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DEPARTMENT OF MECHANICAL AND MANUFACTURING ENGINEERING

ANALYSIS OF ELECTRICAL ENERGY UTILIZATION AND MANAGEMENT IN DATA CENTRES: CASE STUDY OF WANANCHI GROUP (K) LIMITED DATA CENTRE

By

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Project report submitted in partial fulfillment for the Degree of Master of Science in Energy Management in the Department of Mechanical and Manufacturing Engineering at the University of Nairobi

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DECLARATION OF ORIGINALITY FORM

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CASE STUDY OF WANANCHI GROUP (K) LIMITED DATA CENTRE

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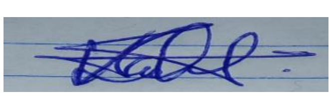
Signature:  Date: 10/06/2022

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This Project Report is submitted with our approval as University Supervisors:

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DEDICATION

I dedicate this research project to my two daughters; Patience Mutanu Katuta and Favor Hannah Katuta as a way of encouraging them to pursue Science, Technology, Engineering and Mathematics (STEM) careers.

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ABSTRACT

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Research Topic: Analysis of Electrical Energy Utilization and Management in Data Centres: Case Study of Wananchi Group (K) Limited Data Centre.

As our current society and economy continues to shift towards digital transformation, there is an increased demand for internet services, storage of data and network communication and hence increased size and number of data centres across the globe. The amount of electrical energy consumed in these data centres has in recent years experienced continuous increase hence leading to high operational energy cost and high carbon footprint since some of the energy is generated from thermal power plants. This study employed the Power Usage Effectiveness and Data Centre Infrastructure Efficiency metrics to analyze the level of electrical energy efficiency at Wananchi Group (K) Limited Data Centre. Data collection involved the use of historical records and real-time measurements using various instruments. The study established that the year 2021 average annual Power Usage Effectiveness and Data Centre Infrastructure Efficiency metrics for the data centre were 1.82 and 55.55% respectively which compares favorably with the average values obtained from data centres in Europe whose metric values were 1.8 and 55.6 %. The maximum electrical load of the data centre facility was found to be 177.06 kW with the average load being 159.504 kW. The reliability of the mains supply to the data centre from the local utility company, Kenya Power, for the year 2021 in terms of availability was found to be 99.79% which is below the recommended value of 99.999%. Several energy conservation measures at the facility were identified and their economic viability analyzed with the replacement of the fluorescent tubes with light emitting diode tubes energy conservation measure having the shortest payback period of 2.22 months. Validation of some of the proposed energy conservation measures was done in terms of the annual energy savings and the CO_2 emission reduction against other studies and it was noted they all had comparable values.

Keywords: Data Centres (DCs), Power Usage Effectiveness (P_{UE}), Data Centre Infrastructure Efficiency (DC_{IE}), Energy Management, Energy Efficiency

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LIST OF ABBREVIATIONS

IT	Information Technology
ICT	Information and Communication Technology
DC	Data Centre
DCs	Data Centres
CAK	Communications Authority of Kenya
kW	Kilowatt
kWh	Kilowatt- Hour
MW	Megawatt
TWh	Terawatt -Hour
CoC	Code of Conduct
COP	Coefficient of Performance
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
HVAC	Heating, Ventilation and Air-Conditioning
RH	Relative Humidity
UPS	Uninterruptible Power Supply
RES	Renewable Energy Source
RE	Renewable Energy
P_{UE}	Power Usage Effectiveness
E_{RE}	Energy Reuse Effectiveness
P_D	Power Density
DC_{IE}	Data Centre Infrastructure Effectiveness
C_{EI}	Clean Energy Index
GHG	Greenhouse Gas
CBD	Central Business District
FTTH	Fiber To The Home
HFC	Hybrid Fiber Coaxial

DTH	Direct To Home
EMS	Energy Management System
EMP	Energy Management Program
KP	Kenya Power
MTTF	Mean Time To Fail
MTTR	Mean Time To Restore
CV	Control Volume
NOC	Network Operations Centre
LV	Low Voltage
CI	Commercial Industrial
USD	United States Dollar
KSHS	Kenya Shillings

CHAPTER ONE: INTRODUCTION

1.1 Background

Data Centre (DC) has been given several definitions, generally it is a facility containing electronic equipment for data processing, data storage and communication. As our current society and economy continues to shift towards digital transformation, there is an increased demand for internet services, storage of data and network communication and hence increased size and number of DCs across the globe. These DCs support services in several sectors of the economy including businesses, universities, government facilities among others [1]. DCs can be classified based on IT power capacity into small DCs (below 1kW), medium DCs (1kW-2MW) and large DCs (above 2MW) [2] .

Analysis of how electrical energy is utilized and managed in DCs is key to enhancing energy efficiency and reliability among the facility operators. The amount of electrical energy consumed in DCs has in recent years been experiencing continuous increase. This energy powers the information technology (IT) equipment and the facility support equipment. The IT equipment involves the servers, data storage and network communication equipment and they are the highest consumers of electrical energy in DCs mainly because they operate 24 hours in a day, 365 days in a year. Major consumers of energy among the IT equipment are the servers and this is due to their high processing speeds. However, with the increasing demand for data storage across the globe, storage equipment are likely to become significant consumers of energy in DCs in the future [3].

DC facility support equipment includes the cooling systems, lighting, power distribution equipment, uninterruptible power supply (UPS) equipment and ancillary systems with the cooling load being the major energy consumer. This is because the operation of the IT equipment generates large amount of heat that needs to be extracted for efficient and reliable operation of the DCs. The amount of electrical energy consumed in DCs can unnecessarily be high due to poor server utilization, unsuitable localization of cooling, packed server rack layouts and the poor airflow management [4].

Several metrics such as Power Usage Effectiveness (P_{UE}), Energy Reuse Effectiveness (E_{RE}), Data Centre Compute Efficiency (DC_{CE}), Data Centre Infrastructure Efficiency (DC_{IE}) and Clean

Energy Index (C_{EI}) have been applied to evaluate the energy utilization in DCs with their applicability varying from one DC to another [1], [5].

Energy management in DCs is a key aspect in achieving efficient use of energy and hence reducing DC electrical load. One major cause of inefficient energy consumption in DCs is the fact that operators are concerned with the DC reliability other than the energy efficiency. Studies on free cooling [6], server consolidation [7], IT equipment load balancing and incorporation of renewable energy sources (RES) in DCs [4] in order to reduce their dependency from the grid have portrayed a positive impact on energy management.

1.2 Problem Statement

The continuous rise in electrical energy consumption has been a major concern to DC operators. The increased energy utilization leads to high operating costs hence making the DCs expensive to operate and maintain. As compared to other DC costs such as labor costs, energy cost is the leading cost in terms of manageability and potential cost saving.

The increased electrical energy consumption has also led to the increase in green-house gas (GHG) emissions associated with the power generation from thermal power plants which forms 14.1 % part of the KenGen's generation mix [8]. With the current world's concern on environmental cleanliness and sustainable energy generation and utilization, there is need for Kenya and other countries across the globe to enhance energy management so as to achieve 100% supply from renewable sources of energy.

Electrical power reliability in DCs located in developing countries is also a major concern since they are served by the grid which receives power from the centralized generating stations. Major DCs in these countries are located in cities located far away from the generating stations hence long transmission and distribution lines leading to high transmission losses and high exposure to faults which leads to frequent power outages.

In spite of research done on free cooling, heat recovery, IT equipment load balancing and server consolidation regarding energy utilization and management in DCs and with the current growth in data and network communication demand, electrical energy consumption in DCs has continued to increase hence creating a need for further research [9]. Limited research has been done locally on electrical energy utilization and management in DCs taking into consideration the operating environmental conditions in Africa are different from the other parts of the world. This provides limited baseline for the regional benchmark. This study addressed this problem by focusing on a DC facility in Kenya. In addition, the study evaluated the reliability of the power from the grid to the DC and proposed energy conservation measures (ECMs) to enhance power reliability and reduce cost associated with the energy consumption at the DC.

1.3 Research Objectives

1.3.1 Main Objective

To analyze the current electrical energy utilization and management in DCs with a view of proposing and evaluating energy conservation measures.

1.3.2 Sub-Objectives

The specific sub-objectives of the study were:

i) Analyze, document and benchmark annual electrical energy usage at a typical DC.
ii) Perform analysis of electricity reliability from the grid at the DC.
iii) Propose energy conservation measures and perform their economic analysis.
iv) Validate the proposed energy conservation measures.

1.4 Research Questions

The research focused on responding to the following research questions:

i) How reliable is the grid to the DC?
ii) Which metrics have been proposed and adopted in analyzing energy utilization in DCs?
iii) How is the performance of the DC in terms of the energy efficiency as compared to other similar DCs across the globe?
iv) Which are the possible energy conservation measures that can be adopted at the DC?

1.5 Research Contribution

i) This study provides a local benchmark on how DCs in the African continent are performing in terms of energy efficiency as indicated by P_{UE} and DC_{IE} metrics taking into consideration the environmental conditions are different from those in other continents.

ii) The study contributed in the development of a research paper with the title; *Analysis of Energy Utilization Metrics as a Measure of Energy Efficiency in Data Centres: Case Study of Wananchi Group (Kenya) Limited Data Centre*. This paper was accepted for presentation during the 2022 IEEE PES/IAS Power Africa Conference after which it will be published in IEEE Xplore Digital Library.

iii) Implementation of the energy conservation measures (ECMs) proposed in this study is projected to have a significant contribution in the reduction of the GHG emissions to the environments i.e. 47,240.67 kgs of CO_2 emissions will be reduced annually.

1.6 Justification

Electrical energy usage in DCs continue to grow rapidly with a considerable impact on worldwide energy consumption. This growth has not only been contributed by the increase in number of DCs but also by their size and power densities' growth. According to the current trend of energy consumption in DCs and with the recent growth in DC infrastructure development accompanied by the development of server components with higher power densities, the average power density (P_D) is expected to reach 50kW per rack in DCs by 2025 [6].

Among the total cost of energy incurred by the DCs operators, about 40-50% is contributed by the energy used at their DCs while the remaining percentage is for the energy used in other facilities [10]. From the recent energy statistics, it has been indicated that approximately 1.3% of the world's electricity is consumed by the DC industry [9]. Energy consumed in DCs is as high as 40 times more per square foot in comparison to the amount of energy used in commercial office space. Study by Lawrence Berkeley National Laboratory (LBNL) on 14 DCs found that power densities were between 120-940 W/m^2 as compared to approximately 50-100 W/m^2 consumed in a typical commercial office space [11].

Climate change has been recognized as one of the major problem the humankind is facing. The increased DC energy consumption has contributed to the increased level of CO_2 emission across the globe. Estimates have indicated that up to 2% of the CO_2 emissions across the globe has been contributed by the IT sector [11]. DCs have been considered to have the fastest growing rate of CO_2 emission across the whole ICT sector and this is mainly associated to technological advances such as the cloud computing and the rapid growth of the use of internet services.

According to Energy Intelligence Africa Limited (2016) general energy audit report, Wananchi Group (K) Limited spent an average of Kshs 1.75 million per month to pay for the electrical power utilized in its DC facility located at Pension Towers in Nairobi Central Business District (CBD). This accounts for about 46% of the total amount of energy cost incurred by Wananchi Group (K) Limited [10].

Researches have been done in developed countries such as USA and other European countries regarding electrical energy utilization and management in DC facilities but limited focus has been done on local area DCs. Therefore this study is important in creating a better understanding regarding energy utilization and management in DCs located in developing countries such as Kenya taking into consideration the environmental and operating conditions are unique and different from those of the other parts of the world. The study also provided basis for DC energy utilization benchmark and development of appropriate ECMs.

1.7 Scope

The study focused on the assessment of electrical energy utilization and management at Wananchi Group (K) Limited DC facility located at Pension Towers 1st Floor in Nairobi CBD. It relied on real-time measurements and historical data obtained from power equipment at the facility and the local utility company, Kenya Power. Data obtained was used to evaluate the amount of electrical energy consumed by various components of the DC facility, calculate the P_{UE} and DC_{IE} metrics, evaluate the reliability of power from Kenya Power utility company and analyze energy consumption trend at the facility. The values of P_{UE} and DC_{IE} metrics indicated the level of energy efficiency at the facility and was used to perform benchmarking of the DC with other DCs located at various locations in the world. Possible ECMs whose implementation can reduce energy consumption at the DC, reduce GHG emissions and improve power reliability were identified and their economic analysis performed. Validation of ECMs was done taking into consideration what has been achieved by other facilities in terms of annual energy savings and CO_2 emission reduction.

1.8 Organization of the Report

The project report is organized as follows:

Chapter 1: The introduction provides the relevant background of the study that leads to problem statement. This chapter also includes the research contribution, justification of the proposed study, its scope and objectives.

Chapter 2: Literature review discusses the existing knowledge regarding energy utilization and management in DCs specifying the existing research gaps.

Chapter 3: The methodology section gives an explanation of how the research was performed in a logically organized manner.

Chapter 4: This includes the results and analysis of the collected data.

Chapter 5: This chapter contains the conclusion and the recommendations of the study.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Covid-19 pandemic has increased the demand for internet services globally. According to the first quarter of 2020/2021 Communications Authority of Kenya (CAK) financial year report, there was a positive growth in demand for internet and data services mainly due to the increased usage of the digital platforms at work places, learning institutions, shopping and healthcare facilities [12]. From this report, the number of internet and data subscribers in Kenya rose by 4.8 % to 43.5 million users from 41.5 million subscribers reported in the previous quarter. This has led to the increased utilization and need for DCs and it is projected to cause further increase in electrical energy utilization in these facilities.

This chapter begins by giving a background information about Wananchi Group (Kenya) Limited company which owns the DC facility used as case study in this research project. A broad discussion of electrical energy assessment and management is given followed by literature regarding how energy is utilized in DCs taking into consideration various equipment and systems.

A detailed description of the related research is given taking into consideration metrics commonly used to evaluate energy utilization in DCs. This also includes research done on energy management strategies in DCs and their associated energy savings. Towards the end of the chapter, research gaps are identified from the already discussed literature and an overview is given regarding how this study addressed the gaps.

2.2 Background of Wananchi Group (Kenya) Limited

Wananchi Group (Kenya) Limited which owns the DC facility used as the case study in this research is a telecommunications company providing internet, telephony and television services in Kenya. The Company was founded in the year 2000 and it’s headquartered in Nairobi with branch offices in Kisumu, Nakuru, Mombasa, Nyeri and Eldoret [13]. The company comprises of four subsidiaries (business units) namely; Zuku, Simbanet, Wananchi Telecoms and Isat Africa [14].

According to third quarter (Q3) of 2020-2021 CAK financial year fixed data subscription statistics report summarized in Table 2.1 covering January to March 2021, Wananchi Group (Kenya) Limited is the second in terms of the market share (30.3%) with 216,219 fixed data subscribers [15]. This is after Safaricom Company Limited which dominated the market with a share of 35.8% comprising of 255,594 subscribers. Mobile Telephone Network (MTN) is the 9th in the market share with only 474 fixed data subscribers. Safaricom dominated the market possibly because it has deployed FTTH network across several towns in Kenya as compared to the other telecommunication companies.

Table 2. 1: January-March 2021 Fixed Data Subscriptions per Service Provider [15]

Name of Service Provider	**Number of Data/Internet Subscribers**	**Percentage Market Share (%)**
Safaricom PLC	255,594	35.8
Wananchi Group (Kenya) Ltd	216,219	30.3
Jamii Telecommunications Ltd	135,602	19.0
Poa Internet Kenya Ltd	61,867	8.7
Liquid Telecommunications Kenya	14,921	2.1
Mawingu Networks Ltd	11,708	1.6
Dimension Data Solutions East Africa Limited	9,439	1.3
Telkom Kenya Ltd	4,739	0.7
Mobile Telephone Network (MTN)	474	0.1
Other Fixed Service Providers	2,692	0.4

2.3 Energy Assessment and Management in Data Centres

2.3.1 Energy Assessment

Energy assessment is the process of identifying how energy is utilized in a facility. At the end of the assessment process, various energy conservation opportunities are identified which when implemented contributes to cost savings through reducing energy consumption. In order to reduce GHG emissions across the globe, assessment of energy consumption in facilities such as DCs is of key importance [11]. Among the various proposed metrics that are used to measure energy utilization and efficiency in DCs, Power Usage Effectiveness (P_{UE}) and Data Centre Infrastructure Efficiency (DC_{IE}) also known as Data Centre Efficiency (DC_E) are de facto standards within the DC industry. In 2009, the Green Grid in collaboration with other organizations around the world made a global agreement that P_{UE} is the preferred DC infrastructure efficiency metric defining its measurement methodology and reporting convention [16].

P_{UE} was first proposed in the year 2006 [17] and it represents how much power from the one supplied is used to power the IT equipment in contrast to the one used for overhead i.e. cooling, lighting, security system and other additional plant within the DC and it needs to be measured for a given duration of time probably a month or a year. P_{UE} calculated using data collected over a year gives a true presentation of the energy consumed in a DC since it will capture all the influences from the variation of climatic conditions and the power demand of the IT equipment. P_{UE} measures the energy efficiency of a DC and it is used for DC benchmarking [1], [18]. It is defined as shown in Equation (2.1) [19].

$$P_{UE} = \frac{TFP}{ITEP} \tag{2.1}$$

DC_{IE} is the reciprocal of P_{UE} as defined in Equation (2.2) [19].

$$DC_{IE} = \frac{1}{P_{UE}} = \frac{ITEP}{TFP} \tag{2.2}$$

Where *TFP* is the total facility power; the amount of power consumed in the entire DC facility as measured using utility meter while the *ITEP* is the IT equipment power which refers to the power feeding the IT equipment used for managing, processing, storing or routing data within the DC [16], [19].

DC_{IE} metric represents the IT load as a percentage of the total input power to any DC facility. Sun and Lee [20] also discussed about the DC_{IE} metric although they referred to it as IT Effectiveness metric. More energy efficient DCs have a P_{UE} whose value is close to 1 [21]. However, achieving a P_{UE} value of 1 is not practically achievable since some energy is always consumed in supporting the IT equipment. Also, it is impossible to have P_{UE} value which is less than 1 since this will mean that the amount of power utilized by the IT equipment is more than what is delivered to the DC

[22]. P_{UE} and DC_{IE} are useful in determining opportunities to improve operational efficiencies in DCs, benchmarking in DC industry and opportunities to audit energy for additional installation of IT equipment.

However, P_{UE} and DC_{IE} metrics don't take into consideration the waste energy from DCs which can be used for other purposes outside the facility. To account for this, The Green Grid, a non-profit making organization composed of IT companies with a main aim of improving the energy efficiency in DCs proposed Energy Reuse Effectiveness (E_{RE}) metric [23]. The concept of control volume (CV) which is an imaginary boundary surrounding a DC and its infrastructure support areas was brought by The Green Grid to account for the energy that crosses this boundary in E_{RE} metric. Figure 2.1 shows DC components enclosed inside a CV represented by the dotted line. Any energy (F) reused outside the CV instead of being rejected to the atmosphere is considered as reuse energy in determining E_{RE}.

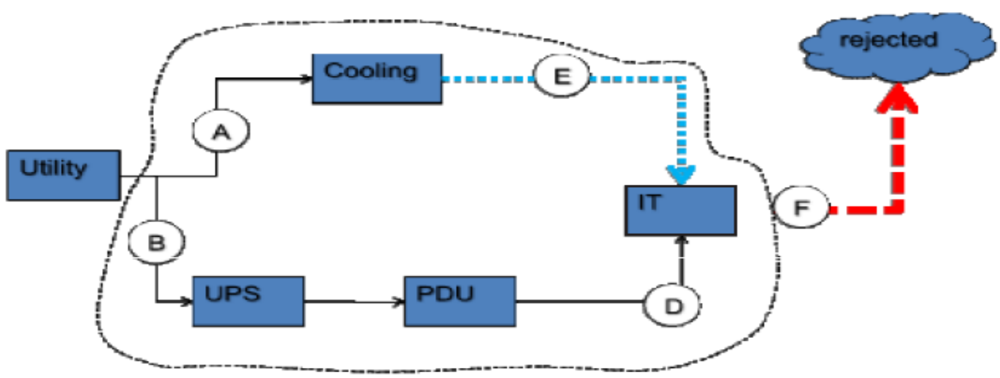

Figure 2. 1: Data Centre Components and Control Volume [23]

E_{RE} in a DC facility is defined by Equation (2.3) with its value ranging from zero to infinity. A zero value of E_{RE} indicates that the entire amount of energy supplied to the DC facility is reutilized elsewhere outside the CV.

$$E_{RE} = \frac{C+P+L+IT-R}{IT} \tag{2.3}$$

Where C represents the amount of energy utilized by the cooling system in the DC facility, P is the amount of energy loss associated with the power distribution within the DC, L represents the amount of energy consumed by the lights and the support services in the DC, IT represents the energy used by the IT equipment in the DC and R represents the amount of energy from the DC re-used outside CV.

Another commonly used metric in measuring energy utilization in DCs is the Power Density (P_D) which measures the amount of energy used per given area [18]. However, P_D metric is not suitable for making comparison between several DC facilities since there is always a big difference between the values obtained covering the entire floor area of the DC and that for a small area e.g. one rack hence leading to uncertainty in the real meaning of the values [20], [24]. According to Karlsson and Moshfegh [25], P_D in a DC facility is defined as shown in Equation (2.4).

$$P_D = \frac{Ptot}{A} \tag{2.4}$$

Where $Ptot$ represents the total electricity supply and A is the footprint which is the area occupied by a rack or the entire area of the DC facility.

Heating, Ventilation and Air Conditioning (HVAC) Effectiveness is a metric commonly used to measure the amount of energy needed for heat cooling in DC facilities in comparison to the IT load and it is used to analyze energy performance and efficiency improvements in HVAC systems with its formula defined in Equation (2.5) [20].

$$HVAC_{Effectiveness} = \frac{P_{HVAC}}{ITEP} \tag{2.5}$$

Where P_{HVAC} is the power consumed by the HVAC systems in a DC facility and $ITEP$ is as defined earlier.

2.3.2 Basics of Energy Management

Energy Management is a tool used to ensure energy effectiveness and efficiency so as to minimize energy consumption hence reducing energy cost and emissions associated with the energy use and therefore protecting the environment [26], [27]. Energy Management is the stepping stone for conservation of energy and the process of reducing the energy cost in residential, commercial and industrial sectors. About 5-15% energy cost saving is usually achieved with implementation of aggressive energy saving measures that doesn't involve any capital expenditure and energy savings of up to 60% resulting from retrofit measures [28].

Energy management is a continuous process involving monitoring, targeting and reporting (MT&R) techniques as illustrated by measure-analyze and action cycle in Figure 2.2 [28]. The MT&R cycle begins with any measured data on energy consumption possibly in the form of electricity bills. The data is then analyzed to establish the energy consumption patterns or trends of the involved organization after which the obtained information provides a guidance on the actions to be taken. When the proposed actions are implemented, results are produced which could possibly be the reduction of the energy consumed and the associated cost. The obtained results are compared with the set target and process enters the next phase to address the available variance.

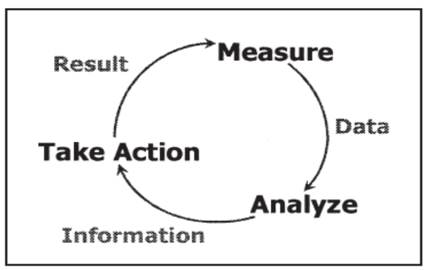

Figure 2. 2: Measure-Analyze and Action Cycle [28]

America in the year 2013 issued Executive Order 13653 with directives to enhance reduction of the amount of energy consumed through optimizing energy consumption and with a requirement that all the new infrastructure equipment should meet the Energy Star and Federal Energy Management Program (FEMP) efficiency [29]. The major objective of the Europe 2020 strategy was to ensure achievement of energy efficiency in all the economic sectors. Energy Performance of Buildings Directive (EPBD) which initiated nearly Zero-Energy Buildings (nZEB), European Codes of Conduct (CoC) with the recent one being Data Centres CoC programme are some of the policies focusing on energy management in Europe all aiming at reducing the economic, environmental and energy security impacts [29], [30], [31].

In Kenya, the Energy Regulatory Commission (ERC), now referred to as Energy and Petroleum Regulatory Authority (EPRA) developed an Energy Management Regulations 2012 through an energy act 2006 [32]. These regulations provided guidelines for ensuring energy efficiency in all the Kenyan sectors through energy management policy development, energy audits and energy investment plans, ECMs and energy audit licensing. All this focuses on the reduction of the amount of energy consumed while maintaining the same amount of output quantity and quality.

2.4 Data Centre Electrical Energy Consumption

Energy efficiency has been a major concern in all the economic sectors across the globe. DCs represent one of the large and growing energy use sector with a remarkable impact on global energy consumption [29]. According to Sadler [33], ICT sector which includes DCs consumes approximately 7% of the total global electricity and this was projected to rise up to 8% by the year 2020 [34] and 13% by the year 2030 [33]. According to U.S Environmental Protection Agency (EPA) report, DCs in USA alone in the year 2006 consumed 61 billion kWh of electrical energy which was equivalent to 1.5% of the country's total amount of electrical energy consumed in that year [35]. Also according to Chalise et al. [34], DCs in the USA consumed 2% of all the electricity usage in 2010.

The continuous increase in energy consumption in DCs is attributed to the increase in demand for internet and digital services as well as the doubling of transistors in integrated electronic circuits after every two years as per the Moore's law [18]. From Table 2.2, it can clearly be seen that there is a continuous increase in energy consumption in DCs in America, European countries and in the globe [30].

Table 2. 2: European, American and Global Data Centre Energy Consumption in TWh [30]

Consumption (TWh)	Reporting Year
	EU consumption
18.3	2000
41.3	2005
56	2007
72.5	2010
104	2020
	US consumption
91	2013
140	2020
	Global consumption
216	2007
269	2012

2.4.1 Information Technology (IT) Equipment

IT equipment in DCs are mainly the servers, storage devices, network equipment, monitoring and control workstations [3]. They are the main consumers of electrical energy in DCs representing about 45-55% of the entire electrical load [2]. Among the IT equipment in DCs, servers are the greatest energy consumers accounting for more than 75% of the total IT equipment load with a fully populated blade server rack requiring up to 20-25kW of power to operate [3]. Storage devices are the second in terms of energy consumption among the IT equipment after servers accounting for 10-15% of the total IT equipment energy consumption [3].

