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IDENTIFYING OPPORTUNITIES FOR ENERGY SAVING IN A METAL FABRICATION WORKSHOP:

A CASE STUDY OF TRANSPOWER TECHNOLOGIES LTD

Report submitted in partial fulfilment for the Degree of Master of Science in Energy Management.

Declaration

I **Dennis Kuria**, **F56/6971/2017**, hereby declare that this Report is my original work, and has not been submitted for examination in any other University. Any acknowledgement and references to previous work has been quoted accordingly.

Signature Date 12/05/2021

Approval by Supervisors

I confirm that the study was carried out under my supervision and has been submitted for examination with my approval as University supervisor.

Eng. Prof. Mwangi Mbuthia Signature………….. Date..**20/05/2021**……

Dr. Wilfred Njoroge Mwema Signature… Date……19-05-2021

Dedication

This report is dedicated to my parents for their support and encouragement throughout my life. It is for their prayers and good will that this report is a success.

Acknowledgement

First, I thank God for giving me health, peace of mind and guiding me to access resources during the study period. Second, I appreciate my supervisors for their technical guidance and support while writing this report. Lastly, special thanks to the management of Transpower Technologies Ltd for their support through access to the workshop, tools and equipment.

Abstract

The objective of this study was to identify energy saving potential in metal fabrication workshops in Kenya with a case study done at Transpower Technologies Ltd (TTL) located along Eastern By-pass in Kiambu County. The main focus was to lower the annual energy bill which had escalated from Ksh 4,014 in April 2017(light production of samples of each item and setting operating standards of machines during this month) to Ksh 81,107 in December 2018. Therefore an audit was carried out to identify potential areas for energy savings and hence lower the energy bill. From a walk through preliminary evaluation of the main power consumers, energy savings possibilities were in the following areas; use of variable speed drives on motors, retrofitting conventional lights with LED lights, observing housekeeping measures and use of LPG instead of electrical elements in drying/curing ovens. A correctly installed LPG infrastructure allows maximum combustion of the gas and hence carbon foot print of the workshop is maintained. After carrying out the actual audit, the proposed changes would contribute an energy saving of 48,276.46 kWh. Economic evaluation was conducted in a manner that made it easy to calculate payback period from the total of the investment divided by the total annual energy cost savings. A payback period of 2 years and 1.8 months was estimated.

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List of Abbreviations

TTL	Transpower Technologies Ltd
LPG	Liquefied Petroleum Gas
KPLC	Kenya Power & Lighting Company
EPRA	Energy & Petroleum Regulatory Authority
MCCB	Molded Case Circuit Breaker
CFL	Compact Fluorescent Lamp
fc	Foot candles
LED	Light Emitting Diode
VFD	Variable Frequency Drive
IR	Infrared

CHAPTER ONE: INTRODUCTION

1.1 Introduction and Background

Energy sources in Kenya consist of imported fossil fuels, renewable sources including hydro power, geothermal, solar and wind. The total installed (grid connected) capacity of electricity is 1.429MW [1]. However, this energy is inadequate due to a demand of 1.6MW that outstrips supply [1]. High cost of building new energy infrastructures as well as the inability to get electricity from points of generation to point of use are challenges leading to inadequate energy.

Petroleum forms the main sources of energy and the price of this energy on the world market has steadily risen over the years from 53.59US$ per barrel in Jan 2017 to 76.73US$ per barrel in Oct 2018 [2]. The cost of this fuel affects cost of electrical energy since this cost is shifted to customers as fuel charge. In an endeavor to reduce over reliance on fossil fuels, several technologies have been considered to harness renewable energies. They include use of solar PV to tap solar energy.

Energy auditing requires evaluation of the amount of energy used by various systems and equipment in a building over a given audit period. Metering in Kenya is rather limited to KPLC and for such cases data would be obtained from electricity bills which cover the whole building. For individual systems or equipment, energy efficiency would be estimated from consumption.

There are several factors that determine energy consumed in a building which include how a building is used, the age of the building, the type of construction and the insulation of a building. Each of these factors has to be evaluated in identifying energy saving potential in a building and the economic viability of each.

In Kenya EPRA is the body that sets, reviews and adjusts electricity power tariffs, structures and investigates tariff charges. The commission is also mandated with approving electric power purchase and network service contracts for all persons engaging in electric power generation. The commission is responsible for categorizing the different type of consumers in the country based on energy consumption.

Effective energy management practices not only reduce cost and increase profit margins but also drive the whole enterprise into improved performance through its effects on operations, maintenance and environmental issues, furthermore improved energy practices raise the competitiveness of a facility.

1.2 Problem Statement

Energy is an integral factor of production in most organizations. High energy bills in the workshop, as will be illustrated in the report, had been increasing the cost of production. This should not be the case since there was considerable scope to reduce energy consumption and hence cost. Savings may be achieved for little or no cost at all. Investments could be made to save energy further.

Reduction in energy use generated from fossil fuels lead to reduction in carbon dioxide emissions. Carbon dioxide contributes negatively to the environment through global warming effect. Energy savings therefore go a long way in conserving the environment.

Metal fabrication workshops of equal level of production utilized less energy as evident in lower pricing of similar products from one of the competitor. This was evident as raw materials were obtained from the few suppliers available in the country and at relatively the same cost. The difference in pricing was therefore attributed to how workshops utilize other resources, energy playing a big role. These observations provided an opportunity to research on energy saving opportunities in the workshop.

1.3 Research Objective

The objective of this research was as follows;

i. Investigate the energy stream in the workshop to establish how energy was being used and uncover possible waste.

1.4 Expected outcomes

i. To quantify energy consumed by various loads in the workshop prior and after introduction of possible energy saving solutions.

1.5 Transpower Technologies Ltd (TTL)

TTL is an engineering fabrication solution provider located along Eastern By-pass behind Kenya Clay Products Ltd in Kiambu County. The company was founded in January 2017. Its management structure includes one director, a production manager, Human Resource Manager, Finance manager and one Engineer. The company is supported by a workforce of 22 persons in various capacities that include machine operators, general fitters and electricians.

The company deals with fabrication of cable management systems that include trunking, cable trays, cable ladders, single and twin metallic plates, various brackets to support the cable management systems, galvanized street light poles and floor boxes. They also fabricate and assemble LV boards, Power Factor Correction units, and machine starters and pump control panels. The average production of the above items per year is 4,468 units.

The primary source of energy for this company is electricity supplied by KPLC and metered by a three-phase meter located at the main metering panel. The energy is used to power various machines used for production in the company.

Table 1.1 shows annual energy consumption parameters for TTL. 300 days have been considered in a year based on the number of days indicated on the energy bills by the power supplier.

