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DEPARTMENT OF MECHANICAL ENGINEERING

A THESIS REPORT ENTITLED

OPTIMISATION OF ENERGY USAGE IN SOME SENIOR HIGH SCHOOLS IN TARKWA AND ITS ENVIRONS

BY

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN MECHANICAL ENGINEERING

THESIS SUPERVISOR

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OCTOBER 2023

DECLARATION

I declare that this project work/thesis is my own work. It is being submitted for the degree of Masters of Science in Mechanical Engineering in the University of Mines and Technology (UMaT), Tarkwa. It has not been submitted for any degree or examination in any other University.

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Daniel Offei

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ABSTRACT

In line with the worldwide efforts to reduce carbon emissions and promote sustainability in energy generation, renewable energy sources offer the most advantageous option.

This thesis seeks to optimise the energy consumption and the possibilities of harnessing maximum solar energy on gable roof types predominant in Senior High Schools using Tarkwa and its environs as a case study.

The study presents an analysis of energy efficiency in four selected Senior High Schools located within the Tarkwa Nsuaem and the Prestea-Huni Valley Municipalities, with a focus on reducing energy usage. An energy audit was conducted using the American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards, to identify areas of high energy consumption. The results of the energy audit demonstrated that significant reductions in energy usage and cost could be achieved through the implementation of energy-efficient technologies. The proposal recommends replacing existing Compact Fluorescent Lights (CFL) and Incandescent lamps with energy-efficient Light Emitting Diodes (LED) and replacing old refrigerators with modern and efficient models. The adoption of these technologies promotes sustainable practices and reduces energy consumption by an average of 40 %.

The thesis also compared solar energy technologies usable in these schools. Off-grid Solar PV, Grid-connected Solar PV and purchasing power from the grid as the base case scenario. The grid-connected solar technology was selected due to its relatively lower initial cost of investment and a good levelised cost of electricity which was GH₵ 0.58/ kWh.

Finally, a prototype of a tracking system specifically designed for the gable roof was developed to optimise the collection of maximum solar energy and improve on the carbon footprint in Senior High Schools. Data collected from this tracking system was compared to data collected

from a stationary solar photovoltaic system at the same site. The results from this experiment suggested that tracking systems can significantly increase the amount of energy generated by solar panels on these types of roofs by 31 %.

The study concludes by recommending the exclusive use of the LED bulbs in these educational facilities. Also, as a means to reach the countries energy goals, the government should continue to incentivise solar panels to promote the use of sustainable and clean energy sources.

This study thus provides valuable insights into the benefits of energy efficiency and renewable energy in educational institutions, and highlights the importance of adopting sustainable practices to mitigate the effects of climate change.

DEDICATION

I dedicate this work to my parents especially my father whom throughout my whole life has been keen on helping with every aspect of my education. You encouraged me and pushed me to my limits throughout the times I have been in school. And to my mother, the little you did, the love and care has brought me where I am. I hope this achievement will fulfil the dream they envisioned for me.

Also, to my brother who has been a constant inspiration throughout this journey. Your belief in my dreams has been a source of strength and I am fortunate to have you by my side.

And to my esteemed supervisor, Prof. Anthony Simons. Your mentorship, expertise and guidance have been instrumental in shaping this thesis. Your dedication to the pursuit of knowledge and your commitment to excellence have been a true privilege to witness and learn from.

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NOMENCLATURE

IPPs	-	Individual Power Producers
PV	-	Photovoltaic
DSM	-	Demand Side Management
CCE	-	Cost of Conserved Energy
ASHRAE	-	American Society for Heating, Refrigeration and Air Conditioning Engineers
IESNA	-	Illuminating Engineering Society of North America
IRENA	-	International Renewable Energy Agency
CAESCO	-	Canadian Association of Energy Service Companies
AEE	-	Association of Energy Engineers
IEA	-	International Energy Agency
ADSM	-	Active Demand Side Management
NASA	-	National Aeronautics and Space Administration
UNFCC	-	United Nations Framework Convention on Climate Change
OECD	-	Organisation for Economic Co-operation and Development
RES	-	Renewable Energy Sources
GRIDCO	-	Ghana Grid Company
CSP	-	Concentrated Solar Power
WEC	-	World Energy Council
HVAC	-	Heating, Ventilation and Air Condition
LED	-	Light Emitting Diodes
SHSs	-	Senior High Schools
QTY		Quantity

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background to the Research

Electricity has become a crucial aspect of modern life (Eshun & Amoako-Tuffour, 2016), and it is a key determinant of a country's economic prosperity (Nyarko, 2017). However, as global concerns for food, water, and health continue to rise, so does the importance of ensuring a sustainable energy supply (Jamil *et al*., 2012). With the introduction of new technologies, energy demand continues to grow, and it is expected to increase by 5 % in 2021 and 4 % in 2022 (IEA, 2021). In response, governments, individuals, and private corporations are exploring different ways of meeting their energy needs (Alun *et al*., 2012). The focus of this thesis is to optimise energy consumption in Senior High Schools located within the Tarkwa and its environs. In addition, the thesis proposes exploring solar tracking options as a means of integrating renewable energy systems into the schools' power supply systems, to enhance efficiency and lower overall cost of purchasing energy.

1.2 Description of Study Area

The Tarkwa Nsuaem Municipality and Prestea-Huni Valley Municipality are situated in the Western Region of Ghana, with coordinates between Latitude 4°5′ and Longitude 5°5′ (Ghana Statistical Service, 2014). The municipality shares its boundaries with Prestea Huni-Valley to the north, Ahanta West to the south, Nzema East to the west, and Mpohor Wassa East to the east. (Ghana Statistical Service, 2014).

Within the municipality, there are two prominent state-owned Senior High Schools: Fiaseman Senior High School and Tarkwa Senior High School. Both schools provide boarding facilities capable of accommodating approximately 1,500 students each. Additionally, the region is home to several other notable educational institutions, including

St. Augustine's Senior High School, Prestea Senior High School, St. Mary's Senior High School, and Huni Valley Senior High School.

1.3 Problem Definition

The purpose of this thesis is to address the issue of energy waste in Senior High Schools in Ghana. A document from Wikipedia shows that there are a total of 981 Senior high schools in Ghana which have a significant toll on the power grid (Anon, 2023). The study focuses on the energy waste in classrooms and hostels, where students often leave lights, fans, and other appliances on when not in use, leading to undesired energy consumption. Apart from the negligence of students, managers of these schools have limited knowledge of demand-side management (DSM) and this is a significant barrier to overall energy efficiency (Asare, 2020).

These two problems to some extent have made the running of Senior High Schools expensive since a significant amount of funds goes into the purchasing of electricity. The high cost of energy is also in part due to the sources of energy available to these schools.

