FRAMEWORK FOR SUSTAINABLE DESIGN OF PHOTOVOLTAIC HOME SYSTEMS IN NORTH-WESTERN NIGERIA

By

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DECLARATION

I declare that the work in this dissertation entitled 'FRAMEWORK FOR SUSTAINABLE DESIGN OF PHOTOVOLTAIC HOME SYSTEMS IN NORTH-WESTERN NIGERIA' has been performed by me in the Department of Building under the supervision of Prof. I. Mbamali, Prof. K. Bala and Prof. I. K. Zubairu.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at any university.

…… …….

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CERTIFICATION

This dissertation entitled 'FRAMEWORK FOR SUSTAINABLE DESIGN OF PHOTOVOLTAIC HOME SYSTEMS IN NORTH-WESTERN NIGERIA' by Abdulsalam Dalhatu meets the regulations governing the award of the degree of Doctor of Philosophy of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This dissertation is dedicated to my Beloved late mother for the training and guidance given to me, and to the entire family for their support.

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All praises and thanks are due to Allah; we thank Him and seek His help, guidance and forgiveness. May the peace and blessing of Allah be upon the noblest of the prophets and messengers, Prophet Muhammad (SAW).

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ABSTRACT

This study aims at establishing monthly average electric energy demand of various household types and the Insolation level in order to develop a sustainable design framework and design kit for Photovoltaic home systems application in the area. A field survey using multi stage stratified purpose sampling was adopted in Zaria Metropolis where a sample of one hundred and twenty (120) households were drawn from twelve (12) clusters to assess basic household energy demand. Meteorological data were also collected from the seven states of north western Nigeria to estimate and evaluate insolation potentials of twenty one (21) locations drawn through stratification method. Web-based computer design Kit running on the Hypertext preprocesses (PHP) and MySQL scripting language was also developed. The design kit utilises the averages of different household's energy demands and Insolation levels of locations as data base for sustainable implementation. Six household types: single member; nuclear; shared; extended; collective living and provider managed were identified in Nigeria with 1456.67 kWh as the overall average monthly energy demand of the households. The extended household recorded the highest average of 1841.70kWh per month while the single member household had the lowest (808.50kWh). The study found out that, both the sunshine and temperature base estimation models are adequate for estimating insolation level within the study area. The study also established the insolation levels of between 5.0257kWh/m^2/day and 11.5337kWh/m^2/day throughout the year within the locations. The estimated insolation data of locations is recommended for use in similar climatic conditions. The design criteria/method developed is therefore recommended for manual use and the Solar Home System Design Kit is adequate and appropriate as an alternative households power supply in Nigeria.

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LIST OF ACRONYMS AND ABBREVIATIONS

AC:	Air Conditioning
BIPV:	Building Integrated Photovoltaic
BOS:	Balance of System
CEC:	California Energy Commission
cf:	correction factor
CRM:	Coefficient of Residual Mass
DBMS:	Data Base Management System
DISCOS	Distribution Companies
DSM:	Demand Side Management
DOD:	Depth of Discharge
ECN:	Energy Commission of Nigeria
ECOs:	Energy Conservation Opportunities
EIA:	Energy Information Agency
EMS:	Energy Management System
ESE:	Earth Science Enterprise
GHG:	Green House Gas
GUI:	Graphic User Interface
Homer:	Hybrid Optimization Model for Electric Renewable
I PPs:	Independent Power Producers
lf:	loss factor
MSE:	Mean Square Error
MVC:	Model View Control
NASEF:	National Solar Energy Forum
NCERD:	National Centre for Energy Research and Development
NEP:	National Energy Policy

NEPA: National Electricity Power Authority

NERC: National Electricity Regulation Commission

NIALS: Nigerian Institute of Advanced Legal Studies

NREL: National Renewable Energy Laboratory

NPC: National Population Commission

PIER: Public Interest Energy Research

PB: Parsons Brinckerhoff

PHCN: Power Holding Company of Nigeria

PHP: Persona Home Page or Hypertext Processor

PV: Photovoltaic

PSRA: Power Sector Reform Act

R^2: Coefficient of Determination

RETs: Renewable Energy technologies

RDBMS: Relational Data Base Management System

RISE: Research Institute for Sustainable Energy

REA: Rural Electrification Agency

REMP: Renewable Energy Master Plan for the Federal Republic of Nigeria.

REPG: Renewable Energy Policy Guideline

REN21: Renewable

RMSE: Root Mean Square Error

SBTM: Sustainable Building Technical Manual

SCI: Solar Centre Information

SDLC: Software Development Life Cycle

SELF: Solar Electric Light Fund

SERC: Sokoto Energy Research Centre

SET: Sustainable Energy Technology

SHPS: Solar Power Home System

SHS: Solar Home System

SHSDK: Solar Home System Design Kit

SFS: SECO FACT SHEET N0. 24

SPV: Solar Photovoltaic

SRETs: Sustainable Renewable Energy Technologies

SSE: Surface metrology and Solar Energy

SSM: Supply Side Management

STC: Standard Test Condition

TRI: Technology Research Institute

TRANSCO: Transmission Companies

UNDP: United Nation Development Project

UNESCAP: United Nation Economic & Social Commission for Asia and the Pacific

UPC: Uninterrupted Power Supply

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THE STUDY

One of the basic indices of development of any society is the steady supply of electric power towards the attainment of its diverse energy needs (which ranges from environmental comfort to commercial and industrial infrastructural support base). In Nigeria, however, erratic power supply by Power Holding Company of Nigeria (PHCN) has given cause for concern to the general populace leading to the optional use of electricity generating sets for household and commercial uses in homes, streets and market places. The use of these generating sets contributes to sizeable amount of air, water, soil and noise pollution particularly in urban areas.

In terms of infrastructure, PHCN has an installed generating capacity of 6,000MW, compared to a peak national demand of 30,000MW. It could provide a maximum of 3,000MW with losses of 30-35% during transmission (Stanley, 2008; Hall, 2006). A summary of the Nigerian Electricity Industry Scorecard for the first half of 2008 shows some improvement with the total energy generated at 5,567,706MWh and 3,761,794MWh during the first and second quarters respectively with losses of 10-20% during transmission (NERC, 2008). Thus, the improvements remain unreliable within a decade.

In recent years, there has been a move towards using sustainable renewable energy because they are clean and non-polluting energy that is obtained from sources that are inexhaustible. These sources include solar, wind, nuclear, geothermal, biomass and hydro, all of which are natural resources and are naturally replenished. Sustainable energy refers to the way of generating and using energy in a more efficient and environment friendly manner without compromising the ability of future generations to meet their energy needs. For instance, in 2006 and 2008 about 18% and 19% of the global energy consumption respectively came from renewable sources.

Perhaps, most renewable energy projects and production are large-scale but they are also suitable for small off-grid applications, sometimes in rural and remote areas where energy is often scarce, even in advanced countries (REN21, 2009; RISE, 2010).

Considering the environmental pollution of fossil (fuel) power, high cost of geothermal power, harmful effect of nuclear power and the inconsistency of hydro and wind power, solar energy seems to be the best solution. The longevity, simplicity and minimal resources used to produce electricity via solar systems make it a highly sustainable technology. According to Bugaje, (1999) solar energy ranks high with many advantages including its availability irrespective of location. Solar Photovoltaic (SPV) systems are costly to install and the modules are often warranted for upwards of 20 years. The long run easily offset the increased cost of the installation and will produce electricity without additional cost until the inverter needs replacement. Inverters convert the produced direct current electricity to alternating electricity with an energy loss of 4-12% (REN21, 2010).

Photovoltaic home system commonly known as Solar Home System (SHS) is a method that provides energy services such as lighting, radio, television and operation of small appliances for rural households or for domestic power supply to those that lack access to electricity grids. Various forms of SHS exist and solely depend on the design and application of the systems. These are off-grid SPV (stand alone), grid-supported SPV, and Building Integrated Photovoltaic (BIPV). The World Bank and many government agencies have begun to perceive that SHSs could provide least-cost rural electrification and could supplement grid based electrification system (Martinot *et al*, 2001).

In Nigeria, grid-supported SPV systems have gained wide application in most of the homes and institutional buildings due to erratic power supply from the national grid. It protects specific

equipment or critical loads from power interruptions. The need and importance of this technology is enormous as the energy production from this technology has been increasing by an average of more than 20% each year since 2002. At the end of 2009, the cumulative global SPV installations surpassed 21,000 megawatts. This makes it the world's fastest-growing energy source among the sustainable renewable technologies. (Martinot et al, 2001; Anthel, 2002; NREL, 2003; Chwieduk, 2004; Ren21, 2009; Russel, 2010).

Research works by Bugaje (1999); Iloeje (2004); Akpabio *et al* (2005); Li *et al* (2008); Madugu *et al* (2010); Ogolo (2010); and Okundamiya and Nzeako (2010) among others described many requirements that are essential for the solar system technology and its applications. These requirements include: solar radiation information which is usually a localized meteorological data base, SPV panel and its performance assessments, availability of other components and their accessories. The success of SPV applications and SHSs depends heavily on the quantity and quality of these resource data. Abdulsalam *et al*, (2010) considered the prediction of global solar radiation as a prerequisite for sustainable implementation of SHS in Nigeria, as required throughout the world.

Incoming solar radiation (Insolation) at any location of the earth is a function of time of the year, time of the day and latitude where the amount is received and the mean distance of the earth from the sun. The amount of solar radiation depends upon the type of surface and its controls, amount of radiation reflected by the surface and consequently the amount absorbed. It also depends largely on atmospheric conditions of location and the slope and elevation; so that other things being equal, the solar radiation received at high elevation will be considerably greater than that received nearer sea level (Tiwari, 2002; Akpabio et al, 2004: Rai, 2005).

Depending on the SHS applications; stand alone (off-grid) or grid supported, the design require sizing of several components and accessories based on the available data. The common available values are usually used or applied in the preliminary design of solar energy installation where solar radiation data are scarce. Solar radiation data is therefore considered as an essential requirement for feasibility studies of solar energy systems (Kuye *et al*, 2008; Augustine and Nnabuchi 2010; Victor *et al*, 2010).

To obtain a more precise and complete system design that takes into consideration particular power needs, site location, local weather conditions and specific equipment use, the service of qualified PV designer or installer is required. Therefore, this work seeks to identify the differences that exist between sites and the existence of local conditions that would significantly affect the available solar energy. It will also provide ways of assessing valuable information that would lead to good design and sizing of PV module, battery system, inverter and other accessories for reliable and efficient SHSs applications.

1.2 STATEMENT OF RESEARCH PROBLEM

The first concern in the design of SPV systems is the availability of the Insolation and its duration in a region, at present and some other time in the future. Other factors to be considered include: cost per unit area of a panel, module efficiency and lifetime. SPV power capacity is then measured as maximum power output under Standardized Test Conditions (STC) in watts peak 'wp'. The actual power output at a particular point in time may be less than or greater than this standardized or 'rated' value depending on geographical location, time of the day, weather conditions and other factors. NASEF (2007) postulated that, an orientation and space requirement of the SPV panels also has a great influence on the availability of the solar radiation used for generating the electricity, which perhaps remain among the major constrain in design and sizing of SHSs.

The power output of the solar cells increases with an increase in solar radiation and decreases with an increase in cell temperature. However, to be able to calculate the yield of a solar energy conversion system, it is necessary to know the amount of radiation available at the location of the system and its variation in time. The total energy received on a horizontal surface, is not uniform throughout the world; the respective values depend on the location and on the climate (Kuye et al, 2008; Augustine and Nnabuchi, 2009).

For the developing countries (such as Nigeria) where there is an acute shortage of conventional source of energy, solar radiation data is still very scarce for PV applications. The largest solar radiation and other climatologically databases available in Nigeria reside with the Nigerian Meteorological Agency (NIMET), mostly from airport and airdrome weather stations that were originally set up to aid civil Aircraft navigation. To obtain a good solar radiation database there is the need to create more purpose-built radiation measurement stations all over the country (REMP, 2005).

Several models have been developed using some available data, especially the sunshine hours, for the estimation of the daily solar insolation needed in the design and application of SPV systems. For example, the results from Nigeria, according to Bugaje (1998); Kuye *et al* (2008); Burari *et al*, (2010); and Ogolo (2010) show that the predictive ability of the Angstrom and Angstrom-Page or Angstrom Prescott type model, correlate the global solar radiation to relative sunshine duration in a simple linear regression form. Other investigations also demonstrated the predictive ability of temperature based models where sunshine hour data is not available or used simultaneously for reliability and validation of results. Such models as suggested by Chiemeka (2008); Ogolo (2010); and Augustine and Nnabuchi (2010) were that of Garcia (an Angstrom-Prescott model with slight modification) and Hargreaves & Samani that proposed an empirical

equation expressed in the form of linear regression between the clearness index and the square root of the change in temperatures.

This study stems from the need for knowledge of solar radiation in north-western Nigeria and to fill the gap of the radiation data for places lacking direct radiation measurements for the sustenance of all forms of SPV systems design and operation. This is in response to addressing gaps in key research and development areas as one of the barriers of sustainable solar energy applications in Nigeria outlined by REMP (2005). Perhaps reform will unleash the potentials of diversified and abundant applications of SPV system towards lowering the energy prices and expanding access to remote areas and poor Nigerians.

The need for designing/sizing SHSs based on precise radiation data becomes more imperative due to the fact that, solar electricity is not available at night and is less available in cloudy weather conditions; the system works within the limited power density of their location's insolation apart from their own efficiency figures. A storage or complimentary power system is required for both the off-grid, supported-grid and building integrated photovoltaic home systems application. Therefore, CEC, (2001); Martinot et al, (2001); Tiwari, (2002); Rai, (2005) and UNEP, (2011); opined that design/sizing, installation and performance of SHS depend on the detailed information of basic energy demand (Load estimation), insolation data and component specification and cost. Perhaps, the application in Nigeria is inhibited by the non availability of the design tools or comprehended design tips and procedures or stages.

The available design tools or tips seem confidential to their developers or inaccessible, while the accessible computer based design tools are relatively localized for certain locations such as that of the UK, the US and other similar developed nations (REMP, 2005; FreeSunPower, 2010). DIY Solar Panel Help is one of such available on-line computerized design tools for SHS with

interfaces; system sizing estimator, battery bank design and wire size calculator. However, the solar radiation (sunshine data) were mainly for major locations of US, coded data of utilities and wire sizes (cables) are also localized for the US design code and specifications. Therefore there is need for purpose based design tool or procedure with the basic requirements (FreeSunPower, 2010).

1.3 JUSTIFICATION FOR THE STUDY

It is against the background and problem statement that, this research aims to establish the monthly average energy demand of various household types for reliable electric power supply in North-West region of Nigeria, with a view to developing a sustainable design framework and components sizing kit for Photovoltaic home system. The Photovoltaic home system is a method that provides energy used in buildings to those lacking access to or faced with inadequate supply from national grid networks, and its solar based technology referred to sustainable renewable energy.

With rapid population growth and increase in industrial activities, more energy (usually fossil fuel generated) is consumed resulting in increased environmental pollution and economic difficulties. Therefore the need for utilizing renewable energy resources emerged globally. More than 70 percent of Nigerians do not have access to reliable electricity for their domestic needs; this is in spite of the fact that, Nigeria receives abundant solar energy that can be usefully harnessed, with an annual average daily solar radiation of about 5.2kWh/m^2/day (Chineke et al, 2010; Victor et al 2010). Sambo (2009b) also revealed that, it is possible to generate 1850X10^3 GWh of solar electricity per year if SPV systems were used to cover 1% of Nigeria's land area of 923,773 km^2. This is over one hundred times the current grid electricity consumption level in the country.

Renewable energy is therefore considered a viable solution to the energy challenges of Nigeria. As such the introduction of SPV technology has become imperative because it came to the fore that in Nigeria, for decades, power supply has been complimented by personal generating sets. There is, therefore a massive demand for energy and a need to keep pollution to the barest minimum. Solar energy is therefore a viable power supply system for remote locations in Nigeria (Bugaje, 1999). Adopting SPV technology as an alternative source of energy in Nigeria would reduce significantly the cost of many industrial and engineering services product which will in turn reduce some of the unnecessary expenditures by the end-user/subscribers.

On the whole, the strategy for solar energy policies should include continuous active support of research and development activities to cater for site specificity of design for all parts of Nigeria as studies relevant to the availability of the solar energy resource had fully indicated its viability for practical use (Sambo, 2005). Technology has been the dominant factor for initiating and accelerating human progress and development. All Nations are aware of the vital role of technology in the transformation of their economies and improving the living standards of their people. Special attention must therefore be paid to the acquisition and application of technology in the effort to develop. Indeed, massive importation of foreign and borrowed technology remain the common approach and solution to the problem of technological development.

It is in line with the above background that this study is set out to examine the meteorological data of Nigeria with a view to establishing the available solar radiation that will ensure the implementation of sustainable SHS. The long term benefit can out-weigh the cost constraints as the system will last for long without changing any system component and without payment of any power supply bill. The cost will continue to be high if there is no utilization and patronage, and if the research and development of components are not done locally (Sambo, 2009a).

The availability of more comprehensive solar radiation data is invaluable for the design and evaluation of solar based conversion systems. In many parts of the world, particularly the developing countries, the basic solar radiation data for the surfaces of interest are not readily obtainable. Despite the importance of solar intensity information, most developing and under developed countries are not well equipped with wide spread networks of pyranometers for mapping of solar radiation over large areas. Thus, the cost is very high and data measurement is regarded as the most effective and reliable method of developing solar radiation database (Danny, Tony and Cheung, 2009; Madugu et al, 2010).

The availability of solar resources is not the only factor undermining the potential use of SHS. Three other factors are equally important in determining the uptake. They are; the availability of efficient and low-cost technologies to convert solar energy into electricity, effective energy storage technologies, and high efficiency end-use technologies. This study therefore, intends to come up with ways in which the energy demand and supply problems of residential buildings in Nigeria will be alleviated through solar energy technology. Thereby, a roadmap for achieving a substantial share of the national energy supply mix is optimized, which is one of the key objectives of REMP. The study also addresses certain gaps in research and development towards sustainable implementations of SHS design and application.

The design package will not only help develop and improve the life of people in the rural areas and where there is erratic power supply; it will also help the development of the PV industry in Nigeria by encouraging investors to set up factories and develop local initiatives. Abubakar (1983) opined that, if technological development is to be achieved, a meaningful investment must be made on human resources to ensure the necessary capacity to initiate, generate and sustain such development.

Indigenous research efforts should be encouraged to stimulate the invention of new technologies and it is man rather than the machine that create development. Despite improvements in SPV technologies through local research and development and the increasing acceptance in Nigeria, REMP (2005) also opined that, the body of knowledge on the technologies and their market potentials are considerably inadequate and that launching major national initiatives require a robust knowledge base and capacity. This study hopes to contribute to such needed knowledge base.

1.4 AIM AND OBJECTIVES OF THE RESEARCH

1.4.1 Aim

The study aims to develop a design framework and design kit for Photovoltaic home systems application, with a view to enhancing sustainable application of solar photovoltaic home system as an alternative electric power supply in North-Western Nigeia.

1.4.2 Objectives

The objectives of the study are:

i. To assess the basic energy demands of various household types for domestic purposes.
ii. To study solar radiation potentials of the study area and establish the Insolation level.
iii. To establish Photovoltaic home system design criteria/method for efficient electric power supply.
iv. To develop a design kit for sustainable implementation of Photovoltaic home systems.

1.5 RESEARCH QUESTIONS AND HYPOTHESES

1.5.1 Research Questions

The following questions were raised to further direct the study.

i. Is there significant difference in the amount of solar radiation between locations?
ii. What is the monthly variation of mean daily solar radiation data?

iii. Are there any data on the monthly average energy demand of Nigerian households?

iv. What are the basic requirements and procedures for sizing SHS components?

1.5.2 Research hypotheses

The following hypotheses were designed for ascertaining the quality of data designed to be collected for achieving the aim and objectives of the study.

I. There is no significant difference between the estimated (predicted) average monthly solar radiation value using sunshine hours and ambient temperature based prediction models.

II. There is no significant difference between the monthly variations of average mean daily solar radiation data of each city within the North-Western Nigeria cities under study.

1.6 SCOPE AND LIMITATIONS OF THE STUDY

1.6.1 Scope

The research work covers all the states within the North-Western Nigeria namely Kaduna, Kano, Katsina, Jigawa, Zamfara, Sokoto and Kebbi by selecting three (3) other locations/cities in each of the states. The choice of the study area was based on the high level of insolation, non availability insolation data and lack of awareness of the PV technology. More precisely, north – western Nigeria is per from the power source and there is a maximum power loss during transmission and distribution.

Monthly mean daily global solar radiation on horizontal surface ($KwHm^{-2}$ per day or Jm^{-2}per day), monthly mean daily extraterrestrial radiation on horizontal surface ($KwHm^{-2}$per day or Jm^{-2}per day), sunshine hours (hr/day), monthly mean daily maximum and minimum ambient temperature (^{o}C) are the meteorological parameter used for evaluating solar energy potentials of

the study area. Meanwhile, power rating (kW) duration of use/day (Hrs) and energy consumed by household are the parameter used in assessing household's energy demand.

Solar or short-wave radiation originating from the wavelength range of 0.3 to 3μm, including both the beam and diffuse components are not considered in this work. Utilizability and total utilizable energy is also delimited in the scope of the study. Maintainability study is not covered in this study because several researches confirm that, the SPV system is free from maintenance.

The scope of the proposed SHS design method is limited to the assessment of the insolation level that varies directly from one point (location) to another, grid power supply and sizes of major components of the system. While, other factors ware based on the manufacturers specifications and it does not also concern with the sizing of cables, control system, protection systems, component cost and their installation. Meanwhile, the solar home system design Kit (SHSDK) was developed to cover the aspect of SHS design and sizing of the relevant components such as PV panels or modules, battery charger controller, and inverters.

1.6.2 Limitations

Monthly mean daily global solar radiation ($KwHm^{-2}$ per day) data is not available in Jigawa state because there is no Airport or any airdrome station that are taking the data. Thus, satellite data were used instead of ground data. The same hold in Kebbi state were the sunshine hours (hr) and ambient temperature data are not available. There is no clearness index value in Birnin Kebbi, Yawuri and Zuru due to over estimation of the models used, which may be attributed to the use of satellite measurement instead of the ground measurement which was not available.

The Kit is limited to window operating system only during the development and therefore not compatible to other operating system such as Mac and Linux. It was also designed such that a

complete design process must be completed for a valid output, in case of a mistake or correction the process must be started from the beginning. The Kit is only appropriate for use by a trained person or any other person familiar with sustainable renewable energy technology.

CHAPTER TWO

LITERATURE REVIEW

2.1. CONCEPT OF ENERGY CONSUMPTION IN BUILDINGS

Energy consumption study in buildings deals with the amount of energy that is spent on the different appliances used within a building. Household energy consumption as defined by Ogunniyi *et al*, (2012), is any energy consumed in homes to meet the needs of the householders and may be consumed by a person, activity or an apparatus. UNESCAP (2013) defined it as the energy consumed in homes to meet the needs of the householders themselves excluding any consumption need for enterprise purposes.

The amount of energy used per household varies widely depending on the standard of living of the country, climate, age and type of residence. In the past, Heating, Ventilation, Air conditioning, Lighting and other domestic use of electricity were relatively cheap and designers were able to work without taking energy conservation into account. (Public interest Energy Research: PIER, 2004)

A key issue in any building energy analysis is the choice of the tool or programme used to estimate energy consumption. An hourly simulation is often necessary to fully evaluate the time-dependent energy impacts of advanced systems used in buildings. Thermal mass, solar heat gain and wind-induced air infiltration are examples of time-dependent effects that can only be accurately analyzed using a model that calculates heat transfer and temperature in short time intervals. In addition, an hourly simulation program is necessary to accurately estimate peak energy loads (Danny *et al*, 2009).

The situation has now changed because of increasing price and potential shortage of energy. This means that in the future, designers of buildings will have to give careful consideration, not

only to building regulations which prescribes a minimum standard but also to the other factors in design which will reduce energy consumption (PIER, 2004).

2.1.1 Modes of Household Energy Consumption

Domestic energy needs in Nigeria was described to include cooking, domestic water pumping and distribution, television and radio, powering of computers, water heating and refrigeration (Sambo, 2005). Yaro (2009) therefore, reported an average total of 895.90kWh/month and 9331.10kWh/month for two different buildings with similar consumption pattern. The estimation in both cases is on the basis of utility system power rating, system models or brand and duration of use. Sunusi *et al*, (2010) estimated a total load of typical household to be 57.96kWh/day in a 4-Bedroom bungalow, Abdulsalam *et al,* (2009) also estimated the total load in 2-Bedroom twin bungalow to be 59.06kWh/day and the basic utilities used include television set, radio, DVD, satellite receiver, fan, lighting, electric kettle and stove, and GSM chargers.

The U.S. household electricity unit classifies the energy consumption pattern into three types namely; HVAC and water heating, kitchen and laundry appliances, and lighting and home electronics. These modes of consumptions are described thus:

a. Plug loads: The term "plug load" is commonly used to describe the energy used by a product that is powered by means of an ordinary AC plug (e.g. 100, 115, or 230 V), this generally excludes building energy that is attributed to major end uses such as lighting and water heating. Plug loads are often synonymous with terms such as "receptacle loads", or "process energy/loads" (PIER, 2004; Oforeh, 2008). One confounding factor with estimating plug load energy use is the discrepancy between the rated or nameplate energy power consumption and actual average power consumption, which can be as little as 10- 15% of the nameplate value.

b. Lighting and Fan: Illumination is the deliberate application of light to achieve some practical or aesthetic effect. Lighting includes the use of artificial light sources such as lamps, fluorescent

tubes and light fixtures. Fan is solely for ventilation purposes and is commonly used in conjunctions with lightings in buildings.

c. Air conditioning: Building uses air conditioning in the tropic basically for the purpose of sensible cooling process. It is usually a high voltage appliance plug that is 15amps and above socket outlet, and most often a single circuit in the building wiring system (Althouse *et al*, 1988). According to Abdulsalam (2007), an average of 1kW energy consumption is usually associated with the AC system operation against adequate compliance to working characteristics and loss of cooled and through building fabrics. Consequently, turning off the power switch will have more saving than turning the system off with remote control that continue to consume about 2.5 w of electricity.

d. Water heater: Domestic uses of hot water are for cooking, cleaning, bathing, and space heating. Domestically, water is traditionally heated in vessels known as water heaters, kettles, cauldrons, pots or coppers. It is a thermodynamic process using an energy source to heat water above its initial temperature and appliances for providing a more-or-less constant supply of hot water are previously known as water heaters or boilers (Akintate and Hyde, 1983). Energy efficiencies of water heaters in residential use can vary greatly particularly based on manufacturer and model, and are solely independent circuit like the air conditioning system.

e. High Voltage: In electric power transmission engineering, high voltage is usually considered any voltage exceeding 35,000Volts and it is based on the design of the apparatus. The International Electro-technical Commission and its national counterparts define high voltage circuits as those with more than 1000Volts for alternating current and at least 1500Volts for direct current, and distinguishes low voltage and extra-low voltage with the 50- 1000Vvolts AC or 120- 1500Volts DC and <50V AC or <120V DC respectively (PIER, 2004).

It is therefore, imperative to that user behavior is a factor in overall increase in energy use and according to PIER (2004) most plug load products have 'off' and 'on' states, the sleep or low power states that represent a wide range of power saving, from 55% in desktop computers to 94% in CRT monitors. Without proper design, energy can be wasted by using too much light, or using out-dated technology (PIER, 2004). According to Energy Information Agency (EIA) United State household monthly average energy consumption is 920 kWh with a monthly bill of $95.66 (Anonymous, 2013a). Thus, Anonymous (2013b), postulate that even in the industrialized countries, an average European household consumes 4667 kWh, whereas a household in the US consumes 11209 kWh and in Japan 5945 kWh per year.

A US household uses three times a lot of electricity for lighting and twice as a lot in refrigerators than in the EU on the account of seasonal variations. Therefore, there is need for measuring and evaluating the energy demand and perhaps the total consumption of various household types in the residential context. Based on these, this study was designed to respond to the need of establishing the monthly total energy consumption of various types of households in Nigeria as well as the average cost per month.

2.1.2 Household Energy Demand

Household consumption is solely concerned with the demand side management (DSM) and it is a more effective tool for curtailing the demand from utility company(s) where supply infrastructures are not readily available or insufficient. The amount of energy used per household varies widely depending on the standard of living of the country, climate and the age or type of residence (Govender *et al*, 2007).

Household sector is responsible for about 15 to 25 per cent of primary energy use in developed countries and for a higher share in many developing countries. Average per capita household

energy use in developed countries is about nine times higher than in developing countries, even though in developing countries a large share of household energy is provided by non-commercial fuels that are often not reflected in official statistics. The per capita energy consumed in Nigeria in 2002, 2004, 2006 and 2007 is 0.153, 0.125, 0.089, and 0.079pce respectively. When the values are compared with the World and African average of 1.78pce and 0.68pce respectively a great margin that requires an urgent attention was observed (Oleg and Ralph, 1999).

Households require energy primarily for cooking, lighting and space conditioning. In Africa, cooking often accounts for between 90 and 100% of household energy consumption because of limited space conditioning loads. Household energy consumption levels and the types of energy used depend on the variety of factors, which include the availability and costs of energy sources (Field, 1992; Karekezi and Kithyoma, 2003). As the income increases, the use of modern energy becomes more prevalent in rural households. For instance, while low-income rural households rely mainly on biomass fuels for cooking, high-income households use modern fuels such as kerosene, LPG and electricity. Among the poor, biomass resources are used in unsustainable and inefficient ways due to lack of access to information, financial resources and technology (Kaneff, 1991; Karekezi and Kithyoma, 2002).

Energy data bank profile is another essential tool that is designed to purposely document and maintain an ongoing robust, credible and up-to-date statistical data of energy consumption. It consolidates macroeconomic, microeconomic, social sector and human development indicator in a coherent and cumulative manner. The Data bank profile in Nigeria according to Sambo (2009) indicates that the fraction of households with A/C is 10.71% and those with water heaters 7.14%. Table 2.1 presents the household activities and the percentage of the energy type consumed.

TABLE 2.1: Households Activities and Percentage of Energy Type Consumed

Household Activity	Percentage of Energy Type (%)				
	LPG	**Kerosene**	**Coal**	**Fuel wood**	**Electricity**
Cooking	12.58	76.79	1.79	67.86	7.14
Water heating	8.93	67.86	0	66.86	25.00
Lighting	0	87.50	0	0	42.86

Source: Sambo (2009)

Sambo (2009) shows that, household sector is responsible for about 15 to 25 per cent of primary energy use and average per capita household energy use in developed countries is about nine times higher than in developing countries. Though in developing countries, a large share of household energy is provided by non-commercial fuels that are often not reflected in official statistics. According to United Nation Statistics Division, disparities in household energy use exist between rural and urban populations, between high and low income groups within the country, and among countries. The major factors contributing to these differences are levels of urbanization, economic development, and living standards. Other factors are country or region specific, such as climate or cultural practices.

General determinants of electricity demand is widely accepted to be based on two factors; the household's income and electricity prices (tariffs) and other factors that include efficiency improvement, structural changes and household's lifestyles. They are also important factors when estimating energy demand functions in order to avoid producing biased estimates (Udo *et, al,* 2011). However, several studies considered price of electricity, population, price of substitute and real income as determinant of the residential demand of electricity with respect to Nigeria (Babatunde and Shuaibu, 2009; Oluremi and Able, 2011).

In developed countries, two opposing trends have determined household energy consumption since the 1970's. One is the increase in energy-based living standards due to increases in household incomes. This trend by itself led to growth in household energy consumption ranging from about 30 to 70 per cent in different countries. The opposing trend had several components.

Most important was more efficient energy use and a slight lowering of indoor temperatures. In the U. S. and U. K., where there are substantial natural gas resources, real prices in the 1990s are close to or below those in the early 1970s.

A. Supply Side Management (SSM): The energy use in buildings particularly electricity is usually managed based on supply side management (SSM) and demand side management (DSM). The DSM is essentially considered a more effective tool for curtailing the demand when supply availability is less as it involves all aspect of energy-use management within the buildings. Thus, DSM has some indices for measuring building energy-use such as total final energy demand, commercial and non-commercial energy demand, factors changed in energy demand by energy form etc. consequently, energy study and managements with the demand side is achieve through the use of energy management techniques such as energy matrix, monitoring and targeting, energy load and consumption study, contract energy management etc (Abdulsalam, *et al*, 2009). Consequently, for the purpose of this study SSM is the intent for measuring how effective is the supply based on the residential demand.