Table1.1: Annual average energy details for TTL

Annual Electricity Cost (Ksh)	973,284
Annual Energy Consumption (kWh)	62,390

1.5.1 Electricity Metering

Energy cost can be complicated if no effort is made to understand how its various forms are metered. In the past, many institutions have not treated energy as a substantial component of a product’s cost. These costs have been assumed to be an overhead rather than a direct cost. Energy management awareness has changed the above notion and energy managers are continually endeavouring to understand how energy in its various forms is metered, the electric tariff they fall under and how much they are charged for various components in their electric bills. The chargeable items include consumption, demand, power factor and taxes [4].

Kenya Power is the body responsible for distribution and sale of electricity to customers in Kenya. They use tariff structures that have been set by EPRA. The structures serve several classes of customers. The classes vary in complexity of energy use, amount of consumption and priority of need.

Table 1.2 shows the tariff structure that is applicable to various customer classes in Kenya. It shows that the typical customer categories are domestic, commercial, industrial and street lighting. It further shows the chargeable components under each tariff [5].

Table1.2: Tariff Schedules in Kenya [5]

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

In addition to the charges shown, there are additional charges on each tariff as shown in Table 1.3.

Table 1.3 shows extra charges that are applied to all tariff categories to complete the electricity bill. These extra charges are directly proportional to the energy utilized by the customer.

Table1.3: Surcharge applied on all Tariff categories on 15/07/2018 [5]

Levy name	Description	Surcharge Rate(Kshs/kWh)
EPRA LEVY	This is the amount that goes to EPRA.	170.5
REP LEVY	This levy is passed on to the Rural Electrification Authority (REA) for implementation of the rural electrification projects.	284.29
FUEL ENERGY COST (FEC)	This is published monthly in the Kenya Gazette. It is reflective of the cost of generating electricity from thermal sources during the previous month. This money is collected by KPLC and all of it is passed on directly to electricity generation companies, who in turn pay fuel suppliers.	917.68
WRMA LEVY	Water Resources Management Authority Levy is charged on the cost of all units generated from hydropower plants above 1MW. The rate is variable per kWh and amounts collected are passed on to WRMA.	7.96
INFLATION ADJUSTMENT	Consumer price index is the underlying pricing factor.	114.56
FOREIGN EXCHANGE RATE FLUCTUATION ADJUSTMENT (FERFA)	This component is related to the fluctuation of hard currencies against the Kenya Shilling for expenditure related to the power purchasing agreement between Kenya Power and the Power Producers.	195.87
VAT	16% Value Added Tax on total bill incurred excluding levies.	909.72

The information provided on the bill in most cases, will include at least the following items:

Kilowatt Hours used - This is the energy consumed since the previous meter reading.

Billing Demand (kW) – This is the maximum demand that occurred during the billing period.

Days – Number of days covered by the current bill.

Tariff Code – Indicates which billing tariff is applicable to the energy and demand readings.

TTL falls under Small Commercial (SC) tariff on Table 1.2. As shown on the table, energy limit per month is 15,000 kWh and demand is not considered when billing. Demand refers to the average value of KVA measured over a given time interval. Maximum demand is the highest demand value registered during any given period.

1.5.2 Electrical Characteristics of TTL Workshop

In order to meet goals and customers' needs, TTL is equipped with a workshop where machines are housed and production occurs. The bulk of these machines are motor powered. The electric load in the workshop can be categorized as inductive or resistive. Electric motors are often the costliest items to run. It is therefore well worth understanding how induction motors use electrical energy and investigating possible energy conservation measures.

Table 1.4 shows the electrical characteristics of various loads found in the workshop. From the type of load column, it can be seen that most of the loads are inductive in nature.

Table 1.4: Electrical rating for various machines in the workshop

Item	Description	Quantity	Total Power	Voltage	Type of Load
1	Shearing Machine	1	7.5kW	415V	Inductive
2	Compressor	1	4kW	415V	Inductive
3	Power Press	1	7.5kW	415V	Inductive
4	Punching Machine	1	4W	415V	Inductive
5	Bending Machine	1	11kW	415V	Inductive
6	Spot Welding Machine	1	20kVA	240V	Resistive
7	Oven	1	18kW	415V	Resistive
8	Mig Welding Machine.	1	5.5kW	415V	Resistive
9	Arc welding machine.	2	7.6kW	240V	Resistive
10	Angle grinders	4	1.2kW	240V	Inductive
11	Hand Drills	3	900W	240V	Inductive
12	Incandescent Lights	16	960W	240V	Resistive
13	Vertical Drill	1	1100W	240V	Inductive
14	Powder coating machine	1	35W	240V	Resistive
15	Fluorescent Lights.	64	1152W	240V	Inductive
16	Exhaust Fan	1	22kW	415V	Inductive
17.	High Pressure Sodium Lamps.	3	750W	240V	Inductive

A walk-through audit was conducted in the workshop to become familiar with the building operation in regard to energy waste or inefficiency. A walk-through of the workshop revealed that operational practices associated with some machines in the workshop were inappropriate. They were continually operated “the way it has always been done”. These machines included angle grinders and powder coating exhaust fan. They were left running during short/lunch breaks and during powder coating preparations. If better operational practices were introduced and operators trained accordingly, energy could be saved [14]. General maintenance is another area that needed to be addressed. Records from the maintenance department indicated that maintenance is done once every three months. It was noted that machines with moving and rotating parts were insufficiently greased. In a machine that is poorly maintained, 5% more energy is utilized in moving these parts as compared to lower energy that could be used if greasing was thorough [14].

Powder curing oven in the workshop uses electricity as the only source of energy, the price of unit kWh is Ksh 15.60/= according to EPRA records for small commercial electricity tariff [5]. This is relatively expensive since there are other cheaper heat sources. It was noted that lighting is composed of fluorescent lamps, and incandescent lamps. Fluorescent fittings with magnetic ballast utilize 2% more than the rated power due to the ballast [6]. Incandescent lamps lose energy in form of dissipated heat [6]. The power responsible for this heating is wasted since it did not contribute towards direct lighting. Retrofitting fluorescent and incandescent lamps with other energy saving lamps could be a potential energy saving venture.

These observations indicated an existing potential to save energy in the workshop. Savings in energy and hence savings in cost would contribute to low cost of production hence improve competitiveness of the products in the market which are relatively expensive compared to other products of equal quality from other manufacturers.

CHAPTER 2: LITERATURE REVIEW

2.1 Energy Management

Energy management is the efficient and effective use of energy to maximize profits (minimize costs) and enhance competitive positions [3]. In Kenya, the government, businesses and industries have been under economic and environmental pressure in the recent past. In most organizations, operational and capital costs investment decisions are largely informed by factors such as being economically competitive in the market and meeting increasing environmental standards to reduce air and water pollution. Energy management has been an important tool that has assisted many institutions in meeting the above objectives [4].

Environment quality can be improved by reduction in global warming. The primary cause of global warming is carbon dioxide, CO_2.

