	84	126

4.6.2 Determination of the Operating Characteristics of the Induction Motors

The operating characteristics of the induction motors used for the laundry, renal dialysis machine and the boiler feed water were determined by the following methods:

i. Input power measurements. ii. Line current measurements.

For example, for the Pedrollo pump motor with the following operating details:

Output power = 0.75 kW, Voltage (V) = 240 V Full load current (I_{fl}) = 5.8 A and assuming a standard 90 % efficiency at full load for laundry and renal dialysis machine. Using Equation 3.22.

From $Efficiency = \frac{P_o}{P_i} \times 100,$ $\quad Input\ Power, P_i = \frac{Output\ Power}{Efficiency} = \frac{P_o}{Efficiency}$

$$= \frac{0.75}{0.9}$$

$$= 0.833\ kW$$

Using Equation 3.23, to find Full Load Power Factor;

$$PF_{fl} = \frac{Input\ Power}{V \times I_{fl}}$$

$$= \frac{830}{240 \times 5.8}$$

$$= 0.6$$

The boiler feed water pump motor had an efficiency of 78 % on the nameplate. From power consumption measurements during operation, it was found that the power drawn by the laundry, renal dialysis machine and boiler feed water pumps motors, were averagely at 0.5 kW, 0.7 kW and 1.2 kW respectively as tabulated in Table 4.28.

The operating efficiencies were derived using Equation 3.22 as shown below;

$$Efficiency = \frac{P_o}{P_i} \times 100$$

$$= \frac{0.5}{0.833} \times 100$$

$$= 60\ \%$$

The operational efficiencies for the laundry, renal dialysis machine and boiler feed water pumps motors were calculated and found to be 60 %, 84 % and 62.5 % respectively. These were also tabulated in Table 4.28.

Table 4.28: Operational Data for the Electrical Motors

Room No.	**Equipment Name**	**Model**	**Voltage (V)**	**Rated Current (A)**	**Operating Current (A)**	**Power Input (kW)**	**Power Consumption (kW)**	**PF**	**Operational Efficiency (60%)**
Laundry	Water pump	Pedrollo	240	5.8	3.47	0.833	0.5	0.6	60
Renal Dialysis Machine	Water pump	Grundfos	240	3.65	3	0.833	0.7	0.97	84
Boiler Feed Water	Water pump	Catco	415	3.39	2.5	1.92	1.2	0.67	62.5

4.6.3 Determination of Rated Input Power of the Generator

From preliminary information obtained from the machine nameplates the following parameter was determined by mathematical analysis:

Rated input power and energy of the generator were determined using Equations 3.20 and 3.21.

For the generator rated at 750 kVA, 1043.4 A and 0.8 power factor,

$$\begin{aligned} Rated\ Input\ Power &= kVA \times pf \\ &= 750 \times 0.8 \\ &= 600\ kW \end{aligned}$$

$$\begin{aligned} Rated\ Input\ Energy\ in\ 1\ hr &= Rated\ Input\ Power \times operational\ time \\ &= 600\ kW \times 1\ hr \\ &= 600\ kWh \end{aligned}$$

4.6.4 Performance Efficiency of the Generator

From Tables 4.8 to 4.10, the generator consumed diesel fuel as follows:

In the year 2017: 9,000 litres at Kshs 78.70 per litre, that was Kshs 708,300.

In the year 2018: 10,970 litres at Kshs 78.70 per litre, that was Kshs 863,339.

In the year 2019: 7,300 litres at Kshs 99.80 per litre, that was Kshs 728,540.

Averagely, in one year the generator consumed 9,090 litres which was averagely Kshs 766,726.

The rated input energy of the generator was 600 kWh when operated at 100 % (full load). Assuming the generator averagely operated at 80 %, the input energy in one hour would be given as follows:

$$\begin{aligned} Input\ energy\ at\ 80\ \% &= Rated\ input\ energy \times Loading \qquad (4.2) \\ &= 600 \times 0.8 \\ &= 480\ kWh \end{aligned}$$

According to [17], one litre of diesel fuel (auto) has an energy content of approximately 38 MJ, which approximates to 10 kWh (using a ballpark figure) but the efficiency of conversion into kinetic energy is only about 30% - that is better than petrol which is typically 25% depending on the design.

So one litre of diesel will give up about 3.3 kWh (30% of the 10 kWh), the remainder of the energy goes out of the exhaust pipe mainly as hot gas!

The 9090 litres consumed at the DFMH annualy for 182 hours translated to an hourly consumption of 50 litres.