2.4.2 Cooling and Air Conditioning Systems

In accordance to the first law of thermodynamics which requires conservation of energy, electrical energy consumed by IT equipment in DCs is dissipated in form of heat. Approximately 99% of the total amount of electrical energy consumed by electrical equipment is dissipated in the form of heat energy. IT equipment accounts for 70% of the heat generated in DCs with the rest being produced by the power distribution systems, UPS, lighting and DC engineers [18]. The amount of power generated as heat when electrical current flows through a semiconductor is released to the external environment. The power P dissipated as heat can be calculated by multiplying the voltage drop V across the semiconductor with the current I flowing through the semiconductor as defined in the Equation (2.6) [36].

$$P = VI \tag{2.6}$$

However, Equation (2.6) applies only if direct voltage and current are applied to the semiconductor. In the case of application of alternating current and voltage to the semiconductor, then the dissipated power, P_m is a mean value and is calculated as defined by Equation (2.7) [36].

$$P_m = \frac{1}{t}\int_{t1}^{t2} V(t)I(t)dt \tag{2.7}$$

Allowing the accumulation of heat generated in DCs compromises the lifetime of the IT equipment and hence affecting the reliability of the DC. Therefore immediate extraction of the generated heat is required in order to ensure proper operation and reliability of the IT equipment hence creating the need for cooling and air conditioning systems in DCs which accounts for 40% average of the total amount of energy consumed. Most energy efficient cooling systems consumes about 24% and the least efficient above 60% of the total DC energy [37]. However, DC site location is a key component in defining the cooling and air conditioning systems' energy consumption [11]. According to the experiments performed at the HP Laboratories Smart DC, it was found that 0.8W of energy was utilized by the cooling equipment to remove every 1W of heat energy dissipated by the IT equipment [38].

2.4.3 Power Distribution, Lighting and Ancillary Systems

Power distribution system in a DC refers to the equipment responsible for the delivery of reliable and high quality electrical power to the DC load [2]. To avoid the danger of the longer power outages from the grid, DCs have backup diesel generator(s) which provide electrical power in the absence of power from the main grid. DC power distribution systems also includes UPS unit(s) which provides quality electrical power and it contains batteries for load powering before the starting of the diesel generator in order to ensure IT equipment doesn't experience any power disruptions.

Some power is consumed in the distribution switchgear in form of losses though the amount is minimal as compared to IT equipment and the cooling systems loads in DCs [3]. The efficiency of UPS system is a key consideration in addressing the DC energy efficiency due to the associated losses in its energy conversion processes. Power from the UPS is distributed via Power Distribution Units (PDUs) to the racks hosting the IT equipment. Lighting and ancillary systems which includes fire detection systems, security systems and staff support equipment makes up the balance of the remaining DC load accounting for about 3% of the DC overall energy consumption [3].

Based on the discussed components that contribute to energy consumption in DCs, energy flow in a DC can be summarized as indicated in Figure 2.3 taking into consideration a diesel backup generator [35]. However, energy division among equipment in DCs vary based on the designs and categories of the DC.

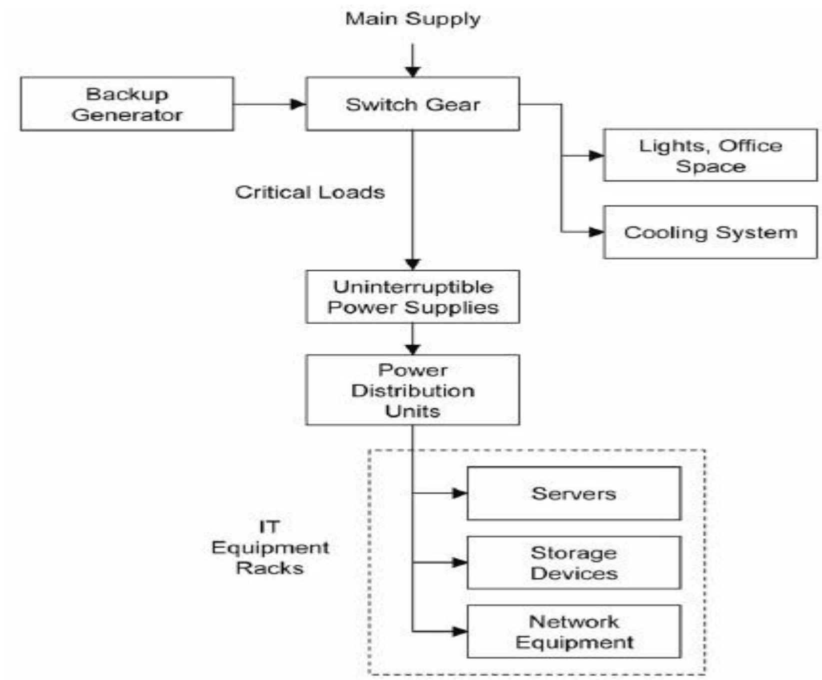

Figure 2. 3: Typical Power Delivery Infrastructure to a Data Centre [35]

2.4.4 Data Centre Environmental Operating Conditions

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) provides various suitable environmental conditions within which the electronic equipment should operate. ASHRAE has provided two envelopes; recommended and allowable envelopes as shown in Table 2.3 within which DCs can operate [39]. The allowable envelope has a wider scope of operating conditions but with a higher risk of equipment failure in DCs due to its associated wide range of operating temperatures which subjects the IT equipment to mechanical stresses.

Table 2. 3: Summary of 2011 ASHRAE Thermal Guidelines for Data Centres [39]

	Dry-bulb temperature	**Humidity range**	**Maximum dew point**
	Recommended		
Class A1 and A4	18 to 27 °C	5.5 °C DP to 60% RH and 15 °C DP	–
	Allowable		
Class A1	15 to 32 °C	20% to 80%	17 °C
Class A2	10 to 35 °C	20% to 80%	21 °C
Class A3	5 to 40 °C	8% to 85%	24 °C
Class A4	5 to 45 °C	8% to 90%	24 °C

The four DC operating classes are indicated on a psychrometric chart in Figure 2.4 and they were provided to ensure adequate information is available to DC companies inorder to ensure energy efficiency while still meeting the customer needs. From Figure 2.4, ASHRAE recommends the operation of DC at a dry bulb temperature ranging from 18^{o}C to 27^{o}C and a relative humidity (RH) of up to 60% for guaranteed safety of the IT equipment. ASHRAE indicates the possibility of operating DCs at classes A1, A2, A3 and A4 which have a wide range of dry bulb temperatures and RH as indicated in Table 2.3 so as to conserve energy. However, the operational safety of the IT equipment at these classes is not guaranteed.

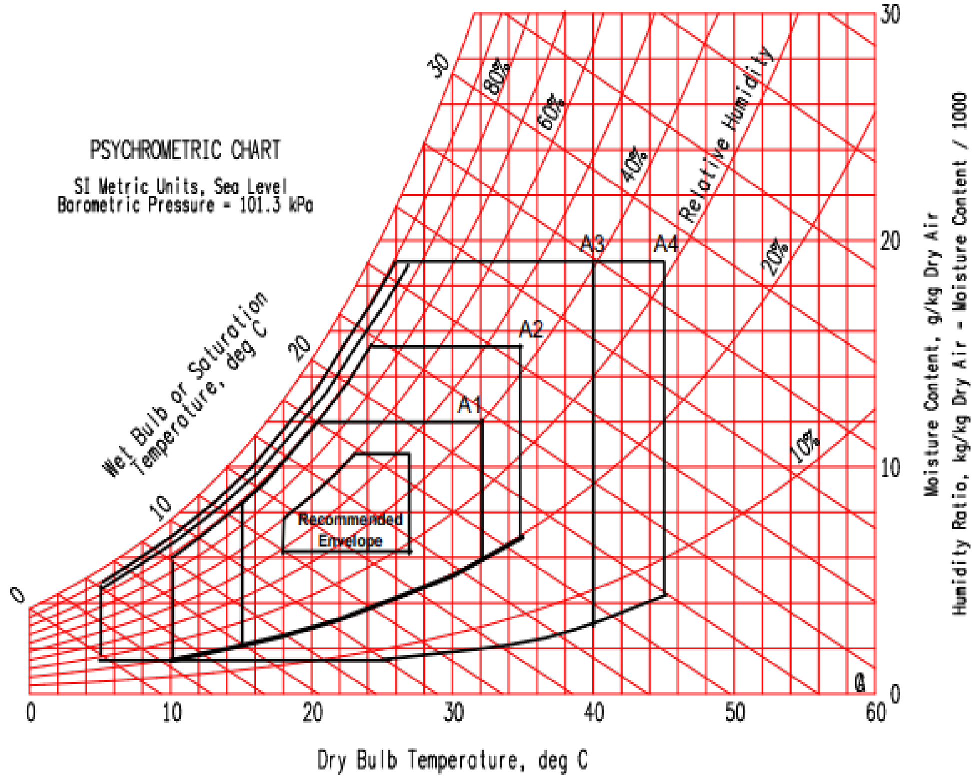

Figure 2. 4: Data Centre Envelopes on a Psychrometric Chart [39]

2.5 Related Research on Electrical Energy Utilization and Management in Data Centres

2.5.1 Electrical Energy Utilization in Data Centres

According to the study on P_{UE} assessment at Prineville DC, Oregon in USA which is operated by Facebook, the P_{UE} was found to be 1.08 [11]. The study involved the sum of the energy consumed by triplet racks hosting severs, energy used by the DC cooling system and the energy losses in the power distribution losses as the total DC load. The cooling load for this DC was small i.e. 1048 kWh/annum as compared to the IT load and the electrical losses which were found to be 212,868 kWh/annum and 15,854 kWh/annum respectively per triple rack assuming each server operates at 60% rated power. Figure 2.5 shows the changes in P_{UE} resulting from changes in humidification by ±20%, power distribution efficiency by ±1%, IT load by -40% and +20%. It is evidenced that changes in the IT load and the power distribution efficiency had significant effects on the P_{UE} value unlike the changes in cooling system.

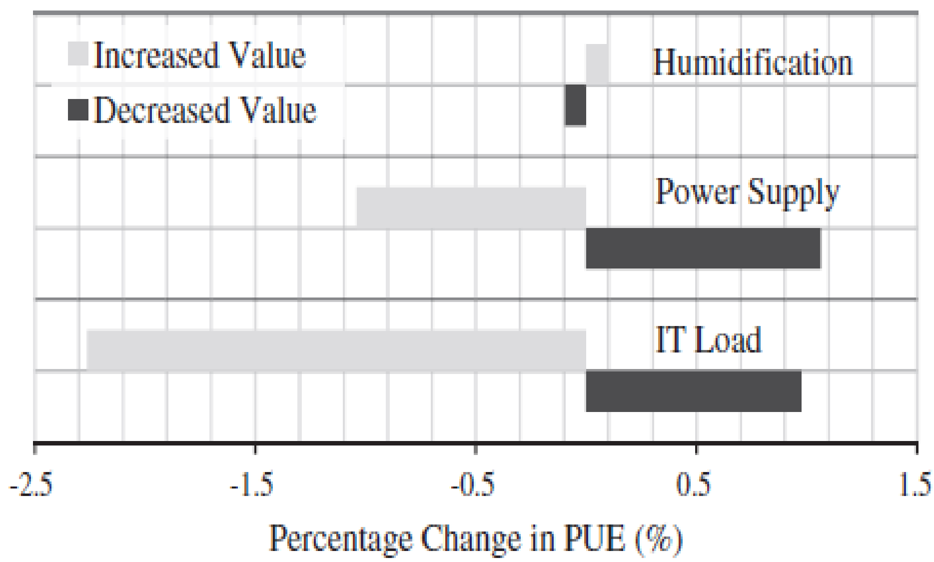

Figure 2. 5: Percentage Changes in P_{UE} [11]

The study on evaluation of energy consumption in European Union DCs by Avgerinoue et al. [30] involved using data presented by DC companies applying to participate in the European Code of Conduct (CoC) for DC energy efficiency programme. The analysis was done using a sample of 289 DCs whose energy consumption data had been submitted and approved by December 2016. The data was used for evaluating, analyzing and presenting energy consumption trends in the involved DCs. The findings of this study which are summarized in Table 2.4 indicated an average P_{UE} of 1.80 from all the approved DCs. The data contained in the report from the involved DCs was either recorded on annual or on monthly basis. In most cases, the presented data didn't cover the required 12 months period and therefore the annual consumption was extrapolated based on the presented data.

Table 2. 4: Reported Facilities Average Data [30]

Total Dataset	289 Data Centres Which Have Reported the Data
Total annual electricity consumption	3,735,735 MWh
Average DC floor area	2616 m^2
Average rated IT load	1956 kW
Average annual electricity consumption	13,684 MWh
Average annual IT consumption	7871 MWh
Average PUE	1.80
Average high temp set point	25 °C
Average low temp set point	19.5 °C
Average high RH set point	59% RH
Average low RH set point	35% RH

Majority of the DC facilities reported an average P_{UE} of 1.6-1.8 followed by 1.8-2.0 range excluding values less than 1 and more than 3 as shown in Figure 2.6. However, the research was done based on real data from European DCs and therefore can't be generally applied to global DCs due to different climatic conditions.

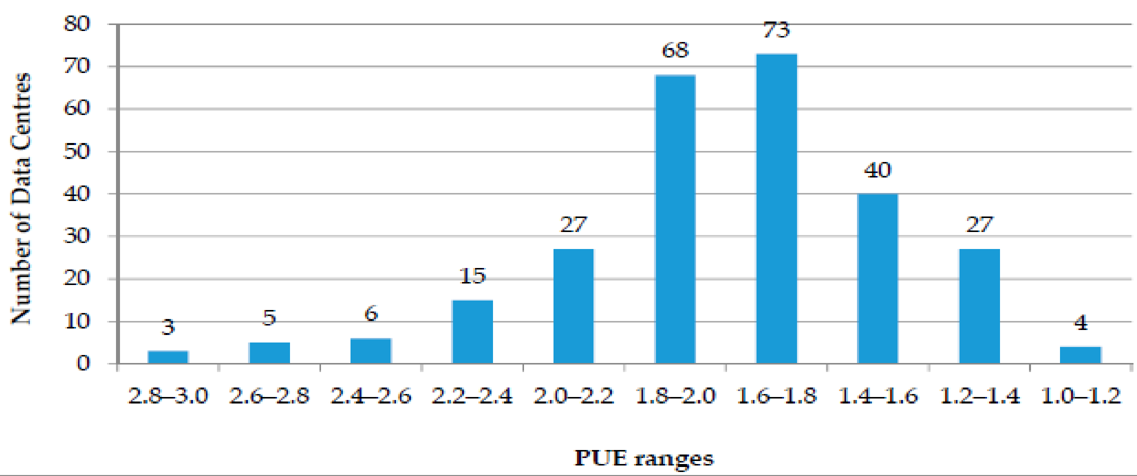

Figure 2. 6: Number of Data Centres per P_{UE} Range [30]

2.5.2 Electrical Energy Management in Data Centres

The following researches have been done on electrical energy management in DCs with a view of reducing the energy consumption.

2.5.2.1 Data Centre Server Consolidation Technique

In their study, Uddin and Rahman proposed a virtualization technique called server consolidation with an aim of improving utilization of underutilized servers in order to reduce the amount of electrical energy they consumed and hence the minimizing GHG emissions associated with the operation of DCs [7]. The study focused on a DC with 500 servers having between 3% to 10 % utilization ratios.

Based on the workload and usage, the researchers grouped the servers into three categories as indicated in Tables 2.5 and 2.6 after which they applied server consolidation based on the server's utilization ratios in the DC. This process consolidated the load of several servers on a single server and hence reducing their numbers in the DC facility. At the end, the amount of electrical energy consumed by different servers was compared and analyzed using SPECpower_ssj tool and the results were as indicated in Tables 2.5 and 2.6.

Table 2. 5: Server Details Before Consolidation [7]

Server Categories	Innovation	Production	Mission Critical	Total Power
Server Count	250	175	75	500
Utilization	3%	6%	10%	5%
Watts per server=173* server count	43250	30275	12975	86500

Table 2. 6: Server Details After Consolidation [7]

Server Categories	Innovation	Production	Mission Critical	Total Power
Consolidation ratio	15:1	10:1	5:1	10:1
Post Consolidation Utilization	50%	50%	50%	50%
Post Consolidation Power (watts)	3910	4140	3450	11500
Power Saving (watts)	39340	26135	9525	75000

From Table 2.5 the average server utilization is taken to be 5% with each server consuming 173 watts and therefore the 500 servers consumed 86500 watts of power. The servers' consolidation ratios are as shown in Table 2.6 which yielded a total of 75kW power saving.

2.5.2.2 Free Cooling in Data Centres

In a research by Dong et al, analysis of energy efficiency in DCs using free cooling was done taking into consideration five cities in China namely; Harbin, Beijing, Wuhan, Guangzhou and

Kunming each representing severe cold area, cold area, hot summer and cold winter area, hot summer and warm winter area and moderate area respectively [40].

Analysis of the available time per year and the utilization ratio of the natural free cooling resource in the five cities with different climatic conditions was done using Chin Meteorological Data at 16℃ critical temperature as represented in Figure 2.7.

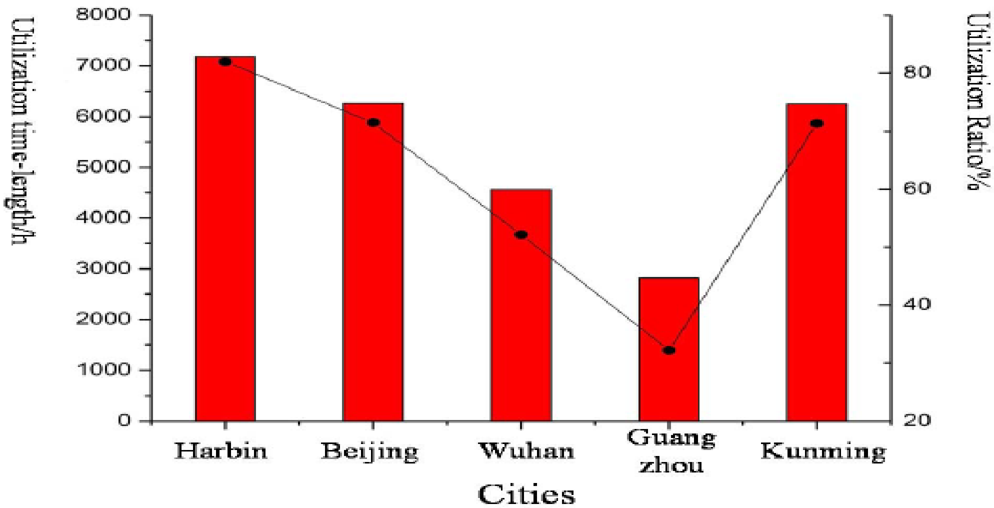

Figure 2. 7: Utilization Time and Ratio of Free Cooling in China [40]

From the findings of the research summarized in Figure 2.7, it can be concluded that the natural free cooling resource utilization time in Harbin is over 7000 hours, in Beijing over 6000 hours, in Wuhan over 3500 hours, in Guangzhou over 1000 hours and in Kunming over 6000 hours. The highest utilization ratio is more than 80% in Harbin which represents cold severe areas and the lowest is over 30% in Guangzhou representing hot summer and warm winter areas. Finally an analysis of Coefficient of Performance (COP) of a DC air conditioning system in the hot summer and warm winter region was done taking into consideration the application of free cooling resource. An improvement of the COP of the DC air conditioning system by 1.4 which reflects to 23.7% energy saving when free cooling resource is used was achieved.

2.5.2.3 Renewable Energy Integration in Data Centres

Many companies across the globe have considered investing in generation of electrical energy from renewable sources of energy especially solar and wind for consumption in their DCs. For example, Apple Company in the year 2020 constructed solar power plants in Nevada, USA producing more than 180 MW of energy and wind power plants producing 130MW in Denmark and Chicago both for powering the company's DC facilities [41].

Authors in [42] proposed a RE management system called REDUX to provide a smart means of managing energy consumption in a DC facility from distributed UPS system, main grid and RES. The system aimed at addressing the challenges of RE fluctuations and the frequent changes in the electricity price and would make decisions on charging or discharging the UPS based of the level of the RES and the grid price. This system whose framework is shown in Figure 2.8 ensures charging of the UPS system when the RES is stable and adequate and also when the price for the grid power is low and then discharge when the RES is low or fluctuating or when the grid power price is high hence conserving energy and also reducing energy consumption cost.

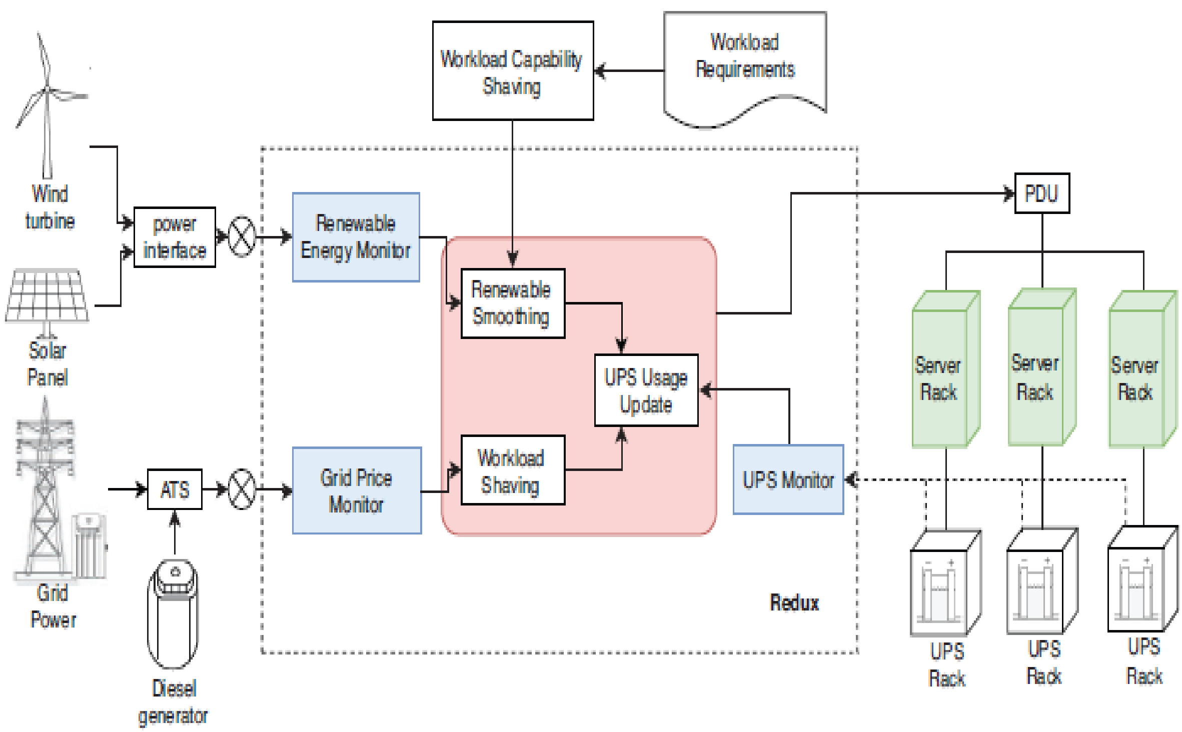

Figure 2. 8: REDUX System Framework [42]

2.6 Research Gaps

From findings in the literature on research that has been done on analysis of electrical energy utilization and management in DCs, majority of the studies have been conducted in US and European countries and China as well which are among the developed countries in the world with some of the studies not considering all the IT equipment in DCs and others not including detailed economic analysis of the proposed energy management techniques. Limited studies exist in developing countries like Kenya and others in the African continent which are experiencing tremendous growth in internet connection and digital platforms usage which all depend on DC facilities. Therefore DC industry requires a local benchmark on how energy is utilized and managed in local DCs which operate in unique climatic conditions and can vary as compared to the ones in the developed countries. The proposed research will address these gaps by focusing on electrical energy analysis in a local DC facility located in Kenya from which economic analysis will be done on the identified ECMs.

Table 2. 7: Summary of Research Gaps

Study Title and Reference	**Data Centre**	**Country**	**Year**	**Research Gap**
A case study and critical assessment in calculating Power Usage Effectiveness for a Data Centre [11].	Prineville Data Centre	USA	2013	Only servers among the IT equipment were considered.
Trends in Data Centre Energy Consumption under the European Code of Conduct for Data Centre Energy Efficiency [30].	European Data Centres	European Union	2017	Economic analysis of the implemented energy best practices not computed.
Server Consolidation: An approach to make Data Centers Energy Efficient & Green [7].	Not indicated	Not indicated	2010	Only servers are considered ignoring other IT equipment
Research on Free Cooling of Data Centers by Using Indirect Cooling of Open Cooling Tower [40].	Not named	China	2017	Detailed economic analysis not provided.
REDUX: Managing Renewable Energy in Data Centers using Distributed UPS Systems [42].	Not indicated	New York USA	2018	Detailed Cost-benefit analysis of the proposed energy management system not provided
Analysis of Energy Utilization and Management in Data Centres: Case study of Wananchi Group (K) Limited Data Centre	Wananchi Group Limited Data Centre	Kenya	2022	

2.7 Inferences Drawn

Electrical energy consumption in DCs has continued to increase in spite of the various studies already conducted to ensure better energy utilization and management in these facilities. This has contributed to high operational energy costs in DCs and the GHG emissions which has led to global climate change. Analysis of how electrical energy is used and managed in DC facilities is key in creating an insight on how to use the available energy efficiently and hence reducing the energy cost and the effects of energy usage to the environment. The results of this study provides an understanding of how energy is utilized in local DCs hence providing the basis for global benchmarking as well as identification and economic analysis of ECMs.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter gives a brief description of the case study DC including the sources of electrical energy utilized at the facility. It also gives a description of the various methods and tools which were used to collected and analyze data during the study. Two techniques used to evaluate the economic viability of the proposed ECMs are also discussed in the chapter.

3.2 Case Study Data Centre Facility

Wananchi Group (Kenya) Ltd DC, the case study DC facility in this research, is located in First-Floor of Pension Towers commercial building along Loita Street directly opposite Nyati House. It is a tier II DC hosting several IT equipment supporting the provision of internet, television and telephony services. The floor space of this DC is divided into: the DC section, power room section, NOC section and the support room which contains the kitchen and the toilets. DC section hosts various types of IT equipment and air conditioning systems and therefore consumes the largest percentage of the power supplied to the DC facility. The DC facility is manned by NOC engineers throughout the year with four engineers on duty during the day shift and two during the night shift.

3.3 Energy Sources

The main energy source at the Wananchi Group (Kenya) Limited DC is the Kenya Power (KP) grid supply. The electrical power is supplied and metered using 415V 3-phase 4-wire system and billed under CI 1 tariff. There are also two 500kVA standby diesel generators which are automated to provide power to the DC in the absence of KP main supply. Generator 1 is given the priority of power supply while generator 2 provides power in case generator 1 has a failure. IT equipment located at Wananchi Group (Kenya) Limited DC are powered through two online MGE Galaxy 5000 UPSs, each rated 120kVA in order to ensure high quality power free from any power fluctuations. Other than this, the two UPSs also provides power from the batteries to the IT equipment before diesel generator kicks on after KP mains is lost hence ensuring continuous power supply. Figure 3.1 shows one of the MGE Galaxy 5000 UPSs located at the DC facility while Figure 3.2 shows a section of racks hosting IT equipment at the DC section.