The current energy structure in Ghana heavily relies on fossil fuels, which is relatively expensive (Energy Commission, 2020). Ghana produces 59.8 % thermal, 39.9 % hydro, and about 0.3 % renewable energy (Energy Commission, 2020) as shown in Table 1.1.

Table 1.1 Existing Generation Sources Available at the end of 2020

Plant	Installed Capacity (MW)	Dependable Capacity (MW)	Percentage per source
Hydro Power Plants			
Akosombo	1,020	900	
Kpong	160	140	
Bui	404	360	
Sub-Total	**1,584.00**	**1,400.00**	**39.9 %**
Thermal Power Plants			
Takoradi Power Company (TAPCO)	330	300	
Takoradi Power Company (TICO)	340	320	
Tema Thermal 1 Power Plant (TT1PP)	110	100	

Table 1.1 (Cont'd)

Tema Thermal 2 Power Plant (TT2PP)	87	70	
Cenit Energy Ltd	110	100	
Kpone Thermal Power Plant	220	200	
Ameri Plant	250	230	
Sunon Asogli Power (Ghana) Ltd	560	520	
Karpowership	470	450	
Trojan	44	39.6	
Amandi	203	190	
AKSA	370	350	
Cenpower	360	340	
Early Power / Bridge	144	140	
Genser	155	131	
Sub-Total	**3,753.00**	**3,480.60**	**59.8 %**
Other Renewables			
On-grid			
VRA Solar (Navrongo)	2.5	2	
VRA Solar (Lawra)	6.5	4.5	
VRA Solar (Kaleo)	13	10	
BXC Solar	20	16	
Meinergy	20	16	
Bui Solar	51	46	
Safisana Biogas	0.1	0.1	
Tstatsadu Hydro	0.05	0.05	
Distributed Solar PV	30.9		
Sub-Total	**144.05**	**94.65**	
Off-grid			
Solar	7.42		
Wind	0.02		
Sub-Total			
Mini-grid			
Solar	0.314		
Wind	0.011		
Sub-Total	0.325		
Total Renewables	**119.865**	**96.65**	**0.3 %**
TOTAL	**5,488.82**	**4,975.25**	**100 %**

(Source: Energy Commission, 2020)

To reduce the cost of energy, it is crucial to adopt energy-efficient practices. It is also a widespread fact that the long-term use of renewable energy is cheaper compared to buying from the utility companies. However, the majority of schools in Ghana still rely solely on the national grid, which is expensive. In July 2019, new electricity tariffs were released by the Government through Public Utility Regulation Commission (PURC) announcing an increment of 11.17 % across all sectors (residential, commercial and industrial). Table A1 in Appendix A compares electricity tariffs from 2018 to 2022. In fact, in August 2022, new PURC tariffs released shows an increase in electricity cost by 27 %, effective September 2022. This shows an upward trend of energy cost over the years making purchasing of energy from the grid increasingly expensive.

Solar power is readily available in most parts of the country. However, the varying amounts of sunlight received by the two sides of the gable roof at different times of the day pose a challenge that needs to be addressed. Conventional tracking systems are not suitable for these roof types as they are designed exclusively for flat surfaces. This study also proposes a practical solution for the installation of solar tracking systems on the gable roofs in these schools.

1.4 Objectives of Research

The main objective of this research is to perform an energy audit on electricity consumption in the selected schools and design a prototype tracking system for solar PV to minimise dependency on the national grid.

This can be addressed with specific objectives and these are to:

i. Conduct an electrical energy audit to examine the energy consumption trends in the schools.
ii. Recommend energy saving measures and opportunities based on audit report; and
iii. Develop a prototype tracking system capable of harnessing maximum solar energy during different times of the day across the gable roof system.

1.5 Research Questions and Hypothesis

Research Question:

i. What is the energy consumption patterns and energy waste areas in senior high schools in Tarkwa and its environs?
ii. What is the viability of implementing a gable roof tracking system for solar photovoltaic in senior high schools located in Tarkwa and its environs?
iii. How does the design effectively increase the efficiency of energy collected from the sun?
iv. How can demand-side management practices be effectively integrated into senior high schools in Tarkwa and its environs to ensure sustained energy efficiency?

Hypotheses:

i. Energy consumption patterns and energy waste areas in senior high schools in Tarkwa and its environs can be identified through a comprehensive energy audit.
ii. The design and installation of a solar rooftop installation and gable roof tracking system can effectively increase the efficiency of solar panels while the sun moves across the gable roof system.
iii. The implementation of a solar rooftop installation and gable roof tracking system is technically and financially feasible in senior high schools in Tarkwa and its environs.
iv. Effective integration of demand-side management practices into senior high schools in Tarkwa and its environs can ensure sustained energy efficiency and cost savings.

1.6 Research Methods Used

For this research, a case study was conducted using schools in Tarkwa and its environs as the boundary. Data collection formed a significant part of the audit and was the main methodology employed. In summary, the following methods were utilised in the research:

i. Review of past energy consumption trends in selected schools in and around Tarkwa;
ii. Data collection on site;
iii. Computer simulations using the HOMER software;
iv. Mathematical modelling;
v. Modelling a new design for the solar tracking system using AutoCAD inventor;
vi. Designing and building the solar tracker on a roof-like structure; and
vii. Recommendations to management about potential areas for energy saving opportunities.

1.7 Scope of the Research

The research specifically targeted schools located in Tarkwa and its environs, focusing on various facilities within these schools, such as classroom blocks, administration offices, canteens, boarding houses, laboratories, and assembly halls. The electrical demands of the selected schools were found to be similar, including basic equipment like light bulbs, fans, an air-conditioner for the headmaster's office, and refrigerators in the canteens.

It is important to note that the design proposed for the tracking system is not a final design usable in these schools, but rather a demonstration of the potential use of such technologies with the gable type roofing system. The research did not delve into aspects such as design optimisation, durability, or cost analysis of this system. These factors were not examined in the study.

1.8 Facilities Used for Research

i. Library, Laboratory, Computer and Internet facilities of University of Mines and Technology (UMaT);
ii. Electrical and Electronic Engineering Department laboratory of UMaT;
iii. All departments and facilities of the four selected schools;

1.9 Significance of Research

The significance of this research is viewed from multiple angles, including environmental, economic, and social impacts.

i. Environmental Impact: The reduction in energy waste and the adoption of renewable energy sources through the proposed solar rooftop installation and gable roof tracking system will help to mitigate the impact of energy consumption on the environment. This will contribute to Ghana's effort to reduce greenhouse gas emissions, promote sustainable development, and address climate change challenges.

ii. Economic Impact: The adoption of energy efficiency measures and renewable energy sources will lead to cost savings for senior high schools in Tarkwa and its environs. The reduction in energy consumption and electricity bills will result in direct financial savings that can be invested in other school activities.

iii. Social Impact: The proposed solar rooftop installation and gable roof tracking system will help to increase access to modern energy services for senior high schools in Tarkwa and its environs. This will enhance the quality of education by ensuring uninterrupted power supply and creating a conducive learning environment for students. Also, the awareness created through this research will educate the students and staff on energy conservation, which will help to create a culture of energy efficiency and sustainability.