Equation 2.1 shows that combustion of natural gas, mostly methane, results in release of carbon dioxide to the atmosphere.

$$CH4 + 2\ O2 = CO2 + 2\ H2O \qquad \text{Equation 2.1}$$

Commercial and industrial energy use accounts for about 45% of the carbon dioxide released from burning of fossil fuels [4]. Energy management in industries involves implementing new energy efficient technologies, new materials and new manufacturing processes and the use of new technologies in equipment and materials. All these activities aim at reducing kWh consumption in industries reducing load on thermal power plants and hence reduction in emitted carbon dioxide.

2.2 Electric Motors

In almost every process in manufacturing, motors are involved. Energy costs incurred through use of motors account for nearly half the energy bill in any institution. Their widespread application in many industrial processes makes them a ready target for study on how to improve their efficiency and their energy consumption. Consequently, any small improvement in the efficiency of motors in an installation will go a long way in reducing energy cost for the installation.

There are many machines fitted with motors in buildings today. These machines include pumps, escalators, fans, compressors and lifts. They use induction motors and energy inefficiencies in motors happen due to losses.

There are different ways of stemming energy wastage in motors; one of the ways is purchase of high efficiency motors (HEMs) and use of several factors that obscure the high cost of motors already in use. These options range from low cost solutions such as installation of time switches to sophisticated variable speed drives (VSDs) and an improvement in power supply for motors [9]. This wide variety of solutions makes it difficult to decide which option is best for a particular application. Concentrating on the drive itself is not enough. Attention should be given to the driven system as well so as not to miss the energy saving opportunities.

2.3 Energy saving opportunities in motors

The power supply characteristic can be damaging to a motor power uptake. Harmonic distortion, voltage imbalance, a high or low supply voltage can contribute to the aforementioned [9].

Switching the motor off when it is not needed is the simplest way of reducing energy wastage in motors. Techniques for switching off can include [9]; manual switching off, interlocking, time switch, and sequencing of multiple motor loads and load sensing. Manual switching off is the cheapest but the most unreliable since people can forget. There is also the inconvenience brought about by waiting for the machine to start again in this mode of switching. An example of interlocking is when an extract fan starting whenever a powder coating gun is active. In time control, a timer switch can be fitted to an extract fan to ensure that the motor starts after some set time.

Reducing the load in motors can result in efficiency improvement. Different energy saving opportunities exist for various applications. For example, in pumping, selecting a pump that is efficient and operating it close to its rated design flow and head will lead to energy savings. In a fan system, filters should be kept clean to minimize pressure drops. In a conveyor, a sensor can be installed to detect when the conveyor is unloaded and switch it off.

A common application of induction motors in buildings and factories is in fan and pump drives. A common approach that has been practiced before is to decide on oversized pumps and fans and then use controllers and dampers in the pipes and ducts during commissioning to control the flow rate. The constriction leads to energy loss. This situation is highly undesirable and is one of the main reasons why the energy consumption associated with fans and pumps is higher in buildings [10]. The alternative to this is to control the speed of the motor in the fan or pump. The speed control is achieved by use of variable speed drives. They operate by electronically matching the speed of the motor, and the power input to it, to the requirements of the load. Hence iron and other losses are reduced to a minimum resulting in substantial energy savings in buildings and factories [10].

Choosing the right motor size for the right task is important for their efficient operation. A small load for a relatively oversized motor will result in low power factor and low efficiency. At a low speed the efficiency is below 50% [6]. Typically motors exhibit efficiencies which are reasonably constant down to approximately 75% full load. Thereafter they may drop approximately 5% down to 50% of full load, after which the efficiency rapidly falls as shown in Figure 2.1 [6].

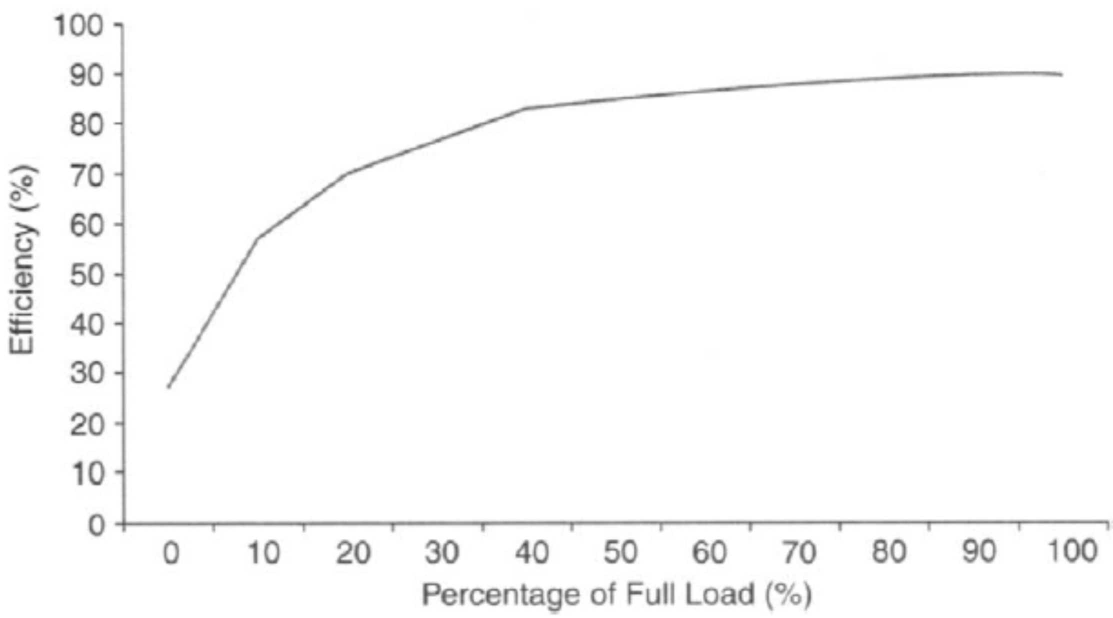

Figure 2.1: Graph showing motor loading against efficiency of the motor [6]

2.4 Lighting

Lighting consumes approximately 20% of electricity in most commercial and industrial buildings [11]. Today's economy demands that institutions should be cost competitive. To fulfill this endeavor, everyone is seeking technologies and other ways that will reduce energy costs in lighting systems and care for the environment too. Retrofitting and housekeeping are two methods in which energy consumption in lighting can be managed. The methods aim at reducing the rate of energy consumption (kWh). Lighting is expressed in three primary units [11]; watts, lumens and foot-candles (fc). It is of importance to consider these units when selecting the light lamp identified for energy saving. For example, it is recommended to choose a lamp with lower wattage and more lumens than an existing lamp.

In order to analyze the energy saving opportunity available in lighting systems, it is important to consider the components of the lighting system; lamp, ballast and the fixture. The choice of lamp determines the lighting quantity, the frequency of re-lamping and the operational cost. Different lamp technologies exist as follows [12];

Tungsten Filament Lamps **-** These lamps are inefficient and their use should be discouraged. Their efficacy lies between 8-15lm/W [12]. Their lifetime is short, typically-1000h of use. Despite their inefficiency, these lamps are still sold in large quantities due to their low initial cost.

