DESIGN OF A GRID-CONNECTED SOLAR PHOTOVOLTAIC SYSTEM FOR REFRIGERATION PURPOSES IN NAIROBI CARGO HUB AT JOMO KENYATTA INTERNATIONAL AIRPORT,NAIROBI COUNTY,KENYA.

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DECLARATION AND APPROVAL

Declaration by Post graduate student

This thesis is my original work and has not been presented for a degree in any other University or for any other award.

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Supervisors' approval

We confirm that the work reported in this thesis was carried out by the candidate under our supervision.

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DEDICATION

I appreciate my primary school mathematics teacher Mr.Ochieng and my late mother who instilled confidence in my early school life and believed in possibilities.

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ABSTRACT

Electrical energy demand in the world is increasing each and every day. Africa is among the continents, which are mostly affected by less accessibility of electrical energy. Solar PV technology has been the most promising renewable energy in Kenya. The study presents design of a grid-connected solar photovoltaic system for refrigeration purposes where it focuses on cold storage facilities based in Jomo Kenyatta International Airport Cargo hub. The utilization of solar photovoltaic (PV) for refrigeration system have drawn much attention in Kenya due to rising cost of conventional electrical energy. The main purpose of this study was to design and provide an alternative energy cost appraisal for refrigeration purposes using solar photovoltaic. The study addressed three specific objectives, which are, to evaluate refrigeration energy demand in Nairobi cargo hub at JKIA, to design and optimize a grid connected solar PV for refrigeration processes in sampled refrigeration facility and to evaluate the social economic benefits of the grid connected system. Descriptive research method is adopted where qualitative approach is employed. The data is analyzed by the use of descriptive statistics and correlation. The study established that the average peak load and daily energy consumption are 67kW and588.4 kWh/day respectively. The cold-rooms store horticultural produce such flowers, fruits and vegetables which are maintained at temperature settings of +4 to +8 degrees centigrade. The economics analyses of the grid-connected solar PV system have resulted to positive NPV of approximately $136098.75, LCOE is $0.0034/kWh and PBT is 3.79years. The research proves the worthiness of a grid connected solar PV system for refrigeration purposes due to favorable solar isolation of 4 to 6kWh/day at JKIA in Nairobi, grid parity achievement, reduction in cost of energy, creation of opportunities and adoption of clean energy.

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LIST OF ABBREVIATIONS AND ACRONYMS

AC	Alternating current
ASDS	Agriculture sector development strategy
ACM	Air-conditioning machine
AP	April
AU	August
AML	Africair Management Limited
BOS	Balance of system
BNEF	Bloomberg News Energy Finance
CBA	Cost Benefit Analysis
DE	December
DC	Direct Current
ERC	Energy regulation commission
EPRA	Energy and petroleum regulatory authority
FE	February
ELEV	Elevation
GWh	Giga-watts-hours
GoK	Government of Kenya
GP	Grid parity
Gt	Grid-tied
H	Enthalpy
JKUAT	Jomo Kenyatta University of Agriculture and Technology
JKIA	Jomo Kenyatta International Airport
KPLC	Kenya Power and Lighting Company
Kes	Kenya shillings
KW	Kilowatt
LCOE	Levelized cost of electricity
Lat	Latitude

Lon	Longitude
MW	Megawatts
MET	Meteorological
MM	Month
MCCB	Molded case circuit breaker
MA	March
MPPT	Maximum power point tracking
MIS	Missing
MY	May
NPV	Net present value
NO	November
OT	October
PPA	Power purchase agreement
PV	Photovoltaic
PVGIS	Photovoltaic geographical information system
PBT	Payback time
PDC	Present discounted cost
PDB	Present discounted benefits
R_S	Series resistor
R_{SH}	Shunt resistor
STC	Standard test condition
SE	September
SPSS	Statistical package for social science
TMPMIN	Minimum Temperature
TMPMAX	Maximum Temperature
To	Ambient temperature
Tc	Evaporator temperature
V_{MP}	Voltage at maximum power
I_{MP}	Current at maximum power

V_D	Voltage across diode
V_{OC}	Open circuit voltage
VFD	Variable frequency drive
W_P	Watt peak
YY	Year

CHAPTER ONE: INTRODUCTION

1.1 Background of study

Electrical energy demand in the world is increasing each day. Every person in the world is entitled to clean and health environment. (Shyu, 2014) approximate19percentage of the world population lives without access to electricity. For sustainable development globally emphasis on social equity which addresses good living, equal opportunities and improving human capital(Owusu & Asumadu-Sarkodie, 2016). Africa is among the continents which are mostly affected by lack of accessibility of electrical energy where approximately 30% of the population in sub-Sahara Africa has no access to electricity(Mohammed, Mustafa, & Bashir, 2013).On the development path, the African continent, specifically Sub-Saharan Africa (SSA), is delayed by the main challenge of extremely low energy services accessibility and a poor level of energy consumption(Adwek et al., 2020).While in Northern Africa (NA), electricity access is slightly higher than 90%, the electrical plants of the whole fifty sub-Saharan countries, except South Africa (SA), are equivalent to that of Argentina (generation capacity:28GW) and approximately the fifth of the population in this area has access to electricity. Moreover, in the areas where an electrical grid exists, there is frequently power outage in the year, mostly in dry or hot seasons(N'Tsoukpoe, Yamegueu, & Bassole, 2014) Kenya annual consumption approximate10700-gigawatts-hours (GWH) and most of the electrical energy is consumed by industries(ERC, 2018b)The increase in fossil fuel price has necessitated the need to focus on renewable energy. Renewable energy has proven over time that when well utilized can bridge the gap of electrical energy scarcity. Kenya has been ranked among the top 10 countries in the clean energy development composite index(He, Jiao, & Yang, 2018).Other countries are United States of America, China, Germany, Peru, France, Italy, Philippines, Spain and Japan Table 1.1 illustrates top 10 countries in the clean energy development composite index.

Table 1:1Clean energy development composite index(He et al., 2018)

RANK	COUNTRIES	INDEX
1	United States of America	100
2	China	91.4
3	Germany	69.4
4	Peru	53.4
5	France	52.3
6	Italy	45.7
7	Philippines	44.3
8	Spain	41.7
9	Japan	37.6
10	Kenya	36.9

Solar photovoltaic technology has been the most promising renewable energy in Kenya with adequate irradiation throughout the year but only managed capacities of 50.6and 31 megawatts grid connected and off-grid respectively (ERC, 2018b). The fact is that presently only a small percentage of solar power is integrated into the grid making many industries and commercial businesses to depend solely on conventional power. Kenya is a major exporter of fresh produce in the worlds, which earns foreign exchange and spur economic growth. Designing solar PV for refrigeration integrated to the grid will be a big win in safeguarding the agriculture sector. Refrigeration is the process of cooling where temperatures need to be kept at specific settings. Fresh produce after been harvested from farms have to be stored at +4 and +8 degrees centigrade to avoid damage. The export of fresh produce goes with seasons and designing solar PV running the refrigeration machine when integrated into the grid is advantageous in the preservation of the fresh produce(Rosiek, Romero-Cano, Puertas, & Batlles, 2019). It is, therefore, necessary to utilize the solar PV in running these systems. The electrical grid been interconnected network of electricity from sources to substations have over time proved less reliable due to many factors, for instance, electrical disruptions. The design of solar PV for running refrigeration has positive impact on growth of the agriculture sector. The challenges on food security is mostly attributed to the cost of production, processing, agricultural inputs, and frequent drought experienced in many parts of the country, preservation of perishable agricultural products and also inadequate expertise and training in the agricultural sector(Mwadalu & Mwangi, 2013). Grid-connected solar PV for refrigeration system can mitigate some of the factors contributing to food insecurity. Solar energy contribution to the national grid minimum thus effort towards uplifting generation has to be put into consideration(ERC, 2018a). The study also focuses on economic efficiency where factors such as increase in consumption, international trade where horticultural products play a bigger part. Environmental sustainability under sustainable development looks into consumption of resources where the consumption should not exceed regeneration. Solar resource is abundant and plenty in Kenya and only a small percentage is utilized. Economic benefit has positive impact on the cost of power from utility company. The study employs net metering in the design. This is a bidirectional meter, which calculates difference of power supplied by utility company to the power exported to the grid. The economic analysis is used in this study since it gives viability of grid connected solar PV system for refrigeration purposes.(ERC, 2018a)Outlines how energy is consumed in Kenya where industrial plants leads with 60% in energy consumption.

Figure 1.1 illustrates the electrical energy consumption in Kenya.

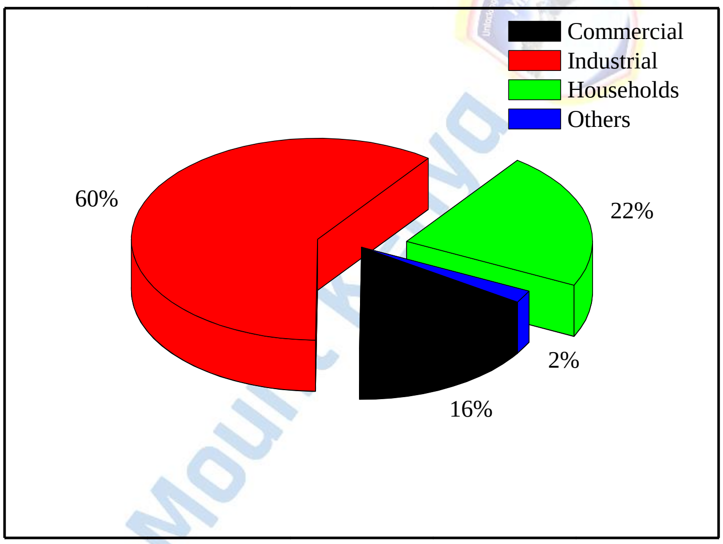

Figure1.1: Energy consumption in Kenya(ERC, 2018b)

The study primarily considers essential baseline data, which are energy consumption for refrigeration facilities and solar insolation. Energy security is the ability of a nation to deliver the energy resources needed to ensure its welfare and implies secure supply and stable prices. Energy is vital for progress and development of a nation’s economy(Hassan & Mohamad, 2012). The economic growth and technological advancement of every country depends on it and the amount of available energy reflects that country’s quality of life. Solar energy is an alternative energy source for cooling systems where electricity is expensive. Solar refrigeration technology engages a system where solar power is used for cooling purposes(Sarbu, Valea, & Sebarchievici, 2013). Cooling can be achieved through four basic methods: solar PV cooling, solar thermo-electrical cooling, solar thermo-mechanical cooling, and solar thermal cooling(Otanicar, Taylor, & Phelan, 2012).When new investment decisions need to be made regarding an existing loading capacity, it is critical to assess the total costs and savings associated with the proposed investments(Hoang et al., 2008).

1.2 Statement of the problem

Refrigeration is essential in preserving fresh produce for daily consumption or before export(Ekren, 2017). High utility bills have made it difficulty in running and maintenance of the storage facilities like chillers and cold rooms(Lagesse, 2016) .Tariff method C11 is applicable in Kenya to commercial and industrial consumers whose consumption exceeds 15000kWh per month (EPRA, 2018). Solar PV has proved over time that it can offer alternative source of energy. Preliminary investigation shows that there is less academic study, which has been carried out on the grid, connected solar PV for refrigeration application on the area under this study. According to(Njoroge, Ndunya, & Kabiru, 2018) hybrid solar-wind power system for truck refrigeration in Kenya is readily available.(Ogumo, Kunyanga, Kimenju, & Okoth, 2020) addresses the performance of a fabricated solar powered vapor compression cooler in maintaining post-harvest quality of French beans in Kenya. This study has not been done hence the need to carry out the research. It addresses the use of solar energy and grid power in running the refrigeration facilities, which stores horticultural products by designing grid-connected solar PV system. Currently the refrigeration facilities under the study utilize the grid power. The preference of solar energy will have a positive impact in running the cold store facilities boosting economy of scale. The level of penetration of grid connected solar PV system for refrigeration facilities is a desirable gap, which this study demonstrates.

1.3 Purpose of the study

The main purpose of this study is to design and provide an alternative energy cost appraisal for refrigeration system using solar photovoltaic.

1.4 Research questions

1. What are the energy demands for every refrigeration firms in Nairobi cargo hub at JKIA?

2. How can solar PV be optimally integrated into the electrical grid for refrigeration applications?
3. What are the social-economic benefits of the grid-connected solar PV system?

1.5 Main objectives

1. To evaluate refrigeration energy demands in refrigeration firms in Nairobi cargo hub at JKIA.
2. To design and optimize a grid-connected solar PV for refrigeration processes in sampled refrigeration facility.
3. To evaluate the social-economic benefits of the grid-connected solar PV system

1.6 Significance of the study

The use of grid-connected solar PV system saves on power lines transmission losses. Reduction of air pollution by the use of solar power, which is clean energy, minimizing emissions of greenhouse gases, which cause global warming. The use of refrigerant (R404A) with reduced hydrocarbon, which have a positive impact on ozone layer. Solar PV system has less operations and maintenance cost compared other sources of energy such as fossil fuel. Reduced monthly energy bills by approximately 50% due to utilization of solar energy during the day though utility power is used to run the refrigeration machines at night. Positive net present value and shorter pay back from the investment make this investment attractive. Favorable LCOE resulting to achievement of the grid parity. The grid connected solar PV system has no battery backup making it less costly compared with the installed grid connected system with battery backup. The government of Kenya and policy makers will deliberate guidelines on the optimal utilization of solar PV using this study. This study will also open up to grid-connected solar PV technology advancement to more researchers, which creates job opportunities improving livelihood.

1.7 Scope of work

The purpose of the study is to design and provide an alternative energy cost appraisal for refrigeration system using solar photovoltaic. The research entails evaluation of a typical energy demand and consumption trends within the study area. This is followed by designing a grid-connected solar PV, which includes the sizing of the solar modules, and grid tied inverter. Social and economic viability is determined by calculating the NPV, LCOE and PBT. The study addresses electrical supply from conventional sources in comparison to solar PV and sustainable electrical energy supply for ten refrigeration firms in Nairobi cargo hub at JKIA.

Location of the study is Nairobi cargo hub at JKIA where many of the refrigeration facilities, which store horticultural produce, destined for export market.

1.8 Study limitation

The study is limited to the design of the grid –connected solar PV system without altering the already installed refrigeration systems components.

1.9 Operational key terms

1. Refrigeration-This is the process of cooling or removing heat from an enclosed space or a substance for lowering the temperature.
2. Solar energy-The type of energy generated by the sun
3. Solar module-is a single PV panel that is an assembly of connected solar cells.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter discusses the overview of refrigeration, solar resource, solar PV technologies, the grid, empirical literature and conceptual framework. This is imperative for the study since it gives more insight and generate positive outcome.

2.1.1 Refrigeration

Most of the commercial refrigeration in Kenya are vapor compression systems and are powered from conventional power tapped from the grid. Refrigeration system is composed of the following parts, compression, condensing, and evaporating and expansion units. The processes of refrigeration exhibit a continuous flow of the refrigerant. From the evaporator cold refrigerant absorbs heat and boils where the pressure and temperature remain constant. The performance of the vapor compression cycle is quantified by the coefficient of performance(COP)(Chamarthi, Saxena, & Ratna) describing on solar refrigeration system elaborate more on coefficient of performance of vapor compression cycle.

Variable frequency drives (VFDs) on compressor and condenser motors when used appropriately gives optimal in energy conservation. Complete integrated automation system for the solar PV is preferred. A simplified refrigeration system cycles illustrates the four main components and the flow of the refrigerant. The environment friendly refrigerant currently in use is R404A for this study.

Figure 2.1 gives elaborate illustration of vapor compression refrigeration cycle. The low pressure and temperature vapor is compressed by the compressor resulting to high temperature and pressure vapor. The high temperature and pressure vapor passes to the condenser where it condenses to high temperature and pressure liquid. The liquid flows to expansion valve, which reduces the pressure of refrigerant spreading to evaporator. Evaporator absorbs heat into refrigeration system effecting the cooling of the horticulture produce. This is continuous and repetitive cycle.

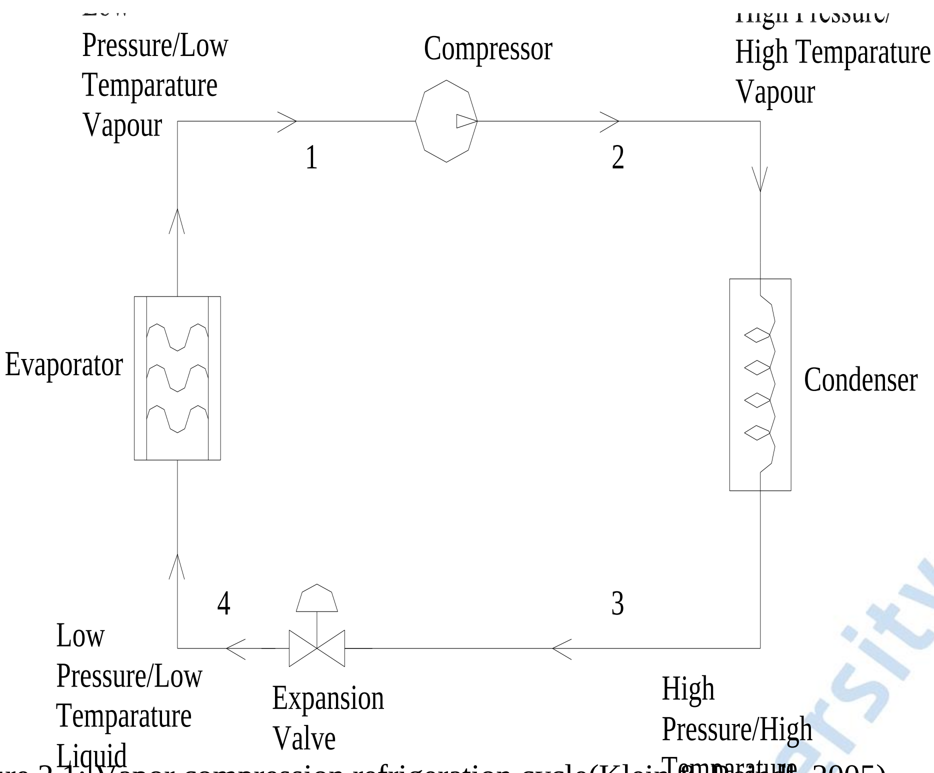

Figure 2.1: Vapor compression refrigeration cycle(Klein & Reindl, 2005)

The enthalpy flow chart of vapor compression process describes the coefficient of performance (COP) = hi-h4/h2-h1.The high the COP the more efficient the refrigeration system.(Klein & Reindl, 2005)The study maintains the system variable with accordance with preferable settings of the system to maintain the coefficient of performance. Figure 2.2 illustrates enthalpy chart of vapor compression process

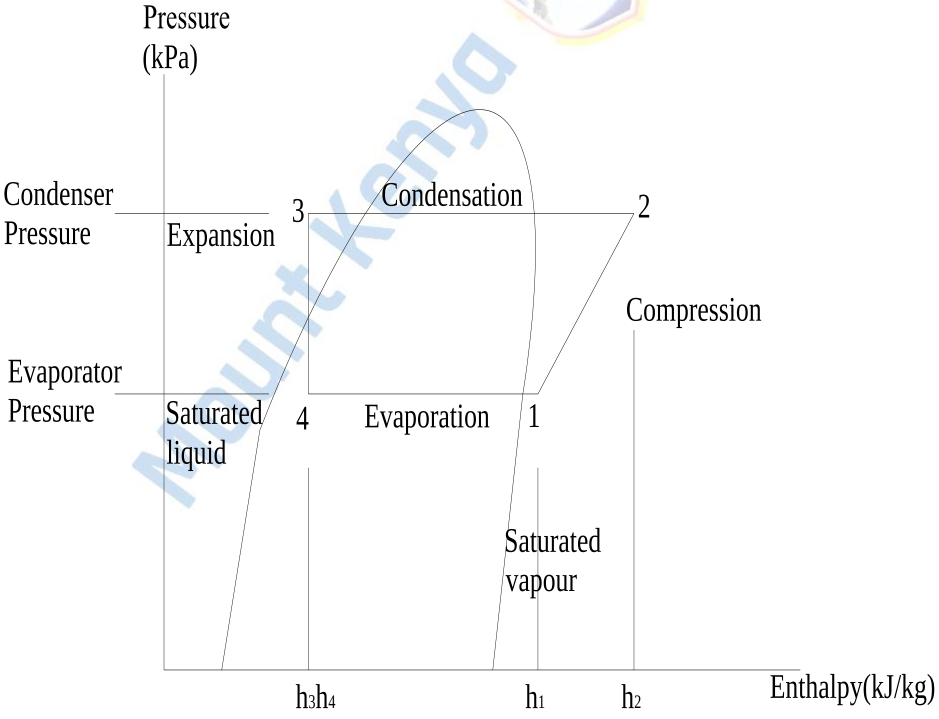

Figure 2.2: Enthalpy chart of vapor compression process(Klein & Reindl, 2005)

Most of the refrigeration machines are rated in kilowatts (kW) or horse power (hp) and designing a refrigeration system considering the products to be preserved and temperature settings give an overview of the machine capacities(Chaomuang, Flick, & Laguerre, 2017)

For this study the refrigeration facilities are already established and the lookout is the energy demand to be able design grid-connected solar PV system

2.1.2 Solar energy

Solar energy is key enabler of economic growth in Kenya. The consumption of electricity has been increasing making renewable energy as the alternative to fill the gap between power generation and consumption. The following illustrates the energy mix in Kenya, hydro: 836 MW, thermal: 716 MW, biogas, 2 MW, wind: 336 MW, cogeneration: 28 MW, solar (grid-connected):50.6 MW, solar (off-grid): 31 MW, others: 28 MW. (ERC, 2018b)

Solar energy is currently one of renewable resource with high potential if well utilized. Kenya having irradiation of 4 kWh/m^{2}to6 kWh/m^{2,} which is significant in generation of surplus solar energy.(N. W. Wasike, 2015)

Figure 2.3 gives illustration how the energy mix in Kenya is distributed. These shows how solar energy is underutilized making this study significance since it will maximize solar resource usage.

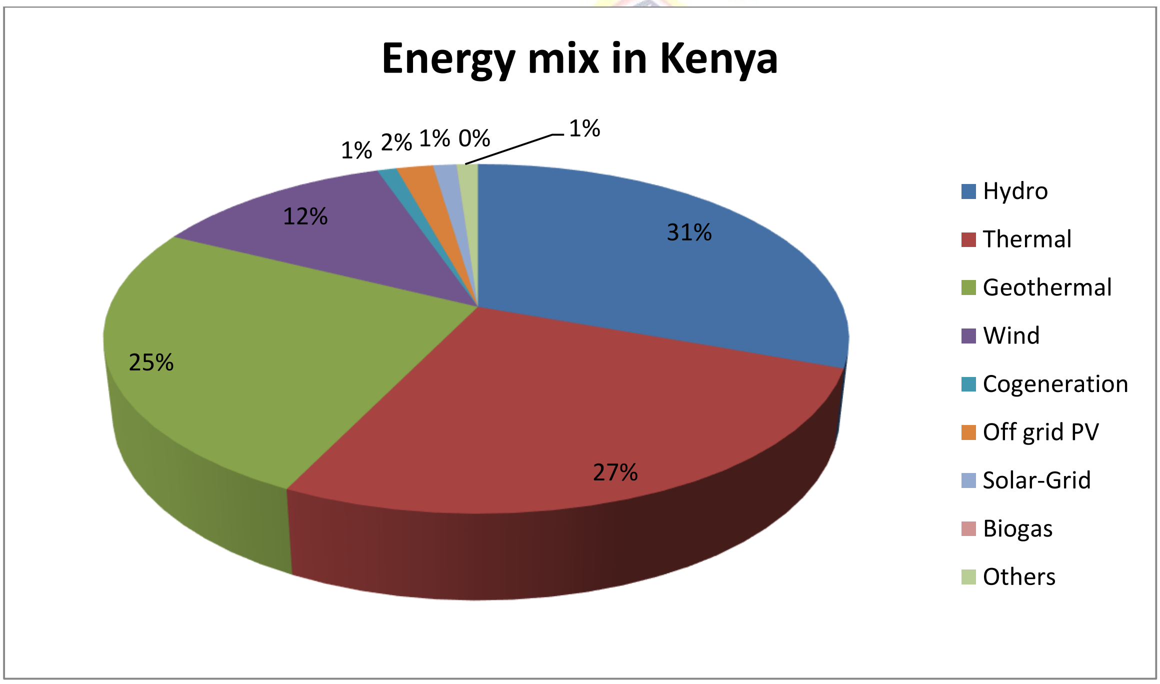

Figure 2.3: Energy mix in Kenya(ERC, 2018b)

The main component of photovoltaic system is the module and has characteristics defined by current-voltage curve. Sunlight is composed of protons or particles of solar energy. The characteristic of photons striking, results to reflection, absorption or passing through of photons. Only the absorbed photons generate electricity. Modules connected in series form arrays where large quantities of current and voltage can be produced. The solar panel parameters which this study focuses, describes short circuit current (I_{SC}), open circuit voltage (V_{OC}), Current at maximum power (I_{MP}), voltage at maximum power (V_{MP}) and maximum power (I_{MP}) at a standard test condition (STC) which is 25 degrees centigrade, irradiance of $1000W/m^2$, 1.5 of air mass. Some of the factors that mostly affect the module output are shading, module orientation, tilt angle, temperature and the atmospheric conditions such as dust. Measurement of module efficiency is quantified by fill factor. Figure 2.4: illustrates current-voltage curve of a module.

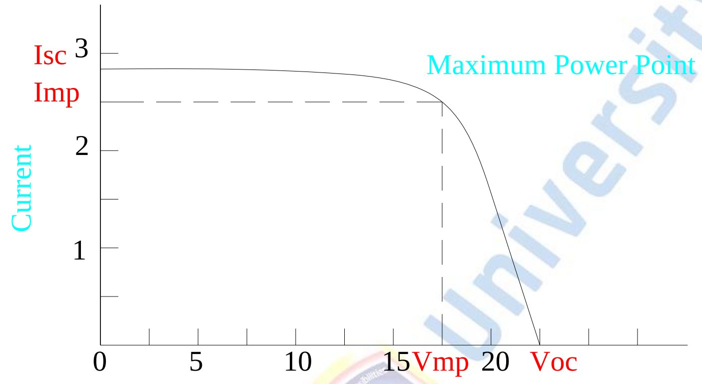

Figure 2.4:Current-Voltage curve(I-V curve)(D. J. Simiyu, 2015)

The solar cell model consists of a diode, shunt and series resistors. The shunt and series resistors, controls diode and load respectively. Figure 2.5 shows circuit of a solar cell model.