Therefore;

$$Output\ Energy\ in\ 1\ hr = Energy\ content\ in\ 50\ litres\ of\ diesel \tag{4.3}$$

$$= 3.3\ kWh \times 50$$

$$= 165\ kWh$$

Hence,

$$Output\ Energy\ in\ the\ 182\ hrs = Energy\ content\ in\ 9090\ litres\ of\ diesel$$

$$= 3.3\ kWh \times 9090$$

$$= 29{,}997\ kWh$$

If this energy was to be acquired from the utility company (KPLC), then;

Cost of this energy from the KPLC would be:

$$Cost\ of\ energy = 29{,}997 \times 21.21$$

$$= Kshs\ 636{,}236.40 \text{ per year.}$$

The generator efficiency was also determined by;

$$Generator\ efficiency = \frac{P_o}{P_i} \times 100$$

$$= \frac{165}{480} \times 100$$

$$= 34.4\ \%$$

For the generator, the tabulation of rated input power, input energy and ouput energy generated were done and indicated in Table 4.29.

Table 4.29: Generator System Analysis.

Generator Name	Model No.	Size (kVA)	Voltage (V)	Current (A)	Rating (kW)	Input Energy in 1 hr (kWh)	Output Energy in 1 hr (kWh)	PF	Generator Efficiency %
Cummins	1029826B001	750 3 Phase	415	1043.4	600	480	165	0.8	34.4

Table 4.30 below shows the carbon dioxide emissions for common fuel types.

Table 4.30: Carbon Dioxide Emissions for Common Fuel Types [18]

Fuel type	**Unit consumed (Litres)**	**CO2 emitted per unit litre (kg)**
Petrol	1	2.3
Diesel	1	2.7

Based on the annual consumption of 9,090 litres, it was determined that the annual carbon dioxide emissions for DFMH from the diesel generator was given by:

$$Annual\ CO2\ emission = 9{,}090 \times 2.7$$
$$= 24{,}543\ kg \text{ per year.}$$
$$= 24.543\ tonnes \text{ per year.}$$

4.6.5 Discussions

From the analysis it was noted that laundry and boiler feed water pumps motors had operating efficiencies below 75 % and would require regular mantenance and servicing. It was also notable that the same machines had low power factors which required appropriate measures to improve, example by insertion of capacitors for power improvement. The efficiency would improve with increased loading, meaning any increase in the load would lead to increase of output power hence increased efficiency. Therefore this would call for strategies to ensure the motors operated at above 75 % full load. Through the observations made in the generator performance efficiency of 34.4 %, it could also be noted that if the generator size was halved to 300 kW operating at 80% full load, it would serve the facility more efficiently with an improved efficiency of 68.8 %. Therefore, this was an indicator that the generator was oversized for the daily energy demands. The cost of diesel (9,090 litres) used to generate energy of 29,997 kWh by the generator was Kshs 766,726, while the energy generated would cost Kshs 636,236.40. From the two costs, power failure of the utility company (KPLC) costed the DFMH a loss of Kshs 130,489.60 (17 %) per year. Also, considering the environmental effects, it emitted 24.543 tonnes of green house gases emissions to the environment per year.

4.6.6 Suggested ECOs for Electrical Motors and Generators

The electrical motors and generators were evaluated according to the machine nameplates and the following measures were identified as possible energy conservation opportunities:

i. **Installation of Power Factor Correction Equipment**.

   Using capacitor banks for power factor correction. Operating a machine at less than unity power factor implies that high apparent power is drawn from the system hence high current. The increased current would lead to the need to increase the transformer size and installation power wiring. Capacitor banks would ensure that the systems operate at nearly unity power factor hence drawing less current, dissipating less heat, and promoting the longevity of the electrical system.

ii. **Use of Solar Powered Water Pumps in Place of Grid Powered Machines**

   Solar powered water pumps will ensure minimized operational costs in terms of energy cost. This will reduce the operational costs at DFMH.

iii. **Prompt and Proper Preventive Maintenance of All Electrical Machines**

   By employing a preventive maintenance program, machines will work at full efficiency hence creating profitable uptime, while reducing downtime. This helps to reduce the chances of complete machine breakdown hence reducing the operational costs, emergency repair calls and helps to save money on electricity due to machines operating at their best efficiency. Properly maintained machines have a prolonged lifetime.

iv. **Adoption of variable speed drives.**

   The use of variable speed drives would provide precise electric motor control. The speed regulation of a machine with respect to the load would ensure utilization of only the energy required rather than having a motor run at constant speed and using excess energy.

v. **Enhancing Energy Efficiency of the Electrical Machines and Generators**

   The energy efficiency of electrical machines is dependant on the machine size. Properly sized electrical machines operate between 80 % and 95 % full load. Right sizing of motors based on the load would minimize power consumption thereby enhance energy efficiency.

vi. **Regular Maintenance of Generators**

For consistency in the consumption rate of the standby generator, regular maintenance is recommended. From the three-year generator diesel consumption trend the amount of diesel consumption in 2017 and 2018 had increased progressively from 9,000 litres to 10,970 litres, an increment of 1,970 litres. In 2019 the diesel consumption dropped significantly to an annual consumption of 7,300 litres which was a 33.5 % drop, this could be associated to reduced grid power failure in 2019.