Figure 3. 1: 120kVA UPS at Power Room

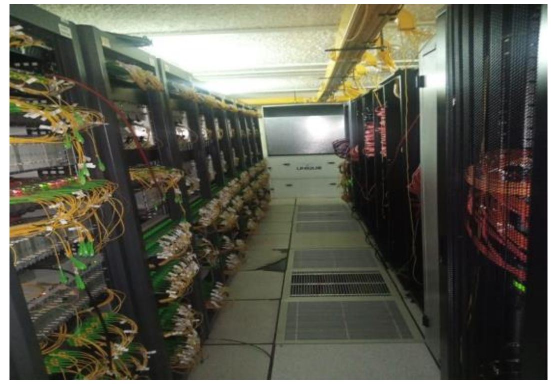

Figure 3. 2: IT Equipment Racks at the DC

3.4 Proposed Method

This research employed descriptive and historical research approaches of study relying on real time measurements and past data collected regarding the DC facility. The study focused on analyzing energy utilization and management at the DC using several methods and tools.

3.4.1 Research Methods and Tools

3.4.1.1 Documents and Records

DC monthly energy consumption bills obtained from KP were be used to get the monthly energy consumption of the facility. This was the monthly total DC energy. Since all the IT equipment at the DC facility are powered through online UPSs to ensure power quality and reliability, data downloaded from the UPSs' databases was used to get the monthly IT equipment energy assuming no power losses at the UPSs and the power cables feeding the power distribution units (PDUs) where the IT equipment are connected. However, the two MGE Galaxy 5000 UPSs are able to store a maximum of 5000 logs (events) and therefore data available did not cover the entire one year hence extrapolated to cover a period of one year. The two parameters i.e. monthly total DC energy and the monthly IT equipment energy were used to calculate the monthly P_{UE} and DC_{IE} metrics for the DC facility using Equations (3.1) and (3.2).

$$P_{UE(monthly)} = \frac{MTDCE}{MITEE} \tag{3.1}$$

$$DC_{IE(monthly)} = \frac{MITEE}{MTDCE} * 100 \tag{3.2}$$

Where $MTDCE$ is the monthly total data centre energy while $MITEE$ is the monthly IT equipment energy. The monthly P_{UE} and DC_{IE} values were used to calculate the annual values of the DC metrics as shown in Equations (3.3) and (3.4).

$$P_{UE(annual)} = \frac{\sum_{1}^{12} P_{UE(monthly)n}}{12} \tag{3.3}$$

$$DC_{IE(annual)} = \frac{\sum_{1}^{12} DC_{IE(monthly)n}}{12} \tag{3.4}$$

Where n represents the month and ranges from n =1, 2, 3………, 12.

The obtained values of annual P_{UE} and DC_{IE} metrics were used to benchmark the performance of the DC in terms of energy utilization performance by comparing the metric values with other DC across the globe.

Data obtained from Kayako Ticketing System, a system used at Wananchi Group (Kenya) Limited DC facility to track outages was used to evaluate the reliability of the mains power supply from Kenya Power in terms of availability as shown in Equation (3.5).

$$Kenya\ Power\ Reliability\ (A) = \frac{MTTF}{MTTF+MTTR} * 100 \tag{3.5}$$

Where, $$MTTF = \frac{\sum_{1}^{N} Uptime_n}{N} \tag{3.6}$$

$$MTTR = \frac{\sum_{1}^{N} Downtime_n}{N} \tag{3.7}$$

Where $Uptime_n$ is the duration in hours the KP mains power was available with N being the maximum number of times, $Downtime_n$ is the duration in hours the KP mains power was not available with N being the maximum number of times.

3.4.1.2 Measurements

The researcher carried out real time-measurement as a method to measure air conditioning load for a period of 4 days. DC indoor dry bulb temperature and RH were measured for a period of one month. Real time measurement were also employed to measure the energy parameters at the DC local utility power entry point for a period of 3 days. The level of lighting intensity at the DC was also measured once every day for a period of 3 days.

3.4.1.3 Observation

Observation method was used to identify the ECMs that have already been implemented at the DC in order to ensure efficient use of energy. The method was also used to identify energy saving opportunities at the case study DC facility.

3.4.1.4 Data Collection and Analyzing Tools

The following tools were employed to collect and analyze data:

a) **UPS Tuner MGE Galaxy 5000 software**: This software was used to download the data logs from the two 120kVA MGE Galaxy 5000 UPSs located at the facility. This data indicated the IT equipment load at facility for P_{UE}, DC_{IE} metrics analysis.

b) **Energy Measurement tools**: Fluke 435-II Power Quality and Energy Analyzer, Extech EN150 lux metre and Fluke 323 clamp metre equipment were used for real time energy measurements as indicated in section 3.4.1.2. Details of these specialized energy tools are indicated in the appendices section.

c) **ThermoPro TP49 Hygrometre**: This tool was be used to measure the DC indoor RH and the dry bulb temperature once every day for a period of one month. Its details is contained in appendices section.

d) **GSM Module**: This instrument was used to get the dry bulb temperature readings inside the DC once every day for a period of 1 month. This temperature reading were used together with the hygrometer temperature reading to get the DC indoor daily average dry bulb temperature.

e) **Excel spreadsheet**: This too was used to analyze the DC energy consumption bill, calculate and analyze P_{UE} and DC_{IE} metrics.

f) **Matlab (Psychro.m)**: This software was used to analyze the DC operating zones (classes) on a Psychrometric chart for the purpose of investigating the possibility of operating the DC facility at higher temperatures.

3.5 Economic Analysis

Two economic analysis techniques were employed to perform the cost-benefit analysis of ECMs identified at the case study DC. These techniques are the Simple Payback Period and the Net Present Value methods.

3.5.1 Simple Payback Period (SPB)

This method involves calculating the duration of time taken by the benefits of a project to offset the initial investment cost and it is calculated as shown in Equation (3.8).The most viable project is the one with the shortest payback. The Payback period method was used in this study because it is simple to calculate and easy to understand.

$$SPB = \frac{Initial\ Investment\ Cost}{Annual\ Savings} \tag{3.8}$$

3.5.2 Net Present Value (NPV)

NPV technique involves determining the difference between the project's expenses and benefits with everything discounted to present value. A project with negative value of net present value indicates that the project will make loss and hence not viable. A positive value of net present value indicates that the project will make profit and hence worth for implementation. NPV method was used to evaluate the viability of the proposed solar PV plant at the DC facility because it takes the time value of money into consideration. NPV is calculated as indicated in Equation (3.9).

$$NPV = -I_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} \tag{3.9}$$

Where I_o is initial investment cost, t is the time duration ranging from 1 to n years, r is the annual discount rate and CF_t is the cash flow in a given year.

3.6 Conceptual Framework

As shown in Figure 3.3, this research project focused on addressing the problem of increased electrical energy consumption in DCs which has contributed to high energy demand across the globe as well as the increased GHG emissions to the environment. The approach employed data collection for P_{UE}, DC_{IE} and reliability analysis. The results were benchmarked against other global

DCs. The obtained data was also used to identify possible ECMs which when implemented can minimize the amount of energy consumption which in turn reduces the energy cost and the GHG emissions.

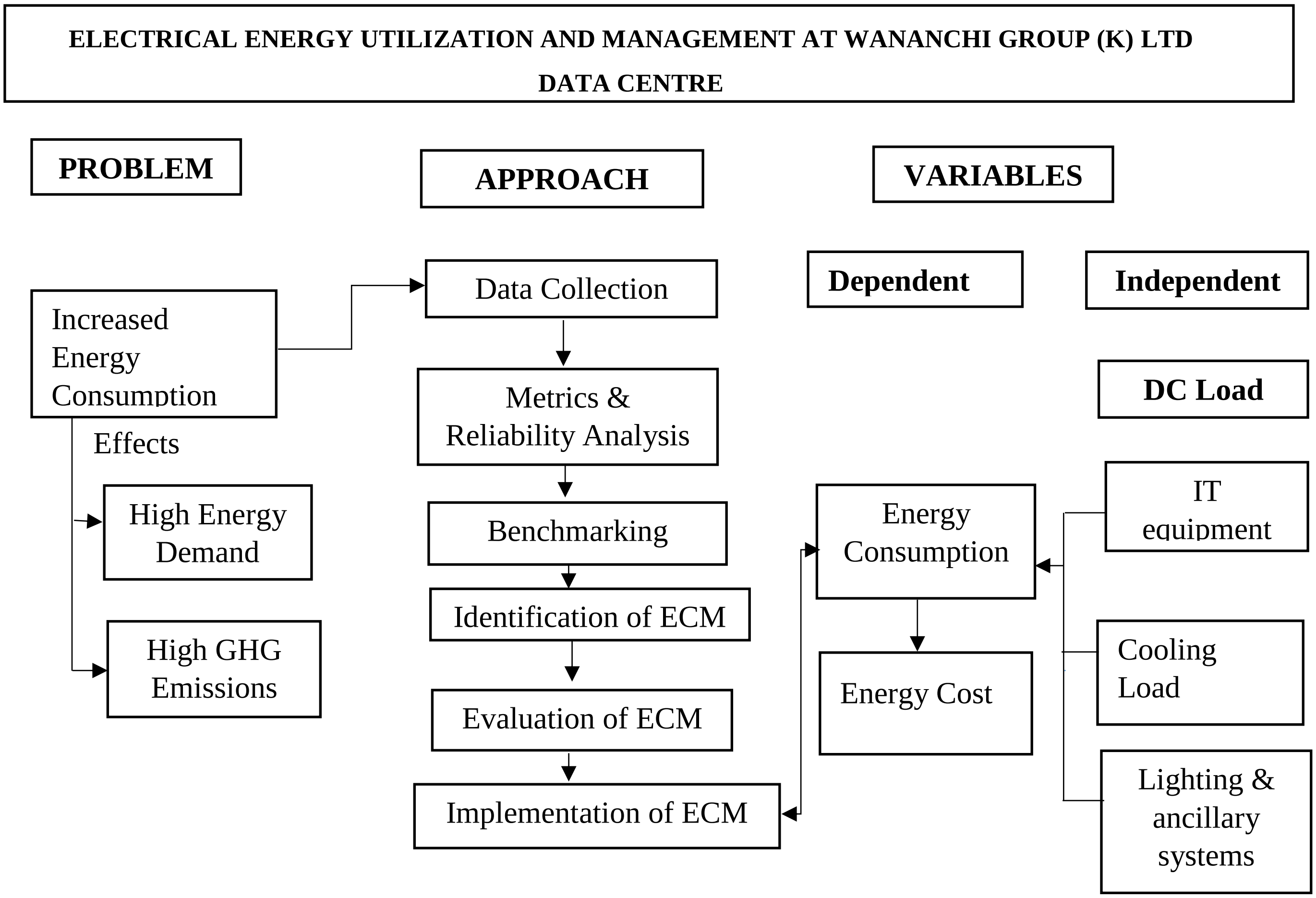

Figure 3. 3: Research Conceptual Framework

3.7 Assumptions

The following assumptions were made during this study;

i) No power losses are incurred in power cables feeding the power distribution units (PDUs) where the IT equipment are connected.

ii) The collected data reflects the IT energy for the last one and half years.

iii) The cost of the electrical energy consumed at the DC facility from the local utility company is Kshs 12.00 per unit.

iv) In the economic analysis of ECMs, 1 USD is taken to be equal to Kshs 116.

v) About 0.116kgs of carbon dioxide (CO_2) is associated with the generation of 1kWh [43].

vi) The average load of the case study DC (159.504kW) is used in calculating the monthly energy generated by the onsite diesel generator(s).

3.8 Conclusion

Several methods and tools were employed to collect and analyze data. The findings concerning the DC under consideration were used to evaluate its performance in terms of energy utilization and management in comparison with other DCs across the globe. The electrical energy utilization performance was depicted by P_{UE} and DC_{IE} metrics which are the recommended standards for benchmarking in DC industry. The findings on DC operating zones were compared with the ASHRAE guidelines to evaluate possibility of operating at higher temperatures. Finally from the identified DC energy performance, ECMs were identified and their economic analysis performed to determine their viability.

CHAPTER FOUR: RESULTS AND ANALYSIS

4.1 Introduction

This chapter contains the results of the data obtained from the historical records and real-time measurements of the electrical energy consumption, local utility mains power outages and the indoor operating condition at the case study DC. Analysis of the DC annual electrical energy consumption trend, P_{UE} and DC_{IE} metrics, envelope operating classes, possible ECMs including their economic analysis and validation is contained in the chapter. Benchmarking of the energy metrics and analysis of the local utility mains reliability at the DC facility is also captured.

4.2 Historical Electrical Energy Data for Wananchi Group (K) Limited Data Centre

4.2.1 Total Data Centre Energy

The annual electrical energy supply at the DC facility was studied from the data obtained from the local utility company bills for the entire year 2021 and the results were indicated in Table 4.1 with Figure 4.1 indicating a summary of the trend. From this data, the following observations are made;

i) The facility average power factor is 0.98 which is a good value. This has been achieved because there is a power factor correction bank installed at the facility. The ideal power factor should be 1. However, this can’t be achieved in ideal situation because of the inductive loads.

ii) The total electrical energy consumption per month varies between 89455kWh to 127468kWh. The variation noted throughout the year is as a result of variations in the outdoor environmental conditions which in turn causes changes in the cooling load. The lowest energy consumption noted in the month of August is attributed to the cold outdoor environmental condition within Nairobi which led to the reduced cooling load. Hot environmental condition normally experienced in Nairobi in the month of March is attributed to high energy consumption due to increased cooling load.

iii) Consolidated Cost (kshs/kWh) calculated using Equation (4.1) varies between 20.35 kshs/kWh to 22.70 kshs/kWh. Since the facility is billed by Kenya Power under CI1 tariff which has a unit energy charge of 12 kshs, there is a clear indication that other energy changes other than the demand charge contributes to less than half of the entire energy cost.

$$Consolidated\ Cost\ \left(\frac{kshs}{kWh}\right) = \frac{MEB}{MEC} \quad (4.1)$$

Where *MEB* is the monthly energy bill in Kshs and *MEC* is the monthly energy consumption in kWh

iv) Throughout the year, there is high electrical energy consumption during the high rate as compared to the low rate. This is because of the hot environmental condition which leads to high cooling load during the daytime.

Table 4. 1: Wananchi Group (Kenya) Ltd DC Energy Consumption Trend (Year 2021)

Month	High Rate (kWh)	Low Rate (kWh)	Total Energy (kWh)	Maximum Demand (kW)	Maximum Demand (kVA)	Power Factor	Monthly Bill (Kshs)	Consolidated Cost (kshs/kWh)
Jan-21	60767	61255	122022	170	174	0.98	2,515,083.00	20.61
Feb-21	55401	51746	107147	174	179	0.97	2,180,270.00	20.35
Mar-21	65006	62462	127468	176	179	0.98	2,672,606.00	20.97
Apr-21	55472	51975	107447	175	179	0.98	2,270,673.00	21.13
May-21	57082	52554	109636	181	185	0.98	2,272,580.00	20.73
Jun-21	60354	53233	113587	178	182	0.98	2,449,493.17	21.56
Jul-21	60751	57956	118707	168	171	0.98	2,556,187.00	21.53
Aug-21	47689	41766	89455	172	176	0.98	1,977,853.00	22.11
Sep-21	63281	61122	124403	165	168	0.98	2,671,548.00	21.47
Oct-21	54742	51247	105989	168	171	0.98	2,376,145.00	22.42
Nov-21	64099	62182	126281	170	174	0.98	2,752,055.00	21.79
Dec-21	61505	55292	116797	169	172	0.98	2,651,109.00	22.70

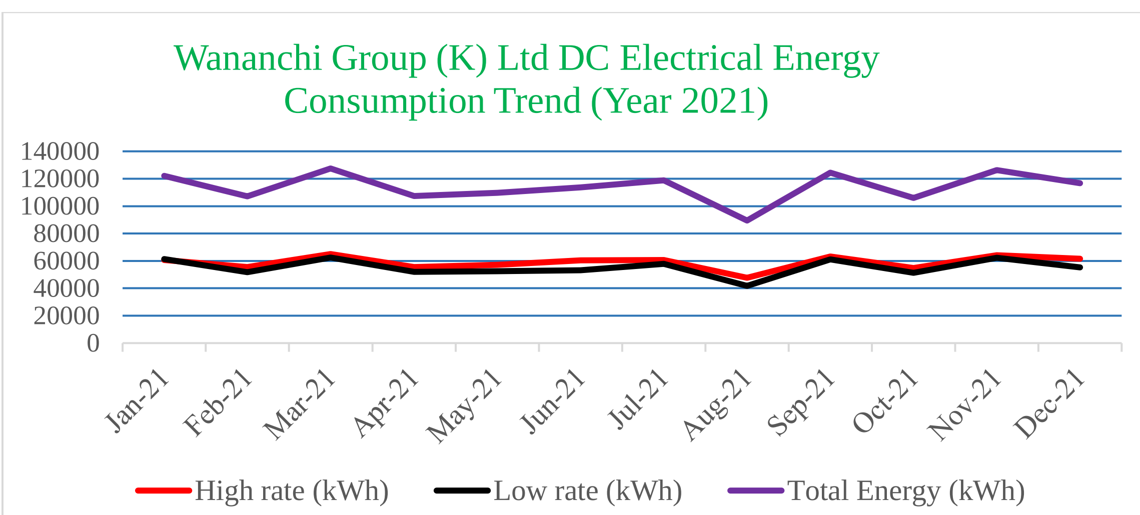

Figure 4. 1: Energy Consumption Trend Year 2021

4.2.2 IT Equipment Energy

From the data downloaded from the two 120 kVA UPSs' databases, it was noted that UPS 1 and UPS 2 store event logs with power parameters after every five and ten minutes respectively. Due to the limited storage memory in the two UPSs, power consumption data could only be stored for a maximum of three days after which the old data begins to be overwritten by the new data. To ensure continuous data, data was downloaded from the memory using the Tuner MGE Galaxy 5000 software after every two days and stored in excel covering a period of three weeks (21 days).

From Figure 4.2 and Table 4.2, there is a clear indication that the average UPS 2 load varies between 37kW to 38kW with the study period (21days) average load being 37.32kW. The daily average load variation ranges from 0.00 % to 0.03 %. This is expected since the power consumption of the IT equipment doesn't vary extensively with changes in the number of connected customers.

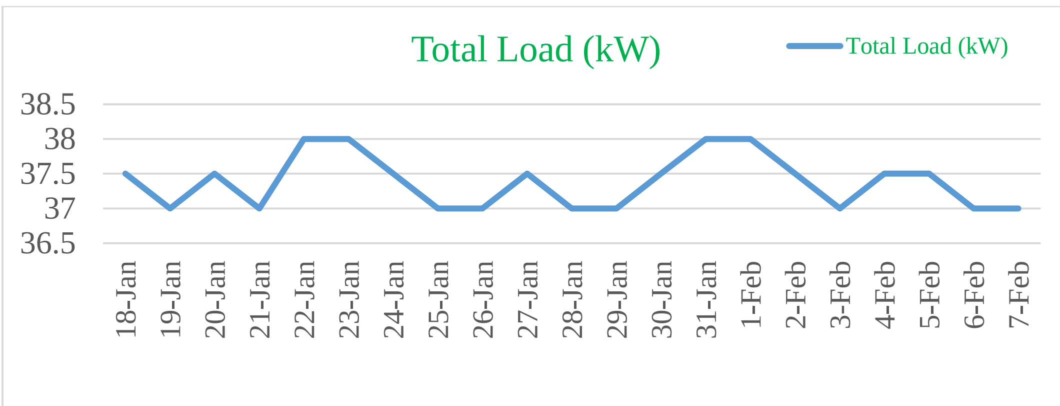

Figure 4. 2: UPS 2 Power Consumption Trend (for 21 days)

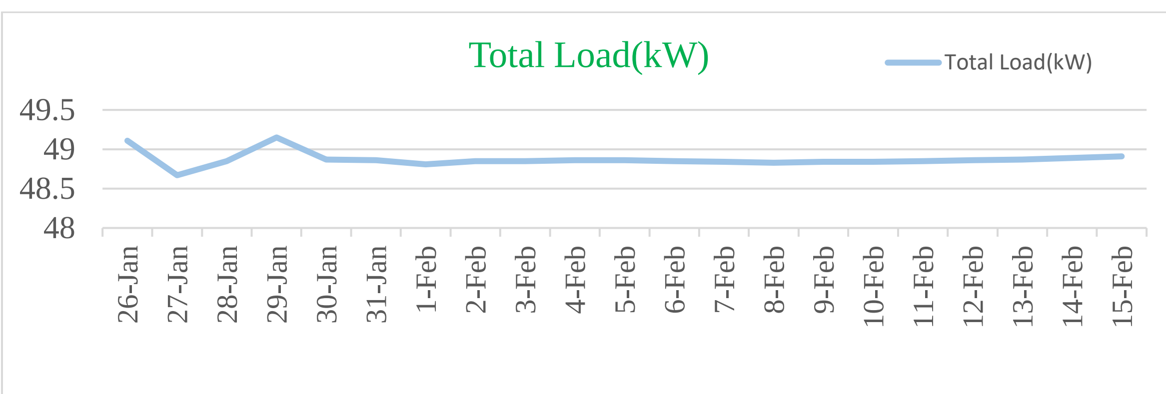

Figure 4. 3: UPS 1 Power Consumption Trend (for 21 days)

Table 4. 2: UPS 2 Data (18th Jan-14th Feb; 2022)

Date	Red Phase			Yellow Phase			Blue Phase			Total Load (kW)	Total Load (kVA)	Power Factor
	V(V)	I (A)	Load (kW)	V(V)	I (A)	Load (kW)	V(V)	I(A)	Load (kW)			
18-Jan	231	47	10	232	51	11	231	71	16	37.5	39	0.96
19-Jan	232	46	10	232	50	11	231	70	15	37	39	0.95
20-Jan	231	47	10	232	51	11	231	71	16	37.5	39	0.96
21-Jan	231	47	10	232	52	11	232	70	16	37	39	0.95
22-Jan	231	46	10	232	51	11	232	69	15	38	39	0.97
23-Jan	231	47	10	232	54	12	232	70	15	38	39	0.97
24-Jan	232	47	10	232	52	11	231	70	16	37.5	39	0.96
25-Jan	231	47	10	231	51	11	232	69	15	37	38	0.97
26-Jan	231	46	10	232	52	11	231	69	15	37	39	0.95
27-Jan	232	47	10	232	52	11	231	69	15	37.5	38	0.99
28-Jan	231	46	10	232	50	11	231	69	15	37	38	0.97
29-Jan	231	46	10	231	51	11	231	68	15	37	39	0.95
30-Jan	231	46	10	232	54	12	232	70	16	37.5	39	0.96
31-Jan	231	47	10	232	53	12	231	71	15	38	39	0.97
1-Feb	232	46	10	232	52	11	231	69	15	38	39	0.97
2-Feb	232	47	10	232	54	12	232	71	15	37.5	40	0.94
3-Feb	232	46	10	232	51	11	231	70	15	37	38	0.97
4-Feb	232	47	10	232	52	11	232	69	15	37.5	39	0.96
5-Feb	232	47	10	232	51	11	231	70	15	37.5	39	0.96
6-Feb	232	47	10	232	51	11	231	70	15	37	39	0.95
7-Feb	232	46	10	232	51	11	231	69	15	37	39	0.95
8-Feb	232	48	10	232	53	11	231	68	15	37	39	0.95
9-Feb	231	46	10	232	53	11	232	69	15	37	39	0.95
10-Feb	231	46	9	232	54	11	232	70	15	37.5	39	0.96
11-Feb	232	47	10	232	53	11	231	69	15	37	39	0.95
12-Feb	232	47	10	232	53	11	231	69	15	37.5	38	0.99
13-Feb	231	47	10	232	52	11	232	68	15	37	38	0.97
14-Feb	232	47	10	232	51	11	231	70	15	37	39	0.95

Table 4. 3: UPS 1 Data (26th Jan – 15th Feb; 2022)

Date	Output Voltage (V)	Output Load (%)	Output Current (A)			Battery Capacity (%)	Remaining Time (min)	Total Load (kVA)	Total Load (kW)
			Phase 1	Phase 2	Phase 3				
26-Jan	400.77	42.63	100.40	88.24	33.43	100.00	51.68	51.16	49.11
27-Jan	400.94	42.24	99.40	87.82	33.08	100.00	52.04	50.69	48.67
28-Jan	400.92	42.41	99.64	88.08	33.05	100.00	52.02	50.89	48.85
29-Jan	400.89	42.66	100.88	88.16	33.07	100.00	51.53	51.19	49.15
30-Jan	400.89	42.42	100.00	88.00	33.00	100.00	51.94	50.90	48.87
31-Jan	400.89	42.41	99.84	88.08	33.06	100.00	51.88	50.90	48.86
1-Feb	400.90	42.37	99.58	88.08	33.04	100.00	51.93	50.84	48.81
2-Feb	400.90	42.40	99.75	88.07	33.04	100.00	51.86	50.88	48.85
3-Feb	400.90	42.40	99.75	88.07	33.04	100.00	51.86	50.88	48.85
4-Feb	400.89	42.41	99.82	88.07	33.02	100.00	51.83	50.90	48.86
5-Feb	400.89	42.41	99.84	88.05	33.02	100.00	51.86	50.89	48.86
6-Feb	400.88	42.41	99.81	88.04	33.01	100.00	51.88	50.89	48.85
7-Feb	400.87	42.39	99.77	88.04	33.00	100.00	51.87	50.87	48.84
8-Feb	400.86	42.39	99.71	88.07	32.99	100.00	51.87	50.87	48.83
9-Feb	400.86	42.40	99.68	88.14	33.00	100.00	51.84	50.88	48.84
10-Feb	400.84	42.40	99.63	88.18	32.99	100.00	51.82	50.87	48.84
11-Feb	400.82	42.40	99.62	88.23	33.00	100.00	51.79	50.88	48.85
12-Feb	400.82	42.42	99.62	88.27	33.01	100.00	51.77	50.90	48.86
13-Feb	400.82	42.43	99.61	88.31	33.02	100.00	51.75	50.91	48.87
14-Feb	400.82	42.44	99.63	88.35	33.03	100.00	51.72	50.92	48.89
15-Feb	400.83	42.45	99.68	88.38	33.03	100.00	51.70	50.95	48.91

From the collected data regarding UPS 1 as shown in Figure 4.3 and Table 4.3, the UPS load varies between 48.67 kW to 49.15 kW with the study period average load being 48.87 kW. The daily average load variation ranges from 0.00 % to 0.90 % indicating a small change in the UPS load. It is also noted that UPS 1 has a higher load as compared to UPS 2. This is because more IT equipment are connected to the former than the latter. Using Equation (4.2), the DC facility total IT equipment load was 86.19 kW.

$$Total\ IT\ load = UPS\ 1\ Load + UPS\ 2\ Load \tag{4.2}$$

4.3 Energy Metrics for Analyzing Energy Efficiency at Wananchi Group (K) Ltd DC

Monthly P_{UE} and DC_{IE} metrics were calculated using Equations (3.1) and (3.2) and the results contained in Table 4.4. For the entire year 2021, the monthly total DC energy was the sum of the energy supplied by the local utility company as indicated in the monthly Kenya Power bills and the energy supplied by the onsite diesel generator in the respective month. The monthly IT equipment energy was obtained using Equation (4.3) assuming a constant IT equipment load of 86.19kW and extrapolated to cover the entire year.

$$Monthly\ IT\ Energy(kWh) = Total\ IT\ load\ (kW) * 24\ (hrs) * Days\ in\ month \tag{4.3}$$

Data contained in Table 4.4 includes the energy generated by the onsite diesel generator during the local utility power outages. The data was used in the analysis of P_{UE} and DC_{IE} metrics contained in Figures 4.4 and 4.5.