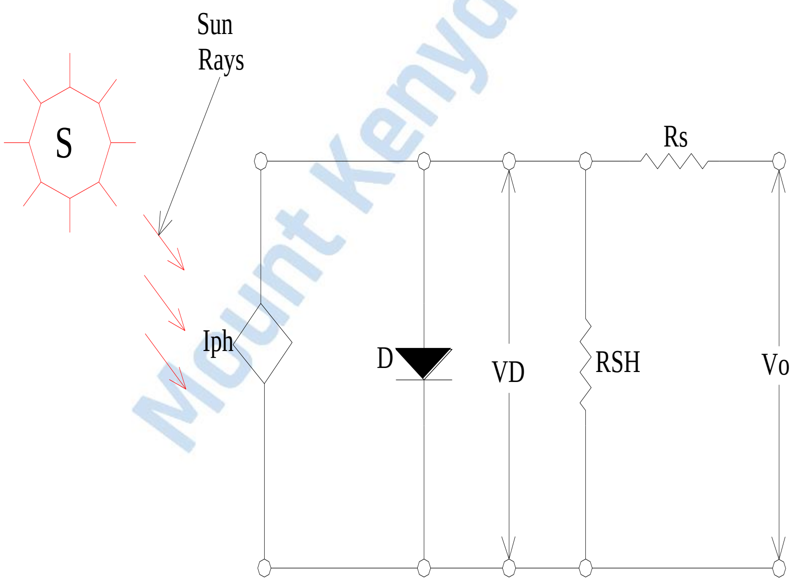

Figure 2.5: Solar cell model (photovoltaic model)(Adnene & Ahmed, 1996)

The commonly used solar modules in the market are classified as first and second-generation solar cell. The commonly used solar technologies are:

a. Poly-crystalline silicon PV module

This is among the first-generation solar cell suitable and preferred for this study because of lower cost. It is made from grain of crystal structure cutout of different crystal fused together. Poly-crystalline wafer is full square shape and has lower efficiency compared to mono-crystalline wafer. Also having better efficiency in reference to amorphous and it has useful life of 10years at 90% rated power and 25years at 80% rated power. Commonly available sizes range from twenty to one and fifty watts.(D. J. Simiyu, 2015)

b. Mono-crystalline silicon PV module

It made from uniform Si-lattice cutout of a single crystal. Mono-crystalline wafer is in the form of semi-square shape but full square is also possible. It has higher efficiency potential though it is more expensive and has useful life of 25years rated at 90% and 30years rated at 80%.(D. J. Simiyu, 2015)

c. Amorphous PV module

It is made from disordered thin film PV material a-Si and has useful life of 10years.Commonly available sizes ranges from five to nineteen watts and the installation area for the PV module is limited.(D. J. Simiyu, 2015)

Figure 2.6 gives three commonly used solar modules

Polycrystalline Module	Amorphous Module	Mono-crystalline Module

Figure 2.6: Common PV module technologies (J. Simiyu, 2015)

Solar module efficiency is key in determining the suitable type of solar panel in a given installation.

Table 2.1 demonstrates the conversion efficiencies of amorphous, polycrystalline and mono-crystalline modules. Mono-crystalline module has better efficiency compared to polycrystalline and amorphous modules.

Table 2.1 Conversion efficiency for commonly used PV module technologies(J. Simiyu, 2015)

Technology	**Module efficiency**
Amorphous silicon (a-si)	6-7%
Polycrystalline silicon	15-18%
Mon-crystalline silicon	16-20%

2.1.3The Power grid

This is interconnected network for electricity delivery from producers to consumers. It comprises a network of electrical transmission lines connecting a multiplicity of generating stations to load over a wide area. The types of grid solar PV system are:

a. Grid-tied system

b. Grid-tied with battery backup

c. Grid-tied hybrid system

d. Solar water pumping system

Table 2.2: Types of solar PV system and proportion of contractors(EPRA, 2019b)

TYPES OF SOLAR PV SYSTEM	PROPORTION OF CONTRACTORS
Grid-tied system	75%
Grid-tied with battery backup	68%
Grid-tied hybrid system	59%
Solar water pumping system	49%

The average installation cost for solar PV system depends on the capacity rated in kW and the proportion of installed system. Table 2.3 shows size and cost of solar PV system

Table 2.3: Size and cost of own generation solar PV systems(EPRA, 2019a)

INSTALLED GENERATION CAPACITY(KW)	**PROPORTIONOF INSTALLED SYSTEMS**	**AVERAGE INSTALLATION COST(USD/kW)**
≤ 50	32%	1216
51-300	27%	1128
301-500	14%	1881
> 500	27%	1876

There are different topologies for PV array that have great influence on energy production and the choice of one or the other form to connect the PV panels among themselves and the inverter system will be a determining factor on aspects such as the use of solar radiation, the shading and mismatch losses(Díez-Mediavilla, Dieste-Velasco, Rodríguez-Amigo, García-Calderón, & Alonso-Tristán, 2014).The grid-tied inverter with the most commonly used connections topologies are: centralized, modular and string. In a centralized system, some PV panels are connected in a serial to form a string and connected in parallel to a single inverter. Strings work independently from one to the other and in the event that inverter fault occurs, configuration ensures the continuity of power transmission. The other configuration is the modular inverter which uses a DC to DC converter with its own MPPT for each string and the entire system is connected to a single DC to AC inverter(Jana, Saha, & Bhattacharya, 2017). For this study, string topology is most suitable since the layout can accommodate various modules in line with the inverter. Figures 2.7 illustrates the mostly used topology which are centralized,string and modular(AC module).

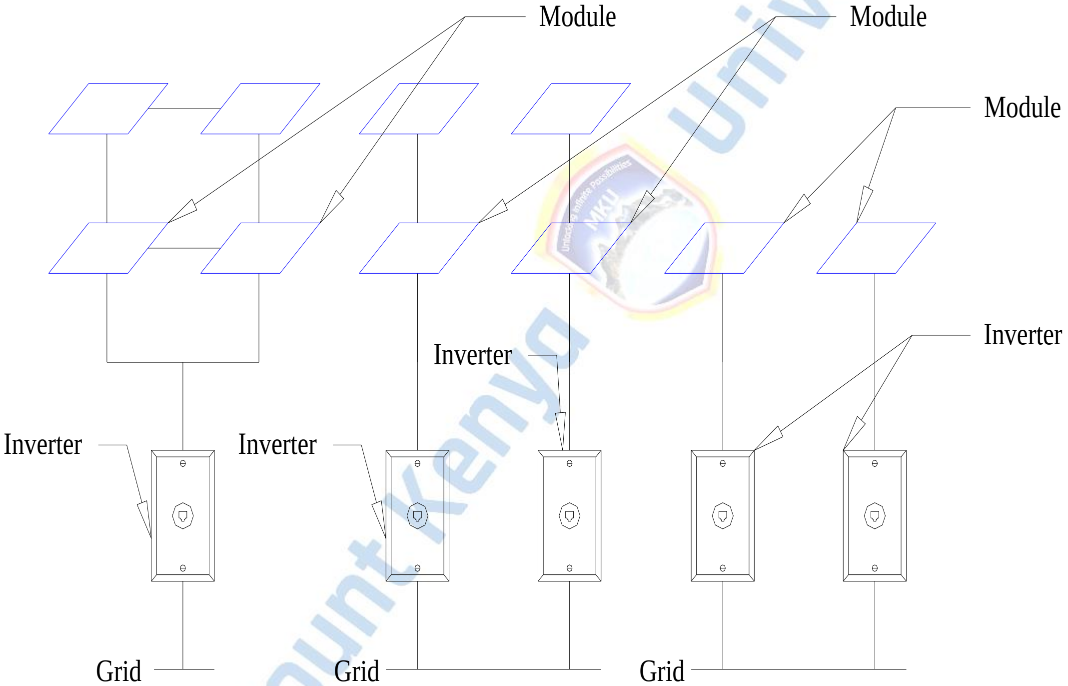

Figure 2.7: Topologies (Centralized, string and modular)(Jana et al., 2017)

Table 2.4 illustrates comparison between different inverter topologies outlining the advantages, disadvantages and the power rating

Table2.4: Comparison between different inverter topologies(Jana et al., 2017)

Topology	Advantage	Disadvantage	Power rating
1.Centralized	-A low cost due to central	-DC losses in high voltage	3kW

	inverter	DC cable -Working of solar module is compromised due to partial shading -In case of failure of inverter, there is no option of feeding power to utility grid -Low reliability -Power loss due to centralized MPPT, string diodes and mismatch in PV module -Non flexible design	5kW 1MW
2. String	-Reduction in energy loss that result from partial shading -Losses in string diodes are eliminated -Better stability and safety against failure as the AC signal is coming from each PV module for a common AC bus -Good reliability and flexible in design	-Mostly used for low power rating -High cost as compared to centralized	1kW 20kW 500kW
3.Multi-string	-Reduction in energy loss that result from partial shading -Losses in string diodes are	-All strings are connected to a single inverter thus the reliability of the system decreases	50kW

	eliminated -MPPT and current control are separated -Voltage amplification can be achieved by the DC-DC converter	-Occurrence of additional losses inside the DC-to-DC converter -The cost is higher compared to centralized topology	
4.Modular (AC module)	Appropriate for residential applications where partial shading is a critical issue -No mismatch losses between modules -Easy in failure detection of the modules -Flexible and expandable in design -Good for mass production as it is modularized -Average life is 28 years due to elimination of bulk electrolytic	-Replacement of inverter in case of fault is not easy -Mass production costs are high compared to string inverter	500 to 600W

2.1.4 Net metering (bi-directional meter)

In net metering the company is only billed for the net energy that is used which is the difference between total energy produced by the solar system and total energy consumed.Net metering account the difference of excess power exported back to the grid. It has several advantages such as:

a. Eliminate the need for battery storage and backup generator. In this regard, save on expensive solar batteries.
b. Low and inexpensive maintenance
c. Lower cost of energy and create small power generation units. This enables refrigeration machines operate optimally.

The main disadvantage is that net metering laws and energy rates could change making it difficult to calculate the payback period for grid-connected solar powered system.

2.2 Empirical literature

2.2.1 Refrigeration energy demands in refrigeration firms in cargo hub

The study by(kishor Verma & Dondapati, 2017) reveals that the power requirement of a compressor for a lower pressure reduces the capacity of the compressor and conversely the case is of high suction pressure(Zhao, Li, Wang, Zhao, & Taylor, 2018) analysis the method of performance evaluation of solar photovoltaic air conditioner. According to(Akerma, Hoang, Leducq, & Delahaye, 2020) demand response is one of the energy management strategy that can relieve the strain on power grid by balancing the refrigeration energy consumption and product demand. The study by(Makule, Dimoso, & Tassou, 2022)enhances refrigeration systems by integrating the cold storage with modern intelligent methods such as programmable logic control technology and frequency controlled technology which optimizes the control of cold storage for low energy consumption. Suitable cooling system for use in rural areas in Kenya is illustrated by(Ogumo, Kunyanga, Okoth, & Kimenju, 2020) where fresh produce are stored in cold-rooms for preservation.

2.2.2 Designing and optimizing a grid connected solar PV for refrigeration process.

The major consideration in the design for photovoltaic for refrigeration system involves matching the electrical characteristics of the motor driving the compressor with available current (Klein & Reindl, 2005). (Chen, Liu, Wang, Wang, & Dong, 2017) discusses direct drive air conditioning system illustrating the layout of the system which includes photovoltaic array, storage battery, charge controller and the load which is the air-conditioner. (Xu et al., 2017) analysis static ice refrigeration air-conditioning and found that battery bank can be employed in refrigeration system.(Oh, Binns, Park, & Kim, 2016) consider and determine the most energy efficient operating conditions for each refrigeration design and when applied illustrate the economic benefits(Oh et al., 2016) consider and determine the most energy efficient operating conditions for each refrigeration design and when applied illustrate the economic benefits. Also demonstrate what savings when pure refrigerants are replaced with mixed refrigerant optimizing operating conditions.(Dezhi & Mingshun, 2010) demonstrates design and simulation of marine refrigeration system based on system integration and shows how the main refrigeration system components which are compressor, condenser, evaporator and the expansion valve can be modeled an simulated using Mat-lab environment thus increasing real time of the operation and management.(Dong & Han, 2016) gives model-free controller design for advanced energy saving of the refrigeration system addressing response and dynamic performance where simulation results of variable control parameters show improvement of the system.(Dubey, Saxena, & Sharma, 2016) employ design of Photovoltaic system for refrigeration plants in isolated areas and control approach of quasi resonant boost converter fed solar photovoltaic based permanent magnet synchronous motor drive with variation in solar irradiation. Noting that in vapor compression based cooling system, load torque is the function of square of the permanent magnet synchronous motor.(Chattouna, Boukhchana, Fellah, & Brahim, 2014) discusses simulation of the absorption phase of an intermittent absorption solar refrigeration system making suitable application for the storage of foodstuffs and pharmaceutical products. This can be ensured through compression and absorption cycles in continuous or in intermittent operation. Purpose is to develop of a numerical model in order to study the dynamic behavior of a cooling liquid. The study by(Njoroge et al., 2018)shows that hybrid solar-wind power system for truck refrigeration in Kenya.

2.2.3 The social-economic benefits of the grid-connected solar PV system

The study by (Gao, Ji, Guo, & Su, 2018) gave comparison of the solar photovoltaic cooling to conventional cooling.(Ghaith & Abusitta, 2014) analyses energy of an integrated solar powered heating and cooling systems by potential energy saving while optimizing the daily operation of refrigeration systems noting that refrigeration is listed among the large energy consumer.(Xu et al., 2017) analysis static ice refrigeration air-conditioning and found that battery bank can be employed in refrigeration system.(Oliden, Manrique, & Ipanaqué, 2017) illustrates model and control of a refrigeration system for fruit preservation and analyses the energy saving oriented control strategy for vapor compression systems.(Oliden et al., 2017)Further describes advanced topology to minimize leakage current grid-tied PV system addressing the barriers for the penetration and reach of PV system noting that the efficiency of transformer less grid connected PV inverter is high due to the three level output voltage and generate no leakage current.(Qureshi & Tassou, 1996)explain in practice refrigeration system considering variable speed drive which have been applied successfully to control the capacity of compressor which results to potential energy saving.(Han, Dong, & Chang, 2017) illustrates energy saving method of refrigeration system based on model-free control algorithm focusing on strategy on energy conservation. While the model-free algorithm is ineffective for dynamic refrigeration system where there is considerably time delay making not possible to efficiently track the input signal..(Yin, Li, Li, Zheng, & Cai, 2014) discusses energy saving oriented control strategy for vapor compression refrigeration cycle systems and develops predictive control strategy to improve system efficiency while meeting changing demands for cooling capacity. The difference between condenser pressure and super heat are regulated output making expansion valve opening and compressor speed been controlled inputs.(Oh, Binns et al. 2016)gives performance of refrigerator taking consideration current and voltage curve analyses (I-V) of standalone system and comparison of power PV and conventional electrical energy in operating low power refrigeration system which demonstrates the economic effectiveness..(Ravindra, Rao, & Chaitanya, 2017) suggested the relevance on the PV research focusing on control strategies which can smoothen the photovoltaic generation and give economic analysis of a hybrid solar PV grid connected powered air-conditioner machine, noting that electricity generation have low levels of renewable energy where sunlight is in abundance considering the continent of Africa.

From captured literature review concerning grid-connected solar photovoltaic for refrigeration purpose, there exist a wide gap, which needs to be addressed in Kenya and most preferably Nairobi County. Many reviews touch off grid solar PV with less solar grid-connected.

The study main concern is the cost of running the refrigeration systems. Well-designed model demonstrates the effectiveness of solar PV to the refrigeration energy demand where the surplus power is fed to the grid. The utilization of net metering enables the utility company give energy credit through power purchase agreement (PPA) resulting to power bills reduction and saving on energy cost per kilowatt-hour (kWh).

2.3 Conceptual framework

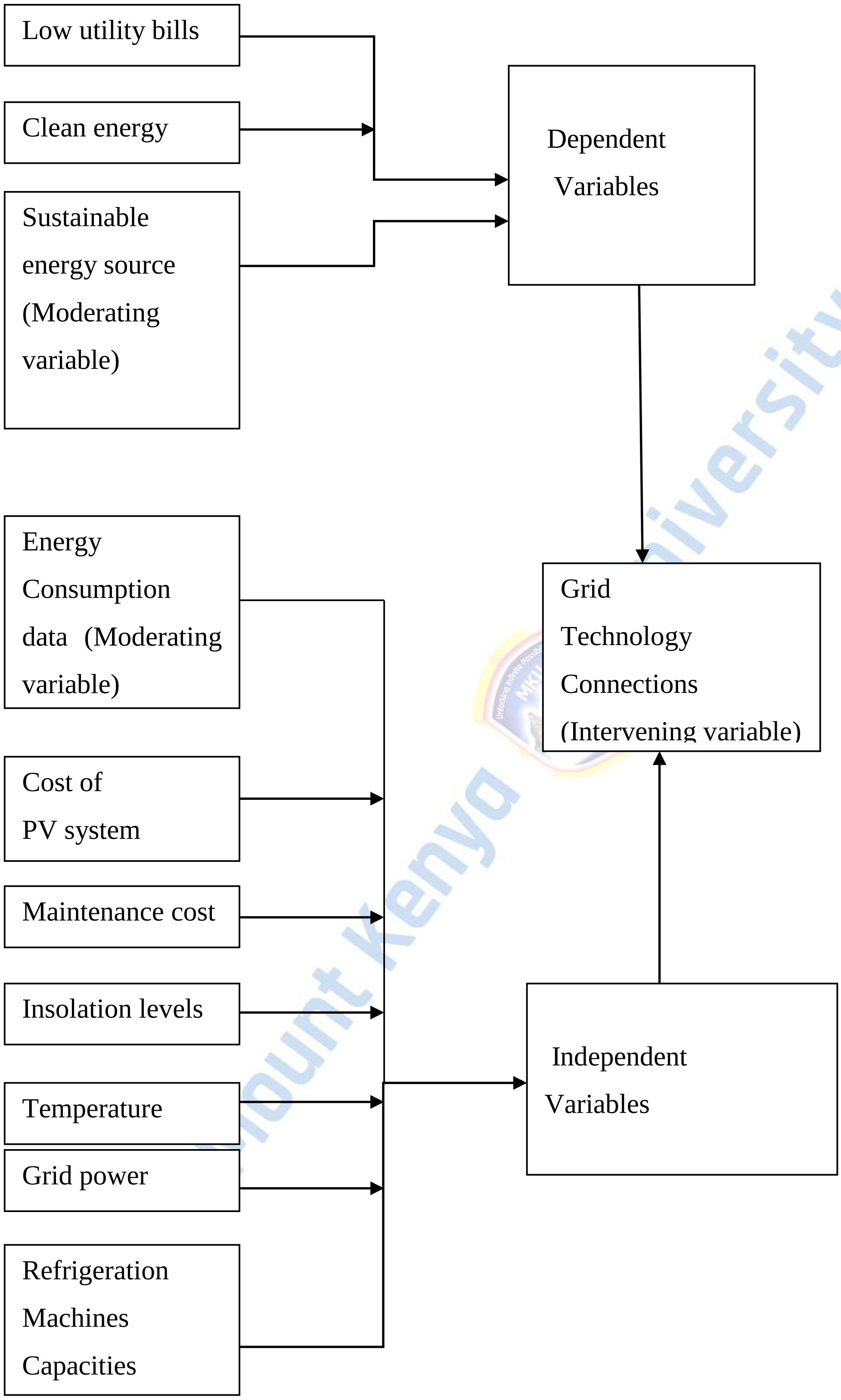

Figure 2.8:Conceptualframework(Kaira, 2022a)

CHAPTER: THREE: RESEARCH METHODOLOGY

3.1 Introduction

The research study addresses the immediate problem encountered in running of refrigeration system. The research method applied is descriptive research where qualitative approach is been employed. Focus is to design a grid-connected solar PV for refrigeration purposes. The methodology comprises of research design, sampling procedure and technique, data collection methods and procedure, data analysis technique and procedure and sample population.

3.2Research Design

The study employs both observational and statistical research designs.

Observation design is most imperatively used for the study considering solar resource as essential variable. Insolation levels for each and every day, month and year constitute a good research design. Variable such as temperature is managed so that output in terms of maximum power can be harvested from the solar resource.

Through statistical design, the measures of energy demand and sustainable energy source for design of grid-connected solar PV for refrigeration system can be evaluated and analyzed. Considering variables such as insolation levels, temperature, peak loads, refrigeration machines capacities, energy consumption data, grid power and maintenance cost.

3.3 Location of the study

The study is based at JKIA in Nairobi that is the capital city of Kenya. Nairobi city is located at latitude 1^{0}19'S and longitude 36^{0}55'E degrees west and at 1624m above sea level(N. Wasike, Soitah, Waweru, & Kariuki, 2014). The reason for choosing JKIA is that most of horticulture produce such as flowers (flower roses), fruits and vegetables are sorted, packaged and stored in cold storage (cold rooms) before been exported to the markets. JKIA is the hub where flights connect to other destinations. Preliminary study indicates tremendous increase of cold storage facilities in this area.

3.4 Target population

Nairobi cargo hub has ten horticultural refrigeration facilities, which preserve horticultural products from agriculture farms in Kenya.

3.5 Sampling procedure and techniques

This study employs probability and purposeful sampling technique. Under the probability sampling every item of the universe has an equal chance of inclusion in the sample whereas non probability sampling procedure does not afford any basis for estimating the probability that each item in the population has being included in the sample(Kothari, 2014).Non probability sampling can be categorized as purposive, deliberate or judgment sampling. Through random sampling of entire population, Facility A is purposively selected as a sample.

3.6 Sample population

The working principle of the refrigeration machines and layout precisely vapor compressions is the same but the rating and capacities differs. Facility A is picked which represent sample population where purposive sampling is utilized.

3.7 Data collection methods and procedures

The type of data utilized for this study is secondary data and methods of data collection are the documents and records. Monthly energy bills data for the month with low insolation for the population under the study are utilized. Monthly energy bills are reserved secondary data, which illustrates the energy demand and peak loads. Through thorough scrutiny, this study found the secondary data to be reliable, suitable and adequate First objective was to evaluate refrigeration energy demands in refrigeration firms in Nairobi cargo hub at JKIA. Data was collected from reserved records for monthly energy bills. Data collection procedure is:

1. Tabulate daily, monthly, yearly energy consumption data and peak load for entire population.
2. Present daily, monthly, yearly energy consumption and peak loads trends for the population using bar graphs and line diagrams
3. Tabulate refrigeration components power consumption and present power consumption trends for the sampled refrigeration facility.

. The second objective is to design and optimize a grid connected solar PV for refrigeration processes in sampled refrigeration facility. The data was collected from JKIA meteorological department reserved records indicating solar radiation and temperatures. The setup and procedures for this objective are:

1. A lay out plan of a grid-connected solar PV system for refrigeration purposes. The materials used for design of the PV system are solar modules, grid connected inverters, bi-directional meters, connecting cables, accessories, electrical distribution board that consists of rated circuit breakers. The roof top area of the sampled cold-room facility is 240m^2, which accommodates the PV modules. The solar modules are connected in string and terminated to string inverter. The tilt angle is 15 degrees and orientation of the solar module is south.

Figure 3.1 indicates solar modules connected in strings.

Figure 3:1 Solar modules connected in strings(Kaira, 2022d)

2. Tabulate the reserved solar radiation, temperatures, relatively present solar radiation, and temperatures trends from JKIA meteorological department. Metrological data for three Nairobi stations which are Kabete, Dagoreti and JKIA informs the data trends for the past two decades which is relevant for this study

.3. Solar PV system sizing for the sampled refrigeration facility where formulae for solar module and inverter sizing are utilized.

The third objective is to evaluate the social-economic benefits of the grid-connected solar PV system. The data was collected from reserved records for monthly bills, which stipulate the monthly energy cost. The procedures for this objective are:

1. Tabulate reserved monthly and yearly cost of energy for entire population.

2. Present the monthly and yearly cost of energy trends for the population

3.8 Proposed data analysis techniques and procedures

Statistic package for social science (SPSS) software is been applied in the study. The first objective is to evaluate energy demands in refrigeration firms in Nairobi cargo hub at JKIA. The variables for this objective are the energy demands, which are the peak loads (kW), and energy consumption data (kWh). The data is presented, evaluated and interpreted by the use of tables, bar charts and line diagram. Data is analyzed by use of descriptive and correlation analyses. For descriptive analysis, the study considers the measure of central tendency, which are the mean, median, and the mode. Correlation analysis indicates whether the variables are positively, negatively no correlation. The second objective is to design and optimize a grid connected solar PV for refrigeration purposes. The variables for the objectives are solar energy, insolation levels,, grid power, refrigeration machines capacities, optimization and data is analyzed by descriptive statistics and correlation analysis. Correlation analysis indicates whether the variables are correlated while descriptive statistics shows measure of central tendency, which the study utilizes. The third objective is to evaluate the social economic benefits of the grid connected solar PV system. The variables for the third objectives are the cost of the PV system, maintenance cost and economic of solar PV system. The study considers three parameters, which are PBT, NPV and LCOE where economic analyses by use of formulae are applied.

3.9 Ethical considerations

.Confidentiality and privacy have been observed throughout the research study since secondary data such as monthly bills are quite sensitive. Due to proprietary conflicts, the study population is abbreviated as Facilities A, B, C, D, E, F, G, H, J. and I

CHAPTER FOUR: RESEARCH FINDINGS AND DISCUSSIONS

4.1 Introduction

This chapter effectively deals with research presentation, finding and analyses of the study on the design of grid connected solar PV system for refrigeration purposes. The study involves a population of ten refrigeration firms. The outcomes of the study are presented based on the objectives of the study, which are:

1. To evaluate refrigeration energy demands in refrigeration firms in Nairobi cargo hub at JKIA
2. To design and optimize a grid-connected solar PV for refrigeration processes in sampled refrigeration facility.
3. To evaluate the social-economic benefits of the grid-connected PV system

4.2 Research presentation and interpretation

4.2.1 Energy consumption data

The first objective is to evaluate energy demands in refrigeration firms in Nairobi cargo hub at JKIA.