4.7 Laundry Equipment

The laundry equipment was mainly used for cleaning and preparation of hospital fabric. Most of the machines used were power intensive. They took in water at low temperatures thereby drawing a lot of electric power.

The laundry equipment was composed of two washers/extractor rated at 38 kW, two steam dryers rated at 51 kW, one steam press machine rated at 13 kW, one calendar machine rated at 18.5 kW and one air compressor rated at 1.8 kW. Their specifications were as shown in Table 4.31.

Table 4.31: Laundry Equipment

No.	Equipment Name	Model	Capacity	Production	Quantity	Voltage (V)	Current (A)	Rating (kW)	Frequency (Hz)
1.	Washing/Extractor Machine	Electrolux	45 kg	45 kg/h	2	400	56	38	50
2.	Drying Machine	Electrolux	45 kg	45 kg/h	2	400	74	51	50
3.	Steam Press Machine	Electrolux	N/A	N/A	1	400	21	13	50
4.	Calendar Machine	Electrolux	N/A	0.5-5.5 m/min	1	400	32	18.5	50
5.	Air Compressor	AICO	25 litres	178 l/min	1	220	7.5	1.8	50

The machines received water at ambient temperatures and independently heated it to required process temperature. For example, the steam dryer took in water at room temperature and pressure and released it as saturated steam at 4 bar. Washers took in water at room temperature and pressure and used it at varying temperatures depending on loaded fabric. For example, light fabric was washed at 85 ^{0}C.

4.7.1 Determination of Rated Power Consumption for Laundry Equipment

From preliminary information obtained from the machine nameplates the following parameters were determined by mathematical analysis:

Power consumption of the machines was determined by Equation 3.7.

Thus;

For the two Washing/Extractor Machines rated at 400 V, 56 A and 38 kW running for 8 hrs,

$$Power\ consumption = power\ rating \times operational\ time$$
$$= 38\ kW \times 8\ hrs \times 2$$
$$= 608\ kWh\ per\ day$$

For the available laundry equipment, the power consumptions were calculated and indicated in Table 4.32.

Table 4.32: Laundry Equipment Analysis

No.	Equipment Name	Model	Capacity	Production	Quantity	Voltage (V)	Rating (kW)	Operating Hours per day	kWh per day
1.	Washing/Extractor Machine	Electrolux	45 kg	45 kg/h	2	400	38	8	608
2.	Drying Machine	Electrolux	45 kg	45 kg/h	2	400	51	8	816
3.	Steam Press Machine	Electrolux	N/A	N/A	1	400	13	8	104
4.	Calendar Machine	Electrolux	N/A	0.5-5.5 m/min	1	400	18.5	8	148
5.	Air Compressor	AICO	25 litres	178 l/min	1	220	1.8	8	14.4

4.7.2 Replacement of Laundry Equipment

This would entail replacing the current two Washer Extractors and two Dryers with more efficient Washer Extractors and Dryers.

For Washer Extractors, the replacement would be two Fagor Washer Extractors LN-45C TP2 E, with 45 kg capacity, 45 kg/h production, 400 V and 23 kW rating.

For Dryers, the replacement would be four Fagor Heat Pump Dryers SR-23 TP2 Plus HP, with 23 kg capacity, 23 kg/h production, 400 V and 8.77 kW rating.