Table 4. 4: Wananchi Group (Kenya) Ltd Data Centre Energy Metrics (Year 2021)

Month	Monthly Total DC Energy (kWh)	Monthly IT Energy (kWh)	P_{UE} Metric	D_{CIE} Metric (%)
Jan-21	122022	64125.36	1.90	52.55
Feb-21	107966.851	57919.68	1.86	53.65
Mar-21	127511.067	64125.36	1.99	50.29
Apr-21	107447	62056.8	1.73	57.76
May-21	109982.124	64125.36	1.72	58.31
Jun-21	114102.198	62056.8	1.84	54.39
Jul-21	118892.024	64125.36	1.85	53.94
Aug-21	89455	64125.36	1.40	71.68
Sep-21	124403	62056.8	2.00	49.88
Oct-21	105989	64125.36	1.65	60.50
Nov-21	126281	62056.8	2.03	49.14
Dec-21	117690.22	64125.36	1.84	54.49
		Annual Metrics	**1.82**	**55.55**

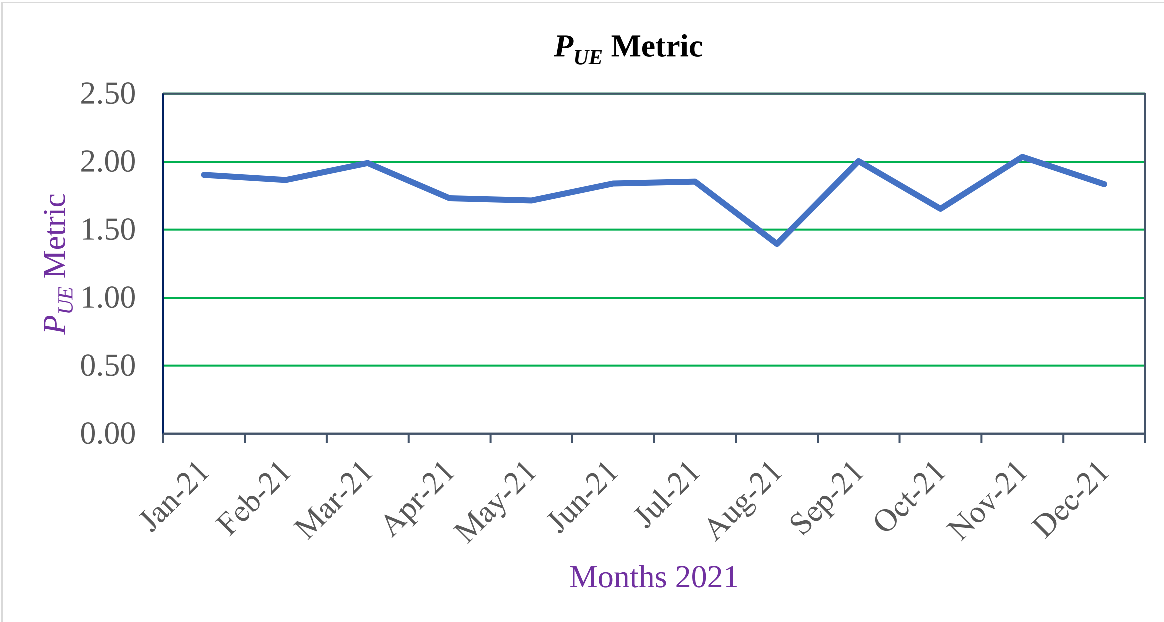

Figure 4. 4: Wananchi Group (K) Ltd Data Centre P_{UE} Metric Trend for the Year 2021

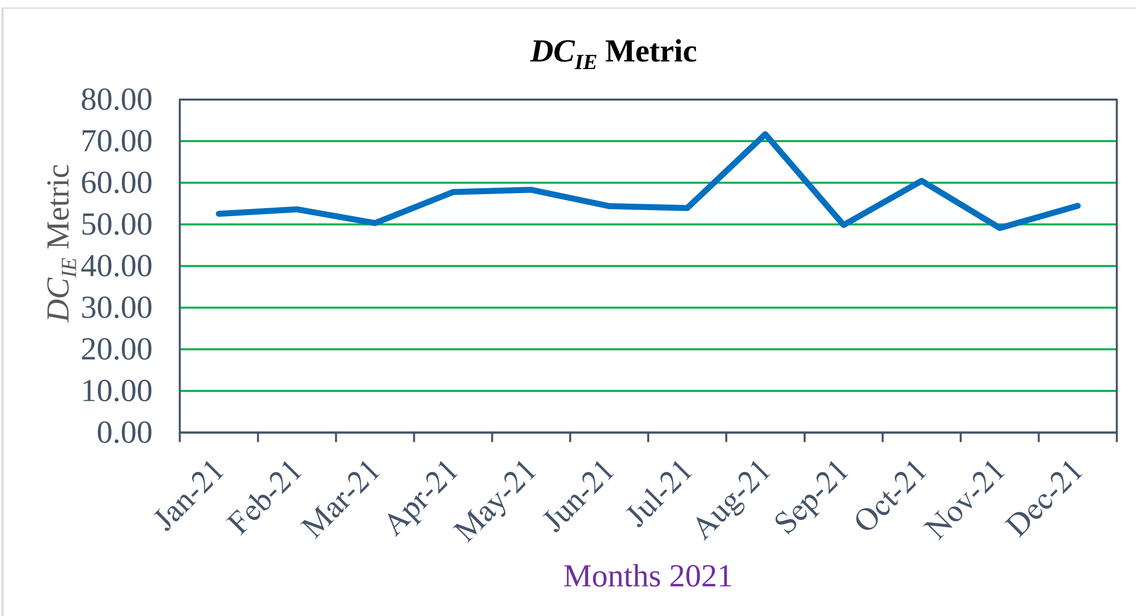

Figure 4. 5: Wananchi Group (K) Ltd Data Centre DC_{IE} Metric Trend for the Year 2021

The following observations were made from the analysis of P_{UE} and DC_{IE} metrics as indicated in Figures 4.4 and 4.5 and Table 4.4.

i) The DC P_{UE} metric varies from 1.40 to 2.03 with the best value being noted in the month of August and the worst in November. The best P_{UE} noted in August is attributed to the cold outdoor environmental condition in the month which led to the reduced cooling load at the DC facility hence minimized energy consumption taking into consideration the IT equipment load is constant. In November, the outdoor environmental condition was hot hence increased cooling load at the DC facility leading to increased energy consumption.

ii) DC DC_{IE} varies between 49.14% to 71.68% in the months of November and August respectively. This is also attributed to the variations in the outdoor environmental conditions within the months which affected the cooling load.

iii) The DC facility annual P_{UE} and DC_{IE} metrics are 1.82 and 55.55% indicating an average energy efficiency as indicated in Table 4.5. The DC_{IE} annual value of 55.55% indicates that in the year 2021, 55.55 % of the energy supplied to the facility was used to power the IT equipment with the remaining amount (44.45 %) being consumed by the DC support systems.

Table 4. 5: Metrics as a Measure of Level of Energy Efficiency [44]

P_{UE}	DC_{IE}	**Level of efficiency**
3.0	33%	Very Inefficient
2.5	40%	Inefficient
2.0	50%	Average
1.5	67%	Efficient
1.3	83%	Very Efficient

4.4 Benchmarking of Energy Metrics

Results obtained from the analysis of the case study DC facility metrics in section 4.3 were compared with the results available in the literature from the others DCs across the globe as summarized in Table 4.6. It is observed that Wananchi Group (K) Ltd DC has a better P_{UE} value compared to PCTL DC in Pakistan, same average value as the one obtained from European Union DCs involving a sample of 289 DCs. However, the Wananchi Group (K) Ltd DC has a poor P_{UE} value compared to Prineville DC in USA. A better P_{UE} (1.08) obtained in Prineville DC was as a result of minimal energy consumption by cooling system due to the DC design [11]. A poor P_{UE} (3.3) obtained in a DC from Pakistan was due to the lack of awareness of green and energy-efficient concepts among the DC managers and high outdoor temperatures in the region [30]. The average level of energy efficiency (P_{UE} =1.82) at Wananchi Group (K) Ltd DC has been achieved due to the already implemented ECMs at the DC facility.

Table 4. 6: Benchmarking of Energy Metrics

Data Centre	***P_{UE}* Metric**	***DC_{IE}* Metric (%)**	**Level of Efficiency**
Wananchi Group (Kenya) Ltd DC, Kenya	1.82	55.55	Average
PCTL DC, Pakistan [44]	3.3	30.3	Very Inefficient
Prineville DC, USA [11]	1.08	92.59	Very efficient
European Union DC, Europe [30]	1.8	55.56	Average

4.5 Real-time Data Measurements

4.5.1 Energy Measurements

Fluke 435-II power quality and analyzer was installed at the local utility supply point of the case study DC from 2nd March to 5th March 2022 and the obtained results were indicated from Figure 4.6 to Figure 4.11.

Summary / **Upper extreme values** / **Lower extreme values**

Summary				Upper extreme values: Date / Time	Value	Lower extreme values: Date / Time	Value
From	3/2/2022 10:12:49 AM	5% percentile	1.495E5 W	3/5/2022 2:38:39 PM	177060	3/4/2022 6:23:19 AM	139920
To	3/5/2022 2:40:49 PM	95% percentile	1.688E5 W	3/3/2022 3:57:29 PM	176760	3/5/2022 3:53:54 AM	139980
Maximum value	177060 W	% [85% - 110%]	0%	3/4/2022 4:08:09 PM	176580	3/3/2022 4:45:34 AM	139980
At	3/5/2022 2:38:39 PM	% [90% - 110%]	0 %	3/4/2022 3:00:14 PM	176400	3/4/2022 4:33:29 AM	140040
Minimum value	139920 W			3/4/2022 3:03:44 PM	176220	3/4/2022 6:23:04 AM	140220
At	3/4/2022 6:23:19 AM						
μ (Avg)	159504 W						
s	5649.73 W						

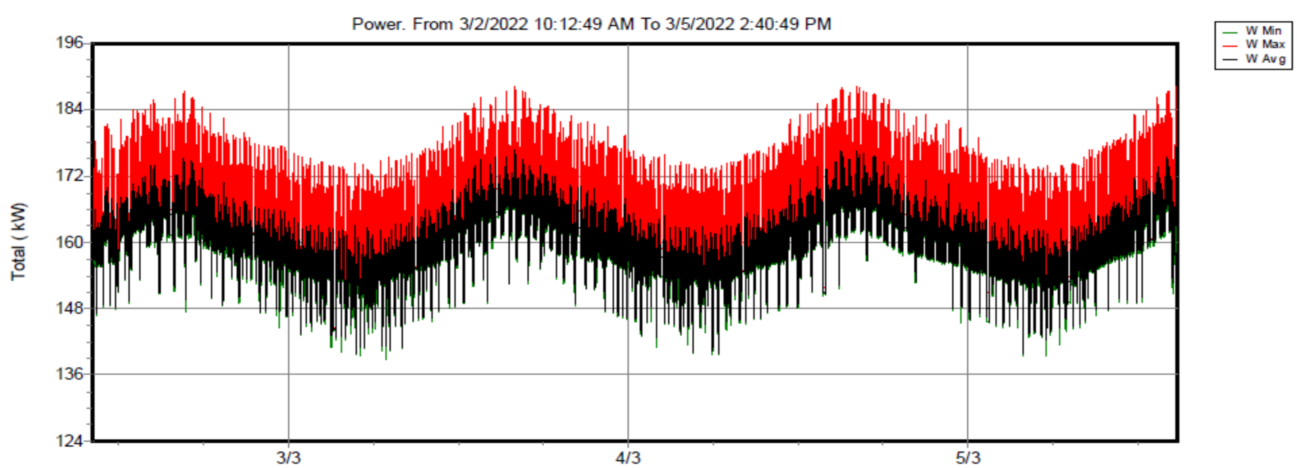

Figure 4. 6: Total Active Power Consumption Trend (2nd March to 5th March 2022)

From Figure 4.6, it was noted that the total DC energy consumption trend is repetitive within the 3 days. The highest load was noted to be 177.06 kW, the minimum load was 139.920 kW and the average load 159.504 kW. It was also noted that the maximum (peak) load at the DC facility occurred in the afternoon hours between 2 pm to 4.30 pm every day. This peak load was attributed to high cooling load due to the hot environmental conditions in Nairobi experienced in the afternoon hours with the peak being between 2pm to 4pm. The minimum load was noted to be in the early morning hours between 4 am to 6.30 am every day due to the reduced cooling load as a result of lower outdoor temperatures. It was therefore concluded that the DC cooling load defined the facility energy consumption trend.

Summary				Upper extreme values		Lower extreme values	
				Date / Time	Value	Date / Time	Value
From	3/2/2022 10:12:49 AM	5% percentile	5.184E4 W	3/4/2022 4:09:29 PM	61440	3/3/2022 5:19:49 AM	47560
To	3/5/2022 2:40:49 PM	95% percentile	5.916E4 W	3/4/2022 4:08:59 PM	61440	3/3/2022 3:59:04 AM	47840
Maximum value	61440 W	% [85% - 110%]	0%	3/4/2022 4:09:14 PM	61400	3/3/2022 5:20:04 AM	47860
At	3/4/2022 4:08:59 PM	% [90% - 110%]	0 %	3/4/2022 4:06:19 PM	61320	3/3/2022 3:59:09 AM	47900
Minimum value	47560 W			3/4/2022 5:32:49 PM	61280	3/3/2022 3:58:59 AM	47900
At	3/3/2022 5:19:49 AM						
μ (Avg)	55707.9 W						
s	2213.57 W						

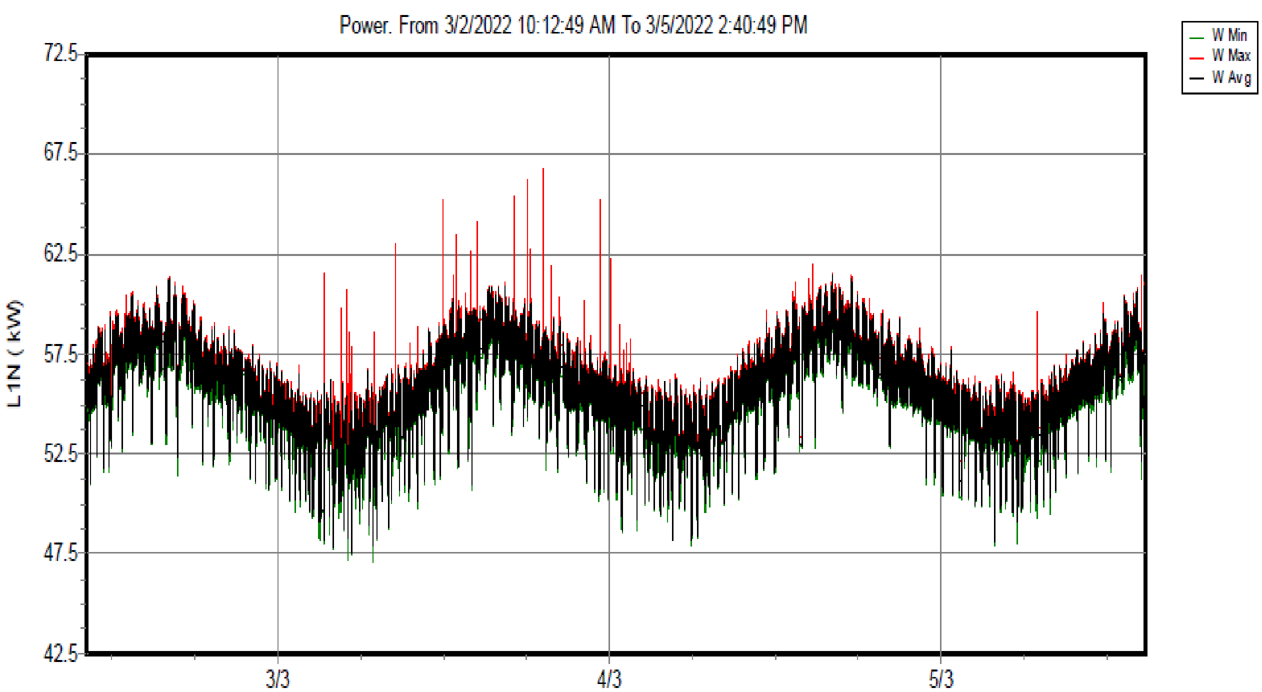

Figure 4. 7: Phase 1 Power Consumption Trend (2nd March to 5th March 2022)

Summary

From	3/2/2022 10:12:49 AM	5% percentile	4.81E4 W
To	3/5/2022 2:40:49 PM	95% percentile	5.442E4 W
Maximum value	59700 W	% [85% - 110%]	0%
At	3/3/2022 3:57:29 PM	% [90% - 110%]	0 %
Minimum value	44700 W		
At	3/4/2022 6:23:19 AM		
µ (Avg)	51195 W		
s	1863.9 W		

Upper extreme values

Date / Time	Value
3/3/2022 3:57:29 PM	59700
3/3/2022 2:42:59 PM	59540
3/4/2022 4:39:04 PM	59460
3/3/2022 3:54:04 PM	59360
3/4/2022 3:00:14 PM	59340

Lower extreme values

Date / Time	Value
3/4/2022 6:23:19 AM	44700
3/4/2022 6:23:04 AM	44760
3/5/2022 3:53:54 AM	44780
3/3/2022 4:45:34 AM	44820
3/4/2022 6:23:34 AM	44840

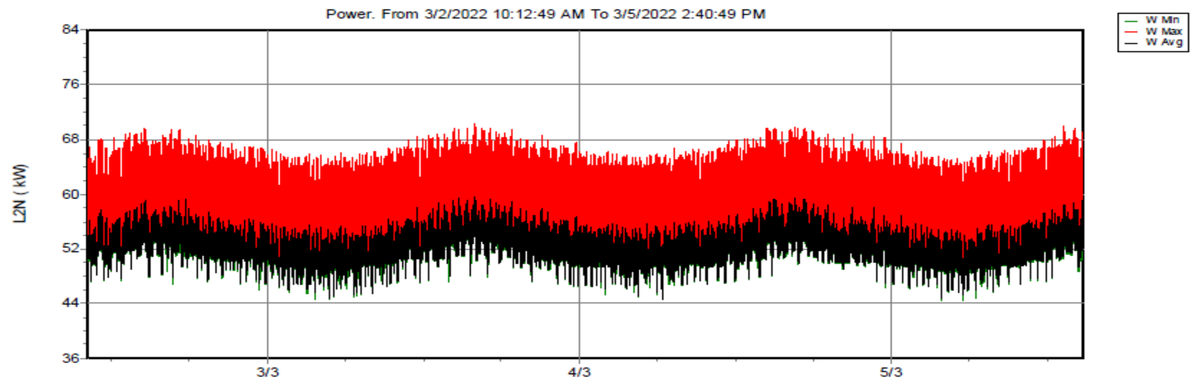

Figure 4. 8: Phase 2 Power Consumption Trend (2nd March to 5th March 2022)

Summary

From	3/2/2022 10:12:49 AM	5% percentile	4.954E4 W
To	3/5/2022 2:40:49 PM	95% percentile	5.55E4 W
Maximum value	57440 W	% [85% - 110%]	0%
At	3/5/2022 2:38:39 PM	% [90% - 110%]	0 %
Minimum value	46400 W		
At	3/3/2022 4:45:34 AM		
µ (Avg)	52601.2 W		
s	1760.55 W		

Upper extreme values

Date / Time	Value
3/5/2022 2:38:39 PM	57440
3/5/2022 2:38:49 PM	57300
3/5/2022 2:39:04 PM	57260
3/5/2022 2:39:39 PM	57200
3/5/2022 2:38:44 PM	57180

Lower extreme values

Date / Time	Value
3/3/2022 4:45:34 AM	46400
3/4/2022 5:58:49 AM	46540
3/4/2022 5:59:04 AM	46560
3/3/2022 4:45:49 AM	46560
3/3/2022 4:45:19 AM	46600

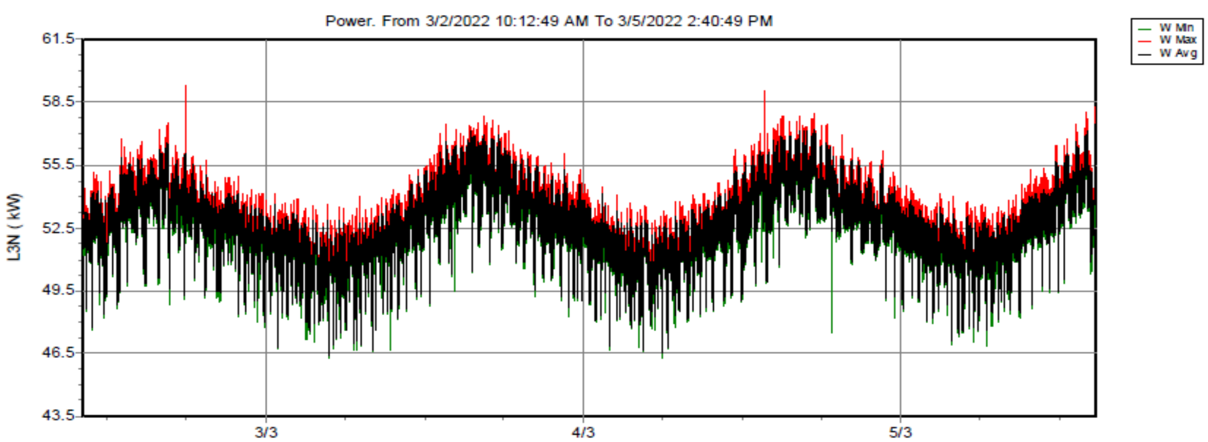

Figure 4. 9: Phase 3 Power Consumption Trend (2nd March to 5th March 2022)

Figure 4.7 to Figure 4.9 shows the power consumption trend per phase which resembled the total active power consumption trend. However, phase 1 (red phase) had a higher load (average 55.707kW) followed by yellow phase (average 52.601 kW) and finally the blue phase (average 51.195kW). This indicated more IT equipment are connected to the red phase as compared to the other two phases.

Figure 4.10 to Figure 4.12 shows the current utilized per phase from 2nd March to 5th March 2022. Red phase (Phase 1) had the highest load current (average: 236.12 A) followed by yellow phase (average: 222.53 A). Blue phase (phase 2) had the least load current (average: 215.93 A). It was also noticed that the peak current occurred during the afternoon hours due to the high cooling load with the minimum current being noted in the early morning hours.