The following tables captures the data collected in the study. Tables 4.1, 4.2,4.3 and 4.4 illustrates the daily high and low energy consumption, monthly high and low-rate energy consumption, yearly high and low-rate energy consumption and peak load for refrigeration machines respectively. The energy consumption for each facility varies and this is attributed to refrigeration machines capacities. High-rate energy consumption is during the daytime where low-rate energy consumption is energy consumed at night. Figure 4.1 shows the average daily high and low-rate energy consumption. Facility C indicates the highest energy consumption while Facility G takes lowest energy consumption. The study utilizes the daily high-rate energy consumption in sizing of the solar module

Table 4.1: Average daily high and low-rate energy consumption

SAMPLED FACILITIES	HIGH-RATE ENERGY CONSUMPTION (kWh)	LOW-RATE ENERGY CONSUMPTION (kWh)
Facility A	719	705
Facility B	424	416
Facility C	797	782
Facility D	390	382
Facility E	563	552
Facility F	756	739
Facility G	346	340
Facility H	780	765
Facility I	459	450
Facility J	650	637

Table 4.2 illustrates the average monthly energy consumption by the Facilities. All facilities consume energy above 10000 kWh per month. The difference of energy consumption during the day and night is quite significance.

Table 4.2: Average monthly high and low-rate energy consumption

SAMPLED FACILITIES	HIGH-RATE ENERGY CONSUMPTION (kWh)	LOW-RATE ENERGY CONSUMPTION (kWh)
Facility A	21,567	21156
Facility B	12,732	12,490
Facility C	23,906	23,450
Facility D	11,693	11,470
Facility E	16,890	16,568
Facility F	22,606	22,176
Facility G	10,394	10,196
Facility H	23,386	22,940
Facility I	13,772	13,509
Facility J	19,488	19,117

Table 4.3 elaborates the yearly energy consumption by the facilities. This data is summation of the energy consumed for twelve months. All facilities illustrate both high and low-rate energy consumption

Table 4.3: Average yearly high and low-rate energy consumption

SAMPLED FACILITIES	HIGH-RATE ENERGY CONSUMPTION (kWh)	LOW-RATE ENERGY CONSUMPTION (kWh)
Facility A	3,105,648	3,046,464
Facility B	1,833,408	1,798,560
Facility C	3,442,464	3,337,800
Facility D	1,683,792	1,651,680
Facility E	2,432,160	2,385,792
Facility F	3,255,264	3,193,344
Facility G	1,496,730	1,468,224
Facility H	3,367,584	3,303,360
Facility I	1,983,312	1,945,296
Facility J	2,806,272	2,752,848

Table 4.4 illustrates the peak loads for each facility. Peak load is the highest energy that refrigeration machines draw from the grid in a set period. The study uses the peak load for the sampled refrigeration facility to size the solar inverter

Table 4.4: Average peak load for refrigeration machines

SAMPLED FACILITIES	PEAK LOAD (kW)
Facility A	83
Facility B	49
Facility C	92
Facility D	45
Facility E	65
Facility F	87
Facility G	40
Facility H	90
Facility I	53
Facility J	75

4.2.2 Energy consumption trends

The energy consumption trends indicate the tendency of each facility illustrated by the bar graphs and line charts. Energy consumption trends 1 and 2 sums up the energy consumption tendencies for all refrigeration facilities. Daily high-rate energy consumption for refrigeration facilities A and E ranges from 395kWh to 795kWh as illustrated by Figure 4.1. This is the energy consumed by the refrigeration machines during the day.

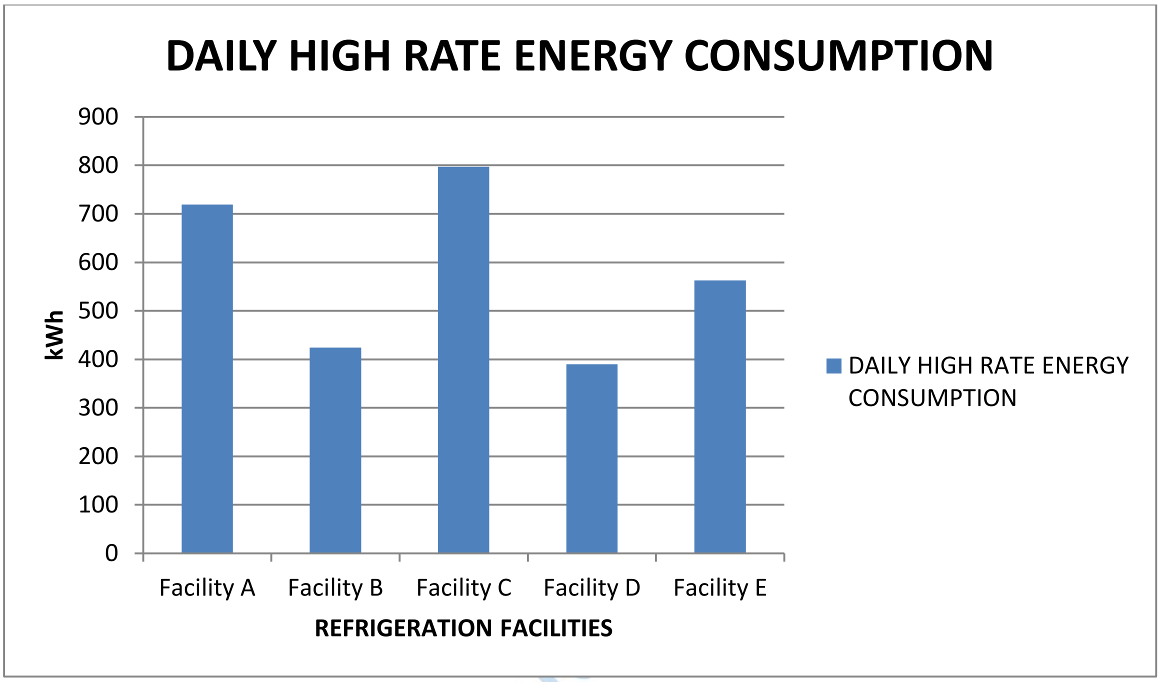

Figure 4.1: Daily high-rate energy consumption trend1

Figure 4.2 shows energy consumption for facilities F to J, which ranges from 350kWh to 780kWh.This is the energy consumed by the facilities during the day.

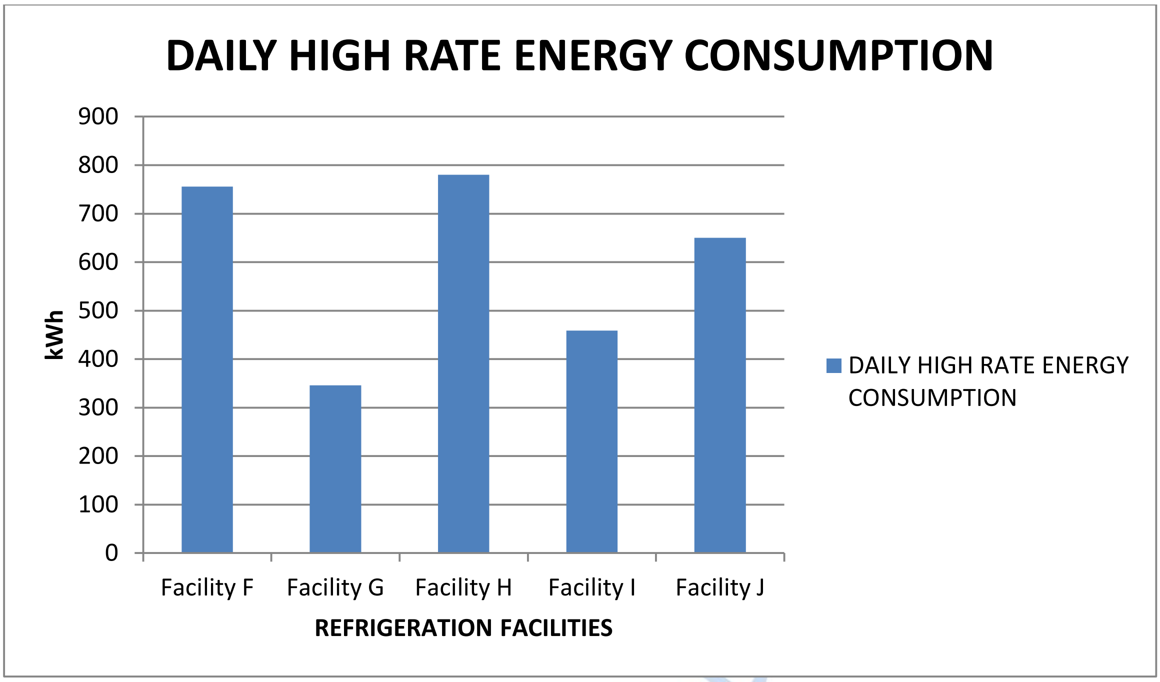

Figure 4.2: Daily high-rate consumption trend2

Figure 4.3 indicates daily low energy consumption tendency for facilities A to E, which ranges from 380kWh to 780kWh.This is the energy consumed by the refrigeration machine at night starting from 6pm to 6am.

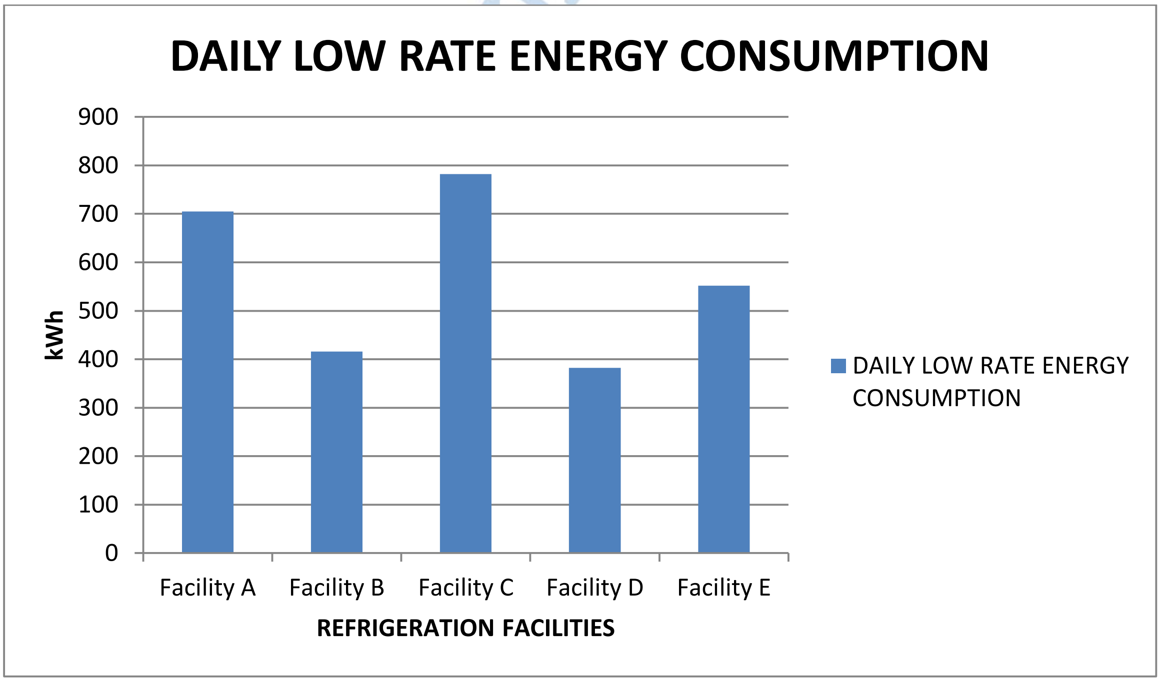

Figure 4.3: Daily low-rate energy consumption trend

Figure 4.4 shows daily low-rate energy consumption for facilities F to J, which ranges from 330kWh to 760kWh.This is the energy consumed by facilities at night starting from 6pm to 6am.

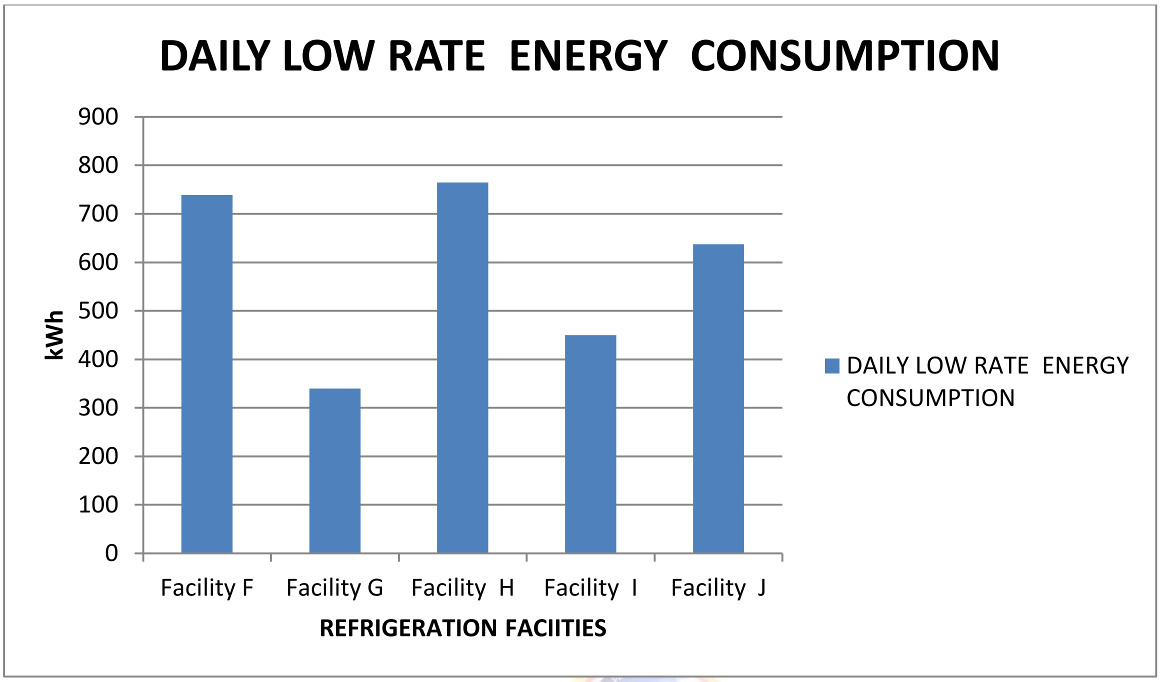

Figure 4.4: Daily low-rate energy consumption trend2

Figure 4.5 illustrates monthly high-rate energy consumption for the refrigeration facilities A to E which ranges from 12500kWh to 24000kWh.The monthly high-rate energy consumption represents the summation of daily energy for thirty or thirty-one days.

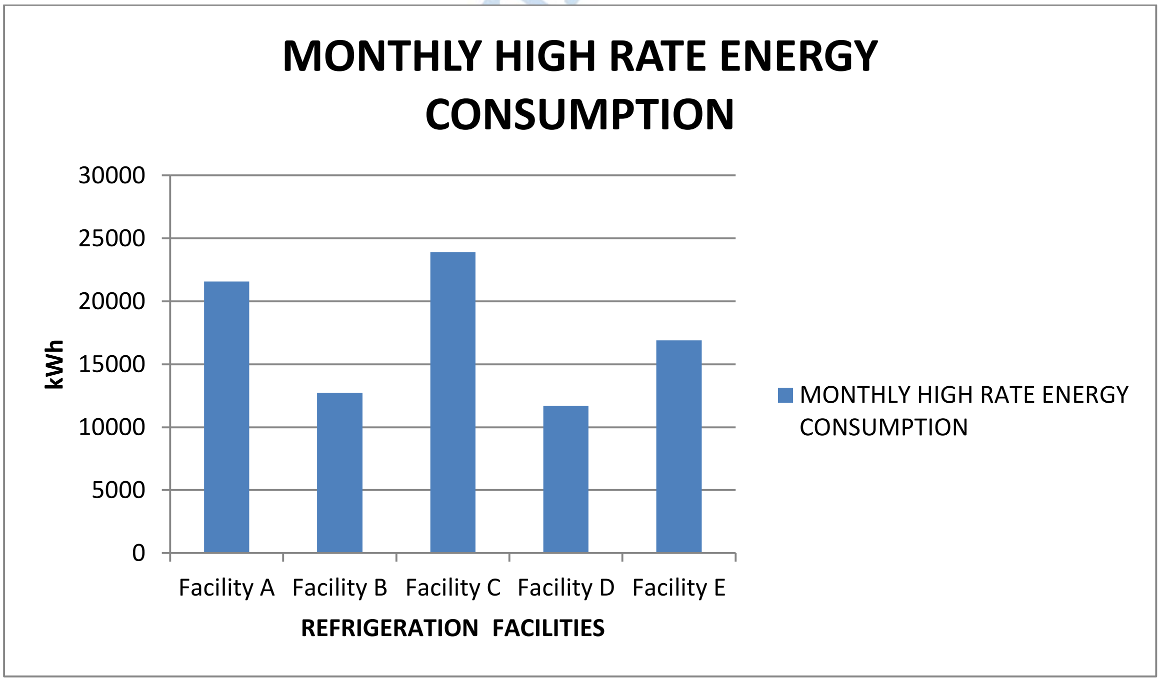

Figure 4.5: Monthly high-rate energy consumption trend1

Figure 4.6 shows monthly high-rate energy consumption for facilities F to J which ranges from 10000kWh to 3000kWh.

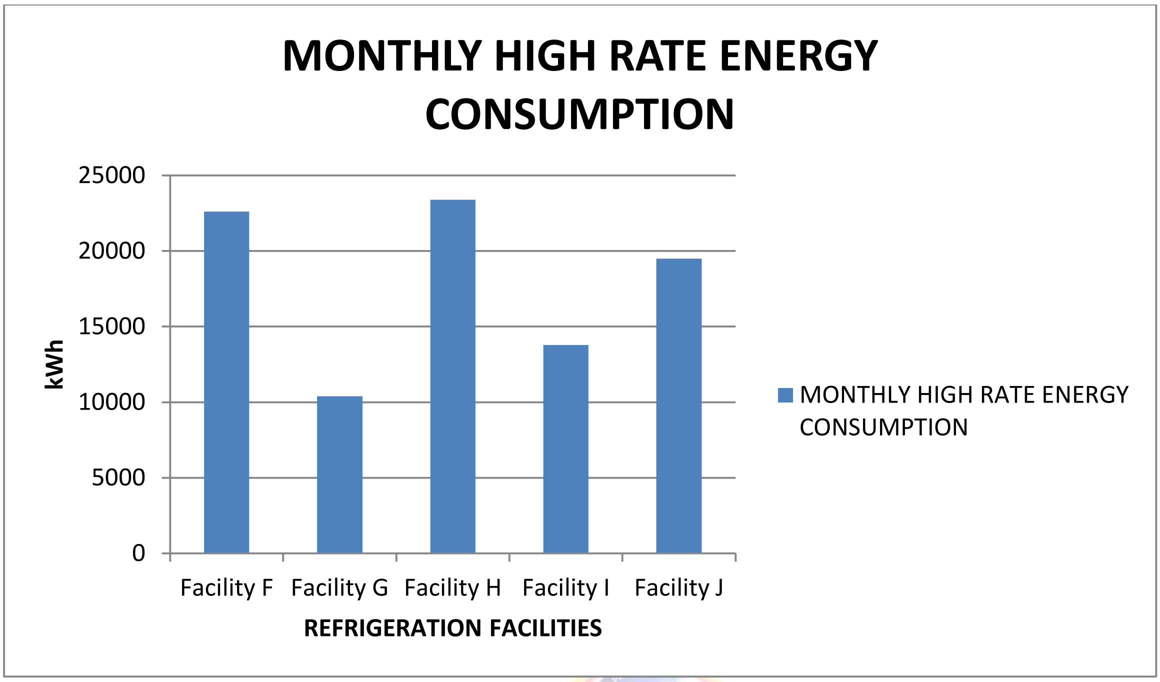

Figure 4.6: Monthly high-rate energy consumption trend2

Figure 4.7 indicates monthly low-rate energy consumption for refrigeration facilities A to E, which ranges from 12000kWh to 23000kWh.The low rate monthly represents the summation of the energy consumed in 30 or 31 days at night starting from 6pm to 6am.

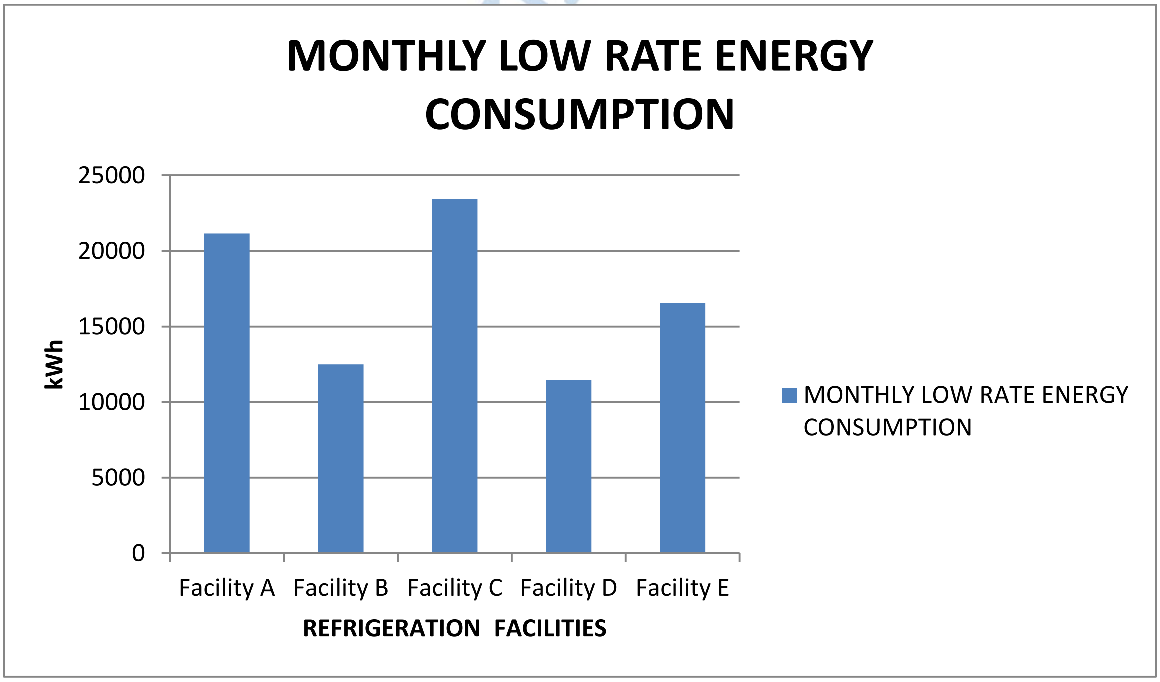

Figure 4.7: Monthly low-rate energy consumption trend1

Figure 4.8 indicates monthly low-rate energy consumption for facilities F to J, which ranges from 10000kWh to 23000kWh.

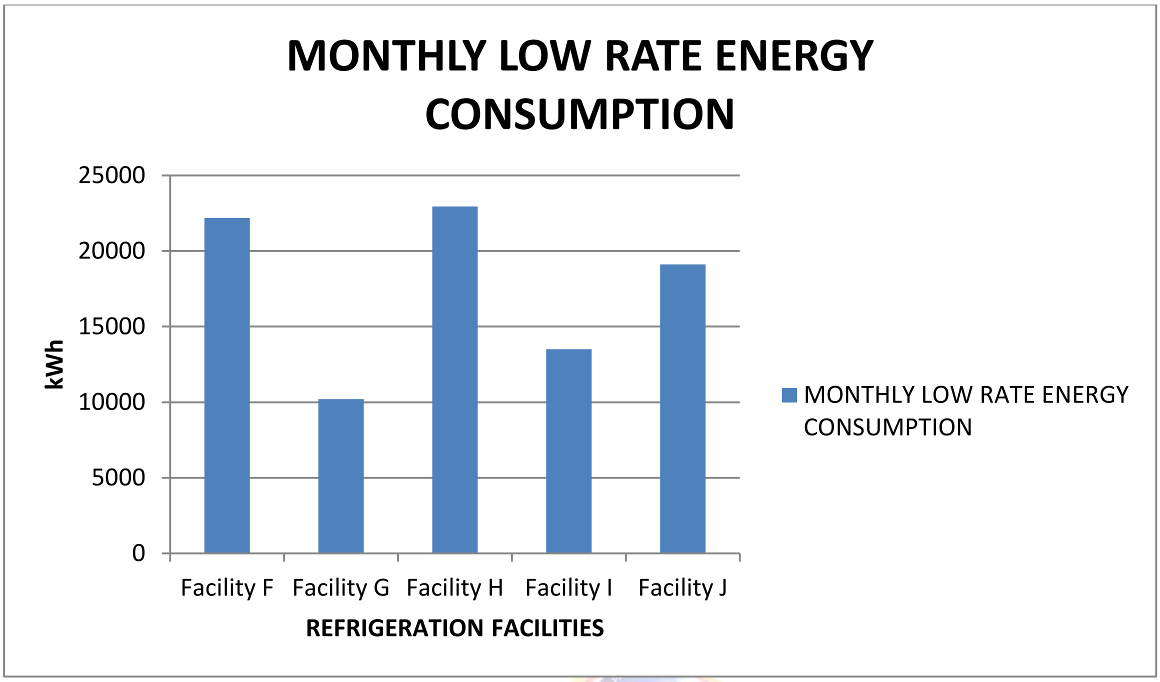

Figure 4.8: Monthly low-rate energy consumption trend2

Figure 4.9 shows yearly high-rate energy consumption for the refrigeration facilities A to E, which ranges from 150000kWh to 280000kWh.The yearly high-rate energy consumption, presents the summation of monthly energy consumption for twelve months. This is the energy consumed by refrigeration machines during the day from 6am to 6pm.