Compact Fluorescent Lamps (CFL**)** **-** These lamps were developed to replace tungsten lamps. They have a longer lifespan compared to the tungsten filament lamp of about 8000-12 000 hours [12]. Their efficacy ranges between 60 -80 lm/W [13].

Fluorescent lamps **-** They exhibit efficacies in the region of 80-100 lm/W. Depending on the type of lamp and ballast used, they can last up to 18 times as long as tungsten filament lamps [13].

Metal Halide Lamps **-** They are common for their vast use in industrial spaces. They are available in a wide range of power ratings, 70-2000 W. They exhibit efficacies in the region of 70-100 lm/W, depending on their power rating [12].

High Pressure Sodium Lamps **-** These lamps are available in a wide range of power rating from 50W to 1000W and an efficacy of 70 -120lm/W [13]. They are commonly used to light high bay areas such as factory shop areas, warehouses, flood lighting and car parks.

LED lamps **-** This is the latest technology in lighting systems. LED lamps have a lifespan many times longer than equivalent incandescent lamps. The LED module inside the lamp consists of a semiconductor that emits light when current flows through it. The most efficient commercially available LED lamps have efficiency of 200lm/W [15]. The following are advantages of LED lighting technology [14];

i. Reduced heat – LED bulbs have been designed with adequate heat dissipation features like the heat sinks which allow their large surface area to release hot air from the LED lamp to the ambient environment surrounding it.
ii. Environmentally friendly – LED bulbs do not contain harmful chemicals or materials unlike incandescent bulbs or CFL bulbs that have harmful coating and mercury.
iii. Reduced maintenance – LED bulbs have a long lifespan therefore the frequency of repair is low.

However, LED lamps require an electronic driver when operated from the mains power lines and losses from this circuit mean the efficiency will be lower than that of the LED chips used to make the lamp. The capital cost of LED lamps is also high compared to any other equivalent lamp.

Lighting Controls

Energy savings can be achieved by lighting control based on availability of day light and switching off lights whenever an area is unoccupied. The most common methods for light control to save energy are [8];

i. Time based controls – a timer is used to switch lights on or off at set times.
ii. Daylight-linked controls – Photo cells are used to switch lights on or off. They can be mounted internally or externally. It is important to provide override timer switches which will prevent the photo cells switching on the lights due to passing clouds.
iii. Occupancy based control – this method uses infra-red, acoustic, ultrasonic or microwave sensors, which detect either movement or noise in room spaces. They should override switches. When movement is detected, they switch on the lights and vice versa when no movement is detected.
iv. Localized switches – applicable in large spaces. It allows turning off artificial lighting in specific areas, while still operating it in other areas where it is required, a situation which is impossible if the lighting for an entire space is controlled from a single switch.

2.5: Assessment of use of LPG in curing Ovens on energy savings.

The process of applying powder to the surface of a product is identical to the traditional way of applying liquid coatings; the parts to be coated go through pretreatment where they are cleaned to remove grease, oil and rust. This process is carried out using degreasing agents, alkali cleaners and rinses. The products then enter the spray booth where the powder is applied using spray guns. After the coat is applied, the products are put in the oven to dry and cure the coating. The oven exposes the powder to extremely high temperatures (200^{o}C) for approximately 45 minutes. The particles melt and chemically react with one another forming a high-molecular weight polymer [14]. The resulting polymer is extremely hard and durable. Ovens exist in different types namely [14];

- Process ovens.
- Infrared ovens.
- Gas ovens.
- Electric ovens.

2.6 Methods and measurement technologies

Energy auditors use different ways to configure energy standards in regard to consumption and efficiency. With the use of such standards, energy consumption before and after the application of energy saving measures can be estimated. Parameters to be measured can be categorized as follows [13];

(a) End use energy input to the unit- like electricity and fuels. In the case of solid fuels, it is necessary to include measurements for the heating value, humidity, ash, stable carbon and volatile substances.
(b) Energy flow, conversion and losses – these are parameters that distinguish between production and building facilities. Example is losses in electricity.

A suitable measuring method is considered for every parameter under investigation. A method could include one or more measurements of a single or more physical quantity.

A power analyzer is a complex instrument that measures all the above electrical parameters. After the instrument's proper connection to the electrical panel of machinery or the substation under examination, measurement readings are presented on its display. In this research electrical parameters were measured using a clamp meter. A lux meter was used to measure illumination levels of the workshop. Historical data on electricity bills was obtained and analyzed to obtain the variation in energy bills over the period. The production data for the same period was obtained as well. Comparison was done between the energy cost and the rate of production to check whether there were any logical relationships.

CHAPTER 3: METHODOLOGY

3.1 Assessment of the use of VSD on motors

To evaluate the application of VSD in an exhaust fan;

i. Voltage and current consumption of the exhaust fan were taken using a clamp meter during the powder coating process. This data was recorded and used in the analysis of the current energy consumption by the fan.
ii. The nameplate data of the exhaust fan motor was also recorded. This data was used to search for a VSD compatible and equal in characteristics to the motor.
iii. The performance of the fan was compared with and without VSD.
iv. Analysis of the possible energy savings if the VSD was to be implemented, was later carried out.

3.2 Assessment of retrofitting conventional lamps with LED lamps and House Keeping Measures.

In this assessment;

i. The illumination of the workshop and the office area due to the existing lighting system was measured by use of a lux meter at different positions. This was to evaluate the effectiveness of the existing illumination against the recommended illumination levels.
ii. During the walk through, the compressor and the exhaust fan were noted to be idle during different times; energy consumption by these machines was computed from the measurements of the clamp meter; current and voltage. The number of minutes each machine was left idle was recorded for a number of days. The average was computed from these records. The average time was used for energy wasted computations.

3.3 Assessment of use of LPG instead of electricity energized elements in curing ovens on energy savings.

To evaluate the effectiveness of LPG in curing;

i. Current and voltage measurements were taken on the existing elements using a clamp meter. The number of hours that the elements were in use was also recorded. Energy consumption and energy cost was computed.

ii. Data (price per kg, best burners for ovens and time taken to burn one kg of gas) on LPG was collected from Total Kenya documents. The efficiency of the LPG was checked from Total Kenya documents as well. Analysis on the fuel that could be burnt for one week was done and comparison of the cheaper source of energy was made to establish the more cost effective source of energy.

CHAPTER 4: RESULTS AND ANALYSIS

4.1 Introduction

4.1.1 Utility power supply

Electricity is the only source of energy in (TTL). It is supplied by Kenya Power using a 3-phase 4-wire system. A three-phase electronic meter has been installed at the metering panel which measures consumption, stores and displays the data on the digital display. The data is then read at intervals of one month from which the electricity bill is generated. The power is fed to a 125A MCCB in the LV Metering Board located in the metering room. From this LV Board, power is reticulated to the workshop through a 25mm^2 4-core armored cable to a 125A distribution board inside the workshop.