SSM program/issues involve the management of all supply system from the point of generating the energy to the point of use. It includes system of generating plants, transmission and distribution networks. The short term, SSM is ineffective since it takes a long time for plants to start up and meet the immediate demand for electricity. The following are the various government institutions/commissions and company responsible for the distribution, transmission and regulation of electrical energy in Nigeria.

i. Nigerian Electricity Regulatory Council (NERC): Nigerian Electricity Regulatory Council (NERC) is an independent regulatory body saddled with the regulation of the electric power industry in Nigeria. The commission's power and duties are solely provided for in the EPSR Act

2005, and effectively ushered the privatization of electric power services in Nigeria unbundling of the defunct National Electricity Power Authority (NEPA) to Power Holding Company of Nigeria (PHCN). NERC was instituted primarily to regulate the tariff of power generating companies owned or controlled by the government, and any other generating company licensed for power generation and transmission in Nigeria (NERC, 2007; Aderibigbe, 2012). NERC's primary duty is to protect the interest of consumers, issue licenses to operators/investors, set and review electricity tariffs and where possible promote competition. However, since the generation capacity is even low and transmission not robust, NERC has aggressively developed regulations to push for the primary production of supply, electric reliability and implementation of new regulations keeping in sight when the sector fully develops (NERC, 2007).

ii. Power Holding Company of Nigeria: The law which established the power Holding Company of Nigeria formally National Electric Power Authority (NEPA) in 1972 stipulated that it should develop and maintain an efficient co-ordinate and economical system of electricity supply for all parts of Nigeria (Aderibigbe, 2012). A critical analysis of the operations of NEPA indicates that a monopolistic NEPA has been literally biting more than it can chew. The fourth National Development Plan (1981-1985) exposed the very rapid increase in power demand at over 20% per annum. That makes it difficult for the installed capacity to cope with the requirement of the present economy. The result is load shedding which generally disrupt domestic life as well as the manufacturing activities (Aderibigbe, 2012; Adamu *et al*, 2012).

iii. Energy Commission of Nigeria: The Energy Commission of Nigeria was established by the Energy Commission Act No. 62 of 1979, as amended by Act No. 32 of 1988 and Act No. 19 of 1989. Under the law, the Commission is charged with the responsibility for the strategic planning and co-ordination of national policies in the field of energy in all its ramifications. The law empowers the Commission to carry out the following functions, Serve as a centre for

gathering and dissemination of information relating to national policy in the field of energy development; Lay down guidelines on the utilization of energy types for specific purposes and in a prescribed sequence; Collate, analyse and publish information relating to the field of energy from all sources, where such information is relevant to the discharge of its function under the Act; Monitor the performance of the energy sector in the execution of government policies on energy (NERC, 2007; Sambo, 2009a).

2.1.3 Sources of Electric Energy in Nigeria

There are basically three sources of electric energy commonly used in Nigeria, which are hydro-electric power generation, thermal power generation and the power generated independently for instant use such as fossil fuel generators and PV power generated as solar based energy.

i. Hydro-electric Power Generation; In hydro electric stations, water is trapped at heights by dam walls, creating artificial lakes and the pressure head created is used to drive turbines, which rotate the soft iron core in a magnetic field. The main hydro-electric power stations in Nigeria are at Jebba, Kaiji and Shiroro.

ii. Thermal Power Generation; in thermal power stations, purified water (free from debris and minerals) is heated in boilers to produce steam at high temperature and pressure, which is used to spin turbines connected to the electricity generator. The common fuels used are coal, oil and gas. The thermal power stations at Ugheli, Sapele and Afam in the Delta areas and at Egbin near Lagos, use natural gas as fuel, but the older station at Oji River uses coal.

iii. Independent generation; these are usually generated as either renewable or nonrenewable energy sources and are used to produce secondary energy sources including electricity and hydrogen for residential household use and other uses. Most of the energy are from nonrenewable sources, source that we are using up and cannot recreate in a short period of time

and which include the fossil fuels oil, natural gas, and coal. Thus, renewable energy are generated from natural resources such as sunlight, wind, rain, tides, and geothermal heat which are renewable or naturally replenished (PIER, 2004).

In 2006, about 18% of global final energy consumption came from renewable, with 13% coming from traditional biomass, such as wood-burning. Hydroelectricity was the next largest renewable source, providing 3% of global energy consumption and 15% of global electricity generation. Wind power growing at the rate of 30 percent annually, with a worldwide installed capacity of 121,000 megawatts (MW) in 2008, and is widely used in European countries and the United States (Chwiduk, 2004; Ileoje, 2004).

While most renewable energy projects and production is large-scale, renewable technologies are also suited to small off-grid applications, sometimes in rural and remote areas, where energy is often crucial in human development. Kenya has the world's highest household solar ownership rate, despite being criticized of being intermittent or unsightly, yet the renewable-energy market continues to grow. Climate-change concerns, coupled with high oil prices, peak oil, and increasing government support, are driving increasing renewable-energy legislation, incentives and commercialization (Kaneff, 1991).

Solar energy has numerous applications when it is converted to heat, electricity or biomass and the technologies for conversion of solar energy into heat and electricity can be classified into solar thermal systems and photovoltaic (PV) or solar electricity respectively (Chwieduk, 2004). Solar thermal devices are for conversion of solar radiation into heat using solar energy collectors. The heat produced could be employed in the solar water heaters, solar cookers, solar dryers, solar stalls, solar pasteurizers and solar chicken brooder devices (Ilenikhena and Mordi 2005; Ilenikhena *et al,* 2008).

Solar electricity mostly from the PV systems are from conversion of insolation into current via photons and are commonly used for street lighting in Nigeria sponsored by government agencies such as Energy Commission of Nigeria (ECN). The systems are also being employed to provide electricity services to rural communities but are not connected to the country's electricity grid. One of the earliest solar photovoltaic (PV) project in Nigeria is 7kWp village PV lighting in Tunga-Buru and Gotomo villages that was financed by Sokoto state government in 1985 (Animalu and Adekola, 2002).

Solar Generating Panels (photovoltaic cells) consist of thin wafers of silicon which are chemically treated to divide them into two layers which acquire different electric potentials. As sunlight falls on the cells, an electric charge is generated and transferred to an external circuit. The current generated is DC (direct current) but can be converted to AC (alternating current) using inverter.

2.1.4 National Grid Network

Electricity generated within Nigeria are in various ways at different power stations in various parts of the country and fed in to a common pool called the national grid networks, before distribution throughout the country and beyond. The grid is a system of overhead lines interconnecting all the main power generating stations. It ensures continuity network of adequate power supply, when one or more power stations have to be shut down for maintenance or repairs. Perhaps, Power Holding Company of Nigeria (PHCN) is responsible for upkeep and maintenance of the whole infrastructures; transmission, distribution and the control of supply voltage.

A. Transmission and Distribution of Electricity: Supply of electricity in to most big cities and town are via the 132 or 330KV lines. A lot of cities with high level of commercial and industrial

activities such as Lagos, Kano, Aba, Ibadan, Porthacort, Kaduna and Abuja have several of such lines from the National Grid (Oforeh, 2008). The household and industrial appliances in Nigeria, consume power on the basis of 240 Volts (S.P.N) or 415 Volts (T.P.N) and the purpose of city network and distribution installation is to bring the high voltage down to these consumer levels. The 330 or 132KV supply is usually stepped down in a main power station at convenient locations within or on the outskirt of the town.

A sub-station is required for the conversion, transformation and control of electrical power. It is used where large buildings or complexes of building require greater power than the standard low or medium potential of 230 and 400 volts. (Hall, 2006).The 33KV lines main (first step down) are run through the street on overhead cables or underground, to various main (second step down) substation, where they are further stepped down to 11KV. The main substation power at 11KV is further transmitted to numerous smaller substations (third step down), at street corners, or to private consumer sub stations where 11KV/415V transformers are installed. It is from the small sub stations at street corners, that public consumers are supplied with electricity at 415 Volts from cables run overhead on precast pre-stressed concrete poles or treated timber poles, in an upright or vertical 4-wire arrangement.

B. Supply Voltages in Nigeria: Nearly all transmissions supplies are 3-phase, at the local authority substation and in the large consumers' premises; a fourth conductor is connected to the supply system to provide a 3-phase 4-wire supply. This conductor is known as the neutral and hence the supply is sometimes referred to as triple-pole-neutral (T.P.N) supply (Akintante & Hyde, 1983). The idea of this neutral conductor is to provide the consumer with a single-phase supply at a lower and safer voltage for lighting and the smaller current-rated appliances. This neutral conductor is also connected at the transformer position to the general mass of earth to provide protection against earth leakage current. The voltage between any one live conductor

and the neutral is 240V, which is referred to as the phase voltage. The supply conductors are identified by colours RED, YELLOW and BLUE (phases) BLACK (neutral).

2.1.5 Challenges and Constraints of Power Transmission and Distribution in Nigeria

Erratic and unstable power supply is common in Nigeria and it's attributed to energy supply and distribution inadequacies; inappropriate energy pricing policies; inconsistent planning system and inadequate manpower training among others (World Bank, 1993). It's evident as the amount of electrical energy supplied by the supply side management is not proportional to the charges and bills incurred on by the demand side management. Consequently, rationing system of energy supply is adopted in the supply of power to residences and a serious disadvantage on the side of flat rate consumers.

Adamu *et, al,* (2012) showed that, the generating units at Kainji hydro power station have not been adequately maintained, which led to frequent and delayed force outage rates indicating unreliable performance of individual units. The Federal Government of Nigeria through the federal ministry of power embarked on a project to build two new hydroelectric power stations in Mambila Taraba state and Zungeru Niger state in order to boost the capacity of power generation with 3,750 MW (Anonymous, 2012c). The projects are a testimony to the inadequate power generation, transmission and distribution to Nigerians and therefore the need for other alternative source remain more imperatives for the sustainable developments of household.

In view of the fact that there are also multiple failures of power supply, basic household needs and businesses that rely on electricity become less efficient and lose profits. Thus, abundance of sunlight makes SPV system a solution to solve some of the problems of energy demand and supply in Nigeria (Abah and Ochagwuba, 2001; Sambo, 2009a). The rapid economic growth of

any country requires the injection of large amounts of energy and since energy cannot be created, it is necessary for every country to diversify its sources of energy.

The Rural Electricity Boards established in the 1980s have almost all been grounded due to problems of maintenance, spare parts and the scarcity of the fuel required powering the generators. It is imperative to recognize that, less than a third of Nigerian has access to electricity many parts of remote and rural areas of Nigeria are yet to be connected to the national grid (Bugaje, 1999). Consequently, sustainable human communities need not to be invented, it can be learned from societies that have lived sustainably for decades or centuries, Sambo (2009a), advocated strategize policy for continuous active support of research and development activities, support demonstration and pilot projects to ensure that the general public becomes aware of the potential of the technology.

In summary, the current installed capacity of grid electricity is about 6000MW, of which about 67% is thermal and the balance is hydro- based. Meanwhile the current generating capacities of 2000MW-400MW, lack of proper maintenance, ageing and overloading of transmission and distribution facilities are some of the causes of poor performances of PHCN in power supply. In addition, locations of most load centers from the grid, which in most cases is too far away and therefore incurring high losses to the system is not an exceptions (Power Sector Reform Act: PSRA,2005; Boyi, 2013).

Consequently, long hours of load shedding, environmental degradations due to excessive use of diesel and gasoline plants and the optimal incorporation of solar energy resources into Nigeria energy mix was considered as a means of mitigating electric power distribution level. However, Boyi (2013), outline that government consider the adoption of Electric Power Sector Reform Act

2005 which gave birth to Nigerian Electric Regulatory Commission, NERC and Rural Electrification Agency, REA as a measures taken to solve power supply problems in Nigeria.

Thus, access to electricity services is low. About 60% of the population-over 80 million people are not served with electricity. Per capita consumption of electricity is approximately 100kWh against 450kWh, 1934kWh and 1379kWh in South Africa, Brazil and China respectively. Under a business-as-usual scenario, the proportion of Nigerians without access to electricity services will continue to increase over time (REPG, 2006).

The relevance of the power sector in the overall development and sustenance of the economy of any nation cannot be overemphasized. Statistics now show that power generation now stands at 3000-4000MW but supply remained generally very erratic and unsatisfactory following faults and deficiencies caused by drop in power generation and transmission network (NIALS, 2013). The Nigerian Institute of Advanced Legal Studies is mindful of the prevailing issues and challenges in the power sector and in pursuit of her statutory mandate organized one-day roundtable discussion. Amongst the 121 issues observed, this study has more interest on the following.

I. There was Poor maintenance of power generation, transmission and distribution facilities, and at the distribution end, power distribution network has not been expanded to all parts of the country, with a good part of the rural areas being without electricity.

II. Only about 40% of the country's population (of about 160 million) has access to electricity, with a total consumer figure of about 4.5 million. While, at the distribution end, power distribution network has not been expanded to all parts of the country, with a good part of the rural areas being without electricity.

III. While most countries aim to produce power (MW) in excess of exact requirement to guarantee availability, Nigeria hardly produced up to 25% of its power (MW) need. Consequently, various estimates show that Nigeria needs about 20,000-40,000 MW over the next decade.

IV. In 2012, power generation stood at 3000-4000mw but supply remained generally very erratic and unsatisfactory following faults and deficiencies caused by drop in power generation and transmission network. Hence, current levels of consumption is less than 150kWh per person per year; one of the lowest in the world.

However, Aderibigbe (2012) postulate that, the current challenge of power sector goes to the fact that university and polytechnic curriculum does not reflect the need of industry or the market despite enormous investment by government and academic staff have not focused research activities on the sector. Consequently, atmospheric resources offer important opportunities for sustainable development and improving human well-being, it is therefore recognized that, Nigeria has energy resource from solar radiation as given in the Renewable Energy Master plan (REMP) Table 2.2.

Table 2.2: Solar Radiation

Reserves (Natural Units)	Production Level (Natural Units)	Utilization (Natural Units)
3.5 – 7.0 KWh/m^2/day (485.1 million MWh/day using 0.1% Nigeria land area)	Excess of 240 KWp of solar PV or 0.01 million MWh/day	Excess of 0.01 million MWph/day of solar PV

Source: REMP, (2005)

It is therefore, pointing to the need for an urgent review of energy policies in Nigeria, and the technologies for solar energy applications are yet to be fully accepted as household commodities. Once this is done, applications of solar energy will augment fossil fuel energy resources to ensure availability of energy to meet the increasing demand in socio-economic activities and

improved standard of livelihood of the people (Ilenikhena and Ezemonye, 2010; Ogunniyi, 2012).

It is also imperative to recognize the fact that based on the Renewable Electricity Policy Guidelines (REPG) of December 2006 from the Federal Ministry of Power and Steel of Nigeria, PHCN has been unbundled into various electric power systems levels as companies or co-operations such as generation companies (GENCOs), transmission companies (TRANSCOs) and distribution companies (DISCOSs). There are also many independent power producers (IPP) who are establishing to generate power to supplement national grid.

Part of the benefit of supplementing power supply according to Boyi (2013) include, injecting power at the distribution voltage levels (33KV, 11KV and 415KV), it effectively reduce the transmission losses and cover for the periods of scheduled and unscheduled maintenance. It also reduces the negative aspects of the use of generating sets and provides affordable, reliable and qualitative electricity to consumers. Incorporation of small and large solar PV and its accessories at the consumer's end and DISCO's supply main are also part of the benefits.

2.1.6 Sustainable Renewable Energy Technologies (SRETs)

Solar energy has been known for thousands of years and presents an inexhaustible source of energy. The energy from the sun gets to the earth's surface by radiation. Out of about 173×10^{12} KW/Hr that reaches the earth's atmosphere only a small fraction of about 2 percent is available for harnessing by earth-based collectors (Fapetu, 1999). The difference is reflected or absorbed by clouds. Solar radiation being abundantly present in Nigeria is one area of focus among the renewable energy resources.

Nigeria receives an average solar radiation of about 7.0kWh/m^2-day (25.2MJ/m^2-day) in the far north and about 3.5kWh/m^2-day (12.6MJ/m^2-day) in the coastal latitudes (Ileoje, 1997 In Ilenikhena and Ezemonye, 2010). It was estimated that Nigeria has a solar radiation of 3.5 to 7.0 kWh/M^2/day across the country with 3.5kWh/M^2/day at the coastal area and about and 7.0kWh/M^2/day at the extreme northern part of Nigeria. This amount to about 5.53 kWh/M^2/day (ECN –UNDP, 2005) average global solar radiations unutilized. This Average amount represents a huge prospect for solar energy generation if a total capacity can be developed for solar PV generation (Oado *et al*, 2012).

Majority of the people in Nigeria live in rural communities where there are difficult terrains, no good roads, electricity grids and no easy access to fossil fuel energy resources. Effective harnessing of solar radiation using solar energy technologies to augment energy supply from fossil fuel energy resources (using cleaner fossil fuel technologies) would enhance availability of energy for socio-economic activities and to improve the standard of livelihood of the people.

Most of the photovoltaic (PV) systems that are currently in use such as PV modules for street lighting are government sponsored projects. Some are pilot projects sponsored by government agency such as Energy Commission of Nigeria (ECN). The photovoltaic (PV) systems are also being employed to provide electricity service to rural communities that are not connected to the country's electricity grid (Ilenikhena and Ezemonye, 2010).

Fapetu, (2006) reported that a unit of photovoltaic cells usually provide a light within an attractive working or living spaces of 170m^2 at a cost of $80 per square meter and produced 15KW of power to fuel its lighting, ventilation, cookers and computers from the effort. It has been estimated that in a year, each kW of solar power saves on tone of carbon dioxide emission. The most successful SETs would not be driven by their environmentally sound benefits alone,

because they also meet other human needs and have lower energy cost in return and lower or no green house gas (GHG) emissions.

The most successful SETs programs focus on new products and techniques that have multiples benefit. It needs no gasoline or diesel and frequent servicing unlike generators, emit no poisonous fumes, always available ready to deliver electricity and completely silent and safe. Solar energy applications are not popular in local building developments and the barriers are due to the high initial costs, the large installation spaces required, low output power and lack of reliable data for design and sizing of the systems within a particular location. The technical data given by manufacturers are under standard test conditions which may never occur in practice.

Measured data are important in giving realistic and accurate information on the performance of PV system under actual operating environments (Danny et al, 2009). Solar energy generation is the fastest growing source of energy, seeing an annual average growth of 35% over the past two years. However, barriers to further solar generation remain the high price of making solar cells (SPV panels) and reliance on weather patterns to generate electricity (Kaneff, 1991; RISE, 2010).

To achieve power reliability, uninterruptible power supply (UPS) system are designed and incorporated into building energy systems to protect specific equipment or critical loads from power interruptions. Nontraditional benefits consist of local reliability enhancement, real and reactive energy loss savings and power plant dispatch savings (NREL, 2003). Development of sustainable solar energy technology and research program must always start with a study of solar radiation data at a site of the region of interest.

Long-term measurements of solar radiation of a horizontal surface, however, exist for only relatively few metrological stations. For places where it is not directly measured, solar radiation are usually estimated using models and empirical correlations (Malik and Roslan, 1996; Rai, 2005; Ogolo, 2010; Madugu, 2010). Typical solar panels have an average efficiency of 12%, with the best commercially available panels at 20%. Thus, a PV installation in the southern latitudes of Europe or the United States may expect to produce I kWh/m^2/day. A typical "150 watt" solar panel is about a square meter in size. Such a panel may be expected to produce I kWh every day, on average, after taking into account the weather and the latitude.

In the Sahara desert, with less cloud cover and a better solar angle, one can obtain closer to 8.3 kWh/m^2/day energy. The unpopulated area of the Sahara desert is over 9 million km^2, which if covered with solar panels would provide 630 terawatts total power. The Earth's current energy consumption rate is around 13.5 TW at any given moment including oil, gas, coal, nuclear and hydroelectric (NREL, 2003; RISE, 2010). Most projects in developed and some developing countries established SPV component and systems standard to ensure quality, safety and long term reliability. Standards allow smaller systems down to 20wp better suited to consumer demand in Indonesia and Sri Lanka (Martinot, 2001). Sambo (2009b) reported that, Sokoto Energy Research Centre (SERC) and National Centre for Energy Research and Development (NCERD) under the supervisions of the Energy Commission of Nigeria (ECN) provides details of the technologies that were developed at the centre and which were ready for adoption into the economy. These ensure implementations of sustainable SPV applications.

Therefore, when considering solar energy as a prospective energy source with its intermittent characteristics the development of energy storage systems is as important as the development of solar energy capture systems. Examples of SPV systems in Nigeria are in home system, water pumping system, street light system, vaccine refrigerators, telecommunication repeater station

and power plant that are providing electricity to entire villages or for a grid system (SBTM, 1996; Sambo, 2005).

Conclusively, from the available data obtained by the research there is no adequate electric power supply from the national grid to most Nigerians and most industries cannot cope with their power demand except by relying heavily on private generating units. This call for immediate response to implementation of Power Sector Reforms is timely as without viable supply of electricity industrial development cannot gear the economy. The REPG: Renewable Electricity Policy Guidelines (2006), outlined technology, policy and regulatory barriers, financing and investment barriers, public awareness, and inadequate resource assessment with intermittency of resource availability are among many challenges confronting the development of the market.

The renewable grid-connected operations diversify the sources of electricity, strengthening energy security, expanding electricity access and enhances sustainable environment. While, renewable off-grid operation will provide Federal Government's policy on the electric power sector and expand access to rural areas in particular, and are some of the designed responses to the challenges within the scope of this study. It is therefore, enough to consider that available power supply from national grid for domestic purposes is incapacitated, and there is need for assessing the basic energy demands of various household types for suggesting alternative sources.

2.1.7 Types of Households in Nigeria

People who live together in a single home are generally referred to as household, and according to the National Population Commission (NPC, 2006) it consists of a persons or group of persons living together usually under the same roof or in the same building/compound, who share the

same source of food and recognize themselves as a social unit with a head of household (NPC, 2006). Household size varies considerably and is defined by the number of persons, culture, and location and generally based on demography.

However, for the purpose of this study regular household is adopted as defined by NPC (2006) to consist of a person or group of persons living together usually under the same roof or in the same building/compound, who share the same source of food and recognize themselves as a social unit with a head of household. The number of persons ranges from one to 25 persons and above. Consequently, this study considered six (6) distinct types of household in Nigeria as defined by Anonymous, (2012a) and Anonymous, (2012b) depending on the size and the relationship of the occupants as they have unique characteristic for both the northern and southern Nigeria.

The description of the household types is as following.

i. Single Member Household: Generally the easiest type and only one person reside in the home and he is therefore referred as household.

ii. Nuclear Household: This is a traditional family household that includes a man or couple and their assorted family members and or parents. It is also called 21st Century nuclear, blended, single parent household.

iii. Extended or Joint Household: It is a complex or joint family where multiple families usually somehow related or employed in some capacity with one or several 'heads' of household's reside.

iv. Shared Household: A shared household is where platonic roommates or housemates share a home or apartment. It is usually have similar age dweller and make a definitive choice to reside together in shared living usually with separate sleeping space.

v. Provider Managed Household: An individual, corporation or landlord household's type that lets out a room and provides 1-3 meals daily. This may be the case in a boarding schools and hospital wards or similar situations.

vi. Collective Living Household: A collective or groups of people live in a dormitory-based community such as religious order or educational institution. They are generally able to function or work relatively well on their own.

2.1.8 Concept of Energy Audit and Survey

Energy that is spent on the different appliances used within housing is referred to as domestic energy consumption, and it needs to be known in order to come with the demand. Thus, energy audit is an essential activity for any organization wishing to control energy and utility cost. It provides a structural review of how energy is purchased, managed and used with the aim of identifying opportunities for cost savings (Abdulsalam *et al,* 2009). According to Wah, (2001), energy audit in a building is a feasibility study that identify energy use among the various services and opportunities for energy conservation, it also produce the data on which demand and supply are measured, managed and evaluated. Though, Blumberga *et al,* (2005) postulate that, energy audit can be done in more or less detailed way depending on the object that get audited and on the aims of the audit that may include reducing the energy consumption volume or finding an alternative source (s). It also makes a valuable contribution in to the development of political and legislative documentation.

An energy audit establishes the quantity and cost of each form of energy input to a building site or organization over a given period. It usually includes evaluation of end use and would include any on-site generation. An audit will also include a breakdown of energy sources by type and unit costs with contract or tariff arrangements in place. There are three main types of audit, depending on the complexity. This includes:

i. A simple preliminary audit: performed with little or no specialist knowledge. It deal primarily with energy invoices and is essentially a desktop evaluation without a site investigation.

ii. An improved audit: it is often possible where records of meters and sub-meters are available. Some engineering knowledge is useful for checking the reliability of site data.

iii. A full audit requires expertise to break down energy use on a service-by-service basis. This process normally involves measurement, analysis or direct assessment of energy consumption to indicate the proportions attributable to heating, lighting, air-conditioning or other major users. Thus, such information can usually be obtained only by performing a site survey.

An energy audit may range from a simple walk-through survey at one extreme to one that may span several phases. These phases include a simple walk-through survey, monitoring of energy use and model analysis using computer simulation of building operation. The complexity of the audit is therefore directly related to the stages or degree of sophistication of the energy systems, management program and the cost of the audit exercise.

i. Walk-through survey of a building may reveal several energy conservation opportunities (ECOs) to the experienced auditor. The survey could be divided into three parts namely; preliminary surveys (prior to the walk-through survey), walk through process that study the equipment/systems that consumed energy, and the last approach that utilizes types and condition of the windows, typical lighting, power requirements, occupancy and operating schedules.

ii. Measurement using in- place instrumentation and temporary monitoring equipment. It refers to existing utility metering, air-conditioning control instrumentation and energy management systems (EMS). Existing instrumentation such as utility meter readings, and energy billings

could be used to establish energy consumption patterns for the building. Utility data could be used to establish useful indices such as kWh/m^2/year to compare relative energy performance of a building.

iii. Model Analysis provides building energy consumption in simplest terms. It is just the product of rate of consumption of a system and the period of operation. In lighting systems energy consumption could be determined manually with precision as it does not interact with other consumption variables.

Henceforth, for the purpose of this study, the first and the third energy audit process were used, thereby the last aspect of the first method is exclusive of this study.

2.2 BASIC ASPECTS OF INCOMING SOLAR RADIATION (INSOLATION)

Development of sustainable solar energy technology and research program must always start with a study of solar radiation data at a site of the region of interest. Long-term measurements of solar radiation of a horizontal surface however, exist for only relatively few metrological stations. For places where it is not directly measured, solar radiation are usually estimated using models and empirical correlations (Malik, 1996; Rai, 2005; Madugu, 2010).

Measured data are important to give realistic and accurate information on the performance of SPV system under actual operating environments (Danny et al, 2009). Thus, geographical location, climate and local conditions are the most important factors that determine the possibilities of applying solar energy and other SPV methods of energy conversion. Domestic certification and testing are also important for the assessment and application of SPV systems toward realizing its potentials. (Gulma and Bajpai, 1983; Martinot et al, 2001; Chwieduk, 2004; Akpabio et al, 2005; RISE, 2010).

It is imperative to note that, solar radiation data and the relevant meteorological variables are crucial to solar engineers and architects in order to predict accurately the available solar energy resource. Solar radiation data is necessary for determining cooling load for buildings, prediction of local air temperature and for estimating power that can be generated from SPV cells, solar radiation data is always important for the design of any solar energy conversion device energy.

The sun's structure and characteristics determine the nature of the energy it radiates in space. Its intensity and spectral distribution are the primary concern in assuming the energy source for harvesting electricity through photovoltaic panels. The amount to harvest depends solely on the intensity of the point, equator or polar region and the sun duration per day and per month respectively. John and William (2006) remarked that, an understanding of the solar geometry; position of the sun in the sky and the direction in which the beam radiation is incident on the surfaces of various orientation and shading are essential data required for solar energy application. In addition to the total energy in the solar spectrum (i.e., solar constant = 1367 W/m^2) it is useful to know the special distribution of the extraterrestrial radiation, that is, the radiation that would be received in the absence of the atmosphere.

2.2.1 Basic Concepts of Global Solar Radiation

Solar radiation while passing through the earth's atmosphere is subject to the mechanisms of atmospheric absorption and scattering. A fraction of the radiation reaching the surface is reflected back into the atmosphere and is subjected to this atmospheric phenomenon again; the remainder is absorbed by the earth surface. The atmosphere absorption is due to ozone (O_3), oxygen (O_2), nitrogen (N_2) carbon dioxide (CO2), carbon monoxide (CO) and water vapor (H_2O) and the scattering is due to air molecules, dust and droplets. The x-rays and extreme ultra-violet radiation of the sun are absorbed highly in the ionosphere by nitrogen, oxygen and other atmospheric gases. Ozone and water vapors largely absorb ultraviolet ($\lambda < 0.40\mu m$) and infrared

($\lambda < 0.40\mu m$) respectively. There is almost complete absorption of short wave radiation ($\lambda < 0.40\mu m$) in the atmosphere.

Thus, from the view of terrestrial applications of solar energy, only radiation wavelength between 0.29 and 2.3 μm is significant. The solar radiation, through atmosphere, reaching the earth's surface can be classified into two components, viz. beam radiation and diffuse radiation. Beam radiation (I_b): It is the solar radiation propagating along the line of the receiving surface and the sun. It is also referred to as direct radiation. Diffuse radiation (I_d): It is the solar radiation scattered by aerosols, dust and molecules. It does not have a unique direction. The total radiation I is the sum of the beam and diffuse radiation and is sometimes referred to as the global radiation or isolation.

The total amount of solar radiation or more precisely insolation received at a point on the earth is made of two components: direct and diffuse insolation, referred to as global radiation and is of interest in this study. Several factors influence the amount of solar radiation received outside the atmosphere: the angle of incidence of the solar beam, the length of the day and the latitudinal variations. Perhaps, these factors influence the maximum possible solar radiation and the amount of solar energy received, though, both the angle of incidence and the length of day depend on latitude (Ojo, 1977; Tiwari, 2002; Rai, 2005).

Thus, all places on a parallel of latitude will receive the same amount of solar radiation, other things being equal. Therefore, on an annual basis, the amount of solar radiation received in the tropical environment is more than outside the tropic.

2.2.2 Measurement and Estimation Methods of Global Solar Radiation

Instruments for measuring solar radiation are basically of two types. The accepted terms for these are: Pyrheliometer an instrument using a collimated detector for measuring solar radiation from the sun and from a small portion of the sky around the sun (i.e. beam radiation) at normal incidence. Pyranometer an instrument for measuring total hemispherical solar (beam + diffuse) radiation, usually on a horizontal surface. If shaded from the beam radiation by a shade ring or disc, a pyranometer measures diffuse radiation.

In addition, the term Solarimeter which is same as pyranometer and actinometer which usually refers to a pyrheliometric instrument can be used. While, Potentiometer is required to detect and record this output. Radiation data usually must be integrated over some period of time, such as an hour or day. Integration can be done by means of planimetry or electronic integrator. Pyranometers have also been base on photovoltaic (solar cell) detectors.

Sunshine Recorder is an instrument for measuring the duration, in hours, of bright sunshine during the course of the day. It essentially consists of a glass sphere mounted in section of spherical brass bowl with grooves for holding the recorder cards. The sphere burns a trace on the card when expose to the sun, the length of the trace being a direct measure of the duration of bright sunshine. There are set of grooves for taking three sets of cards, long curve for summer, and short curve for winter and straight at equinoxes.

Meanwhile, Ojo (1977) observed that, the distribution of sunshine in Nigeria is zonal with the values increasing from the coastal inland. The lowest value less than five hours occurs along the coast in January and February. It increases to more than nine hours in the northwest and northeast of the country with few exceptions where the overhead sun is nearer the equator and consequently the zenith angle has increased. However, the strong influence of cloudiness is from

April to September and reduces the amount of sunshine received. These variations agreed with the results of Augustine and Nnabuchi (2009); Augustine and Nnabuchi (2010); Burari et al (2010); Ogolo (2010) and Okundamiya and Nzeako (2010) based on the comparison between the estimated (predictive) and measured solar radiation of various locations across Nigeria.

Solar radiation increased with increase in temperature and sunshine hours and decreases with increase in humidity. Therefore, latitude variations between locations should not be heavily relied upon, as a basis for using the insolation values from data post, as close locations- less than 15^{o} difference in latitude- has almost the same solar characteristics (Awuchie and Okeke, 1985). It is therefore clear that, the total solar radiation in a place is greatly affected by the climatologically variables such as temperature, sunshine hours, humidity etc, and then a measure of sunshine in a place when the prediction constant is known could give the value of insolation in the location.

Kuye et al, (2008) estimated highest solar intensity of 4.57kWhm^2/day in Abeokuta using Angstrom-Page model with relatively high average daily solar intensity in February, March, May, June and July. While, Okundamiya and Nzeako, (2010), disclosed that the variation of daily horizontal global solar radiation with months of the year in Katsina differs identically from other location in Nigeria due to variation in geographical location. On the other hand, Abdulsalam et al (2010) classify measured solar radiation data of Nigeria and analysed it to three zones; low, medium and high zone stating from the coastal lowland to the Sahelian highland respectively. As a result of the wide variation of solar availability in different locations, the design as well as the need for solar systems varies widely. Selecting the most effective solar system and equipment begins with an analysis of local climatic condition to determine the solar energy available.

Consequently, before designing a SHS, there is need to review the subject further in several specialized texts and government publications. Several methods have been developed around the world to estimate incoming solar radiation using irradiative transfer models and satellites. Most of the models were developed over a complex topography around mountainous areas where there were no radiation data for validation and calibration (Tiwari, 2002; Rai, 2005).

Crucial to the success of RETs is the availability of accurate, global solar radiation and meteorology data. Therefore, the focus of Surface meteorology and Solar Energy (SSE) commercial outreach project by NASA's Earth Science Enterprise (ESE) is to make this resource information available to the renewable energy industry by way of the Internet. This SSE data set is now available free-of-charge at (http://eosweb.larc.nasa.gov/sse/), and was formulated from NASA satellite- and reanalysis-derived insolation and meteorological data for the 10-years period from July 1983 through June 1993. Results are provided for 1^{o} latitude by 1^{o} longitude grid cells over the globe (Charles et al, 2000; Roberta *et al*, 2002).