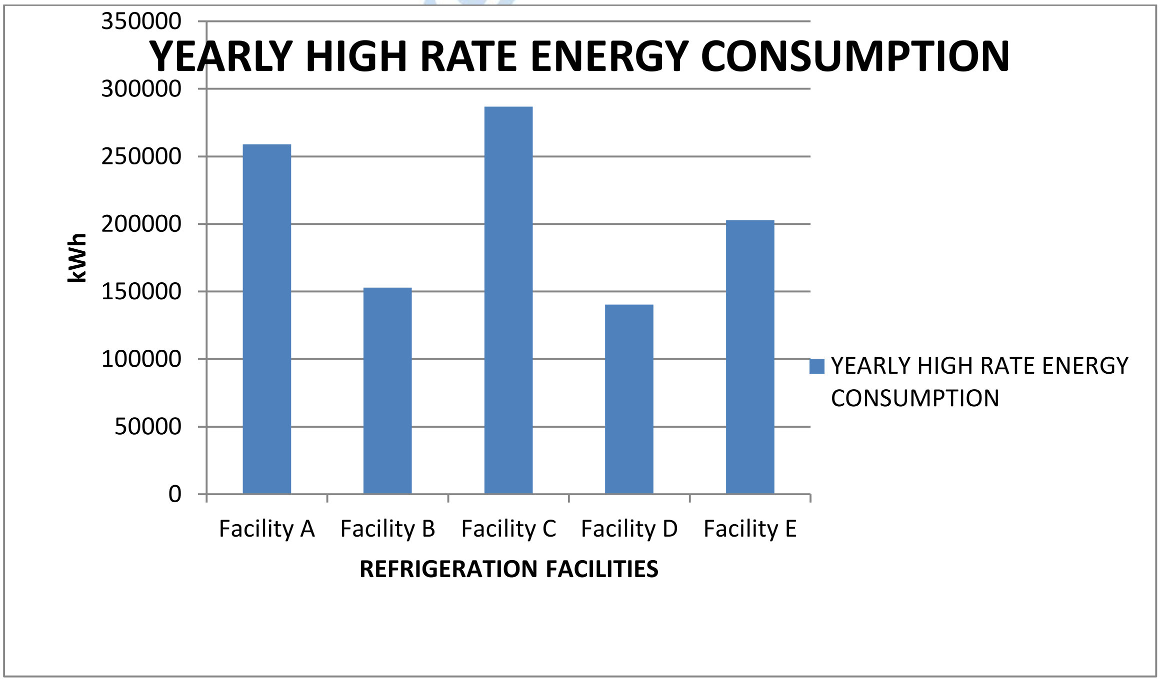

Figure 4.9: Yearly high-rate energy consumption trend

Figure 4.10 shows yearly energy total energy consumption for facilities F to J which ranges from 125000kWh to 275000kWh.

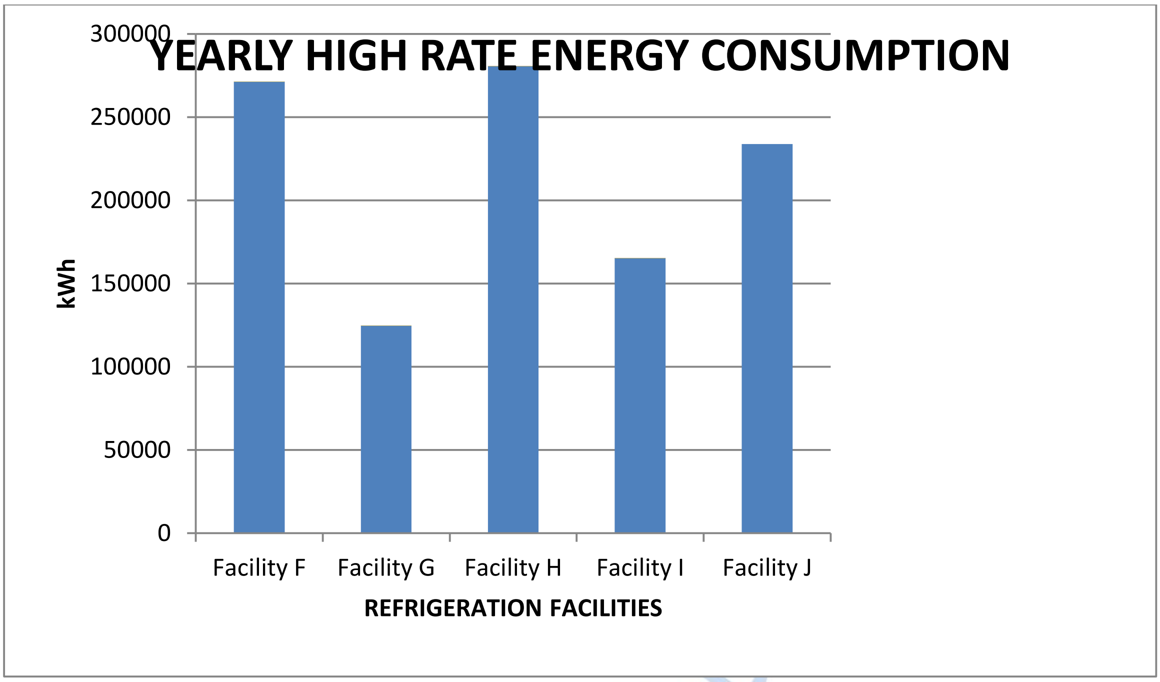

Figure 4.10: Yearly high-rate energy consumption trend2

Figure 4.11 shows yearly low-rate energy consumption for refrigeration facilities for facilities A to E, which ranges from 140000kWh to 275000kWh.The yearly low-rate energy consumption, represents the summation of monthly energy consumption for twelve months. This is the energy consumed by refrigeration machines at night hours starting from 6pm to 6am.

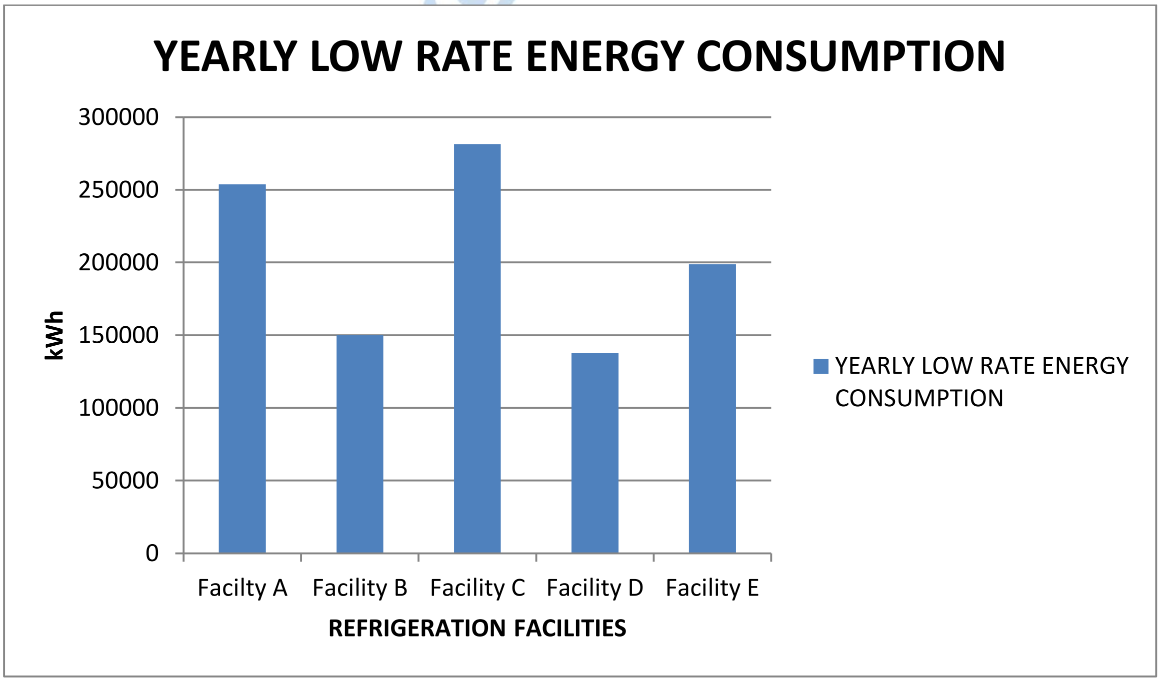

Figure 4.11: Yearly low-rate energy consumption trend1

Figure 4.12 indicates yearly total low-rate energy consumption for facilities F to J, which ranges from 120000kWh to 270000kWh.

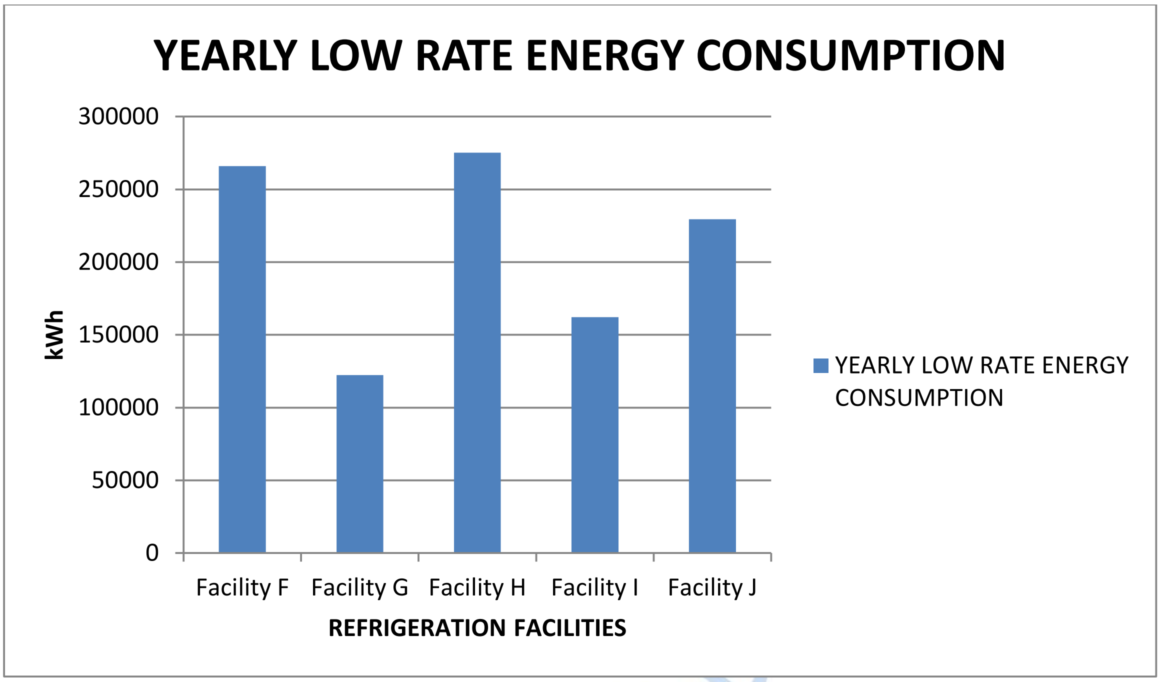

Figure 4.12: Yearly low-rate energy consumption trend 2

Figure 4.13 shows peak loads for refrigeration facilities A to E which ranges from 45Kw to 90kW. The peak load is imperative for the sizing of the grid –connected solar PV inverter.

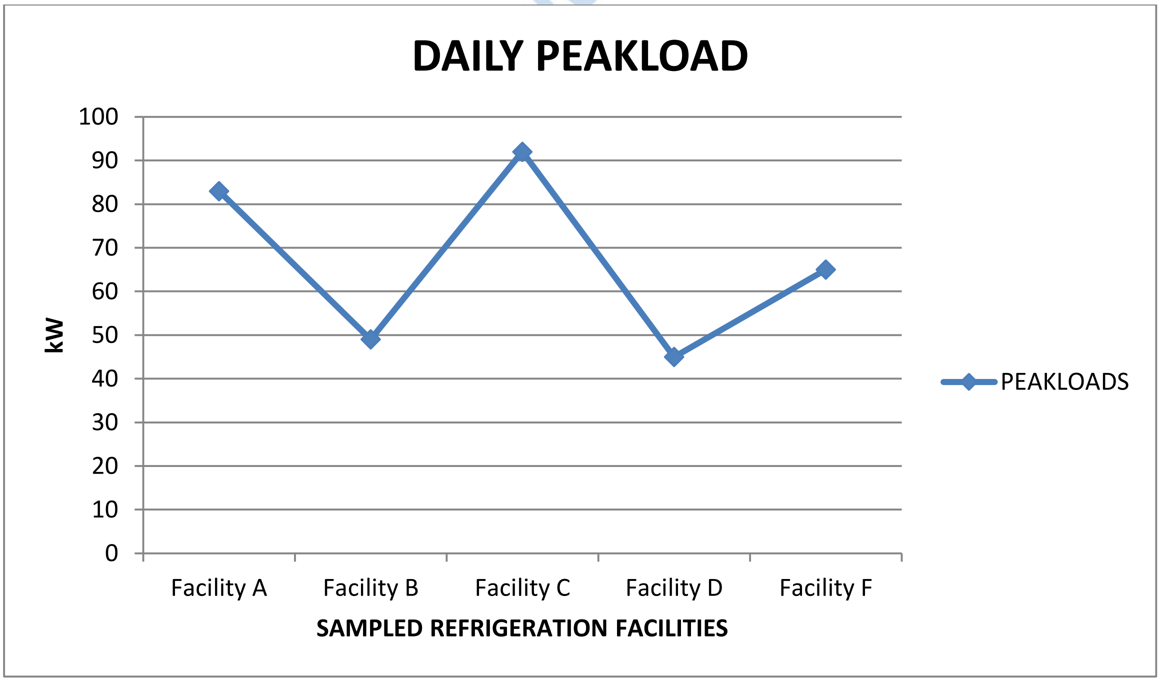

Figure 4.13: Peak load for facilities trend1

Figure 4.14 shows peak loads for refrigeration facilities F to J, which ranges from 40Kw to 90kw

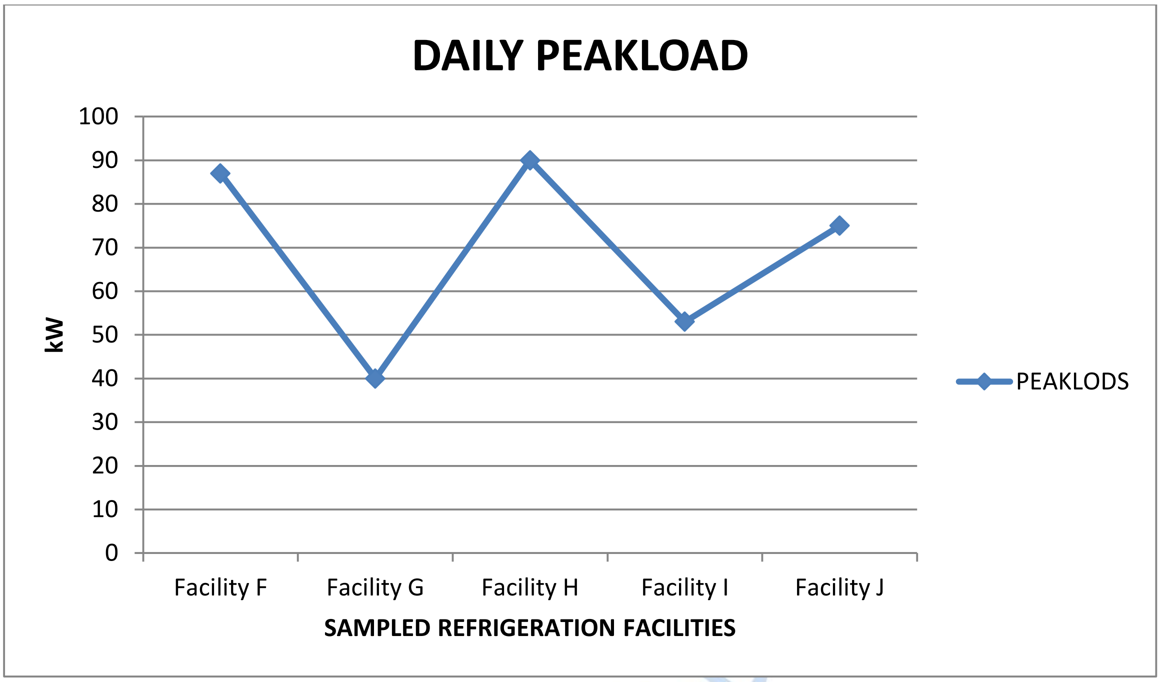

Figure 4.14: Peak load trend2

4.2.3 Refrigeration components power consumption

Refrigeration systems consume more power during the day as compared to the night as illustrated by monthly energy bills. The prevailing high temperatures makes the refrigeration system main components such as the compressor, evaporator and condenser fan motor run more hours before set temperatures for perishable product is achieved. The sampled refrigeration facility has three cold-rooms with each having two refrigeration compressors. Tables 4.5 illustrate the total rated power for cold-rooms 1, 2, and 3.

Table 4.5: Cold-room's compressors and rated power

Cold-rooms	Number of compressors	Rated power (kW)	Total power(kW)
Coldroom1	2	30	60
Coldroom2	2	25	50
Coldroom3	2	28	56

Figure 4.15 shows cold-rooms compressors power consumption during the day from 6am to 6pm where maximum power consumption is achieved at 12 noon for all the cold-rooms.

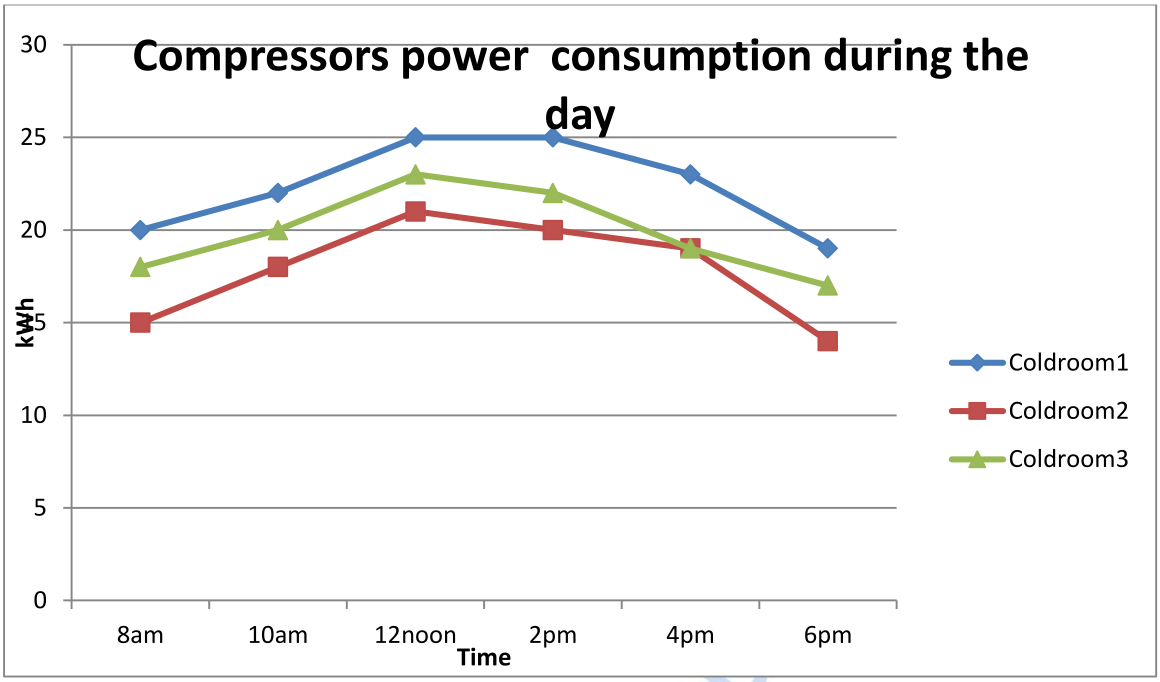

Figure 4.15: Cold-room's compressors power consumption trend during the day

Figure 4.16 shows cold-rooms compressor power consumption at night from 6pm to 6am where all the cold-rooms maintain constant power consumption. Coldroom1, 2 and 3-compressor power consumption are 15kW, 12kW and 10kW respectively

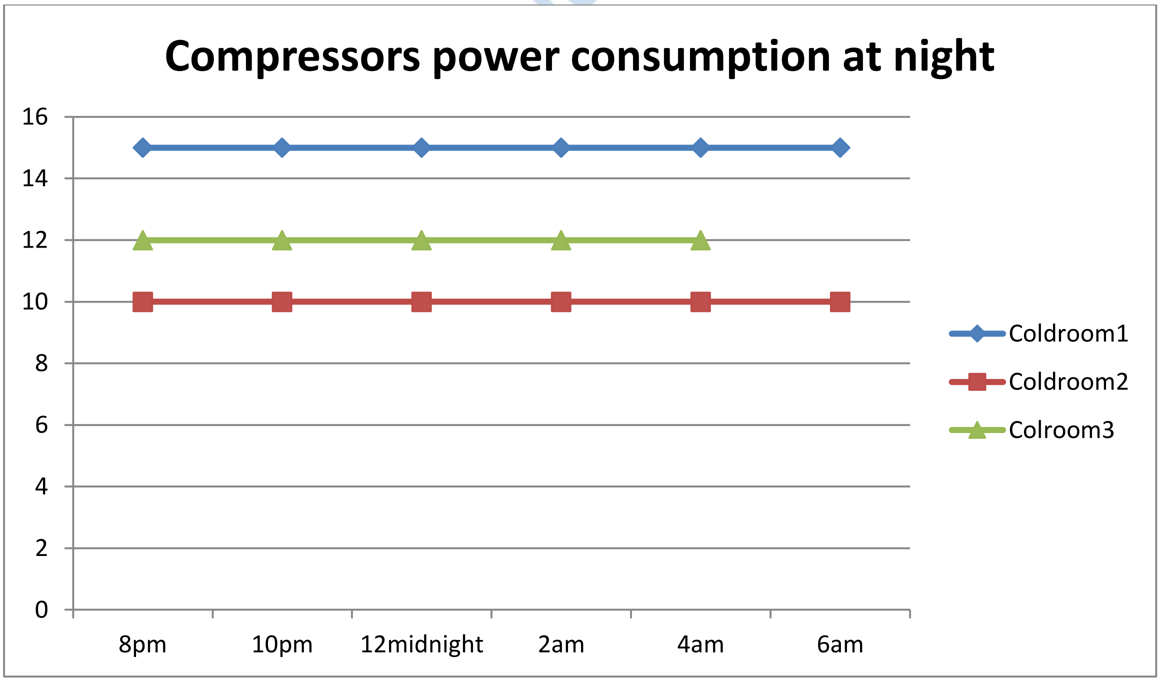

Figure4.16: Cold-room's compressors power consumption trend during the night

Table 4.6 illustrates the number of the condensers and the total power consumption for each cold-room. The cold-rooms have 8, 6 and 2 condensers at 80-, 30- and 3-kW total power respectively

Table 4.6: Cold-room's condensers and rated power

Cold-rooms	Number of condensers	Rated power(kW)	Total power(kW)
Coldroom1	8	10	80
Coldroom2	6	5	30
Coldroom3	2	15	30

Figure 4.17 shows cold-rooms condensers power consumption during the day. The maximum power consumption for the cold-rooms is at 12 noon whereas the morning and evening consume less power.

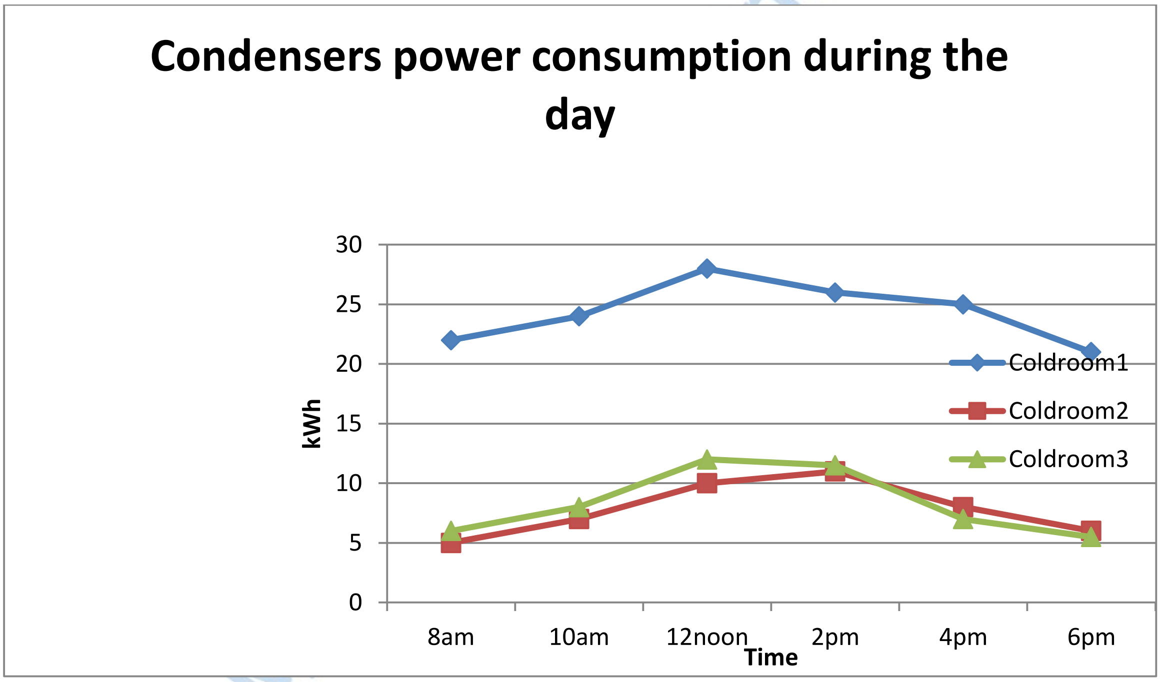

Figure 4.17: Cold-room's condensers power consumption trend during the day

Figure 4.18 indicates cold-rooms condensers power consumption at night, which shows constant power consumption for each cold-room.

