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MSc. (ENG) Energy Management

IDENTIFYING ENERGY SAVING OPPORTUNITIES IN A COMMERCIAL BUILDING IN NAIROBI:

A CASE STUDY OF EQUATORIAL FIDELITY CENTRE IN WESTLANDS NAIROBI.

DECLARATION

I declare that this work has not been previously submitted and approved for the award of a degree by this or other University. To the best of my knowledge and belief, the project report contains no material previously published or written by another person except where due reference is made in the report itself.

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Approval

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Firstly, I wish to thank God for the good health and peace of mind during the entire period of my study and project.

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

EFC	Equatorial Fidelity Centre
EMO	Energy Management Opportunities
BEC	Building Energy Codes.
CO2	Carbon Dioxide
KVA	Kilovolt Amperes
KWh	Kilowatt hours
GHG	Green House Gases
IEA	International Energy Agency
REA	Rural Electrification Authority
IPCC	International Panel on Climate Change
KPLC	Kenya Power Limited Company.
KETRACO	Kenya Transmission Company
O&M	Operation and maintenance record
PV	Photovoltaic
PSH	Peak Sun Hours
LED	Light Emitting Diode
IEA	International Energy Agency
AVG	Average
MAX	Maximum
Eqn	Equation
IEC	International Electro technical Commission for rotating machinery
PF	Power factor

Abstract

The demand for energy keeps rising which requires the generation of vast amount of electricity. Changes have been made to make buildings more energy efficient. Understanding the use of energy in buildings requires an insight into the amounts of energy consumed and the different types of fuels used.

The objective of this dissertation was to identify energy saving potential in commercial buildings in Nairobi outlining measures that would yield energy savings. A case study was done in Equatorial Fidelity Centre (EFC) located in Westlands along Waiyaki way in Nairobi. Improving energy efficiency can deliver a range of benefits to the economy and society at large. In this study the main objective was to identify energy saving opportunities to lower the annual energy bill in EFC which has been escalating since 2011 amounting to Kshs. 8,042,771.0 and Kshs. 12, 682,248.0 in 2015. Therefore an audit was carried out to identify potential areas for energy savings improvement and hence lower energy bill.

In addition economic evaluation was performed to determine economic viability of the implementation of energy savings opportunities identified. The economic assessment captured technical implementation aspect of all measures outlined and finally a simple payback period was performed to appraise the implementation of potential measures that would yield energy savings.

Five major areas were identified that would potentially lower energy bill in EFC namely; Use of Light pipes in the basement to supplement artificial lighting, Use of Roof top Solar PV for Lighting load, replacement of existing Fluorescent tube with LEDs, Power factor Improvement and Tariff Migration. All these measures were found to contribute in lowering energy consumption and hence lowering energy bill. Annual cost saving was found to be Kshs. 4,010,663.93 with a payback period of 3 years and 1 month.

CHAPTER ONE: INTRODUCTION

1.1 Introduction and Background

Energy is the main drive for development in all Industrialized and developing countries. Energy as a source in its various natural forms is getting depleted or is inadequate. With increase of technology, energy use is ever increasing and the demand in some countries is outstripping supply.

The Petroleum product and electricity are the main sources of energy, their prices are ever increasing. The petroleum costs have increased drastically worldwide within the last ten years to an ever high cost of 140US$ per barrel in 2014. The increase in Petrol prices affects the cost of electrical energy in that the cost of fuel is transferred to the customers as a fuel cost charge

The major objective of conducting an energy audit for a building is to find out how efficiently energy is being used in the building, and to identify opportunities for improvement .This requires an evaluation of the amount of energy used by various systems and equipment in the building over the audit period. Unfortunately, provision of metering devices for monitoring energy consumption in buildings in Kenya is in general rather limited. Besides the KPLC meters, you may have few sub-meters, or no sub-meters. For such buildings, only aggregate energy consumption data would be obtainable e.g. from electricity bills, which cover a large group of equipment. As a result, the energy efficiency of individual system or equipment would have to be assessed on the basis of estimated energy consumption.

Energy efficiency factors in buildings vary according to geographical position, climate, building type and location. The distinction between developed and developing countries is important, as is the contrast between retrofitting existing buildings and new construction. In all cases there are different standards of building quality. It is vital that energy efficiency permeates all levels and is not restricted to high end properties.

Energy auditing, while conceptually understood, is a relatively recent phenomenon in Kenya. In fact, energy audits are now mandatory for large commercial and industrial facilities – and a certificate is awarded by the Energy Regulatory Commission. Typically, an energy audit should be carried out after every three years.

ERC classifies energy consumers into 3 major category

Table 1.1: Category of Energy Consumers

Low	Medium	High
< 180,000kWh	<1,200,000kWh	>1,200,000kWh

Source: ERC 2014 Report

As shown in table 1.1 above, low energy consumers are facilities whose energy requirements fall below 180,000 kWh annually. Medium energy consumers are classified as facilities whose annual energy consumption averages between 180,000 kWh and 1,200,000 kWh annually.

Facilities demanding 1,200,000 kWh and above annually are categorized as large energy consumers.

Therefore ERC requires that all consumers beyond 180,000kWh annually i.e. consumers in the category of high and medium, should be audited to evaluate how efficiently energy is being used and to identify measures for improvement, but a lot of emphasis has been put in Manufacturing Industries leaving Commercial buildings.

In addition with respect to high cost of energy related to over-reliance on fossil fuel powered plants, several technologies have been put up to harness renewable energies which include use of solar PV to tap solar energy and use of Light pipes to tap outdoor sunlight and channel it to the interior of the buildings during daytime which would lower the cost of production.

1.1.1 Equatorial Fidelity Centre (EFC)

EFC is a commercial building located in Westland, Nairobi and houses major commercial offices which include ECO-Bank, Equatorial insurance firm, African oil, Trademark center among others. The building comprises of 6 floors together with a mezzanine, basement and parking. It has 1 basement floor for parking. All tenants are billed centrally at the Power Control Centre using one KPLC Meter. The tenants are sub-metered by management and billed according to their consumption. Electrical Energy is the major component of Energy used in this building. The major energy consuming equipment are Lighting Systems, Air Conditioners, Water Pumps and Lifts.

Fig 1.1: A view of Equatorial Fidelity Centre

Figure 1.1 shows a front view of Equatorial Fidelity Centre where a case study was carried out and it consumes energy ranging from 600,000kWh to 800,000kWh annually with an average energy cost ranging from Kshs 8 Million to Kshs.13 Million respectively.

Table 1.2 Baseline Information for EFC

Annual Electricity Consumption	**637,407 kWh**
Annual Electrical energy cost	Kshs. 12,682,248 million per annum
Average Maximum Demand	150 KVA
Average Electrical Energy Cost	Kshs 19.93 per kWh
Demand Charge	800/KVA
Annual Occupancy	75,000 Occupants

EFC receives power from KPLC at 11KV and stepped down to 415V 3phase 4 wire system by a step down transformer rated 630KVA. In addition a standby generator rated 500KVA is installed and is used during power outage from the grid to take up the full load.

Figure 1.2: 630KVA Transformer serving Equatorial Fidelity Centre

Figure 1.3 shows energy cost variation for the year 2014/2015 which was a period of consideration in this study.

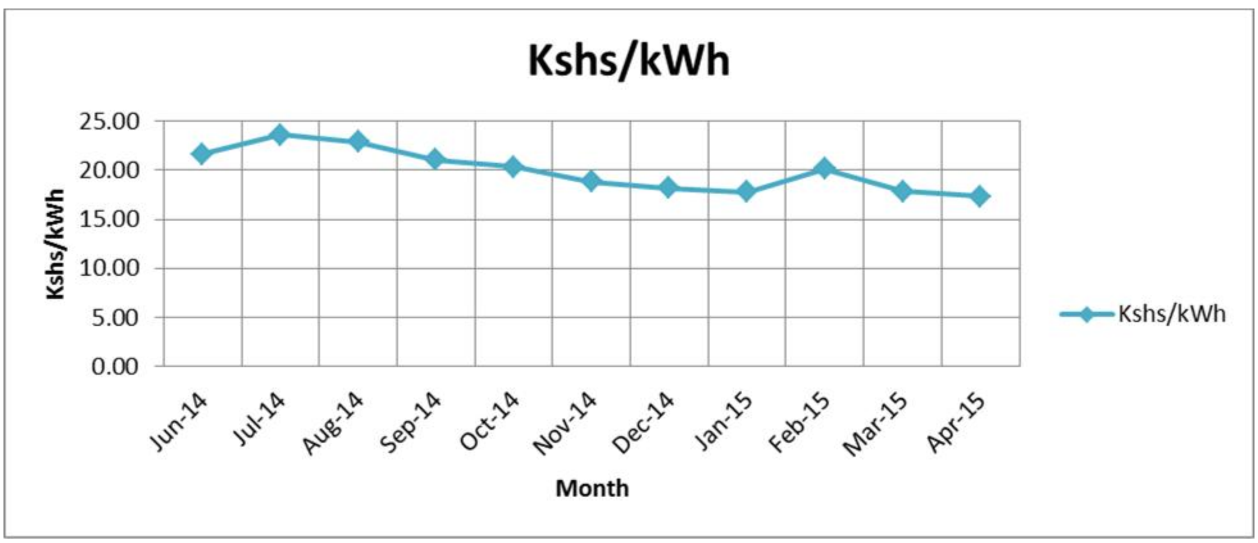


Figure 1.3: Variation of Energy Prices

Source: KPLC records

1.2 Problem Statement

EFC uses Electricity and Diesel for its energy requirements. Electricity takes the highest percentage between the two. Electricity bill incurred in EFC has continued to escalate, increasing by 33% percent from 2011/2012 to 2014/2015 with annual energy consumption of 587,258.7kWh and 637,407 kWh respectively. Table 1.3 below shows the breakdown of annual energy consumption and their respective energy bill from 2011 to 2015.

Table 1.3: Historical Energy Consumption in EFC

YEAR	Consumption (kWh)	Accrued Energy Cost(Kshs)
May 2011- April 2012	587,258.7	8,042,771.0
May2012- April 2013	612,235.6	8,265,558.30
May 2013 – April 2014	621, 872.2	9,887,228.4
May 2014 – April 2015	637,407.0	12, 682,248.0

This indicates that there is a need to bring down energy bill which would in turn lead to low cost of production hence bring competitiveness of the services in the market. From Figure 1.4 it is evident that the escalation of energy surcharges in Kenya has been on the rise.

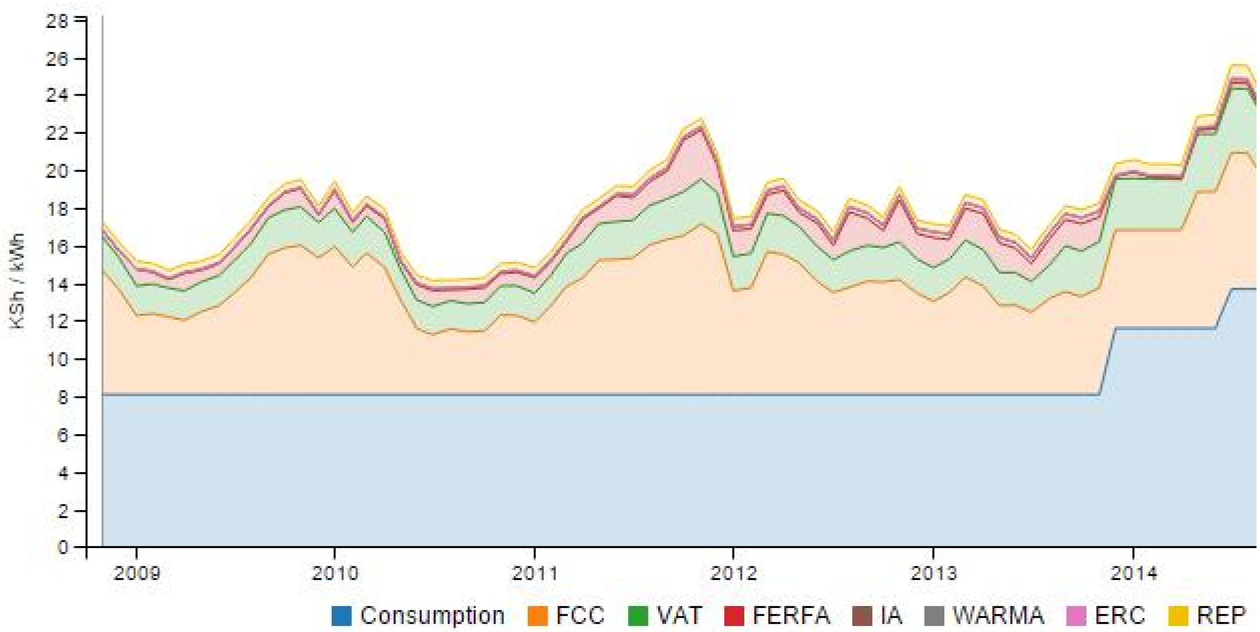


Figure 1.4: Trend of Energy Prices in Kenya from 2009 to 2015

Source: ERC Records

The aim of this research is therefore to carry out an energy audit for EFC and identify energy saving opportunities that would lower energy consumption and in turn lower associated energy cost.

1.3 Research Objectives

The main objective of this study is to identify energy saving opportunities that would contribute in lowering energy cost.

The specific objectives are:

i. Carry out an energy audit and Identify Opportunities of energy savings

ii. Assess use of Light-pipes in the basement (Parking area) during daytime as an addition saving measure
iii. Assess use of rooftop Solar PV for the lighting systems and design of a control system switching between Gen set, mains and solar PV
iv. Carry out an Economic Evaluation of all Identified energy saving opportunities and Payback Period

CHAPTER 2: LITERATURE REVIEW.

2.1 Energy Savings

Even in the context of an enlarged view of the potential outcomes of energy efficiency improvements, the role of energy savings as the primary objective of energy efficiency policy remains unchanged. Reducing energy consumption will remain a goal of energy ministries and well-targeted policies as the best way to achieve energy conservation.

Energy efficiency can produce energy savings at all levels; individual, sectoral, national and international and the impacts of those energy savings can trickle through to generate wider socioeconomic outcomes. If the actual savings delivered by an energy efficiency measure turn out to be lower than predicted, this is often considered to undermine the success of the intervention. In these cases, policy evaluators should investigate why lower than expected energy savings have been achieved, and consider how implementation could be adjusted to capture more energy savings but it is also important to consider what other benefits may have resulted from the measure. It may be that additional energy consumption can be explained as a consequence of achieving those other benefits.

While some multiple benefits can be seen as a result of energy savings and should be counted in addition to energy savings achieved, others can occur independently of energy savings and could provide a different measure of success of energy efficiency programs, to be considered where energy savings are low. Policy-makers should consider any such trade-off between reduced energy savings and socioeconomic welfare gains arising from particular energy efficiency measure and how the balance should be struck between energy savings and other benefits in designing energy efficiency policy.

One advantage of energy efficiency actions compared with other measures is the rapidity with which results are produced. For this reason, energy efficiency is often cited as one of the best near-term options to reduce energy demand and greenhouse gas emissions. An improvement in technical efficiency can have immediate effect on energy consumption and, especially in the case of smaller projects, can be relatively quick to be put in place.

This is an important feature of energy efficiency improvements as society considers which measures are likely to deliver the benefits needed at different moments in time. The short-term outcomes possible through energy efficiency improvements are crucial in helping solve problems facing policy makers such as sudden changes in unemployment, energy supply, energy affordability to name a few. Energy efficiency improvements in other areas can provide longer-term outcomes such as national competitiveness, reduced public health costs, and energy security that ensure economic sustainability for the future.

2.2: Electricity Prices and Pricing Structure in Kenya.

ERC was established under the Energy Act, 2006 as the energy sector regulatory agency, with responsibility for economic and technical regulation of power, renewable energy and downstream petroleum sub-sectors. This mandate includes tariff setting and review, licensing, enforcement of standards, dispute settlement and approval of power purchase and network service contracts.

The existing retail tariffs were approved by the then Electricity Regulatory Board (ERB) in June 1999 and came into force on 1st August 1999 simultaneously with the Interim Power Purchase Agreement (IPPA) between KenGen and Kenya Power and Lighting Company which set the base bulk tariff at 2.36 Kshs/kWh.

The retail tariffs were rebalanced in May 2000 to mitigate the impact of drought but, there has been no other increase in the base non-fuel tariffs since August 1999.

Since 1999, several power industry parameters have changed including but not limited to significant increases in the power purchase costs as a result of inflation adjustment clauses inbuilt into the Power Purchase Agreements between Independent Power Producers (IPPs) and KPLC which have financially exposed KPLC over the years. Power purchase costs from new and upcoming power generation projects, as well as the costs of transmission and distribution projects intended to meet growing power demand have resulted in increased revenue requirements.

The 2016 effective power capacity in the country stood at about 2000 MW (including 146 MW of emergency plants) against a growing peak demand of about 1500 MW. The reserve of margin in 2016 excluding the IPP is about 6% against an international benchmark of 15% for systems of similar size.

There are several power generation projects planned and committed to come on stream in the next four years. These projects involve the development of over 600 MW in new power generation capacity.

2.2.1 Consumer Categories in Kenya

Table 2.1 below shows several consumer categories effected from 1st December 2013

Table 2.1 Summary of Proposed Retail Tariffs.

CUSTOMER CATEGORY		**Unit Cost**			**PROPOSED RATES**			
Code DC	Customer Type Domestic	Charge Method Fixed	Unit Cost KSh/month	Existing Rate 120	2012/2013 200	2013/2014 250	2014/2015 250	2015/2016 300
  SC CI1	“ “ Small Commercial Commercial/Industrial	Energy Energy Energy Fixed Energy Fixed	KSh/kWh KSh/kWh KSh/kWh KSh/month KSh/kWh KSh/month	2.00 8.10 18.57 120 8.96 800	5.10 11.40 19.30 200 13.66 2,000	5.10 11.90 23.36 250 14.55 2,200	5.75 12.30 23.86 250 15.00 2,200	5.75 12.30 23.86 250 15.00 2,500
CI2	Comm/ Industrial	Energy Demand Fixed Energy	KSh/kWh KSh/kVA KSh/month KSh/kWh	5.75 6,00 2,500 4.73	9.75 800 4,000 7.95	10.80 800 4,000 7.95	11.60 800 5,000 10.30	13.00 800 5,000 10.30
CI3	Comm/ Industrial	Demand Fixed Energy	KSh/kVA KSh/month KSh/kWh	400 2,900 4.49	520 4,500 7.35	520 5,000 8.15	520 5,000 8.35	520 6,000 9.35
  C14 C15	 Comm/ Industrial Comm/ Industrial	Demand Fixed Energy Demand Fixed Energy	KSh/kVA KSh/month KSh/kWh KSh/kVA KSh/month KSh/month	200 4,200 4.25 170 11,000 4.10	270 6000 7.05 220 16,000 6.90	270 6500 7.80 220 17,000 7.70	270 6500 8.00 220 17000 7.90	270 7,000 9.05 220 18,000 8.90
		Demand	KSh/KVA	170	220	220	220	220
IT DC IT SC IT SL	Interruptible Street Lighting	Fixed Energy Fixed Fixed	KSh/month KSh/kWh KSh/month	120 4.85 120	200 13.50 200	250 14.50 250	250 14.50 250	300 16.60 300

Table 2.1 shows five major tariffs in Kenya with their respective charges effected from December 1st 2013.

Table 2.2 shows the summary of surcharges which are subjected to all tariffs in Kenya,

Table 2.2: Surcharges applied on all tariffs.