On the average the SSE solar insolation data are higher than ground measurements, and it is suggested that satellite-based SSE solar insolation estimates are reasonably consistent for a wide range of global environments. It should also be noted that usual regional pollution and smoke are accounted for in the SSE LPSA algorithm. For strong smoke or pollution events, satellite estimates of insolation may be higher than ground measurements and may not be accurate within cities that have very high pollution relative to the surrounding countryside (Charles et al, 2000).

In spite of the importance of global solar radiation data, few meteorological stations, especially in developing countries, measure accurately and continuously. This situation can be solved using correlations, which estimate global radiation from available meteorological parameters, such as sunshine duration hours, daily temperature, relative humidity etc. accurate modeling depends on

the quality and quantity of the measured data used and is a better tool for estimating the global solar radiation of location where measurements are not available. Among the reasons for the lack of adequate data are problems over instruments, prohibitive cost and that few have only been constructed for tropical condition. (Akpabio et al, 2004; Burari et al, 2010; Madugu et al, 2010).

The more commonly used variables are the sunshine hour and ambient temperature (Akpabio et al, 2004; Rai, 2005; Burari et al, 2010; Ogolo, 2010). Ezeilo (1985) led credence by remarking that, researchers in area of solar energy and applications would necessary require basic sun data; extraterrestrial irradiation and day-light duration. These data are derived using formulae and evaluation or using reference to existing tables and charts to avoid repeated determination of quantities involved in the computations.

Ojo (1977) postulate with major criticism to the fact that, the best known empirical formulae are those of Angstrom (1916), Brunt (1932), Loenquist (1954), Anderson (1954) and Swinbank (1963) and many other recently developed models. The criticism is that they implicitly assume that the effective outgoing radiation at any given point is determined mainly by surface conditions and that their success is mainly because most of the counter radiations originate in the lowest kilometers of the atmosphere. Sambo (2005) postulated that, for long term evaluation of solar energy appliances, a monthly basis correlation of meteorological data with the temperature, relative humidity as well as the percentage sunshine hours is more appropriate and that percentage sunshine hours only be used for the estimation of the daily global irradiation.

According to Sambo and Doyle (1988), three classes of methods are generally used in global solar radiation. The first class uses empirical approach where meteorological data are employed with regression techniques, second class uses solar constant by considering the depletion of insolation value due to clearness index variation and the third class is based on satellite

measurements. Measured data is important to give realistic and accurate information on the performance of SPV system under actual operating environments and for places where it is not directly measured. The expense of radiometric stations and high maintenance make impossible the spatially continuous mapping of solar radiation.

Availability of qualitative global radiation data remains the pre-requisite for comprehensive design and application of SPV systems. Due to the scarcity of real data however, the use of representative sites where irradiance data are measured or modeled has been a common practice for engineering calculations which usually employs empirical correlations. Resort is being made on the use of reliable estimation model despite the fact that, best radiation data are those procured from the experimental measurements. (Malik and Roslan, 1996; Sambo and Doyley, 1988; Ojosu, 1989; Rai, 2005; Danny et al, 2009; Ogolo, 2010; Madugu *et al*, 2010; Robert *et al*, 2010).

In view of these shortcomings and the scarcity of solar radiation data from direct observations, it become necessary to generate and calibrate empirical relationship that estimate incoming solar radiation as a function of other known meteorological variables such as relative sunshine hour, cloudiness and ambient temperature. Therefore, different models and empirical relations developed and applied within and outside Nigeria are reviewed and discussed for the purpose of this work.

Several models have been developed using some available data, especially the sunshine hours, for the estimation of the daily solar insolation needed in the design and application of SPV systems. For example, the results from Nigeria, according to Bugaje (1998); Kuye *et al* (2008); Burari *et al*, (2010); and Ogolo (2010) show that the predictive ability of the Angstrom and Angstrom-Page or Angstrom- Prescott type model, correlate the global solar radiation to relative sunshine duration in a simple linear regression form.

Other investigations also demonstrated the predictive ability of temperature based models where sunshine hour data are not available or used simultaneously for reliability and validation of results. The temperature based models as suggested by Chiemeka (2008); Ogolo (2010); and Augustine and Nnabuchi (2010) were that of Garcia (an Angstrom-Prescott model with slight modification) and Hargreaves & Samani that proposed an empirical equation expressed in the form of linear regression between the clearness index and the square root of the change in temperatures. The 1st order Angstrom (1924) model is as in Equation (2.1) and the Garcia (1994) model; an adaptation of Angstrom-Prescott with slight modification that makes it ambient temperature type is as in Equation (2.2).

$$\frac{H_s}{H_o} = a + b\left(\frac{n_s}{N}\right) \qquad \text{..... (2.1)}$$

$$\frac{H_s}{H_o} = a + b\left(\frac{\Delta T}{N}\right) \qquad \text{..... (2.2)}$$

Where,
H_s = Monthly average daily global solar radiation on horizontal surface (MJ/m^2 day)
H_o = Monthly average daily extraterrestrial radiation (MJ/m^2 day)
n_s = Monthly average daily bright sunshine hours
N = Maximum possible monthly average daily length ($N = {}^2/_{15}\omega_s$)
ΔT = Difference between maximum and minimum temperature values**.**

According to Ogolo (2010), sunshine hour dependent predictive model is recommended as being suitable for the simulation of solar radiation during the dry season. While, temperature dependent predictive model is better than the sunshine model for wet season in the same climatic condition. On the other hand, Hargreaves ambient temperature model for global solar radiation is locality dependent.

Other models available include the followings: Akpabio *et al* (2004) model based on multiple linear regression using ten parameters of meteorological data of Onne, Nigeria, Okundamiya and

Nzeako (2010) model based on stochastic analysis that employed linear regression theory using monthly mean daily data set for minimum and maximum ambient temperatures of six selected cities in Nigeria. There were also models based on quadratic correlation approach developed by Augustine and Nnabuchi (2010), Udo (2002), and Akpabio *et al* (2004); which were tested, validated and ensured reasonable for predicting solar radiation with adequate conformity to other models in all the climatic zones of Nigeria.

Augustine and Nnabuchi (2010) and Ogolo (2010) studied the coefficients of several models and observed that the regression coefficients are not universal but depend on the climatic conditions. It therefore differentiates one model from another. It is also observed that, the sum of the coefficients increases from the Sahelian region towards the coastal station because they are quite related to geographical and meteorological condition of any given place. Ejeh and Itodo (2010) reported an Angstrom constants *a* and *b* for Makurdi location as 0.10 and 0.12 respectively with no significant difference with the measured solar radiation and other locations.

However, Ogolo (2010) pointed that, third order Angstrom model type does not improve the accuracy of estimation of global radiation and that for improving level of performance, temperature and sunshine hour dependent models are more suitable for the simulation of global radiation in the Shelia and Guinea Savannah climatic conditions respectively. In addition to classical techniques, new methods such as satellite-based techniques have been investigated. Although they are less accurate than ground-based measurements, they may be more suitable to generate site- or time-specific data at arbitrary location and times (Robert *et al*, 2010).

2.2.3 Monthly Average Daily Extraterrestrial Radiation on Horizontal Surface

Thus, prediction, estimation or computation of the monthly average daily global solar radiation on horizontal surface cannot be realized without the monthly average daily extraterrestrial

radiation on horizontal surface (MJ/m^2/day) termed H_0 or R_o which is important in assessing variability of insolation and can be computed for the nth from the following equation as given by Duffie and Beckman (2006).

$$\mathbf{Ho} = \frac{24 \times 3600 G_{sc}}{\pi} \{1 + 0.033 \cos \frac{360n}{365}\} \{\cos\theta \cos\boldsymbol{\delta} \sin\omega_s + \frac{\pi\omega_s}{180} \sin\theta \sin\boldsymbol{\delta}\} \quad \text{..... (2.3)}$$

Where,
G_{sc} = Solar constant (equivalent to 1367W/m^2)
θ = Location latitude
$\boldsymbol{\delta}$ = Solar declination
ω_s = Hour angle
n = Solar design day

The declination ($\boldsymbol{\delta}$) is the angular position of the sun at solar noon, with respect to the plane of the equator and its value in degrees is given by Cooper's equation (1969) as given by Duffie and Beckman (2006): $\boldsymbol{\delta} = 23.45 \sin \{360 \frac{284 + n}{365}\}$ **..... (2.4)**

Where n is the day of year (i.e n =32 for 1st February) and the declination ($\boldsymbol{\delta}$) varies between -23.45^o on December 21 and + 23.45^o on 21st June. While, $\omega_s = \mathbf{Cos}^{-1} (-\tan\theta \tan\boldsymbol{\delta})$.

It is also noted that, solar radiation at normal incidence received at the surface of the earth varies due to change in the extraterrestrial radiation, atmospheric scattering by air molecules, water and dust and the atmospheric absorption by O_3, H_2O and CO_2. Thus, it is then useful to define a standard 'Clear sky' and calculate the hourly and daily radiation which would be received on a horizontal surface under these standard conditions (Iqbal, 1983; John and William, 2006).

The diurnal variation of solar radiation received is always least at sunrise and sunset and vary very little throughout the year and increases during the afternoon. The highest value is usually observed or occurred in between February and November while low values for December and January partly show that the dust content of the atmosphere absorbs, reflects and scatters the incoming radiation.

Thus, before reaching the surface of the earth, radiation from the sun is attenuated by the atmosphere and the clouds. The ratio of solar radiation at the surface of the earth to extraterrestrial radiation is called clearness index. Thus, the monthly average clearness index K_T, is defined as $K_T = \frac{H}{H_o}$ ……. (2.5)

Where,
H = Monthly average daily global solar radiation on a horizontal surface.
H_o = Monthly average extraterrestrial daily global solar radiation on a horizontal surface.
K_T = Values depends on the location and the time of year considered.

Nevertheless, equation (4) can also be used for computing the Monthly average daily global solar radiation on horizontal surface (kW/m^2 /day) where the clearness index of a location is obtainable. Folayan (1988), postulated that Nigeria falls within 25% - 70% clearness index for the year round estimates with most cities having 20% variation from minimum to maximum. Perhaps, the values usually lie between 0.3 for very overcast climates and 0.8 for very sunny location (Robert *et al*, 2010).

In line with the above background, this study is set to examine the meteorological data of Nigeria with a view to establishing the available solar radiation data for sustainable implementation of SHS. The data would also provide a simulation basis in Nigeria just like in the US, where some location data are used to simulate systems throughout the country. The long term benefit can out-weigh the cost constrain, system will last for long without changing any system component or pay any power supply bill. The cost will continue to be high if there is no utilization and patronage, and if the research and development of the system and its components are not done locally (Sambo, 2009a; Robert *et al*, 2002).

2.3 CONCEPT OF SOLAR PHOTOVOLTAIC'S (SPVs)

Photovoltaic (PV) means the direct conversion of sunlight into electricity via a physical reaction. This conversion process is performed by the solar cells, which are normally connected to form

PV panel or module. Solar cells usually made from the semiconductor silicon consist of two layers: one negatively doped layer and one positively doped layer. When sunlight hits the solar cell, this triggers a physical reaction that generates direct current (Sharp, 2013).

Thus, solar cells are energy conversion devices which use photovoltaic effect. Photovoltaic effect is defined as the generation of an electromotive force as a result of the absorption of ionizing radiation, and the performance of such cell is measured by the Watt Peak (Wp) defined as the power output when a solar module is illuminated under standard conditions of 1000 Wm-2 intensity, 25°C ambient temperature and a spectrum that relates to Air Mass 1.5 (Adeoti, 2000; RISE, 2010).

Solar photovoltaic systems have wider application in Nigeria. It includes water pumping systems, solar-powered vaccine refrigerators as well as telecommunication repeater stations. There are also solar PV power plants that are providing electricity to entire villages and some specific projects such as rural health centre and television-viewing centers (Sambo, 2001). Solar Photovoltaic home system (SHS) is a method of generating electric power within a building for the purpose of household use only and it has the advantage of making the user independent on his/her power demand and this helps the planet by not contributing to the pollution from burning coal and natural gas used to produce conventional electricity and their descriptions.

One of the most interesting features of the SHS is the photovoltaic (PV) panel or module that converts sunlight into electricity which can be used by appliances in the homes. Others are the Inverter, Batteries, Charge controller, solar trackers and solar accessories. However, Gulma and Bajpai (1983) remarked that, energy conversion efficiency of a module is defined as the ration of energy that is obtained from the module to the radiation incident on the module. Besides that, spectral distribution of the incident radiation depends to a great extent on the manufacturing

process and material used to make the cells. Several projects and models are available across Nigeria to demonstrate the SPV system application such as Solar Electric Light Fund (SELF) a cutting-edge, independent non -profit organization that designs and implements sustainable energy solutions for enhancements in health, education, agriculture and economic growth (household and community lighting, income generating micro-enterprises) in the developing countries (Gulma and Bajpai, 1983; Bala *et al,* 2000; NASEF, 2007). SELF currently works in partnership with government, industry and non-governmental organizations to facilitate solar electricity projects in more than 15 countries in Africa, Asia and Latin America. Nigeria is one of such countries. Notably, are the National Energy Commission centers, projects and models available across Nigeria (SELF, 2009).

The common threats of Solar Photovoltaic (SPV) application are extensively enormous and include accounting for clouds, and the fact that most of the world is not on the equator, and that the sun sets in the evening, the correct measure of solar power is insolation - the average number of kilowatt-hours per square meter per day. For the weather and latitudes of the United States and Europe according to REN21 (2010), typical insolation ranges from 4 kWh/m^2/day in northern climes to 6.5 kWh/m^2/day in the sunniest regions. Other threats are many photovoltaic cells' electrical output is extremely sensitive to shading and some non-traditional solar cell manufacturers, thin-film that have installed bypass diodes between each cell that minimize the effects of shading and only lose the power of the array. When even a small portion of a cell module, or array is shaded, while the remainder is in sunlight the output falls dramatically due to internal 'short-circuiting' (Chineke *et al*, 2010).

Applications of this PVs for generating and supplying electric power for household purpose fall in three (3) categories; Stand-alone PV System (off-grid), Grid-supported (Grid-Connected) PV System and Building Integrated Photovoltaic (BIPV). The Stand-alone PV System (off-grid) is

an independent SPV system that operates with or without energy storage. Energy is stored often in batteries for periods when there is insufficient solar radiation. They are normally used in remote or isolated places where the electric supply from the power-grid is unavailable or not available at a reasonable cost. It is also known as autonomous PV systems and Plate 2.1 shows the schematic arrangement of the system.

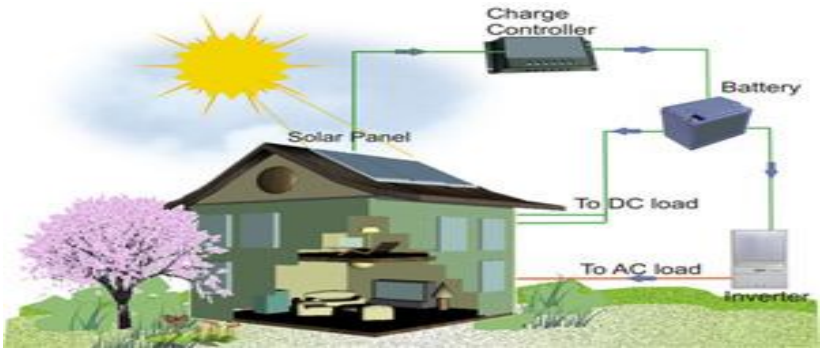


Plate 2.1 Schematic arrangement of the Residential Off-Grid PV System
Source: www.apollopowersystem.com

Grid-supported PV System is a grid connected system where the photovoltaic module is connected to an inverter to the grid supply. It supplements power supply to grid-line (users or buildings) during a poor power voltage or to supplement PV system when there is no insolation. They are normally used where there is grid-line connection and Plate 2.2 shows the schematic arrangement of the system. The grid-supported systems are of two types, systems that interact with the utility power grid and have no battery backup capability and those that interact and include battery backup (CEC, 2001).

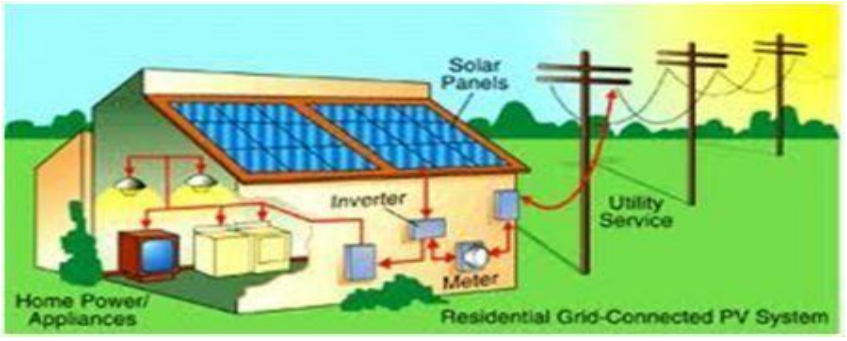


Plate 2.2 Schematic arrangement of the Residential Grid-Supported PV System
Source: www.uspolarsolar.com

The Building Integrated Photovoltaic (BIPV) it is system that consists of integrating photovoltaic modules into the building envelope, such as the roof or the façade. The system simultaneously serves as a building envelope material and a power generator. The electric power generated is used to run the following household appliances based on the size of batteries and inverter; lighting systems, stereo receivers, tape deck, CD/DVD player, television set, computer, printer/scanner, coffee pot or grinder, oven, cleaner/dryer, refrigerator, water pumps and any other domestic appliance that are not high voltage.

In a nutshell, the first two types shown in Plate 2.2 and 2.2 are basic application common in Nigeria and this form the delimitation of this study. The design method and criteria also was delimited to the following basic components that work in similar way for all the types of the systems.

I. **Photovoltaic (PV)** panel or module is a linked collection of cells that convert incoming solar radiation (insolation) into direct current via the photovoltaic effect and are commonly placed on roof tops in urban and suburban areas. The power that one module can produce is seldom enough to meet requirements of a home or a business, so the modules are linked together to form an array. PV modules available today can convert up to 14.5% of the sunlight in to DC electricity (FreeSunPower, 2010). A SPV module performance is generally rated under standard test conditions (STC); irradiance of 1,000 w/m^2 solar spectrum of AM 1.5 and module temperature of 25^oC, electric characteristics include nominal power, open circuit voltage, short circuit current etc. The module efficiency is measured in kWp and does not show the peak performance rather the maximum output according to STC. Solar panels must withstand heat, cold, rain and hail for many years (PB, 2008).

Typical solar panels have an average efficiency of 12%, with the best commercially available panels at 20%. In the Sahara desert, with less cloud cover and a better solar angle, one can obtain closer to 8.3kWh/m^2/day. The unpopulated area of the Sahara desert is over 9 million km^2, which if covered with solar panels would provide 630 terawatts total power. The Earth's current energy consumption rate is around 13.5 TW at any given moment including oil, gas, coal, nuclear and hydroelectric (REN21, 2010; RISE, 2010). Therefore it is extremely important that a PV installation is not shaded at all by trees, architectural features, flag poles, or other obstructions like continuously parked cars. Sunlight can be absorbed by dust, fall out, or other impurities at surface of the module. This can cut down the amount of light that actually strikes the cells by as much as half. Maintaining a clean module surface will increase output performance over the life of the module. Module output and life are also degraded by increased temperature and allowing ambient air to flow reduces this problem, thus module lives are typically 25 years or more without replacement (NASEF, 2007; Oado *et al*, 2012).

California Energy Commission (2001) summarized, by means of measurements, some factors determined to affect the SPV performance by decreasing the output due to losses, such as that from standard test conditions (0.95%), temperature (0.89%), dirt and dust (0.93), mismatch and wiring losses (0.95%), and DC to AC conversion losses (0.90%). Consequently, a 100-watt module output reduced by these losses to about 68-watts during the middle of a clear day, an equivalent of 0.6722 of power factor and by this percentages of losses; 100 watts x 0.95 x 0.89 x 0.93 x 0.95 x 0.90 = 67.22 watts. An array made up of eight 40 Watt PV modules give a total power rating of 3,200 Watts DC (3.2KW) in full sun. PV modules are usually roof-mounted several inches above and parallel to the roof. A 0.12m air space beneath the modules allows free air circulation for improved module cooling and performance (SCI, 2000). Most PV arrays use an inverter to convert the DC power produced by the modules into alternating current that can plug into the existing infrastructure to power lights, motors and other loads.

It is also imperative to note that; average daily solar insolation in units of kWh/m^2 per day is sometimes referred to as "peak sun hours". The term "peak sun hours" refers to the solar insolation which a particular location would receive if the sun were shining at its maximum value for a certain number of hours. Since the peak solar radiation is 1 kW/m^2, the number of peak sun hours is numerically identical to the average daily solar insolation. For example, a location that receives $8kWh/m^2$ per day can be said to have received 8 hours of sun per day at 1 kW/m^2. Being able to calculate the peak sun hours is useful because PV modules are often rated at an input rating of $1kW/m^2$.

II. **Storage facilities usually batteries,** are the reservoir in a solar electric system and offer longer life and better protection from abuse than low cost automotive batteries. Deep cycle batteries are those used for solar electric application for their high capacity and excellent cycle life and are manufactured in different capacity with Amp-Hour (AH) rating. A 100AH battery should deliver 5amps for 20hours or 20amps for 5hours and are available in markets in rating such as 60AH, 70AH, 100AH, 150AH and 200AH usually in 12Volts. Solar batteries usually have two (2) component part a battery bank and monitor. ***Battery bank*** stores electricity produced by the solar array and only discharged when utility power is not available to power the dedicated circuit in the SHS. While, ***battery monitor*** keeps track of energy in and out of the solar battery and displays the state of charge of the battery bank. It is a fuel gauge to let the user know how much of their battery energy is remaining during utility outages.

III. **Inverters are electronic devices** that convert direct current (DC) to standard alternating current (AC) and are designed to have internal protection against shot circuits and over voltage. They allow you to run regular AC appliances, including television sets Computers, microwaves and power tools. With an inverter, your AC loads run off your battery and they can be used any

time of day or night-without a generator- and definitely during a utility power failure. Inverters are usually rated in Volt-amperes (VA) or kilo Volt-amperes (kVA) and are either of the three types: Inverter charger that operates as an invert as well as charger and receive AC power from any power source to charge the backup battery with no capability to work with charge controller and solar panel, Solar inverter that has no charging capacity and uses only the backup battery charged with solar panel and charge controller and the last type is Grid-tie inverter that can be connected directly to National grid and is of high capacity.

Perhaps, use of inverter for small power loads especially extra low voltage (elv) appliances have become common in Nigerian homes, shops or viewing/computer centers and mostly sized for the maximum peak load and for the typical continuous load (Oado *et al,* 2012). However, SECO FACT SHEET N0. 24 suggested that for both off-grid and grid-supported system, inverter should be sized to provide 125% of the maximum loads, as the loads will be run simultaneously at any moment.

IV. **Charge controller or regulator is a power system component** whose functions include regulation of solar charge current and in some cases to provide low battery protection. It also prevents over charging by limiting the current flowing into the batteries with faster recharging increasing the performance of the system by storing more of the SPV arrays limited output. Most of charge controller have six ports 2 for positive and negative solar panel terminals, 2 for battery terminals and the other 2 for load connections, and are usually with voltage and current ratings of 12/24volts and 10/20amps.Consequently, the need for charger controller is desired as insolation falling on the panel varies from day to day and the ratio of average insolation in the best month could be as high as 1.5 to 2 times of that received during a lean month. Accordingly, there may be batteries getting overcharged and to guide against such an undesirable occurrence, a charger controller is required for SHS (CEC, 2001).

A solar tracker greatly improves the performance of the PV system. Trackers let the PV panels follow the course of the sun, so that the panel surface is always in an optimum angle to the sun rays. This guarantees highest efficiency. Tracking devices add cost, and require maintenance, so it is more common for PV arrays to have fixed mounts that tilt the array and face due South in the Northern Hemisphere (in the Southern Hemisphere, they should point due North). The tilt angle, from horizontal can be varied for season, but if fixed, should be set to give optimal array output during the peak electrical demand portion of a typical year.

However, other equipment or components includes: mounting system, utility switch, over current protection and properly sized wiring cable systems used to integrate the solar modules into structural and electrical systems of the home. Accessories such as combiner box(es), uninterrupted power supply (UPS), power module, lighting arrestors and AC meter/feed meter for recording the power yields are also important and are referred to Balance of System (BOS) equipment are also part of the equipment or components. Consequently, this framework development is limited the inclusion of these other equipment or components for siplisity and ease of design and application (CEC, 2001; Solar Direct, 2013).

2.3.1 Basic Requirement of solar home system (SHS) Application

An attempt by several design and research work such as Martinot et al, (2001); CEC, (2001), Tiwari, (2002); Rai, (2005); and UNEP, (2011); observed that, SHS design/sizing, installation, and performance testing require the following detailed information as pre-requisite.

i. Basic energy demand (Load): The energy demand of a building is usually obtained by summing the electric power consumption of all the household appliances and systems that require energy to operate, usually in kWh per day, week or month. Electric power consumption

of appliances is always given in the system trade mark or available in the manual and an ideal technical approach for this is energy audit. For complex loads and sustainable design, there is need for a fudge factor to take care of the difficulty involved in anticipating every electric load as some appliances such as electric clocks and TVs draw small amounts of power even when they are turned off. A fudge factor of 1.5 is recommended for sustainable and reliable design and installation by the SECO FACT SHEET No. 24.

ii. Incoming solar radiation (Insolation) data: These data are essentially relevant and usually based on location; latitude and altitude, and are obtained from the meteorological stations. It provides information on the specific generating capacity of the PV array in accordance with the specified insolation value of location. SECO FACT SHEET No. 24 suggested the worst or minimum monthly insolation value as the design insolation level in order to ensure the system will operate year-round as the monthly values vary with seasonal variation within a year.

iii. Component specification: Components that require specifications mostly include PV module, Battery bank, inverter and charger control. The specification should give information on the system manufacturer, model number and brand, peak Watt or Voltage rating, and size or capacity depending on the particular component.

iv. Component cost and warranty: An idea of the total investment and comparison with other alternative sources are achieved through assessing component cost and warranty. It allows for re-sizing of the SHS or its components based on the specification in an attempt to achieve optimal design of the system. A more accurate approach is a life-cycle cost analysis that includes fuel, maintenance, depreciation, interest and other expenses. PV systems generally have a high capital cost, but a low running cost, as the "fuel" is sunlight. To accurately assess the value of electricity from a PV system, it is necessary to compare the cost of the PV system to the minimum cost of

providing the same energy service by an equivalent alternative. PV modules may operate for 30 years and are usually sold with 10-20 year manufacturer warranty. Although PV modules themselves require little maintenance, other BOS components, particularly storage batteries generally require maintenance. A PV array is usually part of a *system* that may also include energy storage devices (Frank, 2008, UNEP, 2011). However, for the SHS to provide high-quality, reliable renewable electrical power, ConSol, (2001) and CEC, (2001) outlined several criteria to be observed which include the following:

a. Properly size and orient the system (s) to provide the expected electrical power and energy;
b. Install in compliance with all applicable building and electrical codes. Install with a minimum of electrical losses due to wiring and over current protection;
c. Properly house and manage the battery system, should batteries be part of the system;
d. Interconnect with the utility company following accepted procedures (grid-supported); and
e. Produce utility quality electrical output;

2.3.2 Basic approach to design/sizing of solar home system (SHS)

As SHS convert sunlight directly into electricity; a residential PV power system enables a home owner to generate some or all of their daily electrical energy demand at their home, and exchanging daytime excess power for future energy needs. It therefore has battery backup, or uninterruptible power supply (UPS), capable to operate selected circuits in the residence for hours or days during a power outage from the system (s) and utility company in the case of grid-supported type. In order to achieve this backup, several components and accessories are sized and designed to provide the energy requirement as efficiently as possible,

Each of SHS type requires specific components besides the PV modules that convert sunlight to electricity and such components are; power system that has an inverter for converting power from AC to DC and vice-verse, and battery storage system that requires special batteries and a battery charger controller. The final cost of any SHS ultimately depends on the PV array size, the battery bank size, and the other accessories required for the specific application.

Henceforth, BOS is particularly relevant for stand-alone systems in remote areas where the temptation is to simply compare the capital costs between PV and other energy supply options. It requires an inverter because it produce direct-current (DC) electricity but can be configured to produce any required combination of voltage and current – including conventional residential alternating current (AC) voltages (UNEP, 2011).

The procedure and stages involved in designing/sizing SHS consider the basic information or pre-requisite together with other criteria in achieving the task. Several approaches are available either with researchers in the area, renewable energy centers, agencies or laboratories and solar energy product or panel providers such as Simba, SELF, SolarPlus and SolarTown. Some design/sizing procedures were considered here for illustrations such as Frank (2008), design process from 1st principle, Solar Direct, Estimating PV System Size and Cost developed by SECO FACT SHEET N0 24 (SFS 24), and steps to specify and install a residential PV power system by ConSol (2001).

1. **SHS Design/Sizing procedure and Stages, 1st Principle by Frank (2008)**
    1) Select a design configuration (Battery back-up needed or not),
    2) Carry out load assessment (Based on household energy requirement),
    3) Select system voltage,
    4) Size and specify inverter,
    5) Size and specify battery bank,

6) Size and specify PV array,

7) Determine the expected system performance.

2. SHS Design/Sizing procedure and Stages by Solar Direct, 2013.

Step1 Determine your power consumption demands,

Step2 Optimize your power system demands,

Step 3 Size your battery bank,

Step4 Determine the sun hours available per day,

Step5 Size your array.

3. SHS Design/Sizing procedure and Stages by Estimating PV System Size and Cost (SFS 24).

Step 1 sizing components based on available specifications as follow:

1) Determine load,
2) Determine available sunlight,
3) Determine PV array size,
4) Determine battery bank size, and
5) Determine inverter size (if needed)

Steps 2 convert the system specification into a cost:

1) Estimate PV array cost,
2) Estimate battery bank cost, and
3) Estimate inverter cost,

4. SHS Design/Sizing procedure and Stages by ConSol, 2001.

Steps to design and install PV system for maximum performance

i. If PV is being considered as a standard feature or option in the early stages of project design, consider orienting homes so that there is unobstructed southern exposure to at least one large roof area (11.12m^2) on most or all of the home sites, to allow maximum energy production from the rooftop solar array. Also consider installing PV systems on common buildings (e.g. community center), over covered walkways, for shading in common parking areas, and in other common areas.

ii. Select a packaged system or systems that meet both customer desires and building constraints based on the following: first the customer criteria for a system may include price stability for utility costs, reduction in monthly electricity bill, environmental benefits, and desire for backup power. Secondly, building considerations may include subdivision image, initial cost constraints, roof area constraints and visibility and aesthetic concerns and thirdly, the actual performance varies based on size of system and exposure to the sun (orientation of homes in a subdivision, and shading).

iii. Develop site layouts for each system option to ensure the properties are capable of handling the desired system size. For roof-mounting options, each house plan should have at least two roof mounting options to address variations in the orientation of the house.

iv. If roof is mounted, verify that roof is capable of handling additional weight of PV system. Augment roof structure as necessary.

v. Install equipment according to manufacturers' specifications, using installation requirements and procedures from the manufacturers' specifications.

vi. Check for proper PV system operation by following the checkout procedures on the PV System Installation Checklist.

The basic approaches in determining or sizing the components are;

i. Determine load: the preferred method is a "bottom-up" in which every daily load is anticipated and summed to yield an average daily total. Other possible approach is energy audit.

ii. Determine available sunlight: insolation value is usually used here; Kilowatt-hours per day of sunlight energy that falls on each square meter of solar panel.

iii. Determine PV array size: by dividing the daily energy requirement by the insolation value.

iv. Determine battery bank size: this is by multiplying the daily load by 5, and then divide the result by the voltage of the battery bank (usually 12Volts). Capacity of the battery bank should always be five times the daily load.

Several online accesses are available for choosing and sizing the basic components such as Pv panel, Battery, Inverter and charge controller. Examples of such online access are SolarTown available online at (http://www.solartown.com/), Select solar available online at (http://www.selectsolar.co.uk/cat/) and the DIY World available online at http://sizing/calculator%20Solar%20Power%20). Thus, SolarTown has the following as the stages for choosing and sizing components for off-grid solar energy system.

Step 1: Size solar battery; this incorporates determining peak load, inverter size and including a factor for efficiency losses.

Step 2: Size the PV panel array

Step 3: Size Charge controller

Step 4: Size battery wiring; that is serial or parallel

Selectsolar has the following stages for choosing and sizing components for off-grid solar energy system.

Step 1: Find the Wattage of your appliances

Step 2: Calculate your daily total Watt-hour requirement

Step 3: Calculate your panel size; that is based on the sunshine hour(Insolation level)

Step 4: Calculate your battery size

Step 5: Calculate your charge controller size

DIY solar panel handbook is another online means of choosing the right equipment for many solar system needs and it's a calculation that figures out what size of solar panel, batteries, charge controller and inverter are needed immediately and it has the following steps.

Step1: Calculate how much energy is needed in Watt hours.

Step 2: Calculate the size of solar panel needed in Watt based on average daily sunlight hours or insolation level

Step 3: Calculate the size of batteries needed Amp hour's capacity.

Step 4: Figure what size of solar charge controller is needed in Amps and always go larger

Step 5: Calculate what size of inverter is needed

However, to estimate SPV array cost, either through the retailers or putting order notices with manufacturers, there are opportunities to purchase modules for a lower price. Some manufacturers offer modules with 10-20 year warranties. Other components such as battery bank and inverter are also purchased in same approach. Hybrid Optimization Models for Electric

Renewable (HOMER) is computer developed by the U.S. National Renewable Energy Laboratory (NREL) to ease some difficulties by assisting in micro power system design and compare their cost and potentials. Several designer and researchers uses the models. Boyi, Muazu and Wilson (2007) used the model in estimating the energy viabilities and installation cost of Solar-Wind electric power supply to autonomous community in Nigeria, and results shows installation and exploitation cost to be relatively better compared to existing means of connecting community to the national grid.