4.2 Results from energy saving measures

4.2.1 Historical Data

Table 4.1 shows energy cost and production for each month in year 2017.

Table4.1: Year 2017 electricity bill for Meter No. 061577360

Month	**Energy Consumption(kWh)**	**Power Factor**	**Monthly Bill (Ksh.)**	**Production (units)**	**Energy Cost per Unit(Ksh.)**
January 2017	32	0.95	500	-	-
February 2017	60.769	0.95	948	-	-
March 2017	100.448	0.93	1,567	-	-
April 2017	4014.42	0.94	62,625	375	167
May 2017	5371.92	0.95	64,600	380	170
June 2017	4471.15	0.90	69,750	375	186
July 2017	4701.28	0.91	73,340	380	193
August 2017	4725	0.91	73,710	378	195
September 2017	4823.07	0.90	75,240	380	198
October 2017	4880	0.90	76,130	370	205
November 2017	4102.564	0.90	64,000	400	160
December 2017	4557.69	0.91	71,100	395	180
Total	**41,840.311**		**633,510**	**3,433**	

Table 4.2 shows energy cost and production for each month in year 2018.

Table4.2: Year 2018 Electricity Bill for Meter No. 061577360

Month	**Energy Consumption(kWh)**	**Power Factor**	**Monthly Bill (Ksh.)**	**Production (units)**	**Energy Cost per Unit(Ksh.)**
January 2018	5686.35	0.91	88,707	420	211
February 2018	5167.37	0.91	80,611	400	201
March 2018	5230.96	0.90	81,603	410	199
April 2018	5026.41	0.90	78,412	391	200
May 2018	5371.92	0.90	83,802	405	206
June 2018	4225.38	0.90	65,916	395	166
July 2018	5685.76	0.91	88,698	390	227
August 2018	4667.56	0.91	72,814	350	208
September 2018	5730.77	0.90	89,400	390	229
October 2018	4880	0.90	76,130	370	205
November 2018	5518.2	0.90	86,084	390	220
December 2018	5199.17	0.91	81,107	350	231
Total	**62,390**		**973,284**	**4736**	

An analysis on energy cost per unit produced is included. The data under production in units varies each month. If this data is arranged in ascending order, there is a steady increase in energy cost per unit. In some instances the number of units produced decreased but the energy cost increased. This informs the need to explore energy saving opportunities.

4.2.2 Energy savings by use of VSD

Observation carried out showed that the exhaust fan operated continuously on constant speed regardless of the volume of powder to be sucked out of the painting booth. Adjusting the speed of the motor based on the volume of suspended powder at the booth could go a long way in saving energy at the workshop.

In this application the controlled parameter would be the powder particle concentration inside the exhaust duct from the spray booth. The form of control would be by use of sensors located inside the exhaust duct. The sensors would detect particle presence when the air flows inside the exhaust duct. The sensors send signals to the VFD which in turn varies the speed allowing the fan to increase or decrease the flow volume of exhaust powder based on the operator's actions in the booth. For example, when the operator is changing the surface of the item being painted, the sensors would detect less powder particles. The VFD would reduce the speed of the fan. Table 4.3 shows parameters obtained from the fan name plate and by measurements.

Table 4.3: Motor baseline information

Motor size	30Hp
Input voltage as measured by clamp meter.	415V
Full load current as measured by clamp meter.	40A
Efficiency	85
Frequency	50
Speed(RPM)	1800
Hours used per day	11
Days per week	6
Appropriate speed profile(RPM)	1000-1800

4.2.3 Energy Savings through retrofitting Fluorescent lamps and HP Sodium Lamps with LED lamps

During the audit, it was observed that the lighting system in TTL is made up of 2ft fluorescent tube fittings, high pressure sodium lamps and incandescent bulbs in the washrooms. The ratings of these light fittings are 18W, 250W and 60W respectively. Table 4.4 shows illumination level in the workshop at three different locations illuminated by different lamps as measured with the lux meter.

Table4.4: Illumination levels in the workshop

Lux meter	Lux
L1	400
L2	200
L3	131

Reading L1 was taken in the office area where artificial illumination is provided by T8 FTL. Reading L2 was taken in the main workshop floor where artificial illumination is provided by high pressure sodium lamps. Finally, reading L3 was taken in the changing rooms and washrooms where incandescent lamps provided lighting.

4.2.4 Energy saving through housekeeping measures.

The compressor is an integral machine in the workshop. It was switched on at the beginning of a shift in the morning and switched off in the evening. During a two shift working day, it remained on for the whole period. The compressor was left to idle for 10 minutes during tea break and for another 10 minutes during lunch break.

The exhaust fan was switched on immediately the operator got into the spray booth. The first 10 minutes were used to place and set items to be powder coated. Energy was being wasted through the running fan.

4.2.5 Energy Saving by use of LPG instead of heating elements in drying/heating Oven

Technology has been developed to use LPG when drying items for powder coating and for curing the powder after it is applied. In this study, the existing 18kW electric oven was considered for replacement with an LPG oven. This oven consisted of six-3m elements fixed on the side of the oven, each side having three elements. Each element was rated 3kW. The oven measures 3m long x 2m high x 1m wide. During a normal cycle, electrical parameters of the electric oven were measured at the oven distribution board using the clamp meter and readings were as shown on the Table 4.5. The LPG infrastructure should be installed properly so as to ensure maximum primary air supply. Maximum combustion of the gas will be guaranteed to prevent carbon monoxide release into the atmosphere.

Table4.5: Electric oven electrical analysis

Type of Heating	**Current**	**Voltage**	**Max Temperature reached**	**Power (kW)**	**Time Taken (hrs.)**	**Energy utilized**
Drying items after degreasing.	L1 – 31.39A L2 – 30A L3 - 32A	L1 - L2 – 408.90V L2 – L3 – 408.4V L1 –L3 – 409.21V	100^0C	17.752	0.6 (40minutes)	10.6512kWh
Curing Powder.	L1 – 31.39A L2 – 30A L3 - 32A	L1 - L2 – 408.90V L2 – L3 – 408.4V L1 –L3 – 409.21V	200^0C	17.752	1.75 (1hr 45min)	31.066kWh
Total					2hrs 25min	41.7172kWh

Table 4.5 shows the electrical properties of the oven, the total energy utilized during one cycle operation of drying and curing is 41.72kWh. It takes around 2hrs 25min to utilize this energy. In a day, the average number of cycles is three (3) implying that the total energy consumed by the electric oven in a day could be 125.15kWh.

4.3 Analysis of the results obtained for energy saving measures

Historical data was analyzed to obtain information as follows;

Table 4.6 shows the cost per unit of energy for the two years under consideration.

Table4.6: Annual average electricity energy cost per unit 2017/2018

Year	**Energy production cost per unit (Ksh)**
2017	186
2018	206

From the table, there was an increase in the cost per unit of Ksh. 20 in the 2 years under consideration.