Surcharge	Rate / Notes
Fuel Cost Charge (FCC)	Variable rate per kWh, published monthly by KPLC in the Kenya Gazette (but not on their website!). It is reflective of the cost (to KPLC) of generating electricity during the previous month.
Foreign Exchange Rate Fluctuation Adjustment (FERFA)	Variable rate per kWh, published monthly by KPLC. This includes the sum of the foreign currency costs incurred by KenGen, sum of the foreign currency costs incurred by KPLC other than those costs relating to Electric Power Producer, and the sum of the foreign currency costs incurred by KenGen.
Inflation Adjustment (IA)	Variable rate per kWh, published monthly by KPLC. Factors include the Underlying Consumer Price Index as posted by Kenya National Bureau of Statistics and the Consumer Prices Index for all urban consumers (CPI - U) for the US city average for all items 1982 - 84 as published by the United States Department of Labor Statistics. We are not certain why the cost of Kenyan electricity depends on how much folks in the USA are spending.
WARMA Levy	Variable rate per kWh, published monthly by KPLC. It is determined from the amount of energy supplied from hydroelectric facilities in the previous month.
ERC Levy	3 cents per kWh
REP Levy	5% of the base rate
Power Factor Surcharge	A surcharge applied if the consumer's power factor falls below 0.9. The surcharge applied is 2% of the base rate and the demand charge for every 1 per cent by which the Power Factor is below 0.9.
VAT	16% on everything except the WARMA, ERC and REP levies (Prior to 2 September 2013, consumption less than 200kWh was excluded from VAT, and VAT was charged at 12%. These concessions were removed in the VAT Act 2013.)

Table 2.3: Energy Demand in Kenya

Years	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13
URBAN							
Annual Consumption	1,113	1,255	1,254	1,290	1,424	1,531	1670
Off Peak	50	74	43	36	38	31	18
No. Of Customers	791,282	899,029	1,061,911	1,212,583	1,444,061	1,655,994	1,877,418
Average Consumption (kWh)	1,470	1,478	1,221	1,094	1,012	944	899
Share of Urban Consumption (%)	83%	84%	83%	82%	82%	83%	80%
RURAL							
Annual Consumption	221	240	250	279	307	340	406
No. of Customers	133,047	161,354	205,287	251,056	309,287	382,631	453,544
Average Consumption(kWh)	1,661	1,487	1,218	1,111	993	805	895
Share of Rural Consumption (%)	17%	16%	17%	18%	18%	17%	20%
Countrywide							
Annual Consumption	1,334	1,495	1,504	1,569	1,731	1,828	2072
No. of Customers	924,329	1,060,383	1,267,198	1,463,639	1,753,348	2,038,625	2,330,962
Average Consumption(kWh)	1,443	1,410	1,187	1,072	987	897	891

Source: KPLC Annual Accounts and Statistics.

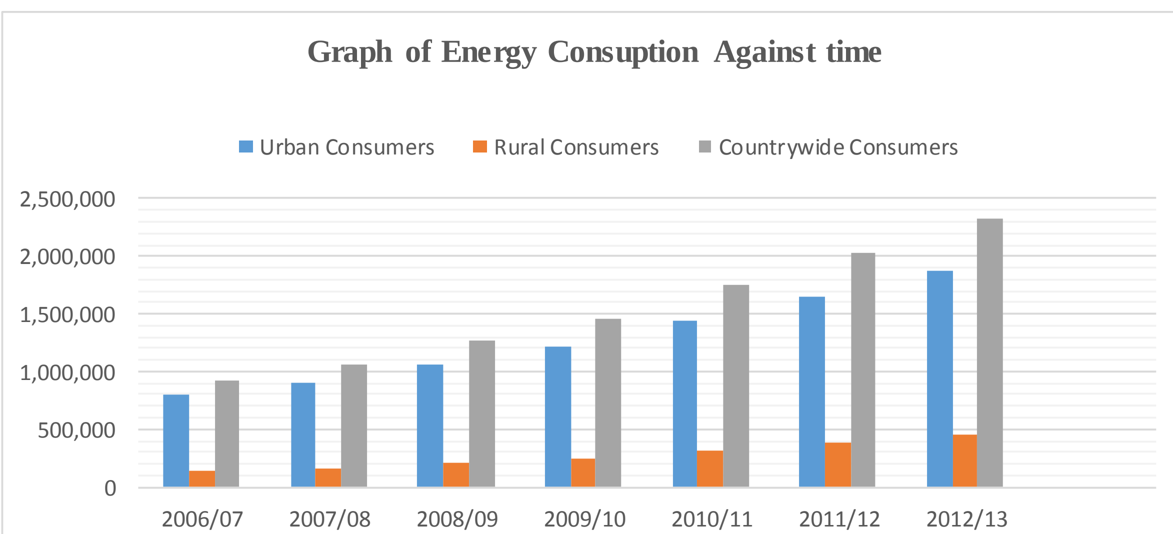


Fig 2.1: Energy Consumption trend in Urban and Rural Areas
Source: KPLC Records

It is a clear indication from the above figure 2.1 that the demand for electricity has been on the rise and at a steady rate, both in urban and in rural areas in Kenya.

2.3 Solar Photovoltaic for Commercial Buildings

Photovoltaic cells can be utilized individually for small applications, however when more power is needed a number of cells are put together to form a module, and modules can also be grouped together to form arrays. In theory arrays can range from a small number of modules to power a building to thousands of modules to power a town.

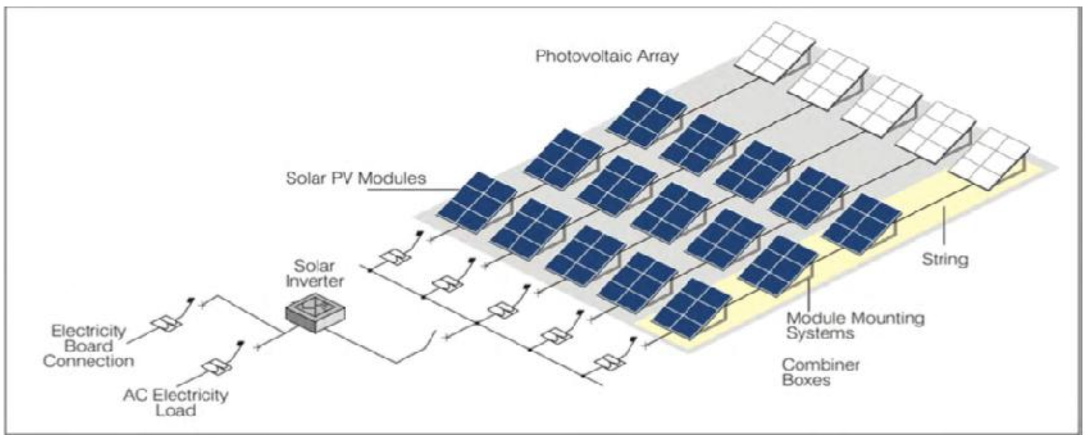


Fig 2.2: Typical Solar PV System Architecture

PV is a flexible building material. It can be used for roofs, curtain walls, decorative screens can be embedded in glazing, and can also directly replace other conventional materials in the building fabric. These products can serve the same structural and weather protection purposes as their traditional alternatives, as well as offering the benefit of power generation. PV generates approximately 100 kWh/m2 depending on the type of PV and system efficiency.

PV arrays can be integrated into the roofs and walls of commercial, institutional and industrial buildings, replacing some the usual wall cladding or roofing materials and minimizing the costs of PV systems.

Commercial and industrial buildings are normally occupied during daylight hours which correlate with the availability of solar radiation. Therefore the power generated via the PV systems can theoretically minimize the need to purchase power from the grid at the standard commercial tariffs. In other words it is economically feasible to use as much onsite PV power as possible utilities; this technology is mostly used in countries such as Germany, Netherlands and Japan.

The PV system begins with the roof-mounted modules, which use semiconductors to convert solar energy into direct current (DC) electricity. Within the building inverters are then used to convert DC power into the form of alternating current (AC). Compatible with standard building devices, the energy enters the Main Distribution Panel. The panel distributes energy to various parts of the building.

Fig 2.3: Major components in Installation of solar PV

Fig 2.4: A 10kW rooftop solar PV, Western District police station- US

2.4 Electrical Systems in Commercial Buildings

For most commercial buildings and a large number of industrial facilities, the electrical energy cost constitutes the dominant part of the utility bill. Lighting, office equipment, and motors are the electrical systems that consume the major part of energy in commercial and industrial buildings.

a) **Lighting**. Lighting for a typical office building represents on average 40% of the total electrical energy use. There are a variety of simple and inexpensive measures to improve the efficiency of lighting systems. These measures include the use of energy efficient lighting lamps and ballasts, the addition of reflective devices, delamping (when the luminance levels are above the recommended levels by the standards), and the use of daylighting controls.

Most lighting measures are especially cost-effective for office buildings for which payback periods are less than one year.

b) **Motors**. The energy cost to operate electric motors can be a significant part of the operating budget of any commercial and industrial building. Measures to reduce the energy cost of using motors include reducing operating time (turning off unnecessary equipment), optimizing motor systems, and using controls to match motor output with demand, using variable speed drives for air and water distribution, and installing energy-efficient motors.

In addition to the reduction in the total facility electrical energy use, retrofits of the electrical systems decrease space cooling loads and therefore further reduce the electrical energy use in the building. These cooling energy reductions as well as possible increases in thermal energy use (for space heating) should be accounted for when evaluating the cost-effectiveness of improvements in lighting and office equipment.

Figure 2.5 and 2.6 below shows graphical representations of the comparison of the efficiencies of standard efficiency motors with high efficiency motors under the IEC 60034-30:2008 standards

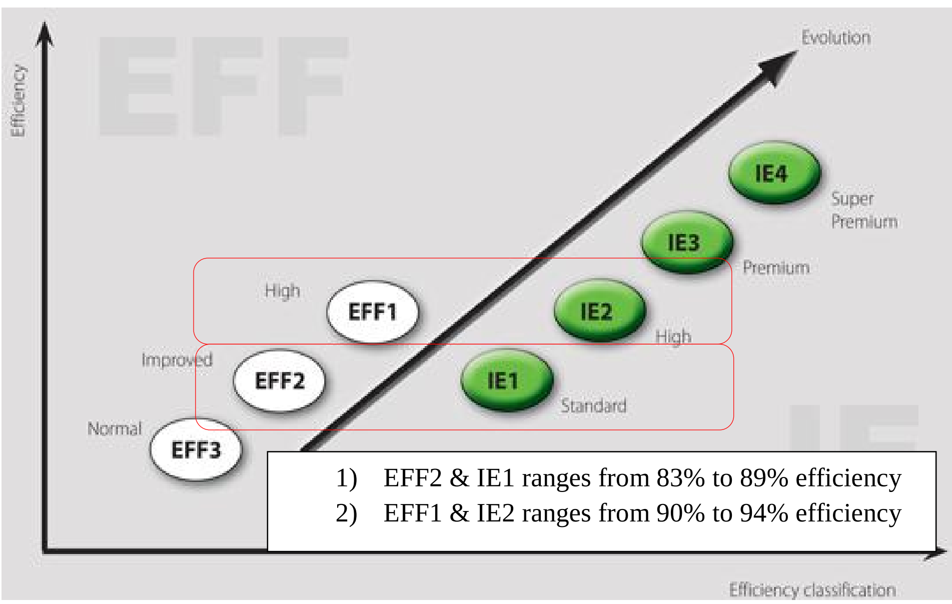


Figure 2.5: World standard motor efficiency classification

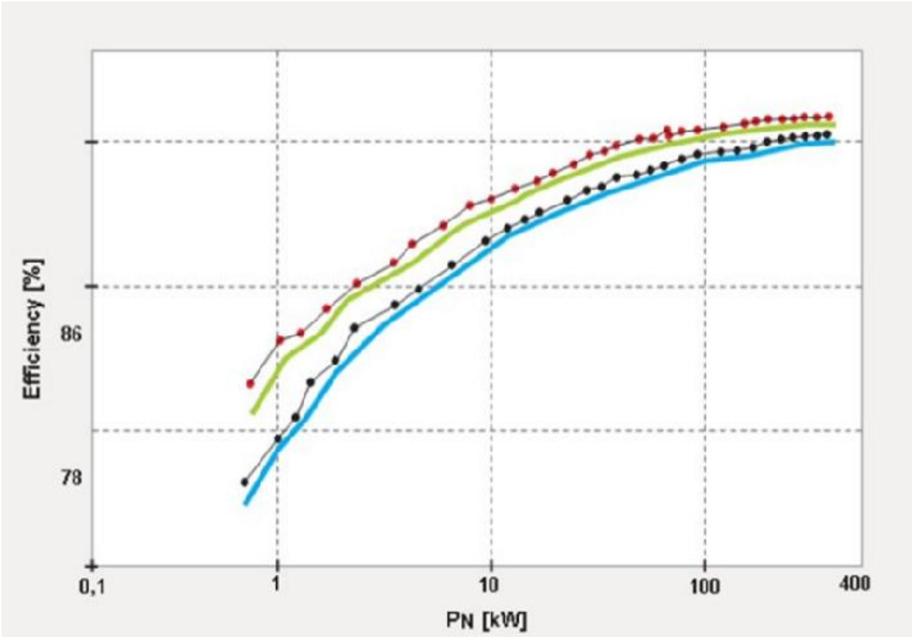


Figure 2.6: Motor Efficiencies graph

IE1 Standard Efficiency Motor

IE2 High Efficiency Motor

A sample calculation is shown below for a replacement of a standard efficiency induction motor with a high efficiency induction motor are shown overleaf

2.5 Day lighting and Illumination in Commercial Buildings

2.5.1 Daylight and energy in Buildings.

The use of natural light in buildings has many implications for the energy use in buildings. A reduction in the energy consumption of a commercial building can be achieved by decreasing the need for, or use of artificial light. Natural light is more efficient than electrical light, by providing more light for less heat than artificial light. For example, at a given level of illumination, a tungsten light produces between 5 and 14 times more heat than a daylight (Bake and Steemers, 2000). As a consequence, daylight also lowers the cooling requirements of a building up to 15% (Muhs, 2000)

Up to 75-80% of electric lighting consumption could be saved through the use of advanced day-lighting technologies and improved integration of day lighting systems with efficient artificial lighting and effective lighting controls, when compared to conventional buildings (Kristensen, 1994, Hayman et al., 2000). In addition, as the greatest consumption of electricity in commercial buildings peaks in the middle of the day when there is also greatest abundance of natural light, the possibilities for energy savings via the use of day lighting are considerable (Muhs, 2000)

Introduction of natural light into buildings is normally achieved through simple apertures in the envelope such as windows or skylights. Side lighting from windows in the buildings decreases rapidly with distance from the window, passively reaching inwards only up to 4 to 6m passive zone. Therefore, a disproportionate amount of daylight must be introduced into the front of the room to achieve small gains in daylight levels at the back of the space (Beltran et al., 1997). Generally spaces at distances further than the passive zones require artificial lighting for illumination. Top lighting (From skylights) is a very good solution to obtain good daylight distribution levels in the space, as long as the ceiling apertures are well designed and do not let direct sunlight in. It is also good for the building that has good plan.

Consequently to attain a good distribution of daylight into the interior of a building, the building plan is limited to having floor plates with depths less than 8 to 10m and should have high ceilings. However, these design limitations have only been applied in European countries (Baker and Steemers 2000); in other places like Australia, Asia, and United States of America, deep plan buildings have become a common practice in modern office design.

2.5.2: Innovative Daylight Systems

Innovative daylight systems are optical devices capable of bringing natural light further into the interior zones of large buildings than is possible with simple day lighting strategies such as windows or skylights. There are two major groups of innovative daylighting devices, light guiding systems and light transport systems.

2.5.2.1 Light transport system

Is used to collect and transport sunlight over long distances within a building, and are usually referred as Light pipes or light guides. Light transport system generally have three elements

i. A collection head which tracks sunlight or simply redirects it inside the pipe

ii. The pipe itself that transports the light to where it is needed. This is dependent on the material selected for the pipe (i.e. lenses, mirrored lights, Prismatic pipes and solid core systems)

iii. A distribution system that include extractor devices, which extracts light from the pipe to the exterior, and diffusers that spread light uniformly across the space

There are two major systems of innovative daylighting devices, Lighting guiding systems and light transport systems. Lighting guiding systems although very efficient in redirecting natural light deeper into the room usually reach distances up to 10 meters, and therefore, light transport systems are required when the core of the building is more than 10 meters from the window.

2.5.3 Typical Light Transport Systems

For deep plan buildings, with, greater than 10M from the window, natural illumination can only be practically achieved by light transport systems. Light transport or remote source systems are devices capable of channeling sunlight to areas in buildings that receive inadequate natural lighting and usually remote from the building envelop. These systems consists of three major components. 1) Light collection; 2) Light Transportation 3) light distribution: Extraction and emissions

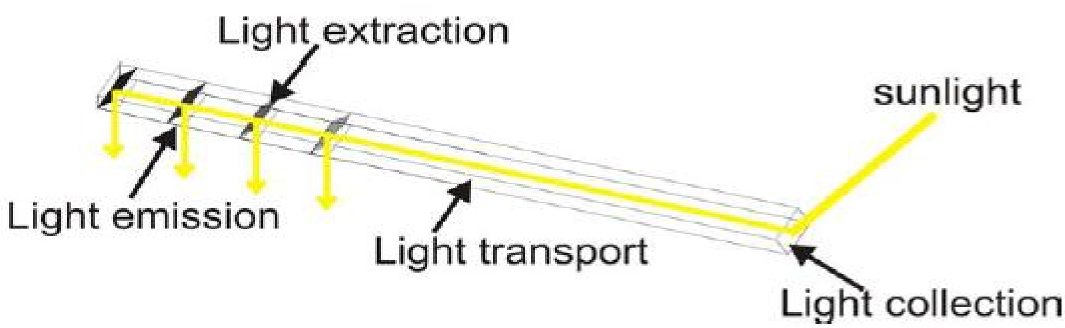


Figure 2.7: Light piping system diagram

A variety of light transport systems have been investigated, built and tested for numerous building projects, and many studies have shown their beneficial use (Tsangrassoulis et al., 2005, Aizenberg, et al., 2003, Audin, 1995, Ayers and Carter, 1995, Bennett and Eijadi, 1980). In addition to the general benefits of daylighting, benefits of light piping systems include:

i. The possibility of a centralized building lighting system that pipes natural light and artificial light to distribution devices replacing electrical cabling and fixtures

ii. Elimination or reduction of infrared or ultra violet radiation from sunlight, although further study is required to quantify this reduction, particularly for Ultra violet radiation

iii. The extraction of desired fractions of the light along the pipe as required

iv. Producing a uniform distribution of light in the space from a small concentrated output