Summary				Upper extreme values		Lower extreme values	
				Date / Time	Value	Date / Time	Value
From	3/2/2022 10:12:49 AM	5% percentile	218.8 A	3/2/2022 4:06:19 PM	261.5999	3/3/2022 5:19:49 AM	200.4
To	3/5/2022 2:40:49 PM	95% percentile	251.2 A	3/2/2022 4:06:24 PM	261.3	3/3/2022 3:59:09 AM	201.3
Maximum value	261.6 A	% [85% - 110%]	0%	3/4/2022 4:09:29 PM	261.0999	3/3/2022 5:20:04 AM	201.5
At	3/2/2022 4:06:19 PM	% [90% - 110%]	0 %	3/2/2022 4:06:14 PM	261.0999	3/3/2022 3:59:04 AM	201.5
Minimum value	200.4 A			3/2/2022 4:05:29 PM	261.0999	3/3/2022 3:59:14 AM	201.6
At	3/3/2022 5:19:49 AM						
µ (Avg)	236.122 A						
s	9.73343 A						

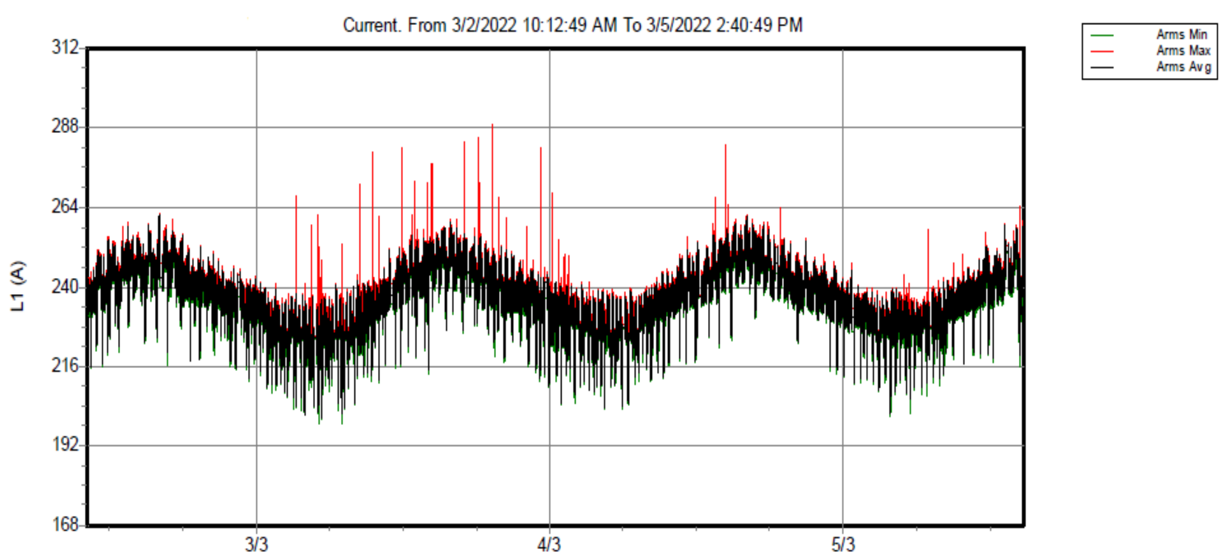

Figure 4. 10: Phase 1 Current Trend (2nd March to 5th March 2022)

Summary

From	3/2/2022 10:12:49 AM	5% percentile	202 A
To	3/5/2022 2:40:49 PM	95% percentile	230.4 A
Maximum value	256.4 A	% [85% - 110%]	0%
At	3/3/2022 2:42:59 PM	% [90% - 110%]	0 %
Minimum value	187.4 A		
At	3/3/2022 4:45:34 AM		
μ (Avg)	215.93 A		
s	8.39873 A		

Upper extreme values

Date / Time	Value
3/3/2022 2:42:59 PM	256.4
3/3/2022 3:57:29 PM	255.3
3/4/2022 3:00:14 PM	255
3/2/2022 5:42:04 PM	254.9
3/3/2022 5:07:14 PM	254.7

Lower extreme values

Date / Time	Value
3/3/2022 4:45:34 AM	187.4
3/5/2022 3:53:24 AM	187.7
3/5/2022 3:53:04 AM	187.7
3/5/2022 3:53:54 AM	187.8
3/5/2022 3:53:39 AM	187.9

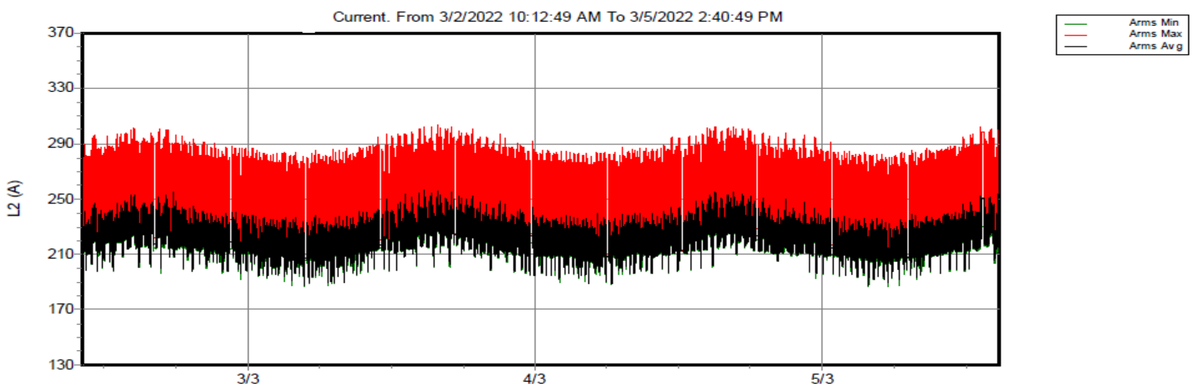

Figure 4. 11: Phase 2 Current Trend (2nd March to 5th March 2022)

Summary

From	3/2/2022 10:12:49 AM	5% percentile	208.7 A
To	3/5/2022 2:40:49 PM	95% percentile	235.6 A
Maximum value	242.6 A	% [85% - 110%]	0%
At	3/3/2022 3:50:19 PM	% [90% - 110%]	0 %
Minimum value	194.7 A		
At	3/3/2022 4:45:34 AM		
μ (Avg)	222.533 A		
s	7.77989 A		

Upper extreme values

Date / Time	Value
3/3/2022 3:50:19 PM	242.6
3/5/2022 2:38:39 PM	242.2
3/3/2022 3:50:34 PM	242.1
3/3/2022 3:49:44 PM	242.1
3/4/2022 2:26:09 PM	242

Lower extreme values

Date / Time	Value
3/3/2022 4:45:34 AM	194.7
3/3/2022 4:45:19 AM	195.6
3/3/2022 4:45:49 AM	195.7
3/3/2022 12:53:59 AM	195.7
3/3/2022 12:53:54 AM	195.8

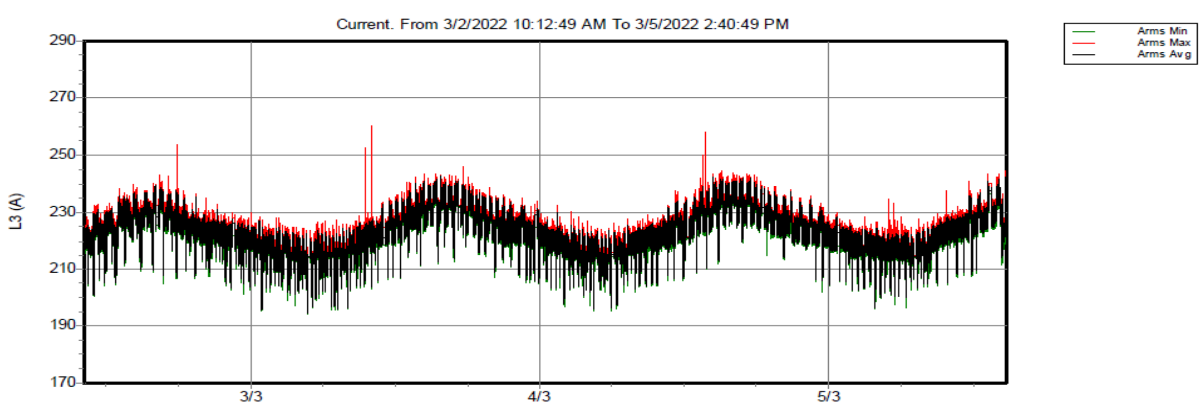

Figure 4. 12: Phase 3 Current Trend (2nd March to 5th March 2022)

Figure 4.13 shows the active, reactive and apparent energy consumption trend. The minimal reactive energy consumption trend indicated a good power factor at the DC facility (average: 0.98) as shown in Figure 4.15 which is above the Kenya Power recommended value (0.9) below which a facility attracts a surcharge from the utility [10]. The good power factor was as a result of the power factor correction bank installed at the DC facility. Figure 4.14 shows the energy losses at the facility.

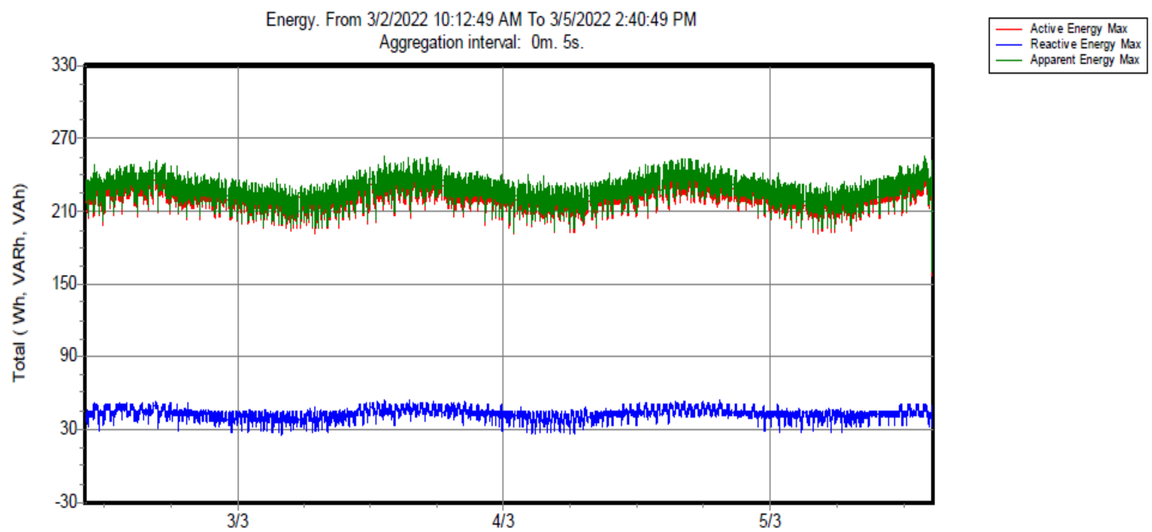

Figure 4. 13: Energy Consumption Trend (2nd March to 5th March 2022)

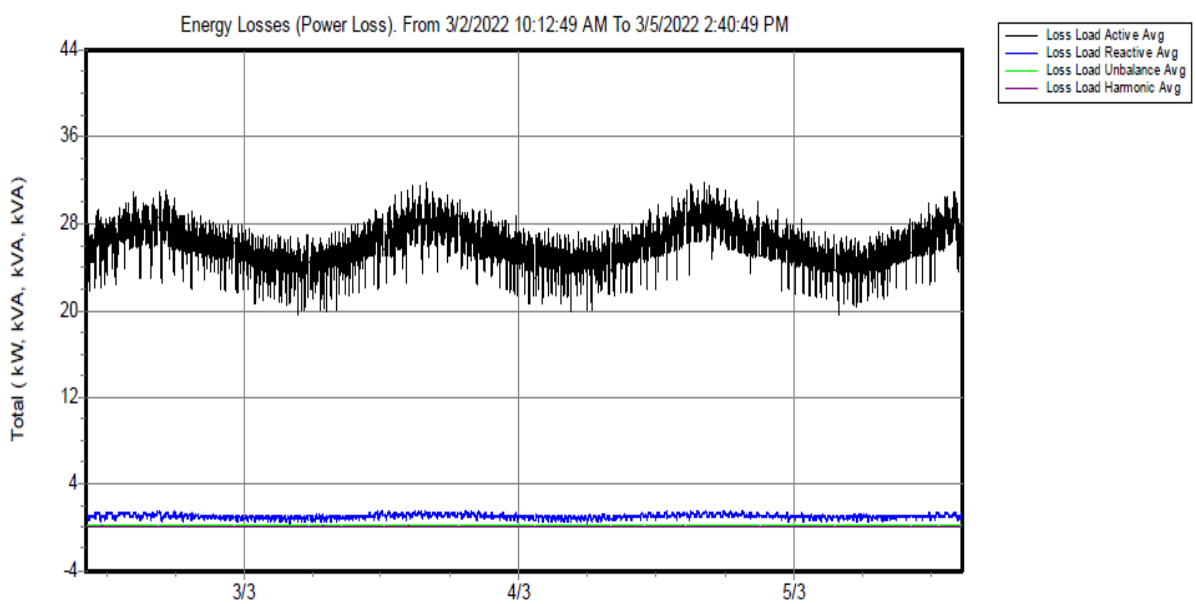

Figure 4. 14: Energy Losses (2nd March to 5th March 2022)

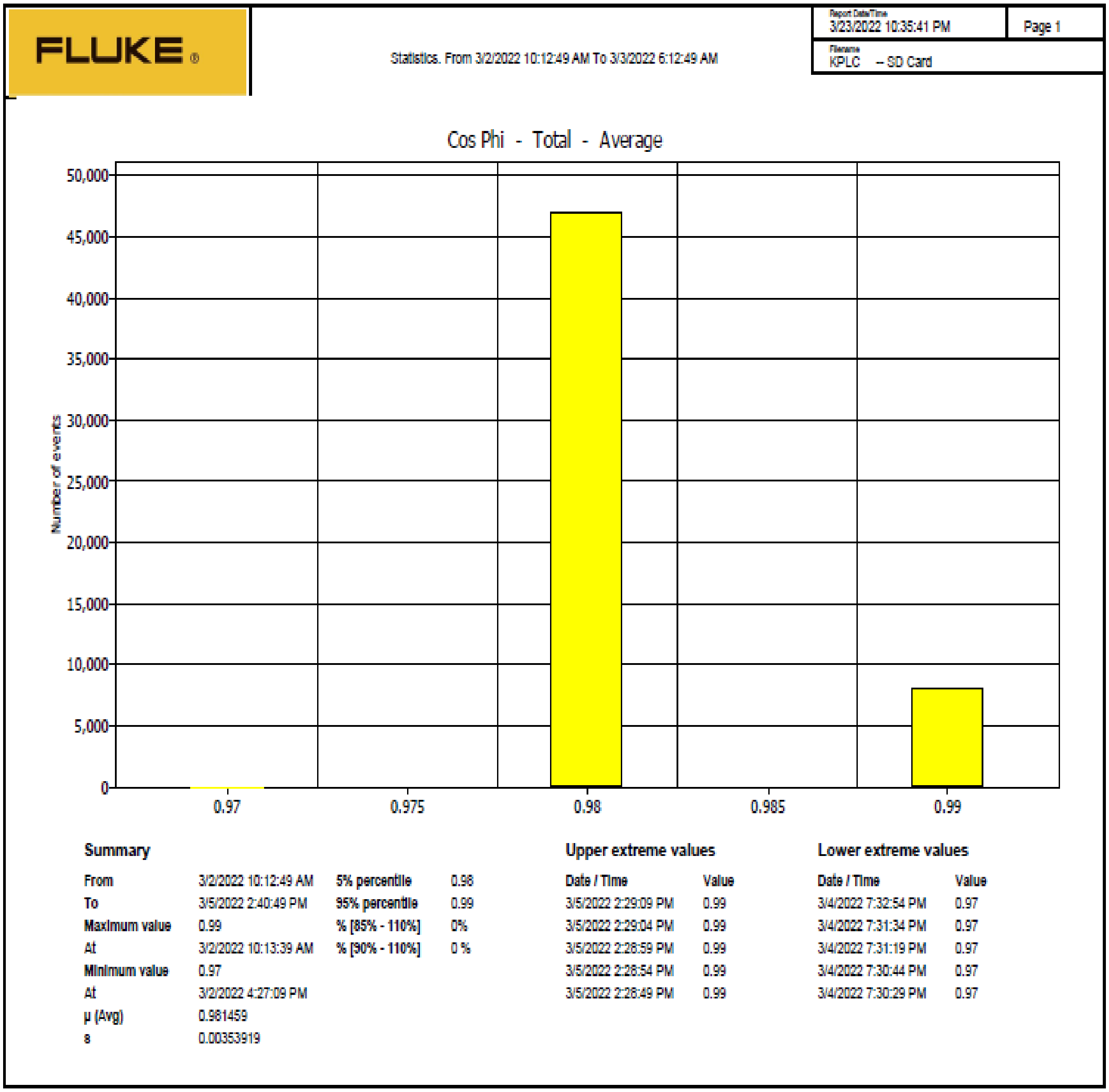

Figure 4. 15: Data Centre Power Factor (2nd March to 5th March 2022)

Figure 4.16 to Figure 4.19 shows the power consumption trend for the four PDX air conditioners located at the DC facility with AC 2 being the major energy consumer (average: 19.65kW) and AC 3 being the least energy consumer (4.96kW). From the power real-time measurements done at the facility, IT equipment power data collected from the UPS and the lighting audit, Figure 4.20 shows the shared load at the facility.

Summary				Upper extreme values		Lower extreme values	
From	2/27/2022 4:22:09 PM	5% percentile	1.236E4 W	Date / Time	Value	Date / Time	Value
To	2/28/2022 4:07:09 PM	95% percentile	1.941E4 W	2/27/2022 4:37:09 PM	19560	2/28/2022 12:07:09 AM	11310
Maximum value	19560 W	% [85% - 110%]	0%	2/27/2022 4:22:09 PM	19530	2/28/2022 5:22:09 AM	11760
At	2/27/2022 4:37:09 PM	% [90% - 110%]	0 %	2/27/2022 4:52:09 PM	19500	2/28/2022 2:37:09 AM	11850
Minimum value	11310 W			2/27/2022 5:07:09 PM	19470	2/28/2022 1:07:09 AM	11970
At	2/28/2022 12:07:09 AM			2/28/2022 3:37:09 PM	19410	2/28/2022 6:37:09 AM	12360
µ (Avg)	17440.6 W						
s	1794.71 W						

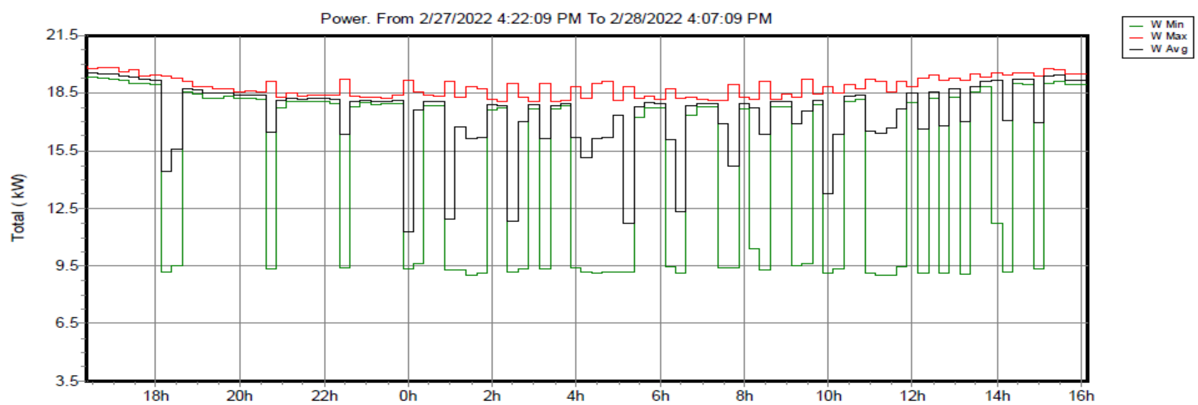

Figure 4. 16: Air Conditioner 1 Power Consumption Trend

Summary				Upper extreme values		Lower extreme values	
From	3/5/2022 3:00:35 PM	5% percentile	1.827E4 W	Date / Time	Value	Date / Time	Value
To	3/6/2022 7:02:35 PM	95% percentile	2.13E4 W	3/6/2022 3:46:35 PM	21630	3/6/2022 6:15:35 AM	18000
Maximum value	21630 W	% [85% - 110%]	0%	3/6/2022 3:28:35 PM	21630	3/6/2022 6:50:35 AM	18060
At	3/6/2022 3:28:35 PM	% [90% - 110%]	0 %	3/6/2022 3:30:35 PM	21600	3/6/2022 6:40:35 AM	18060
Minimum value	18000 W			3/5/2022 4:08:35 PM	21600	3/6/2022 6:36:35 AM	18090
At	3/6/2022 6:15:35 AM			3/6/2022 3:50:35 PM	21570	3/6/2022 6:19:35 AM	18090
µ (Avg)	19647.9 W						
s	1078.18 W						

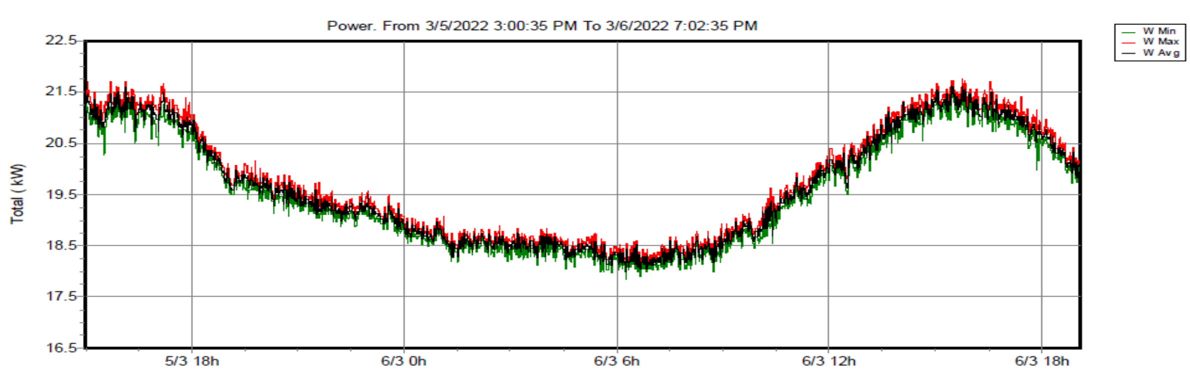

Figure 4. 17: Air Conditioner 2 Power Consumption Trend

Summary

From	2/28/2022 4:35:05 PM	5% percentile	1440 W
To	3/1/2022 4:30:05 PM	95% percentile	5760 W
Maximum value	5940 W	% [85% - 110%]	0%
At	2/28/2022 4:35:05 PM	% [90% - 110%]	0 %
Minimum value	1380 W		
At	2/28/2022 8:50:05 PM		
µ (Avg)	4960.63 W		
s	1222.3 W		

Upper extreme values

Date / Time	Value
2/28/2022 4:35:05 PM	5940
2/28/2022 5:20:05 PM	5880
2/28/2022 4:40:05 PM	5880
2/28/2022 5:15:05 PM	5850
2/28/2022 6:05:05 PM	5820

Lower extreme values

Date / Time	Value
3/1/2022 6:20:05 AM	1380
3/1/2022 4:45:05 AM	1380
3/1/2022 3:30:05 AM	1380
3/1/2022 1:15:05 AM	1380
2/28/2022 9:55:05 PM	1380

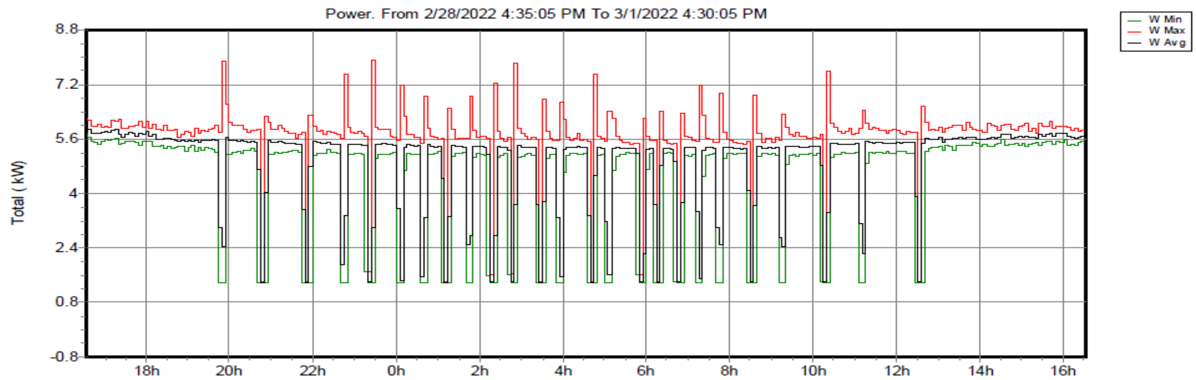

Figure 4. 18: Air Conditioner 3 Power Consumption Trend

Summary

From	3/6/2022 7:14:45 PM	5% percentile	4890 W
To	3/8/2022 6:09:45 PM	95% percentile	7980 W
Maximum value	8790 W	% [85% - 110%]	0%
At	3/8/2022 3:20:45 PM	% [90% - 110%]	0 %
Minimum value	3570 W		
At	3/7/2022 8:30:45 AM		
µ (Avg)	5969.7 W		
s	902.136 W		

Upper extreme values

Date / Time	Value
3/8/2022 3:20:45 PM	8790
3/8/2022 4:55:45 PM	8730
3/8/2022 4:06:45 PM	8730
3/8/2022 4:59:45 PM	8670
3/8/2022 4:34:45 PM	8670

Lower extreme values

Date / Time	Value
3/7/2022 8:30:45 AM	3570
3/7/2022 8:34:45 AM	3600
3/7/2022 8:31:45 AM	3690
3/7/2022 8:32:45 AM	3720
3/7/2022 8:35:45 AM	3780

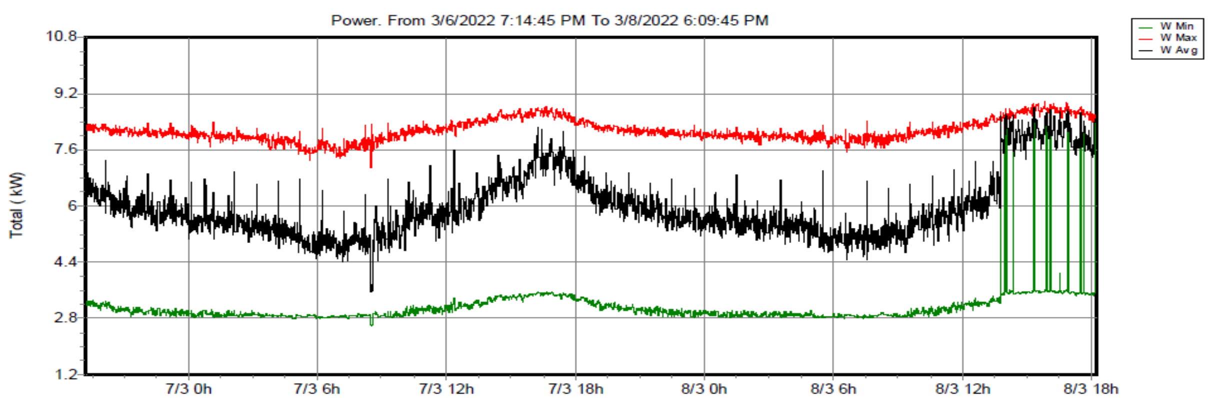

Figure 4. 19: Air Conditioner 4 Power Consumption Trend

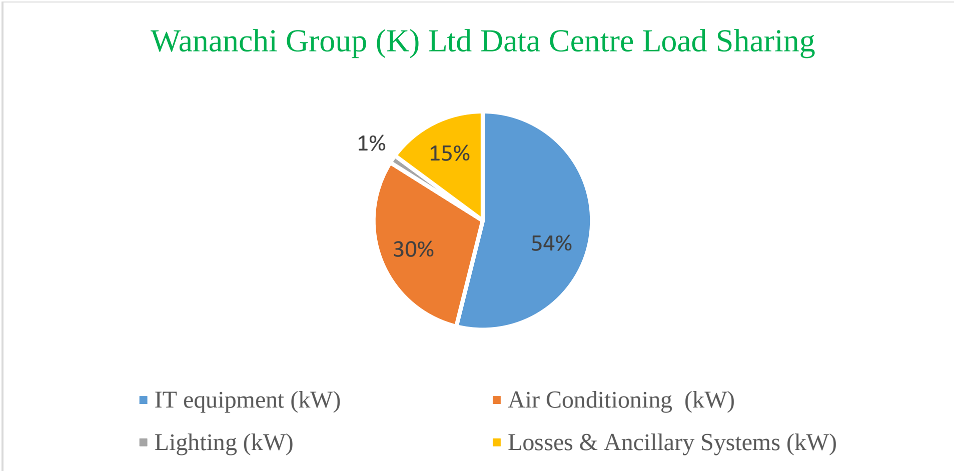

Figure 4. 20: Wananchi Group (K) Ltd Data Centre Facility Load Sharing

Figure 4.21 shows the local utility frequency as measured at the DC mains supply point from 2nd March to 5th March 2022. The highest value noted was 50.67 Hz, lowest value 49.32 Hz and an average value of 50.0 Hz.

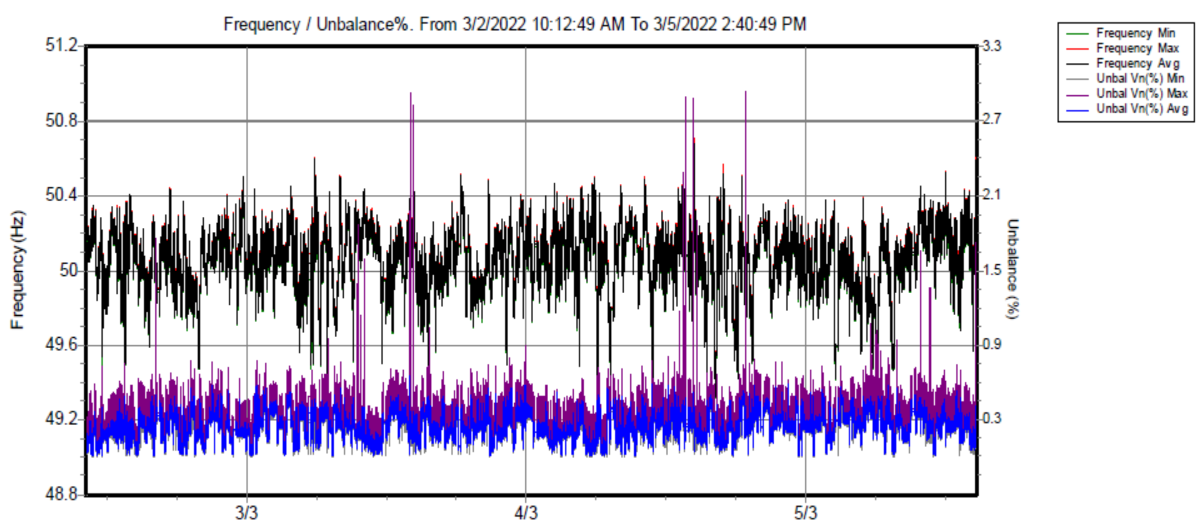

Figure 4. 21: Data Centre Local Utility Supply Frequency

4.5.2 Lighting Intensity Measurement

Lux measurement levels at the DC facility rooms were measured once per day for three consecutive days using Extech EN150 Lux metre. The obtained lux levels contained as in Appendix 2A were found to be within the recommended range as indicated in Appendix 2B.

