THE UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

IMPACT OF ENERGY EFFICIENT LIGHTING ON OVERALL ENERGY USE INTENSITY IN COMMERCIAL BUILDINGS:

A Case Study of Co-op House

By Nancy Mwari Murithi

Registration Number: F 56/35228/2019

A project submitted in partial fulfillment for the Degree of Master of Science in Energy Management in the Department of Mechanical and Manufacturing Engineering in the University of Nairobi

July 2021

DECLARATION

I declare that this project report is my original work which has not been presented in this or any other university for the award of a degree. To the best of my knowledge, the contents of this report have not been published elsewhere except where appropriate reference has been made.

Nancy Mwari Murithi

Signature:

Date: 11.07.2021

APPROVAL

This project report has been undertaken and submitted with our knowledge and approval as university supervisors.

Dr. Peter Moses Musau
University of Nairobi

Signature:

Date: 11th July 2021

Dr. Abraham Nyete
University of Nairobi

Signature:

Date: 11th July 2021

DECLARATION OF ORIGINALITY

This Report is my original work and has not been presented for a degree award in any other Institution for degree award or other qualification.

Name of student: Nancy Mwari Murithi

Registration: F56/35228/2019

Faculty: Engineering

Department: Mechanical and Manufacturing Engineering

Course Name: Master of Science (Energy Management)

Title of work: **Impact of Energy Efficient Lighting on Overall Energy Use Intensity in Commercial Buildings: A Case Study of Co-op House**

1) I understand what plagiarism is and I'm aware of the university policy in this regard
2) I declare that this research proposal is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other works or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements
3) I have not sought or used the services of any professional agencies to produce this work
4) I have not allowed, and shall not allow anyone to copy my work with the intention of passing it off as his/her work
5) I understand that any false claim in respect of this work shall result in disciplinary action in accordance with University of Nairobi anti-plagiarism policy

Name: Nancy Mwari Murithi   Adm. No: F56/35228/2019

Signature: Nmuryth   **Date:** **1st September 2021**

DEDICATION

I dedicate this work to all my fellow energy efficiency and conservation enthusiasts.

ACKNOWLEDGEMENT

I am grateful to God for the gift of good health, a sound mind and for the provision throughout the project.

I thank my supervisors, Dr Peter Musau and Dr Abraham Nyete for the advice and guidance throughout. Special mention to the energy manager at Co-op House for relevant data and for the support accorded throughout the project duration.

I acknowledge my husband, Simon Mateli, for the overwhelming support throughout the project. Thank you for the invaluable input and for constant encouragement to keep going, when giving up seemed the better option.

To my parents, Alice Kajuju and Jackson Murithi, thank you for believing in me, for cheering me along the way and for provision. I thank my siblings for encouraging me all through. Thank you to my course mates for the constant peer to peer review and for the constructive criticism.

ABSTRACT

Energy efficiency is key for organizations that are keen on managing their energy costs. Lighting is one of the low hanging fruits, commonly recommended in energy audit reports, that buildings can implement to achieve savings. However, to fully understand the energy savings potential of buildings proper computation of savings is important. This study sought to quantify the savings potential for efficient lighting in buildings in kilowatt-hours energy savings and improvement in Energy Use Intensity for Co-op House. A literature review of energy efficiency in buildings was done to understand the progress made in the subject matter and the research gaps that exist. Data for the study was collected by the administration of a structured questionnaires that required the energy manager to fill in details on their high-rate energy consumption, low-rate energy consumption, demand in kilowatt and kilovolt-Amperes, power factor as well as the utility bill in monetary terms. An inventory of the existing lighting was taken, detailing the type of fixtures, type of lamps, energy consumption per fixture as well as hours of use. The data was then tabulated and analyzed through Excel sheet. In 2020, The overall Energy Use Intensity averaged at 296 kilowatt-hours per square meter per year against the recommended benchmark of 226 kilowatt-hours per square meter per year. Lighting had an Energy Use Intensity of 124 kilowatt-hours per square meter per year, against the recommended value of 54 kilowatt-hours per square meter per year for a typical office. The analysis showed that replacement of all fluorescent lights with LED equivalent would contribute to 18.3 % improvement in the Energy Use Intensity. It is recommended that the facility replaces the existing fluorescent tubes with LED lighting. This project has a simple payback of 1.7 years and has a positive Net Present Value and is therefore economically viable for implementation.

Keywords: Energy Efficiency, Energy consumption, Lighting, Savings

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

CFL: Compact Fluorescent Tube

CI 2: Commercial Industrial Tariff 2

CUSUM: Cumulative Sum

CRI: Colour Rendering Index

ECM: Energy Conservation Measure

EJ: Exajoule

HID: High Intensity Discharge

IRR: Internal Rate of Return

IPMVP: International Performance Measurement and Verification Protocol

FERFA: Forex Exchange

FL: Fluorescent Tube

KW: Kilowatt

KVA: Kilo Volt-Ampere

LECM: Lighting Energy Conservation Measure

LED: Light Emitting Diode

MR: Malaysian Ringgit

NPV: Net Present Value

WGBC: World Green Building Council

VAT: Value Added Tax

1. CHAPTER ONE: INTRODUCTION

1.1 Background

The concept of green buildings is slowly gaining popularity around the globe. A green building is one that reduces negative environmental impacts in its design, construction, and operation. A key feature of green buildings is that they use energy, water as well as other resources efficiently.

The Kenya National Energy Efficiency and Conservation Strategy 2020 identifies five strategic sectors of focus. Buildings is identified among these five sectors. The Strategy targets to improve the lighting load in public buildings by 50% by the year 2025. This is to be achieved through retrofitting of lighting with more efficient lighting and use of passive energy such as natural light [1].

Lighting forms a key component of energy loads in a building. Therefore, the implementation of efficient lighting can translate into substantial savings in energy costs. Lighting Energy Conservation Measures (LECMs) aim to reduce lighting demand and/or energy use by:

i) Retrofitting existing old technology lamps with more efficient lamps.
ii) De-lamping (removal of unnecessary light fixtures and/or lamps).
iii) Lighting controls such as sensors, dimmers, and timers.

Globally, in 2018, the buildings and construction sector accounted for 36% of total energy use and 39% of energy and process related CO_2 emissions [1]. In Kenya alone the building stock stood at 37 Million m^2 of space distributed as [2]:

i) 30 Million m^2 of residential space
ii) 1.5 Million m^2 of office and retail space
iii) 5 million m^2 of commercial buildings

Co-operative Bank is a commercial building established in 1965 when it began operations as a Co-operative society. It was licensed in 1968 and so far, has grown into 157 branches countrywide. In each of these branches, there were inefficient fluorescent tube lights. The lighting load represented about 30% of the total facility consumption, thereby presenting a good opportunity for energy cost-cutting.

Banks are often viewed from a money lending perspective and can easily be forgotten when promoting energy efficiency in buildings. There are challenges in implementing that hinder energy efficiency:

i) Lack of information on opportunities makes it difficult to allocate finances and other resources appropriately.

ii) The complexity of energy-saving techniques leads to a lack of understanding of how to implement energy efficiency leading to poor decision making.

P. O ‘Callaghan (1992) [3] notes that the principal step in the process of managing energy is to identify and analyze the Energy Conservation Opportunities, thus, it is both technical and managerial. The focus of energy management is monitoring, recording, analyzing, critical examination and control for maximum and efficient utilization of energy.

To identify energy conservation opportunities, Co-operative Bank carried out energy audits for the various branches. Key among the recommendations was the retrofit of fluorescent lights with energy-efficient LEDs. This study seeks to quantify the energy and cost savings that can be achieved by efficient lighting in buildings, using a case study of Co-op House. The study will also investigate the improvement in energy use intensity achieved through these interventions.

1.2 Problem Statement

Co-op House has fluorescent lamps that are high consuming compared to LEDs despite efficient lighting being one of the most popularly recommended energy costs saving measures for buildings. Efficient lighting is key in managing costs, but facilities sometimes do not implement the measures due to ignorance and skepticism of the savings potential. Banks are often viewed as money-lending institutions rather than as commercial buildings with the potential to save on energy. Therefore, their huge energy-saving potential can be easily downplayed leading to high energy inefficiency levels in the banking sector.

The overall Energy Use Intensity of Co-op House averages at 296 kilowatt-hours per square meter per year against the recommended benchmark of 226 kilowatt-hours per square meter per year [4]. Lighting has an Energy Use Intensity of 124 kilowatt-hours per square meter per year, against the recommended value of 54 kilowatt-hours per square meter per year for a typical office.

1.3 Main Objective

To evaluate existing lighting and quantify the energy-saving potential of Co-op House through efficient lighting and improvement on the Energy Use Intensity.

1.3.1 Specific Objectives

i) Evaluate the existing energy parameters at Co-op House: kW demand, consumption in kWh, power factor and Energy Use Intensity.

ii) Evaluate the projected energy parameters at Co-op House: kW demand, consumption in kWh, power factor and Energy Use Intensity post lighting retrofit.

iii) Quantify the achievable savings in Co-op House through 100% transition to LED.

iv) Techno-Financial analysis of potential savings from efficient lighting and their expected improvement in Energy Use Intensity.

1.4 Research Questions

i) What is the current energy consumption, demand in kW, power factor and Energy use intensity of the facility?

ii) What type of lights are currently installed at the facility?

iii) What are the alternatives available to retrofit the current lighting?

iv) What would be improvement in the Energy Use Intensity through LED Retrofit?

v) What is the overall typical savings potential of Co-op House using efficient lighting?

1.5 Justification

World Green Buildings Council (WGBC) estimates that buildings globally generate 1 of 3 tons of CO_2. According to international reports, buildings are the single largest opportunity for abatement of greenhouse gas. This outweighs the energy, industry, and transport sectors.

Of all the world electricity generated, about 21% is consumed for lighting applications. [5] In the case of Europe, some studies show that lighting systems account for 50% of the electric energy in office buildings, 20-30% in hospitals 10-15% in school institutions, and 15-20% in the manufacturing sector. [6] [7] From these statistics efficient lighting would contribute to a global saving on energy consumption. Therefore, this study will contribute greatly to this agenda by creating awareness of the benefits of efficient lighting for commercial buildings, particularly banks.

1.6 Scope

This study established a baseline energy consumption, power factor values, and overall energy use intensity Co-op House. A lighting inventory detailing the type of fixtures, number of fixtures, type of lamps and hours of use was taken. The data to be analyzed was electricity bills for the last 2 years and the lighting inventory. The study then quantified the energy savings and the improvement in Energy Use Intensity through energy efficient lighting, while benchmarking with similar buildings.

1.7 Main Results and Contribution

Retrofitting the lights at Co-op House is a viable project and will result in 18.3% improvement of the overall Energy Use Intensity of the building. The project would pay back in less than 2 years, but the savings would continue to be enjoyed over the life of the lamps.

Previous studies on lighting have only focused on the monetary savings that would accrue from efficient lighting with no specific reference to the improvement in the energy use intensity. With the inclusion of Energy Use Intensity in the analysis, facilities will easily be able to benchmark themselves against the recommended values as well against other organizations of similar operations.

1.8 Beneficiaries

This study is useful to Co-operative Bank in quantifying the impact that energy-efficient lighting will achieve on the overall Energy Use Intensity (EUI), which can help the facility to save on their utility bills.

Energy Auditors and Measurement & Verification experts will find the study useful when computing the expected energy savings from lighting and benchmarking energy use intensities of commercial buildings.

1.9 Report Organization

This project report is divided into five chapters which are summarized as follows: Chapter One highlights the background, objectives, statement of the problem, justification scope, and potential beneficiaries of this project. Chapter Two discusses a literature review of similar studies that have been conducted and the identification of research gaps. Chapter Three highlights the methodology followed in the study. Chapter Four discusses analyses, the results, and discussions for this project. Chapter Five summarizes the report with conclusions and gives recommendations to Co-op House on implementation of the project.

2. CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter reviews what other scholars have researched and documented regarding efficient lighting in commercial buildings and highlights the gaps in the existing literature.

2.2 Lighting in Commercial Buildings

Light is defined as a form of electromagnetic energy that is radiated from a body, which the human eye can receive. For the existence of human life, light is fundamental because all human activities majorly depend on light. The source of lighting may be natural or artificial.

Commercial buildings require lighting to enable visibility and for the productivity of the occupants.

2.3 Common Types of Lighting in Commercial Buildings

i) Fluorescent Tube lights (T 5, T 8, and T 12)

A fluorescent lamp is a type of hot cathode low-pressure mercury-vapor lamp in which an electric current in the gas excites mercury vapor. This current results in a short-wave ultraviolet (UV) light that leads to the glowing of the phosphor coating, which is located on the inner side of the fluorescent bulbs. The luminous efficacy ranges from 50-100 lumens per watt. These types of lamps are quite common in commercial buildings.

ii) Compact Fluorescent (CFL)

These are estimated to last for a longer period as compared to a typical incandescent bulb. Besides, they consume less energy to attain a given lux level. However, they do not perform well in conditions of low temperature. They use mercury vapor in their operations thus are toxic to the environment. They are also commonly used in commercial buildings.

iii) Incandescent Bulbs

These are sometimes referred to as Edison Bulbs and they are temperature dependent. They have tungsten filaments that get heated to about 4000 F which causes it to evaporate. The bulbs have inert gases such as nitrogen and argon to prevent the tungsten from growing dark. These bulbs are wasteful as most of the energy is released as heat rather than light. These are also common in commercial buildings. Figure 2-1 shows an incandescent bulb.

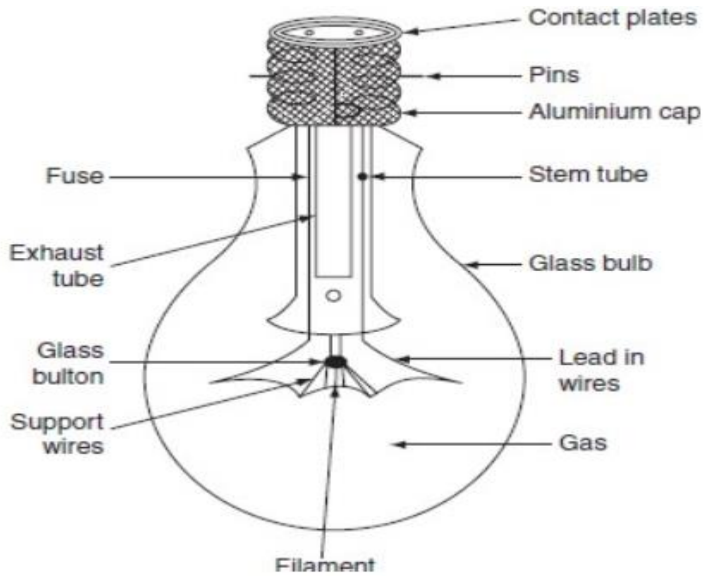


Figure 2-1: Incandescent Bulb

iv) High-Intensity Discharge (HID)

In this type of lamps, an electric current is passed through a gas or vapor to produce illuminance. When the voltage applied across two electrodes is enough, the gases/vapor are ionized producing light by electromagnetic radiation. Neon mercury and sodium are most often used in these lamps. The wavelength of the electromagnetic radiation produced is determined by the gas properties and pressure. These are mostly used in outdoor lighting such as in the security lighting of the commercial buildings. Figure 2-2 shows examples of HID lamps.

Figure 2-2: HID Lamps

v) Light-Emitting Diode (LED) Lamps

LEDs are a type of highly efficient lighting technology that was first invented in 1962 by Nick Holonyak, However, they were initially used as indicators due to the high costs of LEDs. As the world started focusing on sustainability and efficient lighting, LED lamps have been improved. LEDs use solid-state lighting technology. The SSL produces light from a semiconductor which has +ve and -vely charges. When electrons move from -ve to the +ve layer, light is produced. Figure 2-3 shows a circuit diagram of a typical LED lamp.

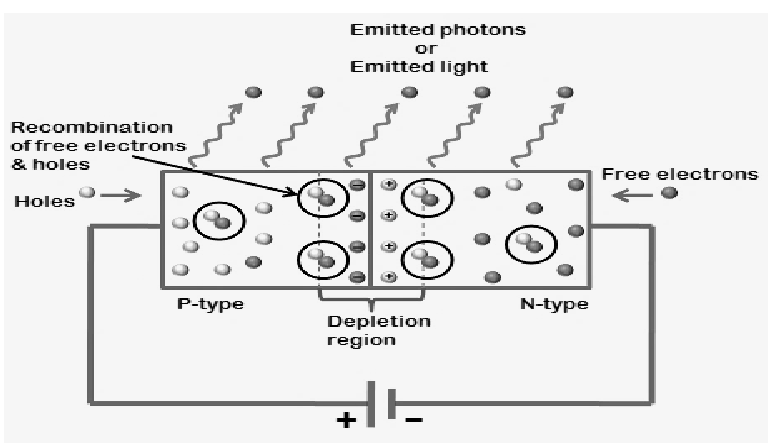


Figure 2-3: LED Lamp Circuit

The Key Features of LED Lamps are:

i) High lumen per watt (efficacy).
ii) They are a mix of red, green, and blue which make white light.
iii) They emit light in a specific direction and are less dependent on diffusers and reflectors.
iv) They emit little heat.
v) They do not have mercury and other pollutants hence are environmentally friendly.
vi) Their life expectancy is not shortened when switched on and off frequently.
vii) They have no warm-up delay.

LED lamps are starting to gain popularity as the commercial buildings learn about their ability to reduce energy cost saving. Banks have often been viewed as lenders and funders of green programs rather than energy consumers. Therefore, their opportunity to save energy has not been explored. Proper analysis and quantification of the energy-saving potential would serve to change the perspective.

2.4 Illumination Laws

There exist two main illumination laws, namely:

i) Inverse-Square Law

This law states that for a given surface the illumination is inversely proportional to the square of the distance between the illuminated surface and the source of light.

$$E = \frac{I}{d^2} \qquad [2\text{-}1]$$

Where E is illuminance, I is Luminous intensity, d is distance between the source and surface.

ii) The Cosine Law of Illuminance

This law states that at a given point on a plane, the illuminance is proportional to the cosine of the incident angle of light.

$$E = \frac{I\theta}{d^2} cos\,\theta \qquad [2\text{-}2]$$

Where E is illuminance, I_θ is Luminous intensity d is distance between the source and surface and θ is the angle between the normal to the plane containing the illuminated point and the line joining the source to the illuminated point.

2.5 Lumen Method (Photometrical Computation of Lighting)

This method is used to determine the total number of luminaires necessary to produce a particular illuminance the number of luminaires is expressed as:

$$N = \frac{E * A}{F * UF * MF} \qquad [2\text{-}3]$$

Where N= Number of Lamps required, E = required lux levels, A= Area in m^2 F= Average luminous flux per lamp, UF = Utilization Factor usually about 0.9 for modern office buildings, MF= Maintenance Factor usually between 0.8-0.9.

2.6 Energy Efficiency and Lighting Nexus

Energy efficiency is a method of minimizing consumption by using less energy to achieve a given useful output level. It is considered an effective way to tackle climate change, ever-increasing energy prices, and diminishing energy supplies, supporting economic growth [8] [9].

The energy efficiency of a building is defined as the level that the Energy Use Intensity (energy consumed per unit area) to which it compares to the set energy consumption benchmarks for the given type of building under set climatic conditions [10].