1.10 Definition of Key Terms and Concepts

Some key concepts which need to be explained are listed below:

Energy efficiency: The process of using less energy to achieve the same level of output, which reduces energy waste and saves money on energy bills.

Demand-Side Management (DSM): A set of actions aimed at reducing energy consumption during peak periods, which helps to balance energy demand and supply.

Energy audit: Analysing energy consumption patterns in a building, facility, or process to identify potential energy waste areas and recommend measures for energy savings.

Solar tracking: A mechanism that adjusts the orientation of solar panels to follow the movement of the sun throughout the day, which maximises the amount of sunlight they receive and increases their efficiency.

Energy Management System (EMS): An automated system that monitors, controls, and optimises energy use in a building or facility to reduce energy waste and save costs.

Net metering: A policy that allows customers with solar PV systems to sell excess electricity back to the grid and receive credits on their energy bills.

Energy storage: A technology that stores energy for later use, which enables the integration of renewable energy sources and helps to balance energy supply and demand.

Carbon footprint: The emission of greenhouse gases by an individual, organisation, or product, which contributes to climate change.

Renewable energy: Energy sources that are replenished naturally and can be used indefinitely, such as solar PV, wind, hydropower, geothermal, and biomass energy.

Levelised Cost of Electricity (LCOE): The LCOE is a financial metric used to evaluate the cost of generating electricity from a particular source over its operational lifetime. It represents the average cost of producing a unit of electricity (kWh) taking into account all of the costs associated with building, operating, and maintaining a power generation system, as well as the total amount of electricity generated over its operational lifetime.

Payback period: It gives the period usually in years when the project will break even and begin to yield profits.

1.11 Organisation of Thesis

The thesis is in five chapters. Chapter one is the general introduction to the subject under study. It describes the energy situation in Ghana and how imbalance in generation and demand is affecting output of the nation is also discussed. Again, the chapter introduces concept of energy audit and its importance and the various renewable energy types available for exploitation in Ghana. In chapter two, a review of documents and research works is made. This review considered related works and topics that intersect with this thesis. Chapter three offers the general methodology for the audit and the solar tracking system. The results and findings are discussed in chapter four. Finally, chapter five gives the conclusion and the recommendation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A review of journals, books and dissertations was done on the project topic. The literature review provided a foundation for the analysis to be carried out in the project and served as a means of comparison and justification for the findings. It was instrumental in defining the objectives and significance of the data collected and contributed to the development of solutions and recommendations by comparing and contrasting various conclusions from different sources.

2.2 Increasing Global Energy Demands

The demand for energy is expected to increase significantly in the near future due to population growth and economic development. The world's energy demand is directly affected by the high rate of population growth, and it is estimated to grow by 37 % by 2040. (Energy Supply and Demand: trends and prospects, 2012). According to the report on the world energy outlook, developing countries will experience the most significant increase in energy demand, where global energy consumption is expected to increase from 46 to 58 percent between 2004 and 2030. (World Energy Outlook, 2014). 50 % of this energy requirement will be for power generation and 20 % for transportation purposes (IEA, 2015). But these increments will be affected by the recent interest in transitioning from fossil fuel-based automobiles to electric ones.

Ghana has recognised the need to reduce dependence on traditional wood fuels and fossil fuels as sources of energy for heating and cooking. To this end, the Renewable Energy Act (Act 832) was enacted (Wisdom, 2014). Over the past few decades, hydropower has been the primary source of energy in Ghana. However, with increasing demand, various thermal generation plants, as well as renewable sources, have been integrated (Mensah *et al.*, 2017).

Despite these efforts, Ghana has experienced frequent power outages due to economic growth, industrial activities, and insufficient generation capacity. Thus, there is a pressing need to transition to renewable energy sources.

As the world's energy future remains uncertain, it is essential to maintain a balanced view and consider transitioning to renewable energy sources. Politicians and decision-makers worldwide must exercise wisdom, vision, and coordination to achieve this transition (Sheffield, 2012).

2.3 Mitigation of Threats from Energy Shortage through Energy Efficiency Improvements

To manage the growing demand of energy, government agencies suggest various procedures, among which is energy efficiency coupled with Demand Side Management (DSM) (Gyamfi and Krumdieck, 2011). Energy efficiency is essential for alleviating strain on energy supply and it helps to mitigate the competitive disadvantages of relying on conventional energy sources.

Many countries are embracing a renewed policy which emphasises on energy efficiency. This end-use electricity efficiency improvements, offer an inexpensive way to reduce grid power shortages and overall demand (Amit *et al*., 2011; World Energy Outlook, 2014; Gyamfi and Krumdieck, 2011). Energy Efficiency Measures (EEMs) lead to benefits for consumers, society, and utility companies. Consumers save money by reducing the amount of electricity used, known as the Cost of Conserved Energy (CCE). Additionally, electricity savings reduce the probability of load shedding, thereby preventing residential consumers from experiencing welfare losses due to power cuts and businesses from losing production margins (Amit *et al*., 2011).

In conclusion, energy efficiency coupled with demand side management is an important tool for managing energy demand and ensuring energy security. By implementing energy efficiency measures, consumers can save money, while society and utility companies can benefit from a reduced demand for energy, thereby reducing pressure on energy supply. These benefits highlight the need for increased attention and investment in energy efficiency programme on a national and global level.

2.4 Energy Audit as a Demand Side Response Strategy

Energy audit, refers to the strategy of optimising energy systems and procedures to locate energy waste areas while maintaining or reducing total costs. This is critical in reducing energy consumption and costs in buildings and facilities (A guide to energy audits, 2011). An energy audit aims to assess energy consumption patterns in a facility and identify methods to improve energy efficiency and reduce costs. The assessment involves identifying where, when, why, and how energy is used in a building or facility to locate areas for improvement (IEA, 2015).

From literature, there is no universal standard for the energy audit process in Ghana. However, various professional associations, such as the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), the Illuminating Engineering Society of North America (IESNA), the Association of Energy Engineers (AEE), and the Canadian Association of Energy Service Companies (CAESCO), have developed their own procedures for energy audits (Saifedean, 2011). These procedures differ in terms of the time required to complete the process, the cost, and the types of equipment that can be studied. The levels of energy audits listed by these associations can range from a simple review of previous energy billings to a detailed analysis of appliances and structures within a facility. Energy audits can also be conducted on an entire building, subsectors, or specific components within a building or facility. Whole building audits provide a more accurate assessment of energy savings opportunities, while targeted audits may miss significant energy-saving opportunities (IEA, 2004).