Other aspects that play a significant role in the design and application of any engineering system are environment and planning in which SHS is not an exception. UNEP (2011) division of technology, describe in the energy technology fact sheet that; most commercial photovoltaic materials pose no threat to humans or the environment, but components such as batteries do contain hazardous materials. Small SPV system projects do not generally require environmental impact assessments as the systems are usually fixed to existing structures. From a government policy perspective, however, recycling or disposal of system components, such as batteries, is important in the design of larger SPV programmes. It also exposed that, off-grid SPV systems need minimal planning approvals.

Grid-connected systems require grid access permits. These permits are usually standardized with fixed tariffs, and therefore project development risk is usually also low for these systems. SPV systems can also be vulnerable to theft and vandalism. Photovoltaic devices are solid state devices with no moving parts and a demonstrated record of reliability.

2.3.3 Need for electric means of SHS Design Kit (SHSDK)

Rapid development of IT in different contexts throughout the World has led to the need for computerizing all forms of scientific design processes through computer programs designed to

help people perform activities. Such designed computer programs are called Applications or Application Software in IT and depending on the activity; it manipulates text, numbers, graphics or combinations of these elements. Various types of application software are usually designed and application suite software was generally considered and it consists of multiple applications bundled together.

The application software has related functions, features and user interfaces and may be able to interface with each other. Usually software gives the opportunity to instruct computers to do relatively difficult calculations quickly, relatively easy and over and over again with provisions of storage, calculations, appending, sorting, filing or sharing data within the database. However, iPlanner, (2013) outline several benefits of online software model and include allowing employers or users work from anywhere and get the data needed, need not to download, install or maintain any program and it has scalability, integrated mobile function, ease of collaboration and social networking function.

Thus, component sizing kit proposed may take different options depending on the type of PV applications chosen by the home owner and some design decisions. The component sizing Kit is defined in this context as web-based computer application suite software designed to help a users perform multiple tasks in the sustainable design of SHS and it is referred as Solar Home System Components Sizing kit (SHSDK). The Kit has several benefits that had to do with provision of services to meet the needs of public and protect the interest of the developer. It also enhances capturing the most reliable means of sizing the components and design implementation. The aim of this is to support design process by providing designers and home owners the basic resources needed for the sustainable design through internet. As at today, application of computer in all form of workplace is inevitable for individual designers.

In public organisations, implementation of e-government in many countries has contributed to their development. In the same vein Ross (2006) describes digital curation as a means of preservation and maintenance of digital assets, encapsulating the many activities involved in caring for digital entities such as selection, documentation, management, storage, conversion, security provision and provision of access. As such, ubiquitous application of ICT has resulted in the creation of enormous number of digital object (s) which this SHSDK is not an exception.

Cumming (2001) postulate that managing most electronic data can only succeed with availability of adequate 'metadata' that function to aid the identification, description and location of networked electronic resources. Metadata are defined as the data providing information about one or more aspect of the data such as means of creation, purpose and creator of the data. Hansen (2003) opined that without metadata, electronic documents in particular lose their original context and become less useful as the metadata function like a map and a compass to make it easier for every one searching for information to find it.

In this work, a web-based package is suggested to put together the basic stages, processes and necessary data required for the design. SHSDK via internet will provide benefits such as saving time and cost, increasing efficiency and reliability of design and system, and enable automation. Other benefits, such as possibility for developer to send regular updates to improve the software as a result of problems or further development from time to time, access restriction to others and virus, spam's and hacking are also considered, and consequently compatibility with other general software is one of the limitations.

2.3.4 Solar Home System Design Kit (SHSDK)

Procedures involved in designing application software for sizing components of SHS considered the basic information or pre-requisite of normal computer application software design. The Kit

provides a simpler way or criterion in achieving the task that is user friendly for sustainable implementations. Computer software (Kit) is usually designed using Java programming language or Personal Home Page (PHP) that now stands for Hypertext Preprocessor and database runs the My-SQL Relational Database Management System (RDBMS). Therefore, the entire system is always based on the Model View Controller (MVC) design pattern. In MVC Graphic User Interface (GUI) is the presentation layer and usually separated from the business logic and the databases, thereby enabling the system to seamlessly integrate with one another both on a local system and remote separate system.

System model is the concept that describes the model incorporated in the design of the system, and evaluation of suitability of chosen model in a web-based application. The model architecture is best achieved through appropriate section of system development and communication of the model. A system development model refers to an organised strategy for executing the steps necessary to create high quality software system. It incorporates in various ways system development phases of establishing requirements, creating design, implementing the design and testing the implementation (Ibam, 2008).

The web-based computing packages are usually designed within one or two communication models: peer-to-peer model and the client-server model. As pointed by Thomas (2004), a three-tier architecture model can be employed as communication model and Figure 2.1 is a pictorial representation of the model. Database tier is at the base of the application and consists of the database manager that maintains the database containing the data which users create, modify and query with MYSQL. It is used to provide the required functionality of Web application. The middle tier contains most of application logic which is built on top of the database tier and communicates data between the other tiers.

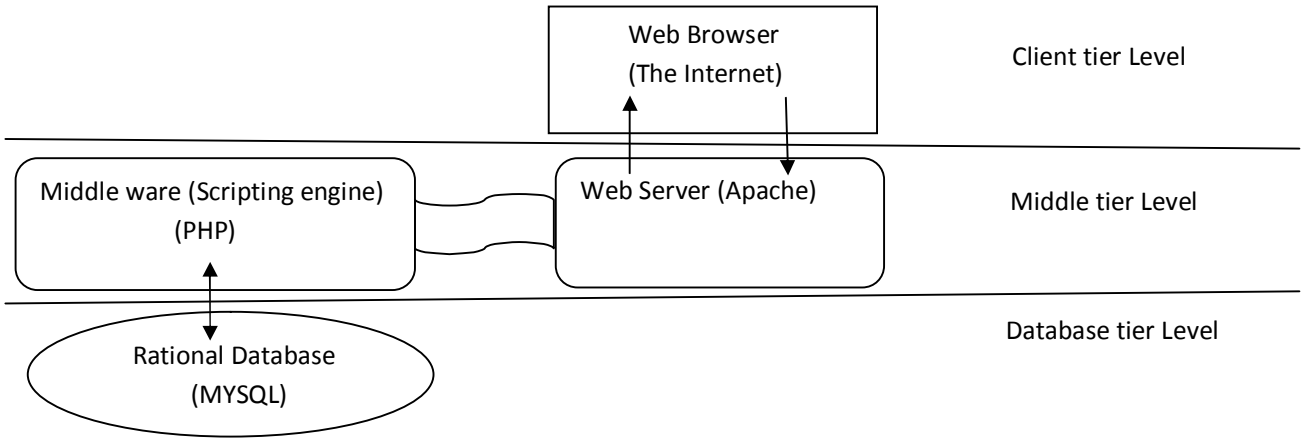


Figure 2.1: Three-Tier Architectural Model of Web-application
Source: Thomas (2004)

It uses Apache as web server to run the Window XP operating system. The scripting engine communicates with the database using server-side PHP functions where all the coordination procedures in the system were implemented. On top is the client tier usually web browser software that interacts with the application.

The utilization of database has spread to such a wide degree that virtually every technology and product relies on database and Database Management system (DBMs) for its development and commercialization. According to AbdulAzeez (2012) a general purpose of DBMs is typically a complex software system that meets many user requirements and the databases that it maintains are often large and complex. The database concept is to ease increasing difficulties in designing, building and maintaining complex information system. Well known DBMs include Oracle, PostreSQL, MySQL and SQlite and Hierarchical, Network and Rational models are examples of theoretical foundation of a database fundamentally determines in the manner that data are to be organized, manipulated and stored in the system.

The life cycle of the process and the coding of the program usually follows a standard software development life cycle (SDLC), defined as the process of creating or altering software systems, and the model and methodologies that people use to develop the system. In such life cycle,

people, process and technology all play a role in success (SDLC, 2013). There are several models for such processes each describing approaches to a variety of tasks or activities that take place during the process.

Grady *et al*, (2005) developed a unified process that categorizes the SDLC into four (4) stages namely; Inception, Elaboration, Construction and Transition. The overall scope of the process and feasibility are determined with client approval at the inception stage by determining whether creating a new or improved system is a viable solution. This will help to determine the costs, benefits, resource requirements, and specific user needs required for completion (James & George, 2010). The basic architecture of the system is decided with emphasis on user needs in the elaboration stage. The construction stage therefore has to do with software production that involves coding the program, and the last stage is concerned with testing and deployment of the software.

Other researchers had different views with the processes, stages and linkage and SDLC, (2013) suggested three (3) basic stages namely; Planning, Implementation, Testing and Documenting and lastly Deployment and Maintenance. Scope of the project activity is discovered in the planning stage through requirements analysis. The coding of the project is carried out in the implementation, defects recognition is achieved in testing and with documenting internal design of the project for the purpose of future maintenance. Deployment is carried out to install, customize and test the project. SDLC is a base upon which software development models are basing their approach and to manage and control any SDLC initiative, each project will be required to establish some degree of a Work Breakdown Structure (WBS) to capture and schedule the work necessary to complete the project (U.S H of R, 1999). Figure 2.2 shows the relationship of the stages pictorially with control objectives and Figure 2.3 gives an elaboration of the SDLC phases with much description.

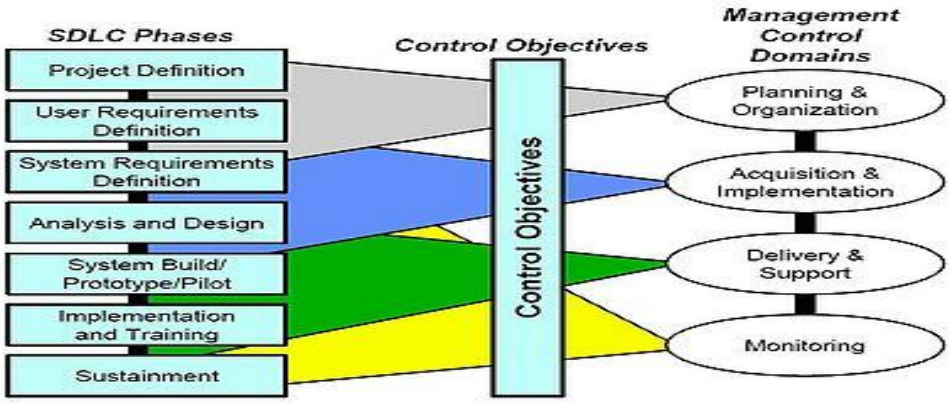


Figure 2.2 Pictorial Representation of Software Development Process
Source: U.S. House of Representatives (1999).

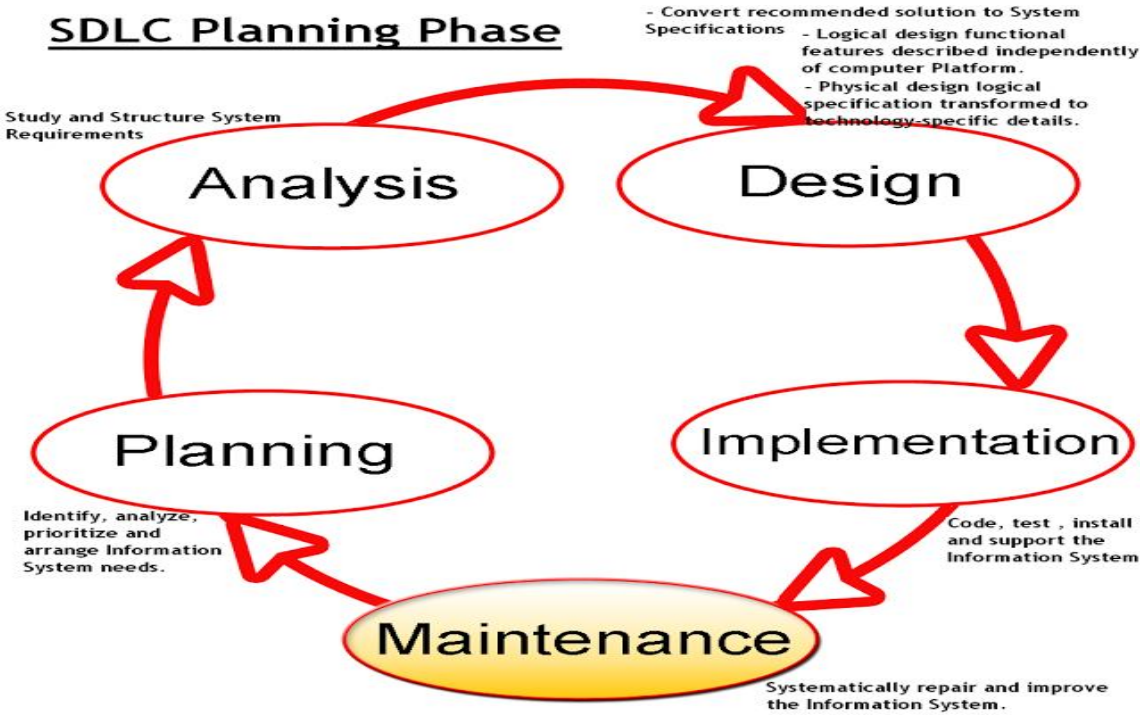


Figure 2.3 Phases of SDLC
Source: Software Development Life Cycle: SDLC (2013)

Furthermore, several models exist to streamline the development process. Each has its prospects and constrains and it is up to the development team to adopt the most appropriate one for the project. Sometimes a combination of the models may be a more suitable approach and perhaps choosing any and applying it to whatever task may be most appropriate for the software being

designed as postulated by Post & Anderson (2006). The following are some of the various models;

i. Waterfall model
ii. Spiral model
iii. V-shaped model
iv. Agile development model
v. Iterative and incremental development model
vi. Rapid application development model
vii. Process improvement model

However, the programming has a procedure to be followed and usually consist of five –stages. Williams and Sawyer (2007) developed robust stages for clarity of the outlined SDLC which was adopted by AbdulAzeez (2012) for developing an electronic document and record management system and it has the following programming process.

1st stage: Clarify/define the problem.

2nd stage: Design a solution by using modeling tools to chart the process.

3rd stage: Code the program by using a programming language syntax or role.

4th stage: Test the program by getting rid of any logic errors or 'bugs' in the program ('debug' it)

5th stage: Document and maintain the program by including written instructions for users.

Baselines are also an important part of the Systems Development Life Cycle (SDLC). These baselines are established after four of the five phases of the SDLC and are critical to the iterative nature of the model (Blanchard & Fabrycky, 2006). Thus, Apache, MYSQL and PHP are the more open source software running on windows operating system; used in most of development and implementation due to the combined advantages of speed, ease of use, cross-platform,

accessibility to functions processing power, cost-effectiveness, flexibility constant improvement and worldwide acceptance (Thomas, 2004; Aighe, 2008; Ibam, 2008).

Validation and evaluation of the Kit is another essential aspect of development, defined as a process of assessing whether a framework or model is in congruence with reality. It seeks to test the extent to which the Kit satisfies its objectives and different approaches exist depending on the nature and type of the model (Brank, 2003; Ibrahim, 2008). Consequently, there is no formalized guide or procedure for selecting the most appropriate approach to be adopted but the simplistic view of the model validation process helps in choosing the appropriate approach. Validation cannot be carried out by the developer alone; rather in communication with the user to enhance the establishment of the process (Martis, 2006).

Unified process developed by Grady *et al,* (2005) is what is commonly used with Inception, Elaboration, Construction and Transition as stages of the process. These could be broken into Iteration contained in construction phase as described by AbdulAzeez (2012). Iteration is a subset of the overall system corresponding to a single task user want to perform and synonymous with use case.

CHAPTER THREE:

RESEARCH METHODOLOGY

3.1. RESEARCH METHODS

This study was pursued mainly through field survey which assessed basic household energy demand, quantified solar radiation potential of north western Nigeria and developed solar home system design Kit for sustainable implementation of PV home system. This chapter is solely concerned with the description of the methods followed in achieving the objectives of the study, such as: study area, data collection instruments and methods of data analysis based on objectives. An intensive literature search and review were also carried out as already presented in chapter 2.

3.1.1 Research Study Area and Sample Size

The study area (North-west Nigeria) is situated between latitudes 8^o and 14^o north of the equator and between longitudes 3.5^o and 11^o east of meridian. It comprises seven states namely: Kaduna, Kano, Jigawa, Katsina, Zamfara, Sokoto and Kebbi. The whole states were used as sample size, comprising three (3) major cities from each making a total of twenty one (21) locations. The sampling of the locations was achieved through the stratification method that comes up with locations that adequately represent the whole state. The bases are where urbanization and development are considerably ahead of others. In each case the latitude, longitude, altitude and axial distances between the cities are considered. Table 3.1 shows the description of geographical location of the cities sampled to represent the study area.

Table 3.1: Geographical location of cities sampled for the study

Sn	STATE	LOCATIONS (CITIES)	*LAT. (^{0})	*LOG. (^{0})	*ALT (M)	CLIMATIC ZONE
1	Kaduna	Kaduna	10.52	07.44	612	Midland zones
2		Zaria	11.07	07.70	671	Midland zones
3		Kafanchan	09.58	08.30	739	Midland zones
4	Kano	Kano Municipal	12.00	08.50	870	Sahelian
5		Tudunwadan Dan kade	12.03	08.57	466	Sahelian
6		Bichi	12.23	08.24	535	Sahelian
7	Katsina	Katsina	13.06	07.60	464	Sahelian
8		Daura	13.04	08.32	474	Sahelian
9		Funtua	11.53	07.32	614	Sahelian
10	Jigawa	Dutse	11.78	09.33	430	Sahelian
11		Hadeja	12.45	10.04	336	Sahelian
12		Kazaure	12.65	08.42	414	Sahelian
13	Zamfara	Gusau	12.16	06.67	419	Sahelian
14		Talatan Mafara	12.56	06.07	319	Sahelian
15		Kauran Namoda	12.60	06.59	383	Sahelian
16	Sokoto	Sokato	13.05	0523	261	Sahelian
17		Isah	13.20	06.41	314	Sahelian
18		Tambuwal	12.40	04.66	279	Sahelian
19	Kebbi	Birnin Kebbi	12.45	04.20	230	Sahelian
20		Yawuri	10.78	04.81	174	Sahelian
21		Zuru	11.42	05.23	446	Sahelian

* Data obtained from the Falling Rain Genomics Inc. (1996-2010) -Online

3.2. HOUSEHOLD ENERGY DEMAND ASSESSMENT

Zaria Metropolis was considered to represent the study area in evaluating household energy demand on the bases of NPC (2006). It defines Six household types within the regular household system of living to be the same having unique characteristics across the North Western Nigeria. Meanwhile, average power ratings of appliances used in the evaluation was also based on the data obtained on the ground and seems not conforming to current energy saving ratings of most appliances.

The Metropolis comprising two (2) local government areas namely Zaria and Sabon Gari is densely populated with several sub-rural and rural settlements. It has an estimated population of 698, 348, comprising 121,758 regular households (NPC, 2006). Zaria is one of the oldest city of Northern Nigeria and second largest city in Kaduna State. The sample size determination was achieve through the formula for estimating sample size of a known population size given by

Guilford and Flurchter (1973) as

$$n = \frac{N}{1 + \alpha \frac{2}{-} N} \quad \text{.....(3.1)}$$

Where; n = Sample size
N = Population Size
α = 0.10 @ d.f = 1 for 90% Confidence interval

Thus, $$n = \frac{121{,}758}{1 + (0.10)2(121{,}758)} = \frac{121{,}758}{1 + (0.01)(121{,}758)} = \frac{121{,}758}{1 + 1217.58} = \frac{121{,}758}{121{,}8.58)} = 99.9 \cong 100$$

Therefore, 100 was determine as sample size and for uniformity amongst the six households types 120 was then choose to be the sample size where multi stage stratified purpose sampling was adopted for the selection. The study area was first stratified into two local government areas. Six clusters of settlements were chosen in each case in such a way as to ensure a mix of urban, sub-rural and rural type of settlements. This help to capture all types of regular households in the sample.

The next stage of sampling chooses ten households in each of the clusters from the two local governments with each representing a regular household type purposively for energy audit. This brings the total number of household to one hundred and twenty (120), sixty (60) from each of the two local government areas. The clusters sampled in Zaria local government are Zaria city, Kofan doka, Tudun wada, Gaskiya, Tukur tukur and Gwargawje while those sampled in Sabon gari local government are Samaru, Zango, Hanwa, GRA, Sabo gari and Dogon Bauchi.

3.2.1 Instrument of Assessment

The audit was solely concerned with identifying key parameters that include stocks of appliances, power rating and usage patterns or user behavior. These provided a basis for a more reliable daily estimate of building energy use and consumption which later gives the monthly energy demands of the households, in accordance with the Public Interest Energy Research

format and standard. The energy audit was carried out using a structured Checklist as data collection instrument that was completed through interviewing heads of households and visual inspections. The major stages in the exercise were: walk through; accessing usage pattern; and analysis.

i-Walk Through; the process began with a walk around the building to identify the electric energy equipment used in the buildings with their power ratings. The process was achieved solely by visual inspection of the equipment and systems specification templates and market survey was also followed for the power ratings of appliances to improve the data for quality assurance. Thus, the study uses only the averages of the ratings due to variations in appliances/systems models and brands.

ii- Accessing usage pattern: This involved estimation of equipment usage durations from which the energy consumption of the households is computed. Oral interviews of the occupants were employed in achieving this. The average duration of use of each appliance is established.

iii- Analysis**;** Computation of the precise energy demand of each household (kilowatts hour) was also achieved by multiplying the averages obtained for the power ratings of the appliances (kilo watts) and their durations of use (hours/day). The estimated values per day were also projected to the monthly average as required in the objective of the study for energy demand of typical Nigerian household types.

3.3 ESTIMATION OF INCOMING SOLAR RADIATION (INSOLATION)

Data from the meteorological stations of several government and non governmental agencies within the North-west Nigeria was collected with the view of ascertaining the source of variation between the measured or estimated and ground or satellites solar radiation data. It is also imperative to note that the study area has a higher potential of solar energy than the southern part due to its proximity to the arid Sahel (Victor *et al*, 2010). The parameters considered for this

purpose are either for a location or a state. The long term averages of the parameters were used in the analysis and include:

1. Sunshine hours (hrs).
2. Minimum/ maximum ambient temperature (^{o}C).
3. Monthly average daily global solar radiation on horizontal surface (KwH/m^2 /day).
4. Clearness Index

The sunshine hours (hrs) and minimum/ maximum ambient temperature (^{o}C) ground measurement data were collected from the Agricultural meteorological (Agricmet) Stations of Agricultural Development Projects of the states except in the case of Katsina where the data were collected from the Ministry of Water Resources and there was no available data in Kebbi State. All set of satellite measurement data required were downloaded online from the NASA SSE Home page available at (http://eosweb.larc.nasa.gov/sse/). The monthly average daily global solar radiation on horizontal surface (kW/m^2 /day) of all the locations were received as ground measurements from the Nimet data bank except that of the Jigawa state that has no airdrome stations/air port.

Two models represented in Equations (2.1) and (2.2) that utilize ambient temperatures and sunshine hours were employed for the estimation using empirical constants based on the monthly averages daily global solar radiation on horizontal surface (kW/m^2/day). The monthly extraterrestrial radiations Ho (kW/m^2/day) of all the locations were also computed based on equation (2.3). The following hypotheses were also considered for the validation of the results in addition to other statistical validation tools.

I. There is no difference between the estimated (predicted) average monthly solar radiation value using sunshine hours and ambient temperature based prediction models.

II. There is no significant difference between the monthly variations of average mean daily solar radiation data of each city within the cities of North-Western Nigeria.

3.3.1 Method of Data Analysis

MATLAB computer package, Micro soft excels and SPSS package were the tools used in the analysis. Presentation of results was by means of tables, charts and graphs with short discussions. The descriptions of how the tools were used are as follows;

i. MATLAB Computer program enabled the computation of the variables of the proposed models and monthly averages of daily extraterrestrial radiation on horizontal surface (MJ/m^2 day) and its variables such as solar constant, solar declination and hour angle.

ii. Micro soft plotter was used to plot monthly ratio of $\frac{Hs}{Ho}$ against that of $\frac{\Delta T}{N}$ and $\frac{n_s}{N}$ for all the seven states in order to obtain the empirical constants based on the trend line that display equation and R-square value on chart using scatter mode plotter.

iii. MODEL VALIDATION: The mean measured monthly averages of daily Insolation values were compared with the estimated values from the two models; sunshine and temperature based for the six states of the study area and the outcomes were discussed. A common method used to analyze or evaluate model is to plot the measured values against estimated values and the correlation between them is used for model evaluation (Kobayashi and Salam, 2000; Suleiman *et al,* 2008; Usman, 2011).

Ideally, this relationship should be linear with a slope of unity and intercept of zero with R^2 that gives some information about the goodness of fit of a model. Generally, R^2 and slope values that are close to unity are more desirables while intercept values that is also close to zero is more desirable. Ideally, estimation should be both accurate and precise. The accuracy of estimation is measured by the bias and the precision is measured by the standard deviation (Navidi, 2008).

Generally, the following quantities are most often used for the model validation:

a. Coefficient of determination (R^2) is a measure of fit between estimated and measured data and it ranges from 0 to 1 to describe how well measured outcomes are replicated by the model, Equation (3.2). An efficiency of 1 indicates that the model estimations are as accurate as the mean of the observation data, whereas efficiency less than zero occur when the observation mean is a better estimator than the model. Essentially, the closer the model efficiency is to 1, the more accurate the model is (Nash and Sutcliffe, 1970).

b. Root mean square error (RMSE) Equation (3.3) is a measure of precision and is the square root of Mean Square Error (MSE) which is a measure of how close the model comes to the field measurement and quantifies the differences between values implied by an estimator and the true values of the quantity being estimated. It combines both bias and uncertainty. A low value of RMSE show a high precision while a high value of RMSE show a low precision. (Antonopolos, 1997; Millard and Nearchal, 2000; Sulaiman *et al,* 2008; Ogolo, 2010).

c. Coefficient of Residual Mass (CRM) is an indicator of the tendency of the model to either over or under estimates measured values, Equation (3.4). A positive value of CRM indicates a tendency of under estimation while a negative value indicates a tendency of overestimation (Antonopolos, 1997; Isikwe *et al*, 2012).

$$R^2 = \frac{\sum_{1}^{N} \left(PHs - MPHs\right)^2}{\sum_{1}^{N} \left(MHs - MMHs\right)^2} \qquad \text{.....(3.2)}$$

$$RMSE = \sqrt{{}^{1}\!/_{N} \sum_{i=1}^{N} \left(MHs - PHs\right)^2} \qquad \text{.....(3.3)}$$

$$CRM = \sum_{i=1}^{N} PHs - \sum_{i=1}^{N} MHs \qquad \text{.....(3.4)}$$

Where: PHs = predicted insolation values

MHs = measured insolation values

MPHs = means of Predicted insolation values

MMHs = means of measured insolation values

N = number of observations

iv. Statistical Package for Social Scientists (SPSS) was also used for testing the hypotheses raised for the validation of result. The analysis was based on the following decision rule for each of the hypothesis.

Hypothesis 1: Paired sample t-statistics test was used and the decision rule is:
Reject the H_o if $p \leq 0.05$, and Accept the H_o when $p > 0.05$

Hypothesis 2: One-way analysis of variance (ANOVA) test, was used and the decision rule is:
Reject the H_o if $p \leq 0.05$, and Accept the H_o when $p > 0.05$

3.4 BASIC STAGES IN THE DESIGN OF SOLAR HOME SYSTEM

Several steps were developed to accommodate the basic requirement and consideration of some factors in Solar Home System design and applications. The steps were based on the various methods and approaches reviewed in chapter two of this work and some postulation acknowledged in this work. The three basic steps are:

Step 1: To establish the basic energy demand (kWh) per day

Step 2: To choose an insolation level of the location.

Step 3: Size the basic components and accessories

The first step considered the establishment of the basic energy demand based on some scenarios in order to utilize the averages established in this work. It allowed the designer to select household utilities with their duration of use in order to come-up with the desired household energy demand in kWh. This stage also considers the back-up time and type of the system in use (whether the off-grid or grid-supported) so as to establish appropriate system voltage for efficient performance.

The second Step is concerned with choosing an insolation level of a location, the least or maximum monthly average, and the annual monthly average insolation level in kWh. Meanwhile, the term peak sun hour (hrs) is considered the same with incoming solar radiation (insolation) and refers to the insolation (kWh/m^2 per day) which a particular location would receive if the sun were shining at its maximum value for a certain number of hours. It also addresses the issue of load shedding as applied by the utility power supply company. It then considers allowing the designer to provide the insolation level or peak sun hour of interest.

The third Step sizes the basic components and accessories of the solar home system such as the PV panel, battery, inverter and the charge controller with verifications. Several factors are therefore introduced to address the issues of decreases or increases, such factors include fudge and depth of discharge (DOD).

3.4.1 Conceptual framework for the SHSDK

The flowchart showing the conceptual framework for the SHSDK is as presented in Figure 3.1. The flowchart captures all the requirements of the SHSDK as presented in section 2.1.6. The design and Development of the framework was based on model view controller (MVC) design pattern. PHP programming language was used in the development and the MySQL Relational Database Management System (RDBs) was employed in running the data base. Security of the conceptual framework was considered at two levels: Administrator and User levels. The administrator operates and manages the Kit effectively with the following roles.

i) Create and provide user name and password of authorized user. This can also be removed if desired.

ii) Upload, edit and delete documents and records in the database.

iii) View, search, run application and print results

The user is given access to the database of the kit based on the user name and password, and can have the following privileges as indicated in the flowchart (Figure 3.1).

i) View, search, run application and print results

ii) Cannot upload, edit or delete anything from the database.

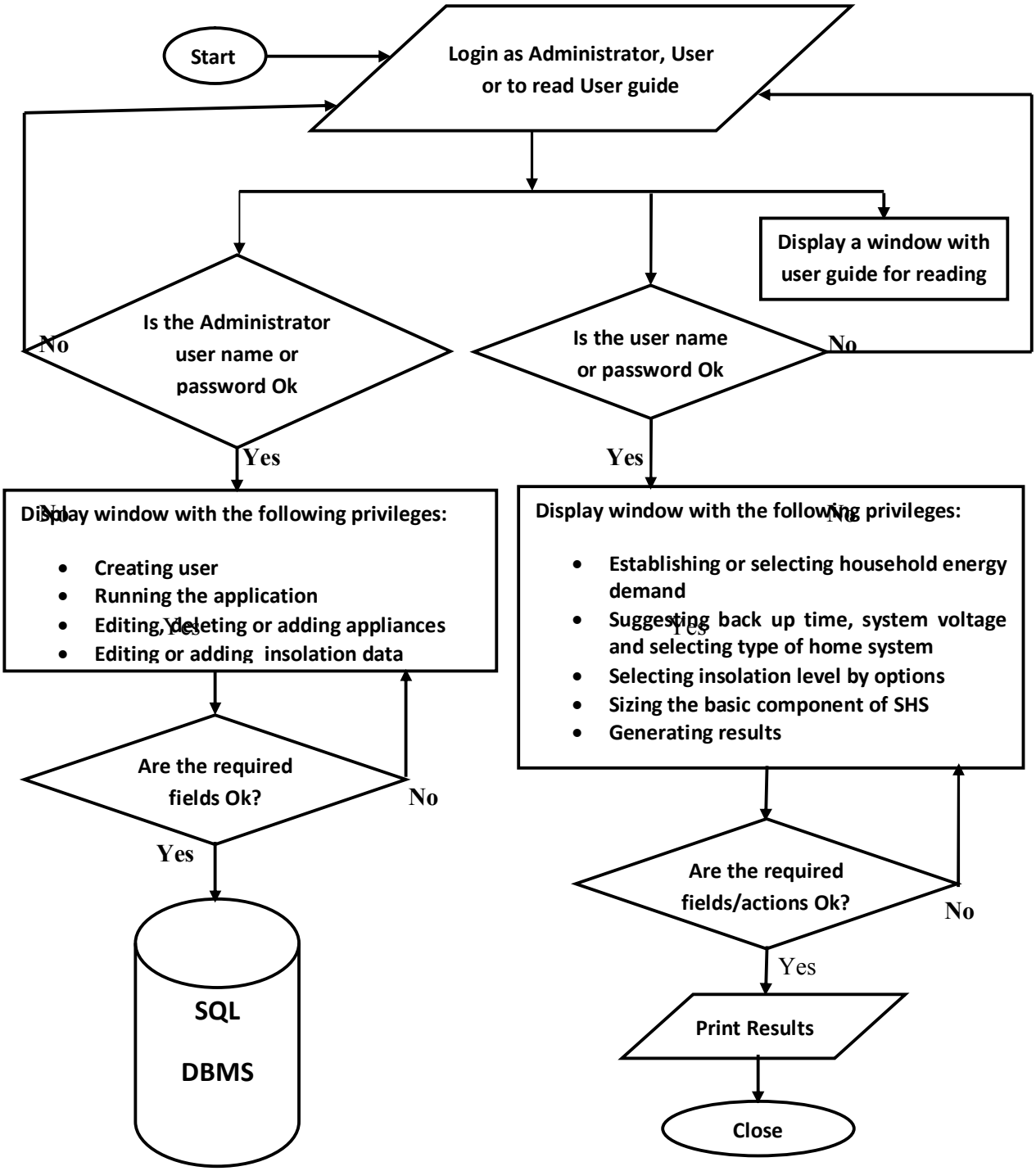


Figure 3.1 Flowchart of the SHSDK

3.4.2 Implementation, Validation and Evaluation of the SHSDK

Programming procedure has several processes including implementation process and validation or evaluation of the Kit to check whether a framework/ model are in congruence with reality and extent to which it satisfies its objectives. For the purpose of this work, an approach simplified by Martis (2006) was adopted and as described in section 2.1.6. The conceptual and computerized model of verification was carried out where coding, testing and debugging were also achieved through writing the program, running and testing after installation. In this design Kit, the following sequence of verification was considered during documentation;

1) Ensuring that the intended objectives are met; in these basic stages, their provisions for selection and entering or suggestion of entries are verified to ensure that computerized model is in accordance with the conceptual procedures. Faults, weaknesses and incompleteness identified were addressed through decoding and debugging the design Kit.