Typically, lighting represents 30-50% of operational costs in buildings hence, it is a key area of cous when targeting to reduce energy consumption. According to statistics by the International Energy Agency (IEA) [11], globally, the building sector is responsible for more electricity consumption than any other single sector, representing 42%.

As countries prosper, the need for building efficiency also increases. According to the 2019 Global Status Report for Buildings and Construction [12], in buildings, the end-use energy demand rose by 1% between 2017 and 2018, compared to an increase of 7% from 2010 to 2018. This represents a rise of over 6.5 Exajoules, a trend that raises concerns on sustainability.

Existing and future buildings represent a large portion of the energy demand globally. Currently, the trends indicate that there is a possibility of a huge increase in energy demand and carbon emissions. In this way, lighting is a key concern among building owners and the entire economy at large. The ever-rising utility tariff rates will further exacerbate the impact of lighting on operating costs [13].

Besides energy cost saving, there are social welfare benefits of efficient lighting. (Fisk, 2000) [14] relates productivity to health. He suggests that there is a great overlap between health and productivity, specifically noting that efficient lamps, ballasts, lighting fixtures can lead to improved quality of lighting and satisfaction of the occupants. He further argues that efficient lighting can improve productivity if the work done is demanding visually, like in commercial buildings.

2.7 Past Studies on Energy Savings of LED Lighting

Vahl et al. [15] analyzed the long-term sustainability of retrofit of inefficient light bulbs with more efficient ones such as CFLs and LEDs. They realized that CFLs have the highest costs annually and the highest toxic waste. On the other FL tubes turned out to be more economical, However, as the prices of LEDs reduced, they noted that, eventually, LEDs would be the most economical and sustainable option.

Chen and Chung [16] undertook a study in China, in which they retrofitted LEDs with T 8 fluorescent tubes. They realized that by replacing the existing 36 W T 8 fluorescent lamps with 20 W LED lamps, a total of, around $288 saving would be saved within 5 years. The study did not analyze in-depth the impact of LED lighting on power factor and energy use intensity. Instead, the energy-saving per bulb is assumed to be:

$$\text{ES per bulb} = 36\text{ W} - 20\text{ W} \quad [2\text{-}4]$$

Ganandran [17] in their analysis of the saving potential of buildings in Universiti Tenaga Nasional in Malaysia. A lighting inventory was done which revealed there were a total of 62,684. The lamps were broken down as:

i) 288431 bulbs 4 pin 36 Watts.
ii) 8751 fluorescents 4 ft tube each 36 Watts.
iii) 12674 fluorescent, 2 ft tube, each 18 Watts.
iv) 12719 PL-C 2 pin bulbs each 13 Watts.
v) 109 Philips CFL bulb each 14 Watts.

The study estimated that a full retrofit of the lamps would save about 1,463,450.56 kWh of energy which translated to RM (Malaysia) 517,622 annually, which is about KES 13 Million. The total daily energy consumption (EC) was computed simply as the multiplication of the lamps (N) by the lamp power consumption (W), by total operation hours (assumed to be 8 hours) i.e.

$$EC = (N \times W \times OH)\ 1000 \quad [2\text{-}5]$$

The Energy Saving (ES) was then calculated by subtracting the energy consumption of the current system (EC Current) from the retrofit lighting (EC Retrofitting) system:

$$ES = \text{EC Current} - \text{EC Retrofitting} \quad [2\text{-}6]$$

The study also does not consider the effect of LED lighting on the power factor which could reduce the cost-saving potential if the facility is surcharged for poor power factor. The energy use intensity is also not mentioned in the study.

Mahlia et al [18] in an analysis of the cost-benefit of efficient lighting in the residential sector in Malaysia, propose a method of calculating the savings as "Energy consumption by the lighting is the multiplication of the number of retrofits, power consumption and operating hour of the lighting. The annual energy consumption can be expressed mathematically by the following equation:

$$NR_i^L = NH_i^L * ST_i^L \quad [2\text{-}7]$$

Where: NR is the Number of Retrofit, NH Number of Households, ST is Saturation Levels of lamps.

$$EC_i^L = NR_i^L * PCL * OH_i^L * 365 \quad [2\text{-}8]$$

Where: EC is Energy Consumption, PC is Power Consumption, OH is Operating Hours.

The study does not consider the impact the LED lighting on the power demand and the overall power factor of the facility.

2.8 Issues of Concern in LED Lighting

Ryckaert et al. [19] researched the pros and cons of retrofitting LED tubes with T 8 FL lamps. Upon analyzing 12 LED tubes, the results demonstrated that a one-to-one lamp replacement can result in inadequate illumination of a surface. This underscored the need for careful analysis in LED retrofit projects to ensure occupant comfort is not compromised.

Whereas the use of LED lighting has gained traction, Xu X et al [20] note that the wide use of LED lamps causes various problems that arise in power grids resulting from the non-sinusoidal waveform of the current consumed by such lamps. Despite the small power and current consumed by a single lamp, problems arise from many such lamps in the same grid and their synchronous operation forced by voltage waveform in the power grid. These issues are discussed in [21] [22] [23].

Oliveira [24] also studied LED and Compact Fluorescent Lamps in terms of the resulting impact on the electricity transmission grid (measurements of power factor and current harmonic distortions) which confirmed that LEDs have unfavorable energy properties such as harmonic distortion factor of current waveform often greater than 100% and low power factor between 0.4 and 0.95 depending on the power supply type.

The study further notes that on the consumer market there are a lot of energy-saving LED bulbs available from various manufacturers. Manufacturers persuade consumers by presenting data on the packaging as catchy phrases that are not informative on the properties of the lamps. (e.g., “4 W = 60 W”), the only data given is often the current, power and the rated voltage. The study further measured the energy parameters of several, arbitrarily selected LED lamps and two compact fluorescent lamps (CFL) available in popular commercial networks and compared the obtained measurement data with the parameters declared by the manufacturers. The power factor of the lamps was found to be low and ranging from 0.5 to 0.65 [25]. This suggests that LED lighting could reduce the overall power factor of a building.

2.9 Quantifying Energy Savings

There are three common protocols that give guidance on how savings on energy projects should be computed. These are International Performance Measurement and Verification (IPMVP), American Society of Heating, Refrigerating & Air-Conditioning Engineers (ASHRAE 14) Federal Energy Management Program (FEMP).

2.9.1 International Performance Measurement and Verification (IPMVP)

The International Performance Measurement and Verification (IPMVP) lays a framework for the computation savings achieved from energy projects. IPMVP outlines four options which are employed according to the project implemented:

i) IPMVP Option A

This is also known as Retrofit Isolation (Key Parameter Measurement). In this method, the savings are computed by taking measurements of the key affected parameter(s) that define the energy use of a particular system affected by a retrofit. Assumptions as well as estimations are allowed in this option. It can be used for lighting retrofits where the key parameter is the power drawn by the lights. The hours of use are estimated from the facility's operational hours.

ii) IPMVP Option B

Also known as Retrofit Isolation (All Parameter Measurement). In this option, the savings are computed by taking measurements of the actual energy use of the systems affected by the implementation of an ECM. The measurements can be spot-checking, short-term, or continuous. Option B can be used for applications such as Variable-speed drive; where controls have been added to a motor to monitor pump flow. A kW smart meter can be used to measure the power drawn by the motor per minute. The meter takes measurements for the stipulated period and indicates any differences in the usage of power.

iii) IPMVP Option C

This is referred to as the Whole Facility. In this method, the savings are computed by taking measurements of the energy consumption in kWh for the entire facility for a stipulated period, e.g., a month. Measurements are taken throughout this period. This can be used e.g., when an energy management program has been installed that affects many systems of the entire facility. The utility bill can be used. This method is particularly suited where savings of 10-20% are expected.

iv) IPMVP Option D

Also referred to as Calibrated Simulation: In this method, the savings are estimated by simulating the energy consumption of the facility or part of the facility. It is most appropriate for new buildings, where historical data is not available. Based on these four Options given under the IPMVP, simulation is not necessary since the baseline historical energy data is available for the different facilities. This study proposes Option A and C to quantify the savings accruing from energy efficient lighting in commercial buildings once the retrofit is completed. Figure *2-4* shows how post retrofit savings are represented. Adjustment of baseline data is allowed in instances where there was a change in variables.

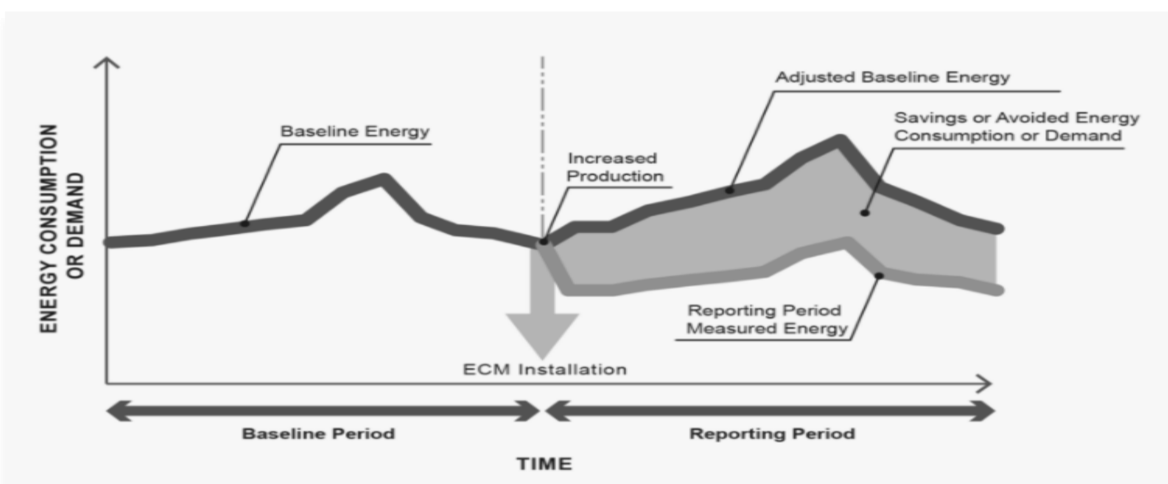


Figure 2-4: Representation of Savings

2.9.2 American Society of Heating, Refrigerating & Air-Conditioning Engineers (ASHRAE 14)

This is a measurement and verification protocol that identifies three approaches of ascertaining savings:

i) **Retrofit Isolation Approach**

This approach measures the consumption of energy and other variables affected by the energy retrofit. Measurements of the baseline and after the retrofit are necessary to ascertain the impact.

ii) **Whole Facility Approach**

This approach uses the measurements of energy consumption or the entire building to ascertain savings. Utility meter data or sub metered sections data as well as variables such as weather are taken.

iii) **Whole Building Calibrated Simulation Approach**

This approach uses a simulation tool that comes up with the energy consumption and demand of a given facility. Measurements must be done before retrofit, then simulation of post retrofit is done.

Whereas ASHRAE provides more in-depth details than IPMVP, it has restrictions when addressing uncertainties. It also emphasizes that measurement be done for all the three approaches.

2.9.3 Federal Energy Management Program (FEMP)

Just like IPMVP, FEMP has four options which are like IPMVP. However, this protocol is not as universal and is mostly used in American Federal Buildings. Of the three methods, this study used IPMVP as the main protocol but referred to ASHRAE 14 where more in-depth details were required.

2.10 Research Gaps

There is little literature on the potential to save energy through LED lighting in Kenyan buildings; more so, the banks. This study seeks to add to the body of knowledge from the Kenyan market. This will be useful to investors and decision-makers. Additionally, scholars do not seem to agree on the impact of LED lighting on the power factor. This study seeks to investigate this impact and form a basis to advise commercial buildings on considerations to make when carrying out LED retrofit projects.

While the studies agree that there is a saving on energy, there is little mention of its net impact on the Energy Use Intensity of buildings.

2.11 Project Approach

The photometrical method has been used to determine the necessary luminaires for Co-op House. The current lux levels were also be matched against the IES code requirement. A comparison of the baseline energy consumption was done against post-retrofit energy consumption. This was extracted from the utility bills.

2.12 Summary of the Literature Review

Table 2-1 shows a summary of the different reviewed literature.

Table 2-1: Summary of Literature Review

	Author	Research area	Key Findings	Research Gap	My Approach
1	Vahl et al.	Long-term sustainability of retrofit	LEDs would be the most economical and sustainable option.	The savings potential of LED lights vis a vis other lamp	Compare energy usage of fluorescent tube with LED
2	Chen and Chung	Retrofitted T8 fluorescent tubes with LEDs.	$ 288 can be achieved in 5 years through the retrofit	No quantification of energy savings in kWh	Project energy savings in both kWh and in monetary terms
				No mention of impact on Energy Use Intensity	Calculate the improvement in Energy Use Intensity.
3	Ganandran	Analysis of the saving potential of buildings in Universiti Tenaga Nasional in Malaysia by retrofitting 62,684 bulbs	1,463,450.56 kWh of energy which translated to RM (Malaysia) 517,622 annually, which is about KES 13 Million	The Energy Use Intensity not mentioned	Calculate the improvement in Energy Use Intensity.
4	Mahlia et al	Analysis of the cost-benefit of efficient lighting	Energy consumption by the lighting is the multiplication of the number of retrofits, power consumption and operating hour of the lighting	Study does not use IPMVP protocol to quantify savings	Explore use of IPMVP in the quantification of lighting savings.
			they have a variable effect at reducing a building's peak demand	Does not consider the impact the LED lighting on the Energy Use Intensity	Calculate the improvement in Energy Use Intensity.
			highest savings were obtained in the restroom application (47% to 60%) types.		
5	Christel et al	The Energy Saving Potential of Occupancy-Based Lighting Control Strategies in Open-Plan Offices: The Influence of Occupancy Patterns	Lighting control has great potential to save energy	Need for analysis in more buildings	Analyze the energy savings potential of Co-op House.

2.13 Chapter Conclusion

From the literature reviewed, there is no contention about efficient energy lighting as being key in the attainment of energy efficiency in buildings. However, the potential needs to be quantified to encourage more buildings, especially the banking sector in Kenya to adopt energy-efficient lighting both as a cost-saving measure and for environmental protection.

3. CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter of the report seeks to highlight the methodologies and procedures followed during the project research.

3.2 Location of the Study

Co-operative Bank was established in 1968 and has 157 branches countrywide, 40 of which are in Nairobi. Co-op House was completed in 1981 and retrofitted between 1998 to 2002 following the Nairobi bomb blast event.

It is a 22-floor building located along Haile Selassie Avenue in Nairobi Community Business District. Co-op House is one of the largest facilities of Co-operative Bank. Figure 3-1 shows a picture of the building as well as the location.

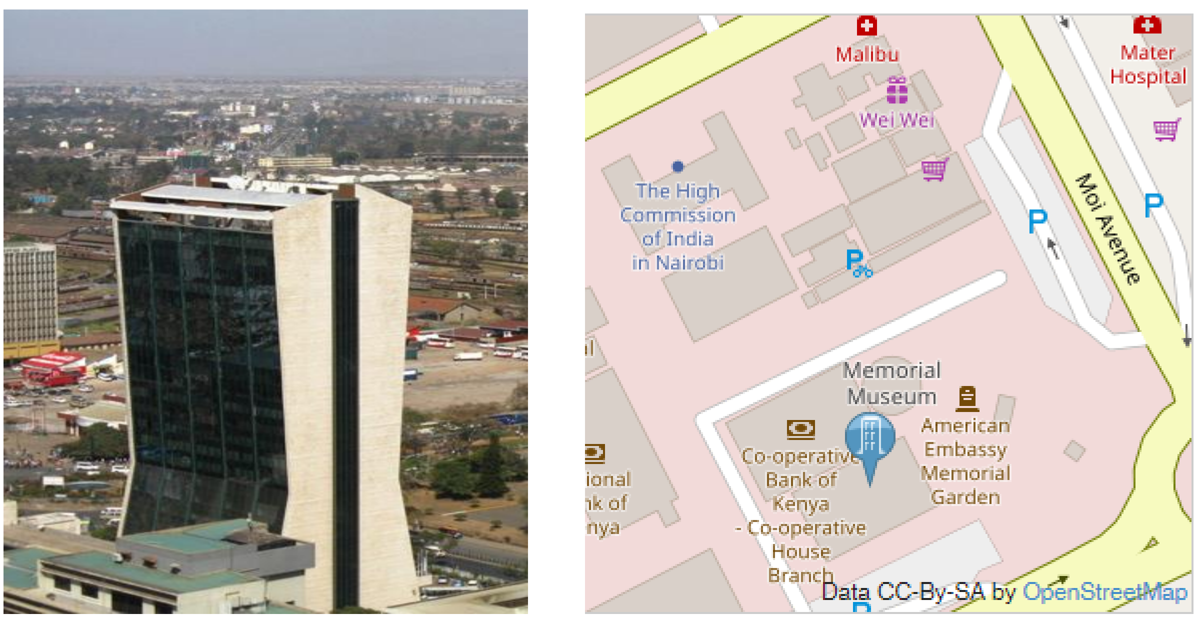
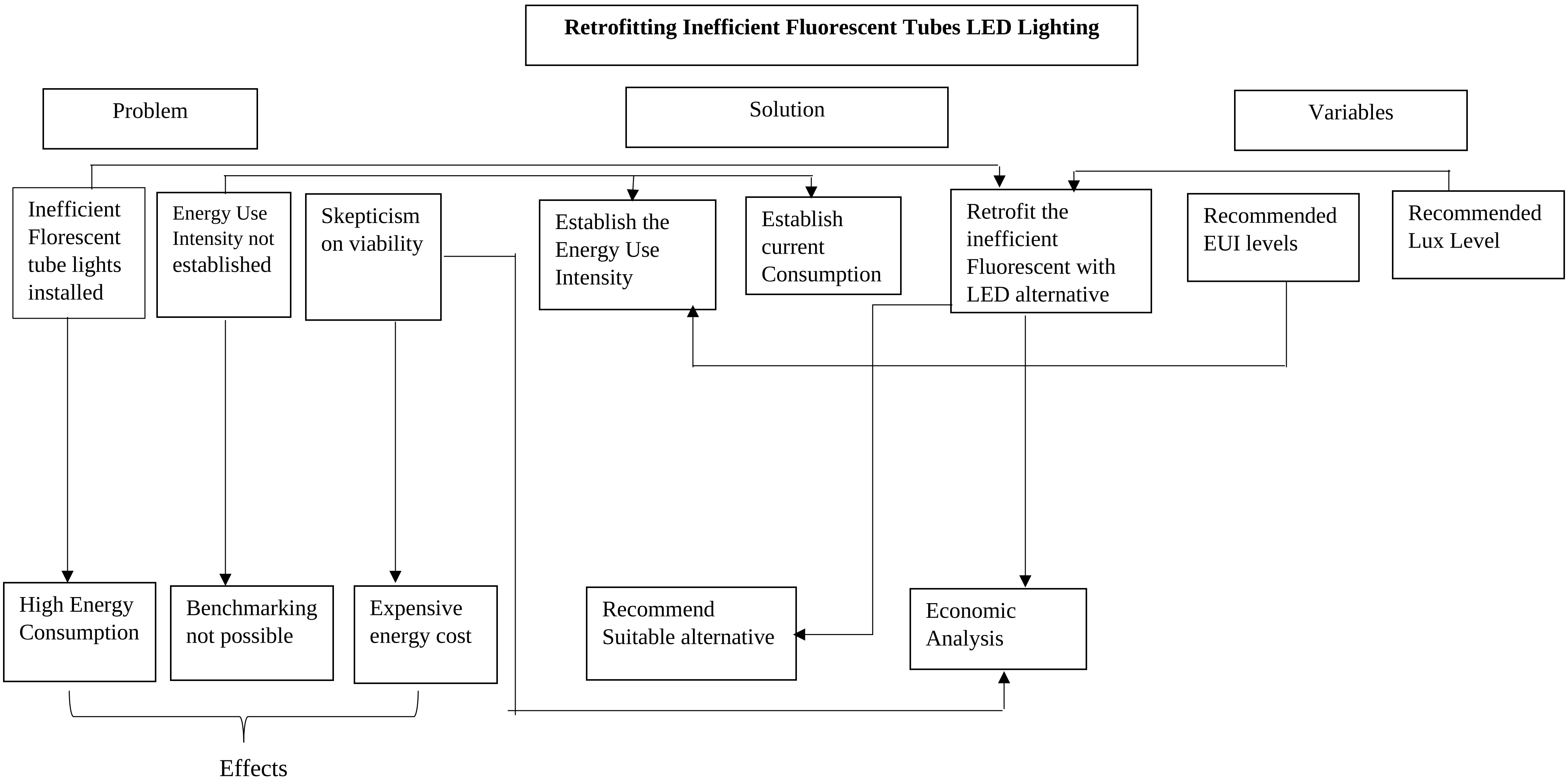


Figure 3-1: Co-op House Location

3.3 Conceptual Framework



3.4 Data Collection

Data was collected through primary data collection methods whereby a structured data sheet was given to the energy manager of Co-op House. The questions targeted data on kWh energy consumption, demand in kW, and power factor for 2018, 2019 and 2020. Table 3-1 represents the data sheet used to capture the various energy related parameters of the facility.