Overall, energy audits are crucial for identifying energy-saving opportunities, reducing energy consumption and costs, and improving energy efficiency in buildings and facilities.

2.5 Energy Efficiency and Renewable Energy Options for Power Generation

According to Mensah *et al*. (2017), one solution to address Ghana's energy crisis is to explore the potential for renewable energy generation across the country. Ghana has abundant renewable energy resources, including bioenergy, solar, wind, hydropower, tidal, and wave power, but they are underutilised (Gyamfi *et al*., 2015; Energy Commission, 2016). To increase the renewable energy contribution in Ghana's energy mix, the government has set a target to produce at least 10 % of electricity from renewable sources by 2020 (Energy Commission, 2016). As part of this effort, the Ghana Energy Commission is promoting self-generation using Solar Photovoltaic (PV) technology installed on rooftops to reduce the dependency on the national grid and decrease the daily peak load by 200 MW (Eshun & Amoako-Tuffour, 2016).

A case study in Canada showed that small dairy farms faced competition from larger commercial farms that purchase power in larger quantities with larger price margins (Hyslop, 2012). To compete in the market, small dairy farms must reduce their energy-related operational costs and greenhouse gas emissions by implementing energy efficiency measures and generating energy from renewable sources (Hyslop, 2012). An energy audit was conducted to identify energy efficiency measures with potential savings and relevant implementation costs. The audit found that upgrading the facility's lighting to LED bulbs, which accounted for 29 % of the operation's total electricity consumption, was the simplest and most beneficial energy efficiency improvement (Hyslop, 2012). Additionally, a heat recovery system could be installed to extract heat from the milk to reduce cooling requirements and preheat water for the wash cycle.

In summary, exploring the potential for renewable energy generation and implementing energy efficiency measures are essential strategies to increase the availability of energy and reduce costs in Ghana and other regions facing energy challenges.

2.6 Demand Side Management

Demand Side Management (DSM) is a strategy employed by utility companies and grid operators to actively influence and manage electricity demand in order to achieve a more balanced and efficient energy system. By focusing on influencing consumer behaviour and energy consumption patterns, DSM aims to reduce peak demand, enhance grid reliability, and optimise energy utilisation.

2.6.1 Effects of Demand Side Management on Renewable Energy Patronisation

The increasing cost of fuel, concerns over energy security, and the need to reduce emissions have led governments to shift their interests to renewable energy sources for electricity generation (Breukers *et al*., 2011). The integration of renewable energy sources into electricity grids can pose challenges due to their intermittent nature, especially when they contribute a significant share of the energy mix, and the availability and cost of energy storage systems may present limitations (Gyamfi & Krumdieck, 2011). DSM strategies can provide a solution by reducing electricity consumption and level off the difference between demand and supply, thus improving efficiency and flexibility in grid management (Bergaentzle *et al*., 2014).

Furthermore, DSM can help utilities delay building further capacity by reducing peak electricity demand (Sustainable Energy Regulation and Policy-Making Training Manual, 2018). By reducing the overall load on the grid, money required for high investments in generating, transmission, and distribution of energy can be channelled into other important sectors, such as agriculture and education.

Opportunities to reduce energy demand exist in all sectors, and many are low-cost or even no-cost items that individuals and industries can adopt through good energy management practices. Utility companies worldwide are highly interested in demand-side management (DSM) strategies, and numerous governments are actively exploring policies to encourage and facilitate their implementation. (Amit *et al*., 2011). To promote DSM, options include promoting energy efficiency plans, behaviour changes at the customer level, or dynamic demand response.

The implementation of DSM strategies, which encompass technological energy efficiency measures, consumer behaviour changes, and the adoption of dynamic demand-side management technologies, is vital for ensuring the long-term sustainability of any region (Bergaentzle *et al*., 2014). These options will play a significant role in facilitating the transition to sustainable energy systems by effectively managing demand levels, allowing renewable energies to be utilised efficiently to meet the energy demand.

DSM is considered for several attractive reasons. Firstly, energy use is directly related to the cost of the energy used. By reducing energy demand or use, the total cost of the desired energy is also reduced. Secondly, DSM is a means of reducing energy waste in the domestic, industrial, and commercial world, allowing energy producers to supply energy efficiently to users. Thirdly, energy efficiency and DSM may be pursued to reduce environmental pollution and achieve social standards for energy production and usage. Fourthly, when demand goes up while supply is limited, costs also rise, but when the demand is maintained and reduced, suppliers are incentivised to reduce costs. Finally, reducing our load on the electrical network will make it more sustainable and reliable by reducing power outages, load shedding, and grid failures resulting from over-dependency and overload on the system.

2.6.2 Environmental Implications of DSM

Demand Side Management (DSM) has been identified as a potential solution for reducing energy consumption and achieving sustainability targets. According to Moura and Almedia (2010), DSM measures can result in significant energy savings, estimated at approximately 8767 GWh over a 10-year period, and peak power savings of about 1814 MW, which is large enough to eliminate one-fourth of electricity shortages. Furthermore, the implementation of selected energy efficiency measures can result in an estimated reduction of about 7715 Gigagrams (Gg) of CO2 emissions over a 10-year period.

The literature suggests that DSM measures can be effective across various sectors, including agriculture, residential, and commercial sectors. In particular, the agricultural sector can benefit from DSM measures, given the abundance of inefficient pumps and irrigation systems that cause deficits to the national installed capacity (Moura & Almedia, 2010). Some of the recommended measures for improving energy efficiency in this sector include the purchase of new energy-efficient pumps, retrofitting of existing pumps, and the use of micro-irrigation systems (Sudhakara & Jyoti, 1997).

In the residential and commercial sectors, energy-efficient refrigerators and air conditioning systems are recommended as a way to improve energy efficiency (Sudhakara & Jyoti, 1997). Replacing existing equipment with energy-efficient alternatives can result in energy savings and cost reductions of between 30 % to 40 % of the existing situation.

While DSM measures have been shown to be effective in reducing energy consumption, the literature highlights the importance of addressing policy issues related to the use of saved electricity. According to Moura and Almedia (2010), saved electricity could be provided as additional power to high-end consumers, such as commercial and industrial consumers, who would pay a higher tariff for this additional power than low-end consumers who provide these savings. The authors suggest that a clear policy framework is required to ensure that saved electricity is used in an equitable and sustainable manner.

Finally, it is important to consider the environmental implications of DSM measures. The use of fossil fuels to generate power means that each generating unit has its own emission levels of CO_2, SO_X, and NO_X (Sudhakara & Jyoti, 1997). DSM measures can result in significant reductions in CO_2 emissions, thereby contributing to climate change mitigation efforts.

In conclusion, the literature suggests that DSM measures have the potential to significantly reduce energy consumption and associated CO_2 emissions across various sectors. However, policy frameworks need to be established to ensure equitable and sustainable use of saved electricity, and environmental implications should be considered in the implementation of DSM measures.