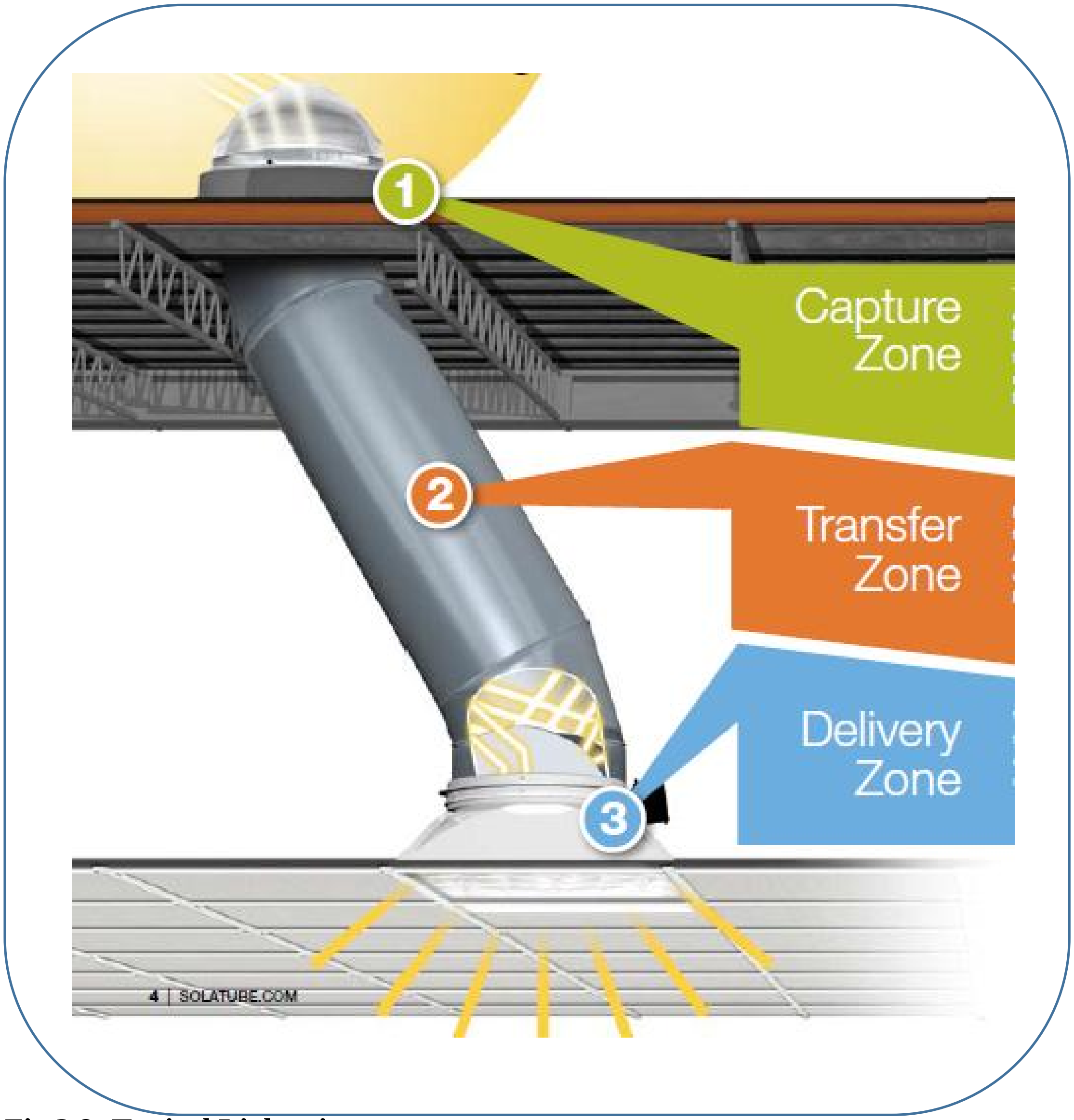


Fig 2.8: Typical Light-pipe system

Light-guiding systems send direct and diffuse sunlight to the interior of the room without the secondary effects of glare and overheating. There are several different systems and they have similarities in their general performance, position in the building, or means of directing the light. They can be grouped as follows

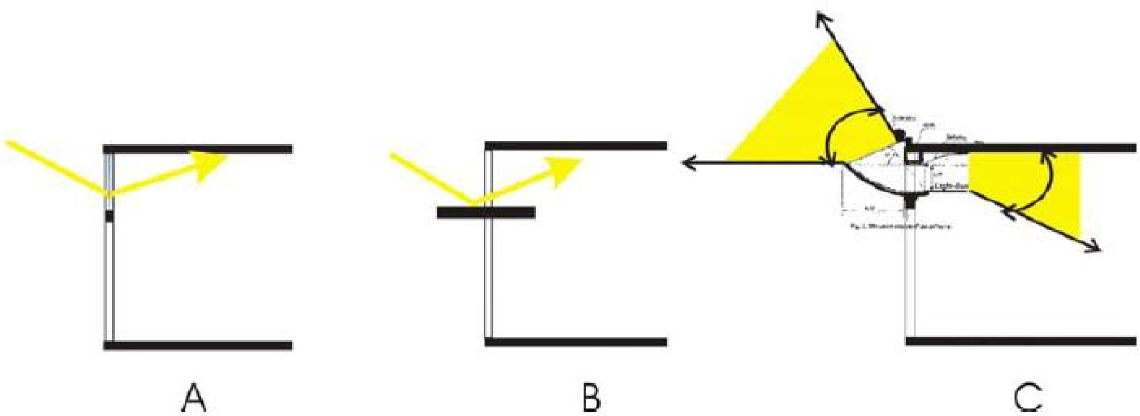


Figure 2.9: **A) Vertical element, B) Horizontal element C) Parabolic collectors**

Vertical elements- This group includes devices that are usually placed in the top of the windows vertical or with some angle of inclination. They redirect the light deeper into the room by means of reflection and refraction

Horizontal Elements- This group includes devices formed by one horizontal baffle (e.g. light shelves, sun scoops), or systems form by multiple horizontal or sloping slats. Their most important benefit is their protection against glare, but they have problems with dust accumulation, and therefore require maintenance. These systems can redirect sunlight to the back of the room, depending on their position.

Parabolic Collectors: The principle behind these devices is a compound parabolic collector. A specific geometric form internally covered with reflectance material accepts light from a specified angular range of the sky, and light is then redirected deeper into the room.

2.5.4 Light Collection for light transport systems.

Collection systems generally consist of reflective or refracting devices. Their main objective is to capture sunlight and direct it through a small aperture into the interior. Collecting and conveying day a specific location can be achieved by active or passive systems (Audin, 1995).

Light collection is achieved either by redirection of sunlight by, for example, flat mirrors, or by concentration of light. Concentration describes the increase of illumination on a surface above the incident solar level. Concentration is achieved by geometrical optics (Imaging or non-imaging optics) of the collector or by fluorescent systems (Smestad et al., 1990). Following is a brief description of passive and active light collection systems, which includes either concentration or redirection systems.

2.5.4.1 Passive Collection systems

A passive collection system implies no mobile parts. Passive collectors have a single orientation and are fixed during installation to maximize redirection down shaft-way. A fixed system requires a larger area for light collection to compensate for the lack of a tracking system which can improve sun collection efficiency during the day and year. Consequently, passive collectors results in larger transport components that can use considerable floor area. Performance increases are therefore correlated with increasing size of the system components i.e. collection and transmission. These include:

2.5.4.2 Luminescent Solar Concentrators (LSC)

This is another system designed to concentrate sunlight. It consists of a thin plate of a highly transparent material e.g. polymethyl methacrylate-PMMA, that is doped with fluorescent dyes. The dye molecules absorb part of the solar radiation incident on the plate and re-emit fluorescent radiation that is transported to the edges of the plate by total internal reflection.

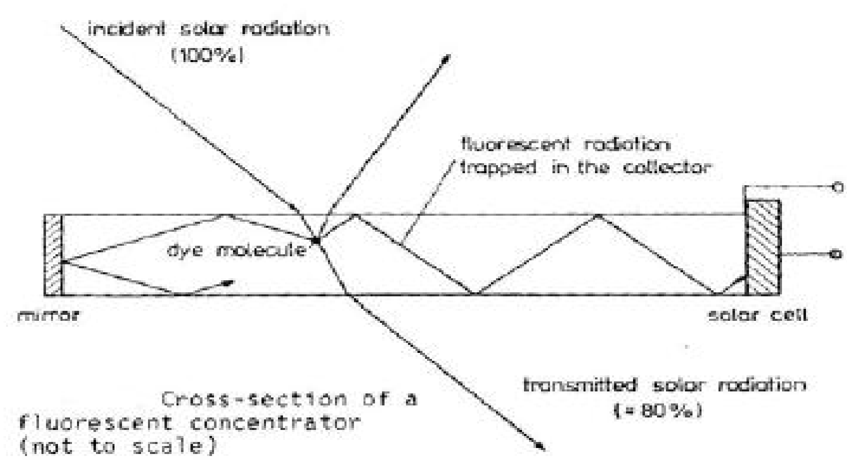


Fig 2.10: Cross-section of a fluorescent concentrator.

Source: Zastrow (1986)

The collectors generally consist of plates 120mm width, 2mm height and 1m to 2m long to provide sufficient area to supply enough output light, about 1000 lumens, for a standard domestic room size. Mirrors added along base and edges of the LSC collector redirect any rays that may have not been absorbed by any of the panels back towards the panels, improving the overall efficiency of the collector.

2.5.4.2 (A) Light redirection collectors

In contrast to the light concentration collector systems, light redirection systems operate on aligning sunlight with the light transport system. The efficiency of light transportation in light pipes depends on the angle at which sunlight enters the light pipe. Sun rays that reach the input aperture of a light pipe with an angle closest to that of pipe orientation will undergo fewer reflections, thereby a collector system that redirects the sun rays more axially along a pipe will increase the performance of the system. Consequently designs of passive collector systems have focused primarily on improving the incidence of the sun angle reaching the aperture of the sun pipe.

2.5.4.2 (B) Light Transmission

The transmission of light through the pipe is given by $T = \rho^N$, where $\boldsymbol{\rho}$ the reflectance of the surface of the light pipe and **N** is the number of reflections along the pipe which bring light to the point of interest.

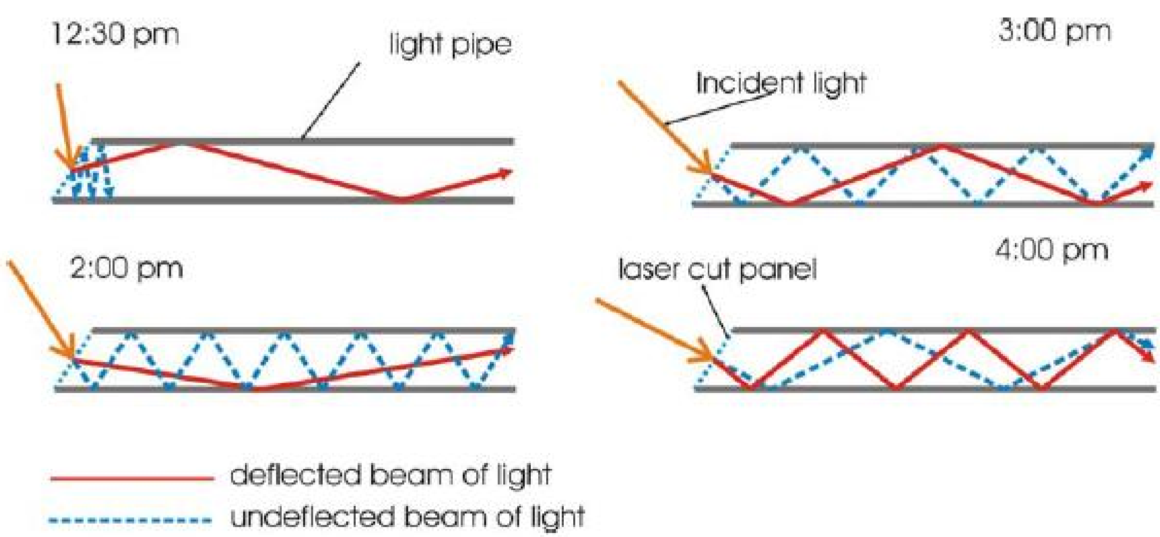


Figure 2.11: transmission of light through horizontal pipes for the deflected and un-deflected beam of light at different times of the day

In the present application the input apertures of the pipes are on the western façade and sunlight enters the apertures from 12 noon through the afternoon as illustrated in figure 2.10. It is from this illustration that the transmission of the light through pipes depends in a fairly complicated way, on the sun elevation angle and, therefore, on time of day.

2.5.5 Efficiency of Light Pipe

The earliest work on the transmission of mirrored light pipe tube seems to be theoretical calculation given by (Zastrow, 2001) gave a simple formulation to relate the transmittance of a mirror light pipe tube to its surface reflectance (ρ), the angle between the incident light and the tube's axis ($\boldsymbol{\theta}$), the length of the tube (L), and the effective diameter of the tube (deff)

$$T = \rho^{L * \tan\theta / deff}$$

…………………………………………………………………….. (2. 1)

Where T is the transmittance, i.e. the ratio of the amount of light transmitted to the incident light

(Swift et al, 1999) gave an equation to describe the transmission of collimating light within mirrored light pipe. The equation is

$$T = (4/\pi)\int_{s=0}^{1}[s^2/(1-s^2)^{1/2}]R^{\mathrm{int}(p\tan\theta/s)} \times \{1-(1-R)[p\tan\theta/s - \mathrm{int}(p\tan\theta/s)]\}ds \quad \text{…... (2.2)}$$

Where T is the transmittance of the light pipe tube, i.e. the ratio of the amount of transmitted light to that of incident light, R is the reflectance of the interior surface of the light pipe tube, P is the aspect ratio of the light pipe, $\boldsymbol{\theta}$ is the angle between the incident light and the light tube axis, int is the integer function, that is int (a) is the integer less than or equal to a.

2.5.6 Light Extraction

As the light traverses the pipe especially mirrored light pipes a certain proportion of light must be extracted at intervals along the light pipe to illuminate several floors for a vertical light pipe to illuminate several floors for a vertical light pipe, or a uniform distribution across a space for horizontal light pipes.

A principle of a light extraction system was developed by Edmonds et al. (1997a) and illustrated in the figure below. In this example the same amount of light is extracted at each aperture. To achieve this, the first extractor panel is made sufficiently reflecting to deflect one quarter of the light. The second deflects one third of the remaining light. More complicated ratios may be derived to account for transmission loss in the pipe that occurs between each extractor

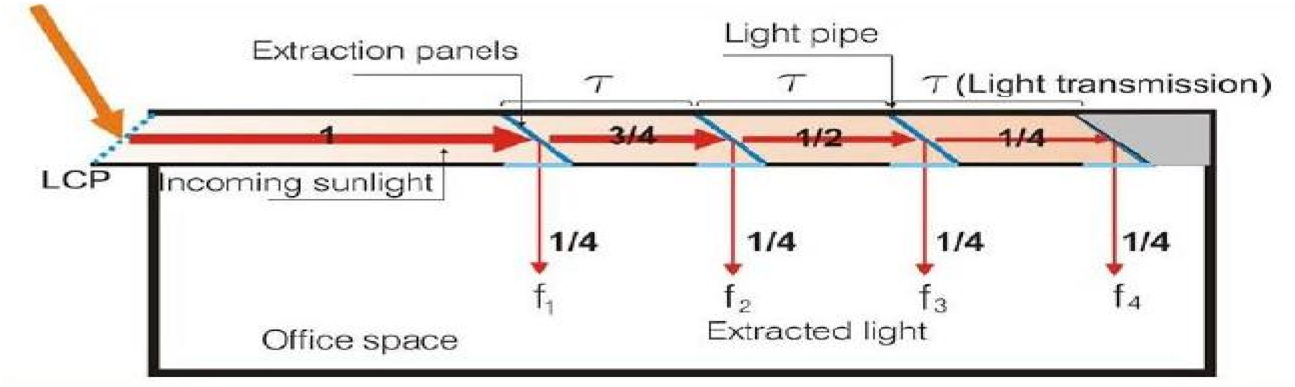


Fig 2.12: Light extraction in the light pipes

Figure 2.13 and 2.14 shows successful implementation of light pipes in commercial buildings in Berlin Germany and Turkey

Fig 2.13: Subterranean Train station at Potsdamer Platz, Berlin

Fig 2.14: Light pipe serving four under-ground floors

Source: Borusan group building in Istanbul, Turkey

CHAPTER 3: METHODOLOGY

3.1 Technical Energy Audit Evaluation

A preliminary discussion was held with senior executives to firm up the operations to be evaluated during the General energy audit. The management was looking for measures that could make a significant mark in energy costs especially electricity. Measurements were done on all major equipment.

It was followed by a survey of the building which was done to identify the types of energy being used, the quantity and energy consumption of all fixed electrical equipment except the standard general office equipment and personal computers for staffs.

Measurements were then conducted by use of portable instruments which included the Power Analyzer, Lux meter and data logger. Specifications of equipment and operating data were collected to assess efficiency and performance of various systems. Discussions with plant personnel, during the energy audit, helped improve understanding operations, various measures already taken and future plans.

3.1.1 Equipment used for Measurements

During the audit specialized equipment were used in logging and measuring various readings. Below is a table detailing some of the equipment and their use.

Table 3.1: Measurements Tools

Tools	Description
Lux Meter	Measures illumination levels. Used to study lighting at particular locations
Power Data Logger and Analyzer	Measures and logs data such as voltages, currents, phase angles, harmonic distortions, and power factors
Clamp Meter	Measures voltages, currents and resistance
Lux Sensors	Measuring outdoor lighting Lux levels.

Figure 3.1: Lux meter, Power Logger and Clamp Meter

Instruments of high precision were used in taking all measurements. The following table 3.2, 3.3 and 3.4 shows the various instrument used with their respective accuracies which was verified by KEBS and met the minimum threshold to carry out a research.

Table 3.2: Lux meter

Equipment Accuracy	
CA 830 Lux Meter	
Incandescent Lamp	± 3 % + 10 counts
Other Sources	± 11% + 2 counts

Table 3.3: Power Analyzer

CA 8435 Power Analyzer	
Voltage Range	10.00 to 1,000 V AC/DC
Current Probe	30A to 10,000 AAC (Typical accuracy ≤ 1%)
Frequency Range	40Hz to 69Hz
Harmonics	THD, orders 0 to 50 per phase
Sample	256 samples / period

Table 3.4: Power Analyzer

PEL 103 Power Analyzer	
Voltage Range	10.00 to 1,000 V AC/DC / ± 0.2% + 0.5 V
Current Probe	200.0 mA to 10.00 kA AC / ± 1.2% + 70 mA
Frequency Range	DC, 50 Hz, 60 Hz & 400Hz

3.1.2 Historical Data

The energy consumption and production levels for the building were obtained from their records for the period under consideration, May 2014 – April 2015. The electrical energy consumption data was obtained from the electricity bills for EFC for the same period. The diesel fuel data was obtained from the fueling cards record and consumption level records for the same period. The generator capacity was obtained from the name plate. In addition summary data for Energy bills from 2010 to 2015 was provided by the property management company Knight Frank to determine energy trend.

3.2 Assessment of the use of Light pipes in the basement of EFC

In this assessment the illumination level in the basement due to artificial lighting were first measured by use of six lux meters placed at different locations to evaluate the effectiveness of light-pipes use in the parking area that would offer the same illumination. Data was recorded and uploaded for analysis. In addition the number and size of the light pipes required was evaluated for implementation.

3.3 Assessment of the use of Solar PV on the roof of EFC

Solar energy was studied to evaluate the number of solar panels that could meet the demand for the lighting systems of the whole building which could be used during daytime.

Data from National Meteorological department was obtained specifically showing the climatic conditions in Nairobi and its environs for a period of one year which was used in evaluation of potential of solar energy that could be tapped by the use of solar panel for the lighting system in EFC.

The rooftop of EFC was assessed to determine the area available and the capacity of solar panel installation that it could support and with the help of Civil Structures Engineer, the structural strength of the roof was as well assessed and the building exposure to sunlight was evaluated to determine the amount of light that directly strikes on the rooftop in a day.

In addition an Energy saving System was designed using at mega 328 microcontroller, TIP 122 transistors, potentiometer, ceramic and electrolytic capacitors, inductor, 16 MHz crystal clock, LEDs, LM358 op Amp and relays. Simulation was done using Proteus2008 for the purpose of trial testing and demonstrating that control systems could play part in maximizing the available solar energy for the lighting system and as well alarming in case of replacement of more energy consuming electrical appliances. It was designed in such a way that if the amount of solar energy available would be enough to meet the demand for all the six floors, it would cut out on the mains up to the point where it could not meet the demand for at least one floor whereby the whole lighting system would now be fed from mains directly.