Table 3-1: Sample Data Sheet for Facility Energy Related Data

Branch							
Tariff							
Floor Area							
Month	**High-Rate kWh**	**Low-Rate kWh**	**Demand in kW**	**Demand in kVA**	**Power Factor**	**Bill in KES**	**Energy Use Intensity**
Jan							
Feb							
Mar							
Apr							
May							
Jun							
Jul							
Aug							
Sep							
Oct							
Nov							
Dec							

A lighting inventory detailing the number of fixtures, type of fixtures, hours of use, type of tube lights used was taken for the entire building. Table 3-2 shows the sample data sheet used to collect details on the facility lighting.

Table 3-2: Sample Lighting Inventory Data Sheet

#	Section	Type of fixture	No. of Fixtures	Total Number of working Fixtures	Rating Per Fixture in Watts	Time duration in Hours
1						
2						
3						
4						

3.5 Data Analysis

The photometrical method was used to determine the necessary luminaires for Co-op House. The current lux levels were benchmarked against the IES code requirement. The room dimensions of sampled rooms were taken and used to calculate the fixture requirements in order to determine the appropriate LED: Fluorescent lamp replacement ratio.

Once collected, the electricity utility bills for the last two years were tabulated and analyzed using Microsoft Excel. A comparison of the baseline energy consumption was done against post-retrofit energy consumption. This was extracted from the utility bills.

The high rate and low-rate energy consumption were analyzed to investigate and quantify the energy savings achieved due to the installation of energy-efficient lighting.

The Bill in Kenya Shillings was analyzed to establish the current cost of energy and to establish the cost per unit of energy. This unit cost was later used to quantify the projected savings in monetary terms and to carry out an economic analysis of the project.

The kW and kVA demand were analyzed to investigate the trends and a establish a baseline that will be used for post retrofit analysis of the effect of lighting on the demand and the associated demand cost.

The power factor values were analyzed to reveal the trends before the retrofit. Power Factor was expressed as

$$Power\ Factor = \frac{Demand\ in\ kW}{Demand\ in\ kVA} \qquad [3\text{-}1]$$

The Energy Use Intensity for the facility due to lighting as well as the overall Energy Use Intensity was computed. The Energy Use Intensity was calculated as

$$Energy\ Use\ Intensity = \frac{Energy\ Consumption\ in\ kWh}{Area\ in\ Sq\ Metre} \quad [3\text{-}2]$$

The Energy Use Intensity of Co-op House was benchmarked against other similar buildings. Analysis of the savings potential of lighting through energy efficient lighting was done.

A lighting inventory detailing the number of fixtures, type of fixtures, hours of use, type of tube lights used was taken.

An economic evaluation for the retrofit project was done using simple payback to determine the viability of the project.

3.6 Quantifying Energy Savings

The International Performance Measurement and Verification (IPMVP) lays a framework for the computation savings achieved from energy projects. IPMVP outlines four options which are employed according to the project implemented.

Based on these four Options given under the IPMVP, this study utilized Option A & D to simulate the projected savings accruing from energy-efficient lighting in commercial buildings.

3.7 Project Assumptions

i) Co-op House majorly operates during weekdays for 12 hours a day.

ii) The manufacturers' power ratings of the lamps are accurate.

iii) Lighting is the main load in all the Co-op House. The luminaires are subject to similar room conditions and hence their performance is uniform and degrade uniformly.

3.8 Case Validation

The project was validated using other case studies on savings accruing from energy efficient lighting are shown on Table 3-3.

Table 3-3: Project Validation

Authors	Project	Location	Building type	No. of LED Lamps	Annual Saving (kWh)	Lighting energy saving (%)	Payback period (year)
Ayman et al	Improving Energy Efficiency of Lighting & Building Appliances Project	Egypt	Public Building	3,600	231,922	77%	3.4
			Public Building	2,295	128,824	66%	3
			Bank	1,601	312,136	77%	1.1
Nancy Mwari	A Case Study of Co-op House	Kenya	Bank	2,743	281,052	50%	1.9

The Energy Use Index was validated using Benchmarking standards of UK and South Africa as shown on Table 3-4

Table 3-4: Validation for Energy Use Intensity

Author	Project	Location	Lighting Benchmark	Overall Energy Use Index	Units
CISBSE	Benchmarking Standards	UK	54	226	kWh/m^2/Year
Sans 204	Benchmarking Standards	South Africa	42.5	185-210	kWh/m^2/Year
Nancy Mwari	A Case Study of Co-op House	Kenya	67	242	kWh/m^2/Year

3.9 Chapter Conclusion

The project acquired data from the facility by filling of baseline energy data questionnaire. An inventory of all the existing lamps was tabulated in excel. The data which was then analyzed using Excel to establish a baseline. This data was represented in bar graphs to give a visual appreciation of the trends. LED equivalent for the existing lamps was added to the lighting inventory to project the savings that would result from the retrofit. Economic analysis for the project was carried out using Simple payback, NPV and IRR.

4. CHAPTER 4: RESULTS, ANALYSIS AND DISCUSSION

4.1 Existing Situation

Co-op House is the headquarters of all the branches, and it is billed on CI 2. The unit cost per kWh for this tariff is KES 10.9 and the unit kVA is charged at KES 520. The area of the building is 5,582 m^2.

Co-op House consumes on average 128,000 kWh units in a month and is billed on Commercial Industrial tariff. The 2020 data showed that most of the energy (69%) is consumed during the day, while the remaining 31% is spent at night. The electricity bill in KES averages at 2.4 Million. The blended unit cost per kWh is KES 19.1. The kW averages at 464 while the KVA demand averages at 504 translating to a power factor of 0.92; Table 4-1 shows a tabulation of the utility bills for 2018, 2019 and 2020.

Despite the 2020 consumption being low due to reduced activity in the facility, occasioned by the COVID 19 pandemic, 2020 was used as the baseline year for the analysis because the facility indicated no plans of resuming physical access for services that have moved online. Therefore, the consumption will likely remain at 2020 level.

4.2 Energy Consumption in kWh

Figure 4-1 shows the energy consumption trends. The energy consumption in kWh averaged at 128,000 units in 2020. The downward trend in the overall energy consumption of the facility in 2020 due to reduced traffic in the facility due to the COVID 19 pandemic.

4.2.1 Demand in kW

Demand in kW refers to the useful power at the facility. Figure 4-2 shows the kW Demand trend. At Co-op House, the demand in kW in 2020 averaged at 460 kW, a decline from the previous year where the demand averaged at 550 kW. This drop in kW is also attributable to the low activity level witnessed at the bank in 2020 because of COVID 19 pandemic that saw lesser people visiting the facility.

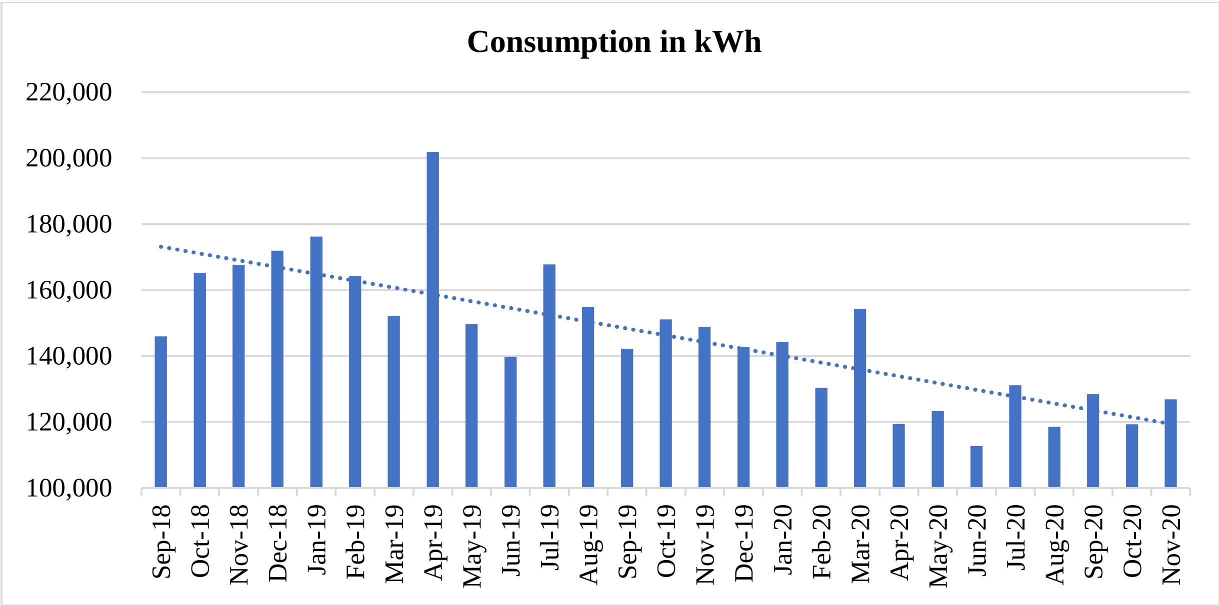


Figure 4-1: Consumption in kWh

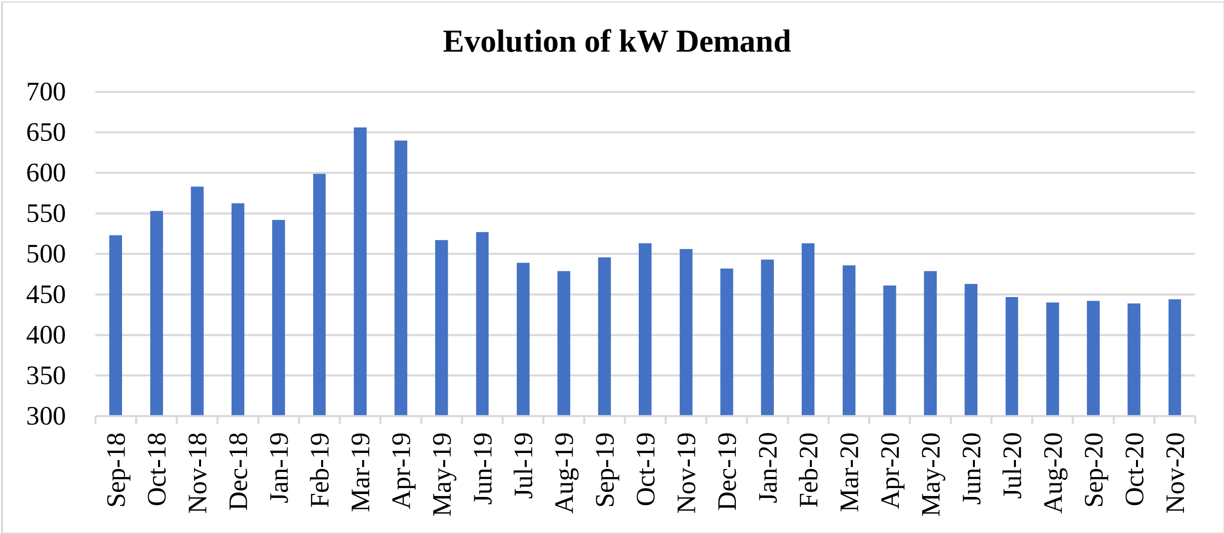


Figure 4-2: Demand in kW

A tabulation of the different electricity bill parameters (including the high rate, low rate, bill in KES, KVA Demand, kW demand and Power factor) is shown in Table 4-1, as obtained from the utility bills of the facility.

Table 4-1: Co-op House Utility Bills

Co-op House									
Date	**High-Rate kWh**	**Low-Rate kWh**	**Total kWh**	**Bill in KES**	**KES/ KWh**	**KVA**	**KW**	**P.F**	**EUI**
18-Sep	103,556	42,442	145,998	2,711,340	18.6	563	523	0.93	28.17
18-Oct	115,040	50,196	165,236	2,989,694	18.1	602	553	0.92	31.89
18-Nov	122,478	45,212	167,690	3,096,738	18.5	640	583	0.91	32.36
18-Dec	123,521	48,442	171,963	3,152,175	18.3	613	563	0.92	33.18
19-Jan	124,564	51,672	176,236	3,207,612	18.2	586	542	0.92	34.01
19-Feb	118,384	45,850	164,234	3,091,797	18.8	659	599	0.91	31.69
19-Mar	112,204	40,028	152,232	2,975,982	19.5	732	656	0.9	29.38
19-Apr	147,400	54,510	201,910	3,736,212	18.5	710	640	0.9	38.96
19-May	108,006	41,678	149,684	3,017,441	20.2	562	517	0.92	28.89
19-Jun	98,966	40,730	139,696	2,831,114	20.3	587	527	0.9	26.96
19-Jul	116,642	51,198	167,840	3,279,672	19.5	532	489	0.92	32.39
19-Aug	111,870	43,074	154,944	3,097,412	20	523	479	0.92	29.9
19-Sep	101,137	41,123	142,260	2,862,053	20.1	553	496	0.9	27.45
19-Oct	106,127	44,975	151,102	2,988,990	19.8	558	513	0.92	29.16
19-Nov	103,000	45,878	148,878	2,887,887	19.4	550	506	0.92	28.73
19-Dec	96,110	46,610	142,720	2,687,814	18.8	518	482	0.93	27.54
20-Jan	102,252	42,076	144,328	2,703,577	18.7	540	493	0.91	27.85
20-Feb	92,522	37,846	130,368	2,485,958	19.1	565	513	0.91	25.16
20-Mar	112,970	41,336	154,306	2,794,196	18.1	533	486	0.91	29.78
20-Apr	77,652	41,778	119,430	2,263,449	19	502	461	0.92	23.05
20-May	83,624	39,738	123,362	2,313,383	18.8	523	479	0.92	23.81
20-Jun	76,222	36,526	112,748	2,152,379	19.1	504	463	0.92	21.76
20-Jul	88,702	42,436	131,138	2,459,302	18.8	487	447	0.92	25.31
20-Aug	80,898	37,626	118,524	2,260,288	19.1	480	440	0.92	22.87
20-Sep	85,638	42,806	128,444	2,445,826	19	482	442	0.92	24.79
20-Oct	83,038	36,286	119,324	2,376,826	19.9	480	439	0.91	23.03
20-Nov	87,324	39,568	126,892	2,413,834	19	448	444	0.99	24.49
Average	**88,258**	**39,820**	**128,079**	**2,424,456**	**18.96**	**504**	**464**	**0.92**	**24.72**

4.2.2 Power Factor

Power Factor is the ration of the useful power in kW to the apparent power in kVA and is a measure of how efficiently the power is being utilized at the facility.

$$\text{Power Factor} = \frac{Useful\ Power\ (kW)}{Aparent\ Power\ (kVA)} \qquad [4\text{-}1]$$

Figure 4-3 shows the power factor trends. The Power factor averages at 0.92 except in November 2020 where it rose to 0.98, which is a good indicator of the electrical efficiency. Below 0.90, the facility would be surcharged by the utility company, and therefore, there is need for the facility to ensure that the power factor is maintained at the 0.98 attained in November 2020.

If a facility is surcharged after having implemented an Energy Conservation Measure such as lighting, the facility might fail to appreciate the energy savings accrued by retrofitting the lights. Therefore, there is need to ensure that the capacitor banks at the facility are well maintained and the power factor controller well-tuned to avoid instances of poor power factor.

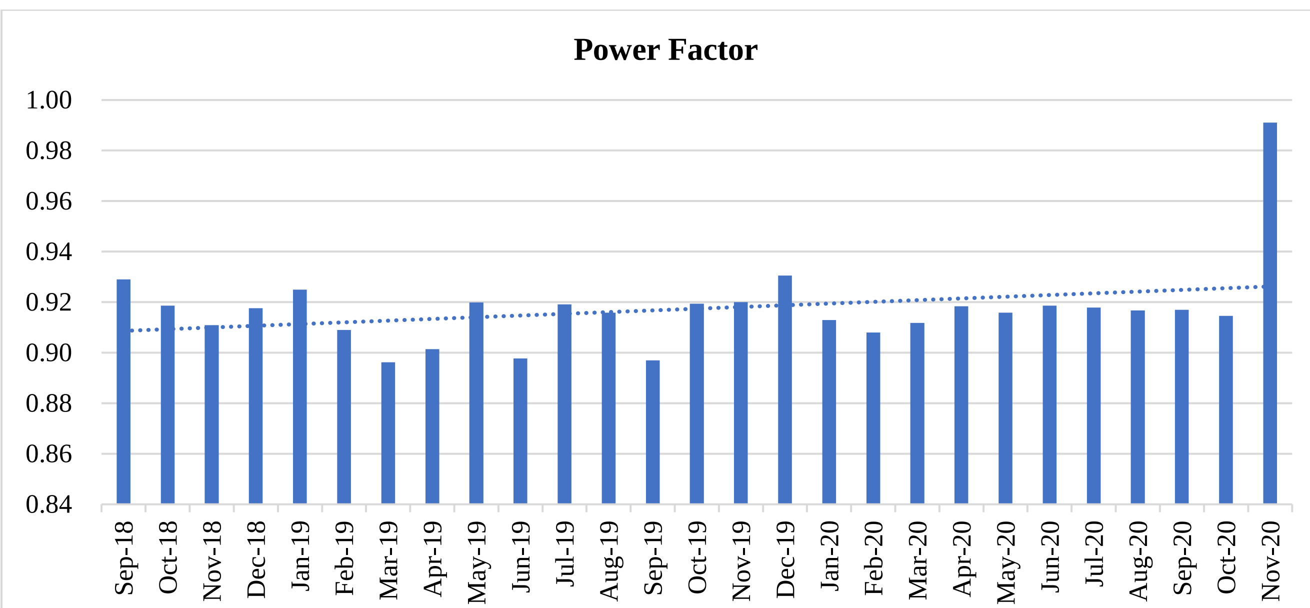


Figure 4-3: Power Factor

4.2.3 Energy Use Intensity

Energy Use intensity refers to the usage of energy per area. It is useful in benchmarking facilities that have similar operations. In 2020, The Energy use Intensity of facility averaged at 24.7 kWh/m^2 /Month, which translates to 296.4 kWh/m^2/Year.

$$\text{Energy Use Intensity} = \frac{\mathit{Energy\ Usage\ in\ kWh}}{\mathit{Area\ in\ M2}} \qquad [4\text{-}2]$$

Table 4-2 shows the Energy Use Intensity for 2020, which is the baseline year against which the post retrofit Energy Use Intensity values would be compared.