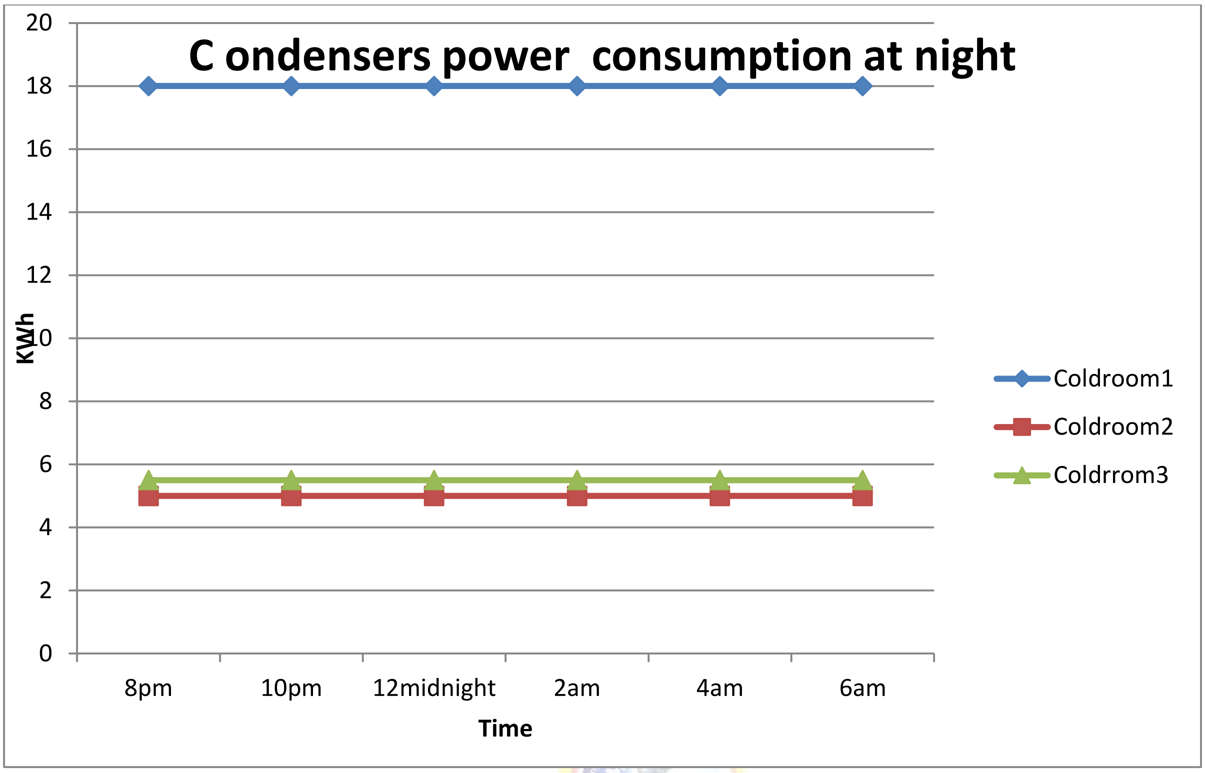

Figure 4.18: Cold-room's condensers power consumption trend at night

Table 4.7illustrates the number of evaporators, rated power and the total power consumption for cold-rooms. The total power for cold-rooms 1, 2 and 3 are 80kW, 40kW and30kW respectively

Table 4.7: Cold-room's evaporators and rated power

Cold-rooms	Number of evaporators	Rated power(kW)	Total power(kW)
Coldroom1	8	10	80
Coldroom2	8	5	40
Coldroom3	2	15	30

Figure 4.19 shows cold-rooms evaporator power consumption during the day is constant for the three cold-rooms. The reasons being that condenser fan motor runs continuously without stopping.

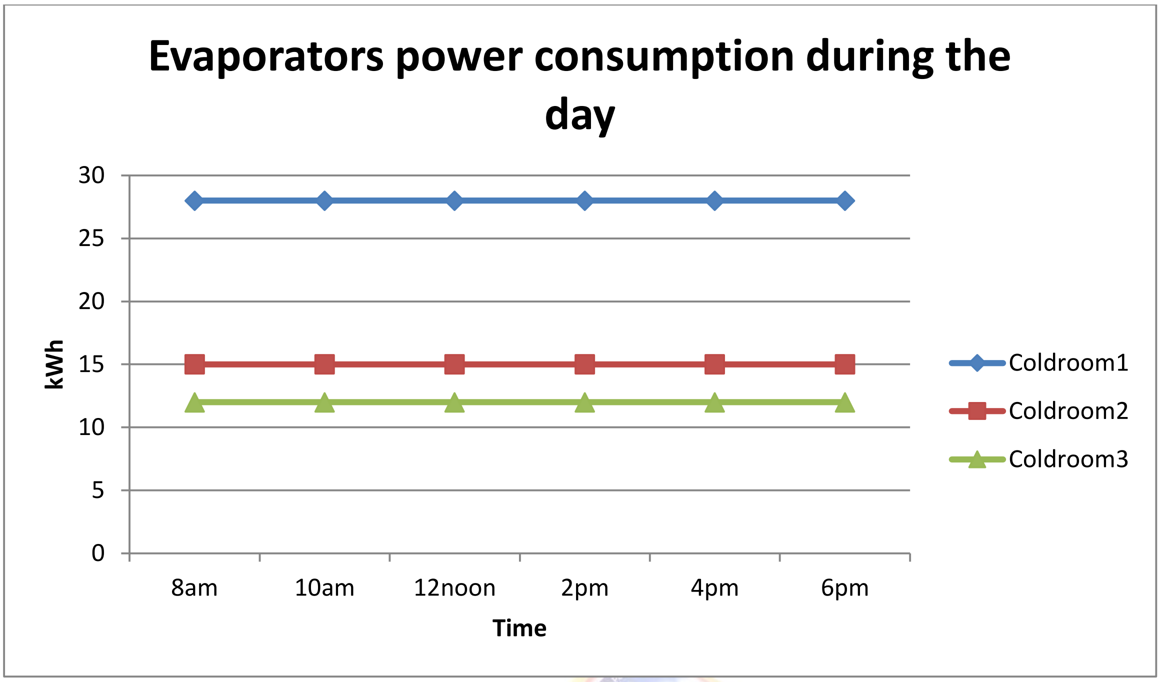

Figure 4.19: Cold-rooms evaporators' power consumption during the day

Figure 4.20 indicates cold-rooms evaporators' power consumption during the night is same as the day. Evaporator fan motor runs continuously without stopping. This will make airflow distribution during defrost time

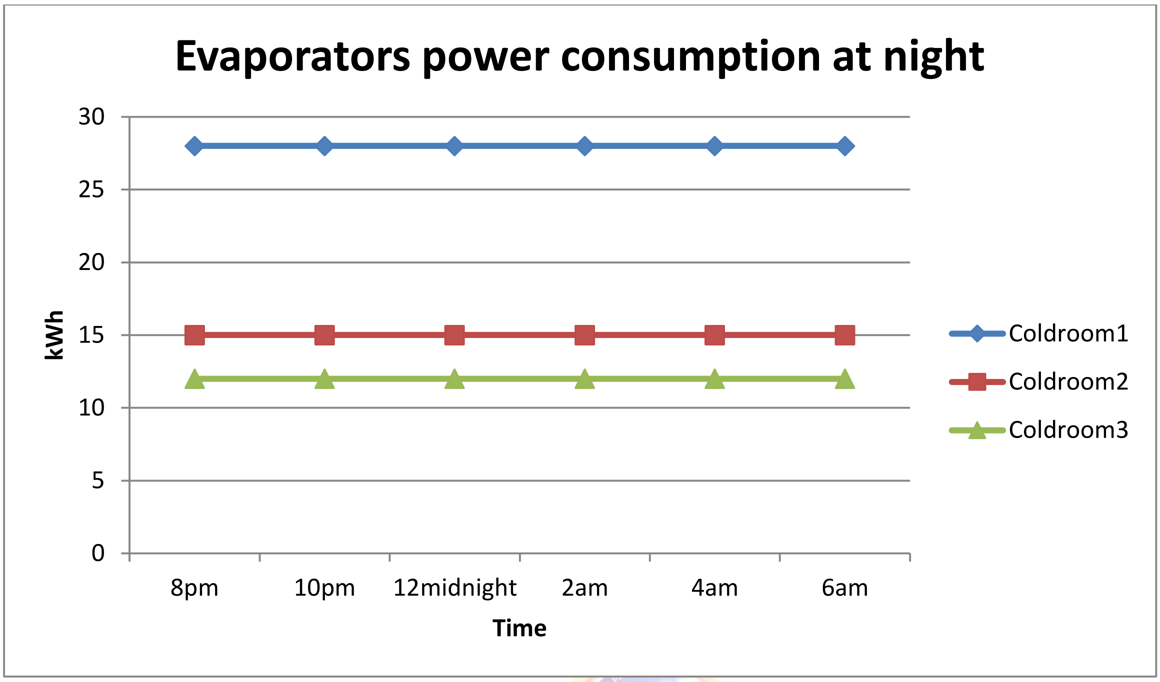

Figure 4.20: Coldrooms evaporators power consumption trend at night

Table 4.8 shows the number of control devices, rated power and power consumption for the cold-rooms. Each cold-room has 12 control devices with total power of 6 kW.

Table 4.8: Cold-rooms control devices and the rated power

Cold-rooms	Number of control devices	Rated power(kW)	Total power(kW)
Coldroom1	12	O.5	6
Coldroom2	12	0.5	6
Coldroom3	12	0.5	6

Figure 4.21 shows cold-rooms control devices power consumption during the day varies according to the load. Maximum power consumption for each cold-room is at 12noon where each cold-room consumes 3.5kW.

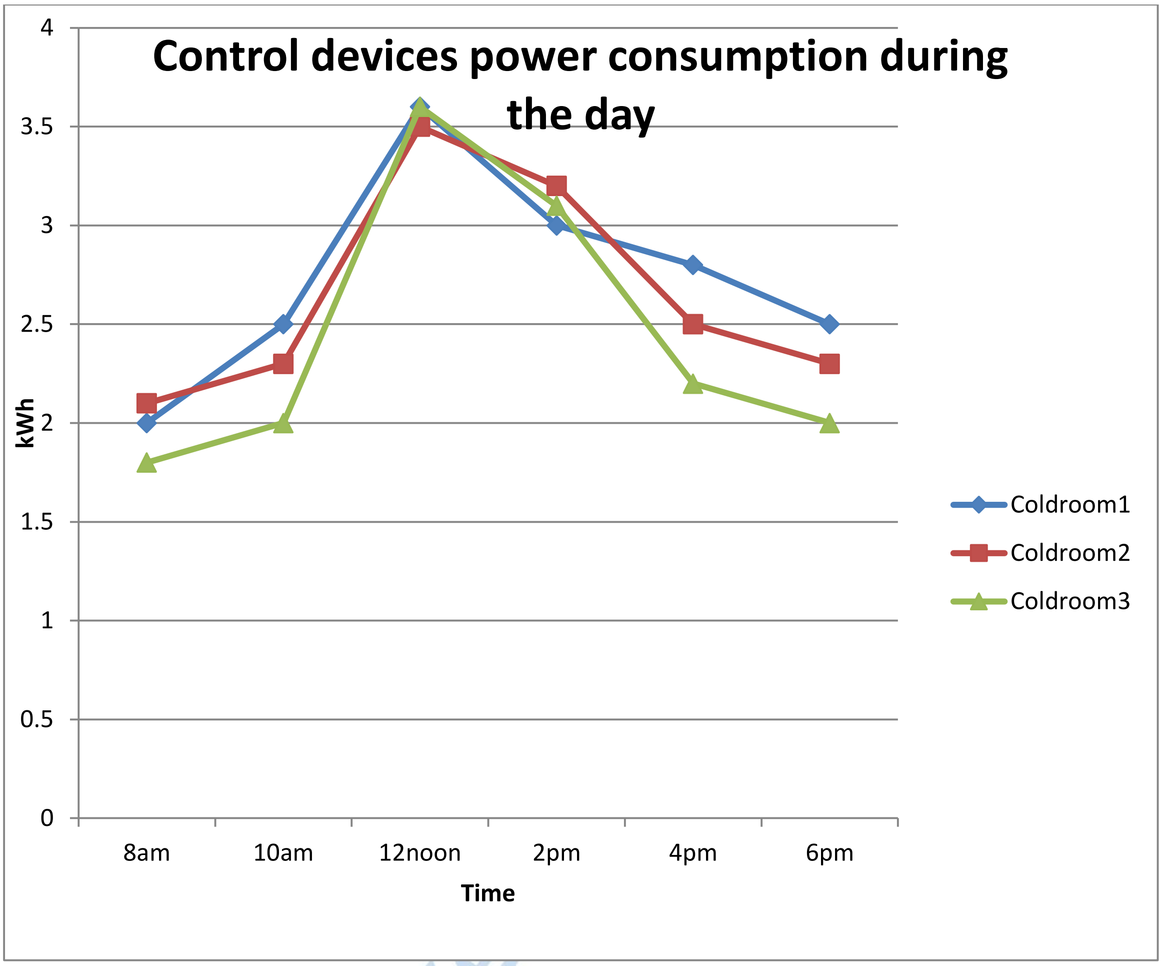

Figure 4.21: Cold-rooms control devices power consumption trend during the day

Figure 4.22 shows cold-rooms control devices power consumption at night indicating constant power consumption for each cold-room where cold-room 1, 2and 3 consumes 2.5kW, 2.1kW and 2.0Kw respectively

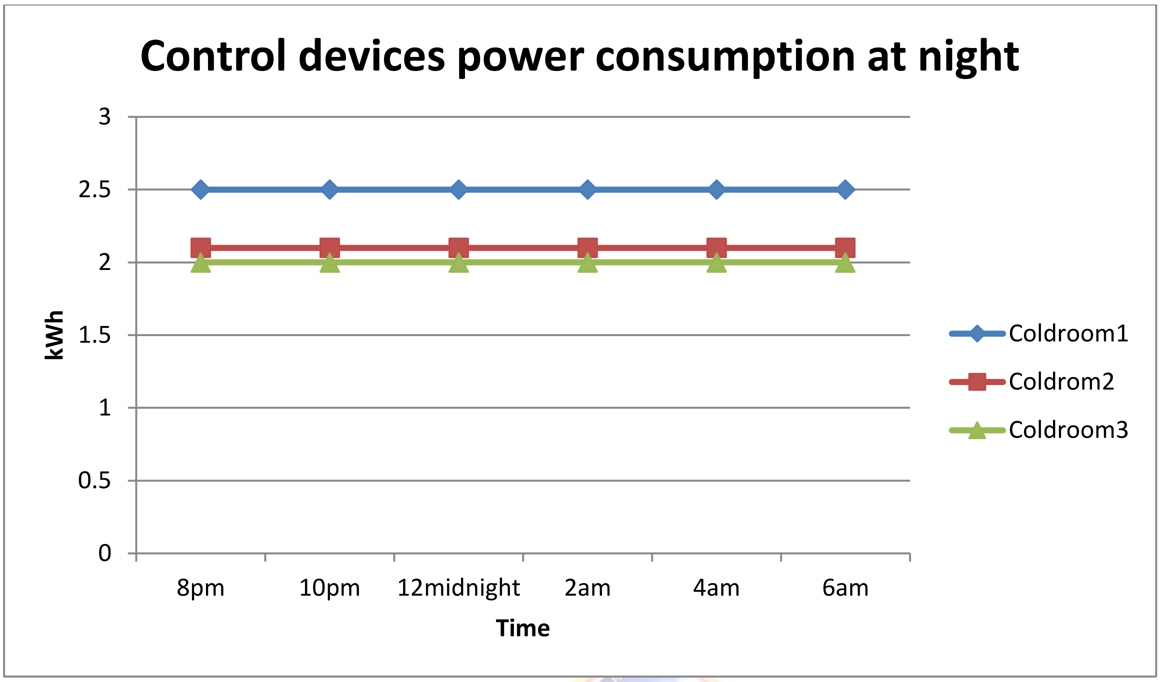

Figure 4.22: Cold-rooms control devices power consumption trend at night

Figure 4.23 shows condensers distribution curve for the cold-rooms indicating how condensers are distributed where N represents the number of cold-rooms. The mean and standard deviation are 5.33 and 3.055 respectively.

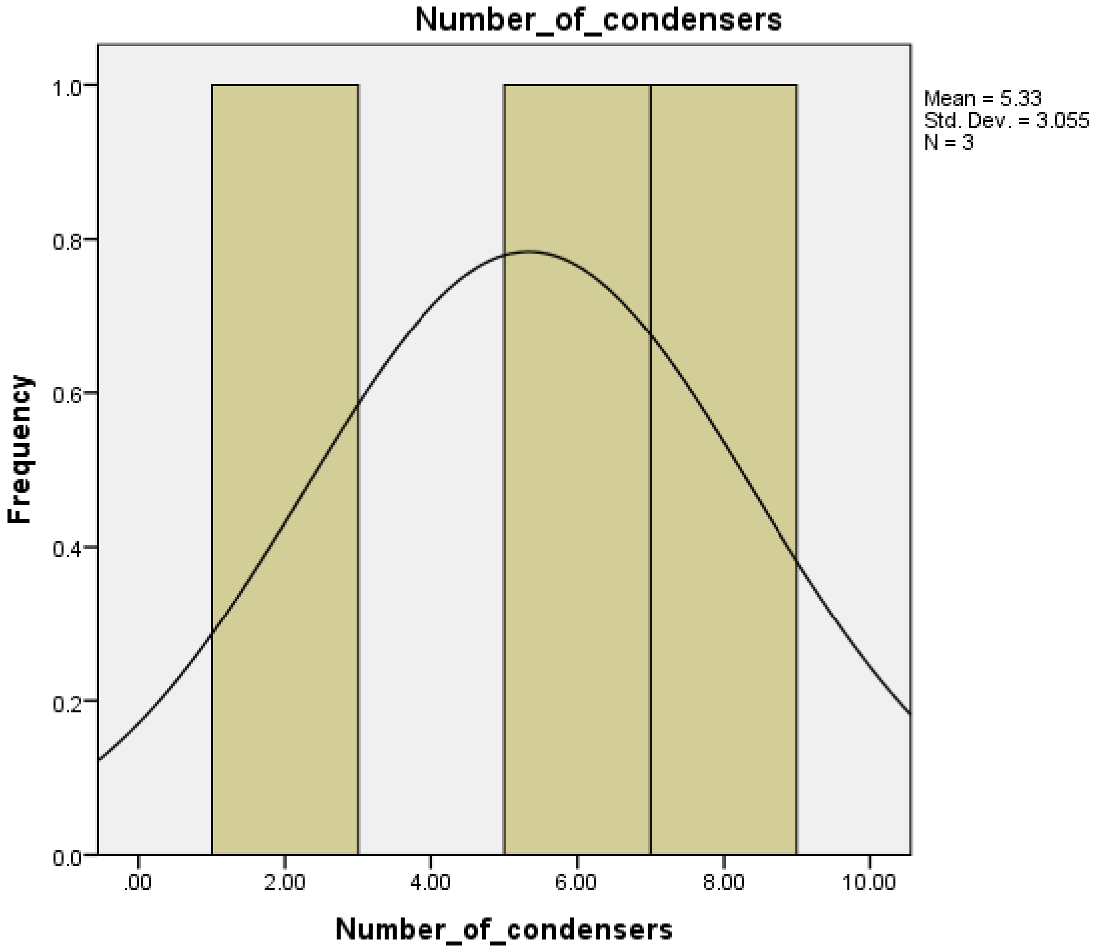

Figure 4.23: Data distribution for the condensers

Figure 4.24 shows evaporator’s distribution curve for the cold-rooms indicating how the evaporators are distributed where N represents the number of cold-rooms. The mean and standard deviation are 6 and 3.464 respectively.

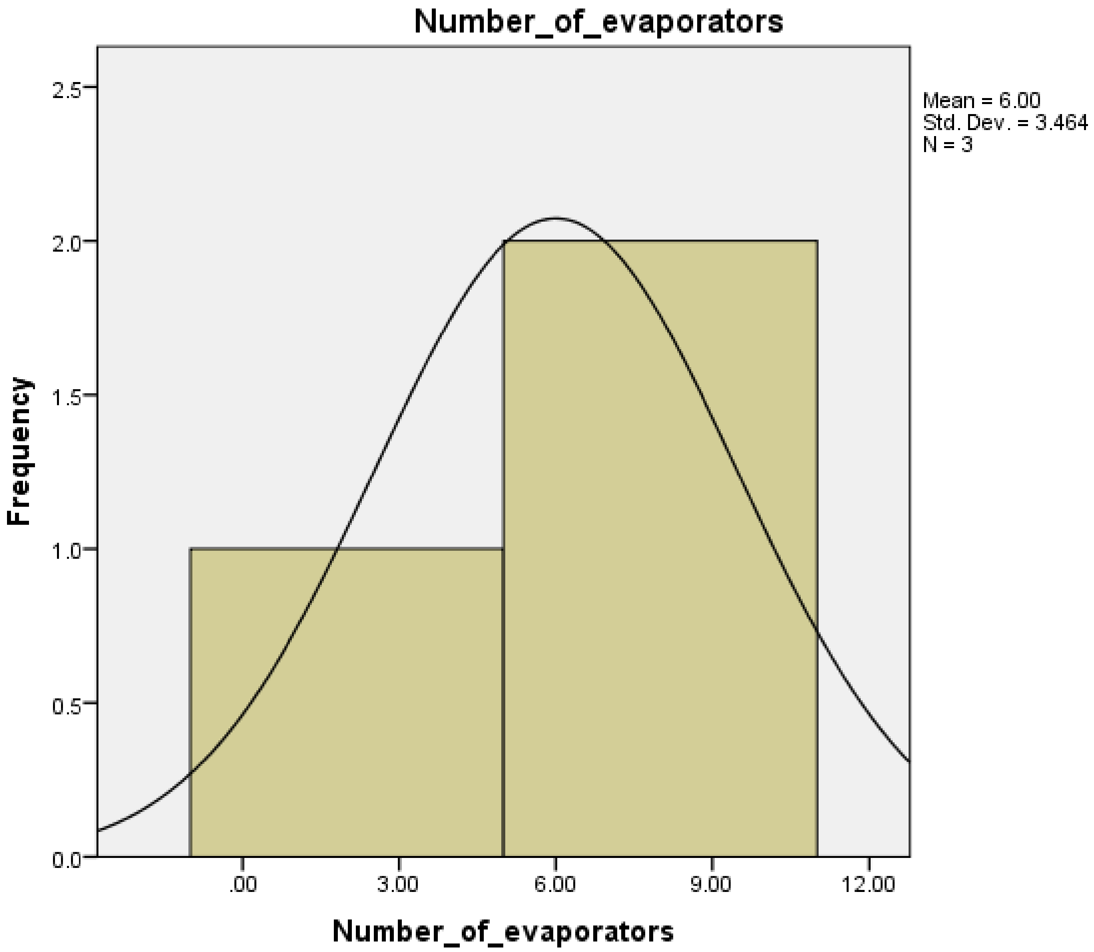

Figure 4.24: Data distribution for the evaporators

4.2.4 Grid-connected solar PV system design

The objective two of this study focuses on the design and optimize a grid- connected solar PV connected for refrigeration processes in sampled refrigeration facility. It is essentially incorporating the modules, grid-connected inverter, the net metering, utility grid and refrigeration system. Other components and accessories are preferably important are the transformer, MCCB, control boards. Power been generated from the PV system has to be distributed to the sub circuits as demonstrated by the designed model as illustrated by Figure 4.25

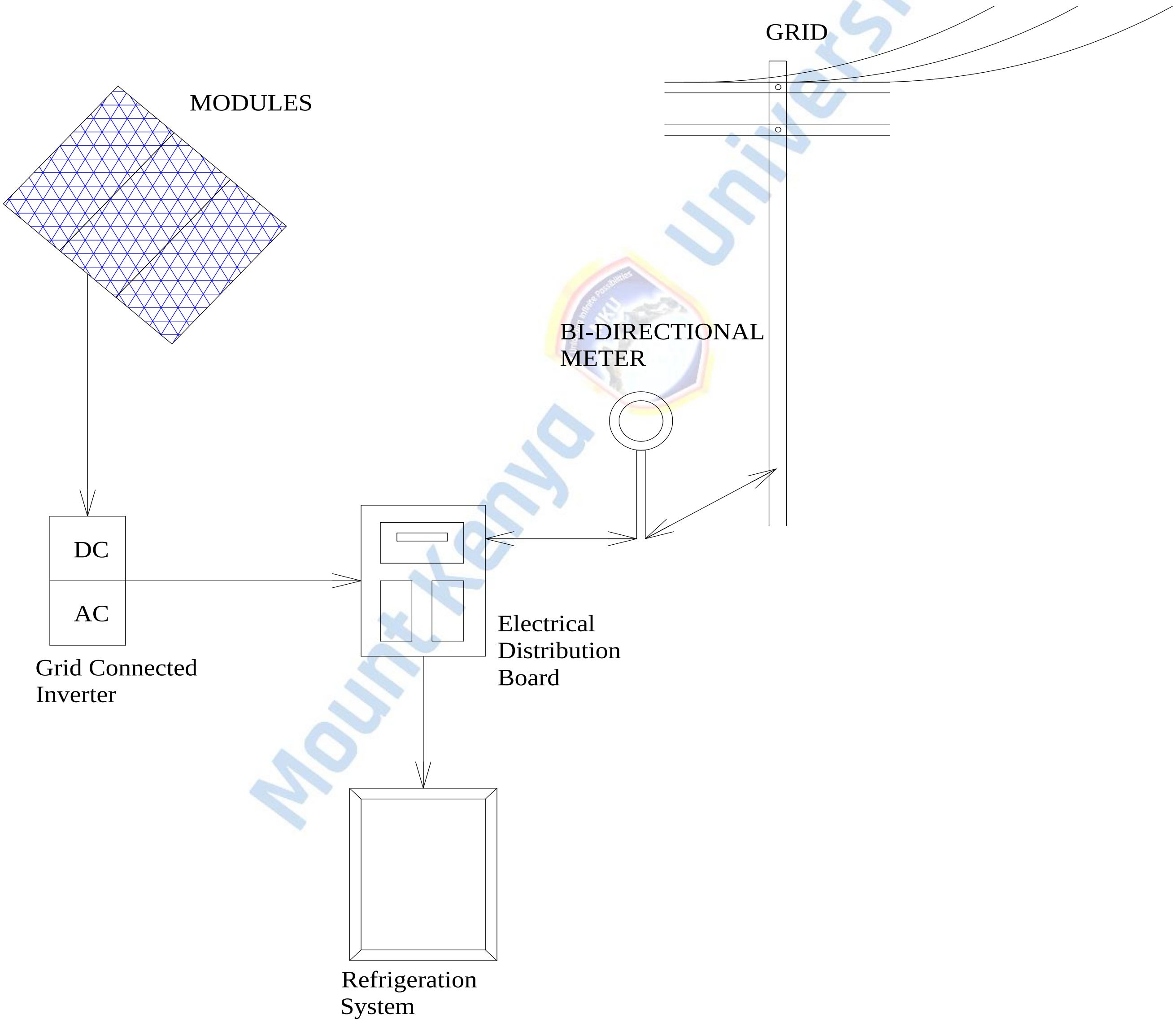

Figure 4.25: Schematic diagram of grid-tied solar PV for refrigeration system(Kaira, 2022b)

The modules or the solar panels are PV cells grouped together in large units and are used to convert the sunlight into electricity. There many types of inverters but for this study, string inverter is preferred due to higher level of efficiency and availability. The electrical switchgears, which incorporate the molded case circuit breakers (MCCB) and electrical power isolators, protects and isolates power in case of short circuits or where line maintenance is required. The anti-islanding is inbuilt in the inverter for protection and when line maintenance is being carried out. It gives safety for technical people working on the power line.