CHAPTER 4: RESULTS AND ANALYSIS

4.1 INTRODUCTION

4.1.1 Energy Sources at EFC

EFC has the following Energy sources in use

i. Electricity

ii. Diesel Fuel

Electrical energy is the primary source of energy at EFC. A diesel generator rated 630kVA is on standby for use when the primary source is not available. Sometimes, electricity can be interrupted when the utility has a planned outage for maintenance or new customer connection and sometimes interruptions could be caused by faults which trip the feeder and an alternative feeder may not be available to back feed. During these interruptions the generator should be able to take on the full load of the building, it uses diesel oil for its operation. Table 4.1 shows annual energy cost from both Utility bill and for Diesel used

Table 4.1: Break down of Annual Energy Cost 2014/2015

Energy Resource	Kshs
Utility Bill	12,682,248
Diesel	1,152,000
Total	13,834,248

Figure 4.1 below illustrates the percentage of energy cost distribution for electricity and fuel as a source of energy

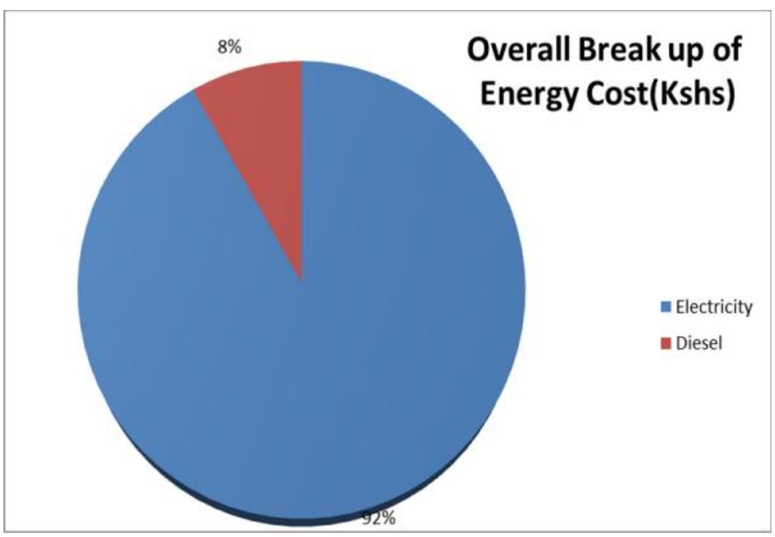
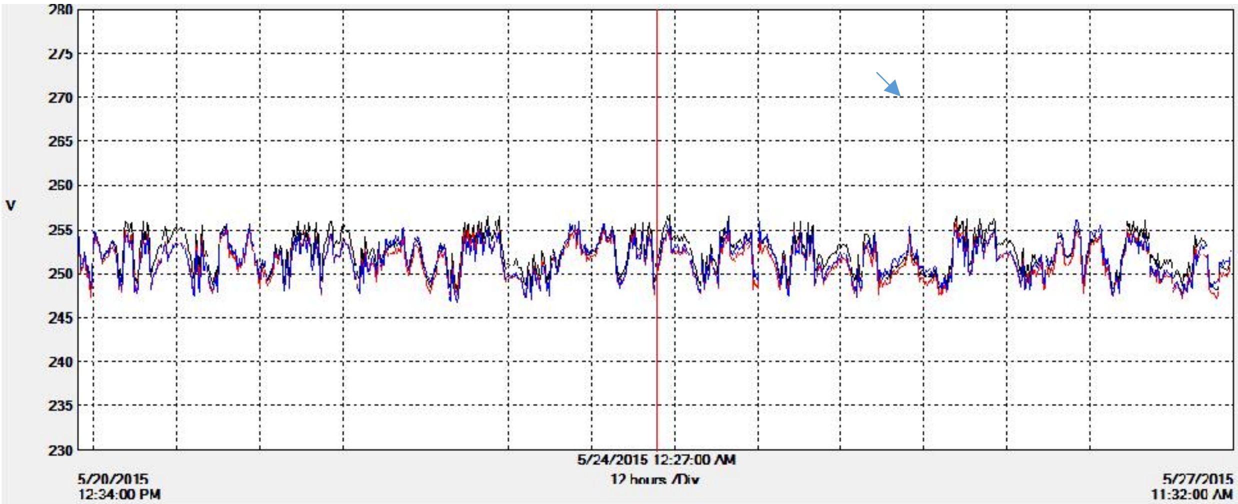


Figure 4.1 Energy Cost distribution in EFC (Electricity vs. Diesel)

4.1.2 KPLC Main Incomer

Figure 4.2 below shows the incomer voltages as recorded by the power logger in EFC.



***4*.2: Incomer Voltages**

Fig 4.3: Power analysis from the bus bars

Table 4.2: Incomer power parameters obtained from the Power Logger

Parameter	**L1**	**L2**	**L3**
Avg Current	**175.6**	**149.5**	**159**
Max Current	**346.9**	**374**	**270.1**
Avg Voltage (LN)	**232.9**	**230.2**	**231.3**
Max Voltage (LN)	**246.1**	**243.8**	**244.5**
Avg Voltage (LL)	**400.1**	**400.7**	**402**
Max Voltage (LL)	**423.3**	**423.9**	**424.6**
Power factor	**0.88**	**0.91**	**0.87**

Table 4.1 above show details of incoming power, i.e. Voltages, Current and power Factor for all the phases as displayed by the power logger.

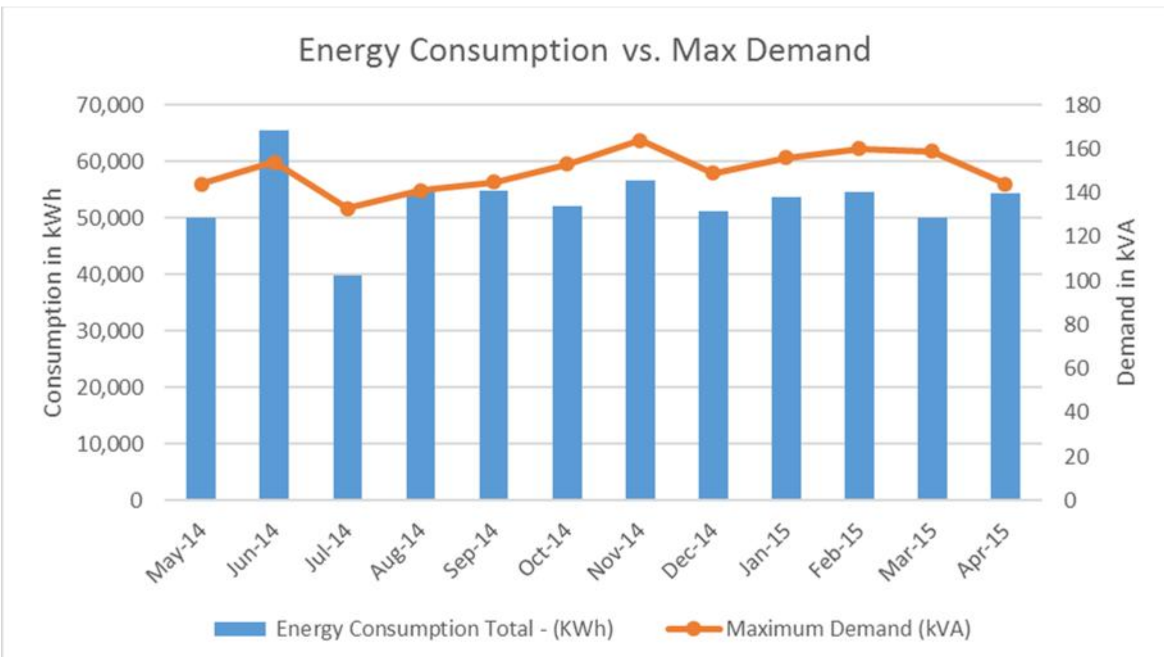


Figure 4.4: Correlation of Electricity Consumption and KVA Demand –May 2014 -April 2015

Figure 4.4 above shows the variation of energy consumption in 2014/2015 as well as variation of Maximum demand in the same period. It shows that a lot of energy was consumed in June 2014 and least energy consumed in July the same year and the highest Peak Demand was experienced in the month of July 2014.

4.1 Historical Information

A survey was first carried out to determine the existing energy consumption so that the energy savings opportunities could be identified as well as the assessment of rooftop solar PV and Light transport system in terms of size and capacity as an additional energy saving opportunities. Historical data for energy consumption was obtained for a period of one year as shown on table 4.3 below.

Table 4.3 Energy Bill Analysis for a Period of one year

Equatorial Fidelity Centre - Electricity Consumption									
Month	**Occupancy**	**Energy Consumption Total - (KWh)**	**Maximum Demand (kVA)**	**Maximum Demand Charges (Kshs)**	**Power Factor**	**Total Monthly Bill (Kshs)**	**Kshs/kWh**	**Specific Energy consumption kWh/Occupant**	**Power Factor Surcharge**
May-14	6,250	49,995	144	115,200	0.88	972,458	19.45	8.00	19,261
Jun-14	6,250	65,619	154	123,200	0.93	1,418,989	21.62	10.50	-
Jul-14	6,250	39,851	133	106,400	0.92	940,956	23.61	6.38	-
Aug-14	6,250	54,504	141	112,800	0.86	1,246,320	22.87	8.72	55,088
Sep-14	6,250	54,818	145	116,000	0.94	1,153,431	21.04	8.77	-
Oct-14	6,250	52,075	153	122,400	0.88	1,058,038	20.32	8.33	19,076
Nov-14	6,250	56,726	164	131,200	0.91	1,067,602	18.82	9.08	-
Dec-14	6,250	51,133	149	119,200	0.95	929,845	18.18	8.18	-
Jan-15	6,250	53,697	156	124,800	0.83	955,362	17.79	8.59	75,088
Feb-15	6,250	54,514	160	128,000	0.92	1,099,044	20.16	8.72	-
Mar-15	6,250	50,001	159	127,200	0.93	894,392	17.89	8.00	-
Apr-15	6,250	54,474	144	115,200	0.89	945,811	17.36	8.72	18,242
Average	**6,250**	**53,117**	**150**	**120,133**	**0.89**	**1,056,854**	**19.93**	**8.50**	**-**
Annual	**75,000**	**637,407**	**1802**	**1,441,600**		**12,682,248**	**239**		**186,755**

As shown in Table 4.3 above, annual energy cost amounted to Kshs. 12,682,248.00 between May 2014 and April 2015 with an annual Maximum KVA Demand averaging to 150 KVA.

In addition it shows that the building doesn’t perform to the expectations in terms of power factor which averages to 0.89 and hence severally penalized by KPLC since it slightly falls below the required minimum of 0.9.

4.2. IDENTIFIED ENERGY SAVING OPPORTUNITIES

4.2.1 ENERGY SAVINGS BY USE OF LIGHT PIPE IN THE BASEMENT.

Technology has been developed to use light pipes to channel outdoor light into the interior of the building, this helps in saving energy from the artificial lighting during daytime, in this study basement was considered for assessment because it wasn't exposed to outdoor lighting leaving artificial lights in use for 24 hours a day. Figure below shows a sample of a successful implementation of a parking area using Light pipes.

Figure 4.5: Light pipe Distribution Network
Source: Parking area in University of Central Florida.

Figure 4.5 above shows how light distribution is done, where inlet transport light pipes are directed to one main light pipe to enable uniformly distribution of light from one source.

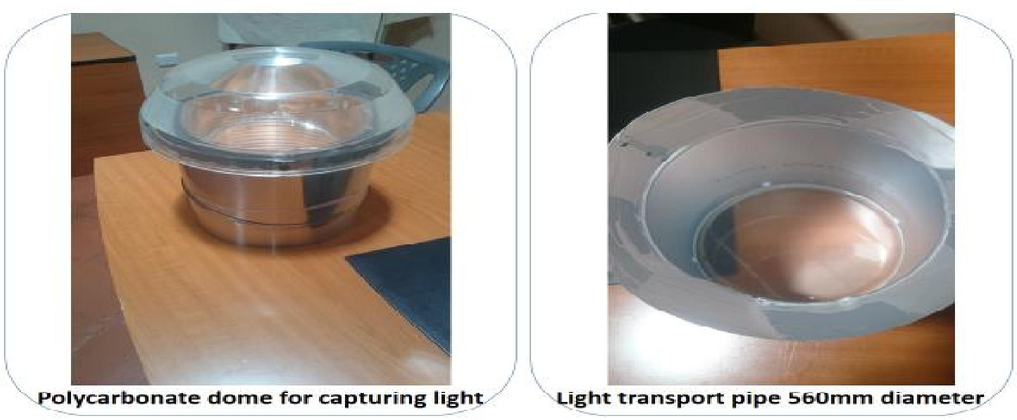


Figure 4.6: Typical look of a light pipe
Source: Steam plant Ltd, Kenya.

Figure 4.6 shows a typical dome that is used in tapping sunlight rays and concentrating them into the tube and is wrapped inside with aluminum foil for high reflectivity. The dome is made of polycarbonate material which has properties that help in blocking light rays with temperatures beyond 28.5 degrees and redirect them during morning and evening times when illumination intensity is a bit low. This helps in optimizing temperature as well as keeping the room illuminated both in the morning and in the evening hours.

Figure 4.7: Light pipe diffuser in operation
Source: Steam-Plant Ltd, Kiambu, Kenya.

Figure 4.9 above was obtained from one of the rooms being illuminated by use of light pipes in Kiambu County, and they were installed by steam Plant Company as a pilot project for demonstration. Figure 4.8 below shows the EFC parking area with lights on. Its size was determined.

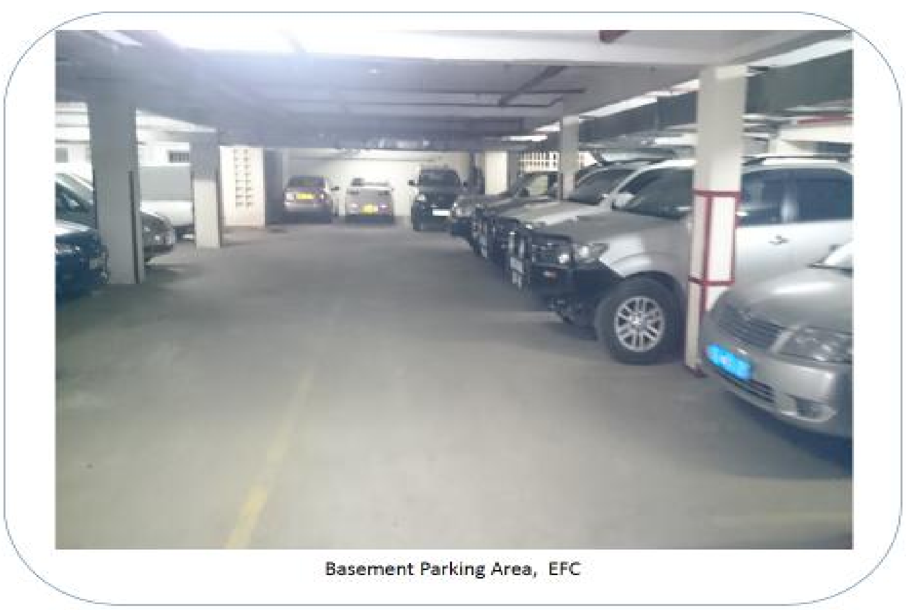


Figure 4.8: Basement parking area, EFC

EFC is located in the epicenter of Nairobi region which has a relatively high potential for outdoor illumination levels that would favor the implementation of light pipes in commercial buildings. Figure 4.9 shows different peaks of illumination for March, August and December with values of 80000, 70000 and 60000 lux respectively. In a year, therefore enough sunlight could be tapped for use in the basement to supplement artificial lighting during daytime.

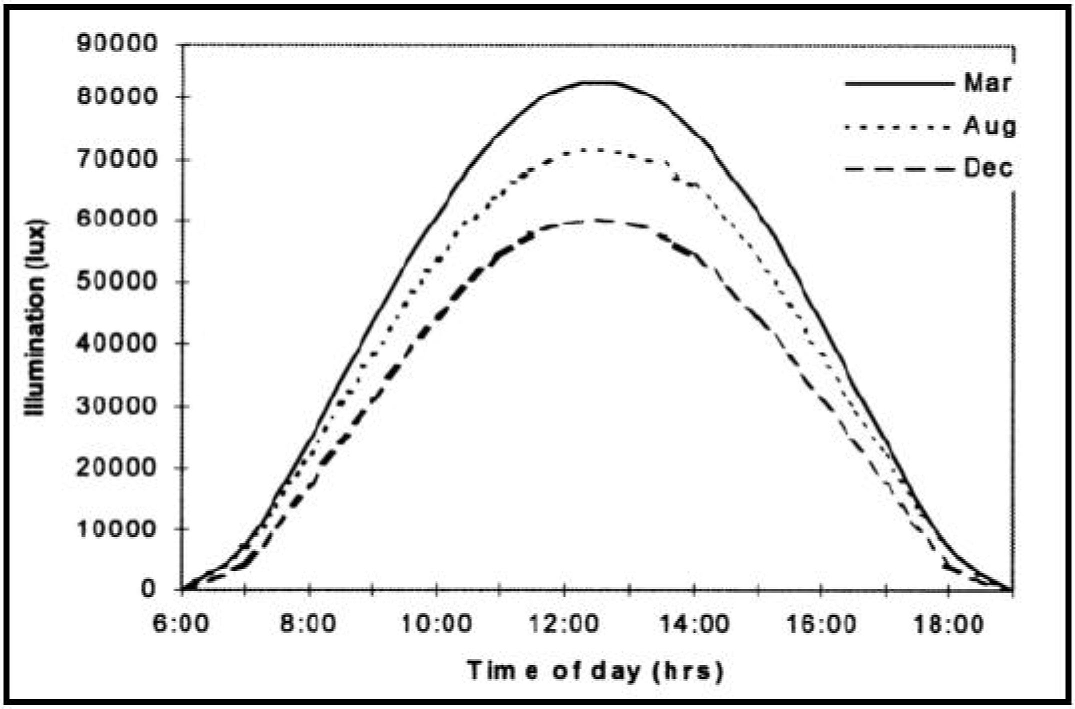


Figure 4.9: Daylight availability in Nairobi
Source: Kenya Meteorological Department

During this evaluation, the building height of EFC was measured and found to be 22.5m from the ceiling of the basement to the rooftop where light tapping would occur. Therefore the most preferred light pipe in this study was as shown in table 4.4 a below.

Table 4.4 (a): Light Pipe Specifications, Source Solartube UK.

No.	Model (Solartube)	Tube Size (Diameter)	EDCS (Effective Daylight Capture Surface)	Light Coverage Area	Potential tube Length
1	160 DS	250mm	1032cm2	14-19m2	9m+
2	290 DS	350mm	1871cm^2	23-28m2	16m+
3	310 DS	560mm	2150cm^2	32-38m2	25m+

The highlighted model of the solar tube (Light pipe) was considered in this study for use in the basements since it meets the required specifications.