Table 4-2: Energy Use Intensity 2020

Date	Total kWh	Area	Energy Use Intensity
Jan-20	144,328	5,182	27.85
Feb-20	130,368	5,182	25.16
Mar-20	154,306	5,182	29.78
Apr-20	119,430	5,182	23.05
May-20	123,362	5,182	23.81
Jun-20	112,748	5,182	21.76
Jul-20	131,138	5,182	25.31
Aug-20	118,524	5,182	22.87
Sep-20	128,444	5,182	24.79
Oct-20	119,324	5,182	23.03
Nov-20	126,892	5,182	24.49
Average	**128,079**	**5,182**	**24.72**
Annual EUI			**296.64**

Figure 4-4 shows the Energy Use Index over the years. The downward trend is attributable to the decreased level of activity at the bank, occasioned by the COVID 19 Pandemic. April 2019 had the highest EUI of 40 kWh/m^2/Month while June 2020 had the lowest EUI.

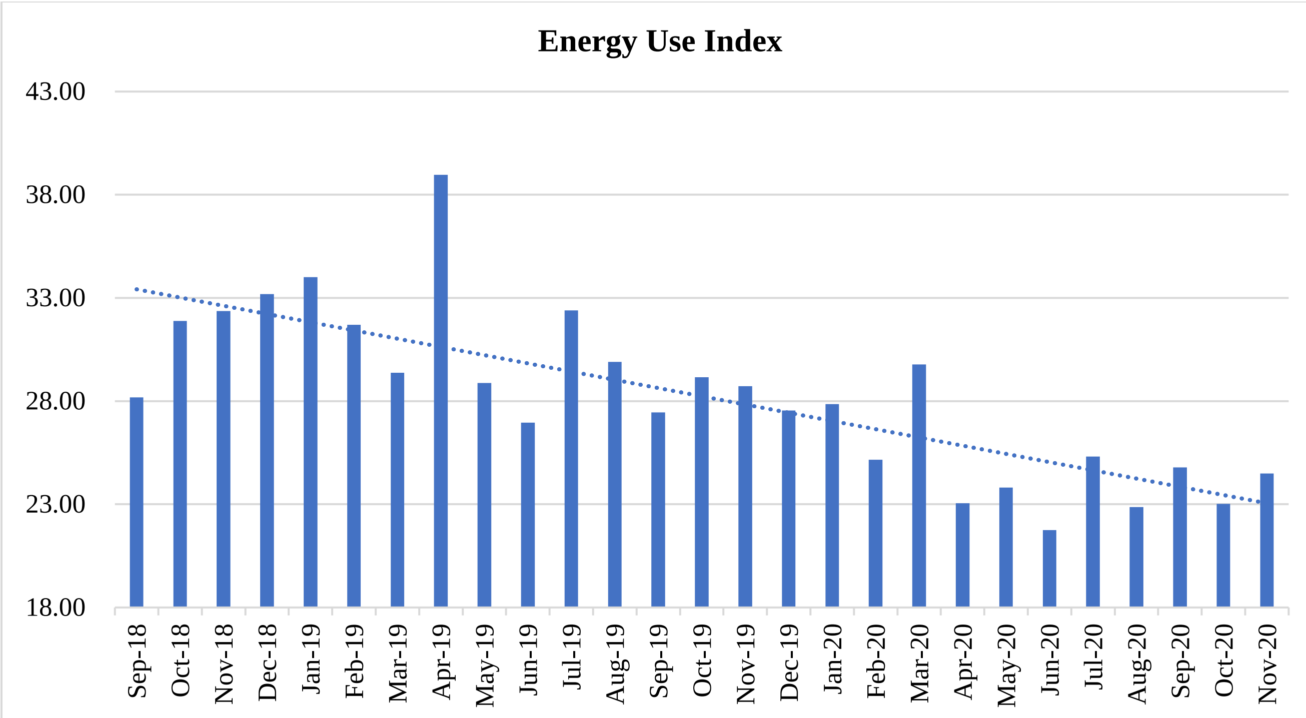


Figure 4-4: Energy Use Intensity

4.2.4 Cost per kWh

Cost per kWh is price charged per unit of kWh consumed. While the rate per kWh for CI 2 consumers such as Co-op House is 10.9, the overall cost is higher due to levies such as Fuel Cost Charge, Forex Adjustment Levy (FERFA), Value added Tax (VAT), REP Levy as well as WARMA Levy. Figure 4-5 shows the Cost per kWh over the years.

The average cost per kwh for the facility averages at 19.9 in 2020. The Cost per kWh shows an upward trend in 2020 due to increase in Fuel Cost Charge levy. The increased trend in the cost per kWh is proof that the facility needs to invest in implementing Energy Conservation Measures (ECM) such as lighting retrofit, to manage the ever-increasing cost of power.

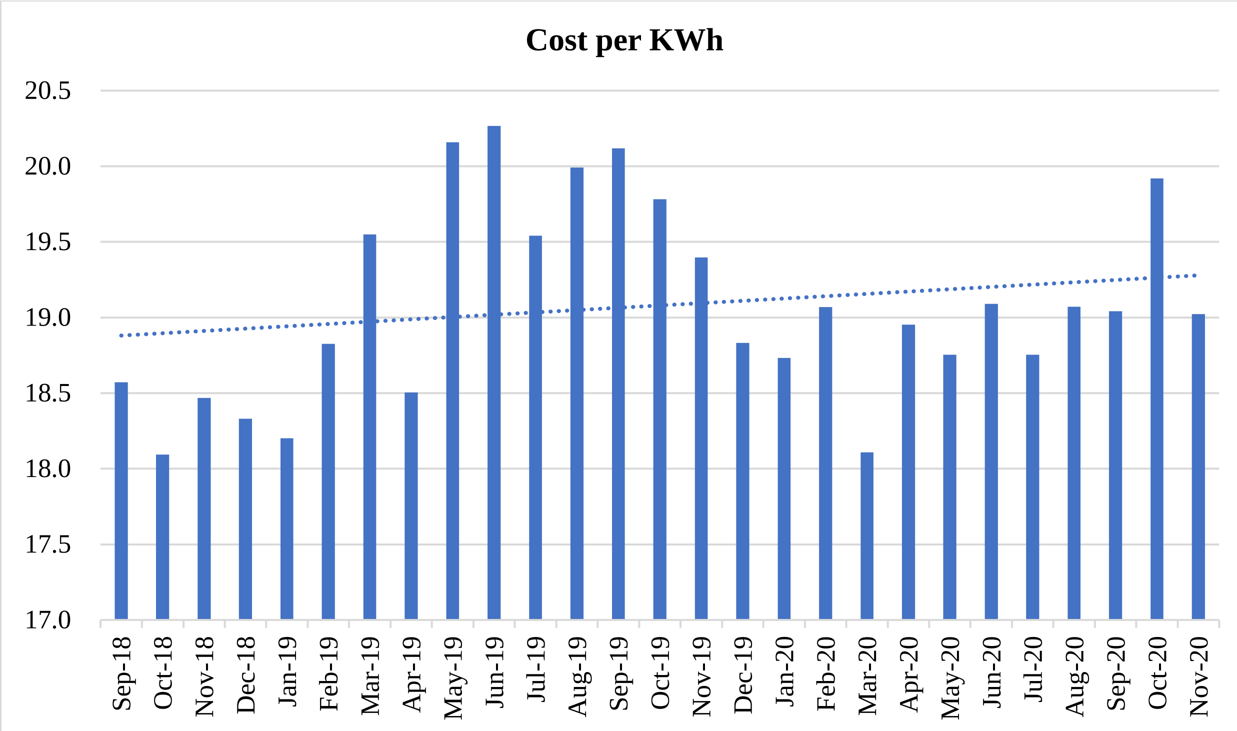


Figure 4-5: Cost per kWh

4.2.5 Bill in KES

Figure 4-6 shows the trends in the utility bills over the years. Despite the increase in Cost per kWh, the bill in KES has remained at relatively the same level. This can be attributed to reduction in consumption due to reduced activity level at the facility in 2020. This shows that reducing energy consumption is one way of managing energy costs. By implementing energy conservation measures, such as efficient lighting, the facility can realize energy cost savings even during full operation. This explains why lighting retrofit should be a priority area for the facility.

4.3 Lighting Inventory

Currently, Co-op House has 2 ft fluorescent and 4 ft fluorescent tubes. These lights are highly consuming as compared to LED Alternative. The 2 ft lights are of Phillips brand rated at 18 W per tube. The overall consumption of the fixture is 72 W. The 4 ft fluorescent tubes are also of Phillips brand, with a lamp consumption of 36 W. The 4 ft fixtures therefore have a total energy consumption of 144 W per fixture. These lights currently contribute to 27% of the overall energy consumption. Figure 4-7 shows a sample of the lighting fixtures currently installed for both 2 ft and 4 ft tubes.

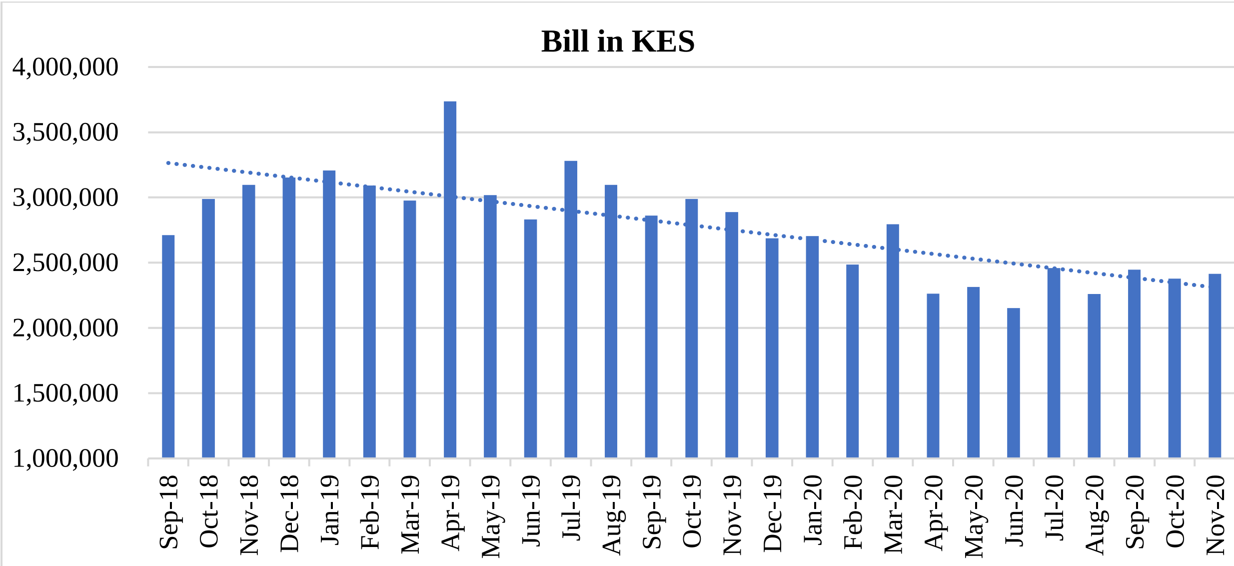


Figure 4-6: Bill in KES

Figure 4-7: Sample Lighting Fixture

The facility has a total of 2,743 fixtures of fluorescent tube lights. Of these, 2,330 are in working condition representing 86% of the fixtures. A detailed breakdown of the lights per section is attached in Appendix 3 The daily energy consumption from the lights is 1,757 kWh.

The lighting inventory shows that the basement has the biggest consumption due to the large number of fluorescent tubes as shown in Figure 4-8. These lights are on throughout for security reasons. Floor 7 and 8 where lighting retrofit was done, after the fluorescent lamps that were previously existing burnt out.

Based on the existing working fixtures, the facility consumes a total of 1,747.53 kWh, this translates to a total of 34,960 kWh. If all the fixtures were working, the daily energy consumption would be 2,074.82 kWh which would translate to 41,496.4 kWh monthly.

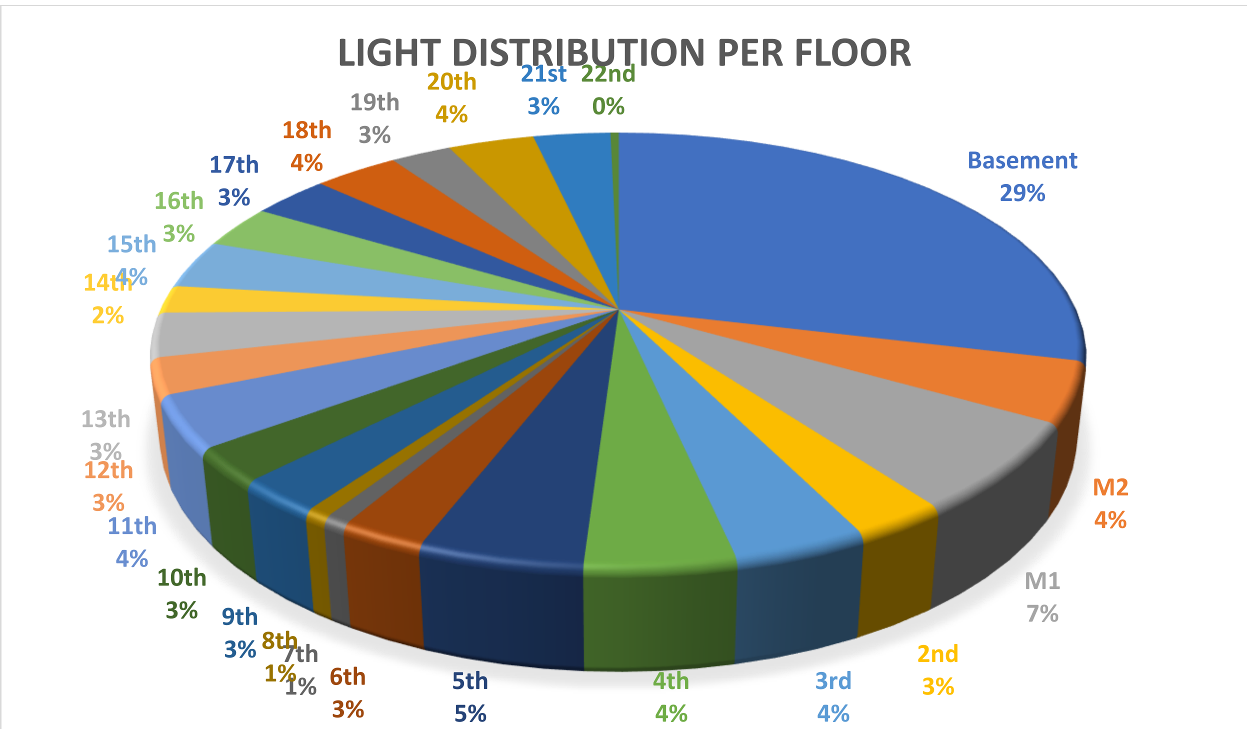


Figure 4-8: Light Distribution per Floor

Table 4-3: Summary Lighting Inventory

Section	No. of Fixtures	Working Fixtures	% of Working Fixtures	Daily Energy Consumption
Basement	253	239	94.5%	502.85
M2	135	134	99.3%	77.90
M1	293	248	84.6%	116.34
2nd	97	69	71.1%	48.32
3rd	135	108	80.0%	68.91
4th	151	86	57.0%	77.09
5th	150	87	58.0%	84.89
6th	130	98	75.4%	44.28
7th	69	68	98.6%	12.47
8th	72	72	100.0%	12.23
9th	86	82	95.3%	44.57
10th	88	83	94.3%	44.44
11th	90	82	91.1%	67.61
12th	106	74	69.8%	46.88
13th	92	85	92.4%	57.82
14th	82	52	63.4%	35.93
15th	98	94	95.9%	63.00
16th	89	83	93.3%	55.66
17th	89	82	92.1%	56.09
18th	147	146	99.3%	61.47
19th	76	69	90.8%	44.07
20th	118	97	82.2%	62.57
21st	87	82	94.3%	56.09
22nd	10	10	100.0%	6.05
Total	**2,743**	**2,330**		**1,747.53**
Average			**86.4%**	
Monthly lighting consumption				**34,960**
Average monthly facility consumption				**128,079**
% of Lighting of the total				**27.2%**

4.4 Existing Energy Balance of Facility Loads

Besides lighting, the facility has other loads such as plugin loads, chillers, and pumps as main loads. Lighting accounts for 30.6% of the energy consumption as per data recorded by the facility energy manager in March 2020 as shown in Table 4-4. The breakdown of the facility loads is shown in Figure 4-9 points to lighting as the second largest load in the facility after plugin loads.

Table 4-4: Consumption of Facility Loads

Equipment	**kWh /Month**
Plugin Loads	53,955.44
Lighting	52,165.96
Annex Chiller	18,260.88
Annex Pumps	2,698.08
Lifts	6,199.20
Main Tower Pumps	2,216.94
Main Tower Chiller	12,386.88
Main Tower Essential Riser	7,011.84
Main Tower Plant Room Pumps	15,544.32
Total	**170,439.54**
Lighting of the total	**30.6%**

4.5 Lux Level Considerations

4.5.1 Replacement ratio

Lux levels is a key consideration in light retrofit projects. This ensures that the user comfort of the lighting is not affected. The recommended lux levels for normal office work, is 500 lux as shown on Table 4-5.