Refrigeration system is composed of the following main components incorporated in refrigeration cycle, the compressor, condenser, expansion valve and the evaporator.

The transformers step up power from the solar power before been fed to the grid and step-down power from the grid before been supplied to the refrigeration machines.

The net meter is a bidirectional meter, which is more useful in the PV system where excess energy is channeled to the grid. As per the energy regulation commission (ERC, 2018b)prevailing displaced cost the excess energy will be credited to the consumer.

The grid-tied inverter converts DC energy into AC energy and then feeds it to the grid. The AC electricity produced by a power inverter is equally the same as the power on the conventional electrical grid. A grid-tied inverter monitors the power from the grid and ensures that the power from inverter stays in synchronization with the phase of the electricity from the grid. Grid-connected PV inverter usually operates with unity power factor. Today improvement of existing grid-connected inverters is mainly linked to a reduction of overall grid connected PV system costs.

4.2.5 Solar radiation and temperature at JKIA

Table 4.9 presents the solar radiation for twelve months at JKIA. The solar radiation ranges from 15.03 to 25.78 kWh/m^{2}per month. The study utilizes the monthly solar radiation to determine the viability of the solar PV installation. Table 4.9 indicates the month of July has the lowest insolation.

Table 4.9: Solar radiation at JKIA(MET, 2021c)

YEAR	MONTH	RADIATION (kWh/m^2)
2020	January	20.81
2020	February	24.7
2020	March	23.66
2020	April	19.53
2020	May	20.46
2020	June	17.54
2020	July	15.03
2020	August	18.13
2020	September	19.45
2020	October	20.14
2020	November	20.59
2020	December	25.78

Table 4.10 presents the mean temperatures at JKIA, which ranges from 17.0 to 20.76 degrees centigrade. This represents the temperatures for one year starting from January to December. The solar PV module is rated under standard test condition, 1000W/m^2/day, 25 degrees centigrade and 1.5 air mass.

Table 4.11: Mean temperatures at JKIA(MET, 2021b)

YEAR	MONTH	MEAN TEMPERATURE (degrees centigrade)
2020	January	20.39
2020	February	20.33
2020	March	21.5
2020	April	20.47
2020	May	19.8
2020	June	18.37
2020	July	17.0
2020	August	18.89
2020	September	19.22
2020	October	20.55
2020	November	20.73
2020	December	20.76

Figure 4.26 presents the solar radiation at JKIA. The solar radiation ranges from 15.03 to 25.78kWh/m^2. The month of July has the lowest solar radiation, which is 15.03kWh/m^2 per month. The study utilizes the month of June for the sizing of the solar modules maximizing the solar energy output.

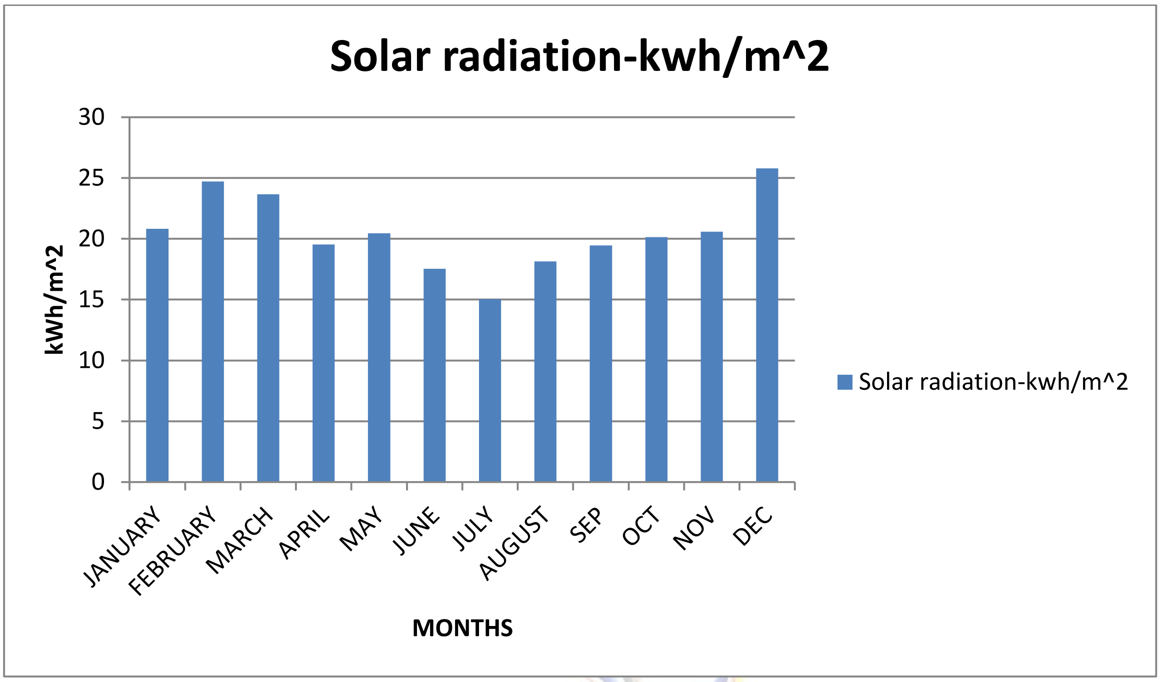

Figure 4.26: Solar radiation trend at JKIA

Figure 4.27 presents the mean temperatures for the twelve months under the study. The mean temperature ranges from 17.0 to 21.5 degrees centigrade. Under standard test conditions for solar PV system, the solar module temperature of 25 degrees centigrade is appropriate. The figure 4.27 shows the mean temperatures throughout the year.

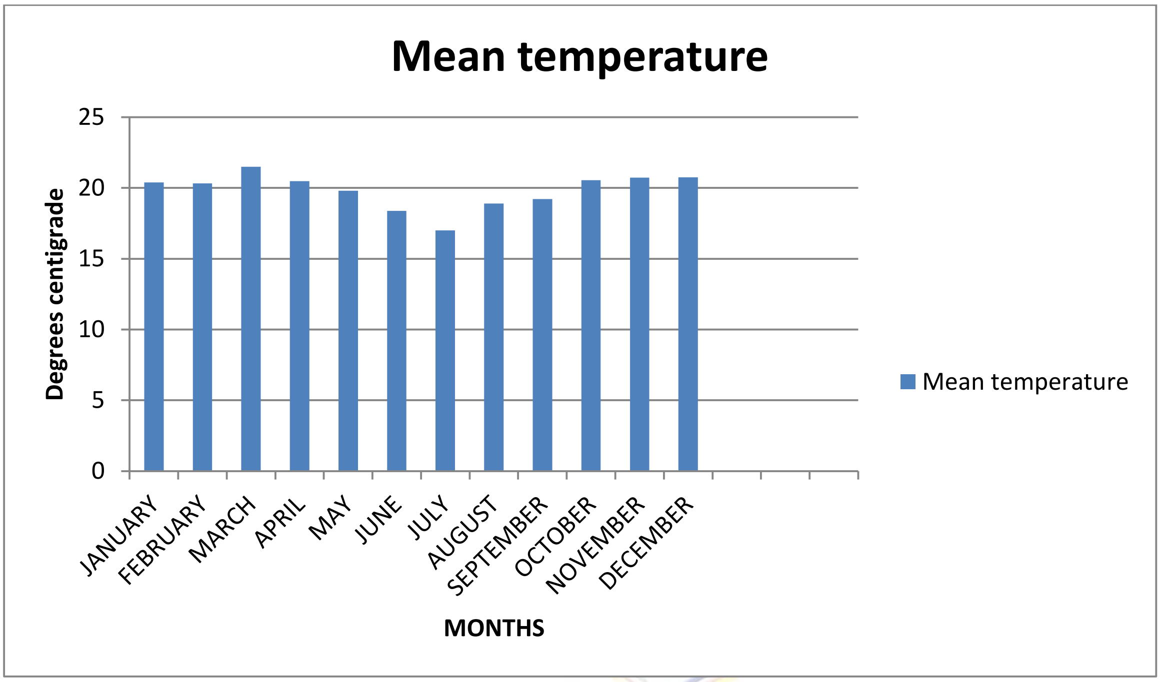

Figure 4.27: Mean temperature trend at JKIA

4.2.6 Solar PV system sizing for Facility A

The objectives of design and sizing are to determine:

a. The total energy consumption by the load. Load in this study are the refrigeration machines.

b. Choose appropriate grid connected inverters

Optimum sizing of components, which will give desirable output

1. The total daily energy consumption from the secondary data =719kWh (Table 4.1)

   i. Multiply the total daily energy consumption (Wh) per day times 1.3(equate to energy lost in the system) generates the total watt-hours per day by the solar panels.

$719x1000x1.3=934700Wh/m^2/day$ (1)

ii. To calculate the watt peak (W_P) of the modules for the study.

Consider the peak sun hours (PSH) at JKIA, Nairobi with the lowest solar insolation levels that is the month of July2020.

Average annual daily insolation range from 4-6 kWh/m^2/day(N. W. Wasike, 2015)

At STC (irradiance=1000W/m^2, temperature=25^0C, AM=1.5)

The study considers the lowest average daily insolation, which is 4kWh/m^2/day

PSH=4000Wh/1000Wh (2)

=4Hours

W_P=934700Wh/4h

=233,675Wp

=234kWp (solar PV system capacity)

iii. To calculate the total number of solar modules for the study

W_P for the solar panel=260 (Table 4.8)

Total number of modules= 233675/260 (3)

=899solar panels (polycrystalline)

Table 4.11 presents the specifications for the PV module, which applies in this study. The choice of the solar module is the availability in the Kenya market and relatively lower cost.

Table 4.11: Specification for PV solar module (polycrystalline)

Maximum power voltage	260wp
Maximum power voltage (V_{MP})	31.4V
Maximum power current (I_{MP})	8.14A
V_{OC}	38.6V
I_{SC}	9.03A
Nominal operating cells temperature	45+ or -2^{0}C
Maximum system voltage	1000VDC
Standard test conditions	1.0kW/m^2,25^{0}C, AM 1.5

iv. Grid connected inverter sizing. The study considers the string inverter with MPPT.

Peak load multiply by 1.3(safety factor) (4)

The peak load=83kW (Table 4.4)

=83x1.3

=107.9kW

Table 4.12 presents the specifications of a grid connected inverter. It has an efficiency of 98.1% and provision of MPPT. The choice of the inverter is due the availability and relatively lower cost

Table 4.12: Specification of a grid-connected inverter

Inverter type	Sunny Tri-power STP 15000TL-10
Inverter efficiency	98.1%
Maximum voltage	1000V
M_{PP} voltage range	360V-800V
String inverter size	35kW
Life time	15years
Electronic MPPT	Yes

4.2.7 Monthly and yearly total cost of energy

The third objective of the study is to evaluate social-economic benefits of the grid-connected solar PV system. Table 4.13 present monthly cost of energy for refrigeration facilities under the study. The monthly cost of energy ranges from Kes.363, 620 to Kes.836, 327.

Table 4.13: Average monthly total cost of energy

REFRIGERATION FACILITIES	AVERAGE TOTAL ENERGY COST(KES)
Facility A	754,512
Facility B	445,435
Facility C	836,327
Facility D	409,073
Facility E	590,883
Facility F	790,874
Facility G	363,620
Facility H	818,146
Facility I	481,797
Facility J	681,788

Table 4.14presents the average yearly total cost of energy for the refrigeration facilities under the study. The yearly total cost of energy ranges from Kes.4363440 to Kes10035924. This is the summation of monthly cost of energy for twelve months.

Table 4.14: Average yearly total cost of energy

REFRIGERATION FACILITIES	AVERAGE YEARLY TOTAL ENERGY COST(KES)
Facility A	9,054,144
Facility B	5,345,220
Facility C	10,035,924
Facility D	4,908,876
Facility E	7,090,596
Facility F	9,490,488
Facility G	4,363,440
Facility H	9,817,752
Facility I	5,781,564
Facility J	8,181,456

Figure 4.28 shows monthly total cost of energy for refrigeration facilities A to E which ranges from Kes.363000 to Kes790000. This is the summation of the daily energy consumption cost for a period of one month.

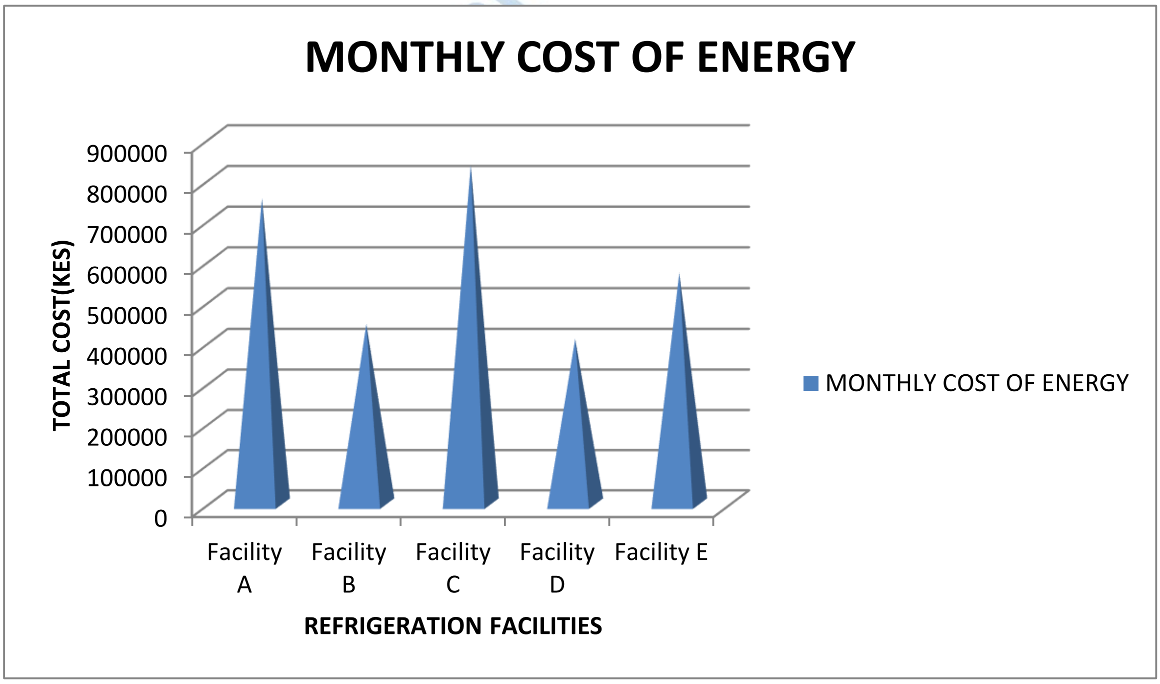

Figure 4.28: Monthly cost of energy trend1

Figure 4.29 shows monthly total cost of energy for refrigeration facilities F to J which ranges from Kes.310000 to Kes.780000 per month

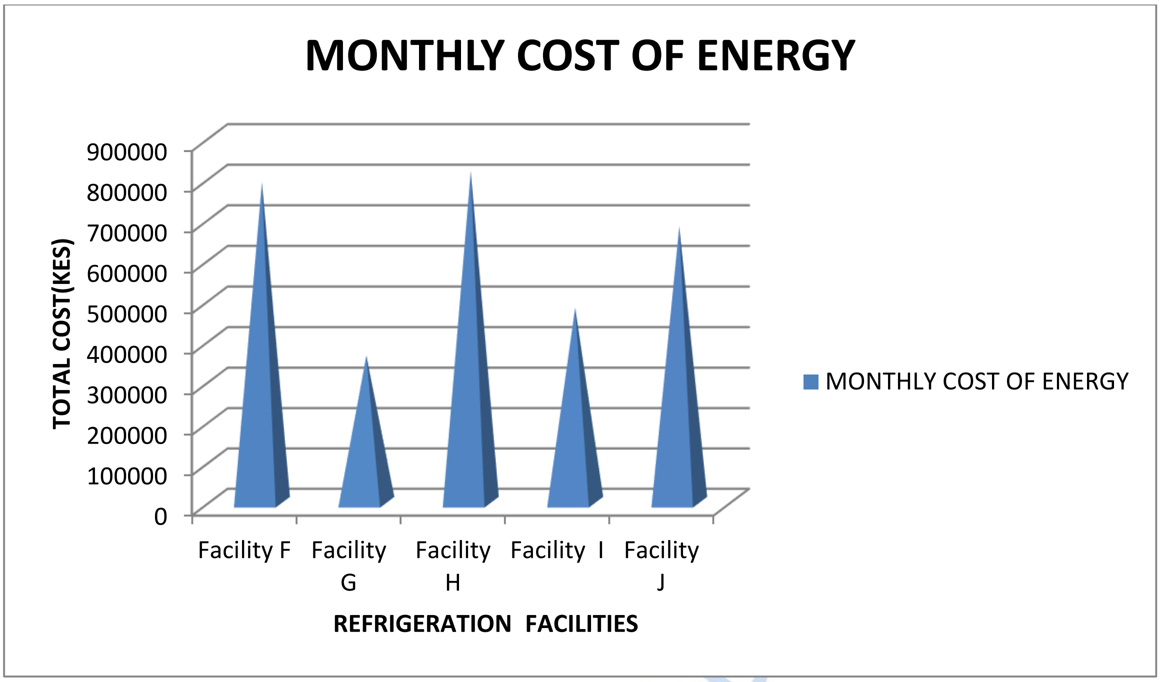

Figure 4.29: Monthly cost of energytrend2

Figure 4.30 indicates average yearly total cost of energy for the refrigeration facilities A to E, which ranges from Kes.4363440 to 8800000.This, represents the summation of monthly total cost of energy for a period of one year.

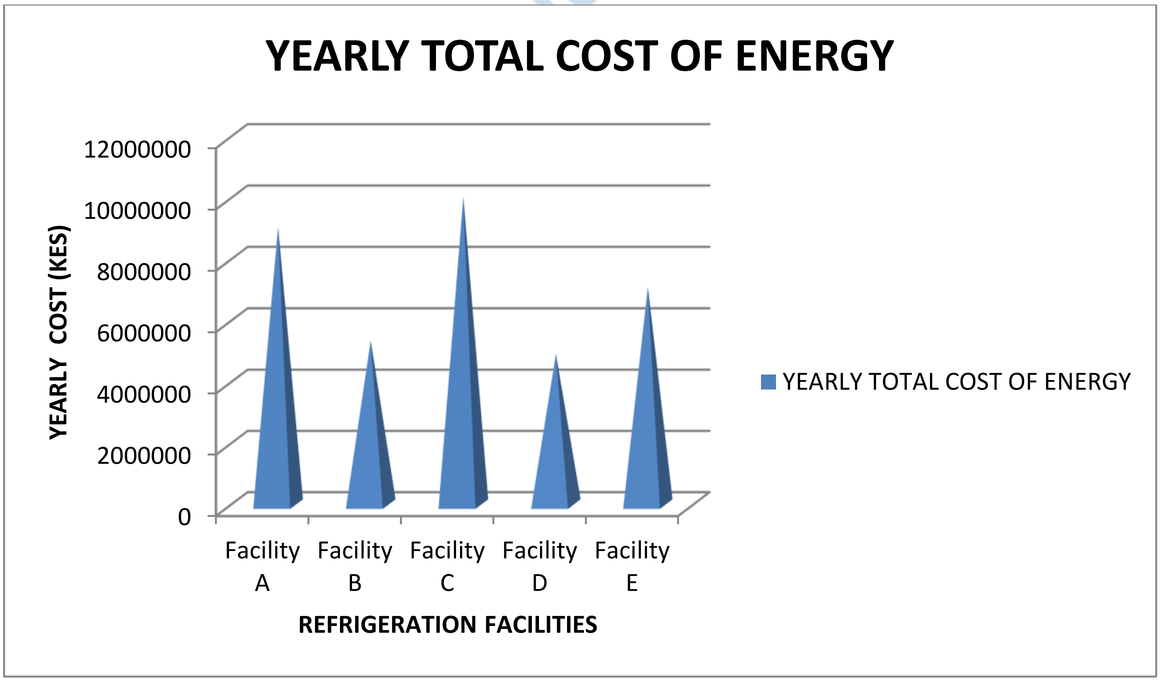

Figure 4.30: Yearly cost of energy trend1

Figure 4.31 indicates yearly total cost of energy for refrigeration facilities F to J, which ranges from Kes.4000000 to Kes.9200000.

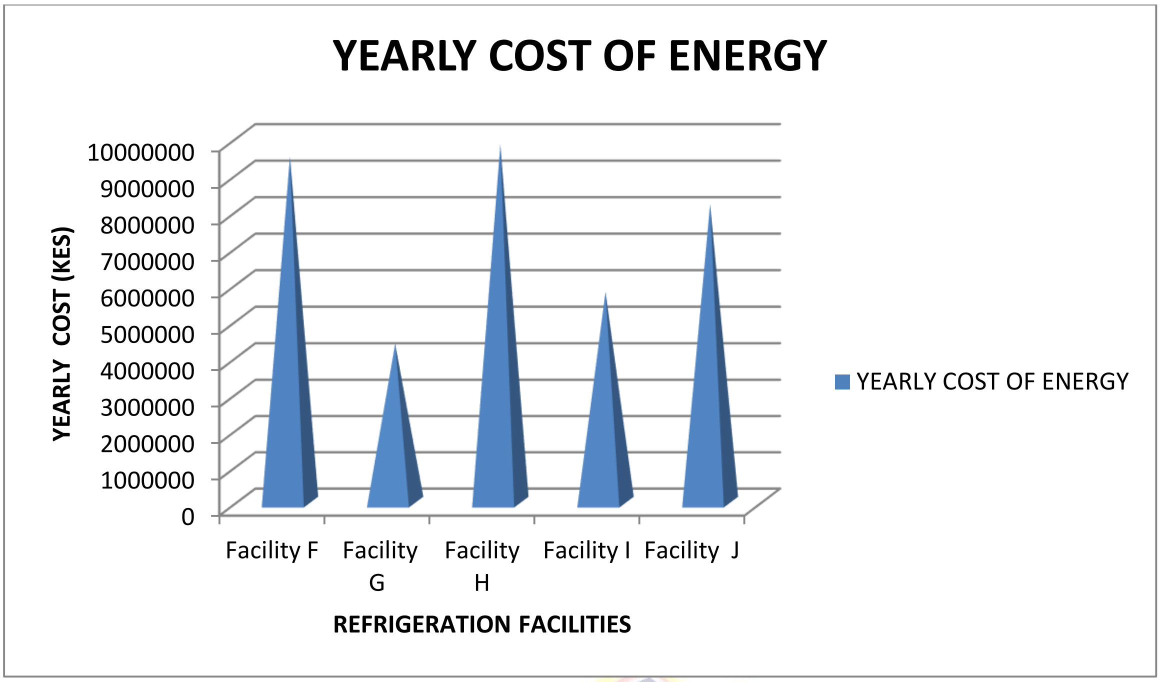

Figure 4.31: Yearly cost of energy trend2

4.3Discussion of individual objective results

4.3.1 Descriptive statistics for daily, monthly, yearly energy consumption and peak load

The first objective of this study, which is to evaluate refrigeration energy demand of refrigeration facilities in Nairobi cargo at JKIA. Table 4.15 analysis the input data for daily, monthly and yearly energy consumption for the population under this study. N represents the population under the study.

Table 4.15: Descriptive statistics for daily, monthly and yearly energy consumption

Statistics

		Monthly_HIGH_RATE_ENERGY_CONSUMPTION_KWH	Monthly_LOW_RATE_ENERGY_CONSUMPTION_KWH	Daily_HIGHRATE_ENERGY_CONSUMPTION_KWH	Daily_LOW_RATEENERGY_CONSUMPTION_KWH	Yearly_HIGH_RATE_ENERGY_CONSUMPTION_KWH	Yearly_LOW_RATE_ENERGY_CONSUMPTION_KWH
N	Valid	10	10	10	10	10	10
	Missing	0	0	0	0	0	0
Mean		17643.4000	17307.2000	588.4000	576.8000	2405957.700	2488336.800
Median		18189.0000	17842.5000	606.5000	594.5000	2619216.000	2569320.000
Mode		10394.00[a]	10196.00[a]	346.00[a]	340.00[a]	149673.00[a]	1468224.00[a]
Std. Deviation		5198.93641	5099.85298	173.75027	170.11944	1026844.289	729244.9176
Variance		27028939.82	26008500.40	30189.156	28940.622	1.054E+12	5.318E+11
Skewness		-.143	-.143	-.143	-.141	-1.168	-.157
Std. Error of Skewness		.687	.687	.687	.687	.687	.687
Kurtosis		-1.859	-1.859	-1.861	-1.860	1.378	-1.872
Std. Error of Kurtosis		1.334	1.334	1.334	1.334	1.334	1.334
Range		13512.00	13254.00	451.00	442.00	3292791.00	1869576.00
Minimum		10394.00	10196.00	346.00	340.00	149673.00	1468224.00
Maximum		23906.00	23450.00	797.00	782.00	3442464.00	3337800.00
Sum		176434.00	173072.00	5884.00	5768.00	24059577.00	24883368.00

a. Multiple modes exist. The smallest value is shown

Table 4.16shows the descriptive statistics for the peak loads for entire population. The peak load averages determine the mean peak load for the population under study. The table indicates the mean of 67.9kW for the entire population. N represents the population under the study.