2.6.3 Who should be Responsible in DSM?

DSM is essential to meet the Kyoto commitments (Houston *et al.*, 2013). While much research has been done in recent years on how to change the DSM framework so that the Kyoto protocol will be met, the quantity of energy-efficient equipment installed is far too low and below the economically justified level (Bergaentzle *et al.*, 2014). It has been suggested that implementing all energy-saving measures in Europe with a payback period of fewer than three years could lead to overall electricity consumption savings between 15 % and 20 % (Houston *et al.*, 2013).

Despite the economic feasibility of energy-efficient measures, their implementation is hindered by market barriers that prevent their widespread adoption. To overcome this problem, many initiatives have been introduced to encourage and influence consumers' behaviour towards adopting more efficient energy usage practices., i.e., DSM initiatives

(Houston *et al*., 2013). It is the responsibility of governments to create a suitable DSM framework to maximise the welfare of their inhabitants, including external costs such as environmental costs due to the emission of gases such as NO_x and SO_x (Houston *et al*., 2013).

A crucial question that arises is who should be responsible for implementing the DSM framework in their country. Houston *et al.* (2013) categorise DSM activities into three groups: frameworks, which define the funding of DSM activities; programs, which involve direct actions targeting customers; and additional mechanisms, encompassing other related activities. It is recommended that countries deliberately select a specific DSM framework for each consumer group, as implementing multiple frameworks can be counterproductive.

Houston *et al*. (2013) concludes that there are suitable DSM frameworks for all consumer groups in which all boundary conditions are fulfilled. The responsibility for implementing energy-efficient measures should be assigned to an actor who does not incur financial losses as a result of framework implementation. Governments should provide alternatives for who should handle the demand side of energy production and consumption. Energy efficiency can be implemented on both the demand end and the production companies. In order for a sustainable future, management should be done in all areas of energy production, transmission, and consumption. There should be no considerations of who wins or who loses.

In conclusion, DSM is essential to meet the Kyoto commitments and reduce electricity consumption, and suitable DSM frameworks should be chosen for all consumer groups to maximise the welfare of inhabitants. The responsibility for implementing energy-efficient measures should be given to an actor who does not suffer a financial loss due to the implementation of the framework. In Table 2.1, the winners and losers of effectively implanting DSM strategies is presented.

Table 2.1 Winners and Losers in a DSM Program

Winners	**Losers**
Manufacturers of energy efficient equipment	Primary energy suppliers
Consumers	Manufacturers of conventional equipment
	Utilities

2.6.4 Optimising Environmental and Social Benefits through DSM

Demand Side Management (DSM) programs have gained renewed interest in recent years as the cheapest and most feasible ways to meet climate change mitigation targets (Bergaentzle *et al*., 2014). Small-scale energy users, including households, schools, the building sector, municipalities, and small and medium-sized enterprises, possess significant potential for energy efficiency improvements (Gottwalt *et al*., 2011).

By implementing DSM strategies, reliance on thermoelectric generation can be reduced, leading to a decrease in associated adverse impacts such as thermal pollution, carbon dioxide emissions, sulphur dioxide pollution, and particulate matter (Miara *et al*., 2014). DSM plays a significant role in reducing carbon emissions and air pollution, resulting in cleaner air and water, which in turn provides social and environmental benefits and contributes to lower healthcare costs for society (Breukers *et al*., 2011).

In the context of the senior high schools in Tarkwa, this project seeks to explore various energy wastage areas and efficiency improvement techniques, with the aim of reducing energy costs. Moreover, the project aims to compare all possible renewable energy technologies on site for exploitation, in order to augment energy production in the country and reduce dependence on the national grid. These energy sources are emission-free and sustainable for the period in which they last.

Given the evident advantages of DSM, there is a growing demand for increased agreement among planners and decision-makers, as well as a more proactive role from governments in creating initiatives and policies that foster the widespread adoption of DSM strategies (Breukers *et al*., 2011).

2.7 Sustainable Energy for the Future (Renewable Energy)

The increasing demand for energy has resulted in the depletion of fuel sources and climate change, which calls for the need to explore alternative sources of energy (Hina, 2014). Fossil fuels, including oil, coal, and gas, currently account for the majority of global energy production, with only 13 % of energy being generated from renewable sources (Energy Commission, 2020; Gian, 2013). However, projections suggest that fossil fuels will be depleted in the near future, posing a threat to the world's economy and development (Sheffield, 2012). Moreover, the production of greenhouse gases from fossil fuels has negatively impacted the atmosphere and life on earth (Vandaele and Porter, 2015).

To mitigate these threats, renewable energy sources have been identified as an alternative to replace conventional energy sources (Energy Commission, 2020). The use of renewable energy sources is expected to expand in the coming years, despite the forecasted dominance of fossil fuels (World Energy Outlook, 2014). The advantages of renewable energy sources include their pollution-free nature, which corrects the error and threat posed by fossils to the environment and human health. Renewable energy sources are also free from politics and can be tapped anywhere on earth, making them a reliable source of energy (Anon., 2012)

In Ghana, the government has recognised renewable energy as a potential contributor to the country's energy mix (Anon., 2019). Factors such as higher fossil fuel prices and government policies and programs that support the development of alternative energy sources make renewable energy competitive against fossil fuels (Energy Commission, 2020). Therefore, renewable energy is a viable solution for sustainable energy in the future.

2.7.1 Renewable Energy Electrification in Ghana

Access to reliable and affordable energy is a critical driver of economic growth and poverty reduction (International Energy Agency, 2019). In Ghana, despite the government's efforts to increase electricity access, about 45 % of the population still lacks access to electricity (Ghana Statistical Service, 2019). To address this challenge, there has been an increasing focus on renewable energy electrification in Ghana in recent years (Alhassan & Abdulai, 2019). This literature review examines the current state of renewable energy electrification in Ghana and identify key challenges and opportunities. Renewable energy electrification in Ghana has made significant progress in recent years, with a range of renewable energy technologies being deployed. Solar energy has emerged as a key renewable energy source in the country, with several large-scale solar projects being developed (Fotouhi & Zuo, 2018). In addition, there has been an increasing focus on mini-grid and off-grid solar solutions to provide electricity to remote and rural areas (Tawiah & Agyeman, 2019). The government of Ghana has also implemented policies and incentives to support renewable energy development, such as the Renewable Energy Act of 2011 (Energy Commission Ghana, 2011).

Despite these developments, renewable energy electrification in Ghana still faces several challenges. One of the key challenges is the high cost of renewable energy technologies, which limits their affordability and accessibility to low-income households (Uba & Liu, 2020). In addition, there are challenges related to the reliability and quality of renewable energy systems, particularly in remote areas (Gyamfi & Krumdieck, 2017). There are also regulatory and institutional challenges that need to be addressed to create an enabling environment for renewable energy development (Bawakyillenuo. & Xu, 2018).