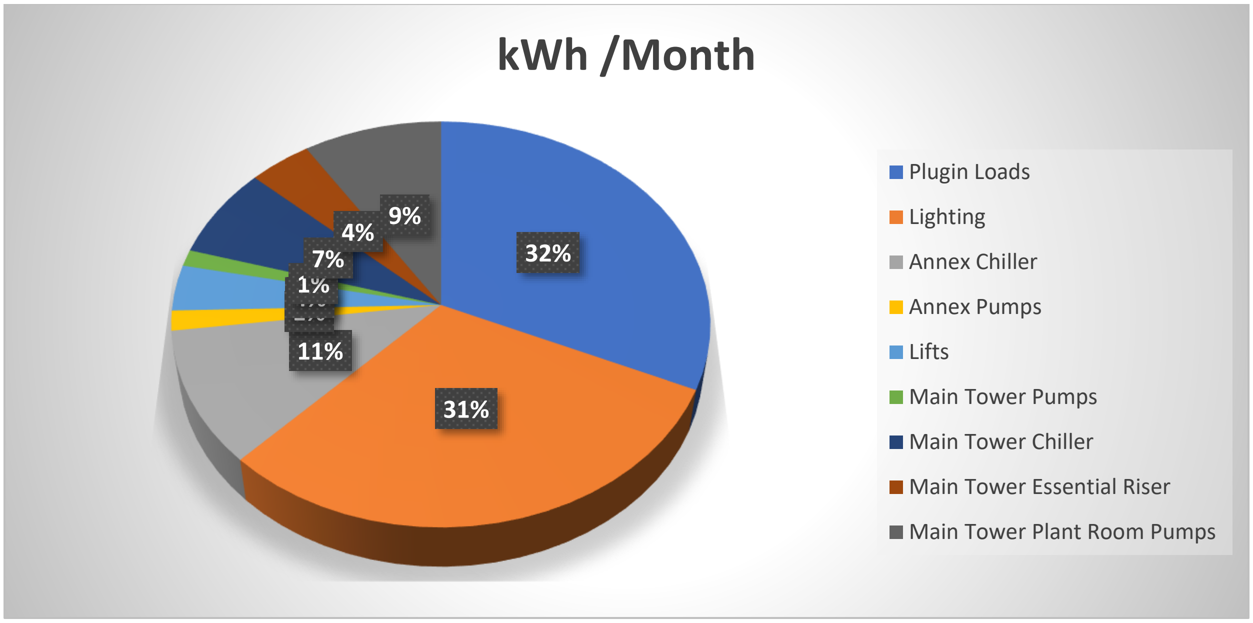


Figure 4-9: Facility Energy Balance

Table 4-5: Recommended Lux Levels

Activity	Illuminance (lx, lumen/m^2)
Public areas with dark surroundings	20 - 50
Simple orientation for short visits	50 - 100
Areas with traffic and corridors - stairways, escalators and travelators - lifts - storage spaces	100
Working areas where visual tasks are only occasionally performed	100 - 150
Warehouses, homes, theaters, archives, loading bays	150
Coffee break room, technical facilities, ball-mill areas, pulp plants, waiting rooms,	200
Easy office work	250
Class rooms	300
Normal office work, PC work, study library, groceries, show rooms, laboratories, check-out areas, kitchens, auditoriums	500
Supermarkets, mechanical workshops, office landscapes	750
Normal drawing work, detailed mechanical workshops, operation theaters	1000
Detailed drawing work, very detailed mechanical works, electronic workshops, testing and adjustments	1500 - 2000
Performance of visual tasks of low contrast and very small size for prolonged periods of time	2000 - 5000
Performance of very prolonged and exacting visual tasks	5000 - 10000
Performance of very special visual tasks of extremely low contrast and small size	10000 - 20000

Source : https://www.engineeringtoolbox.com/light-level-rooms-d_708.html

Once all the lights are replaced with LED the energy consumption will reduce. This study investigated the recommended ratio between existing lamps. This was done by comparing the lux levels before and after retrofitting the lamps. It was clear that a 1:1 replacement of the lamps would not have any negative impact on the overall lux level of the facility. This is shown in Appendix 3 and 4.

Two sampled rooms of different sizes were compared. The first room had measurements of 15 M by 8 M, an area of 120 m^2. From the analysis, the room requires 10 fixtures. Post retrofit, the room would still require 10 fixtures. Therefore, a 1:1 retrofit ratio would not have any negative impact on the current lux levels. The lux levels would remain unaltered as shown on Table 4-6.

Table 4-6: Lux Considerations, Sample Room 1

No of Fixtures as per Sq. M Area		
(Existing Situation)		
Illuminated Area:	120	m^2
Desired Lux:	500	
No of Lamps per Fixture:	4	Nos
Each Fixture Watts:	36	Watt
Ballast Factor:	0.8	
Rated mean Lumens per Lamp:	3,200	
Coefficient of Utilization:	0.62	
Fixtures Burning hours per Year:	3,120	
Energy Rate (KES. Per kWh):	KES 18.96	
Results:		
Required Fixtures	10	Nos
Required Lamps	40	Nos
Required Fixture Spacing	3.5	M
Total kW	0.4	kW
Watts per Sq. M	3.00	
Energy Cost per Year	KES 21,290	

No of Fixtures as per Sq. M Area		
(Post Retrofit Scenario)		
Illuminated Area:	120	m^2
Desired Lux:	500	
No of Lamps per Fixture:	4	Nos
Each Fixture Watts:	18	Watt
Ballast Factor:	1	
Rated mean Lumens per Lamp:	2,500	
Coefficient of Utilization:	0.62	
Fixtures Burning hours per Year:	3,120	
Energy Rate (KES. Per kWh):	KES 18.96	
Results:		
Required Fixtures	10	Nos
Required Lamps	40	Nos
Required Fixture Spacing	3.5	M
Total kW	0.2	kW
Watts per Sq. M	1.50	
Energy Cost per Year	KES 10,645	

The second sampled room had dimensions of 10 by 8 M. Results show the room would require 7 fixtures even post. This implies that a 1:1 replacement ratio would not be detrimental to the current lux levels. The lux levels would remain unaltered as illustrated on Table *4-7*.

Table 4-7: Lux Considerations: Sample Room 2

No of Fixtures as per Sq. m Area		
Existing Situation		
Illuminated Area:	80	m^2
Desired Lux:	500	
No of Lamps per Fixture:	4	Nos
Each Fixture Watts:	36	Watt
Ballast Factor:	0.8	
Rated mean Lumens per Lamp:	3200	
Coefficient of Utilization:	0.62	
Fixtures Burning hours per Year:	3120	
Energy Rate (KES. Per kWh):	KES 18.96	
Results:		
Required Fixtures	7	Nos
Required Lamps	28	Nos
Required Fixture Spacing	3.4	M
Total kW	0.3	kW
Watts per Sq. M	3.15	
Energy Cost per Year	KES 14,904	

No of Fixtures as per Sq. m Area		
Post Retrofit		
Illuminated Area:	80	m^2
Desired Lux:	500	
No of Lamps per Fixture:	4	Nos
Each Fixture Watts:	18	Watt
Ballast Factor:	1	
Rated mean Lumens per Lamp:	2500	
Coefficient of Utilization:	0.62	
Fixtures Burning hours per Year:	3120	
Energy Rate (KES. Per kWh):	KES 18.96	
Results:		
Required Fixtures	7	Nos
Required Lamps	28	Nos
Required Fixture Spacing	3.4	M
Total kW	0.1	kW
Watts per Sq. M	1.58	
Energy Cost per Year	KES 7,452	

4.5.2 Post Retrofit Scenario

4.5.2.1 Projected Energy Savings from Lighting Retrofit

Co-op House can retrofit the current lighting system with efficient lighting system as shown in Table 4-8. The retrofit would not require any change in the existing fixtures. However, the existing ballast would require to be removed or bypassed during the retrofit.

Table 4-8: Proposed Lighting Retrofit Specifications

Specification	Existing	Proposed
Type	Fluorescent T8	LED T 8 Tubes
Size	4 ft	4 ft
Model	Phillips	Phillips
Base	G 13	G 13
Lumen	3200	2500
CRI	72	80
Energy Consumption	36 W	18 W

Specification	Existing	Proposed
Type	Fluorescent T8 tubes	LED T 8 Tubes
Size	2 ft	2 ft
Model	Phillips	Phillips
Base	G 13	G 13
Lumen	140	800
CRI		80
Energy Consumption	18 W	9 W

Through LED retrofit, the facility would save 781 kWh daily which would translate to an energy saving of 23,421 kWh. On an annual basis, the total energy saving will be 281,052 kWh This would translate to monetary savings of KES 5.3 Million in energy cost saving as shown on Table 4-9.

Table 4-9: Energy Cost Savings

Energy Cost Savings				
	Existing	**Post Retrofit**	**Saving**	**Unit**
Current Daily Consumption	1,748	967	781	kWh
Monthly Consumption (30 days)	52,426	29,005	23,421	kWh
Annual Consumption in kWh	629,112	348,060	281,052	kWh
Cost per kWh		19		KES
Saving in KES			**5,327,515**	KES

4.5.2.2 Energy Use Intensity

The CISBSE defines Building energy benchmarks as representative values for common building types, against which one can compare your building’s actual performance. The benchmark gives 4 types of offices:

i) **Naturally, Ventilated Cellular** This is for simple buildings that are, often relatively small the size of residential homes with a size of 100 to 3000 m^2

ii) Naturally, Ventilated Open Plan This classification is for open plan office that have cellular offices with a size of 500 to 4,000 m^2

iii) Air Conditioned, Standard These are purpose-built offices with sizes ranging from 2000 to 8000 m^2

iv) Air-conditioned Prestige These are national/ regional offices of sizes ranging from 4000 to 20,000 m^2

Co-op House has an area of 5,189 m^2. Based on the above classifications, it can be considered a type 3 office. The Good practice Annual Energy Use Intensity is 27 kWh/m^2/year, while the typical Annual Energy Use Intensity is 54 kWh/m^2/Year as shown on Figure *4-10*.

LIGHTING BENCHMARKS	1		2		3		4	
	Good practice	*Typical*	*Good practice*	*Typical*	*Good practice*	*Typical*	*Good practice*	*Typical*
a W/m^2	12	15	12	18	12	20	12	20
b hrs/yr	2500	2500	3000	3000	3200	3200	3500	3500
c percentage utilisation	45%	60%	60%	70%	70%	85%	70%	85%
EUI kWh/m^2/yr	14	23	22	38	27	54	29	60

Figure 4-10: Lighting Benchmarks

Source: Chartered Institute of Building Services Engineers (CIBSE), UK *(http://www.cibse.org/getmedia/7fb5616f-1ed7-4854-bf72-2dae1d8bde62/ECG19-Energy-Use-in-Offices-(formerly-ECON19)*

With Retrofit of lights, the building would be at 68 kWh/m^2/Year which is close to the recommended typical values for offices of 54 kWh/m^2/Year.

Table 4-10: Pre and Post Retrofit EUI Comparison

Existing Situation		**Post Retrofit**		**Units**
Annual energy Consumption due to lighting	637,849	Annual energy Consumption Post retrofit	352,894	kWh
Annual Energy Use Intensity for Lighting	123	Annual Energy Use Intensity for Lighting	68	kWh/m^2/ Year
Lighting Benchmark for a typical office	54	Lighting Benchmark for a typical office	54	kWh/m^2/ Year
Deviation of actual EUI from the recommended EUI	122.09	Deviation of actual EUI from the recommended EUI	67.10	%

4.5.2.3 Energy Use Intensity Improvement

As shown on Table 4-11 a result of the LED retrofit, the overall Energy Use Intensity of the facility would improve by 18.3% monthly from the current average of 24.72 kWh/m^2/Year to 20.20 kWh/m^2/Year.

Table 4-11: Energy Use Intensity Improvement

1	Daily Saving in kWh	780.70
2	Monthly Saving in kWh	23,421
3	Reduced EUI	4.52
4	Overall EUI before retrofit	24.72
5	Overall EUI post retrofit	20.20
6	**% Improvement**	**18.3%**

4.5.2.4 Post Retrofit Energy Balance

After lighting retrofit is done, it is projected that the average consumption would have been 147,018 kWh units as shown on Table 4-12 compared to the existing consumption shown on Table 4-4. The lighting contribution to the overall energy mix would drop from 31% to 20% as shown on Figure 4-11 when compared against the current contribution shown on Figure 4-9. This denotes an 11 % drop in overall consumption.

Table 4-12: Post Retrofit Energy Consumption of Facility Loads

Equipment	kWh /Month
Plugin Loads	53,955.44
Lighting	28,744.96
Annex Chiller	18,260.88
Annex Pumps	2,698.08
Lifts	6,199.20
Main Tower Pumps	2,216.94
Main Tower Chiller	12,386.88
Main Tower Essential Riser	7,011.84
Main Tower Plant Room Pumps	15,544.32
Total	**147,018.54**

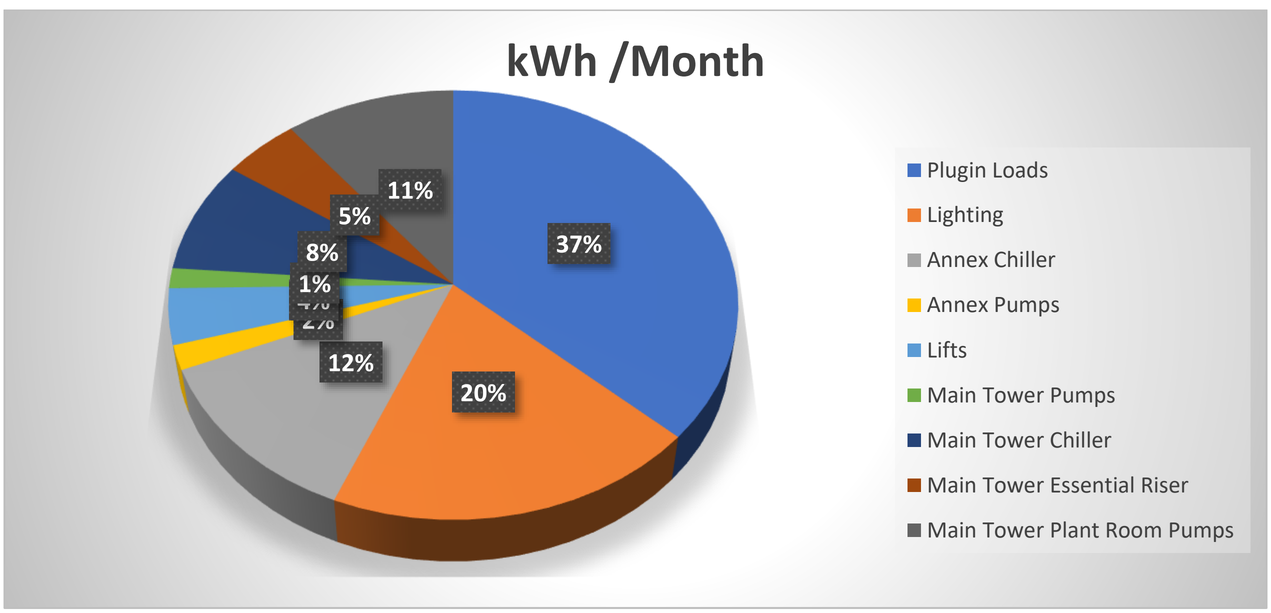


Figure 4-11: Post Retrofit Energy Mix

4.5.3 Economic Analysis

4.5.3.1 Retrofit Cost

A retrofit of the existing fluorescent tubes with LED lights would require an investment of up to 9 Million. The installation would save the facility a total of KES 5.32 Million Annually in energy cost as shown on Table 4-13.

Table 4-13: Cost of Retrofit

Cost of Retrofit					
	Item	**Cost /lamp**	**Cost/fixture**	**No. of Fixtures**	**Amount**
1	4 ft Retrofit	750	3000	477	1429698
2	2 ft Retrofit	500	2000	2266	4531440
3	VAT 16%				1157308.8
4	Installation Cost				1,808,295
	Total			**2,743**	**8,926,742**

4.5.3.2 Payback Period

The payback period is the amount of time it takes to recover an initial investment outlay. This is calculated as

$$Payback\ Period = \frac{Investement}{Savings} \qquad (4\text{-}1)$$

Therefore, the payback period=$\frac{\mathbf{9,041,475}}{\mathbf{5,327,515}}$=1.69 years.

4.5.3.3 Cumulative Cash Flow

Cumulative cash flow refers to all the cash flows into a company since the inception of a project. LED Lamps have a rated lifespan of 50,000 hours which is approximately 6 years. The lighting project would break even by Year 2 and would accumulate a total of 52 Million by Year 6 as shown on Figure 4-12.

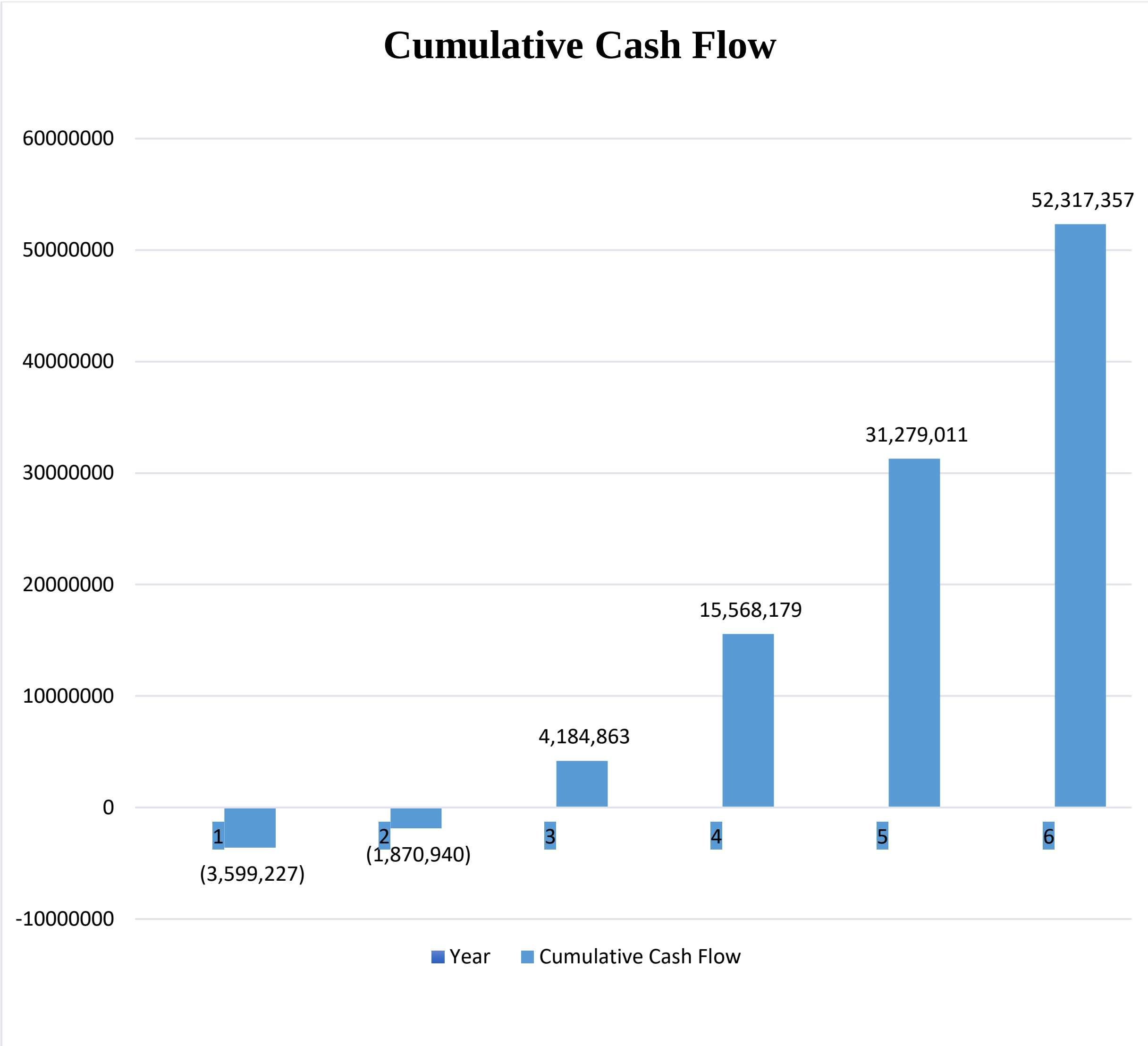


Figure 4-12: Cumulative Cash Flow

4.5.3.3.1 Net Cash Flow

Net Cash flow refers to sum of the total cash received (inflow) through savings less the total amount of money spent (outflow) through initial capital and maintenance, over a given period. The Net Cash Flow of the lighting retrofit over the useful lifetime of six years is positive and totals up to KES 21 million as illustrated in Figure 4-13. This is a good indicator that the project is worth investing in.