2) Ensuring that the quantitative and qualitative aspects of the output are met; several examples were taken manually and the results with its format were compared taken reference to the basic stage and sequence of the design operation to ensure that output of computerized model tallies with the conceptualized model.

3) Ensuring that the provision made for administrator and users are documented to operate adequately. Operational validation is considered here to ensure the verification of username and password with the provision of modification is ok. In achieving these, seven users were sampled to run the software to verify completeness and adequacy of the computerized model based on the various windows, interfaces and print out options.

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND DISCUSSION

4.1 HOUSEHOLD ENERGY DEMAND

Zaria Metropolis comprising two (2) local government areas namely Zaria and Sabon Gari were considered to represent the study area in evaluating household energy demand. Six household types were identified within the regular household system of living in Nigeria. Average power ratings of appliances used in the evaluation was also based on the data obtained on the ground and seems not conforming to current energy saving ratings of most appliances.

The energy use in the various household types shows typical consumption for Plug loads, ventilation, air conditioning and lighting each with its own energy consumption rate depending on the usage and age of the appliance. The Energy use for each specific household type is based on the common appliances or system type, their typical average power ratings (where applicable) and duration of use. Table 4.1 shows typical energy consumption in single member household.

Table 4.1: Energy consumed in Single Member Households per Day

S/N	Appliances	Household Average		Energy consumed
		Power rating (kW)	Duration of use/day (Hrs.)	(kWh)
1	Pressing iron	1.38	0.33	0.46
2	Television	0.92	5	4.60
3	DVD/CD player	0.01	5	0.05
4	Blender	0.59	0.16	0.09
5	Laptop	0.08	6	0.48
6	Electric kettle	2.30	0.16	0.37
7	Stabilizer	0.51	10	5.10
8	Refrigerator	1.20	12	14.40
9	Ring boiler	2.40	0.25	0.60
10	Fan	0.08	5	0.40
11	Electric bulb	0.04	10	0.40
			Total	**26.95**

Source: Field Survey, 2012

The single member household energy consumption of 26.95 kWh daily with the refrigerator having an average power rating of 1.20kW used for 12hrs daily being the highest energy consumer. While, DVD/CD player being the least consumer has an average power rating of

0.01kW for 5hrs duration of use daily. Table 4.2 presents energy consumption in nuclear household.

Table 4.2: Energy consumed in Nuclear Households per Day

S/N	Appliances	Household Average		Energy consumed
		Power rating (kW)	Duration of use/day (hrs)	(kWh)
1	Pressing iron	1.38	0.16	0.22
2	Television	0.92	10	9.20
3	DVD/CD player	0.01	5	0.05
4	Blender	0.59	0.33	0.19
5	Laptop	0.08	5	0.40
6	Electric kettle	2.30	0.33	0.76
7	Stabilizer	0.51	10	5.10
8	Refrigerator	1.20	15	18.00
9	Ring boiler	2.40	0.25	0.60
10	Microwave oven	1.17	0.33	0.39
11	Toaster	1.09	0.33	0.36
12	Vacuum cleaner	1.75	0.50	0.88
13	Air conditioner	1.87	10	18.7
14	Fan	0.08	10	0.80
15	Water heater	5.00	0.25	1.25
16	Electric bulb	0.04	10	0.40
			Total	**57.30**

Source: Field Survey, 2012

A total of 16 appliances were identified consuming up to 57.30kWh daily in nuclear household type with the refrigerator and air conditioner being the major consumers for up to 18 kWh daily and least is also the DVD/CD player as in single member household type. Table 4.3 shows the various appliances/ systems that consume energy in shared household type.

Table 4.3: Energy consumed in Shared Households per Day

S/N	Appliances	Household Average		Energy consumed
		Power rating (kW)	Duration of use/day (Hrs.)	(kWh)
1	Pressing iron	1.38	0.50	0.69
2	Television	0.92	5	4.60
3	DVD/CD player	0.01	5	0.05
4	Blender	0.59	0.33	0.19
5	Laptop	0.08	5	0.40
6	Electric kettle	2.30	0.33	0.76
7	Stabilizer	0.51	10	5.10
8	Refrigerator	1.20	10	12.0
9	Ring boiler	2.40	0.33	0.79
10	Air conditioner	1.87	10	18.70
11	Fan	0.08	10	0.80
12	Electric bulb	0.04	10	0.40
			Total	**44.48**

Source: Field Survey, 2012

In the case of shared household, 5 appliances were found consuming energy for up to 10hrs. These are stabilizer, refrigerator, fan, electric bulb and AC with the highest consumption of up to 18.70 kWh daily. The household has 44.48 kWh total daily energy consumption and less when compared with nuclear household type.

Table 4.4: Energy consumed in Extended Households per Day

S/N	Appliances	Household Average		Energy consumed
		Power rating (kW)	Duration of use/day (Hrs.)	(kWh)
1	Pressing iron	1.38	0.75	1.04
2	Television	0.92	12	11.04
3	DVD/CD player	0.01	7	0.07
4	Blender	0.59	0.50	0.30
5	Laptop	0.08	5	0.40
6	Electric kettle	2.30	0.50	1.15
7	Stabilizer	0.51	15	7.65
8	Refrigerator	1.20	15	18.00
9	Ring boiler	2.40	0.33	0.80
10	Microwave oven	1.17	0.75	0.88
11	Air conditioner	1.87	10	18.70
12	Fan	0.08	12	0.96
13	Electric bulb	0.04	10	0.40
			Total	**61.39**

Source: Field Survey, 2012

Extended or Joint household is the highest consumer amongst the different household types with consumptions of up to 61.39 kWh being the largest and Table 4.5 shows the nature of the energy consumption in collective living household.

Table 4.5: Energy consumed in Collective living Households per Day

S/N	Appliances	Household Average		Energy consumed
		Power rating (kW)	Duration of use/day (Hrs.)	(kWh)
1	Pressing iron	1.38	0.50	0.69
2	Television	0.92	5	4.60
3	DVD/CD player	0.01	5	0.05
4	Blender	0.59	0.33	0.19
5	Laptop	0.08	5	0.40
6	Electric kettle	2.30	0.33	0.76
7	Stabilizer	0.51	10	5.10
8	Refrigerator	1.20	12	14.40
9	Ring boiler	2.40	0.33	0.80
10	Air conditioner	1.87	10	18.70
11	Fan	0.08	10	0.80
12	Electric bulb	0.04	10	0.40
			Total	**46.89**

Source: Field Survey, 2012

The energy consumption in collective living seems not different with the other household types as it has the same pattern with a Lap top computer as an additional appliance there is also found in provider-manager household type. Table 4.6 also shows the energy consumption in provider-manager household type.

Table 4.6: Energy consumed in Provider-managed Households per Day

S/N	Appliances	Average		Energy consumed
		Power rating (kW)	Duration of use/day (Hrs.)	(kWh)
1	Pressing iron	1.38	0.50	1.29
2	Television	0.92	10	9.20
3	DVD/CD player	0.01	10	0.10
4	Blender	0.59	0.50	0.30
5	Laptop	0.08	6	0.48
6	Electric kettle	2.30	0.75	1.73
7	Stabilizer	0.51	12	6.12
8	Refrigerator	1.20	12	14.4
9	Ring boiler	2.40	0.25	0.60
10	Air conditioner	1.87	10	18.70
11	Fan	0.08	10	0.80
12	Electric bulb	0.04	15	0.60
			Total	**54.32**

Source: Field Survey, 2012

The power ratings of appliances in this provider-manager household type is the same with the other household type and it is the duration of use and the number of appliances that gives the difference in the amount of energy consumed. Provider-manager household has a total of 54.32kWh energy consumption daily with a total of 12 appliances in use. Generally, plug appliances have the highest number of equipments in the residential buildings in which some have low energy demand and some has high electric energy demand. Consequently, some have short duration of usage with high power rating such as ring boiler, while some have long duration of usage with low power rating such as DVD/CD player and refrigerator except were the old type is still in use.

Table 4.7 presents the established average energy demand of various household types per day, week, month and annual for comparison. It also presents the averages of daily, weekly, monthly and annual demand of Nigerian household.

Table 4.7: Established average energy demand of various household types

S/N	Household Type	Established average energy demand (kWh)			
		Daily	Weekly	Monthly	Annually
1	Single Member	26.95	188.65	808.50	9702.00
2	Nuclear	57.30	401.10	1719.00	20628.00
3	Shared	44.48	311.36	1334.40	16012.80
4	Extended	61.39	429.73	1841.70	22100.00
5	Collective living	46.89	328.23	1406.70	16880.40
6	Provider Managed	54.32	380.24	1629.69	19555.20
	Average of household energy demand	48.56	339.89	1456.67	17479.73

Source: Field Survey, 2012

With the establishment of the energy demand of various household types and their averages, it is imperative to assess the insolation potential of the study area to come up with exact monthly average of mean daily solar radiation of each location.

4.2 INSOLATION POTENTIALS OF NORTH WESTERN NIGERIA

The data collected from the field were sorted analysed and presented in a long term average of 22years for satellite measurements of sunshine, ambient temperature and insolation values and 10years ground measurements of ambient temperature and sunshine hours with 30years insolation values. It is therefore, presented in Tables 4.8–4.14 for comparison between the ground and satellite measurements. It can be noted from Table 4.11 that, Insolation data is not available in Jigawa state as there is no any Airport where the airdrome station is located and in Table 4.14 there is no ground measurement of ambient temperature in Kebbi state. Thus, satellite measurements were used in the two (2) locations where there is no ground measurement.

Table 4.8: Long term Average of metrological data in Kaduna state

Months	Location: Kaduna					Latitude: 10.52				
	Sunshine (hrs)		Ambient Temperature (^{o}c)						Insolation (KwH/m^2/day)	
	Ground (10yrs LTA)	Satellite (22yrs LTA)	Ground (10yrs LTA)			Satellite (22yrs LTA)			Ground (30yrs LTA)	Satellite (22yrs LTA)
			Min	Max	Δ T	Min	Max	Δ T		
Jan	7.9000	11.5	18.7	30.2	11.5	17.2	40.4	23.2	6.1	5.73
Feb	8.1333	11.8	16.2	30.4	14.2	18.7	42.9	24.2	6.6	6.00
Mar	7.1222	12.0	20.0	35.0	15.0	21.2	42.6	21.4	6.8	6.38
Apr	7.9778	12.3	18.0	35.0	17.0	22.0	36.0	14	6.6	6.84
May	8.0000	12.6	19.0	34.0	15.0	21.9	32.4	10.5	6.0	6.65
Jun	8.2444	12.7	18.0	33.0	15.0	21.4	29.8	8.4	5.6	6.36
Jul	6.2556	12.6	17.0	32.0	15.0	20.8	28.2	7.4	5.2	6.48
Aug	5.4000	12.4	16.0	35.0	19.0	20.4	28.8	8.4	5.2	6.65
Sep	6.7778	12.2	15.0	29.0	14.0	20.6	30.6	10	5.6	6.46
Oct	8.1444	11.9	13.0	32.0	19.0	19.4	32.6	13.2	5.9	6.13
Nov	9.0222	11.6	28.1	36.8	8.7	17.9	38.5	20.6	6.4	6.20
Dec	8.6333	11.5	16.4	32.9	16.5	17.3	39.2	21.9	6.1	5.58

Table 4.9: Long term Average of metrological data in Kano state

Months	Location: Kano					Latitude: 12.00				
	Sunshine (hrs)		Ambient Temperature (^{o}c)						Insolation (KwH/m^2/day)	
	Ground (10yrs LTA)	Satellite (22yrs LTA)	Ground (10yrs LTA)			Satellite (22yrs LTA)			Ground (30yrs LTA)	Satellite (22yrs LTA)
			Min	Max	Δ T	Min	Max	Δ T		
Jan	7.5556	11.5	13.8	31.1	17.3	14.3	41.8	27.5	5.9	5.57
Feb	7.0444	11.7	16.6	32.8	16.2	15.4	44.8	29.4	6.6	6.42
Mar	7.0111	12.0	20.2	36.3	16.1	19.7	50.0	30.3	6.9	6.97
Apr	6.9000	12.3	24.3	40.1	15.8	22.8	48.9	26.1	7.0	7.39
May	7.7667	12.6	24.7	38.9	14.2	23.6	42.7	19.1	6.6	7.34
Jun	7.3556	12.8	23.2	34.8	11.6	22.5	35.0	12.5	6.1	7.06
Jul	7.1000	12.7	21.5	31.8	10.3	21.9	31.0	9.1	5.6	6.76
Aug	7.5333	12.5	21.0	30.8	9.8	21.8	31.5	9.7	5.6	6.69
Sep	7.5111	12.2	21.7	32.1	10.4	21.6	33.8	12.2	5.9	6.41
Oct	7.3111	11.8	20.8	34.4	13.6	20.6	43.0	23	6.2	6.15
Nov	8.0889	11.5	16.3	33.9	17.6	17.9	45.2	27.3	6.1	5.81
Dec	7.3889	11.4	14.2	30.2	16.0	15.0	41.4	26.4	5.7	5.37

Table 4.10: Long term Average of metrological data in Katsina state

Months	Location: Katsina					Latitude: 13.06				
	Sunshine (hrs)		Ambient Temperature (^{o}c)						Insolation (KwH/m^2/day)	
	Ground (10yrs LTA)	Satellite (22yrs LTA)	Ground (10yrs LTA)			Satellite (22yrs LTA)			Ground (30yrs LTA)	Satellite (22yrs LTA)
			Min	Max	Δ T	Min	Max	Δ T		
Jan	7.8333	11.4	10.7	36.9	26.2	13.4	41.1	27.7	5.9	5.60
Feb	8.6444	11.7	12.3	37.8	25.5	14.7	44.8	30.1	6.6	6.47
Mar	8.3222	12.0	16.0	39.2	23.2	18.8	50.8	32.0	7.1	7.12
Apr	8.2667	12.4	19.4	40.6	21.2	22.3	51.4	29.1	7.1	7.56
May	8.3556	12.7	19.3	42.0	22.7	23.6	44.9	21.3	6.7	7.54
Jun	7.7556	12.8	18.5	39.9	21.4	22.7	36.9	14.2	6.3	7.48
Jul	7.2333	12.8	18.3	37.0	18.7	22.1	31.8	9.7	5.8	7.30
Aug	7.5667	12.5	19.1	37.0	17.9	21.8	32.3	10.5	5.7	7.01
Sep	7.1444	12.2	18.0	36.4	18.4	21.5	35.3	13.8	5.8	6.67
Oct	8.2444	11.8	18.3	37.3	19.0	20.3	45.3	25.3	5.7	6.26
Nov	8.4222	11.5	14.1	37.9	23.8	17.2	45.5	28.3	6.2	5.90
Dec	6.9000	11.3	11.7	36.0	24.3	14.2	41.1	27.0	5.8	5.38

Table 4.11: Long term Average of metrological data in Jigawa state

Months	Location: Jigawa					Latitude: 11.78				
	Sunshine (hrs)		Ambient Temperature (^{o}c)						Insolation (KwH/m^2/day)	
	Ground (10yrs LTA)	Satellite (22yrs LTA)	Ground (10yrs LTA)			Satellite (22yrs LTA)			Ground (30yrs LTA)	Satellite (22yrs LTA)
			Min	Max	Δ T	Min	Max	Δ T		
Jan	8.6111	11.5	12.0	29.6	17.6	15.1	42.1	27.0	Absent	5.64
Feb	8.7667	11.7	13.2	31.3	18.1	16.4	45.1	28.7	Absent	6.34
Mar	8.3556	12.0	18.5	35.5	17.0	20.6	49.2	28.6	Absent	6.77
Apr	8.1333	12.3	22.9	38.2	15.3	23.2	46.8	23.6	Absent	7.14
May	8.4000	12.6	24.3	37.2	12.9	23.4	40.8	17.4	Absent	7.05
Jun	9.0333	12.8	23.8	35.9	12.1	22.3	34.1	11.8	Absent	6.73
Jul	7.8667	12.7	22.6	33.3	10.7	21.7	30.6	8.9	Absent	6.63
Aug	7.1222	12.5	20.1	29.9	9.8	21.5	31.1	9.6	Absent	6.67
Sep	8.3889	12.2	20.1	31.8	11.7	21.4	33.3	11.9	Absent	6.46
Oct	8.8667	11.8	20.2	33.9	13.7	20.5	40.6	20.1	Absent	6.10
Nov	9.0889	11.5	16.6	33.1	16.5	18.3	44.1	25.8	Absent	5.71
Dec	8.9333	11.4	12.0	29.6	17.6	15.8	41.4	25.6	Absent	5.34

Table 4.12: Long term Average of metrological data in Zamfara state

Months	Location: Zamfara								Latitude: 12.16	
	Sunshine (hrs)		Ambient Temperature (^{o}c)						Insolation (KwH/m^2/day)	
	Ground (10yrs LTA)	Satellite (22yrs LTA)	Ground (10yrs LTA)			Satellite (22yrs LTA)			Ground (30yrs LTA)	Satellite (22yrs LTA)
			Min	Max	Δ T	Min	Max	Δ T		
Jan	7.6333	11.5	22.1	36.5	14.4	14.9	42.2	27.3	6.0	5.57
Feb	8.2556	11.7	25.5	38.2	12.7	16.2	45.2	29.0	6.7	6.35
Mar	7.500	12.0	29.0	40.5	11.5	19.8	49.2	29.4	7.1	6.86
Apr	7.8444	12.4	31.3	41.8	10.5	22.5	47.1	24.6	7.0	7.21
May	7.7778	12.6	28.9	40.9	12.0	23.3	40.8	17.5	6.4	7.25
Jun	8.2333	12.8	26.3	39.4	13.1	22.5	33.8	11.3	6.0	7.14
Jul	7.0556	12.7	24.9	38.9	14	22.0	30.7	8.7	5.5	6.82
Aug	6.7889	12.5	24.5	36.5	12.0	21.8	31.1	9.3	5.4	6.72
Sep	7.9444	12.2	26.3	36.2	9.9	21.6	33.0	11.4	5.8	6.51
Oct	8.5778	11.8	27.0	36.9	9.9	20.2	40.5	20.3	6.4	6.15
Nov	8.2556	11.5	26.7	37.4	10.7	17.7	45.1	27.7	6.6	5.71
Dec	8.0111	11.4	26.6	38.2	11.6	15.4	42.0	26.6	5.9	5.32

Table 4.13: Long term Average of metrological data in Sokoto state

Months	Location: Sokoto								Latitude: 13.05	
	Sunshine (hrs)		Ambient Temperature (^{o}c)						Insolation (KwH/m^2/day)	
	Ground (10yrs LTA)	Satellite (22yrs LTA)	Ground (10yrs LTA)			Satellite (22yrs LTA)			Ground (30yrs LTA)	Satellite (22yrs LTA)
			Min	Max	Δ T	Min	Max	Δ T		
Jan	8.1778	11.4	17.14	33.26	16.1	14.9	42.0	27.1	5.8	5.56
Feb	8.5000	11.7	19.85	35.86	16.0	16.2	45.6	29.4	6.4	6.47
Mar	7.5444	12.0	23.45	39.72	16.3	20.0	51.4	31.4	6.8	7.06
Apr	7.2556	12.4	27.19	41.43	14.2	23.2	52.7	29.5	6.8	7.49
May	8.3889	12.7	27.40	39.67	12.3	24.6	46.5	21.9	6.2	7.42
Jun	8.6889	12.8	25.59	36.39	10.8	23.6	38.8	15.2	6.0	7.45
Jul	7.9000	12.8	23.83	32.65	8.8	22.8	33.3	10.5	5.3	7.24
Aug	8.5000	12.5	22.93	31.03	8.1	22.3	32.9	10.6	5.3	6.96
Sep	8.0889	12.2	26.26	32.56	6.3	22.1	35.3	13.3	5.6	6.66
Oct	8.4333	11.8	22.94	35.58	12.6	21.1	44.8	23.7	5.9	6.24
Nov	8.4667	11.5	20.44	36.82	16.4	18.2	46.3	28.1	5.9	5.88
Dec	8.0000	11.3	17.72	33.89	16.2	15.7	42.2	26.5	5.6	5.36

Table 4.14: Long term Average of metrological data in Kebbi state

Months	Location: Kebbi					Latitude: 12.45				
	Sunshine (hrs)		Ambient Temperature (^{o}c)						Insolation (KwH/m^2/day)	
	Ground (10yrs LTA)	Satellite (22yrs LTA)	Ground (10yrs LTA)			Satellite (22yrs LTA)			Ground (30yrs LTA)	Satellite (22yrs LTA)
			Min	Max	Δ T	Min	Max	Δ T		
Jan	8.9889	11.4	Absent	Absent	Absent	16.8	43.7	26.9	9.6	5.41
Feb	8.4333	11.7	Absent	Absent	Absent	18.0	46.5	28.5	10.3	6.34
Mar	7.5111	12.0	Absent	Absent	Absent	21.6	50.7	29.1	10.7	6.86
Apr	7.8444	12.4	Absent	Absent	Absent	24.5	50.7	26.2	10.6	7.12
May	7.8667	12.7	Absent	Absent	Absent	25.0	44.6	19.6	9.8	7.18
Jun	7.7556	12.8	Absent	Absent	Absent	23.7	37.6	13.9	9.2	7.13
Jul	6.2222	12.7	Absent	Absent	Absent	22.9	32.9	10.0	8.6	6.87
Aug	5.8111	12.5	Absent	Absent	Absent	22.5	32.5	10.0	8.5	6.79
Sep	7.1222	12.2	Absent	Absent	Absent	22.3	34.4	12.1	8.7	6.60
Oct	8.4889	11.8	Absent	Absent	Absent	21.7	42.4	20.7	9.3	6.17
Nov	8.2667	11.5	Absent	Absent	Absent	19.5	46.3	26.8	9.9	5.76
Dec	8.5000	11.4	Absent	Absent	Absent	17.3	43.3	26.0	9.6	5.30

Extraterrestrial Radiations (Ho) of the twenty one (21) Locations of the study area were computed using equation (2.5) in MJ/m^2/day and converted to KwH/m^2/day for homogeneity and as presented in Tables 4.15 – 4.21.

Table 4.15: Monthly Average Daily Extraterrestrial Radiations (KwH/m^2/day) of Locations (Ho) Kaduna State

Mnts	n	δ	Kaduna	Lat. 10.52		Zaria	Lat. 11.07		Kafanchan	Lat. 9.58	
			N	ω_s	H_o	N	ω_s	H_o	N	ω_s	H_o
Jan	17	-20.91	11.46	85.93	8.81	11.43	85.71	8.65	11.53	86.30	8.94
Feb	47	-12.94	11.67	87.55	9.55	11.66	87.42	9.50	11.70	87.77	9.64
Mar	75	-2.40	11.94	89.55	10.22	11.94	89.53	10.19	11.95	89.60	10.25
Apr	105	-9.43	12.24	91.77	10.54	11.75	88.14	9.56	11.79	88.39	9.64
May	135	18.81	12.48	93.63	10.46	12.51	93.82	10.49	12.44	93.30	10.40
Jun	162	23.09	12.61	94.54	10.32	12.64	94.79	10.36	12.55	94.13	10.24
Jul	198	21.17	12.55	94.13	10.34	12.58	94.35	10.38	12.50	93.75	10.27
Aug	228	13.43	12.34	92.54	10.44	12.36	92.68	10.46	12.44	93.31	10.41
Sep	258	2.19	12.05	90.41	10.32	12.06	90.43	10.27	12.05	90.37	10.29
Oct	288	-9.63	11.76	88.19	9.70	11.75	88.10	9.66	11.78	88.36	9.78
Nov	318	-18.93	11.51	86.35	8.96	11.49	86.15	8.98	11.56	86.68	9.07
Dec	344	-23.06	11.39	85.46	8.52	11.36	85.22	8.48	11.45	85.88	8.69

Table 4.16: Monthly Average Daily Extraterrestrial Radiations (KwH/m^2/day) of Locations (Ho) Katsina State

Mnts	n	δ	Katsina Lat. 13.06			Daura Lat. 13.04			Funtua Lat. 11.53		
			N	ω_s	H_o	N	ω_s	H_o	N	ω_s	H_o
Jan	17	-20.91	11.32	84.91	8.48	11.32	84.92	8.48	11.40	85.53	8.68
Feb	47	-12.94	11.59	86.94	9.31	11.59	86.95	9.31	11.64	87.31	9.46
Mar	75	-2.40	11.93	89.44	10.10	11.93	89.44	10.10	11.93	89.51	10.18
Apr	105	-9.43	11.71	87.79	9.36	11.71	87.79	9.36	11.74	88.06	9.49
May	135	18.81	12.60	94.53	10.61	12.60	94.53	10.61	12.53	93.99	10.52
Jun	162	23.09	12.76	95.68	10.50	12.75	95.67	10.52	12.67	94.99	10.40
Jul	198	21.17	12.69	95.16	10.52	12.69	95.15	10.51	12.60	94.53	10.41
Aug	228	13.43	12.42	93.18	10.52	12.42	93.17	10.52	12.37	92.79	10.48
Sep	258	2.19	12.07	90.51	10.21	12.07	90.51	10.23	12.06	90.45	10.26
Oct	288	-9.63	11.70	87.74	9.49	11.70	87.75	9.49	11.73	88.01	9.62
Nov	318	-18.93	11.39	85.44	8.84	11.39	85.44	8.48	11.47	85.99	8.91
Dec	344	-23.06	11.24	84.33	8.19	11.25	84.34	8.20	11.35	85.09	8.42

Table 4.17: Monthly Average Daily Extraterrestrial Radiations (KwH/m^2/day) of Locations (Ho) Kano State

Mnts	n	δ	Kano Lat. 12.00			Tudun Wada Lat. 12.03			Gwarzo Lat 11.55		
			N	ω_s	H_o	N	ω_s	H_o	N	ω_s	H_o
Jan	17	-20.91	11.38	85.34	8.62	11.38	85.32	8.62	11.40	85.52	8.68
Feb	47	-12.94	11.63	87.20	9.41	11.63	97.19	9.41	11.64	87.31	9.46
Mar	75	-2.40	11.93	89.49	10.55	11.93	89.49	10.15	11.93	89.51	10.18
Apr	105	-9.43	11.73	87.98	9.45	11.73	87.97	9.46	11.74	88.05	9.49
May	135	18.81	12.55	94.15	10.55	12.55	94.16	10.55	12.53	93.99	10.52
Jun	162	23.09	12.69	95.20	10.44	12.69	95.21	10.44	12.67	95.00	10.40
Jul	198	21.17	12.63	94.72	10.44	12.63	94.74	10.45	12.66	94.54	10.41
Aug	228	13.43	12.39	92.91	10.49	12.39	92.92	10.49	12.37	92.80	10.48
Sep	258	2.19	12.06	90.47	10.24	12.06	90.48	10.24	12.06	90.45	10.26
Oct	288	-9.63	11.72	87.93	9.58	11.72	87.93	9.58	11.73	88.01	9.62
Nov	318	-18.93	11.44	85.82	8.78	11.44	85.81	8.76	11.46	85.98	8.41
Dec	344	-23.06	11.31	84.81	8.35	11.31	84.80	8.34	11.33	85.01	8.41

Table 4.18: Monthly Average Daily Extraterrestrial Radiations (KwH/m^2/day) of Locations (Ho) Jigawa State

Mnts	n	δ	Dutse Lat 11.78			Hadeja Lat. 12.45			Kazaure Lat. 12.65		
			N	ω_s	H_o	N	ω_s	H_o	N	ω_s	H_o
Jan	17	-20.91	11.39	85.43	8.65	11.35	85.16	8.56	11.34	85.08	8.53
Feb	47	-12.94	11.63	87.25	9.43	11.61	87.09	9.37	11.61	87.04	9.35
Mar	75	-2.40	11.93	89.50	10.16	11.93	89.47	10.13	11.93	89.46	9.95
Apr	105	-9.43	11.73	88.01	9.46	11.72	87.90	9.41	11.71	87.86	9.41
May	135	18.81	12.53	94.01	10.54	12.57	94.31	10.56	12.59	94.39	10.59
Jun	162	23.09	12.68	95.10	10.42	12.72	95.40	10.47	12.73	95.49	10.49
Jul	198	21.17	12.62	94.63	10.43	12.65	94.91	10.48	12.67	94.99	10.49
Aug	228	13.43	12.38	92.86	10.48	12.40	93.02	10.50	12.41	93.07	10.51
Sep	258	2.19	12.06	90.46	10.25	12.06	90.48	10.23	12.67	90.50	10.51
Oct	288	-9.63	11.73	87.97	9.60	11.71	87.85	9.26	11.71	87.82	9.53
Nov	318	-18.93	11.45	85.90	8.80	11.42	85.66	8.72	11.41	85.58	8.69
Dec	344	-23.06	11.32	84.91	8.38	11.28	84.61	8.29	11.27	84.52	8.26

Table 4.19: Monthly Average Daily Extraterrestrial Radiations (KwH/m^2/day) of Locations (Ho) Zamfara State

Mnts	n	δ	Gusau Lat. 12.16			Talatan Mafara Lat 12.56			Kauran Namoda Lat. 12.60		
			N	ω_s	H_o	N	ω_s	H_o	N	ω_s	H_o
Jan	17	-20.91	11.38	85.32	8.62	11.35	85.12	8.54	11.35	85.10	8.54
Feb	47	-12.94	11.62	87.16	9.41	11.61	87.06	9.36	11.61	87.06	9.35
Mar	75	-2.40	11.93	89.49	10.15	11.93	86.46	10.13	11.93	89.46	10.12
Apr	105	-9.43	11.73	87.97	9.44	11.72	87.88	9.40	11.72	87.87	9.40
May	135	18.81	12.56	94.17	10.56	12.59	94.35	10.58	12.58	94.37	10.58
Jun	162	23.09	12.70	95.23	10.44	12.73	95.45	10.48	12.73	95.47	10.49
Jul	198	21.17	12.63	94.75	10.45	12.66	94.95	10.48	12.66	94.97	10.51
Aug	228	13.43	12.39	92.93	10.48	12.41	93.05	10.51	12.41	93.06	10.51
Sep	258	2.19	12.06	90.47	10.24	12.07	90.49	10.23	12.07	90.49	10.23
Oct	288	-9.63	11.72	87.92	9.58	11,71	87.83	9.53	1171	87.83	9.53
Nov	318	-18.93	11.44	85.80	8.77	12.58	94.38	8.59	11.41	85.60	8.70
Dec	344	-23.06	11.30	84.78	8.34	11.27	84.56	8.27	11.27	84.54	8.26

Table4.20: Monthly Average Daily Extraterrestrial Radiations (KwH/m^2/day) of Locations (Ho) Sokoto State

Mnts	n	δ	Sokoto Lat. 13.05			Isah Lat. 13.20			Tambuwal Lat. 12.40		
			N	ω_s	H_o	N	ω_s	H_o	N	ω_s	H_o
Jan	17	-20.91	11.32	84.92	8.48	11.31	84.86	8.46	11.36	85.18	8.56
Feb	47	-12.94	11.59	86.95	9.18	11.59	86.91	9.29	11.61	87.10	9.37
Mar	75	-2.40	11.93	89.44	10.10	11.93	89.44	10.69	11.66	87.47	10.13
Apr	105	-9.43	11.71	87.80	9.36	13.04	87.77	9.35	11.72	87.91	9.42
May	135	18.81	12.60	94.53	10.61	12.61	94.58	10.62	12.57	94.30	10.57
Jun	162	23.09	12.76	95.67	10.52	12.77	95.74	10.53	12.72	95.38	10.47
Jul	198	21.17	12.69	95.15	10.52	12.69	95.21	10.53	12.65	94.89	10.47
Aug	228	13.43	12.42	93.17	10.52	12.43	93.21	10.52	12.40	93.01	10.50
Sep	258	2.19	12.07	90.51	10.22	12.07	90.51	10.21	12.06	90.48	10.23
Oct	288	-9.63	11.70	87.75	8.51	11.70	87.72	9.48	11.71	87.86	9.55
Nov	318	-18.93	11.39	85.44	8.64	11.38	85.38	8.63	11.42	85.67	8.73
Dec	344	-23.06	11.25	84.34	8.20	11.24	84.27	8.18	11.28	84.63	8.29

Table 4.21: Monthly Average Daily Extraterrestrial Radiations (KwH/m^2/day) of Locations (Ho) Kebbi State

Mnts	n	δ	B/kebbi	Lat. 12.45		Yawuri (Yalwa) lat.10.78			Zuru	Lat. 11.42	
			N	ω_s	H_o	N	ω_s	H_o	N	ω_s	H_o
Jan	17	-20.91	11.35	85.16	8.56	11.44	85.83	8.78	11.41	85.57	8.69
Feb	47	-12.94	12.39	92.91	9.31	11.67	87.49	9.53	11.65	87.34	9.47
Mar	75	-2.40	11.93	89.48	10.13	11.94	89.54	10.21	11.93	89.51	10.18
Apr	105	-9.43	11.72	87.90	9.41	11.76	88.19	9.55	11.74	88.08	9.49
May	135	18.81	12.57	94.31	10.56	12.50	93.72	10.48	12.53	93.95	10.52
Jun	162	23.09	12.72	95.40	10.47	12.62	94.66	10.34	12.66	94.94	10.39
Jul	198	21.17	12.65	94.91	10.48	12.56	94.23	10.33	12.60	94.49	10.41
Aug	228	13.43	12.40	93.02	10.50	12.35	92.61	10.43	12.37	92.78	10.47
Sep	258	2.19	12.06	90.48	10.23	12.06	90.42	10.28	12.06	90.44	10.26
Oct	288	-9.63	11.71	87.85	9.54	11.75	88.15	9.68	11.74	88.04	9.63
Nov	318	-18.93	11.42	85.66	8.72	11.50	86.25	8.93	11.47	86.03	8.85
Dec	344	-23.06	11.28	84.61	8.29	11.38	85.35	8.52	11.34	85.07	8.43

The study was designed to have the same solar design day (nth) in the whole 21 locations and therefore same solar declination ($\boldsymbol{\delta}$) values, while each location had its own hour angle (ω_s) and maximum monthly average daily length (N) values defined by their locations.