4.5.3 Case Study Data Centre Indoor Operating Conditions

Appendix 3 shows the DC facility data on indoor operating condition collected for a period of one month (14th Jan to 13th Feb; 2022). This data was analyzed on a Psychrometric chart using Matlab software as shown in Figure 4. 22 where the areas enclosed by ABCDEA and FGHIJF are the recommended and allowable envelopes respectively. There was a clear indication that Wananchi Group (K) Ltd DC mainly operates within the allowable envelope with minimal operation in the recommended envelope. The average dry bulb temperature and RH values for the DC facility are 23.5 ºC and 31.3 % respectively. On a day when AC 3 (rated 19kW with average operating load of 4.96kW) was faulty, a unique point was noted on the lower end of the recommended envelope. This indicated a possibility of the DC to operate efficiently when this AC is eliminated hence conserving energy.

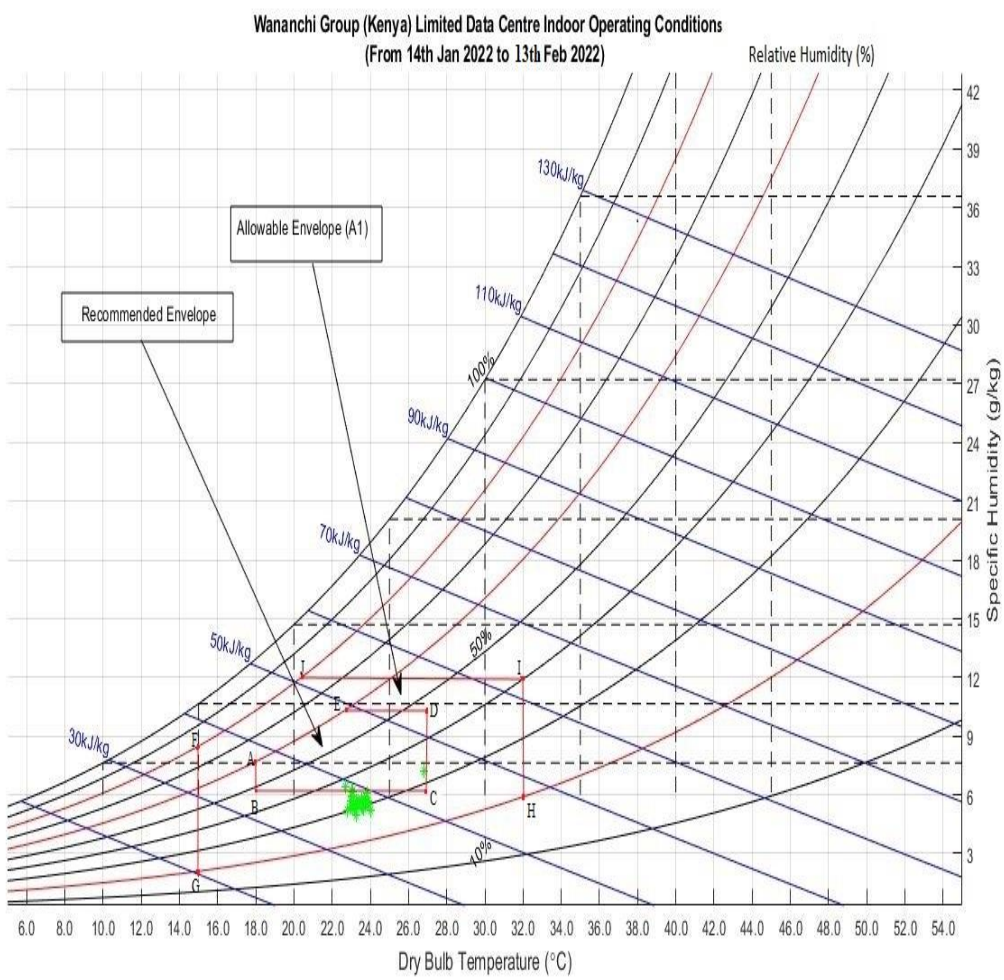

Figure 4. 22: Data Centre Indoor Operating Conditions on a Psychrometric Chart

4.6 Analysis of Local Utility Reliability

Data contained in Table 4.7 was extracted from Kayako ticketing system used at Wananchi Group (K) Ltd DC to track outages. The data contained details of power outages at the DC facility from the local utility Company, Kenya Power, for the entire 2021 and it was used to calculate the reliability of the utility grid at the DC.

Table 4. 7: Kenya Power Outages at the Data Centre (Year 2021)

Ticket Number	Date	Time Mains was lost	Time mains was restored	Duration (Hours)
43426	1/2/2021	1343 hours	1349 hours	0.1
43278	9/2/2021	0850 hours	0855 hours	0.08
44202	21/2/2021	1249 hours	1358 hours	1.15
44378	26/2/2021	1832 hours	1856 hours	0.4
44411	28/2/2021	0345 hours	0710 hours	3.41
44815	8/3/2021	2114 hours	2130 hours	0.27
47448	26/5/2021	2101 hours	2311 hours	2.17
47772	6/6/2021	1935 hours	2004 hours	0.48
47796	7/6/2021	1125 hours	1152 hours	0.45
48285	21/6/2021	1350 hours	1355 hours	0.08
48400	25/6/2021	0919 hours	0923 hours	0.07
48511	29/6/2021	1207 hours	1416 hours	2.15
48775	7/7/2021	1725 hours	1757 hours	0.53
49041	16/7/2021	0957 hours	1035 hours	0.63
54830	23/12/2021	1010 hours	1059 hours	0.82
54877	25/12/2021	0802 hours	1249 hours	4.78
Total				**17.57**

The $MTTR$ was calculated in accordance to Equation (3.7) as follows;

$$MTTR = \frac{\sum_{1}^{16} Downtime\ (hrs)}{16}$$

$$MTTR = \frac{17.57}{16} = 1.098\ hrs$$

$$Uptime\ (hrs) = 8760 - Downtime\ (hrs) \qquad (4.4)$$

$$Uptime\ (hrs) = 8760 - 17.57$$

$$Uptime\ (hrs) = 8742.43\ hrs$$

The $MTTF$ was calculated as defined in Equation (3.6) as follows;

$$MTTF = \frac{\sum_{1}^{17} Uptime\ (hrs)}{17} = \frac{8742.43\ hrs}{17} = 514.26\ hrs$$

The local utility, Kenya Power, availability (A) was calculated as defined in Equation (3.5);

$$Availability\ (A) = \frac{514.26}{514.26+1.098} * 100 = \frac{514.26}{515.358} * 100 = 0.9979 * 100$$

$$Availability\ (A) = 99.79\%$$

Therefore the reliability of the local utility, Kenya Power, at Wananchi Group (K) Ltd DC in terms of availability (A) for the year 2021 was 99.79% which was below the recommended value i.e. 99.999%. The fairly good reliability value obtained at the case study DC was due to the fact that the facility is located within Nairobi CBD which rarely experience power outages. Therefore, any DC facility located outside the CBD is expected to have power reliability value below 99.79%.

4.7 Energy Conservation Measures

4.7.1 Energy Saving Measures Implemented at Wananchi Group (K) Ltd Data Centre

Wananchi Group (K) Limited Company has made several steps towards energy efficiency at their DC facility. The following measures were noted to have been implemented at the DC facility to ensure energy efficiency:

i) **Use of LED lighting**- Several LED lighting tubes were noted to have been installed in several sections of the facility.

ii) **Use of Power Factor Correction (PFC) Capacitor Banks**- A 120kVAR capacitor bank has been installed at the facility mains input with a bid to achieve a high power factor values. This has enabled the facility to achieve a power factor of 0.98 as observed in the results of real measurements indicated in section 4.5.1.

iii) **Cooling System with Raised Floor Configuration (hot aisle/cold aisle layout)-** Wananchi Group (K) Ltd DC has employed the use of raised floor to ensure proper circulation of cold air supplied from the four Liebert PDX cooling systems. The vents in the floor deliver cold air to the front of the racks facing each other (cold aisle) while the hot air escapes through the back of the rack into the hot aisle where it returns to the PDX CRAC units as shown in Figure 4.23. In addition, the PDX cooling systems use variable frequency drives to control the operation of the compressors and the outdoor condensers hence ensuring high energy efficiency.

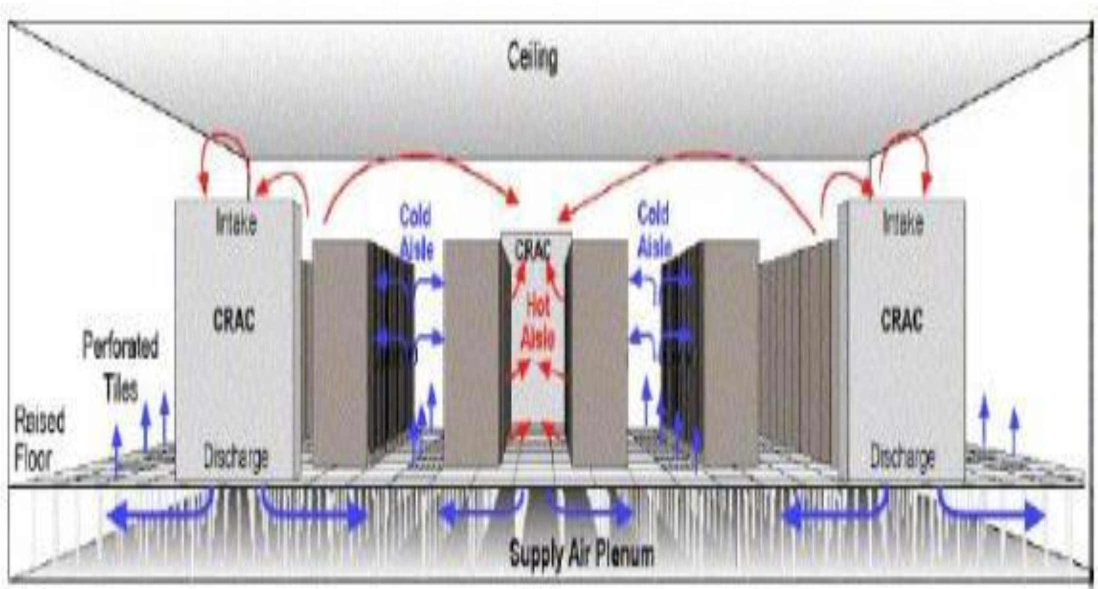

Figure 4. 23: Cooling System with Raised Floor Configuration (hot aisle/cold aisle layout)

iv) **Voltage Optimization and Stabilization-** A iVolt® voltage stabilizer has been installed at Wananchi Group (K) Ltd DC with the aim of reducing the alternating voltage supplied by the local utility from 230V to 220V. This results in increasing the equipment efficiencies and thus reducing power consumption. Additionally, it stabilizes the power hence reducing the risk of equipment failure due to voltage spikes; thus works as a protector.

v) **Server Virtualization**- The facility has employed server consolidation where several DC application software are hosted in the same server achieving high server utilization and hence reducing the number of used servers which reduces the energy consumption at the facility.

4.7.2 Energy Conservation Measures to be Implemented at the Case Study Data Centre

4.7.2.1 Replacement of the Fluorescent Tubes with LED Tubes

At Wananchi Group (K) Ltd DC facility, it was noted that LED tubes have been installed at the monitoring room, corridors, power room, kitchen, toilets and some at the DC room. From the audit done on lighting at the facility, the DC room had 22 4-feet fluorescent tubes (OSRAM L36W/765) and 20 4-feet LED tubes all totaling to 42 tubes. The OSRAM L36W/765 can be replaced with 4-feet LED tubes to conserve energy as indicated in Table 4.8. The calculation done in Table 4.8 assumes that the lights are on 24/7 hours for the entire year.

Table 4. 8: Data Centre Room Lighting Energy Conservation Analysis

Location	Quantity	OSRAM Tube Rating (W)	Equivalent LED Tube Rating (W)	Annual OSRAM Energy Consumption (kWh)	Annual LED Energy Consumption (kWh)	Annual Energy Savings (kWh)
DC Room	22	36	18	6,937.92	3,468.96	3,468.96

4.7.2.2 Adjusting the PDX Cooling Systems Air Supply Set Points

The four PDX cooling systems located at Wananchi Group (K) Ltd DC have been set to supply air to the DC at 19°C dry bulb temperature and 50% RH. The return air was noted to be at an average dry bulb temperature of 23.5°C and RH of 31.3%. In order to conserve energy and ensure the DC still operates within recommended ASHRAE envelope, the supply air should be set at 21.0°C and 50% RH. The return air dry bulb temperature is also expected to rise to an average value of 25.5°C which is still within the required DC operating range. This 2°C increase in supply air will reduce the condenser cooling load and hence reducing the amount of energy consumed by the four PDX cooling systems located at the facility.

4.7.2.3 Tariff Migration

Wananchi Group (K) Ltd Company should consider shifting its DC facility from the current CI1 energy tariff as billed by the local utility company, Kenya Power, to CI2 tariff whose energy charge is cheaper as indicated in Table 4.9. Although this will have high initial investment cost due to 11kV/415v stepdown transformer required including the metering system, the project is expected to be profitable in the long run.

Table 4. 9: Tariffs Energy Charge Comparison

Tariff	Energy Charge (Kshs/kWh)	Energy Charge (Kshs/kWh Off-peak)	Demand Charge (Kshs/ kVA)
CI1	12	6	800
CI2	10.90	5.45	520

The energy saving costs were computed as follows excluding other charges such as VAT, fuel charge, forex charge, EPRA charge, WRA charge, REP charge and inflation adjustment.

$$Energy\ Charge\ Savings = 12.00 - 10.9 = Kshs\ 1.1\ per\ unit\ consumed$$

$$Off - peak\ hours\ energy\ charge\ savings = 6.00 - 5.45 = Kshs\ 0.55\ per\ unit$$

$$Demand\ Charge\ Savings = 800 - 520 = Kshs\ 280\ per\ kVA$$

4.7.2.4 Elimination of One PDX Air Conditioner

From the analysis done on the DC operating condition in section 4.5.3, it was noted that the dry bulb temperature and RH values of the facility shifts from the ASHRAE allowable envelope to the recommended envelope when PDX air conditioner 3 (rated 19kW) operating at an average load of 4.96kW as indicated in Figure 4.18 is switched off. This indicates that the facility can conserve energy when this PDX air conditioner is eliminated. Table 4.10 shows the amount of energy conserved by the DC facility in a year after eliminating air conditioner 3 as calculated using Equation (4.5).

Table 4. 10: Data Centre PDX Air Conditioner Energy Conservation Analysis

Air Conditioner	Power Rating (kW)	Average Operating Load (kW)	Annual Energy Saving (kWh)
PDX 3	19	4.96	43,449.6

$$Annual\ Energy\ Saving(MWh) = Average\ load * 8760 \qquad (4.5)$$

4.7.2.5 Structured Energy Management Program (EMP)

From the study done regarding Wananchi Group (K) Ltd, it was noted that the company doesn’t have any structured approach to energy management at the case study DC. The company needs to establish policies and procedures for long terms results, allocate staff and resources to the energy management program, have the top management support, develop structures that empower staff to address the energy efficiency issues directly and adopt a continuous improvement philosophy. Wananchi Group (K) Limited needs to consider the following key elements of an energy management system at its DC facility;

i) **Energy Policy**-The Company needs to establish an energy policy which gives expectations for performance improvement and publicly expresses the management's commitment to energy efficiency at the DC facility.

ii) **Active Energy Committee-**This should comprise the energy manager and the team leaders from various NOC shifts and they will be responsible for all the activities relating to energy management at the DC facility.

iii) **Training and awareness-**The Company needs to establish a criteria for training and creating awareness among the energy committee and other DC employees on energy efficiency measures so as to reduce energy consumption at the facility.

iv) **Document and record control**- Energy Manager should ensure that records necessary to manage and maintain the energy management systems are current, easily accessible, protected and archived when necessary**.**

Table 4.11 show the energy savings associated with the proposed EMP as calculated using Equation (4.6).

Table 4. 11: Energy Management Program Savings

Data Centre annual energy consumption	1,371,741.49 kWh
Estimated annual energy savings	27,434.83 kWh

$$EMP\ annual\ energy\ saving = 2\% * Annual\ energy\ consumption \qquad (4.6)$$

Where *EMP* is the Energy Management Program

4.7.2.6 Energy Management System (EMS)

Wananchi Group (K) Ltd should consider implementing an Energy Management System (EMS) at its DC facility in order to track the energy consumption. This will help control energy usage, identify wastages, reduce energy costs and enhance operational efficiency at the facility. This will involve the installation of smart sub-meters at the facility mains supply, the inputs and outputs of the two 120kVA UPSs, input of the power distribution board serving the PDX air conditioners and also at the input of the distribution boards supplying power to the lights and the other ancillary systems at the DC facility. All these smart meters needs to be connected to the main gateway connected to the internet for remote access. Though the installation of the EMS doesn't directly lead to the reduction of the energy consumption at the facility, it generates actionable data that can be used by the management in developing energy conservation strategies, operational and investments decisions. It is estimated that by installing EMS capturing energy consumption in the recommended areas, about 2.5 % of the annual energy consumption will be saved with the effecting energy plans which comes due to the Hawthorne effect created by metering and monitoring [45]. Table 4.12 show the anticipated energy savings associated with the implementation of EMS at the DC facility.

Table 4. 12: Energy Management System Savings

Data Centre annual energy consumption	1,371,741.49 kWh
Estimated annual energy savings	37,037.02 kWh

$$EMS\ annual\ energy\ saving = 2.5\% * Annual\ energy\ consumption \quad (4.7)$$

4.7.2.7 Installation of Occupancy Sensors

Wananchi Group (K) Ltd Company should consider installing occupancy sensors to control lighting at the DC facility mainly at the DC room, power room, corridors, waiting room and at the toilets to ensure lights are on only when the room is occupied. Installation of occupancy sensors brings about reduced electricity consumption at the facility hence energy savings. The switching off of lights also increases the operational lifespan of the lamps/tubes and hence reducing their replacement and maintenance costs. Researches have indicated that an average of 30% energy saving is achieved through the installation of occupancy sensors in controlling lighting [46]. Figure 4.24 shows an example of an occupancy sensor with Table 4.13 indicating the associated energy savings.

Figure 4. 24: Occupancy Sensor

Table 4. 13: Occupancy Sensor Energy Saving

Room	Power Room	Corridors Room	DC Room	Toilets	Kitchen Room	Waiting Room	Total (kWh)
Annual Energy (kWh)	1,576.80	788.40	10,091.52	315.36	157.68	315.36	13,245.12
Annual Energy Saving (kWh)	473.04	236.52	3,027.46	94.61	47.30	94.61	3,973.54

$$Annual\ energy\ saving = 30\% * Annual\ energy\ consumption \quad (4.8)$$

There is no need of installing the occupancy sensors at the DC monitoring room since it is occupied 24/7 throughout the year.

4.7.2.8 Installation of a Solar PV System

The amount of electrical energy consumed at Wananchi Group (K) Limited DC facility is supplied by the local utility company, Kenya Power, apart from the diesel generators that operate during the power outages. The company needs to consider supplementing its energy consumption at the DC facility by onsite generation of some of the energy from solar PV system. Figure 4.25 indicates year 2020 annual levels of irradiation for Nairobi region from the data collected using a Photovoltaic Geographical Information System (PVGIS). July is noted to have the lowest level of solar radiation with December having the highest. Solar irradiation shows that Nairobi region has adequate solar irradiance that can support solar PV generation. From Figure 4.26, it is clearly seen that the region as relatively adequate number of sunshine hours for solar PV power generation with an average annual amount of sunshine hours being 2452 hours.

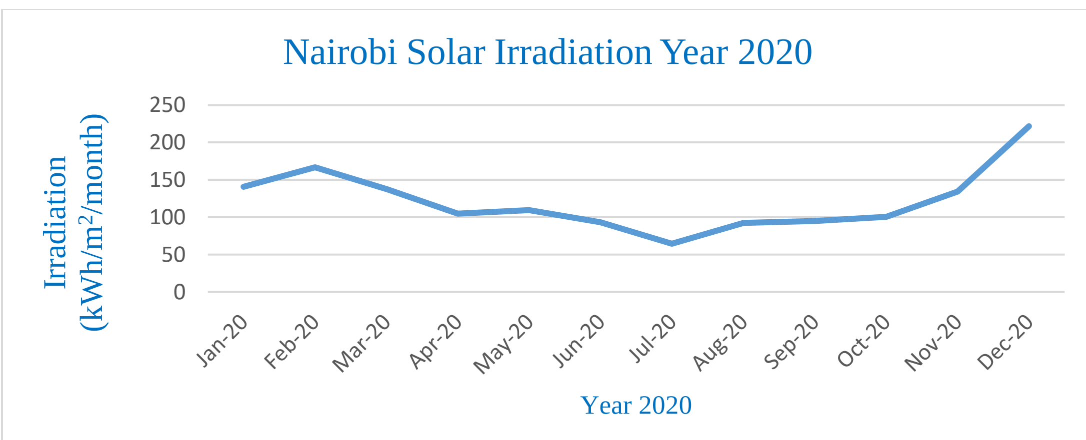

Figure 4. 25: Nairobi Monthly Solar Irradiance for the Year 2020

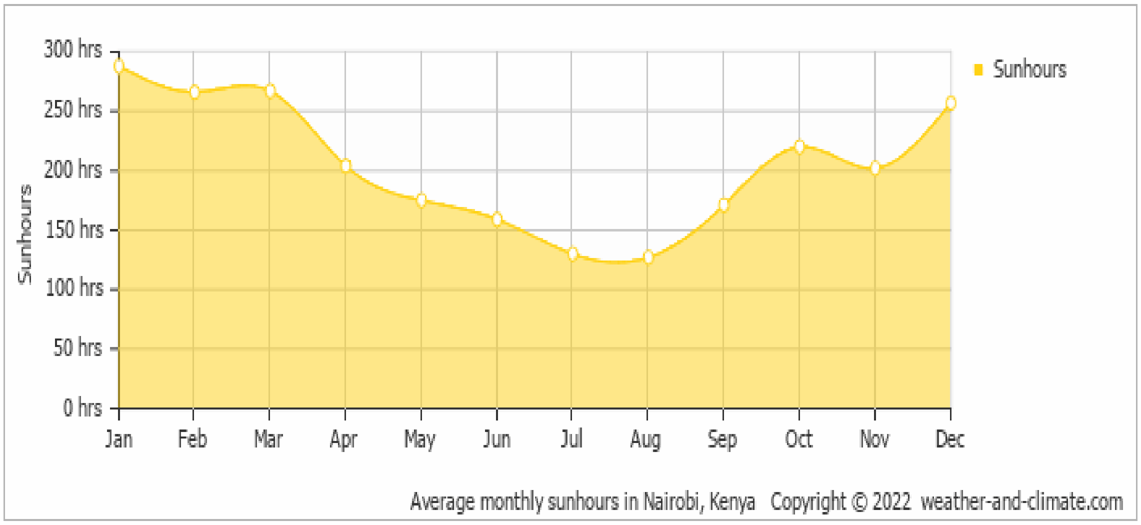

Figure 4. 26: Nairobi Region Monthly Sunshine Hours for the Year 2021

This study proposes the installation of a 140kW solar PV system which will be able to meet the minimum load of the DC facility hence avoiding the injecting excess power to the national grid. With the PV efficiency of 21%, space factor of 0.86 and plant efficiency of 85%, the area required to install the 140kW solar system is calculated as indicated in Equation (4.9).

$$Shade\ area\ (m^2) = \frac{Plant\ Capacity\ (kW) * PV\ Efficiency}{Space\ Factor} \quad (4.9)$$

$$Shade\ area\ required\ (m^2) = \frac{140 * 21}{0.86} = \frac{2940}{0.86} = 3418.60\ m^2$$

This space is available at the terrace space located at the first floor of Pension Towers next to the DC facility as shown in Figure 4. 27. From Figure 4. 26, the sunshine hours per day (SHPD) are calculated as indicated in Equation (4.10)

$$SHPD\ (hours) = \frac{Annual\ sunshine}{365} \quad (4.10)$$

$$= \frac{2452}{365} = 6.72\ Hours$$

$$DPVEO = Installed\ Capacity * \eta * SHPD \quad (4.11)$$

Where *DPVEO* is the daily PV energy output, η is the PV plant efficiency and *SHPD* is as defined earlier

$$DPVEO = 140 * 0.85 * 6.72 = 799.68\ kWh$$

$$EN_{(Annual)} = 799.68 * 365 == 291{,}883.2\ kWh$$

Where *EN* is the energy generated from the plant

Figure 4. 27: Terrace Space for Solar PV System at Wananchi Group (K) Ltd Data Centre

4.7.2.9 Proper Management of Cables in Raised Floor

From the observation made during this study, it was noted that there is poor management of both power and telecommunication cables in the raised floor of the DC facility. This increases the resistance of flow of the cold air from the PDX air conditioners to the racks hosting the IT equipment hence increasing the load which in turn increases the energy consumption by the air conditioners. Proper management of cables into the available U-shaped metallic trunkings needs to be done so as to create clear space for proper flow of cold air hence reducing the cooling load. This will lead to reduced electrical energy consumption by the PDX air conditioners.

4.7.3 Economic Analysis of Energy Conservation Measures

4.7.3.1 Replacement of Fluorescent Tubes (FT) with LED Tubes Economic Analysis

The amount of annual energy saving projected to be achieved by replacing the fluorescent tube with LED tubes is 3,468.96kWh as indicated earlier in Table 4.8.

$$Projected\ cost\ of\ annual\ energy\ saving = 3468.96 * 12 * 0.00862 = USD\ 358.83$$

$$Total\ Cost\ of\ the\ 22\ LED\ tube(Investment\ Cost) = 22 * 3.017 = USD\ 66.22$$

$$SPB\ (years) = \frac{Total\ investment\ cost}{Annual\ energy\ cost\ saving} = \frac{66.22}{358.83} = 0.185\ years(2.22\ months) \qquad (4.12)$$

Where *SPB* is the simple payback period

4.7.3.2 Tariff Migration Economic Analysis

Shifting of Wananchi Group (K) Ltd DC facility tariff to CI2 tariff will require some electrical network changes at the local utility entrance point in order to accommodate the transformer and the new metering panel. Tables 4.14 and 4.15 indicates annual energy cost (year 2021) as metered under tariffs CI1 and CI2 respectively.