4.7.3 Determination of Energy Savings, Costs and Cost Benefit Analysis

Replacement of the Washer Extractors and Dryers with more efficient ones would be at estimated costs of Kshs 5,000,000 and Kshs 8,400,000 as the capital investments respectively and would save energy as follows:

i. Energy Savings and Costs

$$Power\ consumption\ for\ current\ washer\ extractors$$
$$= 608\ kWh\ per\ day$$

$$Power\ consumption\ for\ new\ washer\ extractors$$
$$= power\ rating \times operational\ time$$
$$= 23\ kW \times 8\ hrs \times 2\ = 368\ kWh\ per\ day$$

$$Savings\ in\ energy\ in\ washer\ extractors\ per\ year$$
$$= (608 - 368) \times 300$$
$$= 72{,}000\ kWh\ per\ year \text{ per year}$$

$$Annual\ Financial\ Savings\ in\ washer\ extractors\ per\ year$$
$$= (72{,}000 \times 21.21)$$
$$= Kshs\ 1{,}527{,}120 \text{ per year}$$

$$Power\ consumption\ for\ current\ dryers$$
$$= 816\ kWh\ per\ day$$

$$Power\ consumption\ for\ new\ dryers$$
$$= power\ rating \times operational\ time$$
$$= 8.77\ kW \times 8\ hrs \times 4\ = 280.64\ kWh\ per\ day$$

$$Savings\ in\ energy\ in\ dryers\ per\ year$$
$$= (816 - 280.64) \times 300$$
$$= 160{,}608\ kWh\ per\ year \text{ per year}$$

$$Annual\ Financial\ Savings\ in\ dryers\ per\ year$$
$$= (160{,}608 \times 21.21)$$
$$= Kshs\ 3{,}406{,}495.70 \text{ per year}$$

ii. Cost Benefit Analysis

Cost benefit analysis for the two systems were determined using Equations 3.24 and 3.25 as follows;

$$Payback\ Period\ (PBP)\ for\ washer\ extractors = \frac{Capital\ Investment}{Annual\ Financial\ Saving}$$

$$= \frac{5{,}000{,}000}{1{,}527{,}120}$$

$$= 3.27\ years$$

$$Return\ on\ Investment\ (RoI)\ = \frac{Annual\ Financial\ Savings}{Total\ amount\ of\ investment} = \frac{1}{PBP}$$

$$ROI\ for\ washer\ extractors = \frac{1}{3.27}$$

$$= 0.306$$

$$Payback\ Period\ (PBP)\ for\ dryers = \frac{Capital\ Investment}{Annual\ Financial\ Saving}$$

$$= \frac{8{,}400{,}000}{3{,}406{,}495.70}$$

$$= 2.47\ years$$

$$Return\ on\ Investment\ = \frac{Annual\ Financial\ Savings}{Total\ amount\ of\ investment} = \frac{1}{PBP}$$

$$ROI\ for\ dryers\ = \frac{1}{1.47}$$

$$= 0.405$$

4.7.4 Discussions

The energy consumptions for the current washer extractors and dryers were 608 kWh and 816 kWh per day respectively in the Laundry at the Defence Forces Memorial Hospital. If these current washer extractors and dryers were to be replaced with new ones with energy consumptions of 368 kWh and 280.64 kWh per day respectively, there would be energy savings of 72,000 kWh and 160,608 kWh per year respectively. These would yield financial savings of Kshs 1,527,120 and Kshs 3,406,495.70 per year for washer extractors and dryers respectively.

Considering the capital investment costs of Kshs 5,000,000 and Kshs 8,400,000 on new washer extractors and dryers respectively, there would be payback periods and return on investments of 3 years 3 months and 0.306; and 2 years 6 months and 0.405 respectively.

4.7.5 Suggested ECOs for Laundry Equipment

The laundry machines were evaluated and the following measures were identified as possible energy conservation opportunity in the laundry:

i. Replace the current two Washer Extractors and two Dryers with more efficient Washer Extractors and Dryers.
ii. Install solar water heaters to pre-heat all water requirements for the laundry.
iii. Switch off idle machines at the power socket.
iv. Limit starting of the machines at the same time to reduce kVA demand at pickup.

4.8 Other Preliminary Assessment Recommendations

Other minor glaring ECOs in the facility include upgrading computers and other electronic office equipment. Upgrading and retrofitting computers and other electronic equipment can lead to significant energy savings since these appliances usually contribute a significant amount of an office's energy use.

Ensuring new electronics purchases, such as televisions, laptops and computer systems is also vital.

4.9 Power Quality Measurement

Electric power quality, or simply power quality, involves voltage, frequency, and waveform. Good power quality can be defined as a steady supply voltage that stays within the prescribed range, steady a.c. frequency close to the rated value, and smooth voltage curve waveform. Without proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all. There are many ways in which electric power can be of poor quality and many more causes of such poor-quality power. To determine the power quality, the following parameters were monitored:

i. Voltage Drops
ii. Harmonic content in the waveforms for AC power.

The voltage for the Mains at the facility was measured for a duration of two weeks and a representation of a screenshot is shown in Figure 4.14.