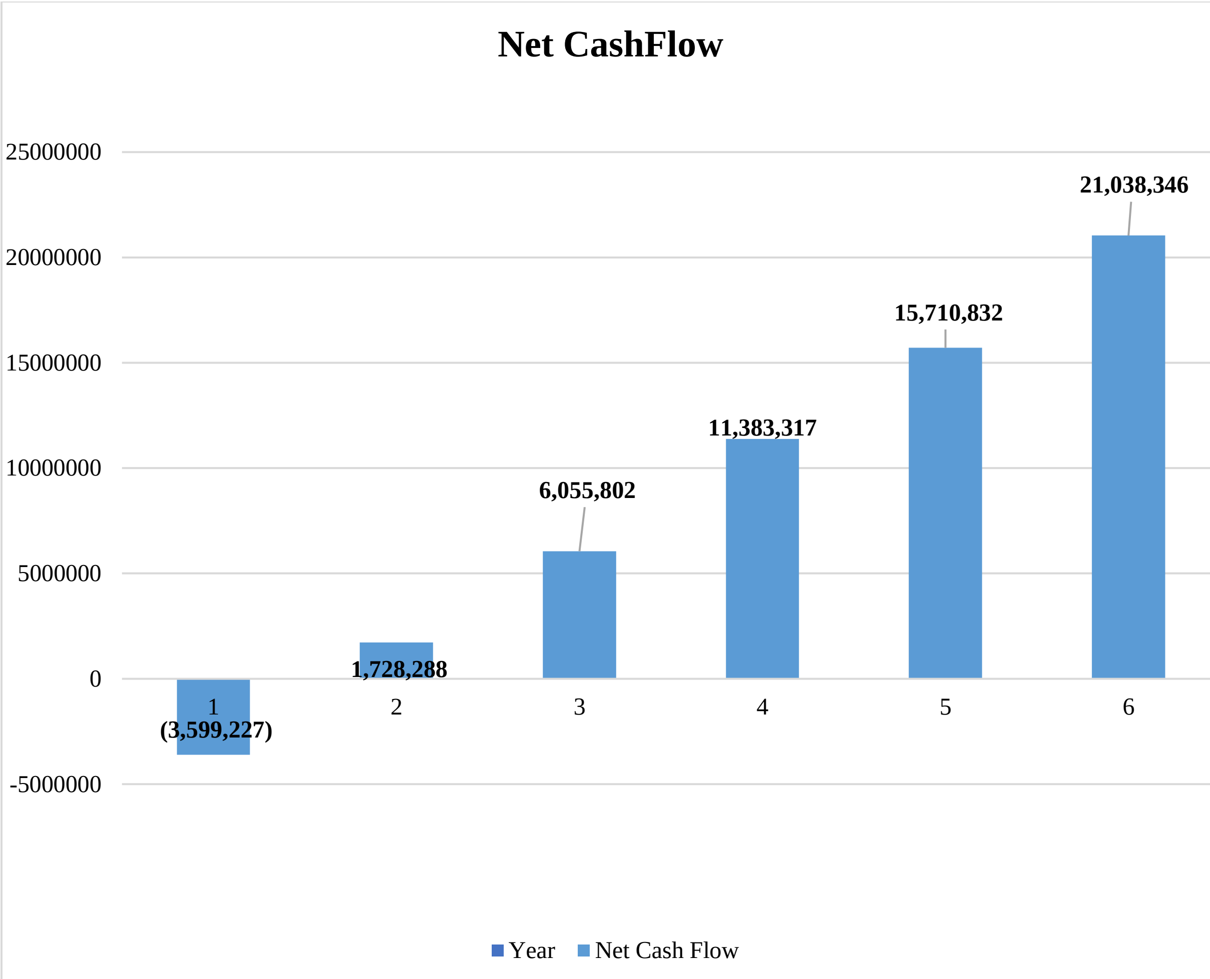


Figure 4-13: Net Cash Flow

4.5.3.4 Net Present Value

Net Present Value refers to the total discounted future cash flows [26]. It factors in the time value of money in that money today is worth more than in the future. Assuming a discount rate of 7% since lighting projects are low risk and that the lights will have a lifetime of 50,000 hours (6 years),

$$\text{Present Value(PV)} = \sum \frac{\text{CFi}}{(1 + \text{rd})^{\text{i}}} \tag{4-1}$$

Where CF_i is the Cash Flows over the time periods

$r_{d.}$= discount rate= 7%

i=Time periods=6 years

The Net Present Value of the project is 36.4 Million as shown on Table 4-14. This positive net present value is an indicator that the project is viable.

Table 4-14: Net Present Value

Discount Rate			**7%**			
Year	**Investment**	**Sum of receipts**	**Sum of expenses**	**Salvage Value**	**Net Cash Flow**	**Present Value**
1	(8,926,741)	5,327,515	0		(3,599,227)	(3,363,764)
2	0	5,327,515	0		1,728,288	1,509,553
3	0	5,327,515	1,000,000		6,055,802	4,943,338
4	0	5,327,515			11,383,317	8,684,278
5	0	5,327,515	1,000,000		15,710,832	11,201,606
6	0	5,327,515		0	21,038,346	14,018,738
Net Present Value						**36,993,750**

4.5.3.5 Internal Rate of Return

Internal Rate of return refers to the interest rate at which the present value is zero. Through iteration method, the IRR of the project would be between 133.8% to 132.9% as shown on Table 4-15.

$$\text{Present Value(PV)} = \sum \frac{CFi}{(1+rd)^i} = 0 \qquad [4\text{-}3]$$

Table 4-15: Internal Rate of Return

IRR		133.00%	132.90%
Year	**Net Cash Flow**	**Present Value**	
1	(3,599,227)	(1,544,732.67)	(1,545,395.94)
2	1,728,288	318,349.49	318,622.93
3	6,055,802	478,744.63	479,361.57
4	11,383,317	386,229.23	386,893.00
5	15,710,832	228,780.80	229,272.37
6	21,038,346	131,484.96	131,824.05
	Net Present Value	**(1,143.57)**	**577.99**

4.5.4 Chapter Conclusion

The analysis of the data shows that efficient lighting can improve the Energy Use Intensity of Co-op House by up to 20%. Retrofitting the fluorescent tubes at Co-op House is a viable project that would pay back in less than 2 years, but the savings would continue to be enjoyed over the life of the lamps.

5. CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Project Conclusion

Energy is a manageable expense and facilities are constantly looking for areas in which to save their energy consumption to save on costs and reduce on their carbon footprint. The existing lighting at Co-op House, which is made up of 2 ft and 4 ft fluorescent lamps is inefficient. These lights should be replaced with LED lamps that are more energy efficient. The lighting retrofit can improve the Energy Use Intensity of the facility by up to 20%.

The current 36 W 4 ft fluorescent lamps should be replaced with 18 W LED lamps, while the 18 W 2 ft fluorescent lamps should be replaced with 9 W lamps. There would be no need for change of the existing fixtures. A 1:1 ratio retrofit of the existing lamps with the LED alternatives would not have any negative impact on the lux levels.

Great advancements have happened in LED technology and more facilities are embracing them as the better and more economic lighting option. The capital costs as well as installation costs has dropped over the years and this has enabled facilities to get a good return on their investment. Retrofitting the fluorescent tubes at Co-op House is a viable project that would pay back in less than 2 years, but the savings would continue to be enjoyed over the life of the lamps. The project has a positive Net Present Value and should therefore be considered.

5.2 Recommendations to Co-op House

Retrofit of existing lamps with energy efficient lighting in order to achieve energy cost savings and improve the energy use intensity of the facility to be within the typical values of buildings similar to Co-op House.

The Energy Service Companies (ESCO) market in Kenya has grown over time and can be a good option for Co-op House, if the capital costs of the project are deemed high. These companies would invest their own capital into the project and Co-op House would pay from the share of the savings for an agreed period. Co-op House would own the lamps for the remaining lifetime of the lamps, once the agreed period with the Energy Service Company lapses. This would ensure that the facility benefits from the retrofit sooner, than when the capital costs are available. The facility would therefore not incur any opportunity cost caused by delay in upgrading the lamps.

Group Re-lamping of the lamps. This is a maintenance practice whereby several lamps are replaced at the same time once the lamps reach 70% of their lifetime. Currently LED lights are installed randomly and therefore the facility may not realize the energy saving accrued from use of LED in the respective areas. In addition, statistics show that group re-lamping can save costs of re-lamping by at least 50%.

A measurement and verification process using IPMVP protocols is recommended once the lighting project has been completed. This will help to verify the savings against the savings projected in this study.

5.3. Contributions to Research

Beyond the monetary savings that facilities look at when implementing energy cost saving projects**,** the project provided a benchmark that commercial buildings and office space can use when carrying out lighting retrofit projects. With such a benchmark, the facilities will be prompted to interrogate their energy consumption further and to optimize their operations further which will in turn result to more energy cost saving and overall competitiveness of buildings.

The economic analysis gives facilities considering energy efficient lighting the confidence that it is a viable investment that has good returns.

REFERENCES

[1] M. o. Energy, National Efficiency and Conservation Strategy, Nairobi, 2020.

[2] Copenhagen Centre for Energy Efficiency, "Energy Efficiency in Buildings," 2018.

[3] O. Callaghan, Energy management: A comprehensive guide to reducing costs by efficient energy use, London, UK: McGraw Hill, 1992.

[4] U. Chartered Institute of Building Services Engineers (CIBSE), Energy use in offices.

[5] F. Salata, G. I, M. Salvatore and d. L. A. Vollaro, "“Energy and reliability optimization of a system that combines daylighting and artificial sources. A case study carried out in academic buildings,," *Appl. Energ,* no. https://doi.org/10.1016/j.apenergy.2016.02.022 , pp. 169, 250–266, 2016..

[6] P. Sathya, R. Natarajan and ”. ” in, "“Energy estimation and photometric measurements of LED lighting in laboratory,," in *International Conference onAdvances in Electrical Engineering (ICAEE),* , Tamilnadu, India, 2014.

[7] B. Atanasiu, C. Despret, M. Economidou, J. Maio, I. INolte and O. Rapf, "“Europe’s Buildings under the Microscope: A Country-by-Country Review of the Energy Performance of Buildings,," 2011.

[8] I. Transport, "Energy and CO2: Moving towards Sustainability; International Energy Agency: Paris, France, 2009".

[9] *Change IPCC Climate and Others The physical science basis,* Cambridge Univ. Press, 2007.

[10] L. Halonen and T. Eino, ""Energy efficient electric lighting for buildings.," IEA International Energy Agency ECBCS Energy Conservation in Buildings and Community Systems, (2010).

[11] I. 2004b., " Energy Balances for OECD Countries and Energy Balances for non-OECD Countries;," Paris., (2004 editions).

[12] t. U. IEA, "2019 Global Status Report for Building and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector," Unite Nations Environment Programme Nairobi, 2019.

[13] R. N. Helms and M. C. Belcher, Lighting for energy-efficient luminous environments, Prentice Hall, 1991.

[14] W. J. Fisk, "Health and productivity gains from better indoor environments and the relationship with building energy efficiency," 2000.

[15] F. P. Vahl, L. M. Campos and F. N. Casarotto, "Sustainability constraints in techno-economic analysis of general lighting retrofits," *Energy and Buildings,* vol. 67, pp. 500--507, 2013.

[16] N. Chen and C. HSH, "A driving technology for retrofit LED lamp for fluorescent lighting fixtures with electronic ballasts," *IEEE Transactions on Power Electronics,* vol. 26, p. 588–601, 2011.

[17] G. Ganandran, T. Mahlia, C. O. Hwai, B. Rismanchi and W. Chong, "Cost-Benefit Analysis and Emission Reduction of Energy Efficient Lighting at the Universiti Tenaga Nasional," *The Scientific World Journal,* vol. 2014, 2014.

[18] T. Mahlia, M. Said, H. Masjuki and M. Tamjis, "Cost-benefit analysis and emission reduction of lighting retrofits in residential sector," *Energy and Buildings,* vol. 37, no. 6, pp. 573--578, 2005.

[19] W. Ryckaert, K. Smet, Roelandts, A. Inge, V. Gils, Mieke and P. Hanselaer, "Linear LED tubes versus fluorescent lamps: An evaluation," vol. 49, pp. 429--436, 2012.

[20] X. Xu, A. Collin, S. Djokic, R. Langella, A. Testa and J. Drapela, "Experimental Evaluation and Classification of LED Lamps for Typical Residential Applications,," in *IEEE PESInnovative Smart Grid Technologies Conference Europe (ISGT-Europe)*, Torino, 2017.

[21] P. Natthanon, J. Chaiyan and N. Atthapol, "Harmonics and Reduction of Energy Consumption in Lighting Systems by Using LED Lamps,," *"Energies",* vol. Vol. 11, no. No. 11, p. DOI: 10.3390/en11113169, 2018,.

[22] A. Adoghe, O. Eberechukwu and T. Sanni, "The Effect of low power factor Led Lamp Invasion on the Utility Grid: A Case Study of Nigerian Market,," in *IEEE PES PowerAfrica, 27-30 June 2017,* Accra, Ghana, 2017. DOI: 10.1109/PowerAfrica.2017.7991260..

[23] S. Bunjongjit, A. Ngaopitakkul and M. Leelajindakrairerk, "Analysis of harmonics in indoor Lighting System with LED and fluorescent luminaire," in *IEEE 3rd International Future Energy Electronics Conference and ECCE Asia, 3-7 June 2017,*, Kaohsiung, Taiwa, 2017.

[24] G. Oliveira, E. de Oliveira, A. da Silva and C. Carvalho, in *Power Quality of LED Lamps, 2016 17th International Conference on Harmonics and Quality of Power (ICHQP), 16–19 Oct. 2016,*, Belo Horizonte, Brazil, DOI: 10.1109/ICHQP.2016.7783359..

[25] Robotyka and P. Automatyk, "Energy Saving LED and CFL lamps, Rated vs True Power and current Consumption," ISSN 1427-9126, DOI: 10.14313/PAR_236/51, pp. R. 24, Nr 2/2020, 51–58.

[26] Michaelides and S. Efstathios E, Alternative energy sources, Springer Science & Business Media, 2012.

[27] L. a. M. A. Price, "Industrial Energy Efficiency and Climate Change Mitigation: Policies and Measures to Realize the Potential in the Industrial Sector,," Prepared in support of the UN, (2009).

[28] S. Galla and M. Włas, "Wpływ systemów oświetleniowych LED na zaburzenia nisko częstotliwościowe,," *Przegląd Elektrotechniczny,* Vols. Vol. 95,, no. No. 3, p. 29–32, 2019 DOI: 10.15199/48.2019.03.07.

[29] L. Halonen and T. Eino, "Energy efficient electric lighting for buildings.," IEA International Energy Agency ECBCS Energy Conservation in Buildings and Community Systems, 2010.

[30] O. Mugenda and A. Mugenda, Research methods: Quantitative and Qualitative Approaches., ACTS Press, 1999.

[31] Building Authority of Kenya, National Building Regulations, 2017.

[32] 2. IEA, "Energy Balances for OECD Countries and Energy Balances for non-OECD Countries;," Paris., 2004 editions.

Appendix 1: Permission to collect data

albert ouma
to me

Fri, Nov 27, 4:11 PM (3 days ago)

This is ok.

I will support you with the data.

On Fri, Nov 27, 2020 at 2:35 PM Nancy Mwari <mwarinancy@gmail.com> wrote:

Dear Albert,

I trust you are well,

I write to seek permission to use data from Cooperative Bank _Nairobi branches for my MSc Project.

As per our phone conversation , I am carrying out a study on the impact of energy efficient lighting on the overall energy use index of commercial buildings and I would like to use a case study of Cooperative Bank. This study will be beneficial to Cooperative Bank in that it will give you a picture of the impact of the implementation of energy cost saving measures efforts.

Please let me know if I can go ahead.

Respectfully,
Nancy Mwari

--
Albert Ouma ,CEM | Licensed Energy Auditor(Class A) |
P. O. Box 62319 - 00200 Nairobi-Kenya.
Telephone: (+254)735-735 826 639 Cell: (+254)723 778 221
Alternate oumaodiyo@gmail.com Skype: albert.odiyo

Nancy Mwari <mwarinancy@gmail.com>
to albert

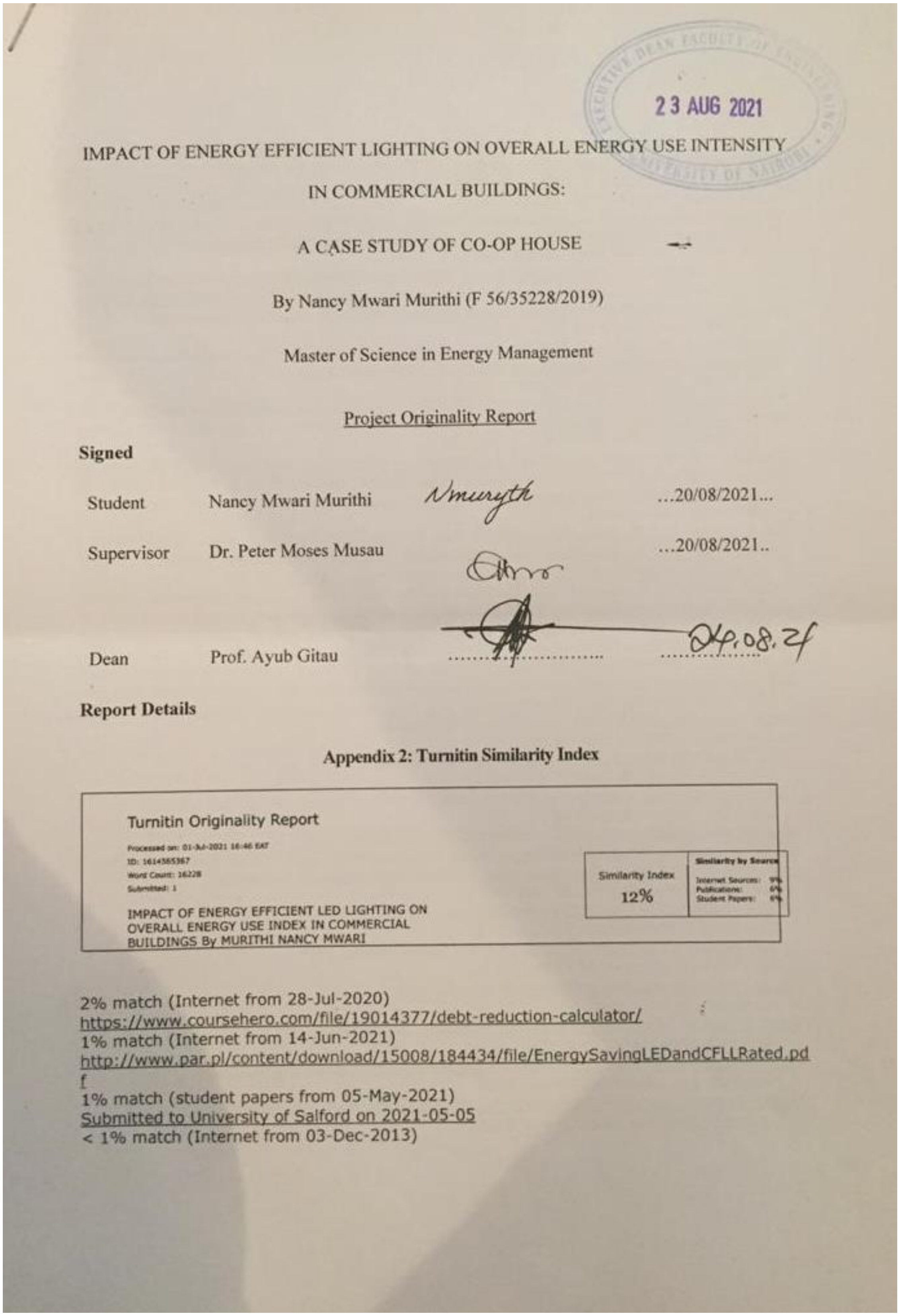
Fri, Nov 27, 4:28 PM (3 days ago)

This is well noted and appreciated.