4.2.1 Derived Empirical Constants of Locations

The empirical constants of each of the seven states covered in the research were derived based on Micro soft plotter. Monthly ratio of $\frac{Hs}{Ho}$ against that of $\frac{\Delta T}{N}$ and $\frac{n_s}{N}$ for all the seven states were plotted in order to obtain the empirical constants and the trend line that display equation and R-square value on chart using scatter mode plotter. The constants *a* and *b* of both the temperature and sunshine base estimation model were derived and plotted. The details of the variables used are presented in Table 4.22. The scattered plot is also presented in Figures 4.1-4.7 with the summary of the empirical constants in Table 4.23.

Tables 4.22: Details of Variables $\frac{Hs}{Ho}$, $\frac{\Delta T}{N}$ and $\frac{n_s}{N}$ for the Seven States

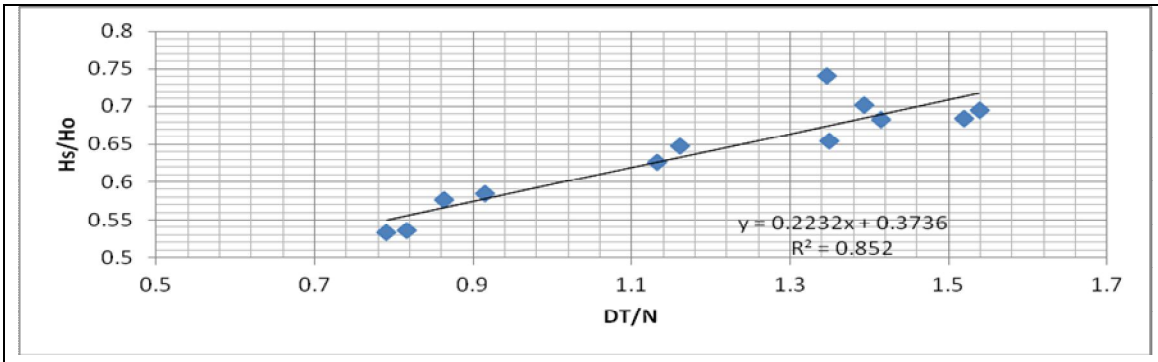
	Kaduna			Kano			Katsina		
Month	**DT/N**	**ns/N**	**Hs/Ho**	**DT/N**	**ns/N**	**Hs/Ho**	**DT/N**	**ns/N**	**Hs/Ho**
Jan	1.0035	0.6894	0.6924	1.5202	0.6639	0.6845	2.3145	0.6920	0.6958
Feb	1.2168	0.6969	0.6911	1.3929	0.6057	0.7014	2.2002	0.7458	0.7089
Mar	1.2563	0.5965	0.6654	1.3495	0.5877	0.6540	1.9447	0.6976	0.7029
Apr	1.3889	0.6518	0.6262	1.3469	0.5882	0.7404	1.8104	0.7060	0.7586
May	1.2019	0.6410	0.5736	1.1315	0.6189	0.6256	1.8016	0.6631	0.6315
Jun	1.1893	0.6538	0.5426	0.9141	0.5796	0.5843	1.6771	0.6078	0.6000
Jul	1.1952	0.4985	0.5029	0.8155	0.5622	0.5364	1.4736	0.5700	0.5513
Aug	1.5397	0.4376	0.4981	0.7909	0.6080	0.5338	1.4412	0.6092	0.5418
Sep	1.1618	0.5625	0.5426	0.8624	0.6228	0.5762	1.5244	0.5919	0.5681
Oct	1.6157	0.6926	0.6083	1.1604	0.6238	0.6472	1.6239	0.7046	0.6006
Nov	0.7559	0.7839	0.7143	1.5385	0.7071	0.6948	2.0896	0.7394	0.7014
Dec	1.4486	0.7580	0.7160	1.4147	0.6533	0.6826	2.1619	0.6139	0.7082

Tables 4.22 Continue

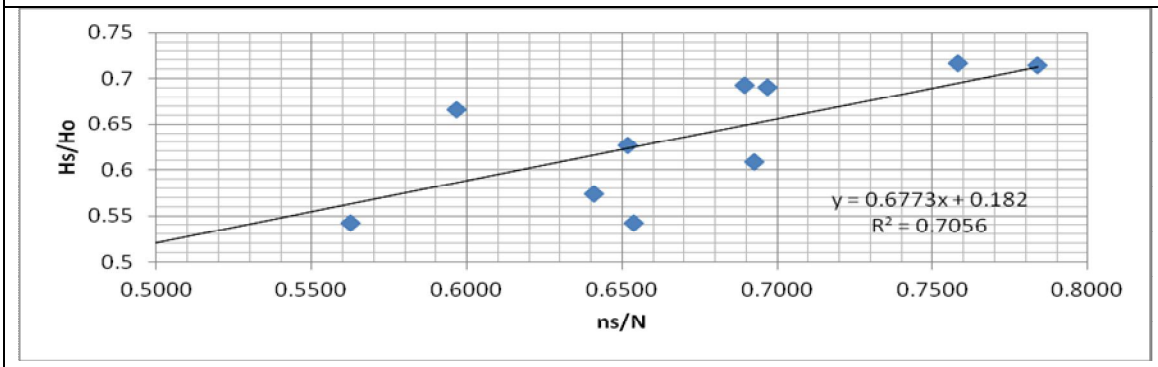
	Jigawa			Zamfara		
Month	**DT/N**	**ns/N**	**Hs/Ho**	**DT/N**	**ns/N**	**Hs/Ho**
Jan	1.5452	0.7560	0.6520	1.2654	0.6708	0.6961
Feb	1.5563	0.7538	0.6723	1.0929	0.7105	0.712
Mar	1.4249	0.7004	0.6663	0.9639	0.6287	0.6995
Apr	1.3044	0.6934	0.7548	0.8951	0.6687	0.7415
May	1.0295	0.6704	0.6689	0.9554	0.6193	0.6061
Jun	0.9543	0.7124	0.6459	1.0315	0.6483	0.5747
Jul	0.8479	0.6234	0.6357	1.1085	0.5586	0.5263
Aug	0.7916	0.5753	0.6365	0.9685	0.5479	0.5153
Sep	0.9702	0.6956	0.6302	0.8209	0.6587	0.5664
Oct	1.1679	0.7559	0.6354	0.8447	0.7319	0.6681
Nov	1.4416	0.7938	0.6489	0.9353	0.7216	0.7526
Dec	1.5548	0.7892	0.6372	1.0266	0.7089	0.7074

Tables 4.22 Continue

	Sokoto			Kebbi		
Month	**DT/N**	**ns/N**	**Hs/Ho**	**DT/N**	**ns/N**	**Hs/Ho**
Jan	1.4222	0.7224	0.6839	2.3700	0.7920	1.1215
Feb	1.3805	0.7334	0.6972	2.3000	0.6807	1.1063
Mar	1.3663	0.6324	0.6733	2.4392	0.6296	1.0563
Apr	1.2126	0.6196	0.7265	2.2355	0.6693	1.1265
May	0.9762	0.6658	0.5844	1.5593	0.6258	0.9280
Jun	0.8464	0.6809	0.5703	1.0928	0.6097	0.8787
Jul	0.6935	0.6225	0.5038	0.7905	0.4919	0.8206
Aug	0.6522	0.6844	0.5479	0.8065	0.4686	0.8095
Sep	0.5219	0.6702	0.5479	1.0033	0.5906	0.8504
Oct	0.0769	0.7208	0.6933	1.7677	0.7249	0.9748
Nov	1.4398	0.7433	0.6829	2.3468	0.7239	1.1353
Dec	1.4400	0.7111	0.6829	2.3049	0.7535	1.1580

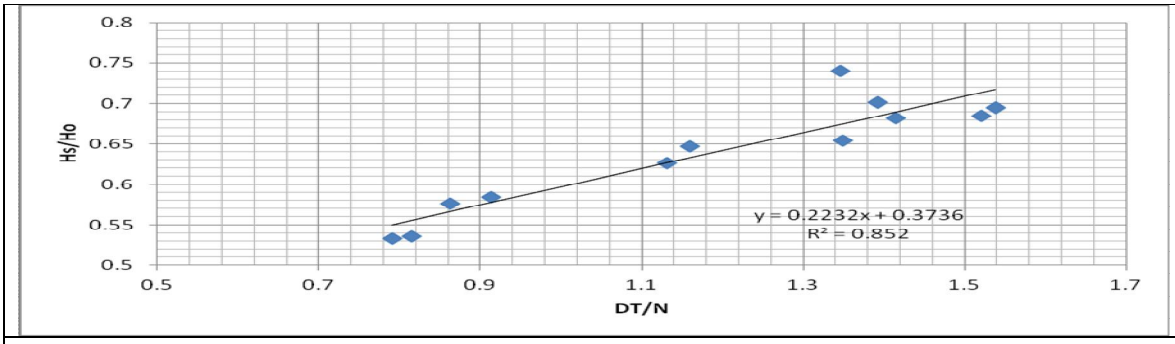


Temperature based

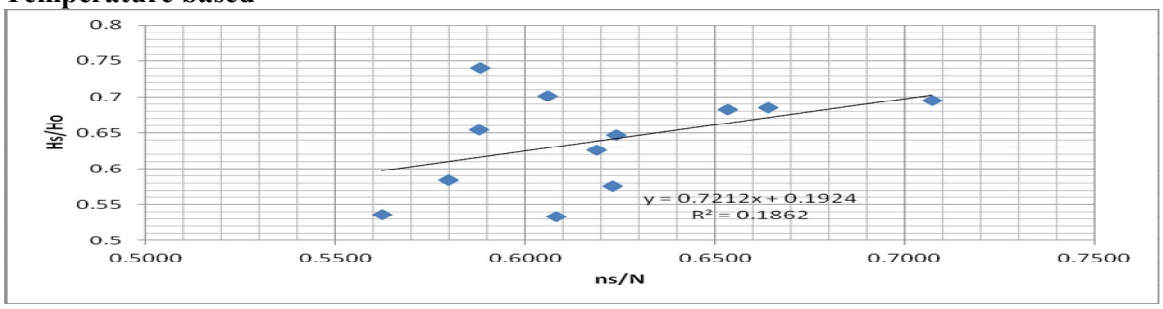


Sunshine based

Figure 4.1: Derived Empirical Constants of Kaduna state

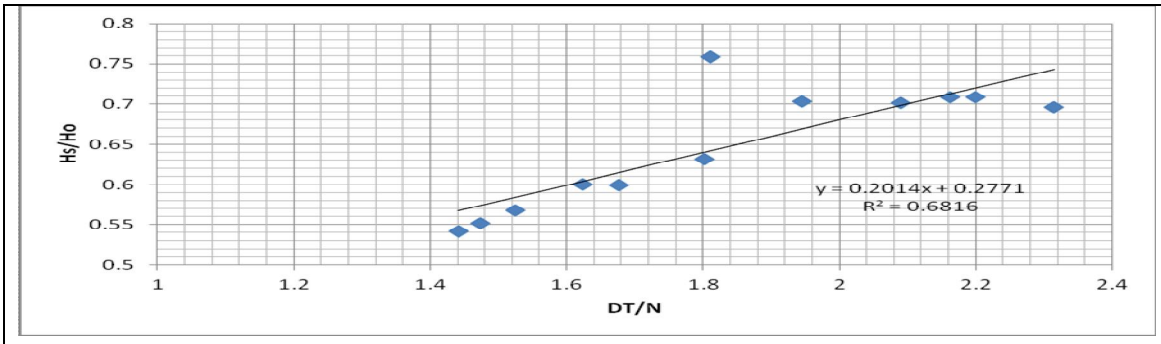


Temperature based

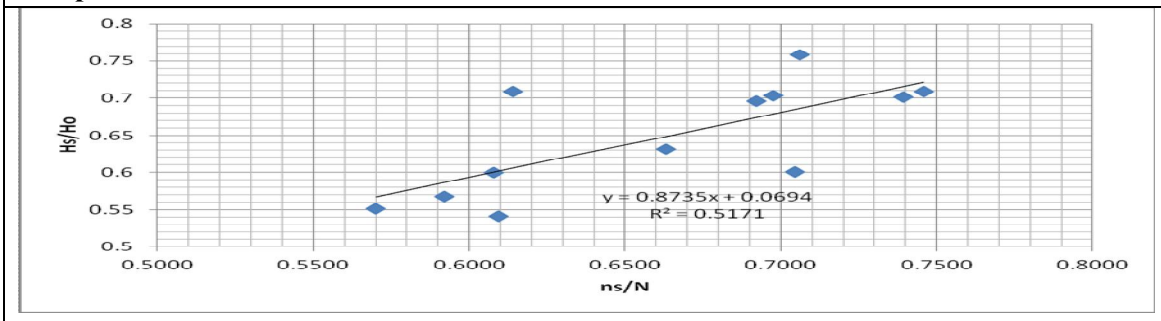


Sunshine based

Figure 4.2: Derived Empirical Constants of Kano state

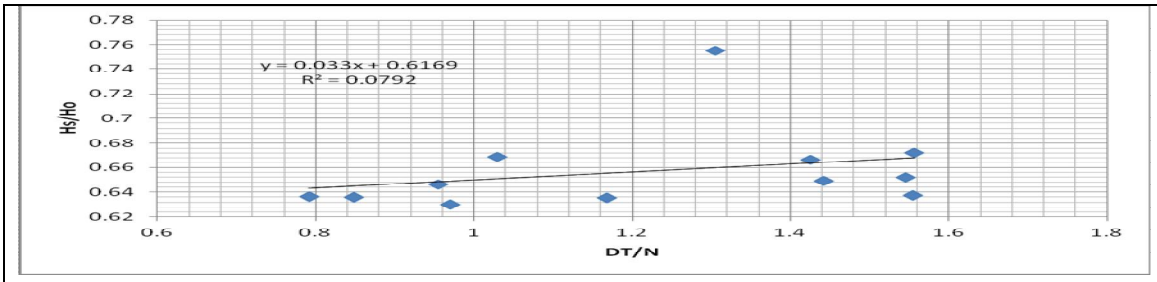


Temperature based

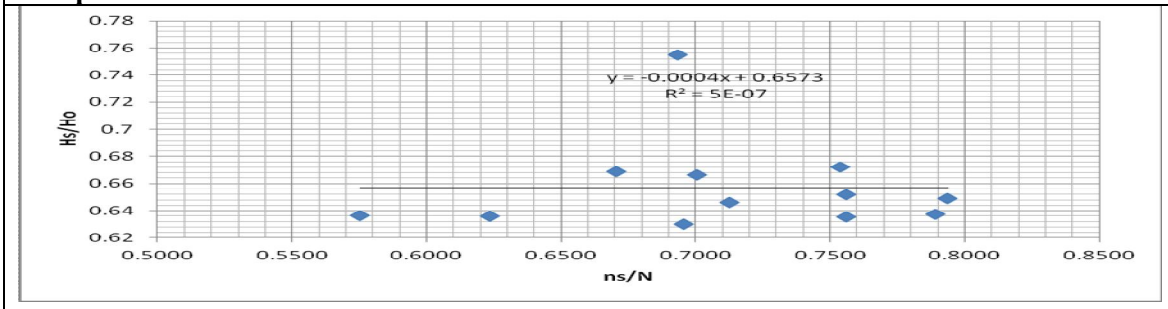


Sunshine based

Figure 4.3: Derived Empirical Constants of Katsina state

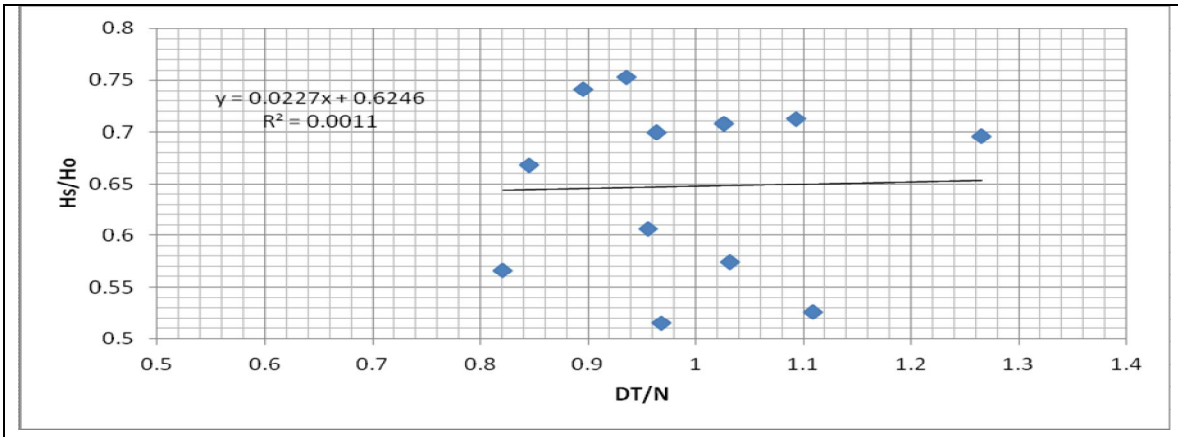


Temperature based

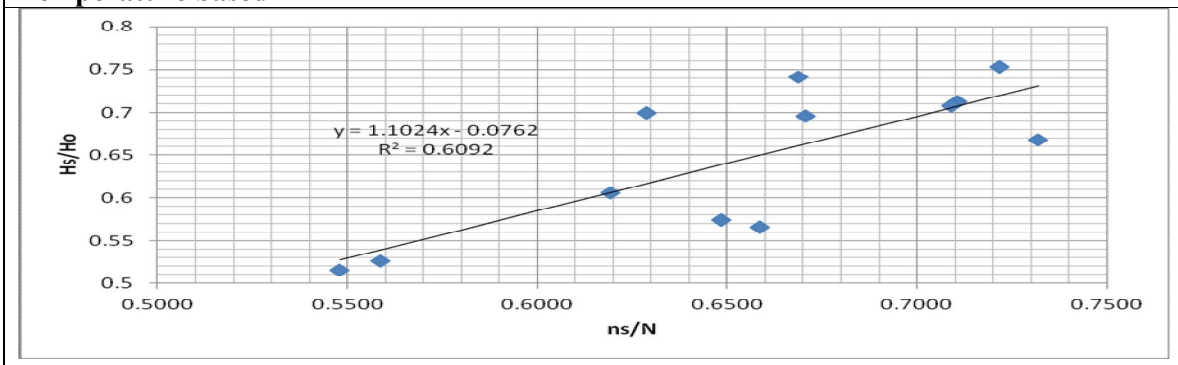


Sunshine based

Figure 4.4: Derived Empirical Constants of Jigawa state

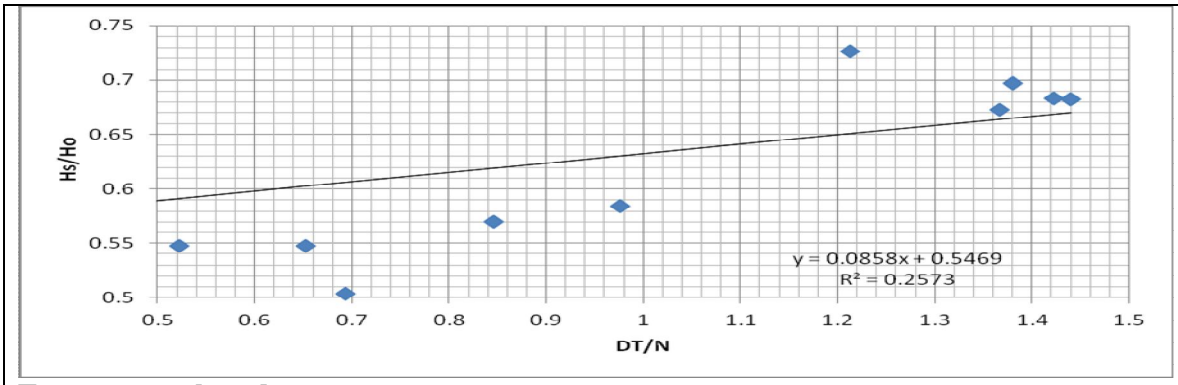


Temperature based

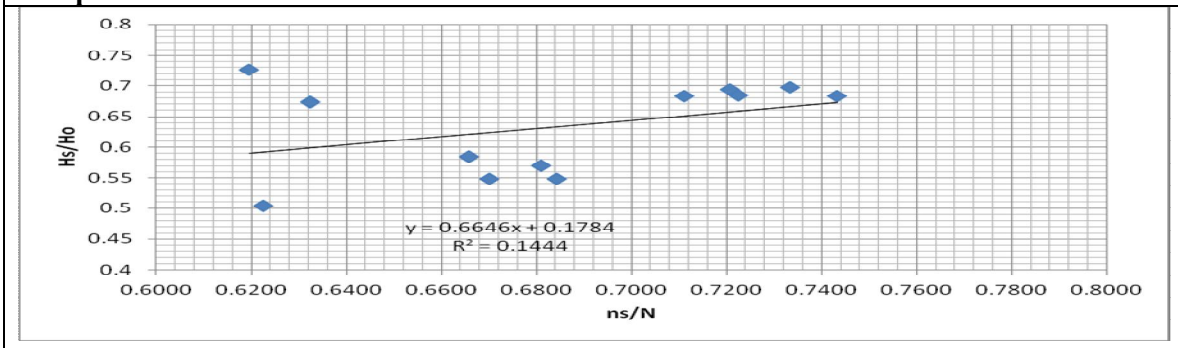


Sunshine based

Figure 4.5: Derived Empirical Constants of Zamfara state

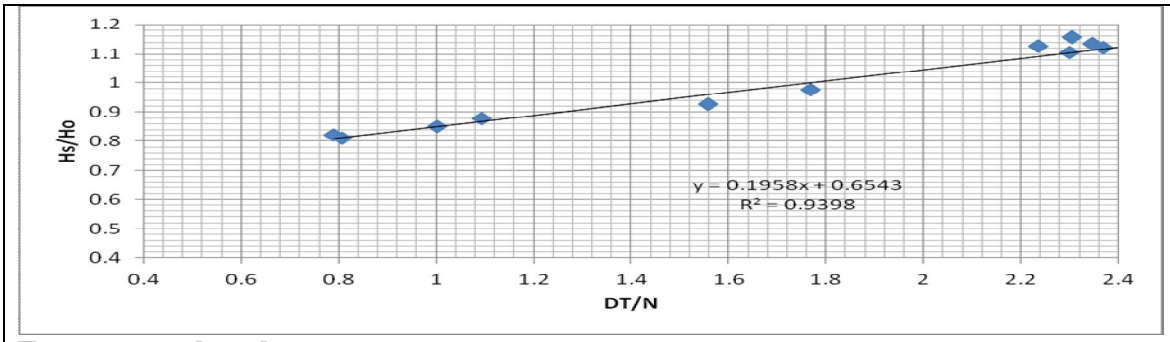


Temperature based

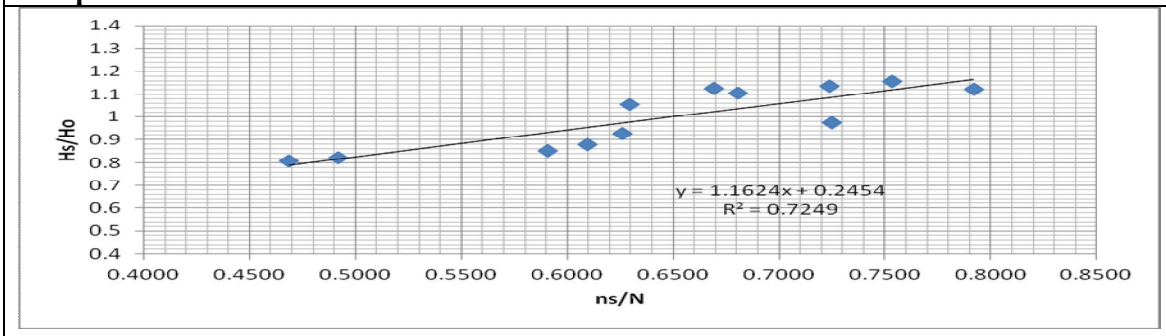


Sunshine based

Figure 4.6: Derived Empirical Constants of Sokoto state



Temperature based



Sunshine based

Figure 4.7: Derived Empirical Constants of Kebbi state

Table 4.23: Summary of Derived Empirical Constants of Location

S/n	Location or State	Empirical Constants			
		Temperature based		Sunshine based	
		a	b	a	B
1	Kaduna	0.373	0.223	0.182	0.677
2	Kano	0.373	0.223	0.192	0.721
3	Katsina	0.277	0.201	0.069	0.873
4	Jigawa	0.616	0.033	0.657	0.000
5	Zamfara	0.624	0.022	0.076	1.102
6	Sokoto	0.546	0.085	0.178	0.664
7	B/Kebbi	0.654	0.195	0.245	1.162

Based on the empirical constants derived summarized in Table 4.23 for each states, Equations (2.1) and (2.2) were used for the estimation (prediction) of insolation levels of the seven (7) locations using the sunshine and temperature based models respectively. The results are presented in Table 4.24

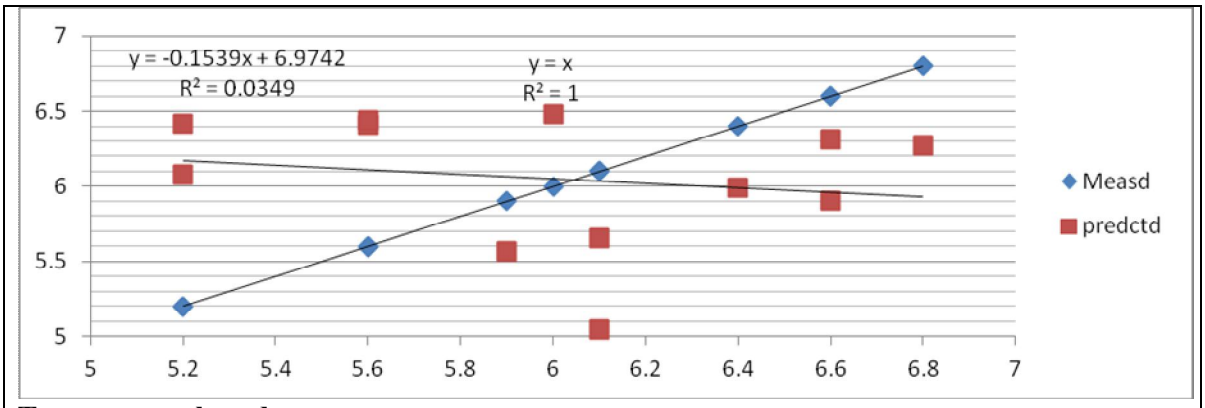
Table 4.24: Estimated insolation levels of the states (kWh/m^2/day)

Month	Kaduna		Kano		Katsina		Jigawa	
	Tempe Rapture	Sun Shine	Tempe rature	Sun Shine	Tempe rature	Sun shine	Tempe rature	Sun shine
Jan	5.6526	5.7149	6.1375	5.7814	6.2940	5.7079	5.7695	5.6830
Feb	5.9034	6.2440	6.4328	5.9162	6.6961	6.7043	6.2932	6.1955
Mar	6.2731	5.9871	7.1101	6.4958	6.7456	6.8477	6.7363	6.6751
Apr	6.3158	6.5691	6.3624	5.8223	5.9987	6.4143	6.2346	6.2152
May	6.4830	6.4430	6.5972	6.7329	6.7811	6.8744	6.8507	6.9247
Jun	6.4105	6.4460	6.0223	6.3675	6.4480	6.2959	6.7469	6.8459
Jul	6.4163	5.3711	5.7927	6.2359	6.0300	5.9607	6.7167	6.8525
Aug	6.0827	4.9929	5.7629	6.6126	5.9615	6.3210	6.7102	6.8853
Sep	6.4418	5.8080	5.7888	6.5643	5.9566	5.9804	6.6422	6.7342
Oct	5.5704	6.3133	6.0523	6.1481	5.7263	6.4926	6.2836	6.3072
Nov	5.9929	6.3855	6.2872	6.1617	6.1616	6.3164	5.8394	5.7816
Dec	5.0494	5.9226	5.7488	5.5363	5.8275	4.9542	5.592	5.5056

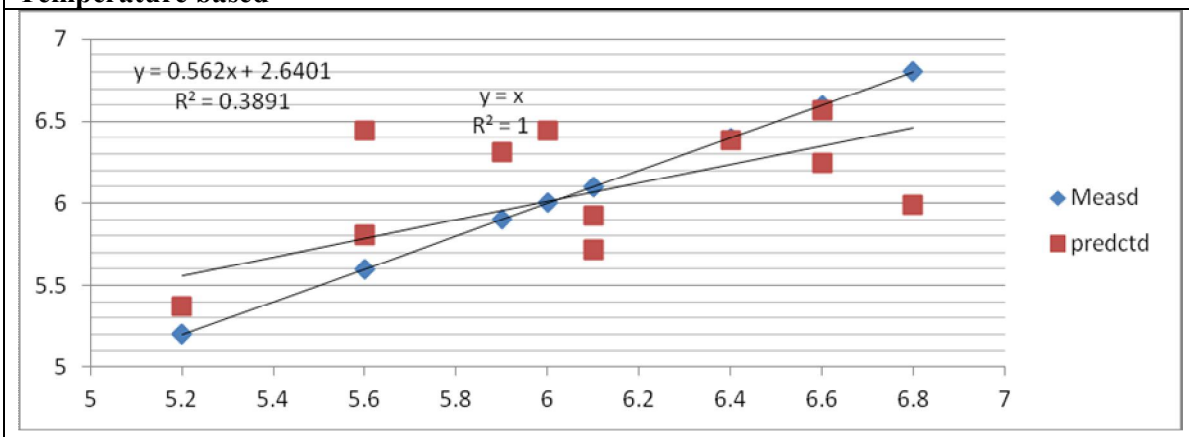
Tables 4.24 Continue

Month	Zamfara		Sokoto		Kebbi- Yawuri	
	Temperature	Sun shine	Temperature	Sunshine	Temperature	Sunshine
Jan	5.6189	7.0268	5.6552	5.5771	9.6993	9.9747
Feb	6.0981	8.0825	6.0895	6.1044	10.4407	9.6444
Mar	6.5488	7.8032	6.6876	6.0388	11.4407	9.8928
Apr	6.0765	7.6743	6.0753	5.5169	10.3434	9.6240
May	6.8114	8.0088	6.6734	6.5790	10.0788	10.2666
Jun	6.7515	8.2519	6.5008	6.6291	9.0091	9.9830
Jul	6.7756	7.2274	6.3640	6.2211	8.4130	8.5575
Aug	6.7628	7.1245	6.3271	6.6531	8.4940	8.2903
Sep	6.5747	8.2117	6.0335	6.3669	8.7177	9.5265
Oct	6.1559	8.4548	4.7021	5.5877	9.6175	10.3734
Nov	5.6529	7.6408	5.7748	5.8024	9.8379	9.4712
Dec	5.3925	7.1495	5.4809	5.3314	9.3021	9.2899

Thus, to analyze or evaluate the models, the measured values against estimated values were plotted and the correlation between them is used for validating the models for all the states in temperature and sunshine based models as described in the methodology. The details of the plots with slopes, intercept and R^2 are presented in Figure 4.8 to 4.14.