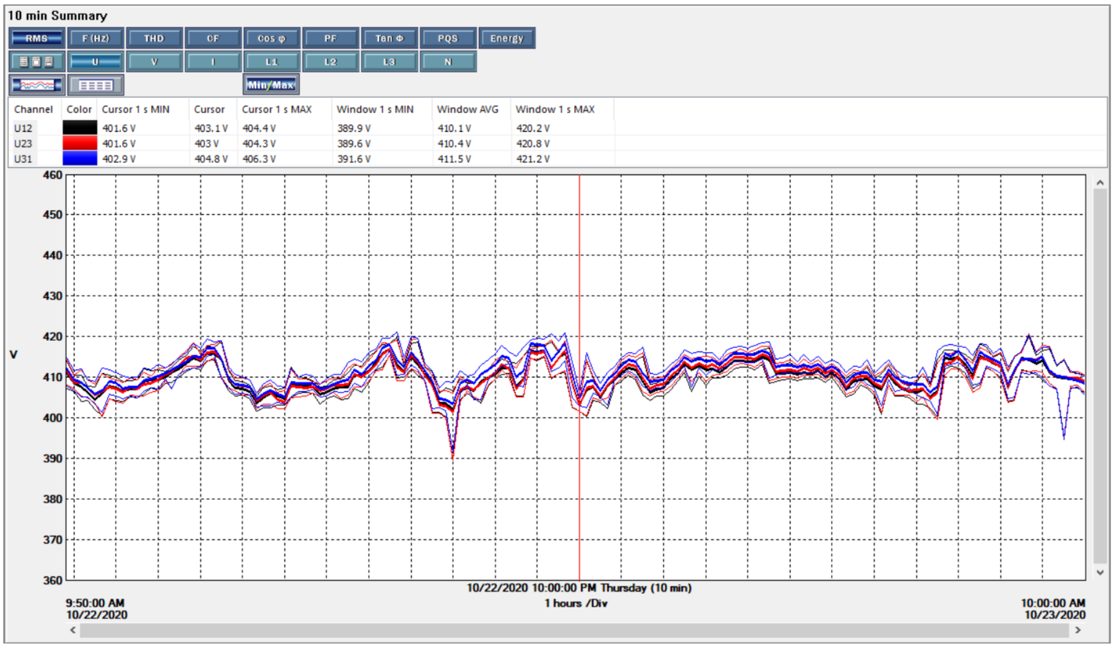

Figure 4.14: Voltage Trend for the Mains

The voltage for the Transformer was found to fluctuate with an average of 410.7 V with a minimum of 390.4 V and a maximum of 420.7 V. The voltages were well balanced.

The harmonic distortion for the Mains was also measured as shown in Figure 4.15.