4.3.1 Energy savings by use of VSD

To determine the suitability of a VSD on an existing powder exhaust fan, the VSD parameters defined in Table 4.7 were considered.

Table4.7: Exhaust fan parameters

Control parameter	Air/Powder flow
Condition Monitored	Low Flow
kW rating of the motor	22kW
Supply Voltage	415V (3-phase)
Horsepower Rating of the motor	30HP
Rated Current	40Amps
Rotations per Minute	1800RPM

Other factors to be considered involved the compatibility of the VFD with the motor and also the cable runs from the fan motor to the drive. These parameters were keyed in the Schneider Electric online drive portal. The compatible drive with exhaust fan motor was identified as the ATV63 380V 3 PHASES from Schneider Electric.

Sucking excess powder from the booth can be achieved over a range of speeds. Energy saving opportunity can be realized by exploring the least possible speed of the motor without affecting functionality. By choosing the appropriate VSD to explore this speed range, energy savings could be achieved.

Therefore the annual expected energy savings cost is **Ksh.72, 750** as depicted on VFD online calculator.

4.3.2 Energy Savings through retrofitting Fluorescent lamps and HP Sodium Lamps with LED lamps

The total electrical load contribution from the lighting system amounts to 2862 watts per day. Considering a 10-hour usage day and 300 days in a year (excluding holidays and scheduled maintenance downtime), 8586 kWh of energy is utilized by lighting load annually.

Figure 4.1 shows the utilization of the lighting power by lamp fixtures.

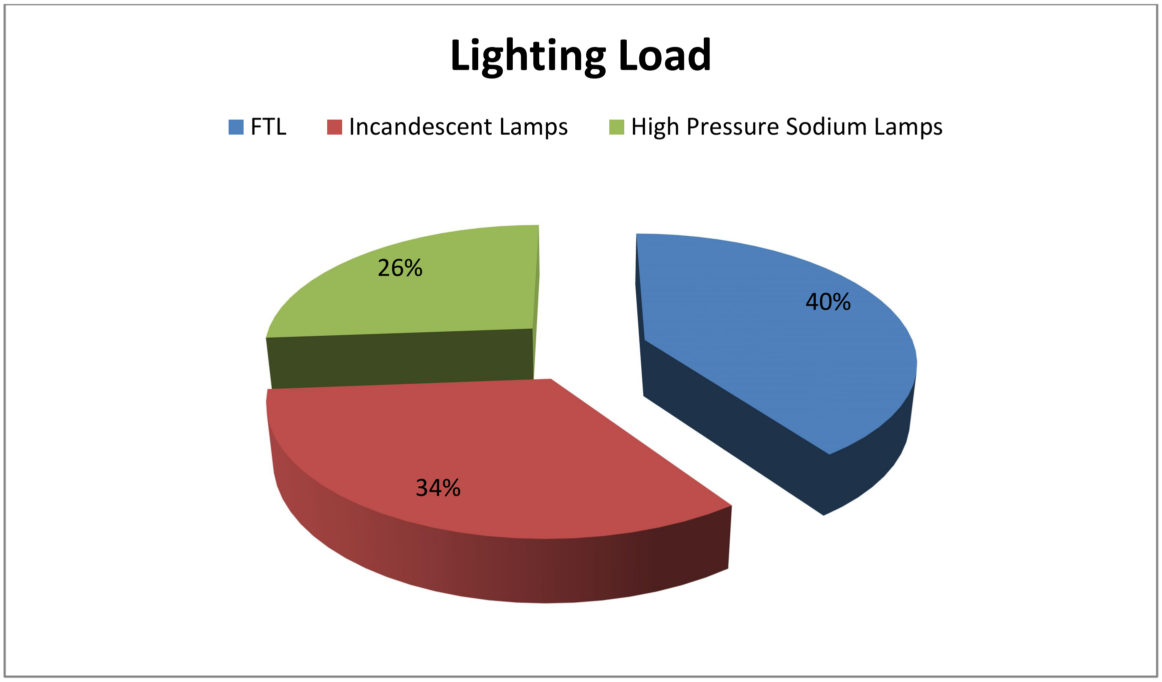

Figure 4.1: Distribution of lighting load

Fluorescent tube light fittings account for the 40% (1152 watts) of power consumed followed by incandescent lamps 34% (960 watts) and HPS Lamps which utilize least power; 26% (750 watts). HPS lamps utilize a relatively high percentage (26%) despite being three in number in the workshop. This is informed by the high power rating of the lamp.

LED lamps were considered to replace the existing lamps in order to save energy and achieve the recommended illumination levels in the International Illumination Standards (IEA, 2012). The T8 18W FTL can be substituted by 9W LED fitting. LED lamp efficiencies range from 80% to 90% compared to conventional lamps which have efficiencies ranging from 40% to 60%. In addition, LEDs have good color rendering.

The recommended illumination levels in the depicted areas by the International Illumination Standards (IEA, 2012) are 500 lux- (lumen/m^2), 250 lux and 160-180 lux respectively.

Table 4.8 shows existing light fixtures, their respective equivalent LEDs considered for replacement and their respective brightness.

Table 4.8: LED brightness used to replace existing lamps [14]

Existing Lamp Type	**Brightness (lumens)**	**Recommended Illumination level in lumens by (IEA,2012)**	**Equivalent LED Lamp**	**Brightness (lumens)**
T8 18W 2ft Fluorescent Tube Lamp	400	500	T8 9W Fluorescent LED 2ft fitting	750
250W High Pressure Sodium Lamp	200	250	100W LED Flood Light	500
60W Incandescent Lamp	140	160-180	18W LED bulb	200

The lighting level would be improved by use of the proposed LED lamps as shown in Table 4.8 on the brightness of the conventional and LED lighting.

Baseline Information

1 day = 10 hours

1 year = 300 days (holidays and non-working days due to planned shutdowns excluded)

Table 4.9 shows that use of LEDs would lead to energy savings amounting to 5,850kWh annually with an annual energy consumption of 2,736kWh down from 8,586kWh.

Table4.9: Energy savings by use of LEDs

Item	Recommendation	Quantity	Annual Energy consumption of Existing Lamps(kWh)	Annual Energy Consumption with LED lamps(kWh)	Expected Annual Energy Savings. (kWh)
1	Replace T8 18W FTL with T8 9W 2ft LED FTL	44	3456	1188	2268
2	Replace 250W High Pressure Sodium lamps with 100W LED floodlights	3	2250	900	1350
3	Replace 60W incandescent lamps with 18W LED bulbs	12	2880	648	2232
	Total		**8,586**	**2,736**	**5,850**

Retaining the number of lamps after retrofit would ensure we had improved lighting levels in the workshop as per International Illumination Standards.

4.3.3 Energy saving through housekeeping measures.

The compressor was left to idle for a total of 20 minutes. The energy savings per day could be 1.3kWh and 390kWh annually if the compressor was switched off during this idling time.