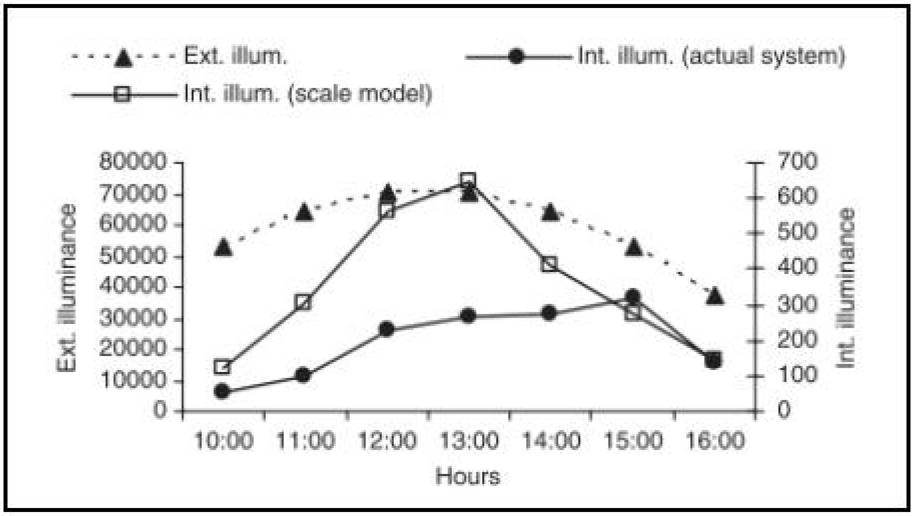


Figure 4.10: Test performance for a 560mm Diameter, 25M Length light pipe
Source: Solartube, UK

From figure 4.10 above, it can be shown that internal illumination by use of this light pipe i.e. 560mm diameter and 25m length can reach to levels of 300 lux, this test was carried out by Solartube UK company to determine efficiency of light pipes when subjected to different lengths. In this study, it was observed that the lux levels required to meet the existing levels were found to be an average of 159 as shown in table 4.4.

Assessment of the existing illumination levels for the basement were first measured and recorded by use of six lux meters placed at different locations in the basement and tabulated as shown in table 4.4 b so that the evaluation and sizing of the light pipes could be determined.

Table 4.4 (b): Basement Illumination Levels.

Lux Meters	**Lux**
L1	161
L2	155
L3	160
L4	153
L5	158
L6	172
Total	959
Average	**159**

International standards requires that lux levels for the parking area should be in a range of 120 - 200 Lux (IEA, 2012) as shown in table 4.5 below and therefore an optimal lux level of 150 was considered to obtain the optimum illumination.

Table 4.5: International Illumination Standards (IEA, 2012)

Activity	Illumination (lux, lumen/m2)
Public areas with dark surroundings	20 – 50
Simple orientation for short visits	50 – 100
Working areas where visual tasks are only occasionally performed	100 – 120
Warehouses, Homes, Theaters, Archives, Parking	120-200
Easy Office Work, Classes	250
Normal Office Work, PC Work, Study Library	500

Total Illuminated area by the existing artificial lighting system in the basement was found to be 640m2 and therefore the evaluation of the number of light pipes required was based on the size of the parking area, and the expected energy savings to be offset by this implementation was based on lighting load in the parking area as shown in table 4.6

Table 4.6: Basement lighting load

SR. NO.	DESCRIPTION	LAMP TYPE	QTY	CHOKE(9W)	RATED WATT PER FIXTURE(W)	Total Wattage
1	Parking area	2 X 36W Fluorescent	40	9	72	3600
2		1 X 36W Fluorescent	1	9	36	45
3		38W CFL	1	0	38	38
	Total Power					**3683**

a) Total operating hours for the lighting system in the basement = **24 hours per day**

b) Expected effective operating hours for the Light pipes= **10 hours,**

c) Number of days considered in a year was =**250**

d) Annual Expected Energy savings. 3.683×10×250 = **9,2075kWh.**

Therefore use of light pipes would yield energy savings amounting to 9,2075kWh annually.

4.2.2 .USE OF LEDs TO REPLACE EXISTING FLUORESCENT TUBE LAMPS.

The total lighting system of the plant was reviewed during the audit. The lighting fixtures in use were observed to be mostly fluorescent tube lamps (FTL) rated at 36W, 18W respectively and

Compact Fluorescent Lamps. All the FTL tubes within the building were generally fitted with electromagnetic (Copper) ballast. Other fixtures found were halogen lamps for outdoor lighting

Table 4.7 below shows the type of the existing lighting fixtures with their respective electronic ballast power ratings.

Table 4.7: Existing FTL in EFC

Type of Lamp	Electromagnetic copper ballast(kW)	Total Power Consumed by the Fixture (kW)
36W Tube light, 4Ft	9	45
18W Tube light, 2Ft	9	27

Figure 4.11: Existing Fluorescent tubes- 18W, 2ft

Figure 4.11 shows a sample of the existing FTL fixture T8, 2ft and 18 W.

In addition table 4.8 below shows a summary of the existing lighting fixture with their respective power ratings.

Table 4.8: Lighting fixtures installed in EFC.

SR. NO.	DESCRIPTION	LAMP TYPE	QTY		RATED WATT PER FIXTURE(W)	Power Rating (W)
1	Parking	2 X 36W Fluorescent	40		72	2880
2	//	1 X 36W Fluorescent	1		36	36
3	//	38W CFL	1		38	38
4	6th Floor	1 X 36W Fluorescent	12		36	432
5	5th Floor(Fidelity Insurance)	4 X 18W Fluorescent	30		72	2160
6	//	2 X 18W CFL	23		18	414
7	ECB	15W LED	40		15	600
8	//	4 X 18W Fluorescent	6		72	432
9	//	2 X 18W CFL	28		18	504
10	4th Floor(Fidelity Insurance)	4 X 18W Fluorescent	34		72	2448
11	//	1 X 36W Fluorescent	12		36	432
12	//	2 X 18W CFL	18		36	648
13	DANONE Nutricia	18W CFL	35		18	630
14	//	12W LED	13		12	156
15	3rd Floor(Fidelity Insurance)	4 X 18W Fluorescent	34		72	2448
16	//	1 X 36W Fluorescent	6		36	216
17	//	2 X 18W CFL	18		36	648
18	Trademark	4 X 18W Fluorescent	40		72	2880
19	//	2 X 18W CFL	20		36	720
20	2nd Floor(Trademark)	4 X 18W Fluorescent	91		72	6552
21	//	2 X 18W CFL	57		36	2052
22	//	50W Halogen	24		50	1200
23	//	100W Halogen	4		100	400
24	1st Floor(Africa Oil)	2 X 18W CFL	50		36	1800
25	//	15W LED	7		15	105
26	//	4 X 18W Fluorescent	46		72	3312
27	ECB	4 X 18W Fluorescent	33		72	2376
28	//	2 X 18W CFL	10		36	360
29	Mezzanine	4 X 18W Fluorescent	73		72	5256
30	//	1 X 36W Fluorescent	10		36	360
31	//	2 X 18W CFL	18		36	648
32	Ground Floor	4 X 18W Fluorescent	27		72	1944
33	//	2 X 18W CFL	18		36	648
34	Basement(ECB IT)	4 X 18W Fluorescent	18		72	1296
35	//	2 X 18W CFL	11		36	396
36	SENATOR	4 X 18W Fluorescent	30		72	2160
37	//	2 X 18W CFL	6		36	216
Total						**49803.00**

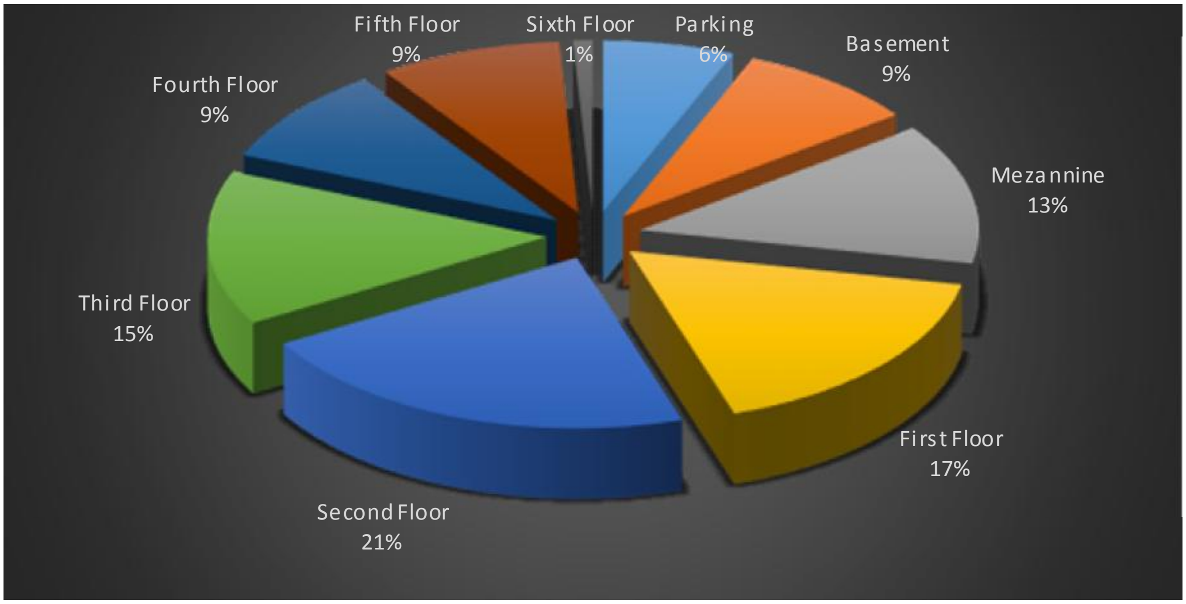


Figure 4.12: Lighting Load

Figure 4.12 above shows the split of the lighting load with second floor having the largest share and sixth floor with the least share of the total Lighting load.

LED lamps were considered to replace the existing FTL to yield energy savings. Designers have been using LEDs to substitute various standard fixtures that are used in commercial spaces. For example 18 Watt LED lamps have significantly substituted 36 Watt fluorescent tube light fixture with an additional choke of 9W; the power saving potential is about 30 Watts per fixture.

Therefore an alternative option in saving energy in lighting would be to replace the Fluorescent Lamps with an equivalent LED Lamps. The description of the type of equivalent replacements and savings expected along with is shown in Table 4.12 in page 41.

Light produced by LEDs provides good color rendering and offer the benefit of greater optical control so that the light can be directed to the locations intended. LED fixture efficiencies are 80 to 90% compared to conventional lights which have fixture efficiencies of 40 to 60%.

Higher efficiencies indicate that more light reaches the source and light trespass is minimized. Additionally they do not require strike time and on/off cycling does not affect LED lifetime.

Table below 4.9 and 4.10 below shows the recommended LEDs to replace FTL.

Table 4.9: LED Brightness

LED Watts	Lumens (Brightness)
4 – 5	450
6 – 8	1285
9 – 13	1750
16 – 20	2850
25 – 28	3150

Table 4.10: LEDs used to replace FTL in EFC

Type (FTL)	Lumens (Brightness)	Equivalent LED
T12 40W 4ft	2900	T12 21 W 4ft
T8 36 W 4ft	2700	T8 18 W 4ft
T5 28W 4ft	2750	T5 15 W 4ft
T8 18W 2ft	1750	T8 10 W 2ft
T5 14W 2ft	1275	T5 8 W 2ft

As highlighted from table 4.10, shows the existing fluorescent tubes and their respective equivalent LEDs considered for replacement.

Table 4.11 below shows the comparison between LEDs and fluorescent tubes of the same size in terms of efficiency. It indicates that LEDs are far more energy efficient than their counterpart fluorescent tubes and therefore they were identified as one of the major energy saving opportunity in EFC.

Table 4.11: LED Lumen

Type	Efficiency
T-8 LED Tube light	110-120 lumens per watt
Regular Fluorescent T-8 Tube light	60-80 lumens per watt (lower for one with electromagnetic ballast)

Table 4.12: Energy savings by use of LED Lighting fixtures

SR. NO.	DESCRIPTION	Recommendation	QTY	Annual Energy consumption for FTL with Magnetic ballast(9W) kWh	Annual Energy consumption with LED kWh	Expected annual Energy savings kWh
1	Parking	Replace 36W Fluorescent tube lights with an equivalent 18W LED	41	6,457.5	2,583	3,874.5
2	6th Floor	Replace 36W Fluorescent tube lights with an equivalent 18W LED	12	1,350	540	810
3	Fidelity Insurance	Replace 18W Fluorescent tube lights with an equivalent 10W LED	98	23,520	9,800	13,720
		Replace 36W Fluorescent tube lights with an equivalent 18W LED	12	1,350	540	810
4	Trademark	Replace 18W Fluorescent tube lights with an equivalent 10W LED	131	31,440	13,100	18,340
5	ECB	Replace 18W Fluorescent tube lights with an equivalent 10W LED	91	21,840	9,100	12,740
6	Africa Oil	Replace 18W Fluorescent tube lights with an equivalent 10W LED	46	11,040	4,600	6,440
7	Mezzanine	Replace 18W Fluorescent tube lights with an equivalent 10W LED	73	17,520	7,300	10,220
		Replace 36W Fluorescent tube lights with an equivalent 18W LED	10	1,125	450	675
8	Ground Floor	Replace 18W Fluorescent tube lights with an equivalent 10W LED	27	6,480	2,700	3,780
9	Senator	Replace 18W Fluorescent tube lights with an equivalent 10W LED	30	7,200	3,000	4,200
			570.00	**138,633.00**	**53,792.2**	**81,195.80**

As shown in table 4.12, use of LED in EFC would result to an annual energy savings of 81,195 kWh with an annual energy consumption of 53,792.20 kWh. Time of operation for the lighting system was considered to be 10 hours per day except that of the parking which operates 24 hours. As discussed earlier on, Parking had been assessed for use of light pipe during day time for 10 hours in average and therefore during this evaluation use of LEDs in the parking was subjected to the remaining 14 hours a day.

4.2.3. ENERGY SAVINGS THROUGH SOLAR PV

4.2.3.1 Potential for Solar PV Power generation for Lighting.

In this study the solar PV was considered for the lighting system during daytime. The evaluation of the solar energy capacity was based on the recommended LEDs lighting load. Solar radiation data for Nairobi was obtained and used in the assessment of potential solar energy generation. Table 4.13 shows the monthly solar insolation data for Nairobi in a year.

Table 4.13: Solar Energy potential in Nairobi City

Month	Temperature	Daily solar radiation – horizontal kWh/m²/d	Daily solar radiation – tilted kWh/m²/d
January	24.2	5.85	5.40
February	25.6	6.14	4.95
March	20.8	5.81	3.86
April	24.3	5.01	2.71
May	23.5	4.59	2.07
June	19.1	4.11	1.80
July	16.9	3.79	1.83
August	17.2	3.96	2.18
September	18.5	4.93	3.09
October	22.7	5.34	4.07
November	22.6	5.08	4.47
December	24.2	5.54	5.27
Annual	**21.6**	**5.01**	**3.47**

Source: NASA Surface Meteorology and Solar Energy, 2013 Global Data sets averaged for 30 years from 1983-2013.

Nairobi has high insolation rate with an average of 5-7 peak sunshine hours i.e. the equivalent number of hours per day when solar irradiance is 1000W/m2 and receives an average daily Insolation of 4- 6 kWh/m2. This gives a good platform for harvesting solar energy by use of solar panels. Figure 4.13 below depicts the monthly variation of solar insolation. High solar radiation is experienced in January and least experienced in July.

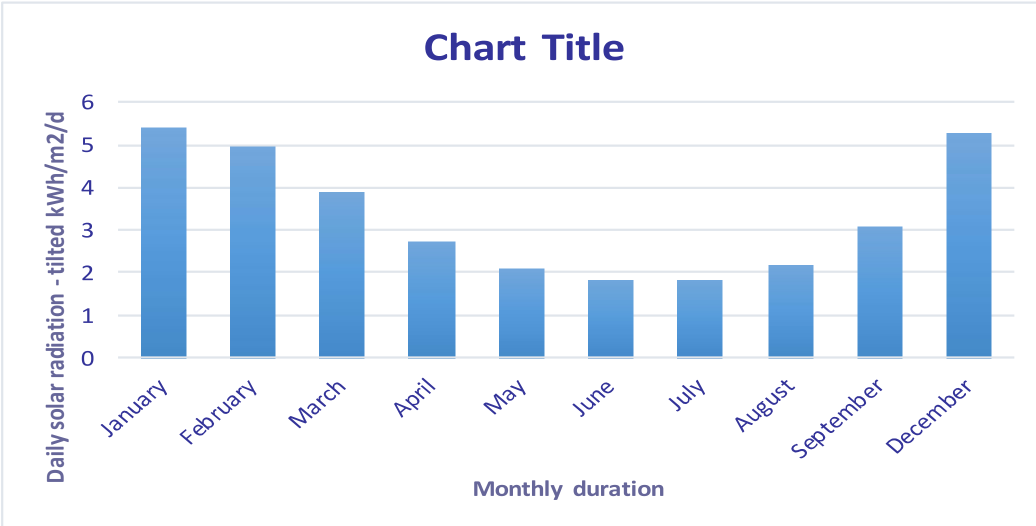


Figure 4.13: Graphical representation of Daily solar radiation in Nairobi

Source: Kenya Meteorological department

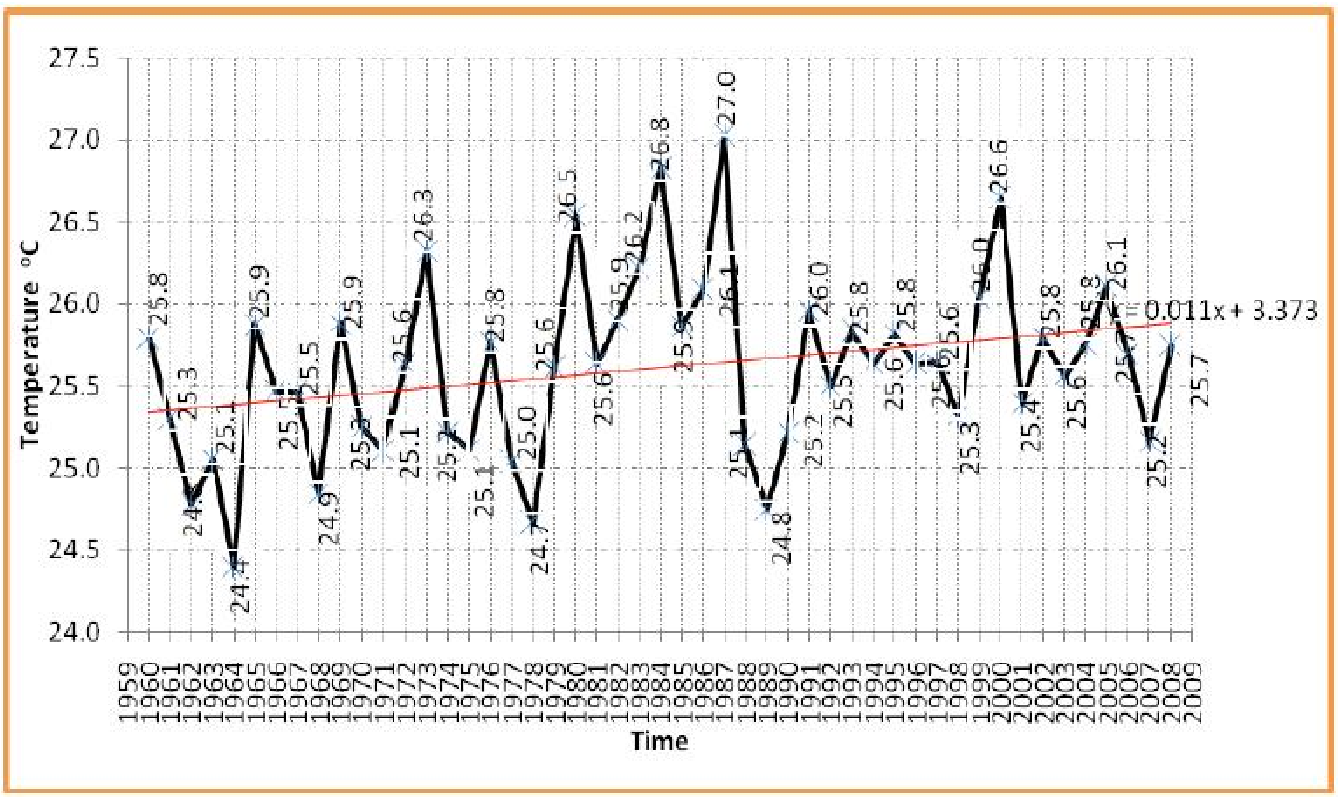


Figure 4.14: Observed annual temperature trends for Nairobi 1960-2008

Source: Kenya Meteorological department 2013 Report

Figure 4.14 shows that Nairobi has been experiencing rise in temperatures for the past five decades, this in turn provides a good platform for tapping solar energy. It shows that current temperatures in Nairobi is given by;

T= 0.011X+ 3.373, substituting Year 2016 in this equation,

T= 0.01(2016) + 3.73 = 23.89 ℃. This indicates that Nairobi has an average room temperature of 23.89℃.