Table 4.16: Descriptive statistic for peak loads

Statistics

PEAK_LOAD_AVERAGE

N	Valid	10
	Missing	0
Mean		67.9000
Median		70.0000
Mode		40.00[a]
Std. Deviation		20.00805
Variance		400.322
Skewness		-.143
Std. Error of Skewness		.687
Kurtosis		-1.859
Std. Error of Kurtosis		1.334
Range		52.00
Minimum		40.00
Maximum		92.00
Sum		679.00

a. Multiple modes exist. The smallest value is shown

4.3.2 Descriptive statistics of solar radiation, maximum, minimum and mean temperatures

The second objective of the study is to design and optimize a grid-connected solar PV system for refrigeration purpose in Nairobi cargo hub at JKIA. The variables under consideration are the mean solar radiation and the mean temperature for twelve months. The standard test conditions for the solar module are rated at 1000W/m^2/day irradiance, 25^{0}centigrade solar cell temperature and air mass 1.5 spectrums. Table 4.17 shows the descriptive statistics for the solar radiation, minimum temperatures, maximum temperatures and the mean temperatures. The mean irradiation and temperature are 20.48kWh/m^2/month and 19.83 degrees centigrade respectively. The averages of solar radiation and the temperatures are quite favorable in the design of solar PV system for the refrigeration machines

Table 4.17: Descriptive Statistics of solar radiation, maximum, minimum and mean temperature

	SOLAR RADIATION (In kilowatt per hour)	MINIMUM TEMPERATURE (In degrees centigrade)	MAXIMUM TEMPERATURE (In degrees centigrade)	MEAN TEMPERATURE (In degrees centigrade)
N	12	12	12	12
Range	10.75	4.16	5.42	4.50
Minimum	15.03	11.10	22.90	17.00
Maximum	25.78	15.26	28.32	21.50
Mean	20.4850	13.8475	25.7983	19.8342
Std. Deviation	3.04630	1.25088	1.48942	1.25598
Variance	9.280	1.565	2.218	1.577
Skewness	.202	-1.001	-.447	-1.097
	.637	.637	.637	.637
Kurtosis	-.014	.578	.229	1.014
	1.232	1.232	1.232	1.232

N=12 Months where N represents number of months under the study.

4.3.3 Economic analysis

The third objective is to evaluate the social economic benefits of solar PV system.

Grid connected solar PV cooling systems are characterized by a higher investment. The specific type of installation mostly affects cost per kW for the grid connected PV systems whether commercial or industrial. Economic analysis has to take into account both the initial investment and maintenance cost.

For this study, the equivalent present value cost consists two parts which are the initial capital expenditure (C_O) and the annual cost accrued in each successive period. There is the period for installation of the grid connected solar PV system(M) and ones the system is ready to operate, there is fixed maintenance cost per year(M+1) to life cycle of the investment.

The economic success of this study is based on three parameters, which are PBT, LCOE and NPV. The payback time (PBT) is the amount of time required to expect a return on the investment. This is the number of years it will take for the investment to get the capital cost. The study considers the initial and maintenance cost of the investment in relation to yearly savings.

Table 2.3(EPRA, 2019a) illustrate average installation cost of 1kw to be $1128.

From the solar PV sizing for facility A (sampled population), the proposed capacity is equivalent to 234kWp.The total cost of installation equate to:

$1128 *234= $263,952 (5)

PBT=Cost of solar PV installation/energy saving per year

Energy saving for the sample refrigeration facility A= Kes9, 054,144/Kes130. (6)

Convert the energy saving into dollar equate to $69647.26 where Kes130=1$

PBT=$263,952/69647.26=3.79years (7)

=3.79years

LCOE is the ratio between the present value of the total costs of PV system plus the maintenance cost and the energy generated by the system during the evaluation period.

Cost of PV installation=$233,952

Cost of maintenance (assume) 1% of solar PV installation cost

=1/100*$263,952= $ 2639.52 (8)

Total cost of PV installation=$(263,952 + 2,639.52

=$266,591.52 (9)

Total energy consumption per year=3,105,648kWh (Table 4.3)

Polycrystalline modules are used in solar PV installation with useful life of 25yrs

LCOE=$ 266591.52/ (3105648*25) kWh (10)

=$.0034/kWh which represents the cost of energy during the entire life of the PV installation.

NPV is a standard method, which uses the time value of money to appraise long-term investments. It presents the viability of the investment, which is the grid connected solar PV system for refrigeration purpose. Considering the present discounted benefits (PDB) and the present discounted costs (PDC). Whereas B_t is the revenues or benefits of the investment during year (t) which is undiscounted and C_t is the cost of the cost of the investment under this study during year (t) which is undiscounted with r and T been the discounted rate and time horizon for the project.

$PDB=\sum_{t=0}^{T} Bt/(1+r)^{t}$ (11)

$PDC= \sum_{t=0}^{T} Ct/(1+r)t$ (12)

NPV=PDB-PDC (13)

$=\sum_{t}^{T} Bt - C□/(1+r)\, t$ (14)

Where B_t=69647.26*25 (15)

=$1741181.5

C_t=$266591.52 (16)

Apply the formula for NPV calculation: where r=10 %(average interest rate) and t=25years (useful life of polycrystalline module)

NPV=$1741181.5-$266591.52/ $(1+10\%)^{25}$ (17)

=$136098.75

CHAPTER FIVE: SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

The main purpose of this study is to design and provide energy cost appraisal for refrigeration system using solar PV with specific objectives. Correlation analysis summarizes the result findings for the ten facilities, which represent population of the study.

5.2 Summary of the result finding

The first objective is to evaluate refrigeration energy demands in refrigeration firms in Nairobi cargo hub at JKIA. This study has summarized the finding by using the correlation analysis. Table 5.1shows the correlation between the peak load, which is the highest power demand at a specified time, and the daily, monthly plus yearly energy consumption. The Pearson correlation measures the strength of linear relationship between the peak load and the daily, monthly, yearly energy consumption. Pearson correlation, which the study utilizes, has a value between -1 to +1 where -1 shows negative linear correlation and +1 positive correlation and 0 shows no correlation. Table 5.1 indicates correlation coefficient between energy consumption and the peak load is +1. This shows that the energy consumption and the peak load are highly and positively correlated for the ten refrigeration facilities. Change of energy consumption impacts the peak load.

Table 5.1: Pearson correlation of daily, monthly, yearly energy consumption and peak load

Correlations

		PEAK_LOAD_AVERAGE	Monthly_HIGH_RATE_ENERGY_CONSUMPTION_KWH	Monthly_LOW_RATE_ENERGY_CONSUMPTION_KWH	Daily_HIGHRATE_ENERGY_CONSUMPTION_KWH	Daily_LOW_RATEENERGY_CONSUMPTION_KWH	Yearly_HIGH_RATE_ENERGY_CONSUMPTION_KWH	Yearly_LOW_RATE_ENERGY_CONSUMPTION_KWH
PEAK_LOAD_AVERAGE	Pearson Correlation	1	1.000**	1.000**	1.000**	1.000**	.932**	1.000**
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.000
	N	10	10	10	10	10	10	10
Monthly_HIGH_RATE_ENERGY_CONSUMPTION_KWH	Pearson Correlation	1.000**	1	1.000**	1.000**	1.000**	.932**	1.000**
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.000
	N	10	10	10	10	10	10	10
Monthly_LOW_RATE_ENERGY_CONSUMPTION_KWH	Pearson Correlation	1.000**	1.000**	1	1.000**	1.000**	.932**	1.000**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000
	N	10	10	10	10	10	10	10
Daily_HIGHRATE_ENERGY_CONSUMPTION_KWH	Pearson Correlation	1.000**	1.000**	1.000**	1	1.000**	.932**	1.000**
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000
	N	10	10	10	10	10	10	10
Daily_LOW_RATEENERGY_CONSUMPTION_KWH	Pearson Correlation	1.000**	1.000**	1.000**	1.000**	1	.932**	1.000**
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000
	N	10	10	10	10	10	10	10
Yearly_HIGH_RATE_ENERGY_CONSUMPTION_KWH	Pearson Correlation	.932**	.932**	.932**	.932**	.932**	1	.933**
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000
	N	10	10	10	10	10	10	10
Yearly_LOW_RATE_ENERGY_CONSUMPTION_KWH	Pearson Correlation	1.000**	1.000**	1.000**	1.000**	1.000**	.933**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	
	N	10	10	10	10	10	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

The second objective is to design and optimize a grid-connected solar PV for refrigeration processes in sampled refrigeration facility. The study uses correlation analysis to summarize result findings. Table 5.2 shows Pearson correlation between solar radiation and the minimum, maximum, mean temperature. Correlation coefficient between the solar radiation and mean temperature is 0.686, which means that temperature and solar radiation are positively correlated. This implies that there exists relationship between the temperature and solar radiation. N represents the number of refrigeration facilities. Figure 4.25 clearly shows how design layout of grid-connected solar PV system indicating all the components. Sizing of the solar modules and grid-connected inverters have been done.

Table 5.2: Pearson correlation for solar radiation and minimum, maximum and mean temperature

Correlations

		RADIATION_KWh	MINIMUM_TEMPERATURE_degrees_centigrade	MAXIMUM_TEMPERATURE_degrees_centigrade	MEAN_TEMPERATURE_degrees_centigrade
RADIATION_KWh	Pearson Correlation	1	.596*	.899**	.686*
	Sig. (2-tailed)		.041	.000	.014
	N	12	12	12	12
MINIMUM_TEMPERATURE_degrees_centigrade	Pearson Correlation	.596*	1	.518	.902**
	Sig. (2-tailed)	.041		.084	.000
	N	12	12	12	12
MAXIMUM_TEMPERATURE_degrees_centigrade	Pearson Correlation	.899**	.518	1	.586*
	Sig. (2-tailed)	.000	.084		.045
	N	12	12	12	12
MEAN_TEMPERATURE_degrees_centigrade	Pearson Correlation	.686*	.902**	.586*	1
	Sig. (2-tailed)	.014	.000	.045	
	N	12	12	12	12

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

The third objective is to evaluate the social economic benefit of grid-connected PV system. The study utilizes the formulae to evaluate the economic benefits of the grid connected solar PV system for refrigeration purposes. The three parameters under the consideration are the NPV, PBT and LCOE. The calculated PBT is 3.79years, LCOE is US$0.0034 per kWh and positive net present value=$136078.75. The main social benefits of the grid connected solar PV system are reduction of respiratory disease by use of clean energy, creation of employment and technological advancement

5.3 Recommendations

1. Engagement with the refrigeration facilities owners, government and other stakeholders on policies and framework regarding the establishment of grid-connected solar PV for refrigeration facilities.

2. Incorporating both refrigeration machines and solar system as one well-designed model for the cold-rooms. This will eliminate over sizing of refrigeration and solar PV system components resulting to reduction in cost.

5.4 Conclusion

The study presents a design of a grid connected solar PV system for refrigeration purposes. It is imperative to note that the cost of the PV system components mainly the solar panels and the inverters have been a hindrance to majority of the refrigeration facilities owners. The first research question is conclusively met by tabulating the daily, monthly and yearly high and low-rate energy consumption for the population under the study. The bar graphs and line charts demonstrate the energy consumption trends for refrigeration facilities. The second research question is how solar PV can be integrated into the electrical grid for refrigeration applications. This is demonstrated by the design of a grid connected PV system as illustrated in figure 4.25.The sizing of the major components, which are the solar modules, and the inverters where the study considers the solar insolation for optimal PV system design. Third research question is about the social economic benefits of the grid connected solar PV system. Through economic analysis, this study has proved its worthiness by having a positive NPV, a shorter PBT and a favorable LCOE resulting to achievement of grid parity.

5.5 Recommendation for further research in this field of study

Relating the gains made by the use of grid connected solar PV for refrigeration purposes to carbon credit markets.

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APPENDICES

I.RESEARCH TOOLS

A.COMPUTER (LATTOP)

B.STATISTICAL PACKAGE FOR SOCIAL SCIENCES (SPSS SOFTWARE)

II. ERC CERTIFICATE

Mount Kenya University

MKU

Unlocking Infinite Possibilities

REF: **MKU/ERC/1616**

Date: 19 May 2020

TO: **JOHN KIMUHU KAIRA** REG: **Faculty**

Dear Sir/Madam,

RE: DESIGN OF A GRID-CONNECTED SOLAR PHOTOVOLTAIC SYSTEM FOR REFRIGERATION PURPOSES IN NAIROBI CARGO HUB AT JKIA.

This is to inform you that **Mount Kenya University** has reviewed and approved your above research proposal. Your application approval number is **690.** The approval period is **19/05/2020 – 18/05/2021.**

This approval is subject to compliance with the following requirements;

i. Only approved documents including informed consents, study instruments, MTA will be used
ii. All changes including amendments, deviations and violations are submitted for review and approval by **Mount Kenya University**
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to **Mount Kenya University** within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affect the safety or welfare of study participants and others or affect the integrity of the research must be reported to **Mount Kenya University** within 72 hours
v. Clearance for export of biological specimens must be obtained from relevant institutions
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal
vii. Submission of an executive summary report within 90 days upon completion of the study to **Mount Kenya University**

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely,

The Chairman
Mount Kenya University
Ethics Review Committee
P. O. Box 342 - 0100, Thika

Prof. Francis W. Muregi
Chairman, Mount Kenya University IERC

Main Campus, General Kago Road, P.O. Box 342-01000 Thika. Tel: +254 67 2820 000,
Cell: +254 720 790 796, 0709 153 000

III. NACOSTI RESEARCH LICENCE

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: **705736**

Date of Issue: **11/June/2020**

RESEARCH LICENSE

This is to Certify that Mr.. JOHN KIMUHU KAIRA of Mount Kenya University, has been licensed to conduct research in Nairobi on the topic: DESIGN OF A GRID-CONNECTED SOLAR PHOTOVOLTAIC SYSTEM FOR REFRIGERATION PURPOSES IN NAIROBI CARGO HUB AT JKIA for the period ending : 11/June/2021.

License No: **NACOSTI/P/20/5225**

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IV.FIELD ENTRY

Picture : Coldroom with frech produce

V. TURNITIN REPORT

John Kaira

DESIGN OF A GRID-CONNECTED SOLAR PHOTOVOLTAIC SYSTEM FORREFRIGERATION PURPOSES IN NAIROBI CARG…

Masters Class **EEEBE**

Mount Kenya University

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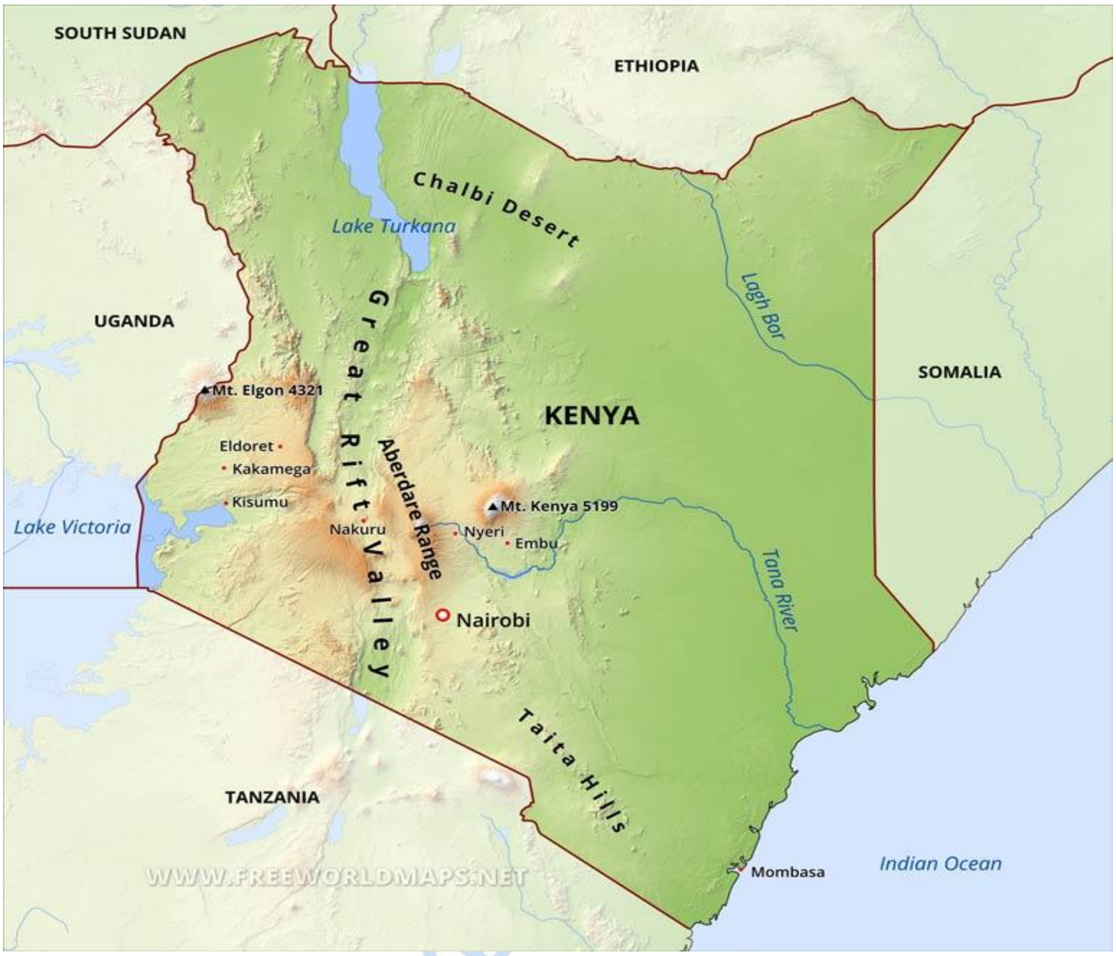
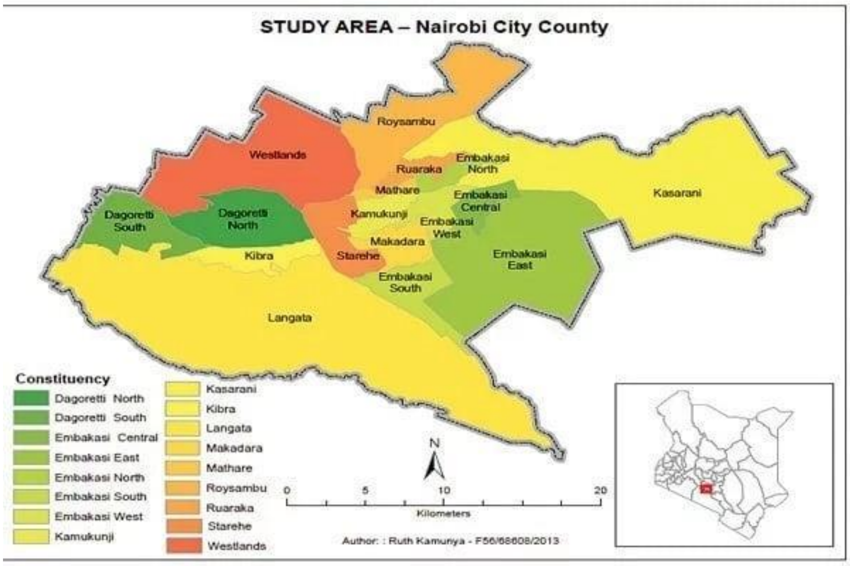
VI.RESEARCH MAPS

The study has been carried out at JKIA, which is based in Nairobi County, Kenya



Picture 1: Kenya map

This is the map of Nairobi County where the study has been carried out.



Picture 2: Nairobi County map

VII.LONG TABLES-MET DATA

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9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2012
9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2012
9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2012
9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2012

9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2012
9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2012
9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2012
9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2013
9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2013
9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2013
9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2013
9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2013
9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2013
9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2017
9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2020

9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2020
9136168	J.K.I.A. METEOROLOGICAL STATION	-1.31	36.91	1624	2020
9136168	J.K.I.A METEOROLOGICAL STATION	-1.31	36.91	1624	2020
9136168	J.K.I.A METEOROLOGICAL STATION	-1.31	36.91	1624	2020
9136168	J.K.I.A METEOROLOGICAL STATION	-1.31	36.91	1624	2020
9136168	J.K.I.A METEOROLOGICAL STATION	-1.31	36.91	1624	2020
9136168	J.K.I.A METEOROLOGICAL STATION	-1.31	36.91	1624	2020
9136168	J.K.I.A METEOROLOGICAL STATION	-1.31	36.91	1624	2020
9136168	J.K.I.A METEOROLOGICAL STATION	-1.31	36.91	1624	2020

MM	RELHUM06	RELHUM12	RADDWN	TMPMIN	TMPMAX
1	68.35	39.1	MIS	13.27	26.22
2	56.21	MIS	MIS	11.07	28.94
5	77.84	MIS	MIS	14.02	26.38
6	79.87	MIS	MIS	12.98	23.84
7	80.65	MIS	MIS	11.83	23.6
8	74.97	MIS	MIS	12.25	24.33
9	74.3	MIS	MIS	12.51	25.71
11	84	MIS	MIS	15.3	25.44
12	79.68	MIS	MIS	15.07	25.56
1	81.13	MIS	MIS	14.83	24.4
2	77.93	MIS	MIS	15.1	26.72
3	80.26	MIS	MIS	14.46	26.71
4	86.3	MIS	MIS	15.1	24.77
5	82.19	MIS	MIS	13.97	24.89
3	72.9	MIS	22.11	14.72	29.1
4	78.8	MIS	19.55	15.76	27.95
5	87.19	MIS	16.1	15.19	24.29
6	85.57	MIS	16.03	13.13	23.56
7	82.48	MIS	14.59	11.58	22.39
8	83.61	MIS	14.19	11.89	23.39
9	76.2	MIS	MIS	13.35	25.32
10	75.42	MIS	19.07	14.38	27.01
11	83.45	MIS	19.77	15.28	24.96
12	75.65	MIS	MIS	14.11	25.94
1	79.32	MIS	20.45	14.85	27.25
2	79.52	46.68	20.94	14.88	27.03
3	77.13	44.45	21.66	14.61	27.94
4	88	40.03	19.09	15.44	25.63
5	85.4	57.52	19.19	14.4	25.51
6	79.43	54.85	14.95	11.42	23.62
7	77.19	50.53	16.94	9.93	25.09

8	77.1	39.68	15.24	11.27	24.57
9	74.7	44.26	19.47	12.99	27.19
10	77.26	37.27	22.86	14.65	26.94
11	81.87	45.03	19.19	15.1	25.5
1	69.9	48.67	18.41	13.75	27.61
2	66.86	36.26	23.65	14.18	28.96
3	78.77	32.54	MIS	15.29	28.64
4	79.57	38.87	MIS	15.32	27.21
5	84.65	44.47	MIS	15.04	24.99
6	86.33	62.19	MIS	12.98	23.08
7	81.65	57.47	MIS	11.15	22.54
8	82.06	55.1	MIS	12.21	23.62
1	83.03	51.65	22.53	14.93	25.14
2	72.96	53.71	15.75	13.63	28.07
3	75.97	39.5	2.16	14.7	29.96
4	85.2	39.03	1.89	15.13	26.25
5	85.16	53.8	1.75	14.26	MIS
6	81.57	58.65	17.38	12.6	MIS
7	83.19	51	13.49	11.7	MIS
8	82.81	55.06	13.26	13.5	MIS
9	76.5	52.71	17.52	13.24	27.73
10	75.55	41.37	18.96	14.22	26.71
11	82.6	38.42	19.03	14.94	25.65
12	75.48	47.3	21.72	14.33	25.64
1	76.58	44.77	22.51	13.33	26.84
2	74.72	39.77	22.29	13.08	27.14
3	81.58	36.67	20.73	14.42	27.43
4	86.77	42.83	19.21	14.36	24.83
5	81.35	49.77	17.21	13.06	24.5
6	81.47	50.58	14.7	MIS	23.22
7	83.23	50.23	13.34	8.6	22.53
8	78.42	53.58	14.43	MIS	24

9	74.1	48.68	20.23	MIS	26.8
10	77.71	39.57	19.5	MIS	26.43
11	81.57	43.9	20.59	15.19	26.26
12	71.71	51.5	22.7	14.24	28.14
1	68.9	36.06	23.42	13.94	27.75
2	79.36	38.94	23.16	14.08	28.26
3	73.74	37.07	23.54	14.39	29.07
4	78.97	31.29	19.2	15.41	27.35
5	83.26	43.43	17.36	15.18	25.38
6	81.77	53.55	17.84	13.66	25.03
7	77.1	47.63	16.27	10.55	23.57
8	77.68	45.42	14.44	12.62	23.89
9	72.13	47.9	19.88	13.33	27.33
10	77.61	36.17	17.96	14.39	26.6
11	80.93	44	20.55	15.11	25.24
12	78.97	45.9	19.77	15.06	27.66
1	76.39	49.84	21.74	14.31	26.06
2	78.86	46.9	20.38	15.53	27.27
3	84.19	48.21	20.28	15.03	25.98
4	85.6	54.74	18.76	15.5	25.83
5	85.29	56.6	17	14.57	24.87
6	84.2	58.13	14.19	12.52	23.52
7	80.32	58.4	14.8	11.07	23.59
8	79.97	50.94	14.78	12	23.96
9	76.63	50.84	18.59	11.3	26.4
10	71.9	41.57	20.92	13.5	28.16
11	83.37	36.55	19.25	15.15	26.13
12	71.16	52.17	22.22	14.69	27.21
1	66.42	41.32	23.97	13.88	28.41
2	65.71	32.39	24.52	13.8	28.99
3	75.97	32.18	22.72	14.49	28.34
4	80.5	37.55	19.86	15.17	27.16