Thank you for the go ahead.

Respectfully,
Nancy Mwari

Appendix 2: Turnitin Similarity Index



23 AUG 2021

IMPACT OF ENERGY EFFICIENT LIGHTING ON OVERALL ENERGY USE INTENSITY

IN COMMERCIAL BUILDINGS:

A CASE STUDY OF CO-OP HOUSE

By Nancy Mwari Murithi (F 56/35228/2019)

Master of Science in Energy Management

Project Originality Report

Signed

Student	Nancy Mwari Murithi	Nmuryth	…20/08/2021…
Supervisor	Dr. Peter Moses Musau		…20/08/2021..
Dean	Prof. Ayub Gitau	………………………	24.08.21

Report Details

Appendix 2: Turnitin Similarity Index

Turnitin Originality Report

Processed on: 01-Jul-2021 16:46 EAT
ID: 1614365367
Word Count: 16228
Submitted: 1

IMPACT OF ENERGY EFFICIENT LED LIGHTING ON OVERALL ENERGY USE INDEX IN COMMERCIAL BUILDINGS By MURITHI NANCY MWARI

Similarity Index	Similarity by Source
12%	Internet Sources: 9% Publications: 6% Student Papers: 6%

2% match (Internet from 28-Jul-2020)
https://www.coursehero.com/file/19014377/debt-reduction-calculator/
1% match (Internet from 14-Jun-2021)
http://www.par.pl/content/download/15008/184434/file/EnergySavingLEDandCFLLRated.pdf
1% match (student papers from 05-May-2021)
Submitted to University of Salford on 2021-05-05
< 1% match (Internet from 03-Dec-2013)

2% match (Internet from 28-Jul-2020)
https://www.coursehero.com/file/19014377/debt-reduction-calculator/
1% match (Internet from 14-Jun-2021)
http://www.par.pl/content/download/15008/184434/file/EnergySavingLEDandCFLLRated.pdf
1% match (student papers from 05-May-2021)
Submitted to University of Salford on 2021-05-05
< 1% match (Internet from 03-Dec-2013)
http://www.coursehero.com/file/3791427/ECG019EnergyUseOfficeBldgsCarbonTrust/
< 1% match (student papers from 21-Dec-2018)
Submitted to University of Salford on 2018-12-21
< 1% match (Internet from 14-Apr-2021)
http://erepository.uonbi.ac.ke/bitstream/handle/11295/90963/Simiyu_Temperature%20profiles%20in%20a%20floor%20heated%20brooderL.pdf?isAllowed=y&sequence=1
< 1% match (Internet from 14-Apr-2021)
http://erepository.uonbi.ac.ke/bitstream/handle/11295/99442/Muathe_A%20Relevance%20Theoretical%20Analysis%20of%20the%20Communicative%20Effect%20in%20Selected%20Contemporary%20Kikamba%20Gospel%20Music.pdf?isAllowed=y&sequence=1
< 1% match (Internet from 03-May-2021)
http://erepository.uonbi.ac.ke/bitstream/handle/11295/76630/Owele_Working%20capital%20management%20approaches.pdf?isAllowed=y&sequence=3
< 1% match (Internet from 03-May-2021)
http://erepository.uonbi.ac.ke/bitstream/handle/11295/6048/AGUYO%20SAMUEL%20OYIEKE%20MBA%2020110001.pdf?isAllowed=y&sequence=1
< 1% match (Internet from 04-May-2021)
http://erepository.uonbi.ac.ke/bitstream/handle/11295/95025/Kirimi_Assessment%20Of%20Energy%20Potential%20Of%20Biogas%20From%20Ongata%20Rongai%20Slaughter%20House.pdf?isAllowed=y&sequence=1
< 1% match (publications)
T.M.I. Mahlia, M.F.M. Said, H.H. Masjuki, M.R. Tamjis. "Cost-benefit analysis and emission reduction of lighting retrofits in residential sector", Energy and Buildings, 2005
< 1% match (publications)
Henrik Johanson. "Chapter 6 Selected case studies illustrating the three streams of action", Springer Science and Business Media LLC, 2009
< 1% match (Internet from 18-Nov-2020)
https://www.hindawi.com/journals/tswj/2014/745894/
< 1% match (Internet from 02-Apr-2021)
http://studentsrepo.um.edu.my/10822/1/Tan_Chin_Teng.pdf
< 1% match (Internet from 01-Apr-2021)
http://studentsrepo.um.edu.my/11891/2/Ramtin.pdf
< 1% match (Internet from 02-Apr-2021)
http://studentsrepo.um.edu.my/10045/8/gao_wei.pdf
< 1% match (Internet from 01-Apr-2021)
http://studentsrepo.um.edu.my/8534/6/fuad.pdf
< 1% match (Internet from 05-Jul-2017)
http://www.ieadsm.org/wp/files/Tasks/Task%2021%20-%20Standardisation%20of%20Energy%20Savings%20Calculations/presentations%20and%20other%20documents/REE%20task%20XXI%20benchmarking.v_final.pdf
< 1% match (Internet from 20-Dec-2020)
https://energywatch-inc.com/ipmvp-options/

< 1% match (Internet from 16-Apr-2018)
http://psasir.upm.edu.my/50412/1/FK%202014%2092RR.pdf
< 1% match (Internet from 22-Mar-2021)
https://www.electrical4u.com/laws-of-illumination/
< 1% match (publications)
Pieter de Wilde. "Building Performance Analysis", Wiley, 2018
< 1% match (Internet from 11-May-2020)
http://docplayer.net/48483563-Texas-loanstar-revolving-loan-program.html
< 1% match (Internet from 29-Jul-2020)
http://docplayer.net/18539432-Fnce-301-financial-management-h-guy-williams-2006.html
< 1% match (Internet from 08-Jun-2021)
https://ir-library.ku.ac.ke/bitstream/handle/123456789/19767/Electronic%20Banking%20and%20Financial%20Performance................pdf?isAllowed=y&sequence=1
< 1% match (Internet from 20-Jun-2021)
https://ir-library.ku.ac.ke/bitstream/handle/123456789/7250/Kiplagat%20Micah%20Kipronoh.pdf;sequence=1
< 1% match (student papers from 21-Jan-2020)
Submitted to Milton Keynes College on 2020-01-21
< 1% match (student papers from 19-Apr-2015)
Submitted to Blinn College on 2015-04-19
< 1% match (publications)
Juliana E. Gonçalves, Twan van Hooff, Dirk Saelens. "Understanding the behaviour of naturally-ventilated BIPV modules: A sensitivity analysis", Renewable Energy, 2020
< 1% match (publications)
Eschenbach, Ted. "Economic Analysis of Industrial Projects", Oxford University Press
< 1% match (student papers from 19-Feb-2018)
Submitted to Kentucky Wesleyan College on 2018-02-19
< 1% match ()
Thereesha, Fathimath. "Students' Perceptions of the Secondary Numeracy Project", The University of Waikato, 2007
< 1% match ()
Holsen, Thomas Moltubakk. "What purpose has new investment models for the gas infrastructure for realization of new gas resources on the NCS?", University of Stavanger, Norway, 2014
< 1% match (student papers from 03-Nov-2014)
Submitted to University of Newcastle on 2014-11-03
< 1% match (Internet from 03-Apr-2021)
http://erepository.uonbi.ac.ke:8080/bitstream/handle/11295/153153/Wanjiru_Long%20term%20Evolution%20anomaly%20detection%20and%20root%20cause%20analysis%20for%20data%20throughput%20optimization.pdf?isAllowed=y&sequence=1

Appendix 3: Lumen Method

Project Information: Lumen Method using LED Tubes

Project Name:	Co-op House 2nd Floor	Type of Activity:	Office Work
Target Illumination Value:	500 lux		
Fixture Type:	G13 bases	# Lamps/Fixture:	4
Lamp Type:	36 W fluorescent tubes	Initial Lamp Lumens:	2000

Room Data

Ceiling Reflectance (*P*cc):	80	Length	*	Width	=	Area	
Wall Reflectance(*P*wc):	50						
Floor Reflectance(*P*fc):	20	4	*	3	=	12	m^2

Room Cavity Ratio (RCR)

Ceiling Height	-	Work surface	=	Cavity Height
2.5	-	0.8	=	1.7

$$\frac{5 * \text{Cavity Height} * (\text{Length} + \text{Width})}{\text{Area}} = \text{RCR}$$

5 * 1.7 * (4 + 3) = 4.96

With RCR, Calculate the Coefficient of Utilization (CU)

Low RCR:	2	CU1:	0.61
Actual RCR:	4.96	Actual CU:	0.4917
High RCR:	3	CU2:	0.57

2

CU1 - CU2 = Y

0.61 - 0.57 = 0.04

1

$$\frac{\text{Actual RCR - Low RCR}}{\text{High RCR - Low RCR}} = X = 2.96$$

3

CU1 - (X * Y) = Actual CU

0.61 - (2.9583 * 0.04) = 0.4917

Light Loss Factors (LLF)

Luminaire Ambient Temp:	1	Luminaire Dirt Depreciation:	0.78
Voltage Variation:	1	Room Surface Depreciation:	0.97
Luminaire Surface Depreciation:	1	Lamp Lumen Depreciation:	0.85
Ballast Factor:	1	Lamp Burn Out:	0.98

Total LLF

1 * 1 * 1 * 1 * 0.78 * 0.97 * 0.85 * 0.98 = 0.63

Calculations

$$\#\text{ of Fixtures Required} = \frac{\text{Target Average Illuminance Level} * \text{Area}}{\#\text{ of Lamps / Fixture} * \text{Lamp Lumens} * \text{CU} * \text{LLF}} = 2.42 = 2$$

$$\text{Illumination due to specific \# of fixtures} = \frac{\#\text{ of fixtures} * \#\text{ of lamps per fixture} * \text{Lamp Lumens} * \text{CU} * \text{LLF}}{\text{Area}} = 500 \text{ lux}$$

Appendix 4: Lighting Inventory

Lighting Fixtures Inventory at Co-op House								
Basement	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time in Hours	kWh/Day	kWh/ day if all fixtures working
	Basement 2	Fluorescent 4 ft	28	27	72	24	46.66	48.38
	Basement 2	Fluorescent 4 ft	74	72	72	24	124.42	127.87
	Basement 2	Fluorescent 4 ft	52	52	144	24	179.71	179.71
	Basement 1	Fluorescent 4 ft	70	62	72	24	107.14	120.96
	Basement 1	Fluorescent 4 ft	29	26	72	24	44.93	50.11
	Total		253	239			502.85	527.04
M2	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	kWh/ day if all fixtures working
	Office	Fluorescent 4 ft	15	15	72	12	12.96	12.96
	Office	LED	74	74	36	12	31.97	31.97
	Office	LED	34	34	38	12	15.5	15.5
	Server room	Fluorescent 4 ft	7	6	144	4	3.46	4.03
	Toilet	Fluorescent 2 ft	8	8	38	12	3.65	3.65
	Lobby	Fluorescent 4 ft	12	12	72	12	10.37	10.37
	Total		135	134			77.9	78.48
M 1	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	kWh/ day if all fixtures working
	Offices	Fluorescent 2 ft	82	40	144	4	23.04	47.23
	Offices	LED	16	16	38	4	2.43	2.43
	Tea room and	Fluorescent 2 ft	1	1	38	2	0.08	0.08
	stairway	fluorescent 4 ft	3	3	72	12	2.59	2.59

	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Offices	Fluorescent 2 ft	4	4	144	4	2.3	2.3
	corridor	Fluorescent 2 ft	2	2	144	12	3.46	3.46
	Corridor	Fluorescent 4 ft	1	1	72	12	0.86	0.86
	Washrooms	Fluorescent 2 ft	5	5	38	12	2.28	2.28
	Offices	LED	8	8	38	8	2.43	2.43
	Offices	LED	30	30	18	8	4.32	4.32
	Offices	Fluorescent 2 ft	44	44	38	8	13.38	13.38
	Office	LED	37	34	38	8	10.34	11.25
	Kitchen	Fluorescent 2 ft	1	1	38	2	0.08	0.08
	Office	LED	32	32	38	8	9.73	9.73
	Lobby	Fluorescent 2 ft	21	21	144	12	36.29	36.29
	Total		293	248			116.34	141.44
2nd floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	kWh/ day if all fixtures working
	Office	Fluorescent 2 ft	36	17	144	4	9.79	20.74
	Legal office	Fluorescent 2 ft	19	11	144	4	6.34	10.94
	Tea room and	Fluorescent 2 ft	1	1	38	2	0.08	0.08
	stairway	fluorescent 4 ft	3	3	72	12	2.59	2.59
	Corridors	Fluorescent 4 ft	32	31	72	12	26.78	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Total		97	69			48.32	64.73
3rd floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	kWh/ day if all fixtures working
	Offices	Fluorescent 2 ft	50	36	144	4	20.74	28.8
	Offices	Fluorescent 2 ft	24	18	144	4	10.37	13.82
	Offices	Fluorescent 2 ft	7	6	144	10	8.64	10.08

	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Offices	bulb	10	10	18	4	0.72	0.72
	Corridor	Fluorescent 4 ft	32	26	72	12	22.46	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Offices	Fluorescent 4 ft	2	2	72	4	0.58	0.58
	Total		135	108			68.91	87.05
4th floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	kWh/ day if all fixtures working
	Office	LED	2	2	18	8	0.29	0.29
	Office	Fluorescent 2 ft	101	36	144	8	41.47	116.35
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		Fluorescent 4 ft	3	3	72	12	2.59	2.59
	Corridor	Fluorescent 2 ft	6	6	38	10	2.28	2.28
	Corridors	Fluorescent 4 ft	32	32	72	12	27.65	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Total		151	86			77.09	151.97
5th floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Corridors	Fluorescent 4 ft	32	32	72	12	27.65	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Offices	Fluorescent 2 ft	108	45	144	8	51.84	124.42
	Total		150	87			84.89	157.47

	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
6th floor	Offices	Fluorescent 2 ft	19	5	144	10	7.2	27.36
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Offices	Fluorescent 2 ft	44	44	72	12	38.02	38.02
	Corridors	Fluorescent 4 ft	32	32	72	12	27.65	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Offices	Fluorescent 2 ft	25	7	144	4	4.03	14.4
	Total		130	98			82.3	112.83
7th floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Offices	LED	30	30	38	3	3.42	3.42
	Toilets	LED	6	6	18	12	1.3	1.3
	Offices	LED	15	15	38	4	2.28	2.28
	Corridor	LED	14	13	18	12	2.81	3.02
	Total		69	68			12.47	12.69
8th floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Corridor	LED	14	14	18	12	3.02	3.02
	Offices	LED	22	22	38	1	0.84	0.84
	Offices	LED	26	26	38	3	2.96	2.96
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59

	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Total		72	72			12.23	12.23
9th floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Corridors	Fluorescent 4 ft	32	32	72	12	27.65	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Offices	Fluorescent 2 ft	6	5	144	2	1.44	1.73
	Offices	Fluorescent 2 ft	26	23	144	2	6.62	7.49
	Offices	Fluorescent 2 ft	12	12	144	2	3.46	3.46
	Total		86	82			44.57	45.72
10th floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Corridors	Fluorescent 4 ft	32	32	72	12	27.65	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Offices	Fluorescent 2 ft	44	39	144	2	11.23	12.67
	Offices	Fluorescent 2 ft	2	2	38	2	0.15	0.15
	Total		88	83			44.44	45.88
11th floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Corridors	Fluorescent 4 ft	32	32	72	12	27.65	27.65

	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Offices	Fluorescent 2 ft	48	40	144	6	34.56	41.47
	Total		90	82			67.61	74.52
12th floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Corridors	Fluorescent 4 ft	32	32	72	12	27.65	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Offices	fluorescent	64	32	144	3	13.82	27.65
	total		106	74			46.88	60.7
13th floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Corridors	Fluorescent 4 ft	32	32	72	12	27.65	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Offices	Fluorescent 2 ft	50	43	144	4	24.77	28.8
	Total		92	85			57.82	61.85
14th floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Corridors	Fluorescent 4 ft	32	32	72	12	27.65	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Offices	Fluorescent 2 ft	40	10	144	2	2.88	11.52

	Total		82	52			35.93	44.57
15th floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Corridors	Fluorescent 4 ft	32	32	72	12	27.65	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Offices	Fluorescent 2 ft	56	52	144	4	29.95	32.26
	Total		98	94			63	65.31
16th floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Offices	Fluorescent 2 ft	45	40	144	4	23.04	25.92
	corridor	LED	2	2	18	12	0.43	0.43
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Corridors	Fluorescent 4 ft	32	31	72	12	26.78	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Total		89	83			55.66	59.4
17th Floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Offices	Fluorescent	47	40	144	4	23.04	27.07
	Corridors	Fluorescent 4 ft	32	32	72	12	27.65	27.65
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Total		89	82			56.09	60.12

	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
18th floor	Offices	LED	61	61	18	4	4.39	4.39
	Offices	LED	2	2	38	10	0.76	0.76
	Offices	Fluorescent	1	1	28	8	0.22	0.22
	Offices	Fluorescent 2 ft	41	40	144	4	23.04	23.62
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Corridors	Fluorescent 4 ft	32	32	72	12	27.65	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Total		147	146			61.47	62.04
19th floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Corridors	fluorescent 4 ft	32	32	72	12	27.65	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Offices	Fluorescent 2 ft	31	24	144	3	10.37	13.39
	Offices	Fluorescent 4 ft	3	3	72	3	0.65	0.65
	Total		76	69			44.07	47.09
20th floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Offices	Fluorescent 2 ft	76	55	144	4	31.68	43.78
	Corridors	Fluorescent 4 ft	32	32	72	12	27.65	27.65
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	2	0.43	0.43

	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Total		118	97			62.57	74.67
21st floor	Section	Type of Fixture	No. of Fixtures	Total Number of Working Fixtures	Rating Per Fixture in Watts	Time Duration in Hours	kWh/Day	
	Tea room and stairway	Fluorescent 2 ft	1	1	38	2	0.08	0.08
		fluorescent 4 ft	3	3	72	12	2.59	2.59
	Corridors	Fluorescent 4 ft	32	32	72	12	27.65	27.65
	Washrooms	Fluorescent 2 ft	6	6	38	12	2.74	2.74
	Offices	Fluorescent 2 ft	45	40	144	4	23.04	25.92
	Total		87	82			56.09	58.97

Appendix 5: Response to Comments Raised During Final Project Presentation

#	Comment	Response	Page Number
1	Include an explanation on the use of 2020 as the baseline	Despite the 2020 consumption being low due to reduced activity in the facility, occasioned by the COVID 19 pandemic, 2020 was used as the baseline year for the analysis because the facility indicated no plans of resuming physical access for services that have moved online. Therefore, the consumption will likely remain at 2020 level	Pg. 28
2	Verify that the KPLC bills are not estimated	Verified that the facility is on CI 2 tariff and has a smart meter, hence the bills are actual, rather than estimated.	Pg. 28
3	Include maintenance expenses in computation of Net Present Value	Expenses included.	Pg. 49
4	Recommendations should be academic	Contribution to Research included.	Pg. 53

Appendix 5: IEEE Paper Submission

Impact Of Energy Efficient LED Lighting On Overall Energy Use Intensity In Commercial Buildings: A Case Study Of Co-op House

mwarinancy@gmail.com pemosmusa@uonbi.ac.ke

Nancy Mwari Murithi
Mechanical and Manufacturing Engineering Department
University of Nairobi
Nairobi, Kenya

Peter Musau Moses
Electrical & Information Engineering Department
University of Nairobi
Nairobi, Kenya

Abraham Nyete
Electrical &Information Engineering Department
University of Nairobi
Nairobi Kenya
anyete@uonbi.ac.ke

Abstract: Energy efficiency is key for organizations that are keen on managing their energy costs. Lighting is one of the low hanging fruits, that buildings can implement to achieve savings. This study sought to quantify the savings potential through efficient lighting in Co-operative House, a commercial building in Nairobi. A literature review was done to understand the research gaps that exist. Data was collected by administration of a structured questionnaire that required the energy manager to fill in the electricity billing parameters. An inventory of the existing lighting was taken, detailing the type of fixtures type of lamps, energy consumption per fixture as well as hours of use. The data was tabulated and analyzed through Excel sheet. The analysis showed that replacement of all fluorescent lights with LED equivalent would contribute to 18.3 % improvement of the Energy Use Intensity.