In this study monocrystalline solar panels were considered for assessment for the lighting load, leaving other loads in the building being fed from the utility. Therefore an evaluation of rooftop solar PV was based on the lighting load for LEDs which was 21.5 kW and addition 10% was considered in the design to allow load stability due to losses leading to a total capacity of 23.6kW solar PV plant.

Figure 4.15 (a) below shows the rooftop of EFC where solar panels would be installed, It clearly shows that the rooftop is well exposed to solar radiation giving room for solar energy potential.

Figure 4.15 (a): Rooftop of EFC

Baseline Information

Total Area of the rooftop= 750M2

Design lighting load = Lighting Load by LEDs + 10% losses

Daily Peak Sun Hours in Nairobi= 5.74

Therefore Lighting load= (53792.2)/ (10×250) = 21.5kW+ 2.1kW= 23.6kW

Therefore Annual Expected Energy savings is = **42,614kWh** as depicted from table 4.23

Figure 4.15 (b) below shows a graphical representation of data logged for existing lighting load and then extrapolated for the prospected lighting LEDs load profile vs. the prospected Solar PV generation. Data was extracted from data logger and using excel a load profile vs. Solar PV generation was obtained.

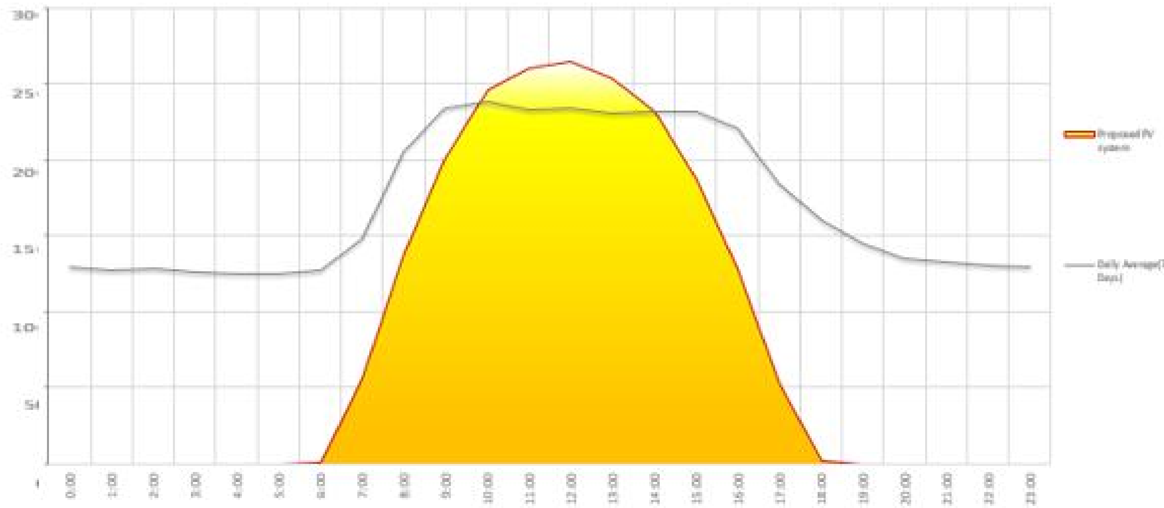


Figure 4.15 (b): Lighting load Profile vs. Projected Solar PV Generation

It depicts that prospected Solar PV generation will cater for the lighting load during daytime with a peak load of 26kW mostly occurring during mid-day. In addition lighting load profile shows that lighting systems are mostly switched on during daytime with an average load of 24kW and low during night time with an average load of 14kW which is prospected to be fed from mains.

4.2.3.2 Energy Dispatch and Saving System

Energy dispatch and saving system was designed and a hardware was built to demonstrate how solar energy could be maximised in the building for all six floors such that, when the level of solar energy goes down and unable to take the full lighting load, the extra load would therefore be cut off from the solar energy source to the mains source. This would continue to a point where solar energy would not be enough to meet the lighting load for atleast one floor and therefore power from the mains would take on the full electrical load of the building.

This was done by the use of microcontrollers, high speed switching relays, current sensor and LEDs and for the purpose of demonstration only the three floors were considered. In addition the system was designed to limit energy consumption beyond a certain limit, so that in case any lighting fixture is replaced and tends to consume more energy than the previous fixture it triggers an alarm and displays through LCD to the client that the fixture replaced consumes more energy for action.

In this design process three power adapters 12V 2A were used to represent the following sources;

i. Solar energy- Variable DC power Supp;y

ii. Diesel Generator

iii. Mains from Utility

This system was designed mostly to dispatch energy efficiently among the three sources. It was designed in such away that solar energy would only feed the lightng system and other loads should be fed directly from the mains unless in cases where there is power outage from the mains and therefore the automatic change-over would automatically switch to generator mode for the stand-by generator to take care of the power outage.

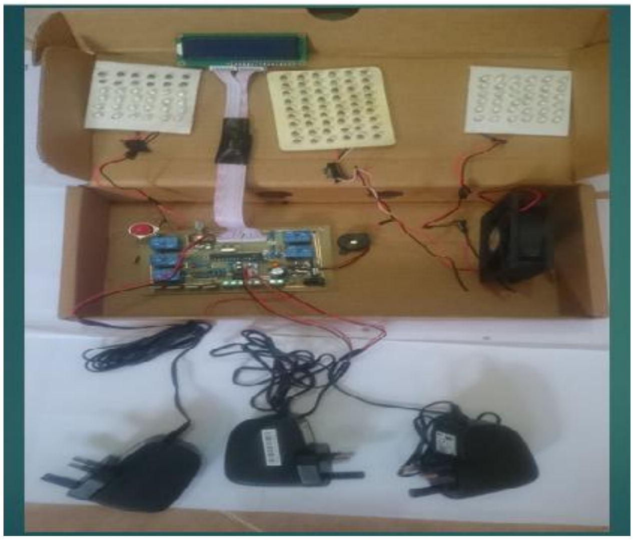


Figure 4.16: Energy dispatch and Saving system

Three LEDs arrays represent the lighting systems in three floors

LCD Display- Displays the type of energy in use in the three floors.

The three 12V, 2A adapters represent the three sources of power and that one for solar being connected to a potentiometer for variation.

Motor represent loads being fed directly fom the mains.

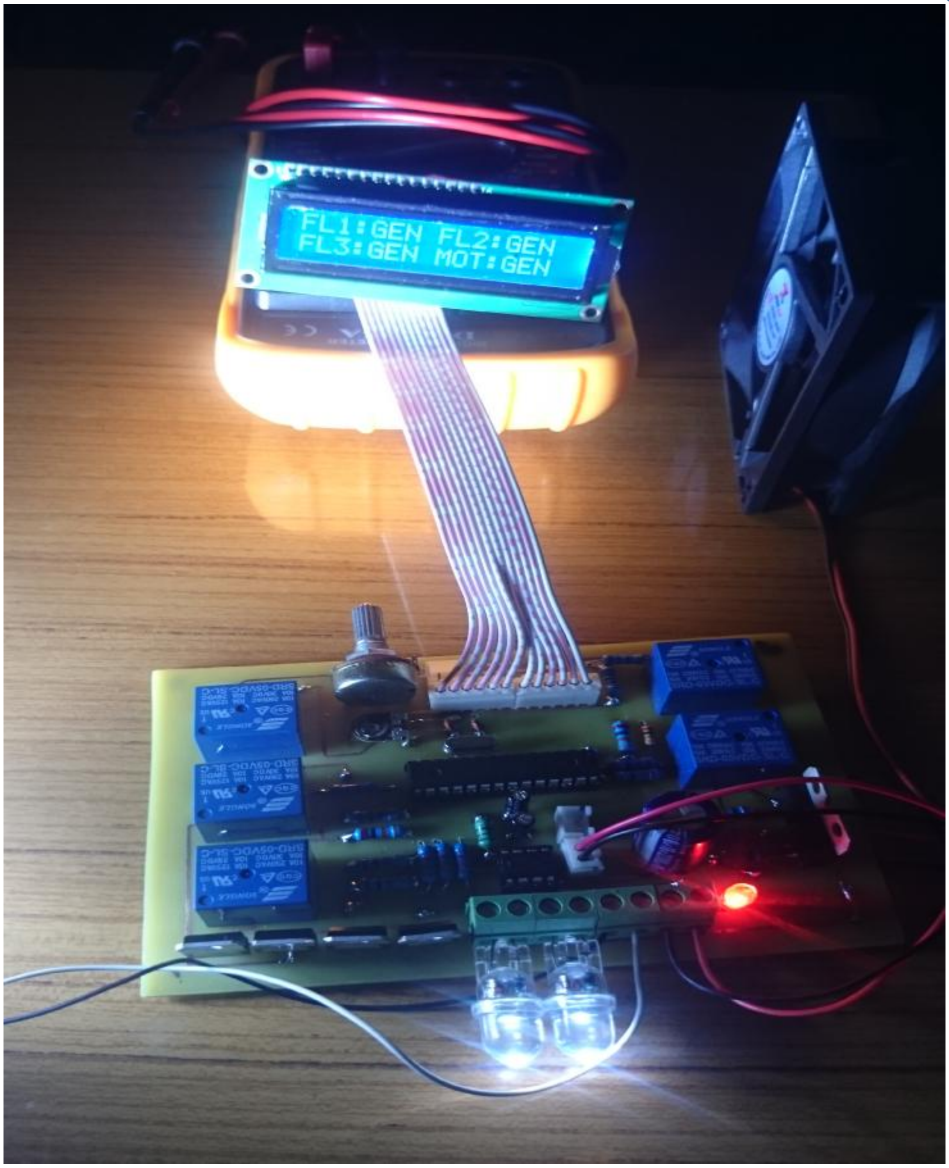


Figure 4.17: Energy saving system in operation

Figure 4.17 shows the display from the LCD that, Floor 1, 2, 3 and the motor are all powered by the Standby Generator. This is a situation whereby in case there is no power from mains and from solar as well Generator should take on the full load.

Table 4.14: Operation of the Energy saving system

1. Solar Energy Available	No. of Floors	2. Lighting load being fed by Mains	No of Floors	3. Source-Generator Set	No. of Floors fed by Generator
100%	3	Nil	0	OFF	0
70%	2	30%	1	OFF	0
40%	1	60%	2	OFF	0
≤ 30%	0	100%	3	OFF	0
≤ 30%	0	(Power outage)	0	ON	3
Finally if there is Power outage from mains and solar energy available is > 30% therefore Generator should take over from the mains					

4.2.4 POWER FACTOR IMPROVEMENT.

From the data collected of the energy bill statement, It showed that the building has an average power factor of 0.89 which slightly falls below KPLC set standards, five out of twelve months fell below power factor of 0.9 which led to power factor surcharges amounting to Kshs.186,755.00. Low power factor is caused by inductive loads such as transformers, electric motors, and high intensity discharge lighting. Unlike resistive loads that create heat by consuming kilowatt, inductive loads require the current to create a magnetic field, and the magnetic field produces the desired work. The total apparent power required by an inductive device is a composite of the following:

i. Real power – measured in kilowatts, KW

ii. Reactive power, the nonworking power caused by the magnetizing current, required to operate the device – measured in kilovars, kVar.

The reactive power required by inductive loads increases the amount of apparent power in the distribution system. The increase in reactive and apparent power causes the power factor to decrease.The power factor surcharge incurred in 2014/2015 as per the energy bill is shown in table 4.15

Table 4.15: Power Factor Surcharge May/2014- April 2015

Month	Power factor Surcharge (Kshs.)
April/2014	19,261.00
August/2014	55,088.00
October/2014	19,076.00
Jan/2015	75,088.00
April/2015	18,242.00
Total	186,755.00

A power factor surcharge is applied if the consumer’s power factor falls below 0.9 and the surcharge applied is 2% of the base rate and the demand charge for every 1% by which the power factor is below 0.9.

Figure 4.18 (a) shows the power factor trend during the period of consideration i.e. May 2014/ April 2015. It indicates that low power factor was experienced in several months and was below the required minimum value of 0.9 by KPLC and this resulted to power factor surcharges in several months which amounted to Kshs. 186,755.00

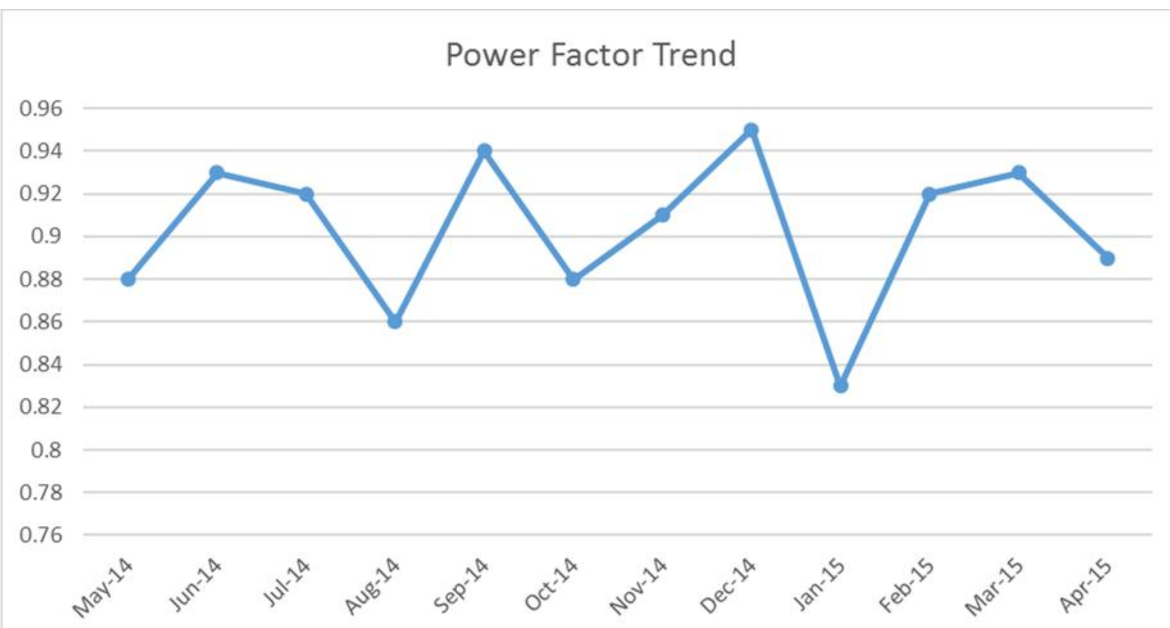


Figure 4.18 (a): Power factor Analysis

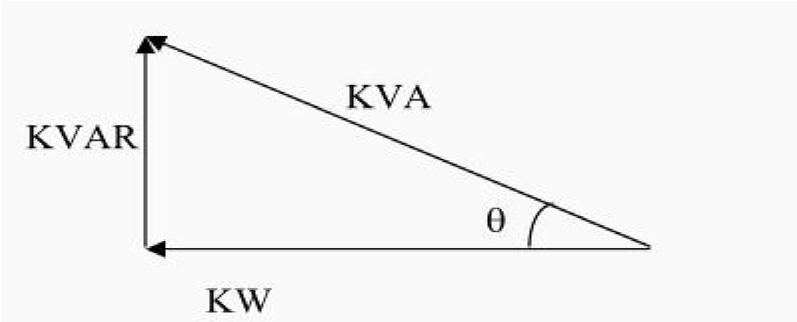


Figure 4.18 (b): Power Factor Vector diagram

Improving Power factor lowers reactive power and apparent leading to low energy cost.

$PF = \frac{kW}{kVA}$ =***Cos Ө***

Using the Pythagoras rule:

Real Power (kW) = PF× KVA

Figure 4.19 below shows the logged power factor from the bus bars. It shows the variation of power factor in different times of the day and clearly indicates that in some instances the power factor was as low as 0.8, which was way much below the required minimum threshold of 0.9.

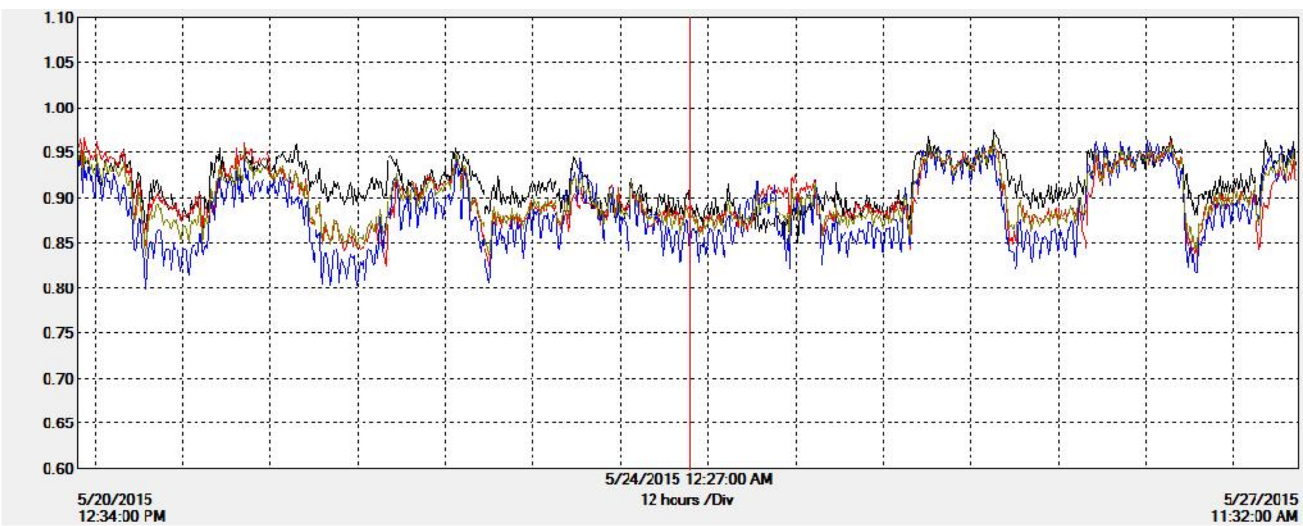


Figure 4.19: Main Incomer logged Power Factor.