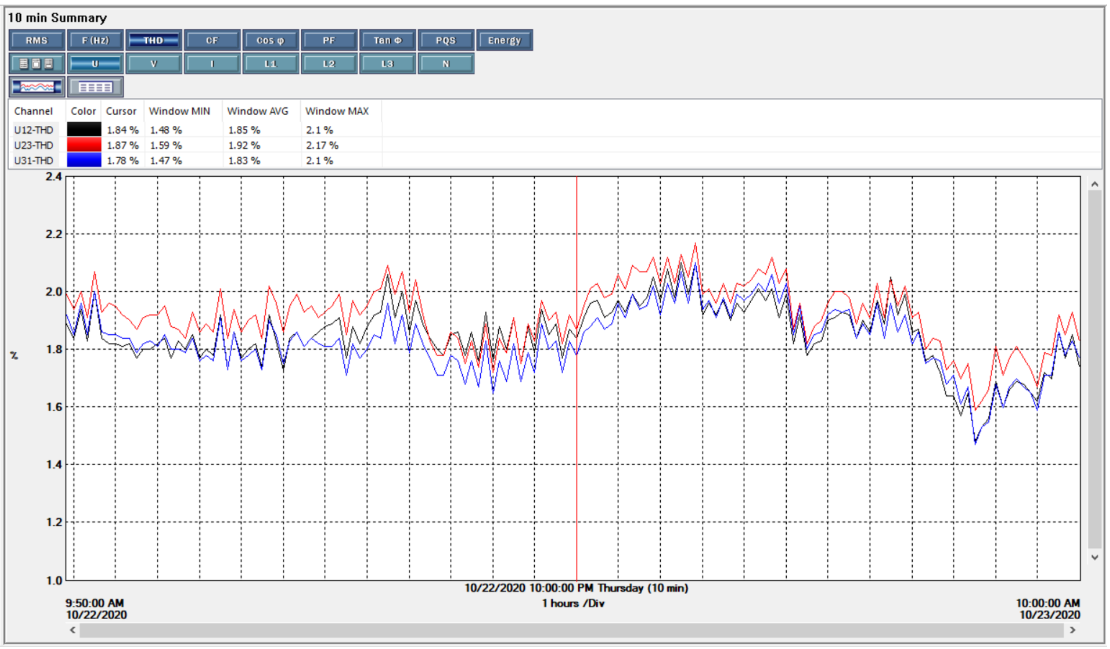

Figure 4.15: Harmonic Distortion for the Mains

The maximum Total Harmonic Distortion (THD) was found to be 2.17 % which was within the recommendation of < 5 % according to IEEE Std 519-1998. In summary the power supply quality for the mains was within specification and one of the main contributions to this was because the raw power passed through a stabilizer hence good power quality.

4.10 Conclusion

From the electricity consumption for the three years under study, February was represented to be the least electricity consuming month with a 18.1 % difference with the highest electricity consuming month which was July. Similar trend was replicated for diesel consumption for the the same facility, subsequently for LPG the annual consumption remained the same within the same period. Transformer voltage fluctuation was averagely at 410.7 V with a minimum of 390.4 V and a maximum of 420.7 V. The Total Harmonic Distortion (THD) was found to be 2.17 % which was within the recommendation of < 5 %.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

This chapter gives a summary of the project conclusion and recommendations for future work.

5.1 Conclusion

The energy conservation opportunities at the Defence Forces Memorial Hospital were identified through a level I and Level II energy audits. The energy bills were reviewed for a period of three years between 2017 and 2019 and the past energy consumption and cost were established. It was established that if all factors were to be held constant an automatic 18.1 % energy saving could be achieved. The average electricity consumption for February was approximately 261.3 GJ and was the least within the three year period of study and July was the highest electricity consuming month with an average consumption of 319 GJ. Energy lossess in the lighting systems were mostly from discharge lamps while the water heating systems and the incinerator energy losses were identified to be due to unlagged parts of the hot water lines and untapped waste heat energy.

In the evaluation of the refrigeration and air conditioning overall efficiency and preset operation temperature, the Coefficient of Performance and Energy Efficiency Ratio were 4.78 and 16.3 respectively, while the preset operation temperature was -10 ^{0}C. The motors performance efficiencies were 60 %, 84 % and 62.5 % for the laundry, renal dialysis machine and boiler feed water pumps motors. The laundry and boiler feed water pumps motors require some maintainance to improve in their efficiencies. The generator performance efficiency was 34.4 %. It could also be noted that if the generator size was halved to 300 kW operating at 80% full load, it would serve the facility more efficiently with an improved efficiency of 68.8 %. Therefore, this was an indicator that the generator was oversized for the daily energy demands. The laundry equipment was one of the highest electricity consuming equipment and their power consumption was determined as 1,690.4 kWh per day.

The energy conservation opportunities for various categories of energy consuming equipment were determined and found to be in the following categories: behavioural category which involved personal initiative, example in management of lighting systems (switching lights when not in use), technological category which involved a cost-benefit analysis and determination of the best option given alternatives, this included decisions like replacement of certain units with others, managerial category involved the management of the facility in developing energy saving policies to be followed by all.

5.2 Recommendations

In this energy audit at the DFMH some challenges were encounterd due to the sensitivity of the facility which could not allow for comprehensive data collection by civilian professionals. This posed a great challenge in the acquisition/hiring of the expensive and delicate Data logger. This research therefore recommends;

i. adoption and implementation of the findings of this energy audit.
ii. a collaboration between the Kenya Defence Forces management and various professionals in the Kenya Defence Forces be initiated to help complete a level III energy audit for the facility to achieve maximum energy and cost savings.

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APPENDIX A1: Lighting Systems

Elgon Ward

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 5ft	1	Glow	240	58	18	50	0.8	Manual	Good
Fluorescent Tube 4ft	63	Glow	240	36	18	50	0.8	Manual	Good
LED Tube 4ft	3	None	240	18	18	50	0.8	Manual	Good
Energy Saver Bulb	26	None	240	7	18	50	0.8	Manual	Good

Buna Ward

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 5ft	8	Glow	240	58	18	50	0.8	Manual	Good
Fluorescent Tube 4ft	5	Glow	240	36	18	50	0.8	Manual	Good
Fluorescent Tube 2ft	8	Glow	240	18	18	50	0.8	Manual	Good