The exhaust fan was idle for 10 minutes .The energy saved could be 3.6kWh in a day and 1080kWh annually if this trend was stopped. Therefore, housekeeping measures could result in an annual energy savings of 1470kWh. The corresponding annual energy cost saved could be Ksh. 22,932.

4.3.4 Energy saving by use of LPG instead of heating elements in drying/heating oven

To switch to an LPG-butane oven, the current oven would be modified as follows; uninstall the heating elements, install gas supply tube, gas tap/valve, gas injector jet, primary air openings, and gas mixing tube, burner head and burner ports (orifices).

According to Total Kenya, a 12MJ burner would be sufficient to heat a $6m^3$ oven. 1kg of LPG has a heating value of 49MJ/kg. Assuming the burner had 90% conversion rate. 49/14 = 3.5 hours. Therefore 1kg of butane gas could burn for 3hrs 30minutes. A 13kg gas cylinder could be sufficient for the drying/curing purpose.

Table 4.10 shows the characteristics of an LPG oven equivalent to the existing one.

Table 4.10: Equivalent LPG oven characteristics

Type of Heating	Desired Temperature	Time Taken to achieve desired Temperature (hrs.)	Butane Utilized Gas(kg)
Drying items after degreasing.	100^0C	0.66 (40 minutes)	0.5
Curing Powder.	200^0C	1.75 (1hr 45 minutes)	1.5
Total		2 hr. 25minutes	2.0

The heating time per cycle is 2hour 25minutes.Total amount of LPG gas utilized is 2.0kgs per cycle. For three cycles in a day, the total gas utilized would be 6kgs.

4.4 Economic Evaluation

4.4.1 Economic Evaluation: use of VFD

The variable frequency drive considered in this case was found to have the following specifications as shown in Table 4.11.

Table4.11: VFD specifications

Supply frequency	50 – 60Hz
Number of phases	3
Rated supply voltage	380-480V
Motor power	22kW/30HP
Line current	39.6A
Apparent power	28.6kVA
Speed drive output frequency	0.1 – 599Hz
Nominal switching frequency	4kHz
Output voltage	= power supply voltage

Table4.12: VFD calculator

Motor Size (HP)	30
Input Voltage(V)	415
Full load Current(A)	40
Efficiency (%)	85
Frequency (Hz)	50
Speed (RPM)	1800
Hours/day	11
Days/week	6
VFD Cost($)	2910
Electricity Cost($/kWh)	0.156
Annual savings($)	727.5
Payback period	48 months

The following can be deduced;

Expected annual energy savings = **4,663.46kWh**

Projected annual energy cost savings = **Ksh. 72, 750**

Capital investment = **Ksh. 326,000**

4.4.2 Economic Evaluation: Retrofitting conventional lamps with LEDs

A 2ft 18W LED fluorescent tube cost Ksh. 1,000 (Philips), an 18W LED bulb costs Ksh.600 (Philips) while a 100W floodlight costs Ksh. 6,500 (Philips). Installation and miscellaneous costs were assumed to be 10% of the total investment cost as per various surveys done by National Construction Authority.

The analysis in Table 4.13 shows the cost of replacing conventional lamps with LED lamps.

Table4.13: Economic analysis of switching to LED lighting

Light fixtures for replacement.	**Quantity**	**Expected Annual Energy Savings(kWh)**	**Expected Annual cost Savings(Ksh)**	**Expected Investment (Ksh)**
Replace T8 18W FTL with T8 9W 2ft LED FTL	44	2268	35,380	44,000
Replace 250W High Pressure Sodium lamps with 100W LED floodlights	3	1350	21,060	19,500
Replace 60W incandescent lamps with 18W LED bulbs	12	2232	34,819	7,200
Total		**5,850**	**91,259**	**70,700**

From Table 4.13;

Annual energy savings by use of LEDs = **5,850kWh.**

Total annual energy cost savings = **Ksh. 91,259**

10% of the total investment (installation cost) = **Ksh. 7,070**

Expected investment cost = $\boldsymbol{Ksh\ 70,700 + ksh\ 7,070 = ksh\ 77,770}$

4.4.3 Economic Evaluation: use of LPG in Drying/Heating Ovens

A 13kgs gas cylinder from Total Kenya retails at Ksh 2,300 to refill. This cylinder lasts for a period of two days. An additional Ksh 500,000 was considered as installation and commissioning costs.

Number of days that oven was in use = 290.

Table 4.14 shows that annual energy cost savings could be Ksh. 232,670 and expected investment could be Ksh. 500,000.

Table4.14: Economic evaluation of LPG drying/Heating ovens

Description	**No. of 13Kgs cylinders per year**	**Expected Annual Gas Cost(Ksh.)**	**Expected Investment (Ksh)**	**Expected Annual cost Savings Compared to Electricity (Ksh)**
Twin Tube carbon IF emitter(2.5kW)	145	333,500	500,000	232,670

13kgs cylinders were settled on due to their ideal space utilization especially the vertical height as compared to other cylinders.

4.5 PAYBACK PERIOD FOR THE ENERGY SAVING MEASURES OUTLINED

Table 4.15 shows a summary of the total capital investment required to implement the outlined energy savings in TTL to give maximum energy savings annually.

Table4.15: Total capital investment and total energy savings

Item	Measures	Annual Energy savings(kWh)	Annual Energy Cost Savings in Kshs.	Capital Investment in Kshs.
1	Use of VFD	4663.46	72,750	326,000
2	Use of LEDs	5850	91,259	77,770
3	House Keeping Measures	1470	22,932	0
4	Use of LPG drying/heating Oven	36,293	232,670	500,000
Total		**48,276.46**	**419,611**	**903,770**

If all the identified energy saving opportunities were implemented, the total annual energy cost savings would be Ksh. 419,611 and the total capital investment would be Ksh. 903,770. Therefore, the payback period can be computed from total capital investment and annual energy cost savings as,

$$\text{Payback Period} = \frac{\text{Total Capital Investment Cost}}{\text{Annual Energy Cost Savings}} \qquad \text{Equation 4.1}$$

$$= \frac{903{,}770}{419{,}611} = 2.15\text{years}$$

$$= 2 \text{ years } 1.8\text{months}$$

From Equation 4.1, the total annual energy cost savings and the total capital investment cost resulted in a payback period of 2 years and 1.8months if all the outlined energy savings opportunities are implemented. This showed that the economic aspect would be sound if the opportunities were to be implemented to lower energy bill in TTL.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The objective of this study was to identify energy savings potential in a metal fabrication workshop with a case study conducted in TTL. From the findings recorded in this report, four energy savings opportunities were identified. The four areas resulted in a projected total annual energy savings of 48,276.46kWh and an annual energy cost savings of Ksh. 419,611. Out of the four identified energy savings opportunities, use of LPG drying/heating ovens yielded the highest predicted energy savings, followed by use of LEDs, use of VFDs and finally practicing the outlined housekeeping measures.

Economic evaluation was conducted in a manner that made it easy to calculate payback period from the total of the investment and total annual energy cost savings. A payback period of 2 years and 1.8 months was obtained as outlined earlier.