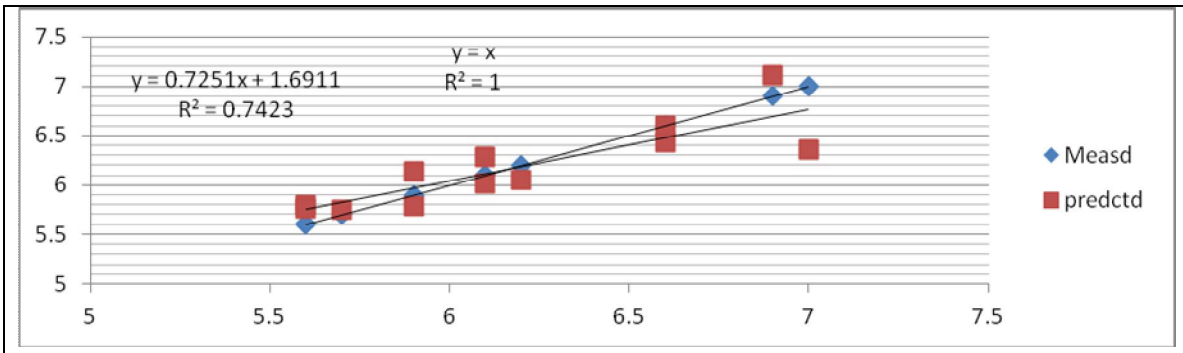


Temperature based

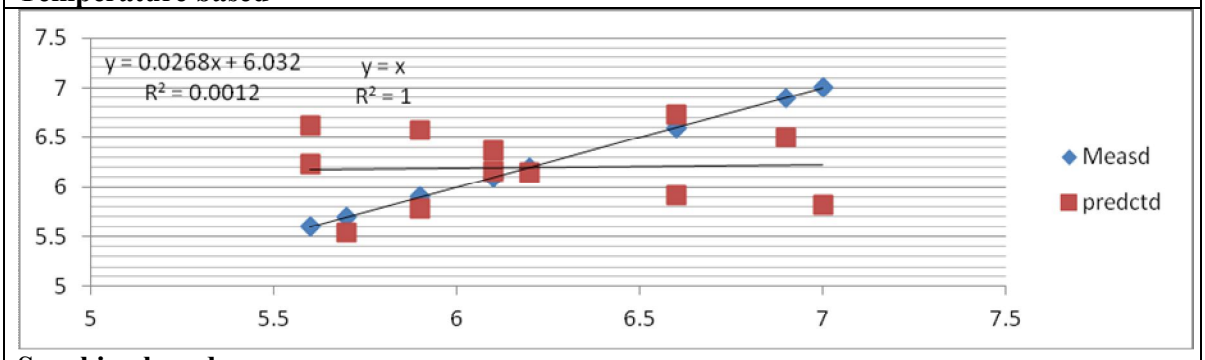


Sunshine based

Figure 4.8: Measured and Estimated insolation levels of Kaduna state

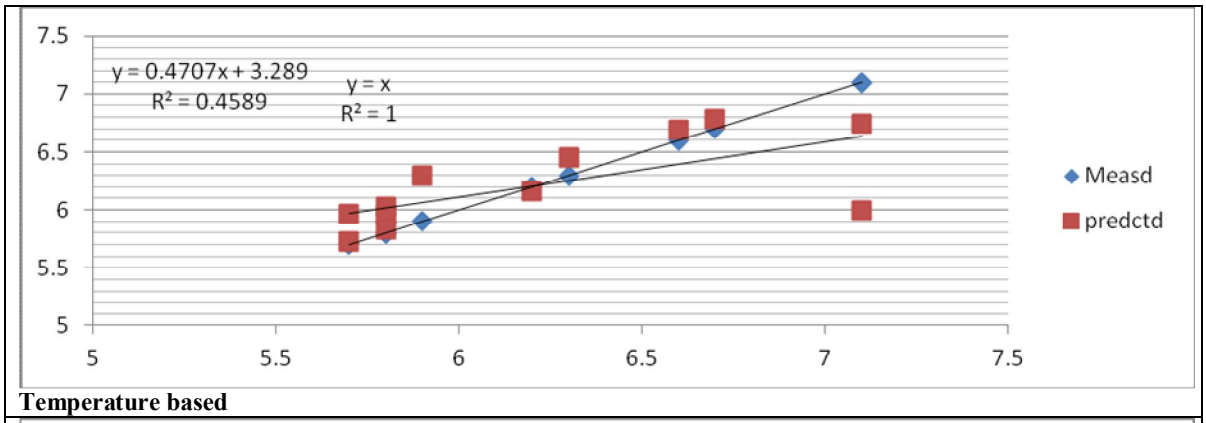


Temperature based

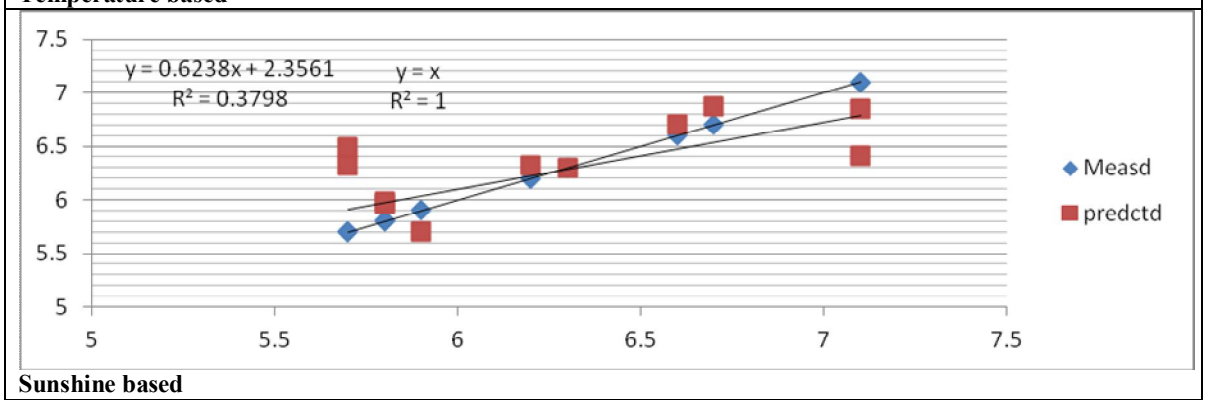


Sunshine based

Figure 4.9: Measured and Estimated insolation levels of Kano state

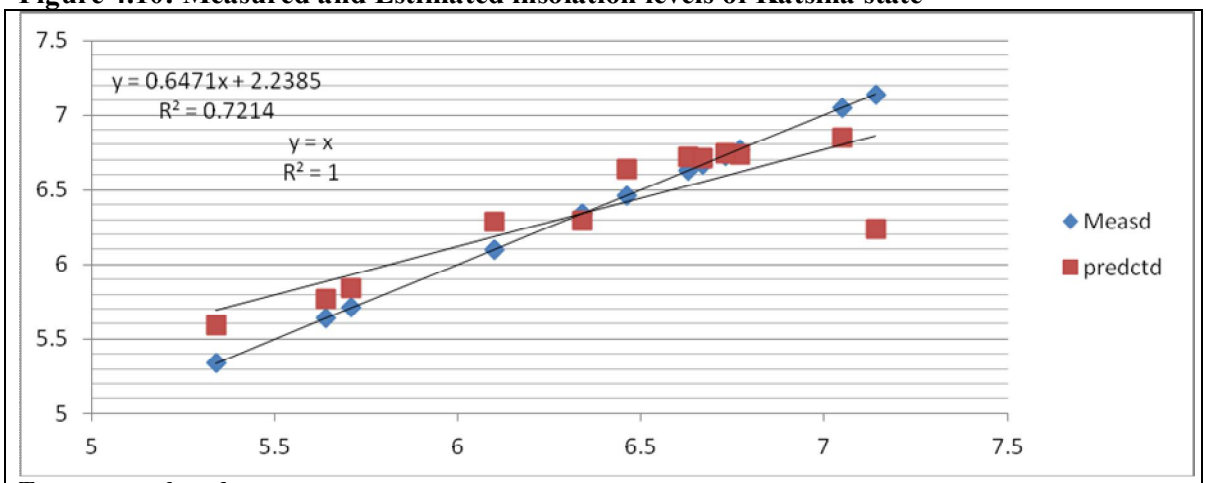


Temperature based

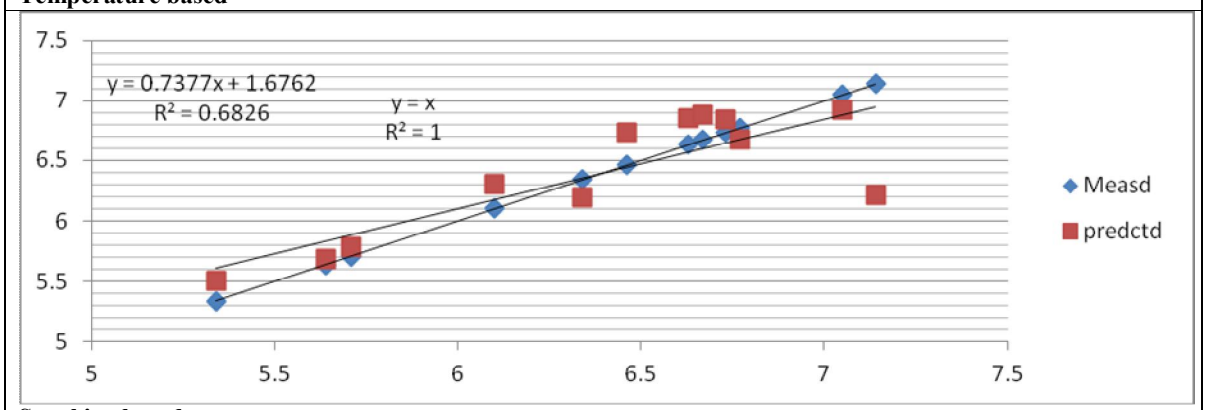


Sunshine based

Figure 4.10: Measured and Estimated insolation levels of Katsina state

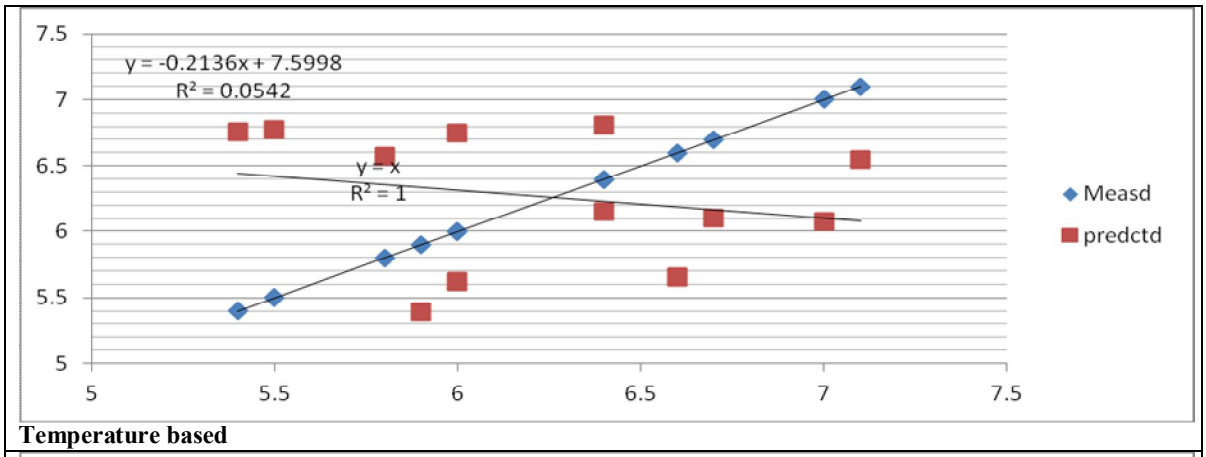


Temperature based

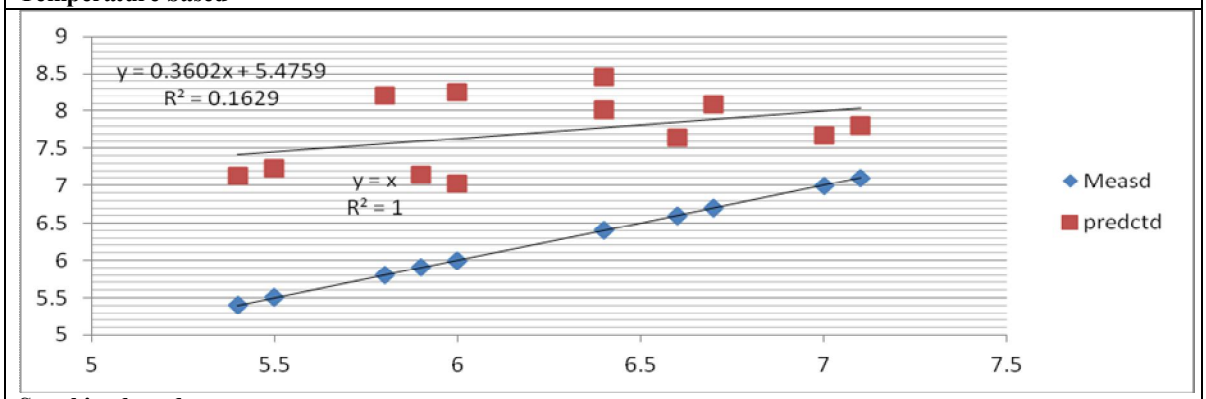


Sunshine based

Figure 4.11: Measured and Estimated insolation levels of Jigawa state

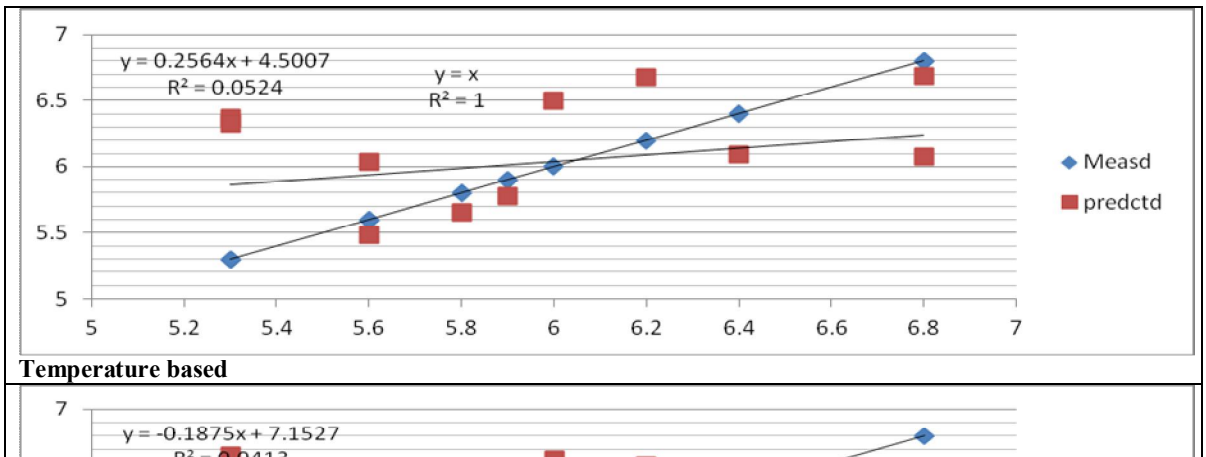


Temperature based

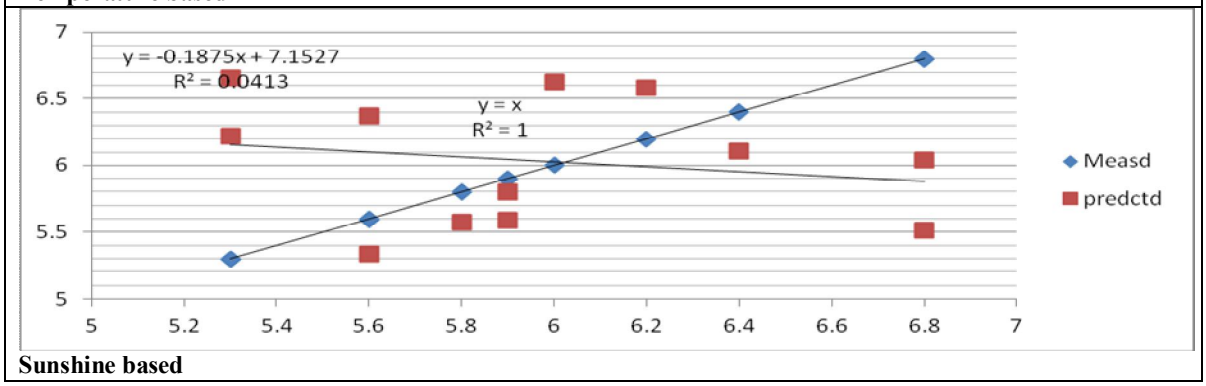


Sunshine based

Figure 4.12: Measured and Estimated insolation levels of Zamfara state

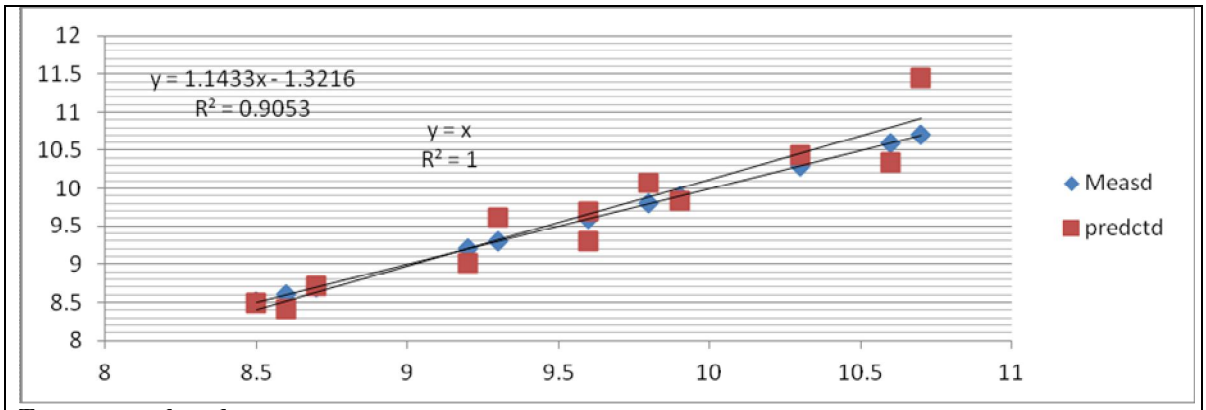


Temperature based

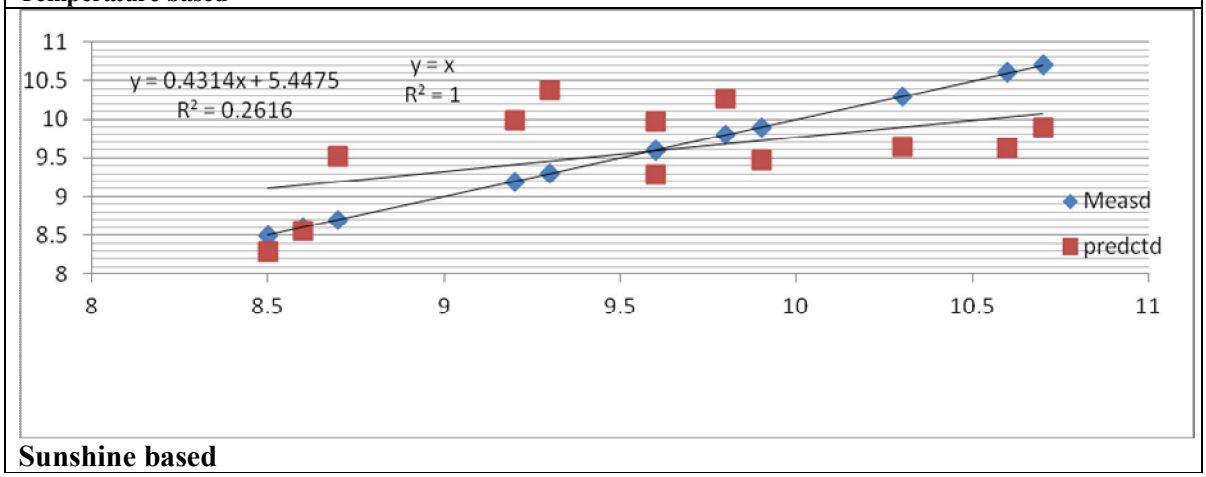


Sunshine based

Figure 4.13: Measured and Estimated insolation levels of Sokoto state



Temperature based



Sunshine based

Figure 4.14: Measured and Estimated insolation levels of Kebbi state (Yawuri)

As the accuracy of estimation is measured by the bias and the precision of its standard deviation earlier described in the methodology, the model validation was achieved through the values of the following quantities; Coefficient of determination (R^2), Mean Square Error (MSE), Root mean square (RMSE) and Coefficient of Residual Mass (CRM). The results of validation based on each state are presented in Table 4.25.

Table 4.25: Model Validation Indicators

State	R^2		RMSE		CRM	
	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine
Kaduna	0.6797	0.8117	0.7233	0.4249	0.4919	0.0982
Kano	0.6210	0.5184	0.2374	0.5792	-0.105	0.1755
Katsina	0.6045	0.8433	0.5242	0.3928	2.527	0.6704
Jigawa	0.8693	0.8503	0.8547	0.6835	4.3153	2.4062
Zamfara	0.9046	0.6210	0.9038	0.2374	3.1196	-0.105
Sokoto	0.9969	0.8964	0.7655	0.7002	0.2642	-1.7914
Kebbi	0.3583	0.6891	3.6320	3.4283	43.2942	40.6947

It is therefore noticed from Table 4.25 that, the model estimation is as accurate as the means of the observation based on the high percentages of the coefficient of determination, R^2 except with the case of temperature base model in Kebbi state. The values of RMSE show low and high precisions depending on the locations and more generous in the temperature base model. The models under estimate only in the case of Zamfara and Sokoto sunshine base estimation and Kano temperature base estimation due to negative values of CRM.

The models are therefore found suitable for estimating insolation values for any location in each of the states and Appendix 1presents the insolation levels of the other two locations. It also implies that, they can fit well in estimating insolation values in all locations within each of the state and locations with similar climatic variables. The estimated insolation levels of the twenty one (21) locations were also use to test the two (2) hypotheses raised using SPSS package. The test result in Table 4.26 for hypothesis 1shows there is no significant difference between the estimated (predicted) average monthly solar radiation value using sunshine hours and ambient temperature models in all the seven (7) locations. The conclusion was based on the paired sample t-statistic test that accept the H_o when $p > 0.05$.

Table 4.26: Paired sample t-statistic test results

Between Sunshine and Temperature base estimation	Paired Differences					t	Df	Sig. (2-tailed)
	Mean	Standard Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Kaduna State	.03287	.63289	.18270	-.36925	.43499	.180	11	.861
Kano State	-.24175	.42073	.12146	-.50907	.02557	-1.990	11	.072
Katsina State	.20153	.72327	.20879	-.25801	.66108	.965	11	.355
Jigawa State	.12767	.63433	.18311	-.27536	.53071	.697	11	.500
Zamfara State	.00615	.44726	.12911	-.27803	.29033	.048	11	.963
Sokoto State	-.04592	1.01358	.29259	-.68992	.59807	-.157	11	.878
Kebbi State	.17921	.78147	.22559	-.31732	.67573	.794	11	.444

Thus, the difference between the monthly variations of average mean daily solar radiation data of each city within the North-Western Nigeria cities under study was also tested. It is tested

using One-way analysis of variance (ANOVA) to validate whether the difference is significant i.e hypothesis 2. The test based on SPSS package Table 4.27 disclosed no significant difference as P< 0.05 and the null hypothesis was accepted.

Table 4.27: One-way analysis of variance (ANOVA) test

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	36.316	11	3.301	1.932	.049
Within Groups	123.036	72	1.709		
Total	159.353	83			

It therefore, follows that any minimum value taken for the design of SPV system would be sufficient within the study area, except where specificity and exact precision is required. Generally, the least monthly average insolation value estimated was 5.0257 KwH/m^2/day in December in Zaria, based on the temperature base model and the highest was 11 5337 KwH/m^2/day in Zuru based on temperature base model. This is in conformity with what Ojosu (1989), measured and presented as the average monthly average radiation level range in Nigeria of between 3.56kwH/m^2/day in harmattan period to about 8.05kwH/m^2/day during the hot seasons.

Consequently, there is over estimation in the case of three Location Insolation data of Kebbi state as confirmed by coefficient of residual mass (CRM) being high up to 43.2942 and 40.6947 for temperature and sunshine base models respectively. It is also interesting to note that, even the highest estimation value ‘more in the case of temperature based estimations in Kebbi state does not greatly over estimate the monthly average global solar radiation based on the validations and comparison with the measured values. Consequently, the over estimation may attribute to the use of satellite measurement instead of ground measurement.

4.2.2 Clearness Index (K_T) of the Locations

The clearness index (K_T) of locations is another important parameter that determines the insolation values and shows their qualities. However, it is possible to come-up with the monthly

average of the clearness index $K_T = \frac{H}{Ho}$ of the locations for both the temperature based model (H_{TP}) and the sunshine based model (H_{SS}) respectively. Table 4.28 present the Monthly Average of Clearness Index of the seven states location and Appendix 2 gives the other locations index.

Table 4.28: Monthly Average of Clearness Index of State Locations (K_T)

Month	Kaduna		Kano		Katsina		Dutse	
	$K_T = \frac{H_{TP}}{Ho}$	$K_T = \frac{H_{SS}}{Ho}$	$K_T = \frac{H_{TP}}{Ho}$	$K_T = \frac{H_{SS}}{Ho}$	$K_T = \frac{H_{TP}}{Ho}$	$K_T = \frac{H_{SS}}{Ho}$	$K_T = \frac{H_{TP}}{Ho}$	$K_T = \frac{H_{SS}}{Ho}$
Jan	0.6416	0.6487	0.7120	0.6707	0.7422	0.6731	0.6670	0.6570
Feb	0.6182	0.6538	0.6836	0.6287	0.7192	0.7201	0.6674	0.6570
Mar	0.6138	0.5858	0.6739	0.6157	0.6679	0.6780	0.6630	0.6570
Apr	0.5992	0.6233	0.6733	0.6161	0.6409	0.6853	0.6590	0.6570
May	0.6198	0.6160	0.6253	0.6382	0.6391	0.6479	0.6500	0.6570
Jun	0.6212	0.6246	0.5768	0.6099	0.6141	0.5996	0.6475	0.6570
Jul	0.6205	0.5195	0.5549	0.5973	0.5732	0.5666	0.6440	0.6570
Aug	0.5826	0.4783	0.5494	0.6304	0.5667	0.6009	0.6403	0.6570
Sep	0.6242	0.5628	0.5653	0.6410	0.5834	0.5857	0.6480	0.6570
Oct	0.5743	0.6509	0.6318	0.6418	0.6034	0.6842	0.6545	0.6570
Nov	0.6689	0.7127	0.7161	0.7018	0.6970	0.7145	0.6636	0.6570
Dec	0.5927	0.6951	0.6885	0.6630	0.7115	0.6049	0.6673	0.6570

Tables 4.28 Continue

Month	Gusau		Sokoto		Birnin Kebbi	
	$K_T = \frac{H_{TP}}{Ho}$	$K_T = \frac{H_{SS}}{Ho}$	$K_T = \frac{H_{TP}}{Ho}$	$K_T = \frac{H_{SS}}{Ho}$	$K_T = \frac{H_{TP}}{Ho}$	$K_T = \frac{H_{SS}}{Ho}$
Jan	0.6518	0.8152	0.6669	0.6577	-	-
Feb	0.6480	0.8589	0.6633	0.6650	-	-
Mar	0.6452	0.7688	0.6621	0.5979	-	-
Apr	0.6437	0.8130	0.6491	0.5894	-	-
May	0.6450	0.7584	0.6290	0.6201	0.9581	0.9845
Jun	0.6467	0.7904	0.6179	0.6301	0.8671	0.9981
Jul	0.6484	0.6916	0.6049	0.5914	0.8081	0.8196
Aug	0.6453	0.6798	0.6014	0.6324	0.8113	0.7510
Sep	0.6421	0.8019	0.5904	0.6230	0.8496	0.8981
Oct	0.6426	0.8825	0.5525	0.6566	0.9987	1.0532
Nov	0.6446	0.8713	0.6684	0.6716	-	-
Dec	0.6466	0.8573	0.6684	0.6502	-	-

The clearness index (K_T) of the locations in Table 4.28 and Appendix 2 conform with what was postulated by Folayan (1988) that, Nigeria fall between 25% - 70% from minimum to maximum and within the variation of 20%. It also conform with varying between 0.3 in very overcast climates to 0.8 for very sunny locations as postulated by Robert *et al* (2010) except in the case of

three (3) locations namely; Birnin kebbi, Yawuri and Zuru that are sunny enough to go beyond his postulations and due to overestimation.

It therefore remains suitable to come up with the sustainable way of designing the SHS that will enhance the implementation. The design criteria/method developed was also considered for electronic means (computer package) where SHSDK was developed and its features and capabilities are presented and discussed in the following section.

4.3. SOLAR HOME SYSTEM DESIGN

Step 1: Establish the basic energy demand (kWh) per day

a. Choose and establish the design basic energy demand depending on the following scenarios;

i) Adopt an established average of the household types energy demand in kWh.

ii) Adopt an established household type energy demand of your choice in kWh.

iii) Select household utilities, specify their duration of use and sum up their power ratings to establish your household energy demand in kWh.

b. Suggest a back-up time, a duration for which the electric energy is required to power the household appliances for the following options.

i) Off-grid system: when the households are to use PV system only for their electric energy need.

ii) Grid-supported system: when the households are to use PV system and national grid for their electric energy need. The duration in hrs for national grid power supply would be subtracted from the suggested back-up to establish the exact back-up time.

c. Suggest a system voltage: for the purpose of this design, 12 or 24 Voltage is recommended for effective battery size and efficient performance.

Caution: Designers should be aware of the fact that, duration in hours of power supply from National grid can never be stable. Therefore, a realistic duration should be decided for sizing the more efficient system components. Verification is also designed through computation immediately after sizing the battery. A designer may carry out several trials on various system voltages in order to come up with an effective battery capacity.

Step 2: Choose an insolation level of the location based on the town or a town close to it according to the following options.

a. Choose the least monthly average insolation level in kWh for off-grid system i.e not connected to grid.

b. Use the annual monthly average insolation level in kWh for grid-connected system with associated load shedding issues.

c. Use the maximum monthly average insolation level in kWh for grid-connection with low events of load shedding –i.e 70%-90% availability of utility power supply.

d. Provide the insolation level or peak sun hour of your interest. That is outside the provision/scope of this data bank. Indicate whether, least monthly average, annual average of the months or maximum monthly average.

Step 3: Size the basic components and accessories

i. Sizing the PV panel:

$$\text{PV panel needed (kW)} = \left(\frac{\text{Basic energy demand in kWh X (cf=1.65)*}}{\text{Insolation level or peak sun hours in hrs***}}\right) \text{X} \left(\frac{1}{\text{lf= 0.6722}}\right) \text{**} \quad \ldots\ldots\ldots\ldots\ldots 4.1$$

ii. Sizing the battery :

$$\text{Battery capacity needed (AHr)} = \left(\frac{\text{Back up time(hrs) X Basic load (Watts)}}{\text{System voltage x [lf = 0.6722]}}\right) \text{X } 1.5@ \quad \ldots.4.2$$

$$\text{Back-uptime (hrs)} = \frac{\text{System voltage (volts) X Battery capacity (AH) X [lf = 0.6722]}}{\text{Basic load (Watts)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 4.3$$

---

* A correction factor (cf) is required for efficiency, that is 1.1 for total efficiency and 1.5 for fudge factor this add to give 1.65 to be used as cf.

** This is a losses factor (lf) because SPV output decreases usually due to losses, such as that from standard test conditions (0.95%), temperature (0.89%), dirt and dust (0.93), mismatch and wiring losses (0.95%), and DC to AC conversion losses (0.90%). Consequently, an equivalent of 0.6722 of output factor (of) should be multiplied for optimization.

*** The term peak sun hours (hrs) refer to the solar insolation (kWh/m^2 per day) which a particular location would receive if the sun were shining at its maximum value for a certain number of hours. Therefore, the number of peak sun hours is numerically identical to the average daily solar insolation. For example, a location that receives 8kWh/m^2 per day can be said to have received 8 hours of sun per day at 1 kW/m^2.