Power factor for two lifts were obtained by use of power logger**.** Figure 4.20 and Table 4.16 shows the power factor variation for Lift 1 and aggregate power factor respectively as recorded by the power logger. The same was repeated for the second lift and Data obtained was uploaded and tabulated as shown in figure 4.21 and Table 4.17 respectively. From the two graphical representations for power factor they indicate that at some point power factor was far much below 0.9

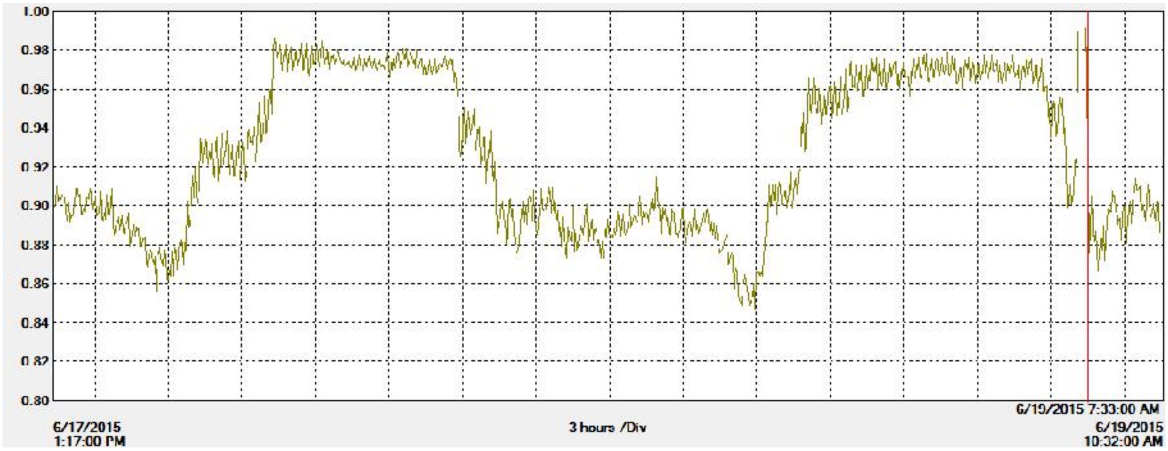


Figure 4.20: Logged power factor for Lift 1

Table 4.16: Power Factor for Lift 1

Red Phase	Yellow Phase	Blue Phase
0.813	0.843	0.842

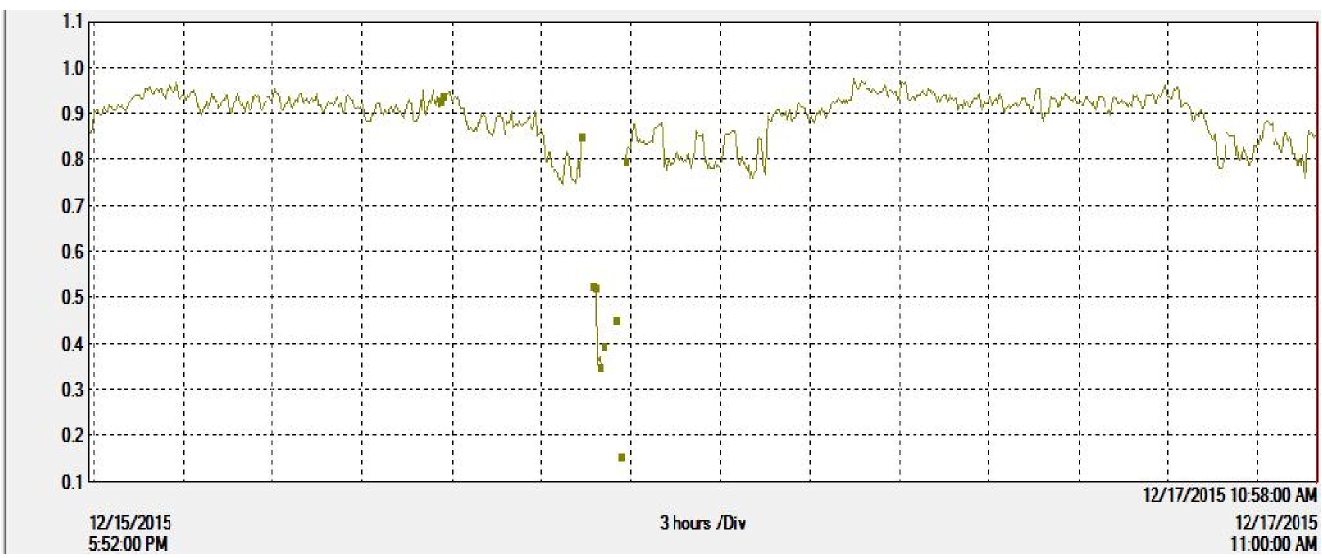


Figure 4.21: Logged Power Factor for Lift 2.

Table 4.17: Power Factor for Lift 2

Red Phase	Yellow Phase	Blue Phase
0.881	0.901	0.843

4.2.4.1 Power Factor for water Pumps.

EFC has a total of four water pumps installed, two of them rated 3KW each and the other two rated 5kW each. The four pumps were evaluated in terms of power factor status and data obtained was tabulated as shown in Table 4.18.

Figure 4.22 Water Pumps, energy consumption evaluation

Table 4.18: Water Pumps and their respective power factor

No.	Equipment	Rated kW	Voltage V	Current A	P.F	Frequency Hz
1	Water Pump 1	3	423	3.9	0.88	50
	// 2	3	423	6.9	0.89	50
2	Water Pump 3	5	423	12	0.62	50
	// 4	5	423	11.5	0.74	50

These water pumps were found to have very low power factor that mostly contributed to the aggregate low power factor in the building. All the four pumps suffered from low power factor with values of 0.88, 0.89, 0.62 and 0.74 respectively. These values were as well far much below the utility provider requirements of 0.9.

4.2.4.2 Power Factor Correction.

To improve power factor, a Capacitor bank is required to correct the low power factor which is mostly due to inductive electrical appliances installed in the plant.

From the audited equipment, it was found that the low power factor was majorly contributed by the two lifts and the water pumps installed. This contributed mostly to the power factor surcharges amounting to Kshs.186, 755.00 annually and therefore the required capacitor bank was computed as shown below.

Average KVA Demand = **150**-- (4.1)

Average Power Factor= 0.89
Real Power = 150×0.89 = 133.5kW

Cos θ = 133.5/150= 0.89

Therefore θ= 27.1 degrees

Existing capacitor bank = 150 Sin 27.1= 68.33KVAr-- (4.2)

Raising Power Factor to 0.99 will lower both power factor surcharge and Maximum KVA Demand charges.

I.e. New Cos θ = 0.99

Therefore θ= 8.10 degrees

Since Real Power is constant

New Apparent Power = 133.5/0.99 = 135KVA--- (4.3)

Capacitor bank = 135sin8.1 = **19.1 KVAR**--- (4.4)

KVA Demand Improvement = Eqn 1- Eqn 3 = 150 – 135 =15KVA

Capacitor Bank required = **Eqn 2- Eqn 4** = 68.33- 19.1 = **49.23 KVAR.**

Therefore to raise the power factor to 0.99, a capacitor bank of 49.23 KVAR is required and yields additional advantage of lowering the apparent power by **15KVA**

4.2.5: TARIFF MIGRATION

EFC can consider tariff migration from Commercial/Industrial 1 to Commercial/Industrial 2, as this shall yield cost saving. The two tariffs have different rates as shown below.

COMMERCIAL/INDUSTRIAL (CI) - METHOD CI

This tariff is applicable to Commercial and Industrial Consumers for Supply provided and metered by the Company at 415 volts three phase four wire and whose consumption exceeds 15,000 units per post-paid billing period.

a) A fixed charge of Kshs. 2,000.00

b) Energy charge of Kshs. 8.70 per unit consumed.
c) Demand charge of Kshs. 800.00 per kVA.

COMMERCIAL/INDUSTRIAL (C12) - METHOD C12

Applicable to Commercial and Industrial Consumers for supply provided and metered by the company at 11,000 volts, per post-paid billing period.

a) A fixed charge of Kshs. 4,500.00
b) Energy charge of Kshs. 7.50 per unit consumed.
c) Demand charge of Kshs. 520 per kVA

From the data above, it shows that tariff CI2 is more favorable since its' Energy and Demand charges are relatively cheaper in comparison to CI1.
Expected cost savings
Energy charge 8.70-7.50=Kshs. 1.20 per unit Consumed.
Demand Charge 800-520 = Kshs. 280 per Maximum KVA Demand
On the other hand, fixed charge is relatively lower for CI1 tariff than CI2 with 4500-2000= Kshs. 2,500 but doesn't outweigh the average cost savings due to tariff CI2. These computations excludes other state levies which include Fuel Cost, REA Levy and WARMA among others,

4.3 ECONOMIC EVALUATION

4.3.1 Economic Evaluation: Use of Light Pipes

Light pipe considered in this case was found to have the following specifications.

i. Diameter =560mm
ii. Length =25M
iii. 99.7% Spectral reflectivity
iv. Diffuser capacity = Illumination area coverage of 36m2
v. Luminance levels = 150 to 200 Lux.
vi. Loss per set is 22%

Table below shows the sizing of different light pipes and their applications

Number of Light Pipes Required

- Expected surface area to be illuminated = 640M^2
- I light Pipe can illuminate an area of 36M^2

Therefore required number of light pipes to illuminate the total parking area is 640/36= 17.7 light pipes.

Table 4.19: Economic Analysis for Light Pipes

No. Light Pipe	Diameter Size(mm)	Length (M)	Area Covered(M^2)	Capital Cost (Kshs)	Installation + Miscellaneous cost (15% capita Cost)	Total Investment	Expected Annual Energy savings(kWh)	Annual cost Savings
1	500	25	36	85,000.00	12,750.00	97,750.00	511.50	10,194.80
18	500	25	648	1,530,000.00	229,500.00	**1,759,500.00**	**9,207.50**	**183,505.50**

Expected annual energy Savings = **9,207.5kWh**

Projected annual Energy Cost savings = **Kshs. 183,505.50**

Capital Investment = **Kshs. 1,759,500.00**

4.3.2 Economic Evaluation: Use of LEDs

Table 4.20 summarizes energy savings incurred by replacing existing FTL with LEDs

Table 4.20: Economic Analysis: Use of LEDS. (Kshs 6000/ 18W LED, Kshs 3000/10W)

Sr No.	Description	Recommendations Replacing Existing Fixtures	Quantity	Expected Annual Energy Savings (kWh)	Expected Annual Cost Savings (Kshs)	Expected Investment (Kshs)
1	Parking	36W FTL with 18W LED	41	9460.80	188,553.70	246,000.00
2	6th floor	36W FTL with18W LED	12	810.00	16,143.30	36,000.00
3	Fidelity Insurance	18W FTL with 10W LED	98	13,720.00	273,439.60	470,400.00
		36W FTL with 18W LED	12	810	16,143.30	36,000.00
4	Trademark	18W FTL with 10W LED	131	18,340.00	365,516.20	628,800.00
5	ECB	18W FTL with 10W LED	91	12,740.00	253,908.20	436,800.00
6	Africa Oil	18W FTL with 10W LED	46	6,440.00	128,349.20	220,800.00
7	Mezzanine	18WFTLwith10W LED	73	10,220.00	203,684.60	350,400.00

Table 4.20 Continued

		36W FTL with 18W LED	10	675.00	13,452.80	30,000.00
8	Ground floor	18W FTL with 10W LED	27	3,780.00	75,335.40	129,600.00
9	Senator	18W FTL with 10W LED	30	4,200.00	83,706.00	144,000.00
	Total			**81,195.80**	**1,618,232.29**	**2,722,800.00**

From table 4.20;
Annual Energy Savings by use of LEDs = **81,195.80kWh**
Total Annual Energy Cost Savings = **Kshs. 1,618,232.29**
Expected Investment = Kshs. **2,722,800.00**

4.3.3 Economic Evaluation: Use of Solar PV for Lighting Load.

Required solar panel is anticipated to take the full lighting load for LEDs during daytime with a capacity of 23.6kW.

Table 4.21 below shows some of the parameters factored in during design of the roof top solar PV. This helps in ensuring efficient design to meet the anticipated load demand.

Table 4.21: Design Parameters for solar panel installation (Pricing structure borrowed from Negawatt Company based in Nairobi)

PV System Size	21,500	W
Cable Losses	5	%
Derating Losses	5	%
Peak Sun Hours	5.74	Hours
Average Cost of Electricity	19.93	Kshs/kWh
Single Panel Power rating	250	W
Single Panel Surface Area	2	M^2
CO2 Emissions	0.3675	KG CO2/kWh

Negawatt Energy Company situated in Kasarani, Nairobi area has been designing roof top Solar PVs for the last one decade. They have wide experience in solar energy and their design criteria was used in this research. Table 5.3 and 5.4 below shows the typical calculator which was used in Pricing and sizing of a 22.6kW solar PV plant which gave data in terms of investment in regards to tapping solar energy, among them, CO2 reduction, annual energy cost savings and payback period.

Table 4.22: Implementation Cost for Solar PV (Source: Negawatt Energy)

Cost of System Breakdown	ksh/W	ksh
Solar panels	68	1,536,800
Balance of system	40	904,000
System Control	14	316,400
Transportation	15	339,000
Installation	18	406,800
Taxes	14	316,400
Total	169	3,819,400

Installation cost are evaluated on the basis of per unit of electricity generated.

Table 4.23: Solar PV Calculator (Source: Negawatt Energy)

SOLAR PV SYSTEM		
System Size	21.5	kW
PSH	5.74	Hours
Total System losses(cable rating and derating factors)	10	%
Watts per 2m^2 Monocrystalline panel	200	W
Total number of Panels	91	Pcs
Total Rooftop Area Required	180.8	m^2
Panel Orientation	20degrees	North
Annual Energy Generation	42,614	kWh
Annual CO2 reductions	16	Tons
Initial Investment (Total system Cost)	3,819,400	Kshs.
Annual Cost of Energy savings	849,304	Kshs.

4.3.4 Economic Evaluation: Power Factor Improvement

The required capacitor bank to raise the power factor from 0.89 to 0.99, as shown earlier is **19.1kVAr.**

Expected Energy cost savings = Savings due to power factor Surcharge + Associated Savings due to lowered KVA Demand

186,755+ (15×800×12) = Kshs. 330,755

Cost of Capacitor bank per KVAR = Kshs. 32,000 (Installation Cost Inclusive)

Therefore 49.23 KVAR 49.23×32,000 = Kshs. 1,575,360.00

4.3.5 Economic Evaluation: Tariff Migration

As per the quotation from KPLC the cost for tariff Migration from CI1 to CI2 was found to be Kshs. 2,500,000. In addition it was advised that the plant would still use the existing transformer and that major changes would occur in the metering point.

Tariff Migration was considered for the new annual energy consumption with the outlined energy saving opportunities having been factored in.

Energy Considered for tariff migration= Total annual energy consumption – Annual Energy savings

637,407- (81,195.8+9,207.5+42,614) = **504,389.7kWh**

Table 4.24: Cost savings due to tariff migration

No.	Tariff	Fixed Charges Kshs.	Cost Per KVA Demand Charge. Kshs.	Cost Per Unit kWh Kshs.	Annual Energy Considered	Total Annual Energy Charges Kshs
1	CI1	2,000.00	800.00	8.70	504,389.7	5,708,190.39
2	CI2	4,500.00	520.00	7.50	504,389.7	4,679,322.75
Tariff (CI1- CI2)						**1,028,867.64**

Table 4.24 shows cost savings due to tariff migration from CI1 to CI2.

4.4 PAYBACK PERIOD OF THE ENERGY SAVING MEASURES OUTLINED

Table 4.25 below shows a summary of the total capital investment required to implement the outlined energy saving measures in EFC to yield maximum energy savings annually.

Table 4.25: Total Capital Investment and total Annual Energy cost savings

	Measures	**Annual Energy Cost Saving Kshs.**	**Capital Investment Kshs.**	**Payback Period (Years)**
1	Use of LEDs	1,618,232.29	2,722,800.00	1.6
	Tariff Migration	1,028,867.64	2,500,000.00	2.4
	Use of Solar PV	849,304.00	3,819,400.00	4.5
	Power factor Improvement	330,755.00	1,575,360.00	4.7
	Use of Light Pipe	183,505.00	1,759,500.00	9.6

Table 4.25 Continued

Total	**4,010,663.93**	**12,377,060.00**	**(3.1 Years)**

If all identified energy saving opportunities were to be implemented, would yield an annual savings amounting to Kshs. 4,010,663.93 with capital investment amounting to Kshs. 12,377,060.00. Therefore Payback period can be computed as = Capital Investment/ Annual savings

Payback period = $\frac{\text{Capital cost of installation}}{\text{Annual Savings}}$

= 12,377,060/4,010,663.93

= 3.1 years

= 3 years 1 month

From the capital investment and annual energy cost savings in this research resulted to a payback period of 3 years and 1 month for all outlined energy saving opportunities. This gives the implementation aspect a sound economic consideration to lower energy bill in EFC.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main objective of this study was to identify energy savings potential in a commercial building in Nairobi, a case study of Equatorial Fidelity Centre, From the findings reported in this study five major areas were identified as potential areas for energy savings and found to contribute to annual energy cost savings amounting to Kshs. 4,377,663.98. Out of the five major identified energy savings opportunities use of LEDs was found to yield highest energy savings followed by Tariff Migration from CI1 to CI2, use of rooftop solar PV for lighting LEDs, Power factor improvement and finally use of light pipes in the basement.

Energy efficiency measures outlined in this research were found to play a critical role in improving energy savings and associated energy cost. EFC having been set up in 2006 was found to have met several of the building energy savings codes which included energy efficient HVAC, but there were several areas that were found not to have met and needed to be worked on to improve energy savings. Energy efficiency measures are meant to reduce the amount of energy consumed while maintaining or improving the level of comfort in the building.

Economic evaluation was done in a systematic way so that the computation of payback period would be as a result of the total savings accrued from the five measures. Implementation of the above measures would result to a payback period of 3 years and 1 month as earlier shown. This makes the implementation to be economically viable and sound. Use of Light pipe is not common in Africa but it has been successful in several countries in Europe and mostly in United Kingdom. During the assessment of use of light pipes in the parking area, Steam plant Company in Kiambu County was severally visited and much was borrowed from them in terms of sizing and pricing as it is the only company in Kenya offering Light pipes services.

Use of rooftop Solar PV in Commercial buildings in Kenya is not a common phenomenal yet the potential for solar energy is quite high. EFC rooftop was found to be well exposed to outdoor sunlight and had enough surface area for solar panel installation that would meet the lighting load demand. During this research an energy dispatch system was designed and a hardware was built to demonstrate how to maximize usage of solar energy and change over to mains if the available solar energy would not be enough to cater for the lighting load of at least one floor where the full lighting load should be switched to the mains.

The light pipe system will have a great impact to the next generation. The natural resource are not enough to serve the next generation, thus there is a need to introduce some renewable energy to maintain our society. Therefore light pipe system is a great technology to preserve the society to keep developing.

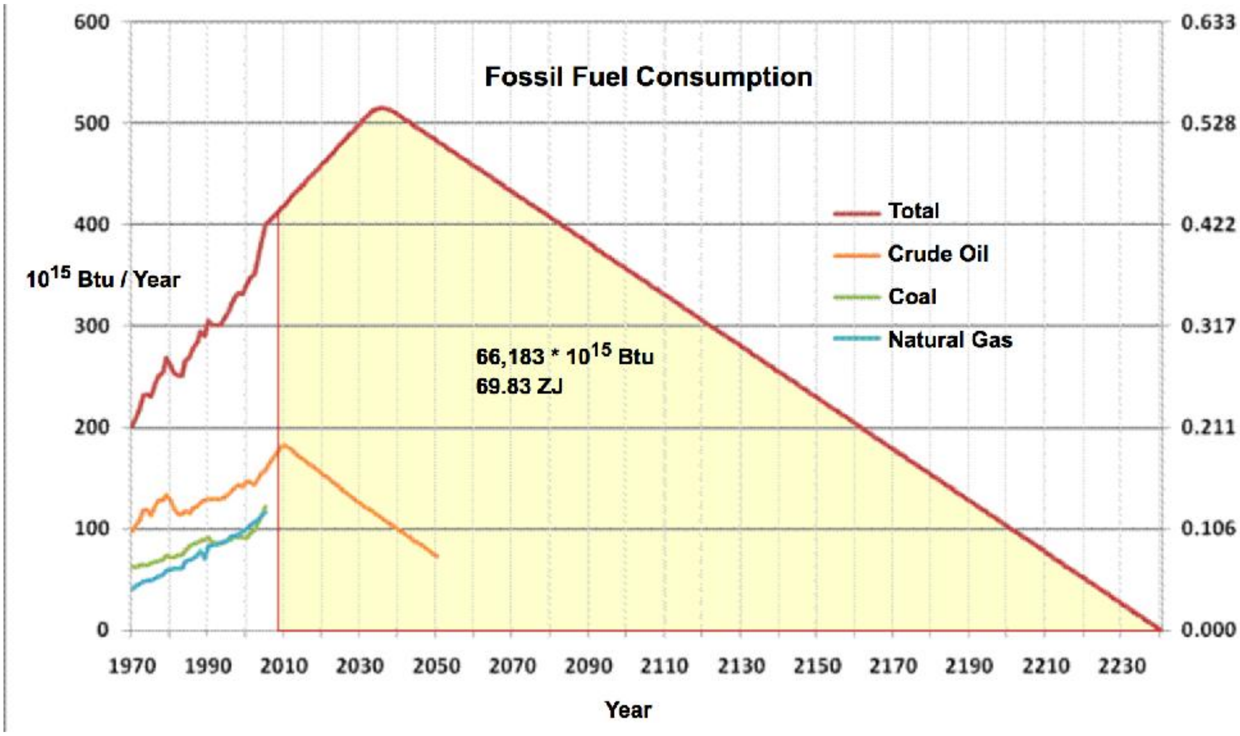


Figure 5.1: Depletion of Fossil Fuels

In addition Figure 6.1 shows that the total fossil fuel are decreasing, it indicates that the development of renewable ways to supply human daily activities are very important. Therefore, the sustainable of Light Pipe represent new ways to replace the electricity supply.