2.7.2 Global Trends in Renewable Energy Usage

Renewable energy usage has grown significantly in recent years, with renewable energy sources accounting for 72 % of global net electricity capacity additions in 2019 (International Energy Agency, 2020). Wind and solar energy have been the fastest-growing sources of renewable energy, with their combined capacity increasing from 59 GW in 2009 to over 1,200 GW in 2019 (REN21, 2020). Other renewable energy sources, such as hydropower, bioenergy, and geothermal, have also seen significant growth (United Nations Environment Programme, 2019).

The growth of renewable energy usage has been driven by several factors. First, declining costs of renewable energy technologies have made them more competitive with traditional fossil fuel-based electricity generation (IRENA, 2019). Second, supportive government policies, such as feed-in tariffs and renewable energy targets, have created an enabling environment for renewable energy deployment (Börner, *et al*., 2021). Third, public awareness of the need to reduce greenhouse gas emissions and mitigate climate change has increased demand for renewable energy (Brown & Sovacool, 2011).

While the utilisation of renewable energy has been expanding, there remain several challenges that require attention. One notable challenge is the intermittent nature of renewable energy sources, which poses difficulties for maintaining grid stability and reliability (Hu, *et al*., 2021). There are also challenges related to the availability of land and resources, as well as regulatory and institutional barriers that can limit the deployment of renewable energy technologies (Sovacool & Dworkin, 2015).

Renewable energy usage has grown significantly in recent years, driven by declining costs, supportive policies, and increased public awareness of the need to address climate change. While progress has been made, there are still significant challenges that need to be addressed to accelerate the deployment of renewable energy technologies and achieve a sustainable energy future.

2.7.3 Future Prospects of Solar Energy in Ghana and Africa

Ghana has made significant progress in the deployment of solar energy technologies, with a total installed capacity of 250 MW as of 2021 (Ministry of Energy - Ghana, 2021). The government has set a target of achieving 10 % renewable energy penetration by 2030, with a particular focus on solar energy (Energy Commision, Ghana, 2019). The country's favourable solar irradiation levels and abundant land resources make it well-suited for the deployment of utility-scale solar power plants and rooftop solar installations.

However, there are still several challenges that need to be addressed to unlock the full potential of solar energy in Ghana. These include the lack of adequate financing mechanisms, limited technical capacity, and the absence of a comprehensive regulatory framework to support solar energy deployment (Mensah & Ansong, 2021).

The African continent has tremendous potential for renewable energy deployment, with abundant solar, wind, hydro, and geothermal resources (United Nations Environment Programme, 2018). The International Renewable Energy Agency (IRENA) estimates that Africa's renewable energy potential could meet the continent's electricity demand four to five times over (IRENA, 2018). Several countries, such as Morocco, Egypt, and South Africa, have already made significant progress in the deployment of renewable energy technologies, particularly solar and wind energy.

Solar energy and renewable energy have significant potential for further deployment in Ghana and the African continent, offering a pathway to sustainable electricity generation and energy access (Ofei, C., 2016). While progress has been made, there are still several challenges that need to be addressed to accelerate the deployment of solar and renewable energy technologies. These include the need for supportive policies and financing mechanisms, as well as the development of technical capacity and regulatory frameworks to support renewable energy deployment.

2.7.4 Shift to Electric Automobiles and its Effect on Renewable Energy Development

The shift towards electric cars is seen as a critical strategy in reducing transportation sector emissions. The widespread adoption of electric cars is expected to increase electricity demand significantly. According to the International Energy Agency (IEA), the total electricity demand for electric vehicles is projected to increase from 54 terawatt-hours (TWh) in 2019 to 1,616 TWh in 2040 (International Energy Agency, 2020). This increase in electricity demand could put pressure on electricity generation systems, particularly during peak demand periods.

However, the impact on energy demand can be mitigated through the deployment of smart charging technologies and the integration of electric vehicles with renewable energy systems. Smart charging technologies can help manage the demand from electric vehicles, while the integration of electric vehicles with renewable energy systems can reduce the reliance on fossil fuel-based electricity generation and support the development of renewable energy.

The shift towards electric cars can also support the development of renewable energy. Electric vehicles offer a significant opportunity to increase the share of renewable energy in the electricity mix, particularly if they are charged with renewable energy sources such as wind and solar power. The integration of electric vehicles with renewable energy systems can also help address the challenge of intermittency associated with renewable energy, by providing a flexible and controllable demand for electricity.

Furthermore, the deployment of electric vehicles can also support the development of energy storage systems, which are essential for the integration of renewable energy into the grid. The batteries used in electric vehicles can be repurposed for stationary energy storage applications, providing a cost-effective solution for energy storage.

2.7.5 Electric Vehicle Market in Ghana and the Country's Readiness to Adapt

Currently, the electric vehicle market in Ghana is still at an early stage of development. However, there is growing interest and support from the government, private sector, and development partners to promote the deployment of electric vehicles in the country. In 2020, the Ghana Grid Company Limited (GRIDCo) announced plans to set up an electric vehicle charging infrastructure across the country (Ghana Grid Company Limited, 2020). Additionally, the Ghana Energy Commission has developed a national electric mobility policy to guide the deployment of electric vehicles in the country (Ghana Energy Commission, 2020).

Despite the growing interest and support for electric vehicles in Ghana, there are several challenges that need to be addressed. One major challenge is the high cost of electric vehicles, which makes them unaffordable for many Ghanaians. The lack of local manufacturing capacity for electric vehicles in the country also means that most vehicles will have to be imported, increasing the cost further.

Furthermore, the limited electricity generation capacity and the unreliable power supply in the country could pose challenges to the deployment of electric vehicles. The current electricity supply system may not be able to support the increased demand from electric vehicles without significant upgrades.

However, the deployment of electric vehicles in Ghana also presents significant opportunities. The integration of electric vehicles with renewable energy systems can support the development of renewable energy in the country. The batteries used in electric vehicles can also be repurposed for energy storage, providing a cost-effective solution for energy storage.

Ghana is still at an early stage of development in terms of electric vehicle deployment. While there is growing interest and support for electric vehicles in the country, several challenges need to be addressed.

Independent Power Producers (IPPs) and homes going renewable can play a significant role in aiding this transition. IPPs are private sector entities that generate electricity for sale to utilities or end-users. In many countries, IPPs have played a significant role in the deployment of renewable energy systems. For instance, in South Africa, IPPs have been instrumental in the deployment of renewable energy systems, with over 6,000 MW of renewable energy capacity added to the grid since 2011 (Anon, 2020).

In Ghana, IPPs have also played a significant role in the deployment of renewable energy systems. For example, in 2019, the Bui Power Authority signed an agreement with a consortium of IPPs to develop a 250 MW solar power plant in the country (Ghanaweb, 2019). This project is expected to increase Ghana's renewable energy capacity significantly.