Sorsbie Ward

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 5ft	8	Glow	240	58	18	50	0.8	Manual	Good
Fluorescent Tube 4ft	5	Glow	240	36	18	50	0.8	Manual	Good
Fluorescent Tube 2ft	2	Glow	240	18	18	50	0.8	Manual	Good
LED Tube 4ft	10	None	240	18	18	50	0.8	Manual	Good

Malkaloni Ward

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 5ft	8	Glow	240	58	18	50	0.8	Manual	Good
Fluorescent Tube 4ft	5	Glow	240	36	18	50	0.8	Manual	Good
Fluorescent Tube 2ft	1	Glow	240	18	18	50	0.8	Manual	Good
LED Tube 4ft	16	None	240	18	18	50	0.8	Manual	Good

Modogashi Ward

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 5ft	8	Glow	240	58	18	50	0.8	Manual	Good
Fluorescent Tube 4ft	5	Glow	240	36	18	50	0.8	Manual	Good
Fluorescent Tube 2ft	2	Glow	240	18	18	50	0.8	Manual	Good
LED Tube 4ft	16	None	240	18	18	50	0.8	Manual	Good

Maternity Ward

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 5ft	6	Glow	240	58	24	50	0.8	Manual	Good
Fluorescent Tube 4ft	7	Glow	240	36	24	50	0.8	Manual	Good
Fluorescent Tube 2ft	3	Glow	240	18	24	50	0.8	Manual	Good

Newborn Unit Ward

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 4ft	18	Glow	240	36	24	50	0.8	Manual	Good

Appendix A1: Lighting Systems contd..

Inpatient Pharmacy Department

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 4ft	3	Glow	240	36	12	50	0.8	Manual	Good

Radiology Department - Old

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 4ft	73	Glow	240	36	18	50	0.8	Manual	Good
Incandescent Bulb	6	None	240	60	18	50	0.75	Manual	Good

Physiotherapy Department

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 4ft	17	Glow	240	36	12	50	0.8	Manual	Good

MOPC Clinic Department

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 4ft	10	Glow	240	36	12	50	0.8	Manual	Good

Comprehensive Care Clinic Department

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 5ft	5	Glow	240	58	12	50	0.8	Manual	Good
Fluorescent Tube 4ft	2	Glow	240	36	12	50	0.8	Manual	Good
Fluorescent Tube 2ft	1	Glow	240	18	12	50	0.8	Manual	Good

OPD Department

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 4ft	40	Glow	240	36	24	50	0.8	Manual	Good

ICU Department

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 4ft	18	Glow	240	36	24	50	0.8	Manual	Good

Renal Department

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 4ft	3	Glow	240	36	12	50	0.8	Manual	Good
Fluorescent Tube 2ft	20	Glow	240	18	12	50	0.8	Manual	Good

Theatre Department

Item	Qty	Starter type	Voltage (V)	Rating (W)	Daily Operating Hours	Frequency (Hz)	P.F	Switching type	Condition
Fluorescent Tube 4ft	56	Glow	240	36	24	50	0.8	Manual	Good

Appendix A1: Lighting Systems contd..

Laboratory Department									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	41	Glow	240	36	24	50	0.8	Manual	Good

Outpatient Pharmacy Department									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	5	Glow	240	36	24	50	0.8	Manual	Good

New OPD Clinics Department									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	16	Glow	240	36	12	50	0.8	Manual	Good

Dental Department									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	17	Glow	240	36	12	50	0.8	Manual	Good

Drug Store Department									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	24	Glow	240	36	12	50	0.8	Manual	Good

Biomedical Department									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	7	Glow	240	36	12	50	0.8	Manual	Good

Eye Unit Department									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	4	Glow	240	36	12	50	0.8	Manual	Good

Farewell Home									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	24	Glow	240	36	24	50	0.8	Manual	Good
Fluorescent Tube 2ft	1	Glow	240	18	24	50	0.8	Manual	Good

Officers' Mess									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	23	Glow	240	36	24	50	0.8	Manual	Good
Fluorescent Tube 2ft	1	Glow	240	18	24	50	0.8	Manual	Good

WO's & Sgts' Mess									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	13	Glow	240	36	18	50	0.8	Manual	Good

Appendix A1: Lighting Systems contd..