Keywords: Energy Efficiency, Energy consumption, Lighting, Savings

1 INTRODUCTION

The concept of green buildings is slowly gaining popularity around the globe. A green building is one that reduces negative environmental impacts in its design, construction, and operation. A key feature of green buildings is efficient use of energy, water as well as other resources.

The Kenya National Energy Efficiency and Conservation Strategy (KNEECS) 2020 identifies five strategic sectors of focus, key among them, buildings. KNEECS targets to improve the lighting load in public buildings by 50% by the year 2025. This is to be achieved through retrofitting of lighting with more efficient alternatives and use of passive energy such as natural light [1]

Globally, in 2018, the buildings and construction sector accounted for 36% of total energy use and 39% of energy and process related CO_2 emissions [1]

Lighting forms a key component of energy consuming loads in a building. Therefore, the implementation of efficient lighting can translate into substantial savings in energy costs. Lighting Energy Conservation Measures (LECMs) aim to reduce lighting demand and/or energy use by:

i) Retrofitting existing old technology lamps with more efficient lamps.
ii) De-lamping (removal of unnecessary light fixtures and/or lamps).
iii) Lighting controls such as sensors, dimmers, and timers.

Cooperative Bank is a money lending institution in Kenya, established in 1965 when it began operations as a cooperative society. It was licensed in 1968 and so far, has grown into 156 branches countrywide. Co-operative House (Co-op House) is one among four premises that offer support services for Cooperative Bank. The building has twenty-two floors.

Efficient lighting is one of the most popularly recommended energy costs saving measures for buildings. This is key in managing costs, but facilities sometimes do not implement the measures due to ignorance and skepticism of the savings potential. Banks are often viewed as money-lending institutions rather than as commercial buildings with the potential to save on energy. Therefore, their huge energy-saving potential can be easily downplayed leading to high energy inefficiency levels in the buildings.

Co-op House has fluorescent lamps that are more energy consuming compared to LEDs. Energy Use Intensity is not commonly calculated hence benchmarking buildings against similar buildings is not possible. This can lead to an assumption that the current energy consumption is optimal.

In 2020, The overall Energy Use Index averaged at 296 kilowatt-hours per square meter per year against the recommended benchmark of 226. Lighting had an Energy Use Intensity of 124 kilowatt-hours per square meter per year, against the recommended value of 54.

2 LITERATURE REVIEW ON LED LIGHTING

Vahl et al [2] analyzed the long-term sustainability of retrofit of inefficient light bulbs with more efficient ones such as CFLs and LEDs. They realized that CFLs have the highest costs annually and the highest toxic waste. On the other hand, FL tubes turned out to be more economical, However, as the prices of LEDs reduced, they noted that, eventually, LEDs would be the most economical and sustainable option.

Chen and Chung [4] undertook a study in China, in which they retrofitted LEDs with T8 fluorescent tubes. They realized that by replacing the existing 36 W T8 fluorescent lamps with 20 W LED lamps, a total of, around $288 saving would be saved within 5 years. The study also did not analyze in-depth the impact of LED lighting on energy use intensity. The energy-saving per bulb was assumed to be:

$$ES\ per\ bulb = 36W - 20W \quad (1)$$

Ganandran [3] in their analysis of the saving potential of buildings in Universiti Tenaga Nasional in Malaysia. A lighting inventory was done which revealed there were a total of 62,684. The lamps were broken down as:

i) 8751 fluorescents 4 ft tube each 36 Watts.
ii) 12674 fluorescent, 2 ft tube, each 18 Watts.
iii) 12719 PL-C 2 pin bulbs each 13 Watts.
iv) 109 Philips CFL bulb each 14 Watts.

The study estimated that a full retrofit of the lamps would save about1,463,450.56 kWh of energy which translated to RM (Malaysia) 517,622 annually, which is about USD 118,181. The total daily energy consumption (EC) was computed simply as the multiplication of the number of lamps (N) by the lamp power consumption (W), by total operation hours (OH) i.e.

$$EC = (N \times W \times OH)1000 \quad (2)$$

The Energy Saving (ES) was then calculated by subtracting the energy consumption of the current system (EC Current) from the retrofit lighting (EC Retrofitting) system:

$$ES = EC\ Current - EC\ Retrofitting \quad (3)$$

The study also does not consider the effect of LED lighting on the power factor which could reduce the cost-saving potential if the facility is surcharged for poor power factor. The energy use intensity is also not mentioned in the study.

Ryckaert et al [4] researched the pros and cons of retrofitting LED tubes with T8 FL lamps. Upon analyzing 12 LED tubes, the results demonstrated that a one-to-one lamp replacement can result in inadequate illumination of a surface. This underscored the need for careful analysis in LED retrofit projects to ensure occupant comfort is not compromised.

Whereas the use of LED lighting has gained traction, Xu X et al [5] note that the wide use of LED lamps causes various problems that arise in power grids resulting from the non-sinusoidal waveform of the current consumed by such lamps. Despite the small power and current consumed by a single lamp, problems arise from many such lamps in the same grid and their synchronous operation forced by voltage waveform in the power grid. These issues are discussed in [6] [7] [8]

Oliveira [9] also studied LED and Compact Fluorescent Lamps in terms of the resulting impact on the electricity transmission grid (measurements of power factor and current harmonic distortions) which confirmed that LEDs have unfavorable energy properties such as harmonic distortion factor of current waveform often greater than 100% and low power factor between 0.4 and 0.95 depending on the power supply type.

Robotyka et al [10] further notes that on the consumer market there are a lot of energy-saving LED bulbs available from various manufacturers. Manufacturers persuade consumers by presenting data on the packaging as catchy phrases that are not informative on the properties of the lamps. (e.g., "4 W = 60 W"), the only data given is often the current, power and the rated voltage. The study further measured the energy parameters of several, arbitrarily selected LED lamps and two compact fluorescent lamps (CFL) available in popular commercial networks and compared the obtained measurement data with the parameters declared by the manufacturers. The power factor of the lamps was found to be low and ranging from 0.5 to 0.65. This suggests that LED lighting could reduce the overall power factor of a building.

3 METHODOLOGY

Data was collected through primary data collection methods whereby a structured data sheet was given to the energy manager of Co-op House. The questions targeted data on kWh energy consumption, demand in kW, and power factor for Year 2019 and 2020. An inventory of the current lighting was done.

The data on high rate, low rate, bill in Kenya Shillings, demand in kW, kVA and power factor was tabulated into Excel Sheets. A post retrofit scenario was projected by calculation of energy consumption, kW demand and lux levels.

The savings from LED lighting retrofit were calculated by subtracting the New Wattage from the Existing Wattage, then multiplied by the number of hours of use of the lamps [3]

The Energy Use Intensity of the building was calculated as:

$$Energy\ Use\ Intensity = \frac{Energy\ Consumption}{Area\ in\ M2} \quad (4)$$

4 RESULTS AND ANALYSIS

4.1 Energy Consumption

Co-op House consumes on average 128,000 kWh units in a month as shown in Table I. The facility is billed on Commercial Industrial tariff. The 2020 data showed that most of the energy (69%) is consumed during the day, while the remaining 31% is spent at night. The electricity bill is USD 21,818. The blended unit cost per kWh is USD 0.17. The kW averages at 464 while the kVA demand averages at 504 translating to a power factor of 0.92.

TABLE I. ENERGY CONSUMPTION

Date	High Rate	Low rate	Total kWh	USD	kVA	kW	Power Factor
Jan	102,252	42,076	144,328	24,578	540	493	0.91
Feb	92,522	37,846	130,368	22,600	565	513	0.91
Mar	112,970	41,336	154,306	25,402	533	486	0.91
Apr	77,652	41,778	119,430	20,577	502	461	0.92
May	83,624	39,738	123,362	21,031	523	479	0.92
Jun	76,222	36,526	112,748	19,567	504	463	0.92
Jul	88,702	42,436	131,138	22,357	487	447	0.92
Aug	80,898	37,626	118,524	20,548	480	440	0.92
Sep	85,638	42,806	128,444	22,235	482	442	0.92
Oct	83,038	36,286	119,324	21,608	480	439	0.91
Nov	87,324	39,568	126,892	21,944	448	444	0.99
Average	88,258	39,820	128,079	22,041	504	464	0.92

4.2 Impact on Energy Use Index

Lighting Retrofit has been carried out for only floor seven and eight. These were installed to replace inefficient lamps that had burnt out.

The current lights at the facility are 4 feet T8 fluorescent tubes which consume 36 Watts each and these can be replaced with LED tube lights of 18 Watts each. There are also 2 feet T8 fluorescent tube lights of 18 Watts; these can be replaced with LED tube lights of 9 Watts. There would be no need to change the current fixtures during the retrofit.

A comparison of the current lighting and a post retrofit scenario was done using the lumen method for sampled rooms in Co-op House This revealed that a 1:1 fluorescent: LED replacement would have no effect on the lux level of the facility. This is because the lumen LED lamps do not have a ballast.

Replacing the current fluorescent lights with LED equivalent would save energy costs the facility. One to One Ratio replacement of both working and faulty lamps with LED lighting would translate to 38% of the facility's energy consumption by lighting. However, retrofitting only, the working lamps would translate into 45% savings on the lighting energy consumption. This would require baseline adjustments to be made when computing for the actual savings

Retrofitting all the existing fluorescent lamps with their LED equivalent would translate to 18.3 % of the overall monthly energy use intensity as shown on Table II.

TABLE II. ENERGY USE INDEX IMPROVEMENT

Daily Saving in kilowatt-hours	780.70
Monthly Saving in kilowatt-hours	23,421
Reduced Monthly EUI	4.52
Overall Monthly EUI before retrofit	24.72
Overall Monthly EUI post retrofit	20.20
% Improvement	18.3%

Lighting benchmarks estimate the Energy Use Index for lighting at 54 kilowatt-hours per square meter per year [11]. Currently the lighting Energy Use Index for Co-op House is at 124 kilowatt-hours per square meter per year. With lighting retrofit, the Energy Use Index would translate to 64 kilowatt-hours per square meter per year, which would be closer to the recommended value of 54 kilowatt-hours per square meter per year.

4.3 Energy and Cost Saving

The facility would save 781 kilowatt-hours daily, 23,421 kilowatt-hours monthly and 281,052 kilowatt-hours annually. At the current cost per kilowatt-hour, the monetary savings would be USD 48,432 Annually.

TABLE III. ENERGY COST SAVINGS

	Existing	Post Retrofit	Projected Saving	Unit
Current Daily Consumption	1,748	967	781	kWh
Monthly Consumption (30 days)	52,426	29,005	23,421	kWh
Annual Consumption in kWh	629,112	348,060	281,052	kWh
Cost per kWh in USD		0.17		USD
Saving in USD			**48,432**	USD

The EUI results were benchmarked against other standards and found to be close to other typical EUI of offices as shown in Table IV. The energy potential energy savings results were also benchmarked against other commercial buildings carried out in Egypt as shown on Table V.

TABLE IV. COMPARISON AGAINST BENCHMARKS OF ENERGY USE INTENSITY

Author	**Project**	**Location**	**Lighting Benchmark**	**Overall Energy Use Index**	**Units**
CISBSE [11]	Benchmarking Standards	UK	54	226	kWh/m^2/Year
Sans 204 [12]	Benchmarking Standards	South Africa	42.5	185-210	kWh/m^2/Year
Nancy Mwari	A Case Study of Co-op House	Kenya	67	242	kWh/m^2/Year

TABLE V. COMPARISON WITH OTHER LIGHTING RETROFIT SAVINGS

Authors	**Project**	**Location**	**Building type**	**No. of LED Lamps**	**Annual Saving (kWh)**	**Lighting energy saving (%)**	**Payback period (year)**
Ayman et al [13]	Improving Energy Efficiency of Lighting & Building Appliances Project	Egypt	Public Building	3,600	231,922	77%	3.4
			Public Building	2,295	128,824	66%	3
			Bank	1,601	312,136	77%	1.1
Nancy Mwari	A Case Study of Co-op House	Kenya	Bank	2,743	281,052	50%	1.9

4.4 Cost of Retrofit

Retrofitting all the lamps at once would cost the facility a total of USD 82,195 as shown on Table VI.

TABLE VI. RETROFIT COST

	Item	**Amount in USD**
1	4 ft Retrofit	15,771
2	2 ft Retrofit	49,985
3	Installation Cost	16,439
	Total	82,195

4.5 Payback Economics

Fig. 1 shows that the project would pay back in 1.7 years and there would be positive cash flow by Year 3.

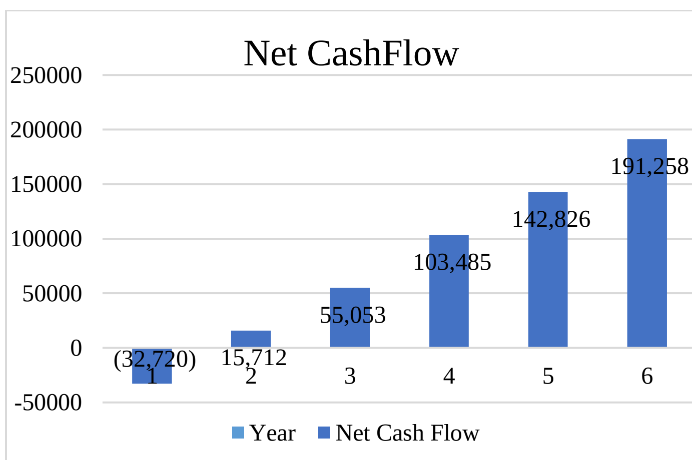


Fig 1. Net Cash Flow

5 CONCLUSION

Lighting accounts for 30 % of the total energy consumption and retrofitting the lights with more efficient options can contribute to improvement of the overall energy use intensity of the building by up to 18%.

Group Re-lamping of the lamps. This is a maintenance practice whereby several lamps are replaced at the same time once the lamps reach 60-80% of their rated lamp life [14]. Currently LED lights are installed randomly and therefore the facility may not realize the energy saving accrued from use of LED in the respective areas. Group re-lamping reduces the cost of maintenance and ensures uniformity hence the lighting quality is maintained [15].

Beyond the monetary savings that facilities look at when implementing energy cost saving projects**,** the project provided a benchmark that commercial buildings and office space can use when carrying out lighting retrofit projects. With such a benchmark, the facilities will be prompted to interrogate their energy consumption further and to optimize their operations further which will in turn result to more energy cost saving and overall competitiveness of buildings

6 REFERENCES

[1] M. o. Energy, National Efficiency and Conservation Strategy, Nairobi, 2020.

[2] F. Vahl, L. Campos and F. Casarotto, "Sustainability constraints in techno-economic analysis of general lighting retrofits,," *Energy and Buildings,* vol. 67, pp. 500-507, 2013.

[3] G. Ganandran, T. Mahlia, C. O. Hwai, B. Rismanchi and W. Chong, "Cost-Benefit Analysis and Emission Reduction of Energy Efficient Lighting at the Universiti Tenaga Nasional," *The Scientific World Journal,* 2014.

[4] W. Ryckaert, K. Smet, A. Roelandts, V. Inge, G. Mieke and P. Hanselaer, "Linear LED tubes versus fluorescent lamps: An evaluation," vol. 49, pp. 429-436, 2012.

[5] X. Xu, A. Collin, S. Djokic, L. R, A. Testa and J. Drapela, "Experimental Evaluation and Classification of LED Lamps for Typical Residential Applications," in *IEEE PESInnovative Smart Grid Technologies Conference Europe (ISGT-Europe),* Torino.

[6] A. Adoghe, O. Eberechukwu and T. Sanni, "The Effect of low power factor Led Lamp Invasion on the Utility Grid: A Case Study of Nigerian Market in IEEE PES PowerAfrica, 27-30 June 2017, Accra, Ghana, 2017. DOI: 10.1109/PowerAfrica.2017.7991260," 2018.

[7] S. Bunjongjit, A. Ngaopitakkul and M. Leelajindakrairerk, "Analysis of harmonics in indoor Lighting System with LED and fluorescent luminaire," in *IEEE 3rd International Future Energy Electronics Conference in and ECCE Asia,* Kaohsiung, Ta, 3-7 June 2017.

[8] P. Natthanon, J. Chaiyan and N. Atthapol, "Harmonics and Reduction of Energy Consumption in Lighting Systems by Using LED Lamps," *Energies,* vol. 11, p. DOI: 10.3390/en11113169, 2018.

[9] G. Oliveira, E. Oliveira, A. Da Silva and C. Carvalho, "17th International Conference on Harmonics and Quality of Power (ICHQP, in Power Quality of LED Lamps," Belo Horizonte, Brazil, 16–19 Oct. 2016.

[10] Robotyka and P. Automatyk, Energy Saving LED and CFL lamps, Rated vs True Power and current Consumption, ISSN 1427-9126, DOI: 10.14313/PAR_236/51, pp. R. 24, Nr 2/2020, 51–58.

[11] U. Chartered Institute of Building Services Engineers (CIBSE), Energy use in offices.

[12] L. Reynolds, *South African energy efficiency standards for buildings,* 2007.

[13] A. El-khalek and K. a. Y. I. Ayman and Youssef, "Opportunities of energy saving in lighting systems for public building," *Renewable Energy and Sustainable Development,* vol. 3, no. 1, pp. 95--98, 2017.

[14] E. Star, "Lighting," in *Energy Star Building Manual*, 2006, p. 34.

[15] L. B. N. Laboratory, Lighting Retrofit Workbook : A PRACTICAL"HOW TO" GUIDE FOR THE NATIONAL PARK SERVICE VISITOR CENTERS, 2000.