The deployment of renewable energy systems at the residential level can also aid in the transition to renewable energy. In recent years, there has been a growing interest in solar energy systems for homes, with many homeowners investing in rooftop solar systems. In Ghana, the government has also launched several initiatives to support the deployment of renewable energy systems at the residential level. For instance, the Ministry of Energy has launched the Renewable Energy Master Plan, which aims to increase the deployment of renewable energy systems at the residential level (Ministry of Energy, Ghana, 2019).

The deployment of renewable energy systems at the residential level can help reduce the demand for electricity from the grid, thereby reducing the reliance on fossil fuel-based power plants. Additionally, homes going renewable can also serve as a source of income for homeowners, with excess energy generated from renewable energy systems sold back to the grid.

IPPs and homes going renewable can play a significant role in aiding the transition to renewable energy. IPPs have been instrumental in the deployment of renewable energy systems in many countries, and Ghana is no exception. At the same time, the deployment of renewable energy systems at the residential level can help reduce the demand for electricity from the grid and serve as a source of income for homeowners.

2.8 Solar Tracking

Solar energy is the most popular and convenient method among other renewable sources for generating electrical energy through photovoltaic panels (Bakos, 2013). However, the continuous change in the position of the sun with reference to the location of interest reduces the energy output from solar panels. To overcome this issue, solar tracking systems are employed. These systems move the panels to face the sun throughout the day and seasons, changing their orientation and positioning to follow the sun's path and maximise the number of photoelectrons that fall on the panels (Rodiek *et al.*, 2010). Solar trackers are specifically engineered to optimise the alignment of solar panels with the sun's rays, thereby minimising the angle of incidence. The highest efficiency is achieved when the sun's rays hit the panels at 90° (Ghassoul, 2013). Single-axis solar trackers rotate on one axis, moving East to West, while dual-axis solar trackers move in two axes (Rajan, 2016).

The solar tracking system consists of several key components, including a tracking device, tracking software, control unit, positioning system, driving mechanism, and sensing devices (Rajan, 2016). The tracking algorithm plays a crucial role in determining the angles necessary for positioning the solar tracker. There are two main types of algorithms employed: astronomical algorithms and real-time light intensity algorithms (Dhanabal *et al*., 2013). Astronomical algorithms rely on astronomical references, while real-time light intensity algorithms utilise up-to-date light intensity readings (Anusha *et al*., 2013).

The control unit is responsible for executing the tracking algorithm and effectively managing the positioning system and driving mechanism. The positioning system, which can be either electrical or hydraulic, operates the tracking device to align it with the sun at the calculated angles. The driving mechanism then moves the tracking device to the designated position determined by the positioning system. To ensure accurate tracking, sensing devices are incorporated, consisting of various sensors and measurements. These sensing devices monitor ambient conditions, measure light intensity (in the case of real-time light intensity algorithms), and determine the tilt angle of the tracker using inclinometers or a combination of limit switches and motor encoder counts. (Dhanabal *et al*., 2013).

Overall, solar tracking systems significantly improve the efficiency of solar panels by ensuring that they always face the sun, thereby maximising the amount of energy produced. Solar tracking systems have become an essential tool for the renewable energy industry, and their implementation can help accelerate the transition to a sustainable future.

2.8.1 Comparing Solar Tracking System to Fixed Panel Installations

Three main components of the sun's radiation reach the earth. These are collected on solar PV panels for electricity production.

In optimal conditions (clear sky), there are three components of solar radiation that reach the Earth's surface: direct beam, diffuse radiation, and albedo radiation. Direct beam radiation refers to sunlight that reaches the Earth's surface without scattering. Diffuse radiation, on the other hand, scatters when passing through the Earth's atmosphere. Lastly, albedo radiation is the solar energy that reflects off the Earth's surface.

In ideal conditions, direct beam radiation accounts for approximately 80 % to 90 % of the total solar energy (Marion *et al.*, 1992). This direct beam radiation serves as the primary source of energy for solar panels. To maximise energy collection, solar panels need to continuously face the direct beams of the sun for as long as possible. This concept is explained by measuring the incident angle (i) between the direct beams and the solar panels.

The effective area of a solar panel that collects this radiation is directly proportional to the cosine of the incident angle (i). Therefore, the power (P) collected by solar panels can be calculated using equation 2.1. This equation takes into account the incident angle and allows for the calculation of the collected power based on the available direct beam radiation.

$$P = P_{max} \times cos(i), \tag{2.1}$$

where P_{max} is the maximum power collected when solar panel is correctly aligned. From Equation (2.1) we can calculate the loss of power a:

$$a = P_{max} - P_{max} \times \cos(i)$$

$$a = P_{max} \left(1 - cos(i)\right). \tag{2.2}$$

Equation (2.2) shows that the more misaligned the angle is; the more sunlight energy is lost. This connection is illustrated in Figure 2.1.

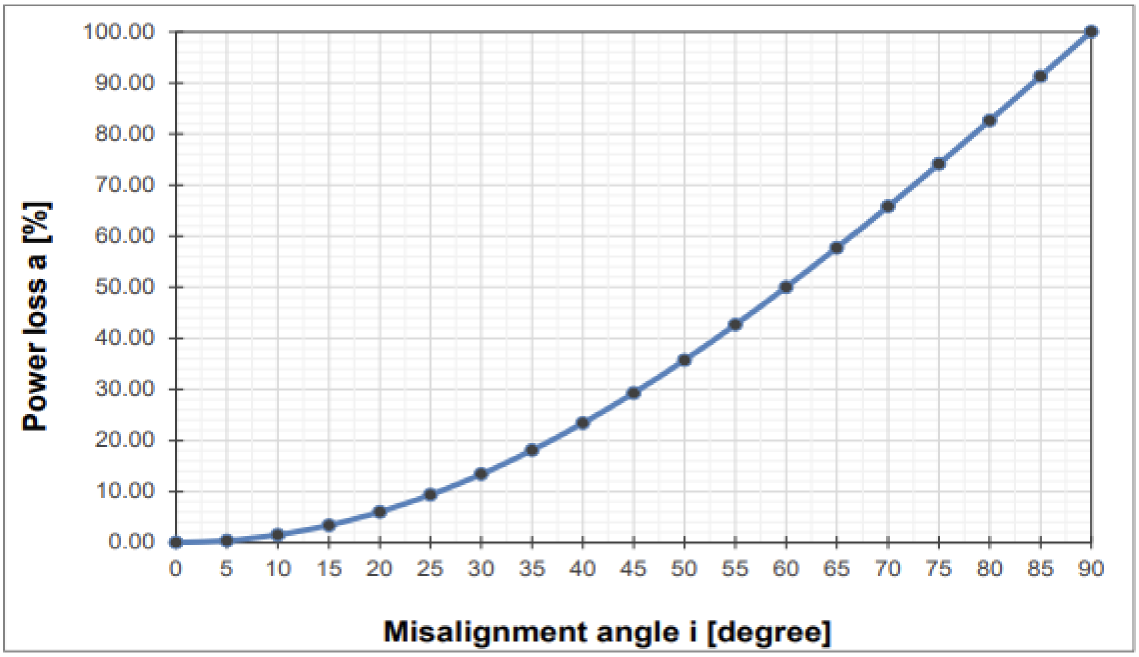

Figure 2.1 Effects of Misalignment on Solar PV Performance

(Source: Docruz, 2014)

The graph presented in Figure 2.1 demonstrates the impact of misalignment on the output power of photovoltaic (PV) modules. It clearly shows that when a solar module deviates by 30 degrees from the optimal alignment with the Sun, the output power drops by approximately 15 %. Moreover, as the misalignment angle increases further, the power reduction becomes even more significant.