Power Factor Improvement was found to contribute 8.2% of the total energy cost savings. This was as a result of inductive loads being installed in the building which includes water pumps and Lifts. Improving power factor would result to;

i. Lowered utility bill with a higher pf. A low power factor requires an increase in the electric utility's generation and transmission capacity to handle the reactive power component caused by the inductive loads. Ideally the industries are expected to operate with PF ranging from 0.9 to 1.0

ii. The electrical distribution system's capacity will increase. Uncorrected PF will cause power losses in the distribution system, voltage drops are experienced as power loss increase. Excessive voltage drops can cause overheating and premature failure of motors and other inductive equipment.

Regarding audits and energy saving measures and despite the fact that the measures were discussed at medium-scale level it is evident that they could actually make a substantial energy savings. These savings could reduce the financial burden of the current energy bills at the commercial buildings and factories.

Significant savings can be achieved not through a relatively small number of direct projects but through the stimulation of widespread replication activities across the country since very little emphasis have been put in Commercial buildings and major emphasis being in Industries.

5.2 Recommendation: Light pipe

Further studies should be done towards the assembling of the light pipe and its integration with the other building subsystems. One aspect would be the design of the light pipe towards its industrialization which would involve the use of a more durable material such as metal. This material will have to be able to receive a reflective coating in its interior that will stay flat and will not deteriorate over the time.

Another aspect would be the particular design of the light pipe output to obtain a better integration with the ceiling parts, and the possible introduction of the electric luminaire together in the same assembly.

Of special concern is the integration with electric light using lighting control systems (zoning and dimming controls). For this purpose, the placement of vertical sensors will be useful to evaluate illumination in the vertical plane, since some dimming controls are positioned in that way.

It is also recommended that an energy conservation fund should be set up to assist with financing future energy conservation related investments.

5.2.1 Other Recommendations

i. The need for a long term commitment from the Government to promote energy efficiency in Commercial buildings.
ii. Better end-use analysis needs to be undertaken in order to know what progress is being made on improving energy efficiency of buildings
iii. Certification needs to be implemented in parallel with effective information campaigns to explain to the wider public
iv. The energy certification programme should be designed to help construct and maintain end-use databases to help in the policy analysis

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APPENDICES

Appendix 1: Tariffs in Kenya

There are five main consumer categories:

i. Domestic Consumers (DC);
ii. The Small Commercial (SC);
iii. The Commercial/Industrial (CI),
iv. The Interruptible (IT) and
v. The Street Lighting (SL).

DOMESTIC CONSUMER (DC) - METHOD DC

The DC will be applicable to domestic consumers metered at 240V or 415V and whose energy consumption does not exceed 15,000 kWh per month. The energy charge will be in three steps based on consumption as follows; 0-50kWh; 51-1500kWh and over 1,500 kWh units per postpaid billing period or pre-paid units purchase period.

a) A fixed Charge of KSH 120.00
b) Energy Charges of
i. Kshs.11.62 per Unit for 51- 1,500 Units consumed;
ii. Kshs. 19.57 per Units Consumed above 1,500.

SMALL CONSUMER (SC) - METHOD SC

Applicable to non- domestic Small Consumers for supply provided and metered at 240 or 415 volts and whose consumption does not exceed 15,000 Units per Postpaid billing period or Pre-paid purchased period.

d) A fixed Charge of Kshs. 150
e) Energy Charge of Kshs 12.00 per units for all units consumed.

COMMERCIAL/INDUSTRIAL (CI) - METHOD CI

Applicable to Commercial and Industrial Consumers for Supply Provided and metered by the Company at 415 volts three phase four wire and whose consumption exceeds 15,000 units per post-paid billing period.

f) A fixed charge of Kshs. 2,000.00
g) Energy charge of Kshs. 8.70 per unit consumed.
h) Demand charge of Kshs. 800.00 per kVA.

COMMERCIAL/INDUSTRIAL (C12) - METHOD C12

Applicable to Commercial and Industrial Consumers for supply provided and metered by the company at 11,000 volts, per post-paid billing period.

i) A fixed charge of Kshs. 4,500.00

j) Energy charge of Kshs. 7.50 per unit consumed.

k) Demand charge of Kshs. 520 per kVA

COMMERCIAL/INDUSTRIAL (C13) - METHOD C13

Applicable to Commercial and Industrial Consumers for supply provided and metered at 33,000 volts, per post-paid billing period.

a) A fixed charge of Kshs. 5,500.00

b) Energy charge of Kshs. 7.00 per unit consumed.

c) Demand charge of Kshs. 270 per kVA

COMMERCIAL/INDUSTRIAL (C14) - METHOD C14

Applicable to Commercial and Industrial consumers for supply provided and metered by the company at 66,000 volts, per post-paid billing period.

a) A fixed charge of Kshs. 6,500.00

b) Energy charge of Kshs. 6.80 per unit consumed.

c) Demand charge of Kshs. 220 per kVA

COMMERCIAL/INDUSTRIAL (C15) - METHOD C15

Applicable to Commercial and Industrial Consumers for supply provided and metered by the company whose consumption does not exceed 15,000 Units per Post-paid billing period.

d) A fixed charge of Kshs. 17,000.00

e) Energy charge of Kshs. 6.60 per unit consumed.

f) Demand charge of Kshs. 220 per kVA

THE INTERRUPTIBLE- METHOD IT

Interruptible off-peak supply of electrical energy applicable to ordinal y consumers provided and metered by the Company whose consumption metered at 240 or 415 volts and does not exceed 15,000 units per post-paid billing period or pre-paid units purchased period.

a) A fixed charge of Kshs. 120.00

b) Energy charge of Kshs. 13.00per unit consumed.

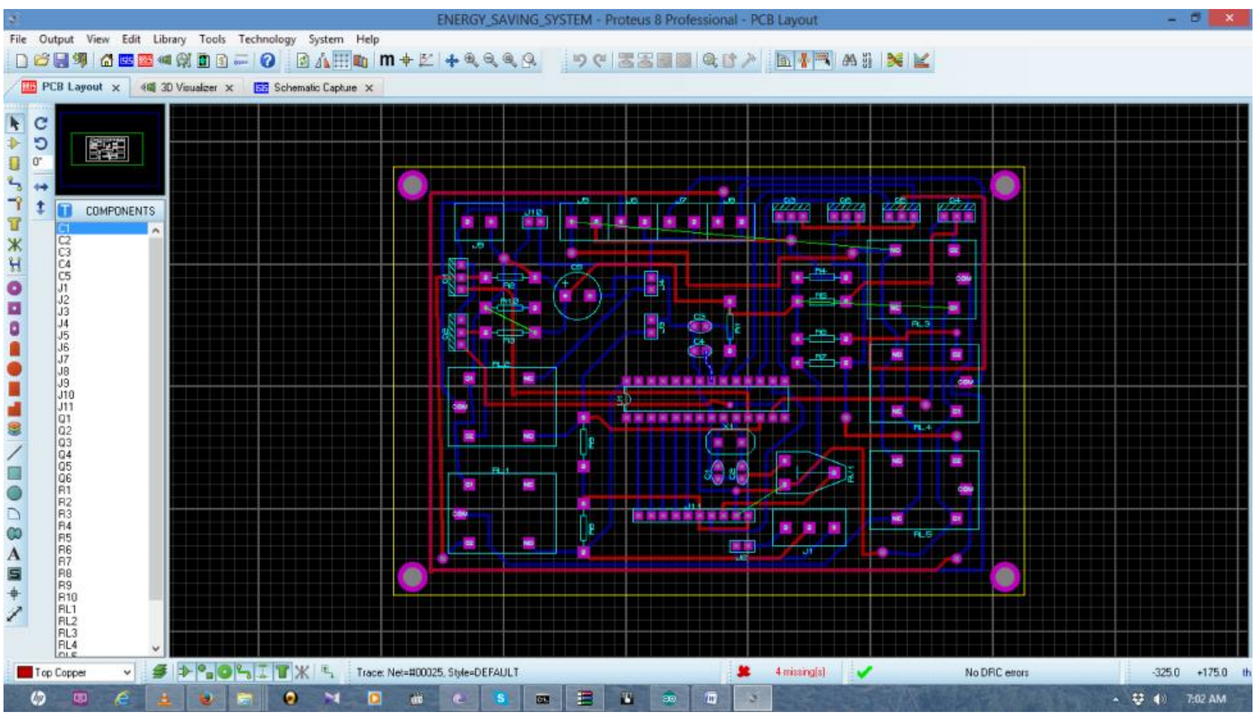
STREET LIGHTNG- METHOD SL

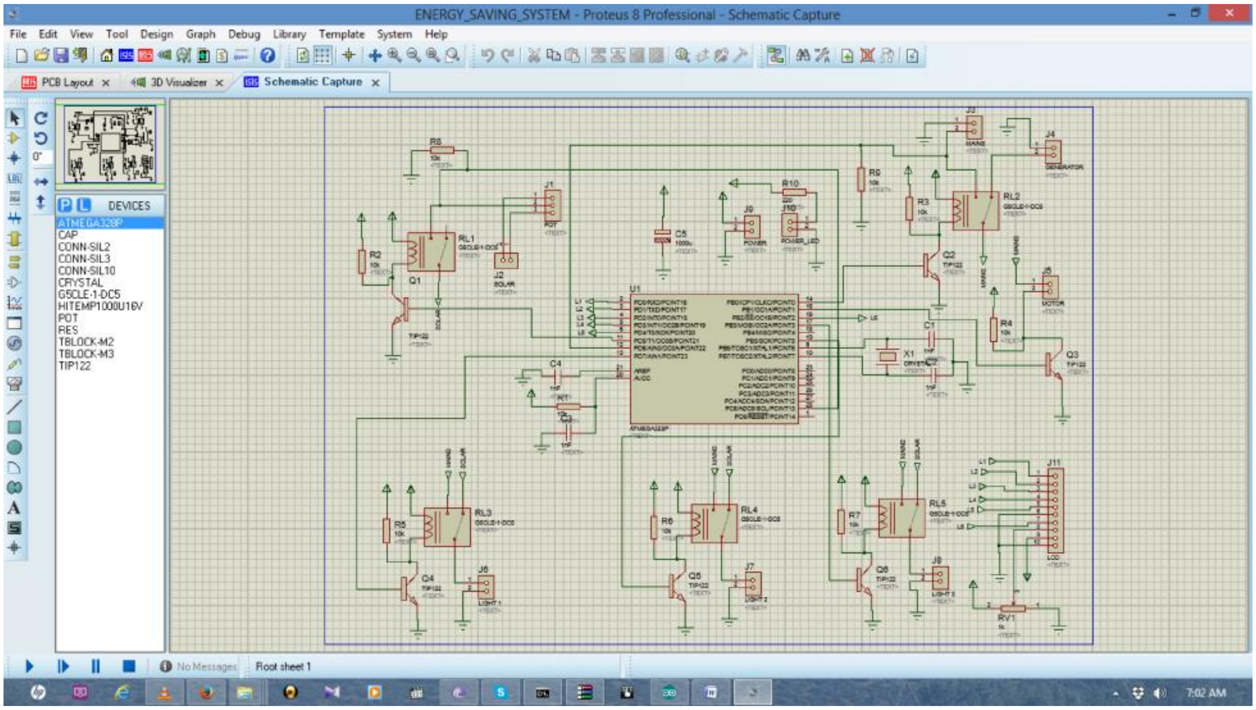
Applicable to public and county governments metered by the company at 240 or 415 volts per post-paid billing period for supply of electrical energy to public lamps.

a) A fixed charge of Kshs. 200.00

b) Energy charge of Kshs. 10.50per unit consumed

Appendix 2: Microcontroller simulation





Appendix 3: Programming code for Microntroller

```
#include <LiquidCrystal.h>

LiquidCrystal lcd(10, 4, 3, A2, 1, 0);

int Solar_Relay = 5;

int Mains_Generator_Relay = 8;

int First_Floor_Lighting = 7;

int Second_Floor_Lighting = 13;

int Third_Floor_Lighting = 11;

int motor = 9;

int Solar_Power_Pin = A5;

int Mains_Power_Pin = 6;

int Alarm_Pin = A1;

int Power_Detector = 12;

int Power_Detection_Activator = 2;

int Indicator_Pin = A4;

////////////////////////////////////////////////////////////

int Active = LOW;
```

```
in buttonState;             // the current reading from the input pin
in lastButtonState = LOW;   // the previous reading from the input pin

// the following variables are long's because the time, measured in milliseconds,
// will quickly become a bigger number than can be stored in an int.
long lastDebounceTime = 0;  // the last time the output pin was toggled
long debounceDelay = 50;    // the debounce time; increase if the output flickers
/////////////////////////////////////////////////////////////////

void setup()
{
  pinMode(Solar_Relay,OUTPUT);
  pinMode(Mains_Generator_Relay,OUTPUT);
  pinMode(First_Floor_Lighting,OUTPUT);
  pinMode(Second_Floor_Lighting,OUTPUT);
  pinMode(Third_Floor_Lighting,OUTPUT);
  pinMode(motor,OUTPUT);
  pinMode(Mains_Power_Pin,INPUT);
  pinMode(Power_Detector,INPUT);
  pinMode(Alarm_Pin,OUTPUT);

  PinMode(Power_Detection_Activator, INPUT);
  pinMode(Indicator_Pin,OUTPUT);
  lcd.begin(16, 2);
  lcd.print(" ENERGY  SAVING ");
  lcd.setCursor(0, 1);
  lcd.print("    SYSTEM     ");
  delay(3000);
  lcd.setCursor(0, 0);
```

```
  lcd.print("FL1:    FL2:    ");
  lcd.setCursor(0, 1);
  lcd.print("FL3:    MOT:    ");
  delay(3000);
  digitalWrite(Solar_Relay,HIGH);
}
void loop()
{
 if( analogRead(Solar_Power_Pin) > 800 )
 {
   digitalWrite(First_Floor_Lighting,LOW);
   digitalWrite(Second_Floor_Lighting,LOW);
   digitalWrite(Third_Floor_Lighting,LOW);
   if( digitalRead(Power_Detector) == LOW && Active == HIGH )
  {
    lcd.setCursor(4, 0);
    lcd.print("H_P");
    analogWrite(Alarm_Pin,1000);
  }
  else
{
  analogWrite(Alarm_Pin,0);
  lcd.setCursor(4, 0);
  lcd.print("SOL");
}
   lcd.setCursor(12, 0);
   lcd.print("SOL");
   lcd.setCursor(4, 1);
   lcd.print("SOL");
```

```
  delay(1000);
 }
 else if( (analogRead(Solar_Power_Pin) > 400) && (analogRead(Solar_Power_Pin) < 800) )
 {
  digitalWrite(First_Floor_Lighting,HIGH);
  digitalWrite(Second_Floor_Lighting,HIGH);
  if( digitalRead(Mains_Power_Pin) == HIGH )
  {
   if( digitalRead(Power_Detector) == LOW && Active == HIGH )
  {
   lcd.setCursor(4, 0);
   lcd.print("H_P");
   analogWrite(Alarm_Pin,1000);
  }
  else
{
  analogWrite(Alarm_Pin,0);
  lcd.setCursor(4, 0);
  lcd.print("MAI");
}
   lcd.setCursor(12, 0);
   lcd.print("MAI");
  }
  else
  {
   if( digitalRead(Power_Detector) == LOW && Active == HIGH )
  {
   lcd.setCursor(4, 0);
   lcd.print("H_P");
```

```
  analogWrite(Alarm_Pin,1000);
 }
 else
{
 analogWrite(Alarm_Pin,0);
 lcd.setCursor(4, 0);
 lcd.print("GEN");
}
  lcd.setCursor(12, 0);
  lcd.print("GEN");
 }
 delay(1000);
}
else
{
 digitalWrite(First_Floor_Lighting,HIGH);
 digitalWrite(Second_Floor_Lighting,HIGH);
 digitalWrite(Third_Floor_Lighting, HIGH);
 If(digitalRead(Mains_Power_Pin) == HIGH )
 {
  if( digitalRead(Power_Detector) == LOW && Active == HIGH )
 {
  lcd.setCursor(4, 0);
  lcd.print("H_P");
  analogWrite(Alarm_Pin,1000);
 }
 else
{
 analogWrite(Alarm_Pin,0);
```

```
 lcd.setCursor(4, 0);
 lcd.print("MAI");
}
   lcd.setCursor(12, 0);
   lcd.print("MAI");
    lcd.setCursor(4, 1);
   lcd.print("MAI");
  }
 else
  {
   if( digitalRead(Power_Detector) == LOW && Active == HIGH )
  {
   lcd.setCursor(4, 0);
   lcd.print("H_P");
   analogWrite(Alarm_Pin,1000);
  }
 else
{
 analogWrite(Alarm_Pin,0);
 lcd.setCursor(4, 0);
 lcd.print("GEN");
}
   lcd.setCursor(12, 0);
   lcd.print("GEN");
   lcd.setCursor(4, 1);
   lcd.print("GEN");
  }
 delay(1000);
 }
```

```
  if( digitalRead(Mains_Power_Pin) == HIGH )
  {
   digitalWrite(Mains_Generator_Relay,HIGH);
   digitalWrite(motor,HIGH);
   lcd.setCursor(12, 1);
   lcd.print("MAI");
  }
  else
  {
   digitalWrite(motor,HIGH);
   digitalWrite(Mains_Generator_Relay,LOW);
   lcd.setCursor(12, 1);
   lcd.print("GEN");
  }

  Button_Debounce();
}

void Button_Debounce()
{
  // read the state of the switch into a local variable:
  int reading = digitalRead(Power_Detection_Activator);

  // check to see if you just pressed the button
  // (i.e. the input went from LOW to HIGH), and you've waited
  // long enough since the last press to ignore any noise:

  // If the switch changed, due to noise or pressing:
```

```
  if (reading != lastButtonState) {
    // reset the debouncing timer
    lastDebounceTime = millis();
  }

  if ((millis() - lastDebounceTime) > debounceDelay) {
    // whatever the reading is at, it's been there for longer
    // than the debounce delay, so take it as the actual current state:

    // if the button state has changed:
    if (reading != buttonState) {
      buttonState = reading;

      // only toggle the LED if the new button state is HIGH
      if (buttonState == HIGH) {
        Active = !Active;
      }
    }
  }

  // set the LED:
  digitalWrite(Indicator_Pin, Active);

  // save the reading.  Next time through the loop,
  // it'll be the lastButtonState:
  lastButtonState = reading;
}
```