5	81.74	44.97	16.06	15.13	26.05
6	81.4	49.84	16.62	14.25	25.41
7	78.23	47.6	17.35	11.95	25.9
8	81.23	43.39	14.04	13.27	23.66
9	77.03	51.1	MIS	14.41	26.02
10	79.77	44.4	MIS	15.29	26.39
11	83.77	45.74	MIS	16.26	24.97
12	77.55	58.97	MIS	15.46	25.78
1	59.61	50.1	MIS	12.62	28.35
2	63.41	30.35	MIS	14.1	28.96
3	66.87	29.48	MIS	14.56	30.01
5	82.84	29.16	MIS	15.04	24.6
6	82.67	59.71	MIS	13.45	23.04
7	85.16	58.93	MIS	12.45	23.04
8	80.32	56.61	MIS	12.05	25.12
9	76.17	45.26	20.54	12.69	27.09
10	74.16	40.07	MIS	14.72	27.8
11	81.4	43	MIS	15.03	27
5	81.68	49.7	MIS	14.07	25.08
6	81.33	51.81	MIS	12.74	23.32
7	79.52	53.2	MIS	11.25	24.56
8	80.65	45.81	MIS	12.73	23.54
9	74.4	52.19	MIS	13.3	27.1
10	66.13	37.64	MIS	13.97	28.64
5	MIS	33.19	MIS	14.07	MIS
1	72.96	45.19	20.81	13.97	26.8
2	71.55	40.63	24.7	13.95	26.7
3	76.74	37.58	23.66	14.67	28.32
4	83.3	40.62	19.53	15.24	25.7
5	83.28	47.71	20.46	14.49	25.1
6	82.33	54.81	17.54	12.97	23.76
7	80.79	52.78	15.03	11.1	22.9

8	79.89	50.36	18.13	12.38	25.0
9	75.22	49.12	19.45	13.04	25.4
10	75.06	39.76	20.14	14.39	26.9
11	82.55	42.38	20.59	15.26	26.2
12	75.89	51.17	25.78	14.71	26.8

Station ID	**Station Name**	**Lat**	**Lon**	**Elev**	**YY**
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2000
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2000
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2000
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2000
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2000
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2000
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2000
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2000
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2000
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2000
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2001
9136164	DAGORETTI CORNER	-1.3	36.75	1798	2001

	METEOROLOGICAL STATION				
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2001
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2001
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2001
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2001
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2001
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2001
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2001
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2001
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2001
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2001
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2002
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2002
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2002
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2002
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9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2002

9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2002
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9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2003
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9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2004
9136164	DAGORETTI CORNER	-1.3	36.75	1798	2004

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9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2004
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9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2011
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2011
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2011
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2011

9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2011
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2011
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2011
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2011
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2011
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2011
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2011
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2012
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2012
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2012
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2012
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2012
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2012
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2012
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2012
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2012
9136164	DAGORETTI CORNER	-1.3	36.75	1798	2012

	METEOROLOGICAL STATION				
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2012
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2012
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2013
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2013
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2013
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2013
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2013
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2013
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2013
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2013
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2013
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2013
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2013
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9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2014
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2014
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9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2014
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9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2014
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2014
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2014
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2015
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2015
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2015
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2015
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2015
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2015
9136164	DAGORETTI CORNER	-1.3	36.75	1798	2015

	METEOROLOGICAL STATION				
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2015
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2015
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2015
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2015
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2015
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2016
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2016
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2016
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2016
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2016
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2016
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2016
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2017
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2017
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9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2017

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9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2017
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2017
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2018
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2018
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2018
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2018
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2018
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9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2018
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2019
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9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2019
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2019
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	METEOROLOGICAL STATION				
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2019
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2019
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2019
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2019
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2020
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2020
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2020
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2020
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2020
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2020
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2020
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2020
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2020
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2020
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2020
9136164	DAGORETTI CORNER METEOROLOGICAL STATION	-1.3	36.75	1798	2020

MM	RELHUM06	RELHUM12	RADDWN	TMPMIN	TMPMAX
1	67.65	MIS	MIS	12.58	24.71
2	53.72	MIS	MIS	11.1	27.19
3	74.26	MIS	MIS	14.55	27.13
4	82.23	MIS	MIS	14.73	25.4
5	83.32	MIS	MIS	13.5	23.84
6	83.77	MIS	MIS	12.5	22.38
7	84.29	MIS	MIS	11.43	22.22
8	77.81	MIS	MIS	12.04	22.83
9	75.37	MIS	MIS	11.78	24.51
10	71.81	MIS	MIS	13.76	25.9
1	81.19	MIS	MIS	13.77	23.31
2	77.21	MIS	MIS	13.97	25.37
3	80.74	MIS	MIS	13.83	24.91
4	88.73	MIS	MIS	14.97	23.51
5	84.45	MIS	MIS	14.06	23.15
6	85.53	MIS	MIS	12.16	21.78
7	87.58	MIS	MIS	11.05	20.82
8	84.48	MIS	MIS	11.24	23.24
9	77.77	MIS	MIS	12.91	25.24
10	79.06	MIS	MIS	13.67	25.42
11	85.97	MIS	MIS	14.3	22.83
12	79.58	MIS	MIS	13.98	23.63
1	75.71	MIS	MIS	13.61	25.48
2	68.68	MIS	MIS	13.26	26.94
3	84.74	MIS	MIS	14.79	25.14
4	87.3	MIS	MIS	15.54	24.38
5	86.03	MIS	MIS	14.45	23.26
6	84.63	MIS	MIS	12.3	21.87
7	85.42	MIS	MIS	11.15	22.78
8	85.03	MIS	MIS	12.2	21.5

9	77.24	MIS	MIS	12.27	24.58
10	78.55	MIS	MIS	14.22	24.97
11	85.87	MIS	MIS	15.2	23.58
12	86.19	MIS	MIS	15.01	23.44
1	74.42	MIS	MIS	13.19	25.13
2	68.57	MIS	MIS	13	27.38
3	74.1	MIS	MIS	14.31	27.05
4	80.5	MIS	MIS	15.48	25.87
1	77.68	50.87	MIS	14.18	25.24
2	76.66	47.24	MIS	14.08	25.41
3	75.94	42.42	MIS	14.74	26.4
4	87.17	57.48	MIS	15.19	24.29
5	85.45	56.94	MIS	13.96	23.35
6	83.93	57.5	MIS	11.22	21.81
7	83.23	47.87	MIS	9.32	23.25
8	84.23	50.19	MIS	10.66	23.03
9	78.43	40.63	MIS	12.6	25.42
10	79.74	47.16	MIS	14.1	24.48
11	84.13	55.93	MIS	14.88	23.28
12	81.77	53.87	MIS	14.65	24.15
1	71.71	41.06	MIS	13.71	26.31
2	67.04	39.25	MIS	13.74	26.85
3	78.13	46.55	MIS	15.28	26.58
4	83.57	52.57	MIS	15.26	25.1
5	85.29	62.84	MIS	14.89	23.41
6	88.17	62.43	MIS	13.12	21.3
7	86.87	63.77	MIS	11.33	20.72
8	88.03	61.71	MIS	11.87	21.58
9	80.67	47.17	MIS	12.59	23.86
10	76.81	40.13	MIS	13.47	25.27
11	83.2	55.5	MIS	14.72	23.63
12	72.26	43.97	MIS	13.53	25.37

1	74.29	42.97	MIS	13.7	25.83
2	71.32	39.86	MIS	14.62	27.59
3	82.29	50.1	MIS	15.34	25.95
4	88.03	67.77	MIS	15.29	23.31
5	85.93	63.47	MIS	14.12	22.99
6	83.83	57.63	MIS	12.5	22.44
7	87	65.16	MIS	12.06	20.66
8	83.65	50.87	MIS	11.89	23.12
9	80.77	50.43	MIS	12.55	23.29
10	76.23	42.26	MIS	14.34	25.7
11	88.47	63.37	MIS	15.13	22.84
12	82.97	60.52	MIS	15.25	23.24
1	78.06	53.61	24.62	14.55	24.2
2	71.14	44.54	25.16	13.67	26.13
3	78.16	43.94	25.7	14.33	26.15
4	86.17	53.43	20.73	15.27	24.84
5	86.1	61.42	17.61	14.79	23.14
6	83.8	58.67	16.91	13.09	22.63
7	85.52	60.06	12.95	12.16	21.27
8	86.19	58.48	14.72	12.79	21.37
9	82.53	51.23	19.11	12.35	23.55
10	83.65	47.9	22.3	14.47	24.01
11	85.37	50.97	22.69	15	23.51
12	76.32	51.65	23.87	13.84	24.23
1	75.19	47.52	25.73	13.65	25.15
2	75.59	42.1	25.64	13.48	25.62
3	80.1	45.9	23.97	14.85	25.93
4	87.23	53.43	21.07	14.84	23.46
5	83.68	55.97	18.01	13.96	22.88
6	85.37	58	14.09	12.43	21.67
7	86.71	60	13.48	11.94	20.83
8	84.55	54.29	15.48	12.53	22.24

9	78.27	46	22.39	12.73	24.87
10	84.42	52.45	20.38	14.93	24.46
11	82.37	54.33	23.52	14.96	24.08
12	75.39	44.32	24.85	14.06	25.09
1	68.42	39.61	26.49	13.39	25.55
2	78.36	41.86	26.26	14.29	25.6
3	73.48	35.16	27.94	14.95	27.39
4	83.03	48.63	22.12	15.72	25.28
5	85.94	56.71	18.69	14.98	23.64
6	83.3	54.83	19.02	13.41	23.33
7	82.97	50.61	16.61	10.77	21.67
8	83.58	53.74	15.5	12.33	22.13
9	76.07	42.1	22.55	13.35	25.64
10	79.58	49.45	19.91	14.43	24.42
11	83.03	52.07	22.81	15.06	24.05
12	81.77	51.39	22.76	14.91	24.35
1	73.61	49.94	24.19	14.15	24.43
2	80.68	51.25	22.92	15.75	25.53
3	82.9	56.65	22.79	15.28	24.54
4	86.87	59.2	19.36	15.77	24.34
5	83.9	63.9	17.12	15.04	23.4
6	86.17	61.83	14.21	13.23	21.74
7	84.94	56.52	14.52	11.5	21.55
8	85.26	55.61	15.29	12.25	22.06
9	80.73	46.57	20.08	12.3	24.23
10	76.32	41	22.47	14.2	25.43
11	85.43	55.67	20.09	14.88	22.93
12	75	46.71	24.95	14.02	24.27
1	67.55	35.13	26.68	13.27	25.78
2	64.48	33.8	27.7	13.42	26.78
3	76.66	41.41	24.79	14.9	26.07
4	84.3	48.73	23.1	15.76	24.9

5	88.19	56.11	17.19	14.97	23.72
6	86.55	54.28	1.75	13.91	24.08
7	82.1	49.55	18.68	11.39	23.51
8	86.55	57.58	13.26	12.57	21.61
9	81.17	48.6	18.52	13.56	23.92
10	82.39	49.84	20.12	14.78	24.24
11	84	57	18.03	14.96	23.65
12	77.81	51.03	22.79	14.55	23.89
1	59.48	31.58	27.53	11.78	26.2
2	64.59	31.38	28.66	13.47	27.05
3	66.84	29.42	27.65	14.5	27.96
4	84.23	56.47	18.43	15.49	24.51
5	84.71	60.1	18.68	14.44	23.15
6	86.13	60.97	14.36	13.09	21.45
7	87.26	61.77	14.76	12.18	21.59
8	83.45	49.29	18.36	11.76	23.03
9	78	42.43	22.24	12.5	24.9
10	78.03	44.35	22.15	14.79	25.15
11	83	51.93	21.22	14.87	24.06
12	81.83	51.88	28.18	14.44	23.81
1	74.32	47.39	25.05	14.04	24.97
2	69.18	33.96	44.14	13.71	26.8
3	81.26	44.61	46.02	15.68	26.12
4	84.27	60.43	19.39	15.29	24.49
5	83.23	52.87	18.55	14.16	23.24
6	85.5	57.23	13.94	12.7	21.68
7	82.03	49.1	17.16	11.54	22.87
8	85.52	56.26	13.71	12.19	21.49
9	78.47	41.63	19.88	12.85	25.02
10	71.29	37.03	23.55	14.19	26.17
11	83.93	50.13	19.84	14.95	24.56
12	79.58	56.42	20.47	14.35	23.41

1	68.19	42.13	27.57	13.74	25.68
2	77.29	48.54	22.29	14.43	25.59
3	81.65	46.55	32.57	15.17	25.5
4	83.03	51.23	22.73	14.85	24.34
5	84.52	51.97	16.18	14.91	24.06
6	87.57	57.6	14.92	13.51	22.57
7	84.03	55.74	13.69	12.62	22.03
8	81.87	49.65	16.82	12.63	23.19
9	81.77	46.7	19.57	12.87	23.79
10	76.23	45.55	20.39	14.57	25.38
11	82.97	52.1	18.84	14.91	MIS
12	78.17	50.81	22.99	14.18	MIS
1	57.52	33.07	23.24	12.71	MIS
2	67.46	34.82	26.03	13.98	MIS
3	68.9	35.74	26.09	14.49	MIS
4	83.2	53.17	21.54	15.72	MIS
5	85.87	57.23	18.41	15.12	MIS
6	83.93	61.23	15.63	13.22	MIS
7	86.81	52.65	18.99	12.23	21.94
8	81.84	49.97	17.95	12.64	22.55
9	70.23	37.37	MIS	12.85	25.08
10	78	43.52	20.64	15.12	25.31
11	84.73	60.63	14	15.36	23.11
12	77.77	55.61	16.62	15.38	24.27
1	72.82	54.65	21.56	15.7	MIS
2	63.12	46.89	23.53	14.29	MIS
3	59.96	MIS	MIS	MIS	MIS
4	75.93	59.93	16.19	16.15	MIS
5	78.66	64.06	3.42	14.52	MIS
6	76.94	61.2	13.91	12.92	MIS
7	82.55	MIS	15.25	11.61	MIS
1	MIS	MIS	MIS	14.15	MIS

3	MIS	MIS	MIS	15.14	MIS
5	MIS	MIS	MIS	14.75	MIS
6	79.8	49.4	MIS	13.57	22.83
7	80.87	49.93	MIS	12.09	22.14
8	MIS	MIS	MIS	13.35	
12	71.89	50.65	MIS	13.97	22.43
1	MIS	MIS	MIS	13.01	MIS
3	MIS	MIS	MIS	15.05	MIS
5	MIS	MIS	MIS	14.22	MIS
6	MIS	MIS	MIS	13.06	MIS
7	MIS	MIS	MIS	11.48	MIS
8	MIS	MIS	MIS	10.69	MIS
9	MIS	MIS	MIS	12.5	MIS
11	MIS	MIS	MIS	15.38	MIS
1	69.06	45.13	MIS	14.45	25.41
2	72.21	37.14	MIS	14.73	26.91
3	68.74	30	MIS	15.53	28.37
4	78.9	41.1	MIS	16.69	27.02
5	84.84	60.58	MIS	15.48	23.15
6	87.87	67.87	MIS	14.13	21.49
7	84.19	53.13	MIS	12.86	22.78
8	84.81	53.03	MIS	12.74	22.99
9	81.63	51.33	MIS	13.64	24.07
10	86.42	62.03	MIS	14.99	23.08
1	86.3	61.3	MIS	15.57	23.83
2	79.28	53.62	MIS	15.65	25.09
3	84.29	56	MIS	16.31	25.52
4	MIS	MIS	MIS	MIS	MIS
5	MIS	MIS	MIS	MIS	MIS
6	MIS	MIS	MIS	MIS	MIS
7	MIS	MIS	MIS	MIS	MIS
8	MIS	MIS	MIS	MIS	MIS

9	MIS	MIS	MIS	MIS	MIS
10	MIS	MIS	MIS	MIS	MIS
11	MIS	MIS	MIS	MIS	MIS
12	MIS	MIS	MIS	MIS	MIS

Station ID	**Station Name**	**Lat**	**Lon**	**Elev**	**YY**
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1	70.58	MIS	MIS	12.64	24.08
2	58.76	MIS	MIS	12.02	26.29
3	79.19	MIS	MIS	14.31	26
4	85.4	MIS	MIS	14.22	24.45
5	86.65	MIS	MIS	13.12	23.15
6	89.1	MIS	MIS	12.13	21.39
7	89.81	MIS	MIS	10.9	21.07
8	83.35	MIS	MIS	11.41	22.04
9	81.7	MIS	MIS	11.15	23.74
10	75.52	25	25.25	13.06	25.22
11	88	MIS	MIS	14.27	23.17
12	81.52	MIS	MIS	14.03	23.3
1	82.03	MIS	MIS	13.63	22.84
2	80	MIS	MIS	14.3	24.68
3	81.9	MIS	MIS	14.21	24.17
4	87.5	MIS	MIS	14.93	23.1
5	84.42	MIS	MIS	14.12	22.51
6	86.23	MIS	MIS	12	21.28
7	87.58	MIS	MIS	10.96	20.27
8	81.71	MIS	MIS	11.02	22.82
9	82.3	MIS	MIS	12.23	24.48
10	83.45	MIS	MIS	13.37	24.28
11	88.87	MIS	MIS	14.07	21.92
12	82.71	MIS	MIS	13.82	22.9
1	79.13	MIS	MIS	13.85	24.55
2	71.18	MIS	MIS	13.53	25.98
3	85.53	MIS	MIS	14.57	24.52
4	89.43	MIS	MIS	15.13	23.42
5	85.61	MIS	MIS	14.26	22.77
6	85.4	MIS	MIS	12.28	21.75

7	84.71	MIS	MIS	11.29	22.19
8	87.9	MIS	MIS	12.12	20.62
9	79.9	MIS	MIS	12.27	23.78
10	82.61	MIS	MIS	14.18	24.25
11	88.6	MIS	MIS	14.76	23
12	86.06	MIS	MIS	14.66	22.91
1	76.77	MIS	MIS	13.58	24.34
2	69.18	MIS	MIS	13.66	26.68
3	75.58	MIS	MIS	14.48	26.42
4	81.57	MIS	MIS	15.23	24.99
5	87.58	MIS	MIS	14.57	22.27
6	86.27	MIS	MIS	12.85	21.3
7	86.35	MIS	MIS	11.42	20.65
8	88.45	MIS	MIS	11.44	21.2
9	85.3	MIS	MIS	12.54	23
10	82.03	MIS	MIS	13.58	24.23
11	84.07	MIS	MIS	14.38	22.77
12	75.71	MIS	MIS	13.23	23.77
1	81.03	55.65	MIS	14.31	24.38
2	79.31	54.62	MIS	14.22	24.5
3	78.48	50	MIS	14.83	25.38
4	88.57	63.63	MIS	15	23.66
5	82.68	59.65	MIS	13.53	22.96
6	82.57	58.47	MIS	11.51	21.2
7	79.65	48.87	MIS	9.94	22.75
8	82.29	51.9	MIS	11.07	22.39
9	79.83	42.77	MIS	12.37	24.52
10	84.29	52.52	MIS	13.92	23.83
11	87.2	59.1	MIS	14.48	22.79
12	83.32	56.23	MIS	14.45	23.83
1	71.23	42.74	MIS	13.77	25.36
2	67.11	37.18	MIS	14.05	26.33

3	79.68	45.61	MIS	15.1	25.62
4	83.8	57.1	MIS	14.95	24.33
5	85.35	65.97	MIS	14.59	23.04
6	88.17	64.1	MIS	12.85	20.9
7	86.58	78.42	MIS	11.29	20.16
8	88.58	73.39	MIS	11.61	20.89
9	81.27	53.1	MIS	12.04	23.18
10	79.35	47.13	MIS	13.32	24.89
11	83.93	54.03	MIS	14.25	23.19
12	68.1	41.71	MIS	13.5	24.84
1	75.77	43.97	MIS	13.65	25.24
2	73.36	42.29	MIS	14.31	26.58
3	82.26	49.29	MIS	15.01	25.16
4	87.4	67.23	MIS	14.9	22.85
5	86.45	63.32	MIS	14.01	22.55
6	82.43	61.13	MIS	12.42	22.21
7	87.8	65.2	MIS	11.98	20.26
8	83.35	52.29	MIS	11.54	22.85
9	83.13	53.03	MIS	12.44	22.77
11	90.7	68.03	MIS	14.68	21.97
12	84.84	68.5	MIS	14.63	22.93
1	75.61	48.94	MIS	13.36	24.51
2	73.54	49.68	MIS	13.88	25.39
3	78.58	48.32	MIS	14.36	25
4	88.3	58.67	MIS	14.94	24.16
5	86.61	64.61	MIS	14.53	22.6
6	85.27	61.87	MIS	12.69	22.17
7	87.48	67.16	MIS	12.11	20.57
8	88.1	66.29	MIS	12.54	20.7
9	82.07	54.07	MIS	12.3	23.25
10	84.84	51.35	MIS	14	23.59
11	87.77	57.97	MIS	14.52	22.94

12	75.97	51.23	MIS	13.64	23.66
1	71.65	44.97	MIS	13.75	24.84
2	79.07	46.45	MIS	13.28	25.07
3	80.58	48.84	MIS	14.48	25.48
4	90.1	57.23	MIS	14.43	23.05
5	84.03	57.35	MIS	13.62	22.39
6	84.8	58.57	MIS	12.07	21.42
7	88.58	63.58	MIS	11.72	20.24
8	87	60.81	MIS	12.45	21.77
9	78.87	50.6	MIS	12.13	24.53
10	86.45	53.48	MIS	14.46	24.25
11	82.43	57.97	MIS	14.43	23.4
12	75.87	45.87	MIS	13.75	24.26
1	70.81	44.97	MIS	13.81	24.84
2	78.39	42.96	MIS	14.03	25.18
3	75.58	37.84	MIS	14.71	26.8
4	84.2	51.1	MIS	15.24	24.68
5	89.06	64.84	MIS	14.68	23.13
6	82.9	54.33	MIS	13.29	22.77
7	83.35	54.32	MIS	10.71	21.37
8	85.48	56.9	MIS	12.37	21.58
9	77.07	43.5	MIS	12.8	25.13
10	83.97	52.19	MIS	14.08	23.83
11	84.97	56.1	MIS	14.61	23.31
12	83.77	60.39	MIS	14.38	23.43
1	76.42	57.23	MIS	14.02	23.72
2	82.86	58.29	MIS	15.04	24.92
3	83.77	60.9	MIS	14.82	23.85
4	87.3	61.77	MIS	15.51	23.79
5	85.52	67.65	MIS	14.83	22.95
6	87.33	65.43	MIS	13.01	21.5
7	85.68	59.48	MIS	11.46	21.12

8	87.61	61.16	MIS	11.83	21.47
9	81.8	51.63	MIS	12	23.75
10	80.29	48.16	MIS	13.81	24.89
11	88.43	60.47	MIS	14.43	22.5
12	77.52	53.81	MIS	13.75	23.66
1	68.45	40.48	MIS	13.3	25.3
2	66.54	39.79	MIS	13.55	26.49
3	77.1	44.77	MIS	14.56	25.75
4	84.69	56.14	MIS	15.28	24.04
5	87.6	62.3	MIS	14.66	23.25
6	82.7	66.17	MIS	13.21	23.24
7	83.25	60.63	MIS	11.17	23.25
8	86.84	63.32	MIS	12.46	21.23
9	83.2	53.5	MIS	13.23	23.89
10	86.03	56.68	MIS	14.44	23.79
11	88.47	65.33	MIS	14.63	23.23
12	81.16	58.06	MIS	14.03	23.24
1	62.84	41.32	MIS	11.89	MIS
2	67.31	39.03	MIS	13.46	27.01
3	70.06	39	MIS	13.94	26.63
4	85.93	62.87	MIS	15	23.94
5	85.19	68.32	MIS	14.21	23.44
6	86.8	68.07	MIS	12.8	22.36
7	89.13	66.13	MIS	12.01	21.43
8	84.9	59.77	MIS	11.66	22.69
9	80.5	53.57	MIS	12.19	24.55
10	84.45	55.23	MIS	14.21	24.58
11	86.68	58.76	MIS	14.02	23.32
12	85.58	59.77	MIS	14.12	22.85
1	79.03	59.55	MIS	13.86	23.94
2	73.71	48.93	MIS	13.54	25.53
3	82.13	53.55	MIS	15.04	25.09

4	86.57	64.87	MIS	14.94	24.11
5	82.35	60.06	MIS	13.79	22.68
6	88	69.97	MIS	11.9	20.85
7	76.29	57.39	MIS	10.94	22.45
8	88.6	62.83	MIS	11.9	20.73
9	77.93	51.33	MIS	12.2	24.5
10	68.94	39.9	MIS	13.32	25.62
11	84.8	58.73	MIS	14.51	23.6
12	83.61	65.48	MIS	14.1	22.97
1	72.4	50.35	MIS	13.41	25.07
2	78.79	55.04	MIS	14.29	25.06
3	78.03	51.55	27.15	14.19	24.64
4	84.53	58.33	MIS	14.17	22.99
5	81.26	54.9	MIS	14.63	23.75
6	87.6	64.43	MIS	14.13	22.27
7	85.74	61	MIS	12.46	21.59
8	80.94	54.26	MIS	12.38	MIS
9	81.53	52.03	MIS	12.21	22.65
10	79.94	51.68	MIS	14.46	MIS
11	84.77	58.6	MIS	14.39	23.81
12	79.29	54.48	MIS	13.83	21.6
1	58.94	41.26	MIS	12.8	25.69
2	69.5	40.75	MIS	13.6	MIS
3	70.77	40.39	MIS	14.23	MIS
4	83.63	54.5	MIS	15.29	MIS
5	87.35	63.61	MIS	15.02	MIS
6	83.4	65.8	MIS	13	MIS
7	83.9	64.48	MIS	12	MIS
8	83.9	58.06	MIS	12.37	MIS
9	76.43	44.8	MIS	12.51	MIS
10	79.35	47.39	MIS	14.7	MIS
11	83.23	64.77	MIS	15.03	MIS

12	80.47	61.68	MIS	14.75	MIS
1	69.94	47.71	MIS	13.65	MIS
2	70.79	38.57	MIS	14.38	MIS
4	76.73	41.47	MIS	15.9	MIS
5	84.1	67.52	MIS	15.44	MIS
6	89.2	73.1	MIS	14.1	MIS
7	85.13	61.97	MIS	12.69	MIS
10	84.87	63.97	MIS	14.6	22.66
11	83.8	60.93	MIS	15.13	23.24
1	85.45	64.42	MIS	14.99	23.27
2	81	55.66	MIS	14.82	23.97
3	86.06	58.58	MIS	15.63	24.67
4	86.13	61	MIS	16.87	23.72
5	81.23	58.16	MIS	15.05	23.2
6	85.43	60.43	MIS	12.94	22.45
7	83.19	61.16	MIS	12.32	21.26
8	84.32	53.39	MIS	12.5	22.83
9	82.93	52.8	MIS	13.25	23.05
10	78.84	49.39	MIS	14.31	23.91
11	87.8	62.76	MIS	14.99	22.92