Table 4. 14: CI1 Tariff Annual Energy Cost (Year 2021)

Month	Energy Consumed (kWh)	Energy Charge	Energy Consumed (Off-peak) (kWh)	Energy Charge	Maximum Demand (kVA)	Demand Charge	Total Energy Cost (Kshs)	Total Energy Cost (USD)
Jan	119,043.00	12	2,979.00	6	174	800	1,585,590.00	13667.786
Feb	107,147.00	12	-	6	179	800	1,428,964.00	12317.67
Mar	121,446.00	12	6,022.00	6	179	800	1,636,684.00	14108.216
Apr	107,447.00	12	-	6	179	800	1,432,564.00	12348.702
May	109,636.00	12	-	6	185	800	1,463,632.00	12616.508
Jun	113,587.00	12	-	6	182	800	1,508,644.00	13004.511
Jul	117,191.00	12	1,516.00	6	171	800	1,552,188.00	13379.861
Aug	89,455.00	12	-	6	176	800	1,214,260.00	10466.921
Sep	119,651.00	12	4,752.00	6	168	800	1,598,724.00	13471
Oct	105,989.00	12	-	6	171	800	1,408,668.00	12142.718
Nov	120,469.00	12	5,812.00	6	174	800	1,619,700.00	13961.814
Dec	116,797.00	12	-	6	172	800	1,539,164.00	13267.594
						Total	17,988,782.00	155063.301

Table 4. 15: CI2 Tariff Annual Energy Cost (Year 2021)

Month	Energy Consumed (kWh)	Energy Charge	Energy Consumed (Off-peak) (kWh)	Energy Charge	Maximum Demand (kVA)	Demand Charge	Total Energy Cost (Kshs)	Total Energy Cost (USD)
Jan	119,043.00	10.9	2,979.00	5.45	174	520	1,404,284.25	12104.93024
Feb	107,147.00	10.9	-	5.45	179	520	1,260,982.30	10869.66743
Mar	121,446.00	10.9	6,022.00	5.45	179	520	1,449,661.30	12496.08041
Apr	107,447.00	10.9	-	5.45	179	520	1,264,252.30	10897.85483
May	109,636.00	10.9	-	5.45	185	520	1,291,232.40	11130.42329
Jun	113,587.00	10.9	-	5.45	182	520	1,332,738.30	11488.20415
Jul	117,191.00	10.9	1,516.00	5.45	171	520	1,374,564.10	11848.74254
Aug	89,455.00	10.9	-	5.45	176	520	1,066,579.50	9193.91529
Sep	119,651.00	10.9	4,752.00	5.45	168	520	1,417,454.30	12218.45607
Oct	105,989.00	10.9	-	5.45	171	520	1,244,200.10	10725.00486
Nov	120,469.00	10.9	5,812.00	5.45	174	520	1,435,267.50	12372.00585
Dec	116,797.00	10.9	-	5.45	172	520	1,362,527.30	11744.98533
						Total	15,903,743.65	137090.270

$$Annual\ tariff\ migration\ savings = CI1\ Energy\ cost - CI2\ Energy\ cost \tag{4.13}$$

$$Annual\ tariff\ migration\ savings = 155063.301 - 137090.270 = USD\ 17973.031$$

Table 4.16 shows the initial cost to be incurred in tariff migration

Table 4. 16: Tariff Migration Cost

Item	Cost (USD)
One 315kVA Transformer (11kV/415V)	12,499
11kV Metering Panel	21,808.6
Installation and Facilitation Fee	11,637
Total	45,944.6

$$SPB = \frac{Investment\ cost}{Annual\ cost\ savings} \tag{4.14}$$

$$SPB = \frac{45944.6}{17973.031} = 2.56\ years$$

The payback period for the tariff migration will be 2 years and 7 months

4.7.3.3 Structured Energy Management Program (EMP) Economic Analysis

From Table 4.11, annual energy savings projected to be achieved through the implementation of an EMP at Wananchi Group (K) Ltd is 27,434.83 kWh.

$$Projected\ annual\ energy\ cost\ saving = Energy\ Saving * 12 * 0.00862$$

$$Projected\ annual\ energy\ cost\ saving = 27{,}434.83 * 12 * 0.00862 = USD\ 2837.859$$

$$Energy\ Management\ Program\ investment\ cost = USD\ 7327$$

$$SPB = \frac{Investment\ cost}{Annual\ cost\ savings} = \frac{7327}{2837.859} = 2.582\ years$$

Therefore the payback period for the Energy Management Program is 2 years and 7 months.

4.7.3.4 Energy Management System (EMS) Economic Analysis

The annual energy savings associated with the implementation of an EMS is projected to be 37,037.02 kWh as indicated in Table 4.12.

$$Projected\ annual\ energy\ cost\ saving = Annual\ energy\ saving * 12 * 0.00862$$

$$Projected\ annual\ energy\ cost\ saving = 37{,}037.02 * 12 * 0.00862 = USD\ 3831.11$$

$$Energy\ meters, EMS\ Gateway, cable\ and\ EMS\ software\ cost = USD\ 6465$$

$$Installation, testing\ and\ commisioning\ of\ EMS\ cost = USD\ 1508.5$$

$$Total\ investment\ cost = 6465 + 1508.5 = USD\ 7973.5$$

$$SPB = \frac{Investment\ cost}{Annual\ cost\ savings} = \frac{7973.5}{3831.11} = 2.1\ \text{years}$$

The payback period for the Energy Management System is 2 years and 2 months.

4.7.3.5 Occupancy Sensors Economic Analysis

As indicated in Table 4.13, the annual energy savings projected to be achieved at the DC facility through the installation of occupancy sensors to control lighting is 3,973.54 kWh.

$$Projected\ annual\ energy\ cost\ saving = Annual\ energy\ saving * 12 * 0.00862$$

$$Projected\ annual\ energy\ cost\ saving = 3{,}973.54 * 12 * 0.00862 = USD\ 411.023$$

$$Cost\ of\ the\ 13\ occupancy\ sensors = 13 * 9{,}700 * 0.00862 = USD\ 1086.982$$

$$Cost\ of\ cable(1.5mm^2)\ 1\ roll = USD\ 56.03$$

$$Installation, testing\ and\ commissioning\ cost = USD\ 162.918$$

$$Total\ investment\ cost = 1086.982 + 56.03 + 162.918 = USD\ 1305.93$$

$$SPB = \frac{Investment\ cost}{Annual\ cost\ savings} = \frac{1305.93}{411.023} = 3.2\ years$$

Therefore the payback period for the proposed occupancy sensors is 3 years and 2.5 months.

4.7.3.6 Economic Analysis of Solar PV System

From section 4.7.2.8, the annual energy projected to be generated from the installed solar PV system is 291,883.2 kWh.

$$Solar\ PV\ annual\ energy\ cost\ saving = Annual\ energy\ generated * 12 * 0.00862$$

$$Solar\ PV\ annual\ energy\ cost\ saving = 291{,}883.2 * 12 * 0.00862 = USD\ 30192.4$$

Monocrystalline Jinko solar panels-610Wp (JKM610N-78HL4) were chosen for the proposed plant with the required number of solar panels calculated as indicated in Equation (4.15)

$$Number\ of\ solar\ panels = \frac{Solar\ PV\ plant\ capacity(kW)}{Power\ rated\ capacity\ of\ one\ panel\ (kW)} \tag{4.15}$$

$$Number\ of\ solar\ panels = \frac{140}{0.61} = 230\ Solar\ panels$$

Selecting 185kW-three phase-Huawei Smart String Inverter (SUN2000-185KTL-H1) with 98.69% efficiency, the required number of inverters for the solar PV plant was calculated as indicated in Equation (4.16).

$$No. of\ inverters = \frac{Plant\ installed\ capacity\ (kW)}{Selected\ inverter\ rating\ (kW) * Efficiency} \tag{4.16}$$

$$No. of\ inverters = \frac{140}{185 * 0.9869} = 0.766 = 1\ inverter$$

The selected smart inverter will have the capability of being integrated into the earlier proposed EMS due to its remote accessibility feature. The datasheets of the Huawei Smart String Inverter and the Jinko solar are contained in appendices 4 and 5 respectively.

Since the SUN2000-185KTL-H1 inverter has a maximum of 9 MPPT trackers, the 230 solar panels will be connected into 9 string. Five strings will each consist of 26 solar panels all in series connection while the remaining four strings will each have 25 solar panels connected in series.

The maximum direct current expected from the strings to the inverter is calculated as indicated in Equation (4.17)

$$Maximum\ direct\ current, I_{dc} = I_{sc} * safety\ factor \quad (4.17)$$

Where I_{sc} is the rated short-circuit of one solar PV panel.

$$Maximum\ direct\ current, I_{dc} = 14.11 * 1.25 = 17.64\ Amperes$$

The maximum alternating current expected from the inverter to the load per phase is calculated using Equations (4.18).

$$Maximum\ alternating\ current, I_{ac} = I_m * Safety\ factor \quad (4.18)$$

Where I_m is the rated inverter maximum output current.

$$Maximum\ alternating\ current, I_{ac} = 134.9 * 1.25 = 168.63\ Amperes$$

From the Electrical Engineering Centre cable sizing chart, Table 4.17 shows the size and the type of cable needed for both inverter input and output connections.

Table 4. 17: Cable Sizing

	Current rating (Amperes)	Size (mm^2)	Cable Type
Direct Current	17.64	6	Single core direct current cable
Alternating Current	168.63	70	4 core alternating current cable

Table 4.18 shows a summary of the cost associated with the implementation of the proposed 140kW Solar PV system at Wananchi Group (K) Ltd DC. The simple payback period for the proposed solar PV system was calculated using the formula indicated in Equation (4.19). The cost of the Jinko Monocrystalline solar PV panel was taken to be USD 0.3448 per watt.

Table 4. 18: Solar PV Plant Cost

No.	Item Description	Quantity	Price per Unit (USD)	Total Amount (USD)
1	Jinko Solar (610Wp/36V)	230	210.328	48375.44
2	SUN2000-185KTL-H1 Inverter	1	8189	8189
3	DC cables (singe core 6mm^2)	180m	0.6465	116.37
4	AC cable (4 core 70mm^2)	15m	37.066	555.99
5	Solar racks and mounting accessories	-	-	9800.2935
6	40A direct current breaker	9	2.586	23.274
7	LV430408 Schneider Electric breaker	1	467.204	467.204
8	Power Distribution Boards	9	14.654	131.886
9	Installation cost	-	-	32201.734
10	Miscellaneous	0	-	1293
			Total	101154.1915

$$SPB = \frac{Initial\ solar\ PV\ investment\ cost}{Annual\ cost\ saving} \tag{4.19}$$

$$SPB = \frac{101154.1915}{30192.4} = 3.35\ years$$

Therefore the payback period for the proposed solar PV plant is 3 years and 5 months.

The proposed 140kW solar PV plant requires a large cost of investment as indicated in Table 4.18. Therefore time value of money which is not incorporated in the simple payback period method in a key consideration in evaluating the viability of the investment. In that capacity, NPV of the project was calculated assuming a loan was secured at an interest rate of 7.2 % compounded annually to cater for the initial investment cost, a monthly maintenance cost of USD 129.3 and a 10% inflation after every 10 years. The salvage value of the Solar PV plant will essentially be zero. The projected cash flows for the project were calculated and captured in Table 4.19 for a lifespan of 30 years. It is clearly seen from the cash flow table that the initial investment cost will have been fully recovered by the end of the plant’s fourth year of operation as indicated earlier by the simple payback method.

The NPV for the proposed project is calculated as indicated in Equation (4.20)

$$NPV = -I_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} \tag{4.20}$$

Where I_0 is the initial capital cost in USD, t is the project's lifetime in years ranging from 1 to 30 years, CF_t is the project's respective years' net cash flow and r is the interest rate.

Table 4. 19: Projected Solar PV Plant Cash Flows

Year	Capital Cost (USD)	Revenue (USD)	Maintenance Cost (USD)	Net Cash Flow (CF_t) (USD)
1	-101,154.1915	30,192.40	1551.6	-72,513.39
2	0	30,192.40	1551.6	-43,872.59
3	0	30,192.40	1551.6	-15,231.79
4	0	30,192.40	1551.6	13,409.01
5	0	30,192.40	1551.6	42,049.81
6	0	30,192.40	1551.6	70,690.61
7	0	30,192.40	1551.6	99,331.41
8	0	30,192.40	1551.6	127,972.21
9	0	30,192.40	1551.6	156,613.01
10	0	30,192.40	1551.6	185,253.81
11	0	30,192.40	1706.76	213,739.45
12	0	30,192.40	1706.76	242,225.09
13	0	30,192.40	1706.76	270,710.73
14	0	30,192.40	1706.76	299,196.37
15	0	30,192.40	1706.76	327,682.01
16	0	30,192.40	1706.76	356,167.65
17	0	30,192.40	1706.76	384,653.29
18	0	30,192.40	1706.76	413,138.93
19	0	30,192.40	1706.76	441,624.57
20	0	30,192.40	1706.76	470,110.21
21	0	30,192.40	1877.436	498,425.17
22	0	30,192.40	1877.436	526,740.14
23	0	30,192.40	1877.436	555,055.10
24	0	30,192.40	1877.436	583,370.06
25	0	30,192.40	1877.436	611,685.03
26	0	30,192.40	1877.436	639,999.99
27	0	30,192.40	1877.436	668,314.96
28	0	30,192.40	1877.436	696,629.92
29	0	30,192.40	1877.436	724,944.88
30	0	30,192.40	1877.436	753,259.85

$$NPV = I_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \frac{CF_3}{(1+r)^3} + - - - - - - - - - - - - + \frac{CF_{30}}{(1+r)^{30}}$$

$$NPV = -101154.192 + \frac{28640.80}{(1+0.072)^1} + \frac{28640.80}{(1+0.072)^2} + \frac{28640.80}{(1+0.072)^3} + \frac{28640.80}{(1+0.072)^4} + \frac{28640.80}{(1+0.072)^5}$$

$$+ \frac{28640.80}{(1+0.072)^6} + \frac{28640.80}{(1+0.072)^7} + \frac{28640.80}{(1+0.072)^8} + \frac{28640.80}{(1+0.072)^9} + \frac{28640.80}{(1+0.072)^{10}}$$

$$+ \frac{28485.64}{(1+0.072)^{11}} \frac{28485.64}{(1+0.072)^{12}} + \frac{28485.64}{(1+0.072)^{13}} + \frac{28485.64}{(1+0.072)^{14}} + \frac{28485.64}{(1+0.072)^{15}} + \frac{28485.64}{(1+0.072)^{16}}$$

$$+ \frac{28485.64}{(1+0.072)^{17}} + \frac{28485.64}{(1+0.072)^{18}} + \frac{28485.64}{(1+0.072)^{19}} + \frac{28485.64}{(1+0.072)^{20}} + \frac{28314.96}{(1+0.072)^{21}} + \frac{28314.96}{(1+0.072)^{22}}$$

$$+ \frac{28314.96}{(1+0.072)^{23}} + \frac{28314.96}{(1+0.072)^{24}} + \frac{28314.96}{(1+0.072)^{25}} + \frac{28314.96}{(1+0.072)^{26}} + \frac{28314.96}{(1+0.072)^{27}}$$

$$+ \frac{28314.96}{(1+0.072)^{28}} + \frac{28314.96}{(1+0.072)^{29}} + \frac{28314.96}{(1+0.072)^{30}}$$

$$NPV = -101154.192 + 26717.164 + 24922.728 + 23248.813 + 21687.326 + 20230.714 + 18871.935 + 17604.417 + 16422.031 + 15319.059 + 14290.167 + 13258.163 + 12367.689 + 11537.023 + 10762.149 + 10039.318 + 9365.035 + 8736.040 + 8149.291 + 7601.951 + 7091.372 + 6575.45 + 6133.815 + 5721.842 + 5337.54 + 4979.048 + 4644.634 + 4332.681 + 4041.68 + 3770.224 + 3517 = USD\ 246{,}122.107$$

Therefore the proposed project is viable since its NPV value is positive.

Table 4.20 shows a summary of the results and analysis of the proposed ECMs

Table 4. 20: Summary of the Proposed Energy Conservation Measures

	Initial Investment cost (USD)	Annual Maintenance cost (USD)	Annual energy savings (kWh)	Annual Energy saving cost (USD)	Net Energy saving cost (USD)	SPB (Years)	NPV (USD)
Replacement of FT with LEDs	66.22	0	3,468.96	358.83	358.83	0.185	
Tariff Migration	45,944.6	0	0	17,973.031	17,973.031	2.56	
EMP	7,327	0	27,434.83	2,837.859	2,837.859	2.582	
EMS	7,973.5	0	37,037.02	3,831.11	3,831.11	2.1	
Occupancy Sensors	1,305.93	0	3,973.54	411.023	411.023	3.2	
One PDX AC Elimination	0	0	43,449.6	4,494.427	4,494.427		
Solar PV Plant	101,154.1915	1,551.6	291,883.2	30,192.4	28,640.80	3.35	246,122.107

From Table 4.20, all the proposed ECMs had a payback period less than 5 years and therefore Wananchi Group (K) Ltd management needs to consider them for implementation at the company's DC facility in order to reduce the facility energy consumption and hence reduce about 47240.67Kgs of CO_2 emissions to the environments per year. Table 4.21 shows a summary of the environmental benefit analysis to be achieved through the implementation of the proposed ECMs.

Table 4. 21: Environmental Benefit Analysis of the Proposed ECMs

ECM	Annual Energy Savings (kWh)	Annual CO_2 Emission Reduction (kg/year)
Replacement of FT with LED tubes	3,468.96	402.3994
Energy Management Program (EMP)	27,434.83	3,182.44
Energy Management System (EMS)	37,037.02	4,296.294
Occupancy Sensor Installation	3,973.54	460.9306
One PDX AC Elimination	43,449.6	5,040.154
Solar PV Plant	291,883.2	33,858.45
Total	407,247.15	47,240.67

4.7.4 Validation of the Proposed Energy Conservation Measures

Table 4. 22: Energy Conservation Measures Validation

Proposed Energy Conservation Measure (ECM)	CO_2 Emission Reduction (kg/year)	
	Proposed Study	Other Studies
Installation of Solar PV Plant	33,858.45	74,800 (DC powered data center with 200 kW PV panels) [47].
Installation of occupancy sensors	460.9306	10,950 (Motion Sensor Application on Building Lighting Installation for Energy Saving and Carbon Reduction Joint Crediting Mechanism) [48].
	Annual Energy Saving (kWh)	
	Proposed Study	Other Studies
Replacement of FT with LED tubes	3,468.96	1,963.2 (Energy Efficient Lighting Control System Design For Corridor illumination) [49]. 291,233.28 (Cost-Benefit Analysis and Emission Reduction of Energy Efficient Lighting at the Universiti Tenaga Nasional) [50].
Installation of occupancy sensors	3,973.54	3,707 (Motion Sensor Application on Building Lighting Installation for Energy Saving and Carbon Reduction Joint Crediting Mechanism) [48].

Some of the proposed energy conservation measures were validated against other studies and summarized in Table 4.22. The values achieved in terms of annual energy savings and CO_2 emission reduction were comparable to those achieved in the other studies.

4.8 Conclusion

The P_{UE} (1.82) and DC_{IE} (55.55%) values obtained from the metrics analysis at Wananchi Group (K) Ltd DC indicated at average performance in energy efficiency. This has been achieved due to the already implemented energy conservation measures at the facility. Annual reliability of the local grid supply to the DC facility in terms of availability was found to be below the recommended value (99.999%) and can be improved through implementation of the proposed onsite solar PV power generation which will reduce load on the local grid hence minimizing the faults caused by peak loads. Implementation of the proposed solar PV plant will bring a significant reduction in energy cost to the DC facility since less energy will be consumed from the local utility company. Among the proposed energy conservation measures (ECMs), replacement of florescent tubes with the LED tubes had the shorted payback period (2.22 months) with the solar PV plant project having the longest payback (3.35 years). However, the solar PV project had a positive NPV value and hence the management needs to consider it for implementation. Some of the proposed ECMs were validated against the other studies and they had comparable values in terms of annual energy savings and CO_2 emission reduction.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

P_{UE} and DC_{IE} metrics evaluated at Wananchi Group (K) Ltd DC were found to be 1.82 and 55.55% respectively. This indicates an average level of electrical energy efficiency at the facility which has been contributed by the implementation of energy conservation measures such as installation of power factor correction bank, installation of LED tubes, use of cooling system with raised floor configuration, voltage stabilization and optimization, server virtualization through server consolidation and the use of Liebert PDX air conditioners employing variable frequency drives (VFDs) to control operation of the compressors and condensers. Analysis of electrical energy consumption trend at the facility was done considering the energy consumption bills issued by the local utility company for the year 2021 with the results indicating least energy consumption in the month of August and the highest energy consumption in March with 1,368,939kWh as the annual energy consumed. From the data collected using real-time measurements, historical records and observations, it was found that the IT equipment are the major energy consumers (54%), followed by air conditioners (30%), then ancillary systems and losses (15%) and finally the lighting (1%).The DC facility peak load was noted to be 177.06kW with the average load being 159.504kW.

Reliability of the local utility company, Kenya Power, in terms of availability at the DC facility was found to be 99.79% which is below the recommended 99.999% value. The DC average operating conditions i.e. dry bulb temperature and RH values were found to be 23.5^{o}C and 31.3% respectively. Analysis done on a Psychrometric chat indicated that the case study DC facility mainly operates within the allowable envelope with minimal operation in the recommended envelope. Several ECMs were identified and their economic viability done all indicating a payback period of less than 5 years. Replacement of the fluorescent tubes with LED tubes at the DC room indicated the shortest payback period of 2.22 months with the installation of solar PV plant at the facility having the longest payback period of 3.35 years. Analysis of NPV for the solar PV plant indicated a positive value though with high initial investment cost. Validation of the proposed ECMs was done against other related studies and it was noted that they all have positive and comparable values in terms of CO_2 emission reduction and annual energy savings.

5.2 Recommendations

Wananchi Group (K) limited management should plan for the implementation of the ECMs proposed in this study since they all have shorter payback periods and they will have significant contribution in the energy saving. In addition the ECMs will contribute in improving the P_{UE} and DC_{IE} metrics at the DC facility.

Companies in the DC industry should conduct regular energy audits at their DC facilities to analyze how the energy is utilized and evaluate the possible ECMs. Implementation plan for the identified ECMs should be developed.

Companies in the DC industry from the African continent should establish an organization similar to the EU code of conduct on DC energy efficiency with the aim of ensuring energy efficiency and reduction of energy consumption in DCs located in Africa. The programme should be voluntary and open to any company willing to participate so long as they submit reports indicating the level of DC metrics i.e. P_{UE} and DC_{IE} metric levels and the annual energy consumption for the agreed period of time and any other energy data prescribed in the programme.

The real-time electrical energy measurements done during this study revealed that the total DC energy consumption trend is defined by the air conditioning systems' energy consumption since the other components at the DC facility including the IT equipment had almost constant electrical load. Further study needs to be done to investigate the effects of varying the air conditioning systems' electrical load on the P_{UE} and DC_{IE} metrics in African DC facilities.

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APPENDICES

Appendix 1: Real-time Measurements Tools

Fluke 435-II Power Quality and Energy Analyzer

This energy analyzer was used to carry out the load measurements of the air conditioning system at the DC facility. The tool was also be used to capture the energy quality and the load profile of the DC at the Kenya Power electrical power input point. It was used to analyze the power consumption, current, voltage, frequency, power factor, phase angles and harmonics.

Extech EN150 Lux Metre

This too was be used to measure the level of illumination at the various sections of the DC facility for the purpose of evaluating whether the lighting is over-provisioned, adequate or in-adequate.

Fluke 323 Clamp Metre

This tool was used to measure the voltage and current at points that can't be accessed using the data logger.

ThermoPro TP49 Hygrometre

This tool was used to measure the DC indoor dry bulb temperature and RH once every day for a period of one month. It measured temperature and RH with accuracies of ±1 Celsius and ±2% to ±3% respectively and it refreshes after every 10 seconds to keep the reading updated about the latest changes in temperature and RH.