VFD is a technology that is widely used today to vary the speed of motors in a number of non-constant load applications. Use of VFDs on existing motor installation is not a common phenomenon yet the potential for energy saving is high. In TTL it was observed that the best application for VFD would have been the exhaust fan since the motor had been on constant speed throughout yet at times no actual powder painting occurred due to delays occasioned by time delay in setting items in the booth and also while moving them into the oven.

Housekeeping could have a great impact on energy savings if well observed. As noted in the report, most of the energy wasted by idle machines is during break times. The few minutes that the machines are left idle may seem an insignificant period but resulted in energy wastage when summed up.

Retrofitting conventional lamps with LED lamps could go a long way in bringing the cost of energy down in TTL. During night shifts energy consumed by 2ft fluorescent tubes, high pressure sodium lamps and incandescent lamps could be lowered greatly as outlined in this study by retrofitting them with LED lamps. Use of LED lighting technology is currently on the rise and this is a step in the right direction as far as energy conservation is concerned. LED lamps are more efficient than the conventional lamps as shown by their higher efficacy [15]. They have better color rendering and have a longer lifespan compared to conventional lamps [17].

5.2 RECOMMENDATIONS

The management of workshops across the industry should appoint personnel responsible for matters pertaining energy. They should be trained on energy management practices and their importance to a workshop. They then head the energy management unit, sensitize other personnel on the need to save energy and be responsible for switching off all machines during breaks. Energy could be saved with minimal investment cost.

Startup workshops should endeavor to achieve energy management from the starting point. They should buy machines with high efficiency motors, extraction fans with VSD, lighting technology should be made up of LED lamps and implement LPG heating/drying oven with the endeavor of saving energy. For existing workshops, an energy conservation fund should be set up to assist with financing of energy conservation measures in the workshop. Contribution to this fund should be made on a monthly basis for a period of about two years. This fund will enable them initiate energy audits and identify energy saving opportunities and explore these opportunities with less struggle.

Another recommendation is that the government should have a long term commitment to promote energy efficiency in industries in Kenya.

REFERENCES

[1] Gwénaëlle Legros, Ines Havet, Nigel Bruce. “A Review Focusing on the Least Developed Countries and Sub-Saharan Africa.” Energy Access Situation in Developing Countries and world energy Outlook (IEA 2009), November 2009, vol 1, pg. 142.

[2] Miguel Barrientos. (2019, May). *World Population Clock,* Retrieved from https://www.indexmundi.com/commodities/ world population clock, 11th May 2019.

[3] Caperhart, B. L., W. J. Kennedy and W. C. Turner, *Guide to Energy Management, International Version, Fifth Edition,* The Fairmont Press, Incorporated, 2008

[4] Turner, Wayne C. and Steve Doty, *Energy Management Handbook*, *Sixth Edition*, The Fairmont Press, Incorporated, 2008.

[5] Energy and Petroleum Regulatory Authority. (2018, July), *Retail electricity tariff review for the 2018/2019 tariff control period*, Retrieved from EPRA website https://www.erc.go.ke , 15th July 2018.

[6] Beggs, C, (2002*) Energy Management, Supply and Conservation* – Elsevier Butterworth-Heinemann, 2nd edition.

[7] Laurent Mischler, *Electrical Installation Guide*, Lyon, Schneider Electric, 2016.

[8] Doug Wayne, *Energy Savings with motor and drives*, Good Practice Guide, volume 2 (1998), pg. 53, GSHPA, December 1989.

[9] Harwell Didcot, *Energy use in offices*, Energy Consumption Guide, vol19, Department of the Environment, Transport and the Regions, 1998.

[10] CIBSE, *Code for interior lighting*, Good practice Guide, Ground Source Heat Pump Association, volume 2, issue 1, pg. 56,1997.

[11] CIBSE, *Energy Management and Good Lighting Practices*, Fuel Efficiency Booklet, Groud Source Heat Pump Association, Volume 12, 1993, pg. 75.

[12] W Muhamad, Wan & Mat Zain, Mohamad Yusof & Wahab, N & Aziz, Hafizah & Abd Kadir, Rosmalini. (2010). “Energy Efficient Lighting System Design for Building”., International Conference on Intelligent Systems, Modeling and Simulation . 10.1109/ISMS.2010.59,pg 282-286.

[13] Charles Hester, *Powder Coating Technology*, 1989, Cary North Carolina.

[14] Hermann Siebert. “Proper lubrication plays a role in energy efficiency”, Plant Engineering, 21 Jun .2011. Retrieved from https://www.plantengineering.com/articles/proper-lubrication, 6th June 2019.

APPENDICES

Appendix 1: Types of Loads

Inductive machines convert electrical energy from the system into work and heat. In order to perform this conversion, magnetic fields have to be established in the machines. Magnetic field is created by circulation of current in coils, the current in these coils lag 90^{o} relative to voltage and represent the reactive current absorbed by the machine. Examples are motors and transformers. In resistive loads current is in phase with the voltage and consist of mainly heating elements and incandescent lighting loads.

Appendix 2: Definitions

Watt is the unit for measuring electrical power. It defines the quantity of power consumed by an electrical device when it is in operation. The amount of watts consumed represents the electrical input to the lighting system.

Lumen is a measure of a lamp's output. The foot candle is a measure of the amount of light reaching a work top.

Foot-candles are the end result of watts being converted to lumens. Foot candles express the result of a lighting system.

Appendix 3: Measurement Instruments used

Specialized instruments were used during the research are listed in the Table 3.1.

Table3.1: Measurements Tools

Tool	Description
Clamp Meter	Measures voltage, current and resistance in a circuit. The clamps measure the current while the probes measure voltage. It has a hinged jaw that allows operator to clamp a conductor at any point in an electrical system, then measure current without disconnecting/de-energizing it.
Lux Meter	Used to measure illumination in a work place.

Clamp Meter Lux Meter

Figure 3.1: Clamp Meter and Lux meter

Figure 3.1 show images of a clamp meter and a Lux Meter respectively that were used to take measurements of workshop power parameters and illumination levels in the workshop respectively.

The instruments used to carry out the measurements were of high precision. Table 3.2 and Table 3.3 show the accuracies and technical specifications of the instruments used.

Table 3.2: Clamp Meter

Clamp Meter PCE-DC 2	
AC Current (50/60 Hz)	200AAC/±2.5%
DC Current	200ADC/ ± 2.0%

AC Voltage (50/60 Hz)	600VAC ± (1.5%)
DC Voltage	600VDC ± (1.5%)
Ohms	999.9Ω ± (1.5%)
Diameter of the conductor	Maximum of 18mm

Table 3.3: Lux Meter

Digital Lux Meter Metravi 1331	
Range	200,2000,20000,50000Lux/fc 1FC= 10.76Lux
Accuracy	± 5% rdg ±10dgts(10000Lux/fc)