@ This 1.5 is to provide an additional 50%efficiency due to depth of discharge (DOD)

Verification of Back-up time: Compute the back-up time based on the battery capacity decided, it should be less than or equal to selected back-up time.

i. Sizing the inverter:

Inverter size needed (VA) = Basic load in Watts + 25%

Verification of Inverter size

Multiply the Selected inverter capacity by loss factor [lf = 0.6722] and must be less than or equals to basic load.

ii. Sizing the charge controller:

Charge controller size needed (amps) = $\frac{\text{Power produce by panel(s) in Watts x [lf = 0.6722]}}{\text{Battery voltage in volts}}$ ……4.4

4.3.1 Solar Home System Design Kit (SHSDK)

Development of SHSDK is the fourth objective of this research work set to couple together objectives 1, 2 and 3 to come up with a means of SHS design for sustainable implementation of the technology. The design kit has been developed to be user friendly thereby a designer with an ordinary basic computer knowledge and skill can run the Kit and come up with the simplified design result. In essence, the design Kit has three (3) basic components namely; Database, Hypertext pre processor (PHP) and the Browser that were coupled to run and process result (s)

a) The database management system (DBMS) hosts the data in files and can be accessed through the following sequence of levels: Web server (Wamp is used in this Kit), local host, PHP myadmin and the list of SHSDK database files. Thus, the list of data base files is accessible either through local host then PHP myadmin or directly to PHP myadmin from Web server interface. The following is a list of some data base file of the SHSDK:

tbappliances,
tbannualaverage,
tbenergydemand and
tbleastmonthlyaverage.

b) The hypertext pre processor (PHP) is a server site scripting language used for making dynamic and interface web site. For this SHSDK it was achieved through coding or programming script language for various interfaces and sub-interfaces or windows for running the application towards designing the home system. PHP is accessible through C-drive, Wamp, www and the SHSDK file. However, the following Plates 1-3 are examples of the coding for creating a user, adding an appliance in database and printing out result respectively as contained in the PHP.

```
<form action='create_user.php'method='post'>
                <table border='0'width='30%'STYLE='margin-top:150px'align='center'>
                <tr>
                                <td>Email Address:</td>
                        <td><input type='text'name='username'id='username'></td>
                </tr>
                <tr>
                        <td>Password:</td>
                        <td><input type='text' name='password'></td>
                </tr>
                <tr>
                        <td colspan='2'align='center'><input type='submit'name='submit'
                        value='Submit'/><input type='submit'name='back' value='Back'/></td>
                </tr>
        </table>
</form>
```

Figure 4.15 Creating a user

```
<form action='add_appliances.php'method='post'>
        <table width='40%'cellspacing='10'cellpadding='5' align='center'>
                <tr>
                        <td>Appliance</td>
                        <td><input type='text' name='app'size='23px'/></td>
                </tr>
                <tr>
                        <td>Model</td>
                        <td><input type='text'name='model'size='23px'/></td>
                </tr>
                <tr>
                        <td>Power Rating</td>
                        <td><input type='text'name='power'size='23px'/></td>
                </tr>
                <tr>
                        <td colspan='2'align='center'><input type='submit'
                        name='submit'value='Enter'/><input type='submit'
                        name='back'value='Back'/></td>
                </tr>
        </table>
</form>
```

Figure 4.16 Adding an appliance in database

```
<table border='1'width='75%' style='border-collapse: collapse; margin-top: 5px;'align='center'>
        <tr>
                <td>S/N</td>
                <td class='no'>COMPONENTS</td>
                <td>REQUIRED SIZES</td>
        </tr>
        <tr>
                <td>1</td>
                <td class='no'>PV PANEL</td>
                <td>$pvsize  KW</td>
        </tr>
        <tr>
                <td rowspan='2'>2</td>
                <td class='no'>BATTERY</td>
                <td>$rbsize  AH</td>
        </tr>
</table>
```

Figure 4.17 Printing out result of Summary

It should also be noted at this juncture that, it is the MYSQL connect or select function that provides links between the scripting language and the database for dynamic and interface action or processes to be affected.

c) The Browser usually Internet Explorer or Firefox is set to provide a user interface for communication between the user and the SHSDK -i.e. the DBMS and PHP. For the purpose of this Kit local host of Wamp server must be active (online not off line) before the homepage interface is displayed for the administrator or user to login.

4.3.2 Basic stages of SHSDK Developed with some snapshot

The description of the basic stages of the design kit is now presented to provide a guide for user/designer to run the Kit developed for sustainable design of SHS. The SHSDK has several windows and interfaces that allow the designer to carry out the design processes. It has the following major stages or interfaces: Homepage, establishing household energy demand, suggesting a SHS type (off-grid or grid-supported), suggesting insolation level, sizing basic components and printing out results. The home page has the three (3) options of interface to enter either as an administrator, user/designer or to read the user guide -see Appendix 1 as shown in Plate 4.1.

If you login as administrator or user you are required to submit username and password and there is privilege to modify the account. Thus, for the Administrator an interface is provided immediately after login for five options; to create user, to run the application and to edit, delete or add appliances, insolation level or household data.



Plate 4.1 Snapshot of SHS Design Kit Home page

However, to run the application for designing SHS, a basic energy demand of household will be required and the interface shows the Kit provision of establishing household energy demand. There are eight options; six for adopting household type energy demand of one choice and one option for adopting their average and the other to select or enter appliances of one choice to established energy demand for any household as shown in Plate 4.2.

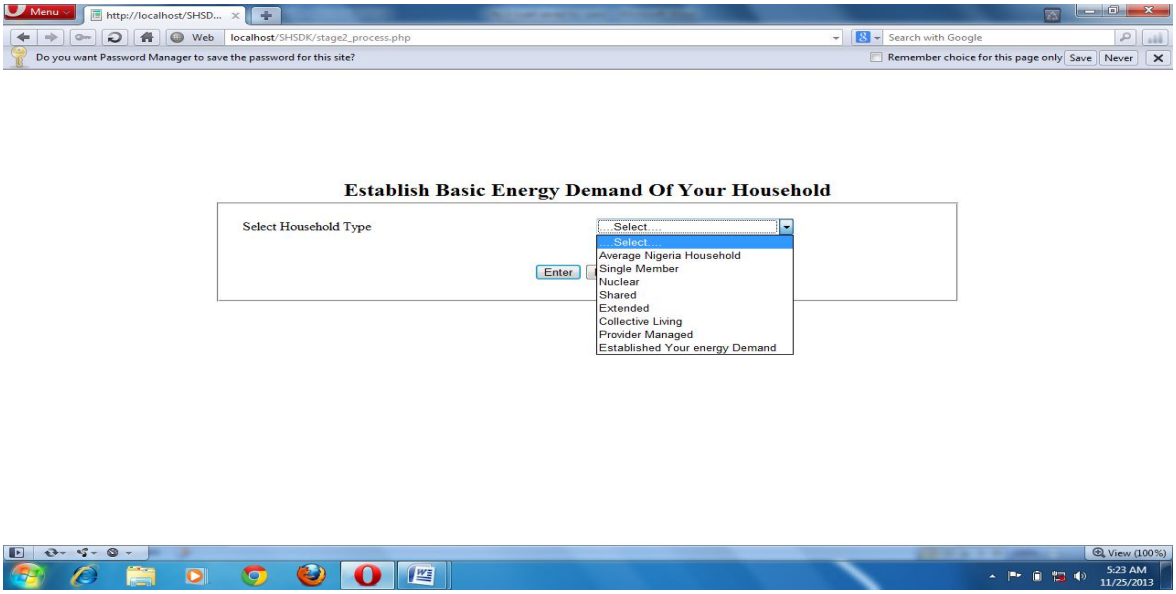


Plate 4.2 Snapshots for Establishing Household Energy Demand

Suggesting a SHS type is the next interface that provides means of suggesting either off-grid system or grid-supported system type of household with the backup time and system voltage. Duration of grid power supply will also be required in addition to for grid-supported system in order to appropriately size the battery system. A caution is also provided before the suggestion to draw the attention of designer for coming up with the appropriate backup time and grid power supply duration for sustainable battery size.

However, for suggesting insolation level, the Kit provides three options for the least, maximum and annual monthly average of twenty one (21) locations of north-western Nigeria. The last option is provided to allow the designer to provide his/her insolation level not covered by the twenty one (21) locations as shown in Plate 4.3.

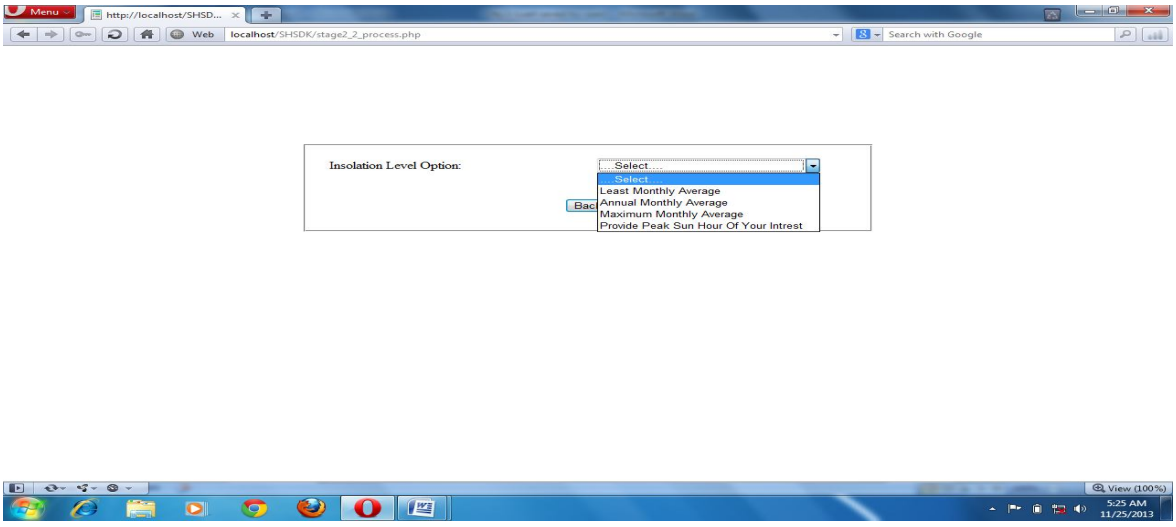


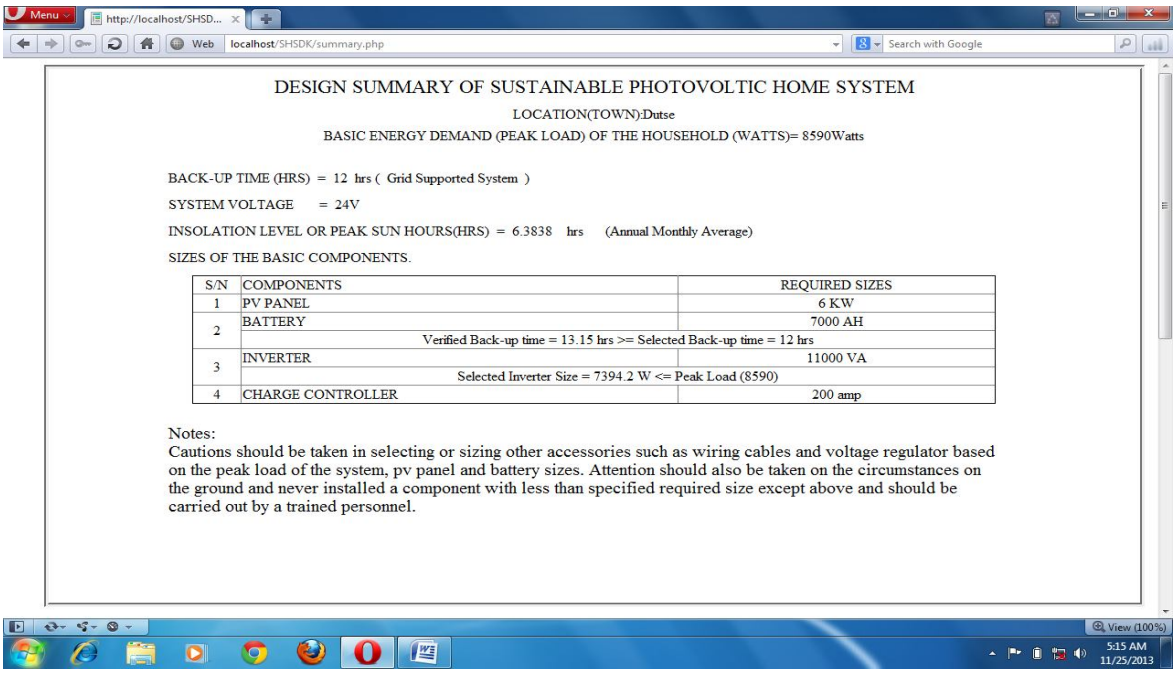
Plate 4.3 Snapshot of Selecting Insolation Level

As the household energy demand and insolation level are provided for a particular location, sizing basic components of home system begins and a snapshot of the interface is shown in Plate 4.4. The sizing has verification of the battery and invert size to ensure appropriateness in sizing the components for sustainable implementation of SHS.



Plate 4.4 Snapshot of Interface for Sizing Basic Components

With sizing the charge controller needed and clicking Ok as usual, the Kit would automatically take the designer to a print out results interface. The interface shows the basic data considered in the design and the basic component sizes with their verification where applicable as shown in Plate 4.5. The Kit is also designed to show the summary of the appliances that make up the household consumption for verification purposes.



DESIGN SUMMARY OF SUSTAINABLE PHOTOVOLTIC HOME SYSTEM

LOCATION(TOWN):Dutse

BASIC ENERGY DEMAND (PEAK LOAD) OF THE HOUSEHOLD (WATTS)= 8590Watts

BACK-UP TIME (HRS) = 12 hrs (Grid Supported System)

SYSTEM VOLTAGE = 24V

INSOLATION LEVEL OR PEAK SUN HOURS(HRS) = 6.3838 hrs (Annual Monthly Average)

SIZES OF THE BASIC COMPONENTS.

S/N	COMPONENTS	REQUIRED SIZES
1	PV PANEL	6 KW
2	BATTERY	7000 AH
	Verified Back-up time = 13.15 hrs >= Selected Back-up time = 12 hrs	
3	INVERTER	11000 VA
	Selected Inverter Size = 7394.2 W <= Peak Load (8590)	
4	CHARGE CONTROLLER	200 amp

Notes:
Cautions should be taken in selecting or sizing other accessories such as wiring cables and voltage regulator based on the peak load of the system, pv panel and battery sizes. Attention should also be taken on the circumstances on the ground and never installed a component with less than specified required size except above and should be carried out by a trained personnel.

Plate 4.5 Snapshot for Summary of result for print out

4.3.3 SHSDK Installation Requirement and Procedure

Software Requirement of the Kit was based on the notepad Text editor, version 2 of Wampserver and browsers such as Internet Explorer, Mozilla Firefox or Opera of any version. The hardware requirement of the Kit would conform to the following current hardware specifications were considered; HDD: 40GB, RAM: 1GB, Processor: Pentium 4.2 GHz, Operating system: any available Window (such as XP Professional, Vista and Window 7 or 8) Database engine: MySQL 5.5 version. However, for the installation the SHSDK three (3) basic documents are required; the script language, DBMS and the Wamp server and are to run in accordance with software requirement of the design Kit.

i) The scripting language will be installed as folder under www files/folder through Wamp directory in C-drive.

ii) The DBMS will also be imported as a folder in PHP myadmin under local host in web server (Wamp).

iii) Wamp server will also run as software in computer system hardware so as to provide a connection between User interface (Browser) and the SHSDK through MYSQL.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 SUMMARY OF MAJOR FINDINGS

Six household types: single member; nuclear; shared; extended; collective living and provider managed were identified in Nigeria. The study showed that the overall average monthly energy demand of the households is 1456.67 kWh. The extended or joint household recorded the highest average of 1841.70kWh per month while the single member household had the lowest (808.50kWh). Appliances or systems that consumed energy in residential building fall in to several categories with some having long duration of use and low energy consumption and some with short duration of use and high energy consumption.

Old or faulty appliances or systems ought to be replaced/retrofit due to their high energy consumption for energy optimization. The available power supply from the national grid falls short of the demand. The federal government of Nigeria is however showing much concern with the current power situation and seeking improvement of the condition through privatization, public private partnership and construction of new generating power plants though out the country.

The empirical constant of locations usually used in the estimation of insolation level derived in the study for each state conform with the established range and can also be used for other locations within each of the states. It was verified that both the sunshine and temperature based models are adequate for estimating insolation levels within the study area and there was no significant difference between the results. The clearness index of the locations conforms to an established average of 25%-70% and 20% variation within the locations except in Birnin Kebbi, Yawuri and Zuru. These are attributed to over estimation, which the validation tool attributed to the use of satellite measurement instead of the ground measurement.

Design criteria/method developed has several steps with scenario and options in each of the steps to accommodate several circumstances. Some major aspects that determine optimization and sustenance of the system such as backup time, system voltage and load shedding aspect in respect of grid supported system were considered. It sizes the basic components with their verifications. Other components and accessories are to be sized during the installation preparation and processes. The design criteria/method is adequate for both manual and computer package application.

It is also imperative to draw the attention that, a correction factor of 1.65 is introduced for total efficiency and fudge factor, and 1.5 is provided to represent an additional 50%efficiency due to depth of discharge (DOD). Consequently, an equivalent of 0.6722 of output factor was also introduced for optimization due to losses, such as that from standard test conditions, temperature, dirt and dust, mismatch and wiring losses and DC to AC conversion.

SHSDK was developed to provide a means of designing a SHS with all the data required in the Kit's database. Such data are basic energy demands of six various household types and their averages and the insolation level of twenty one (21) locations. The Kit provides a privilege of entering an insolation level of location not covered in the DBMS. It also provides several appliances and their power ratings for establishing household energy demand. The Kit also provides an interface where new appliances not in the DBMS are entered and saved to improve the DBMS.

5.2 CONCLUSION

It is concluded that, household energy demand is attributed to several factors and in the case of Nigeria the determinants are: the household income; electricity prices (tariffs); structural changes; household lifestyles, population and price of substitutes. The power generation,

transmission and distribution in Nigeria is facing several challenges and consequently the power supply to households is poor in terms of quality; erratic and inadequate in quantity.

The study established insolation data necessary for sizing/designing the SHS for efficient utilisation of incoming solar radiation within the twenty one (21) locations and their surroundings. The insolation values of the locations are the same and fall within the range of 5.0257kWh/m^2/day to 11.5337kWh/m^2/day throughout the year. It is also imperative to note that, the least monthly average daily solar radiation is used as insolation level in the design, application and performance evaluation of SPV system.

One of the most important features of the framework developed for sustainable design and implementation of SHS is its provision to use data different from those employed in this work. The frame also had some factors and verification to enhance optimisation of the system and energy conservation. The verification was built up in the sizing of battery and inverter to ensure correctness with approved guidelines.

The developed SHSDK has some features that make it different from other earlier approaches; such features are; the Kit was designed to have a DBMS that contained the required data to design the home system for twenty one (21) locations; the data includes insolation level (peak sun hour durations) and power ratings of several household appliances that are used for establishing energy demands; it also provides provisions for other locations and appliances not covered in the study to be included in the design Kit. Caution is also designed in the interface of suggesting backup time and grid power supply duration and sustainable battery size. Such that, a designer must read, understand and comply with the guidelines before carrying any action.

5.3 RECOMMENDATIONS

There is need for government to increase the energy supplied to households in Nigeria and users should also diversify to alternative sources of energy such as renewable type for reliable and sustainable development. Solar energy and more precisely PV system is therefore suggested as an alternative means for power supply to household, in particular photovoltaic home system based on the outlined challenges of grid network system and the viability, availability and abundant solar resources in Nigeria. The use of photovoltaic home system also known as solar home system is recommended for domestic power generation and use; to cushion the effect of poor and erratic power supply in Nigeria in particular and the country in general.

A single insolation level is generally adequate for the study area in the design and application of PV system except for specific circumstances. As there is no significant difference between the monthly variations of average mean daily solar radiation data within the locations. It is therefore recommended for locations that are lacking insolation data and not covered by this study, to use the data of locations very close to them. Otherwise, the two estimation models can be used with respect to the empirical constant described by computing the location extraterrestrial radiation or to use the clearness index computed by this study for their closest locations.

The design criteria/method developed is recommended for manual use and with other data than those documented by this work. The factors and allowances deduced can also be adjusted based on the circumstances during the design. The contributions of this study are also recommended for use in the design of energy efficient buildings, weather forecasting and agricultural system design and application.

The SHSDK has the established monthly average energy demand of various households and the established solar potentials of the north western region as the contents of the DBMs and can be

improved by adding some appliances rating or insolation level of other locations. The Kit is based on either the stand alone or supported PV home system. It can also be used for other PV design provided the designer is able to comprehend where modifications are essential; especially the arithmetic and the bases of factors and allowances provided. The Kit user guide should also be utilised to help designers to understand the fundamental reasoning that build up the kit.

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Appendix 1

Estimated insolation levels of other locations kWh/m^2/day

Months	Zaria		Kafanchan		Gwarzo		Tudun wada		Daura		Funtua		Hadeja	
	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine
Jan	5.5500	5.6218	5.7360	5.7740	6.1802	6.0034	6.1375	5.9695	6.2940	5.7516	6.4424	5.8501	5.7094	5.6239
Feb	5.8724	6.2152	5.9590	6.2912	6.4670	6.5822	6.4328	6.5515	6.6961	6.3460	6.8040	6.4233	6.2531	6.1561
Mar	6.2547	5.9696	6.2915	6.0013	6.8607	6.3364	6.8405	6.3177	6.7456	5.9608	6.7991	6.0080	6.7164	6.6554
Apr	5.7286	6.1342	5.7765	6.1705	6.3893	6.4717	6.3700	6.4552	5.9987	6.2128	6.0820	6.2846	6.2016	6.1824
May	6.5016	6.4507	6.4458	6.4206	6.5784	6.8626	6.5972	6.8744	6.7811	6.6131	6.7236	6.5895	6.8637	6.9379
Jun	6.4354	6.4602	6.3609	6.4178	5.9992	6.8760	6.0223	6.8948	6.4603	6.6644	6.3866	6.6255	6.7792	6.8788
Jul	6.4411	5.3836	6.3728	5.3486	5.7761	5.7074	5.7983	5.7382	6.0243	5.2482	5.9669	5.2302	6.7489	6.8854
Aug	6.0943	4.9975	6.0652	4.9539	5.7574	5.3107	5.7629	5.3104	5.9615	4.7189	5.9388	4.7170	6.7423	6.8985
Sep	6.4106	5.7767	6.4230	5.7912	5.8001	6.1273	5.7888	6.1154	5.9682	5.7209	5.9857	5.7418	6.6292	6.7211
Oct	5.5475	6.2911	5.6164	6.3576	6.0776	6.6629	6.0523	6.6393	5.7263	6.4219	5.8047	6.4949	6.0610	6.0838
Nov	6.0063	6.4081	6.0665	6.4431	6.0223	6.3885	6.2729	6.6630	5.9106	6.4492	6.2104	6.7332	5.7864	5.7290
Dec	5.0257	5.9063	5.1502	6.0175	5.7901	6.2351	6.0861	6.1913	5.8346	6.0593	5.9912	6.1722	5.5320	5.4465

Months	Kazaure		Mafara		Kauran namoda		Issah		Tambuwal		Birnin Kebbi		Zuru	
	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine
Jan	6.6894	5.6042	5.5667	7.1995	5.5667	7.1995	5.6419	5.4296	5.7086	5.4764	9.5542	9.0205	9.7998	9.1205
Feb	6.3733	6.1430	6.0657	7.9373	6.0540	7.9288	6.1625	5.9824	6.2155	6.0264	10.2643	9.3825	10.5068	10.0026
Mar	6,5971	6.5372	6.5259	7.4343	6.5295	7.4270	7.0782	6.1404	6.7074	5.9117	11.4433	9.5092	11.5337	9.5561
Apr	6.2016	6.1824	6.0507	7.7656	6.0507	7.7656	6.0688	5.4626	6.1142	5.9345	10.2562	9.7485	10.4088	9.8186
May	6.8832	6.9576	6.8243	8.2126	6.7662	8.2185	6.6797	6.3641	6.6483	6.3483	10.1172	10.3967	10.0405	10.3822
Jun	6.7922	6.8919	6.7773	8.2760	6.7967	8.2839	6.5070	6.3884	6.4699	6.3696	9.0785	10.4506	8.9658	10.4078
Jul	6.7554	6.8919	6.7951	6.5031	6.8145	6.5217	6.3701	5.3210	6.3880	5.3016	8.4694	8.5897	8.3482	8.5560
Aug	6.7487	6.9051	6.7822	5.8385	6.7822	5.8385	6.3271	4.9072	6.3151	4.9052	8.5183	7.8858	8.4615	7.8762
Sep	6.8107	6.9051	6.5683	7.1080	6.6015	7.1080	6.0279	5.6243	6.0394	5.6385	8.6919	9.1871	8.7343	9.2140
Oct	6.2378	6.2612	6.1238	8.0285	6.1367	7.7973	5.2380	6.0692	5.2767	6.1103	9.5276	10.0473	9.6674	10.1222
Nov	5.7664	5.7093	5.5369	7.4419	5.6078	8.2422	5.7681	6.0792	5.8350	6.1336	9.6934	10.1415	9.9268	10.2573
Dec	5.5120	5.4268	5.3473	7.6099	5.3408	7.6007	5.4675	5.6279	5.5410	5.6886	9.1476	9.4038	9.4014	9.5229

Appendix 2

Estimated Clearness index (K_T) of other locations

Months	Zaria		Kafanchan		Gwarzo		Tudun wada		Daura		Funtua		Hadeja	
	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$
Jan	0.6416	0.6499	0.6416	0.4010	0.7120	0.6916	0.7120	0.6925	0.7422	0.6782	0.7422	0.6740	0.7815	0.6570
Feb	0.6181	0.6542	0.6182	0.3976	0.6836	0.6958	0.6836	0.6962	0.7192	0.6816	0.7192	0.6790	0.6802	0.6570
Mar	0.6138	0.5858	0.6138	0.3573	0.6739	0.6224	0.6739	0.6224	0.6679	0.5902	0.6679	0.5902	0.6512	0.6570
Apr	0.5992	0.6417	0.5992	0.3804	0.6733	0.6819	0.6734	0.6824	0.6409	0.6638	0.6409	0.6622	0.6590	0.6570
May	0.6198	0.6149	0.6198	0.3860	0.6253	0.6523	0.6253	0.6516	0.6391	0.6233	0.6391	0.6264	0.6518	0.6570
Jun	0.6212	0.6236	0.6212	0.3939	0.5768	0.6612	0.5768	0.6604	0.6141	0.6335	0.6141	0.6371	0.6487	0.6570
Jul	0.6205	0.5186	0.6205	0.3266	0.5549	0.5483	0.5549	0.5491	0.5732	0.4993	0.5732	0.5024	0.6446	0.6570
Aug	0.5826	0.4778	0.5826	0.2786	0.5494	0.5067	0.5494	0.5062	0.5667	0.4486	0.5667	0.4501	0.6427	0.6570
Sep	0.6242	0.5625	0.6242	0.3506	0.5653	0.5972	0.5653	0.5972	0.5834	0.5592	0.5834	0.5596	0.6658	0.6570
Oct	0.5743	0.6513	0.5743	0.3687	0.6318	0.6926	0.6318	0.6930	0.6034	0.6767	0.6034	0.6751	0.6736	0.6570
Nov	0.6689	0.7136	0.6689	0.4704	0.7161	0.7596	0.7161	0.7606	0.6970	0.7605	0.6970	0.7557	0.6613	0.6570
Dec	0.5927	0.6965	0.5927	0.4005	0.6885	0.7414	0.7297	0.7424	0.7115	0.7389	0.7115	0.7330	0.6649	0.6570

Months	Kazaure		Mafara		Kauran namoda		Issah		Tambuwal		Yawuri		Zuru	
	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$	$K_T = \frac{H_{av}}{H_o}$
Jan	0.6693	0.6570	0.6518	0.8152	0.6518	0.8430	0.6669	0.6418	0.6669	0.6398	-	-	-	-
Feb	0.6688	0.6570	0.6480	0.8589	0.6480	0.8480	0.6633	0.6440	0.6633	0.6432	-	-	-	-
Mar	0.6750	0.6570	0.6452	0.7688	0.6442	0.7339	0.6621	0.5744	0.6621	0.5836	-	-	-	-
Apr	0.6590	0.6570	0.6437	0.8130	0.6437	0.8261	0.6491	0.5842	0.6491	0.6300	-	-	-	-
May	0.6481	0.6570	0.6450	0.7584	0.6450	0.7762	0.6290	0.5993	0.6290	0.6006	0.9544	0.9722	0.9544	0.9869
Jun	0.6463	0.6570	0.6467	0.7904	0.6467	0.7897	0.6179	0.6067	0.6179	0.6084	0.8605	0.9535	0.8629	-
Jul	0.6434	0.6570	0.6484	0.6916	0.6484	0.6205	0.6049	0.5053	0.6101	0.5064	0.8028	0.8166	0.8019	0.8219
Aug	0.6415	0.6570	0.6453	0.6798	0.6453	0.5555	0.6014	0.4665	0.6014	0.4672	0.8090	0.7896	0.8082	0.7523
Sep	0.6308	0.6570	0.6421	0.8019	0.6421	0.6948	0.5904	0.5509	0.5904	0.5512	0.8522	0.9312	0.8513	0.8981
Oct	0.6360	0.6570	0.6426	0.8825	0.6426	0.8424	0.5525	0.6402	0.5525	0.6398	-	-	-	-
Nov	0.6659	0.6570	0.6446	0.8713	0.6446	0.8663	0.6684	0.7044	0.6684	0.7026	-	-	-	-
Dec	0.6697	0.6570	0.6466	0.8573	0.6466	0.9202	0.6684	0.6880	0.6684	0.6862	-	-	-	-

Appendix 3

User Guide

A basic approach and stages adopted in this Solar Home System Design Kit (SHSDK) are hereby described to guide the designer to effectively use the Kit and come up with a sustainable result. This will enhance implementation of the photovoltaic (PV) home system and similar technology in Nigeria. Steps were adopted in the process of running the application.

Basic arithmetic involved in sizing the system components such as PV panel or module, inverter, and batteries are also presented for some evaluation. However, were verifications are carried out or were some factors are introduced, there bases were also explained for the purpose of clarity.

Step 1: Home page and Login

The home page has the three (3) options of interface to entre either as an administrator, user/designer or to read the user guide. If you login as administrator or user you are required to submit username and password of digits or figures of one interest and there is privilege to modify the account. Thus, for the Administrator an interface is provided immediately after login for five options; to create user, to run the application and to edit, delete or add appliances, insolation level or household data.

Step 2: Establish the basic energy demand (kWh) per day

This interface allows a designer to decide the basic energy demand/day through adopting any of the seven (7) options given to select. The last option is for the designer to select appliances and come up with his basic energy demand /day. Each of the option is user friendly and is selected by clicking enter in all the seven options. While in the case of eight or last option, appliances are being considered selected by allocating a duration of using it before or after adding the appliances and the process is complete by clicking enter as usual.

Step 3: Suggesting a SHS type, back up time and System voltage

Immediately after concluding the step 2 an interface will come with a Caution for the designer to read and comply, the caution says ' Designers should be aware of the fact that, duration in hours of power supply from National grid can never be stable. Therefore, a realistic duration should be decided for sizing the more efficient system components. Verification is also designed through computation immediately after sizing the battery. A trial may be carried out on various system voltages in order to come up with an effective battery capacity'

After reading the caution, the window will require the designer to select grid option either off-grid system or grid-supported system type of household. It then followed with suggesting the backup time and system voltage. Duration of grid power supply will also be required in addition for grid-supported system in order to appropriately size the battery system.

Step 4: Suggesting an Insolation Level

However, for suggesting insolation level, the Kit provides three options for the least, maximum and annual monthly average of twenty one (21) locations of north-western Nigeria. The last option is provided to allow the designer to provide his peak sun hour duration also referred to insolation level not covered by the twenty one (21) locations.

One can observed that, the window is providing the insolation level based on the sunshine and temperature models results with their clearness index to allow a designer to an appropriate choice. By clicking any of the sunshine or temperature insolation level values of your location or closed by, your location is then captured.

Step 5: Sizing the basic components

As the household energy demand and insolation level are provided for a particular location, sizing basic components of home system begins. Sizing is achieved by clicking each of the component and by clicking Ok it will brings you back to select next. The sizing has verification of the battery and invert size to ensure appropriateness in sizing of the components for sustainable implementation of SHS. A description of the arithmetic involved in the sizing is as followed with definitions or bases of some factors suggested.

i. **Sizing the PV panel**:

PV panel needed (kW) = $\left(\frac{\text{Basic energy demand in kWh X (cf=1.65)}^{**}}{\text{Insolation level or peak sun hours in hrs}}\right)$ **X** $\left(\frac{1}{\text{lf= 0.6722}}\right)$ ***

* The term peak sun hours (hrs) refer to the solar insolation (kWh/m^2 per day) which a particular location would receive if the sun were shining at its maximum value for a certain number of hours. Therefore, the number of peak sun hours is numerically identical to the average daily solar insolation. For example, a location that receives 8kWh/m^2 per day can be said to have received 8 hours of sun per day at 1 kW/m^2.

** A correction factor (cf) is required for efficiency, that is 1.1 for total efficiency and 1.5 for fudge factor this add to give 1.65 to be used as cf.

*** This is a losses factor (lf) because SPV output decreases usually due to losses, such as that from standard test conditions (0.95%), temperature (0.89%), dirt and dust (0.93), mismatch and wiring losses (0.95%), and DC to AC conversion losses (0.90%). Consequently, an equivalent of 0.6722 of output factor (of) should be multiplied for optimization.

ii. **Sizing the battery** :

Battery capacity needed (AHr) = $\left(\frac{\text{Back-uptime(hrs) X Basic load (Watts)}}{\text{System voltage x [lf = 0.6722]}}\right)$ X 1.5*

*This 1.5 is to provide an additional 50%efficiency due to depth of discharge (DOD)

Verification of Back-up time

Compute the back-up time based on the battery capacity decided must be less than or equals to selected back-up time.

Back-uptime (hrs) = $\frac{\text{System voltage (volts) X Battery capacity (AH) X [lf = 0.6722]}}{\text{Basic load (Watts)}}$

iii. **Sizing the inverter:**

Inverter size needed (VA) = Basic load in Watts + 25%

To verify Inverter size

Multiply the Selected inverter capacity by output factor [lf = 0.6722] and must be less than or equals to basic load.

iv. Sizing the charge controller:

Charge controller size needed (amps) = $\frac{\text{Power produce by panel(s) in Watts x [lf = 0.6722]}}{\text{Battery voltage in volts}}$

Step 6: Print out of result summary

With sizing the charge controller needed and clicking Ok as usual, the Kit would automatically take the designer to a print out results interface. The interface shows the basic data considered in the design and the basic components sizes with their verification where applicable. It is also designed to provide notes on the quality of the result, then followed with the summary of the appliances that make the household consumption for verifications.