Appendix 2 A: Wananchi Group (K) Ltd Data Centre Lux Levels

Days	DC Room	Power Room	Monitoring Room	Waiting Room	Corridor	Kitchen	Toilet 1	Toilet 2
Day 1 lux Level	267	226	308	215	93	332	125	115
Day 1 lux Level	275	230	307	216	107	313	132	145
Day 1 lux Level	258	222	314	209	94	323	113	111

Appendix 2 B: Recommended Lux Levels

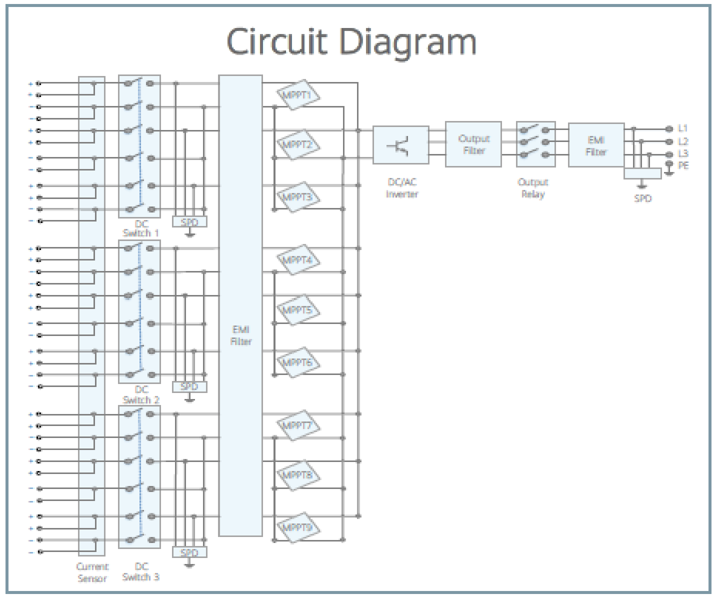
ROOM TYPE	LIGHT LEVEL (FOOT CANDLES)	LIGHT LEVEL (LUX)	IECC 2015 LIGHTING POWER DENSITY (WATTS PER SF)
Classroom - General	30-50 FC	300-500 lux	1.24
Conference Room	30-50 FC	300-500 lux	1.23
Corridor	5-10 FC	50-100 lux	0.66
Kitchen / Food Prep	30-75 FC	300-750 lux	1.21
Laboratory (Classroom)	50-75 FC	500-750 lux	1.43
Laboratory (Professional)	75-120 FC	750-1200 lux	1.81
Library - Reading / Studying	30-50 FC	300-500 lux	1.06
Lobby - Office/General	20-30 FC	200-300 lux	0.90
Lounge / Breakroom	10-30 FC	100-300 lux	0.73
Mechanical / Electrical Room	20-50 FC	200-500 lux	0.95
Office - Open	30-50 FC	300-500 lux	0.98
Office-Private/Closed	30-50 FC	300-500 lux	1.11
Parking - Interior	5-10 FC	50-100 lux	0.19
Restroom / Toilet	10-30 FC	100-300 lux	0.98
Stairway	5-10 FC	50-100 lux	0.69
Storage Room - General	5-20 FC	50-200 lux	0.63

Appendix 3: Real-time Measurement Data

Wananchi Group (K) Ltd DC Indoor Operating Condition Data

Date	Dry Bulb Temperature (Average)	Relative Humidity (%)
14/1/2022	26.8	33
15/1/2022	23.55	30
16/1/2022	23.45	31
17/1/2022	23.05	35
18/1/2022	22.7	36
19/1/2022	23	32
20/1/2022	23.55	31
21/1/2022	23.1	35
22/1/2022	23.05	32
23/1/2022	23	31
24/1/2022	23.25	32
25/1/2022	23.15	32
26/1/2022	22.8	30
27/1/2022	23.25	30
28/1/2022	23.6	30
29/1/2022	23.1	30
30/1/2022	23.25	28
31/1/2022	23.15	30
1/2/2022	23.25	31
2/2/2022	23.1	31
3/2/2022	23.1	31
4/2/2022	23.35	32
5/2/2022	23.9	31
6/2/2022	23.7	32
7/2/2022	23.3	31
8/2/2022	23.65	30
9/2/2022	23.65	29
10/2/2022	23.65	31
11/2/2022	23.85	33
12/2/2022	23.85	31
13/02/2022	23.95	30

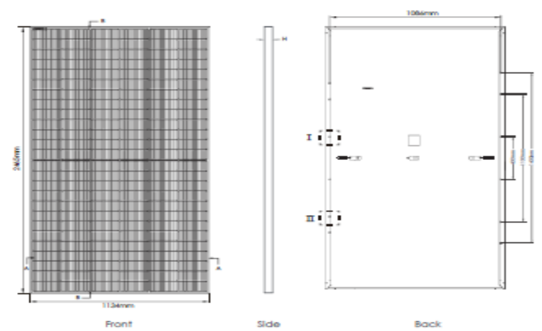
Appendix 4: Huawei Smart String Inverter Datasheet

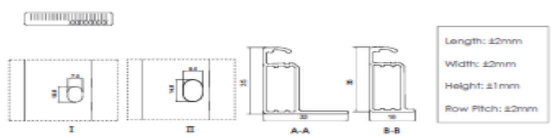


Efficiency	
Max. Efficiency	≥99.00%
European Efficiency	≥98.60%
Input	
Max. Input Voltage	1,500 V
Max. Current per MPPT	30 A
Max. Short Circuit Current per MPPT	50 A
Start Voltage	550 V
MPPT Operating Voltage Range	500 V ~ 1,500 V
Nominal Input Voltage	1,080 V
Number of Inputs	18
Number of MPP Trackers	9
Output	
Nominal AC Active Power	200,000 W
Max. AC Apparent Power	215,000 VA
Max. AC Active Power (cosϕ=1)	215,000 W
Nominal Output Voltage	800 V, 3W + PE
Rated AC Grid Frequency	50 Hz / 60 Hz
Nominal Output Current	144.4 A
Max. Output Current	155.2 A
Adjustable Power Factor Range	0.8 LG ... 0.8 LD
Max. Total Harmonic Distortion	<1%

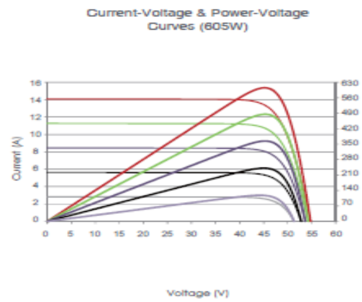
Appendix 5: Jinko Solar (610Wp/36V) Datasheet

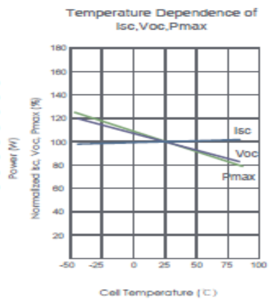
Engineering Drawings





Electrical Performance & Temperature Dependence





Packaging Configuration

(Two pallets = One stack)

31pcs/pallets, 62pcs/stack, 496pcs/ 40'HQ Container

Mechanical Characteristics

Cell Type	N type Mono-crystalline
No. of cells	156 (2×78)
Dimensions	2465×1134×35mm (97.05×44.65×1.38 inch)
Weight	30.6 kg (67.46 lbs)
Front Glass	3.2mm,Anti-Reflection Coating, High Transmission, Low Iron, Tempered Glass
Frame	Anodized Aluminium Alloy
Junction Box	IP68 Rated
Output Cables	TUV 1×4.0mm² (+): 400mm , (-): 200mm or Customized Length

SPECIFICATIONS

Module Type	JKM595N-78HL4 JKM595N-78HL4-V		JKM600N-78HL4 JKM600N-78HL4-V		JKM605N-78HL4 JKM605N-78HL4-V		JKM610N-78HL4 JKM610N-78HL4-V		JKM615N-78HL4 JKM615N-78HL4-V	
	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax)	595Wp	447Wp	600Wp	451Wp	605Wp	455Wp	610Wp	459Wp	615Wp	462Wp
Maximum Power Voltage (Vmp)	45.29V	41.93V	45.39V	42.05V	45.49V	42.16V	45.59V	42.28V	45.69V	42.39V
Maximum Power Current (Imp)	13.14A	10.67A	13.22A	10.73A	13.30A	10.79A	13.38A	10.85A	13.46A	10.91A
Open-circuit Voltage (Voc)	54.80V	52.05V	54.95V	52.20V	55.10V	52.34V	55.25V	52.48V	55.40V	52.62V
Short-circuit Current (Isc)	13.90A	11.22A	13.97A	11.28A	14.04A	11.34A	14.11A	11.39A	14.18A	11.45A
Module Efficiency STC (%)	21.29%		21.46%		21.64%		21.82%		22.00%	
Operating Temperature(℃)	-40℃~+85℃									
Maximum system voltage	1000/1500VDC (IEC)									
Maximum series fuse rating	30A									
Power tolerance	0~+3%									
Temperature coefficients of Pmax	-0.30%/℃									
Temperature coefficients of Voc	-0.25%/℃									
Temperature coefficients of Isc	0.046%/℃									
Nominal operating cell temperature (NOCT)	45±2℃									

*STC: Irradiance 1000W/m² Cell Temperature 25°C AM=1.5

NOCT: Irradiance 800W/m² Ambient Temperature 20°C AM=1.5 Wind Speed 1m/s

 JKM595-615N-78HL4-(V)-F1-EN (IEC 2016)

Appendix 6: Project Defense Panelists' Comments/Questions

Comment / Question	Response	Page Number
Which type of data was collected using measurements and records? The data was collected for how long?	**Measurements:** • Total DC power consumption - Measured for three days. • Air conditioners power consumption- Measured for four days. • DC indoor operating conditions – Measured for a period of one month. • DC lighting intensity- Measured for a period of three days. **Records:** • Annual DC energy consumption- Obtained from KP bills for the entire year 2021. • IT equipment load- Downloaded from the two MGE Galaxy 5000 UPSs for a period of 21 days.	Page 40. Page 47 & 48. Page 50. Page 49. Page 33 Page 34 & 35
Which forms of energy are utilized in DCs? Consider including the specific discussed form of energy in the research topic.	• The form of energy used in DCs is electrical energy. • Amendment of the research title was done to capture electrical energy which is the only form of energy analyzed at the case study DC.	Cover Page
How did you validate your research work?	• Benchmarking of P_{UE} and DC_{IE} metrics. • Validation of proposed ECMs	Page 39 & 40 Page 69
Give an explanation regarding the poor metric values obtained from PCTL DC in Pakistan.	• The poor P_{UE} metric was due to lack of awareness of green and energy-efficient concepts among the DC managers and high outdoor temperatures in the region.	Page 39
Give more information concerning the fairly good mains reliability obtained at the case study DC. Discuss the expected reliability value for the DCs located outside the Nairobi CBD.	• The fairly good reliability value obtained at the case study DC was due to the fact that the facility is located within Nairobi CBD which rarely experience power outages. Any DC facility located outside the CBD is expected to have power reliability value below 99.79%.	Page 52

Appendix 7: Turnitin Originality Report

Submission date: 13-Jun-2022 08:35AM (UTC-0500)
Submission ID: 1856052096
File name: F56_37276_2020_Final_Report.pdf (5.6M)
Word count: 24496
Character count: 130446

ORIGINALITY REPORT

11%	9%	4%	3%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

DR. P. MUSAU

Appendix 8: IEEE Conference Paper

2022 IEEE PES/IAS PowerAfrica

Analysis of Energy Utilization Metrics as a Measure of Energy Efficiency in Data Centres: Case Study of Wananchi Group (Kenya) Limited Data Centre

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***Abstract*—As society undergoes digital transformation, global demand for Internet services, data storage and network communications increases, leading to increased size and number of data centers (DCs) and the associated energy consumption. Some 1.3% of the world's electricity is consumed by the DC industry and about 2% of the CO_2 emissions across the globe come from the IT sector. Because energy is a significant cost to data centre (DC) operators, metrics have been developed to analyze its utilization. Power Usage Effectiveness (P_{UE}) and Data Center Infrastructure Efficiency (DC_{IE}) are among the globally accepted standard metrics. This work applies P_{UE} and DC_{IE} metrics to evaluate energy utilization at Wananchi Group (Kenya) Limited DC, Nairobi, Kenya. Using monthly electricity bills from the local utility company, results show that the 2021 average annual P_{UE} and DC_{IE} metrics for the DC were 1.8 and 56 % respectively. The values compare favorably with those from DCs in Europe (1.8 and 55.6 % respectively). Further, analysis shows that the case study DC facility mainly operates within the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) allowable envelope-class A1 with minimal operation in the recommended envelope.**

***Keywords—Power Usage Effectiveness (P_{UE}), Data Centre Infrastructure Efficiency (DC_{IE}), Energy Efficiency*.**

I. INTRODUCTION

As society undergoes digital transformation, there is increased global demand for Internet services, data storage and network communication, leading to increased size and number of data centres (DCs) and the associated energy consumption. The energy supplied to the data centre (DC) facilities powers the information technology (IT) and other support equipment. The IT equipment – servers, storage devices and network equipment – consumes the highest amount of energy mainly because of their 24 hours a day, 7 days a week operation. While the servers are currently the major energy consumers, the increasing demand for data storage means that storage equipment will become significant consumers in the future [1]. DC facility support equipment includes cooling systems, lighting, power distribution, uninterruptible power supply (UPS) equipment and ancillary systems, with cooling load being the major energy consumer.

Energy is now a significant cost to DC operators, a concern that will continue given the development of server components with higher power densities. Indeed, the average power density (P_D) is expected to reach 50kW per rack in DCs by 2025 [2]. A study [3] found that power densities in DCs were between 120-940 W/m^2 compared to approximately 50-100 W/m^2 consumed in a typical commercial office space [3]. Recent energy statistics indicate that approximately 1.3% of the world's electricity is consumed by the DC industry [4]. High energy consumption has also led to the increase in green-house gas (GHG) emissions, with up to 2% of the CO_2 emissions across the globe being contributed by the IT sector [3], [5].

Several metrics – P_{UE}, DC_{IE}, Energy Reuse Effectiveness (E_{RE}), DC Compute Efficiency (DC_{CE}) and Clean Energy Index (C_{EI}) – have been proposed to evaluate energy utilization in DCs, and their applicability varies from one DC to another [5], [6]. This paper applies P_{UE} and DC_{IE} metrics in evaluating energy efficiency at Wananchi Group (K) Limited DC, Nairobi, Kenya, for the purpose of benchmarking and energy efficiency improvement. Considering that the weather (environmental) conditions in Africa differ from the rest of the world, this study can provide a reference for regional benchmarking. The rest of the paper is organized as follows: Section II provides literature review; Section III elaborates on the methodology, Section IV documents the results, analysis and validation and Section V the conclusion.

II. LITERATURE REVIEW

A. Background

The COVID – 19 pandemic has increased the demand for Internet services globally. Kenya reported 4.8% growth in Internet subscribers [7], a development that has led to

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increased utilization and need for DCs. In the year 2006, DCs in the USA consumed 61 billion kWh of electrical energy, equivalent to 1.5% of the country's total electrical energy consumed [8]; in the year 2010, they consumed 2% of all the electricity usage. As Table 1 shows, there is a continuous increase in energy consumption in DCs in America, Europe and globally.

Table 1: European, American and Global Data Centre Energy Consumption [9]

Consumption (TWh)	Reporting Year
	EU consumption
18.3	2000
41.3	2005
56	2007
72.5	2010
104	2020
	US consumption
91	2013
140	2020
	Global consumption
216	2007
269	2012

IT equipment (mainly the servers, storage devices, network equipment, monitoring and control workstations) account for an estimated 45% to 55% of the total DC energy consumption [1] with cooling and air conditioning systems consuming about 40% of the total energy. Finally, power distribution, lighting and ancillary systems consume the remainder.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) provides guidelines on environmental conditions within which electronic equipment should operate, defining two envelopes for DCs: recommended and allowable envelopes [10]. The allowable envelope contains four classes namely A1, A2, A3 and A4 each with a wide range of dry bulb temperatures and relative humidity values (Figure 1). DCs can operate in any of these classes to conserve energy. However, the operational safety of the IT equipment is only guaranteed in the recommended envelope.

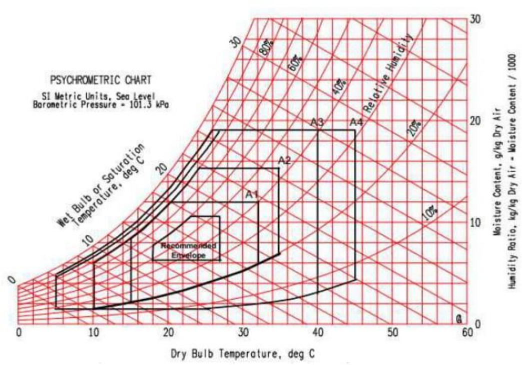

Figure 1: Data Center Envelops on a Psychrometric Chart [10].

The P_{UE} metric is the ratio of total facility energy to the IT equipment energy. Since some energy is always consumed in supporting the IT equipment, achieving a P_{UE} value of 1 is impractical. More energy efficient DCs have P_{UE} values approaching 1. On the other hand DC_{IE}, also known as DC efficiency (DC_E), is the reciprocal of P_{UE}. The metrics are captured in (1) and (2) respectively.

$$P_{UE} = {}^{P_T}/_{P_{IT}} \quad (1)$$

$$DC_{IE} = 1/P_{UE} \quad (2)$$

Where P_T is the total energy supplied to the DC and P_{IT} is the amount of energy consumed by the IT equipment.

P_{UE} and DC_{IE} are useful in determining opportunities to improve operational efficiencies in DCs, benchmarking in the industry and also opportunities to audit energy for additional installation of IT equipment. The next metric, E_{RE}, is given in (3):

$$E_{RE} = \frac{P_{cooling} + P_{loss} + P_{lighting} + P_{IT} - P_{reuse}}{P_{IT}} \quad (3)$$

Where $P_{cooling}$ is energy utilized by the cooling system, P_{loss} is energy loss associated with the power distribution, $P_{lighting}$ is energy consumed by the lights and the support services, P_{IT} is energy used by the IT equipment and P_{reuse} is energy reused outside the DC facility. The metric, E_{RE}, was proposed for usage in evaluating the waste energy from DCs, energy which can be used for other purposes outside the facility such as heating the rest of the building.

The metric, P_D, is given by (4):

$$P_D = {}^{P_T}/_{A} \quad (4)$$

Where P_T is as defined earlier and A is the area occupied by a rack or the entire area of the DC facility. The P_D metric is used to measure the amount of energy used per given area in a DC facility. Another important metric is Heating, Ventilation and Air-Conditioning Effectiveness, $HVAC_{eff}$, as given in (5):

$$HVAC_{eff} = {}^{P_{HVAC}}/_{P_{IT}} \quad (5)$$

Where P_{IT} is defined earlier and P_{HVAC} *is* energy consumed by the HVAC systems. The metric is used to measure the amount of energy needed for air conditioning in DC facilities in comparison to the IT load and it is used to analyze energy performance and efficiency improvements in HVAC systems.

B. Related Research

(a) Energy Utilization in Data Centres

A P_{UE} metric assessment in a DC in the USA established a value of 1.08, a very efficient DC [3]. The cooling load consumed 1048 kWh/annum; the IT load and the electrical losses respectively consumed 212,868 kWh/annum and 15,854 kWh/annum, the assumption being that each server operated at 60% rated power. This study only considered servers ignoring other IT equipment at the facility. An evaluation of energy consumption in European Union DCs, involving a sample of 289 DCs, provides findings summarized in Table 2 [9], indicating an average P_{UE} of 1.80. The majority of the DC facilities reported an average P_{UE} of 1.6-1.8 followed by the 1.8-2.0 range, excluding values less than 1 and more than 3.

Table 2: EU DC Facilities Average Data [9]

Total Dataset	289 Data Centres Which Have Reporte
Total annual electricity consumption	3,735,735 MWh
Average DC floor area	2616 m^2
Average rated IT load	1956 kW
Average annual electricity consumption	13,684 MWh
Average annual IT consumption	7871 MWh
Average PUE	1.80
Average high temp set point	25 °C
Average low temp set point	19.5 °C
Average high RH set point	59% RH
Average low RH set point	35% RH

(b) Energy Management in Data Centers

Server consolidation has been proposed and implemented to improve utilization of servers, facilitating reduction in energy consumption and minimizing greenhouse gas (GHG) emissions. A study [11] realized 86.7% energy saving. However, this study focused only on servers ignoring the other IT equipment located in DCs. Analysis of energy efficiency in DCs using free cooling is reported in [12], reflecting 23.7% energy saving.

Many companies across the globe have considered investing in renewable sources of energy, especially solar and wind, to power their DCs, including Apple Inc. [13]. An energy management system to provide a smart means of managing energy consumption in a DC facility from distributed UPS system, main grid and renewable energy has also been proposed with the aim of addressing the challenges of renewable energy fluctuations and the frequent changes in the electricity price [14]. However, a detailed cost-benefit analysis of the proposed energy management system is not provided.

III. METHODOLODY

A. Energy Metrics

This study involved the evaluation of P_{UE} and DC_{IE} metrics at the case study DC. Monthly total DC and IT equipment energy were used to calculate the monthly P_{UE} and DC_{IE} metrics using (1) and (2). The total monthly energy consumed at the DC is the amount of energy billed by the local utility company, Kenya Power. The monthly P_{UE} and DC_{IE} values were used to calculate the annual values of the DC metrics as shown in (6) and (7).

$$P_{UE(annual)} = \frac{\sum_1^{12} P_{UE(monthly)n}}{12} \tag{6}$$

$$DC_{IE(annual)} = \frac{\sum_1^{12} DC_{IE(monthly)n}}{12} \tag{7}$$

Where n represents the month (n=1, 2, 3……., 12).

B. Data Collection

Monthly energy consumption at the DC facility was obtained from Kenya Power's monthly bills for the entire 2021 period. The monthly IT equipment energy was calculated from the data downloaded from two 120 kVA online uninterruptible power supplies' (UPSs') databases located at the facility using UPS Tuner MGE Galaxy 5000 Software. An assumption was made that no power losses are incurred in power cables feeding the power distribution units (PDUs) where the IT equipment are connected. The DC facility is located within Nairobi Central Business District (CBD), with rare power outages. Thus, the local utility power annual availability was assumed to be 100%. Also, since no new IT equipment has been installed at the DC facility for the last one and half years, it was assumed that the obtained data reflects the IT energy for the last one and half years. The period of consideration for the UPS data was three weeks.

Data on DC indoor dry bulb temperature was obtained using real-time measurements involving the use of Cellulogic-Celllink GSM module and ThermoPro TP49 hygrometre for a period of one month (14th Jan-13th Feb; 2022). The daily temperature values obtained from the two instruments were used to calculate the average value for that day since the instruments were installed at two opposite points within the DC facility. The daily relative humidity (RH) data was taken once in a day from ThermoPro TP49 hygrometre. The indoor operating conditions data was used to evaluate the ASHRAE envelop(s) within which the DC operates and hence evaluating the possibility of operating at higher conditions to conserve energy.

IV.RESULTS, ANALYSIS AND VALIDATION

A. Results and Analysis

Fig. 2 and Fig. 3 show the daily average IT equipment load from UPS 1 and UPS 2 respectively for the three weeks study period. More IT equipment are connected to UPS 1 compared to UPS 2; hence the higher load in the former. The UPS input and output power data was stored in the UPS database after every 5 and 10 minutes in UPS 1 and UPS 2 respectively. This data was used to calculate UPSs' power for every event log. Power calculated from all the event logs in a day was used to calculate the UPSs' daily average power for the entire study period. For the purpose of evaluation of P_{UE} and DC_{IE} metrics at the DC facility, average power was calculated for the two UPSs using the daily average power for the entire study period. The average power for UPS 1 was found to be 49.42 kW while for UPS 2 it was 37.32 kW. Therefore the average IT equipment power at the DC facility was 86.74 kW, used to calculate the total amount of energy consumed by the IT equipment every month for the entire 2021.

The monthly total IT equipment energy and the monthly total DC energy as metered by Kenya Power were used to calculate the DC facility metrics and the results are indicated in Fig. 4 and Fig. 5. From the results obtained, the DC had the best P_{UE} metric (1.39) in the month of August 2021, with the worst (2.02) in the month of November 2021. The average P_{UE} value for the entire year being 1.80. The corresponding values of DC_{IE} metric for the two months were 72.2% and 49.5% respectively with the average value being 56%. The better P_{UE} metric observed in the month of August 2021 is attributed to cold outdoor environmental conditions, hence minimized cooling load. On average, 56.0% of the energy supplied at the DC facility for the entire 2021 was used to power the IT equipment

Figure 2: UPS 1 Daily Average Power, 26th Jan-15th Feb:2022

Figure 3: UPS 2 Daily Average Power, 18th Jan-7th Feb:2022

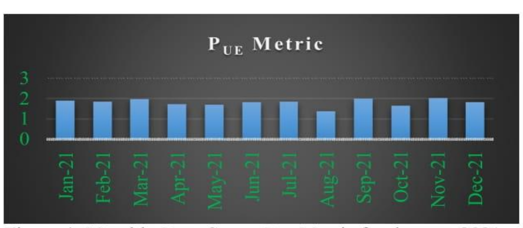

Figure 4: Monthly Data Centre P_{UE} Metric for the year 2021

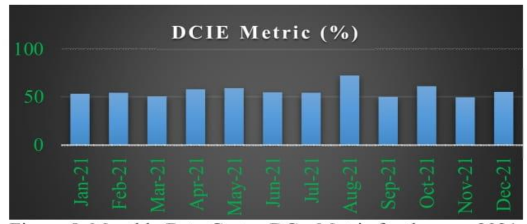

Figure 5: Monthly Data Centre DC_{IE} Metric for the year 2021

Results of the DC indoor operating conditions on a Psychrometric Chart (done using Matlab software) in Fig. 6 shows that Wananchi Group (K) Ltd DC mainly operates in the ASHRAE allowable envelope-class A1, with minimal operation within the recommended envelope. On a day when air conditioner (AC) 3 (rated 19kW) was faulty, a unique point was noted on the lower end of the recommended envelope. This indicates a possibility of the DC to operate efficiently when one AC is eliminated hence conserving energy.

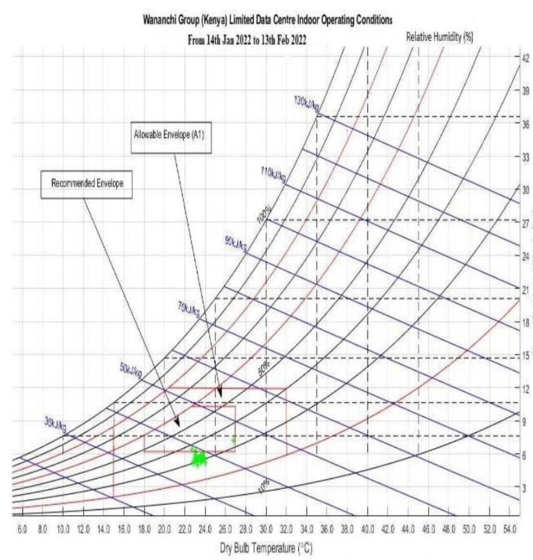

Figure 6: Psychrometric Chart (14th Jan-13th Feb; 2022)

B. Validation

Table 3: P_{UE} and DC_{IE} values and the level of efficiency [15]

P_{UE}	DC_{IE}	Level of efficiency
3.0	33%	Very Inefficient
2.5	40%	Inefficient
2.0	50%	Average
1.5	67%	Efficient
1.3	83%	Very Efficient

Table 4: Validation

Data Centre	P_{UE}	Level of Efficiency
WG(K)L DC , Kenya	1.8	Average
PCTL DC, Pakistan [15]	3.3	Very Inefficient
PV DC, USA [3]	1.08	Very efficient
EU DC, Europe [9]	1.8	Average

Key:
WG (K) L DC-Wananchi Group Kenya Ltd Data Centre.
PV DC-Prineville Data Centre.
PCTL DC-PCTL Data Centre.
EU DC-European Union Data Centre.

From the results obtained in section IV (A), the annual average results of P_{UE} (1.8) and DC_{IE} (56%) indicated an average level of energy efficiency as indicated in Table 3.When the obtained P_{UE} value is benchmarked against the values obtained from the other DCs across the world as indicated in Table 4, it is observed that Wananchi Group (K) Ltd DC has a better P_{UE} value compared to PCTL DC in Pakistan, same average value as the one obtained from EU DCs involving a sample of 289 DCs. However, the Wananchi Group (K) Ltd DC has a poor P_{UE} value compared to Prineville DC in USA. A better P_{UE} (1.08) obtained in PV DC was as a result of minimal energy consumption by cooling system due to the DC design [3]. A poor P_{UE} (3.3) obtained in a DC from Pakistan was due to high outdoor temperatures in the region.

V. CONCLUSION

Energy is a significant cost to DC operators; hence metrics have been developed to analyze its utilization. P_{UE} and DC_{IE} metrics were used to evaluate the level of energy efficiency of Wananchi Group (K) Ltd DC with the aim of providing a basis for regional benchmarking as well as to identify opportunities for energy efficiency. Results show that the performance of the DC facility on energy efficiency was average, with P_{UE} and DC_{IE} values of 1.80 and 56% respectively.

From the analysis done on a Psychrometric chart, it is possible to conserve energy and hence improve the metrics at the DC facility by eliminating one AC. Other appropriate initiatives are also needed to improve the metrics.

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