WO's & Sgts' Canteen									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	2	Glow	240	36	18	50	0.8	Manual	Good
Fluorescent Tube 2ft	2	Glow	240	18	18	50	0.8	Manual	Good

Cpls' & ORS' Mess									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	15	Glow	240	36	18	50	0.8	Manual	Good

Main Cook House									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	12	Glow	240	36	18	50	0.8	Manual	Good

Church RC									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	17	Glow	240	36	24	50	0.8	Manual	Good

Church AC									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	17	Glow	240	36	24	50	0.8	Manual	Good

Mosque									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	17	Glow	240	36	24	50	0.8	Manual	Good

DFMTS School									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	36	Glow	240	36	12	50	0.8	Manual	Good

Camp Admin Wing									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	14	Glow	240	36	24	50	0.8	Manual	Good

ORS Single Accomodation Blocks									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	144	Glow	240	36	18	50	0.8	Manual	Good
Fluorescent Tube 2ft	12	Glow	240	18	18	50	0.8	Manual	Good

Appendix A1: Lighting Systems contd..

Laundry Department									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 4ft	6	Glow	240	36	12	50	0.8	Manual	Good
Fluorescent Tube 2ft	3	Glow	240	18	12	50	0.8	Manual	Good

Security Lights									
Item	**Qty**	**Starter type**	**Voltage (V)**	**Rating (W)**	**Daily Operating Hours**	**Frequency (Hz)**	**P.F**	**Switching type**	**Condition**
Fluorescent Tube 5ft	14	Glow	240	58	12	50	0.8	Manual	Good
Fluorescent Tube 4ft	40	Glow	240	36	12	50	0.8	Manual	Good
Mercury Bulb	2	None	240	60	12	50		Manual	Good
LED Floodlight	16	None	240	250	12	50		Automatic	Good

APPENDIX A2: Instant Showers

Elgon Ward									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	7	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		1.3	

Buna Ward									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	3	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		1.3	
Instant Showers	1	Horizon	240	30	5400	50		1.3	

Sorsbie Ward									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	1	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		2.6	
Instant Showers	1	Horizon	240	30	5400	50		2.6	

Malkaloni Ward									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	4	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		1.3	

Modogashi Ward									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	4	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		1.3	

Maternity Ward									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	2	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		1.3	

Newborn Unit Ward									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	4	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		1.3	

ICU									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	2	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		0.6	

Laboratory									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	1	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		0.6	

Laundry Department									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	1	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		1.3	

Mashujaa Farewell Home									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	2	Horizon	240	30	5400	50		1.3	

Officers' Mess									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	1	Horizon	240	30	5400	50		0.9	
Instant Showers	2	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		0.9	
Instant Showers	2	Horizon	240	30	5400	50		0.9	

Appendix A2: Instant Showers contd..

WOs' & Sgts' Mess									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	1	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		1.8	

Main Cook House									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	1	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		1.3	

Mosque									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	1	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		0.6	

Church AC									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	2	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		0.6	

ORS Single/Student Accomodation Block									
Item	**Qty**	**Model**	**Voltage (V)**	**Current (A)**	**Rating (W)**	**Frequency (Hz)**	**P.F**	**Operating Hours per day**	**Condition**
Instant Showers	39	Lorenzetti	220-240	20.9-22.8	4600-5500	50/60		1.8	

APPENDIX A3: HVAC Systems

Mashujaa Farewell Home															
Location	**Model**	**Type**	**Specs**	**Qty**	**Room space**	**Evaporator unit Location**	**Condenser unit Location**	**Evaporator outside temp.**	**Condenser outside temp.**	**Power input**	**Outside air temp.**	**Cladding condition**	**Door size**	**Set point temp.**	**Manufacturer's recommended temp**
Cold Chamber	Bitzer	2GES-2-40S	400V, 50Hz, 5.0A	3	$252ft^3$	Indoor	Outdoor	-10^0C	45^0C	2.7kW	20^0C	Not good	3ft	-10^0C	
Cold Chamber	Bitzer	2DES-3-40S	400V, 50Hz, 8.6A	1	$252ft^3$	Indoor	Outdoor	-10^0C	45^0C	4.6kW	20^0C	Not good	3ft	-10^0C	

Mashujaa Farewell Home			
Door opening freq	**Wall cover type**	**Leakage of gases**	**Operating Hours per day**
Closed	Block	Yes	24hrs
Closed	Block	Yes	24hrs

APPENDIX A4: Originality Report

ENERGY CONSERVATION OPPORTUNITIES AT THE DEFENCE FORCES MEMORIAL HOSPITAL.

By: Okumu Philip Odhiambo (F56/83424/2015)

Master of Science in Energy Management

Project Originality Report

Signed

Student	Okumu Philip Odhiambo		…20/08/2021…
Supervisor	Dr. Peter Moses Musau		…20/08/2021…
Dean	Prof. Ayub Gitau	…………………	24.08.21 ………………

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