To evaluate the output power of a solar system at a specific location on the Earth's surface, we can perform calculations using solar radiation data obtained from online databases like NASA. For example, by utilising solar radiation data for Ghana on May 1st, 2016, including sunrise at 05:50, sunset at 18:20, and solar noon at 12:10 (Anon., 2016), we can estimate the power output of solar modules for different times throughout the day, assuming clear skies.

By approximating the angle of solar direct beams at various times of the day and applying equation 2.1 to calculate power output, we can generate a graph that compares the calculated power values with the maximum power achievable during the day. This graph, depicted in Figure 2.3, illustrates that the output power remains above 85 % efficiency only between 11:00 and 16:00. Consequently, the fixed mount panels demonstrate high efficiency for a mere five hours during the day. This indicates that for a typical summer day in Helsinki, where the average sunlight duration exceeds 10 hours, relying on a PV system operating at this level of efficiency would not be an effective solution for harnessing solar energy.

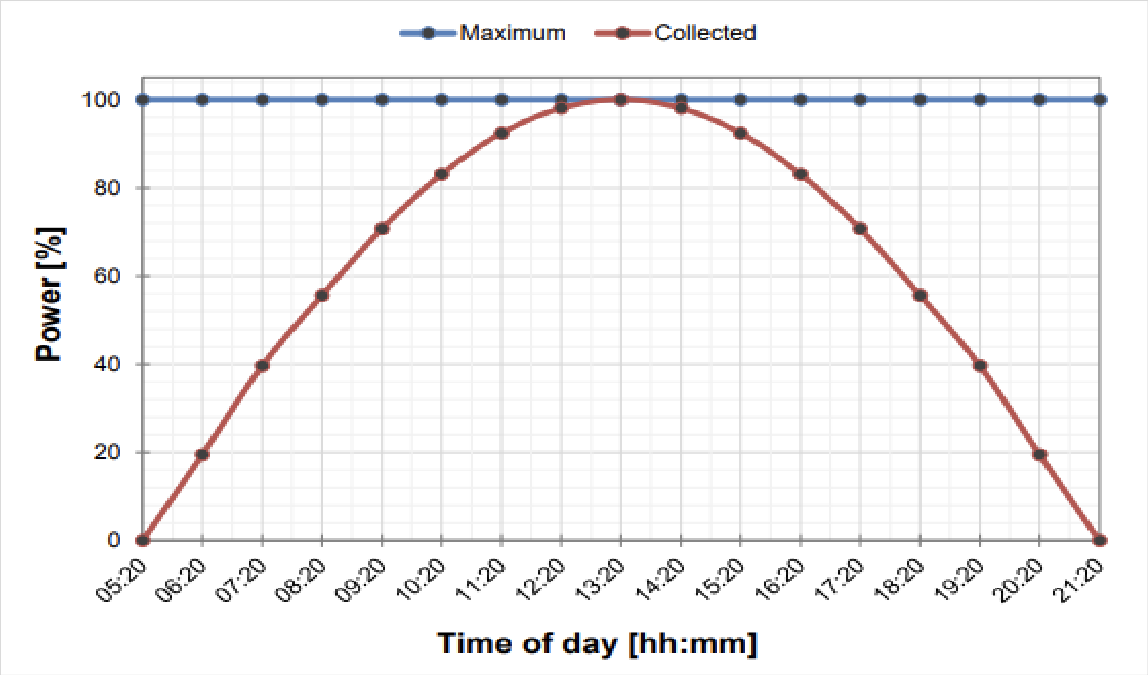

Figure 2.2 Approximation of Power Output Compared to Maximum Output for a Fixed Mounted Solar Module

(Source: Docruz, 2014)

The graph in Figure 2.2 is only based on an assumption such as, no cloud cover during the day, dust free solar panel. The previous response did not provide a comprehensive view of the limitations of fixed-mount solar panels. Indeed, fixed-mount panels have various drawbacks even under ideal weather conditions (Docruz, 2014). In reality, factors such as cloud shading, seasonal angle changes, and limited daylight hours further reduce the production efficiency of PV systems. While fixed-mount panels offer mechanical simplicity and stability, they fail to fully exploit the potential capabilities of solar panels, making them unsuitable for larger-scale and more critical projects. Therefore, there is a clear need for better mounting solutions.

One such solution is the use of solar trackers, which significantly enhance the harvesting of solar power. Solar trackers address the core issue by minimising the misalignment between the direct beams of sunlight and the panels. Through various mechanical modules, solar trackers enable the rotation of panels to optimise their position throughout the system's operation. Table 2.2 provides a comparison of the features of solar trackers versus fixed-mount options.

Table 2.2 Advantages and Disadvantages of Tracking Systems over Fixed Mounts

Advantages	**Disadvantages**
Higher efficiency High accuracy Longer active functioning time Better lifetime for solar cells	Complicated design High cost Bad tolerance against weather condition Trackers consume energy

Solar trackers employ various driving mechanisms to adjust the angle of solar panels, utilising either passive or active methods. Passive trackers function by utilising a two-phase fluid that undergoes vaporisation and expansion when heated by the Sun. These trackers typically consist of canisters on two sides, connected by a tube, where the fluid is contained. As the Sun's position changes, the differential expansion of the fluid causes a shift in weight between the two sides of the tracker. This shift in weight results in the pivoting of the tracker to orient itself towards the Sun (Parmar, *et al*., 2015). Passive trackers are generally considered less favourable and less applicable due to their complex design and lower accuracy. In contrast, active trackers utilise motor systems to precisely control the movement of solar panels in either single-axis or dual-axis configurations. These trackers employ photo sensors to continuously monitor the position of the Sun. The operation of active trackers is typically managed by a controller or computer system.

While active trackers can increase the overall cost of a solar system, they offer the best accuracy and efficiency compared to other solutions. A Dual-Axis Tracker (DAT) is particularly noteworthy, as it has the capability to provide an additional 40 % of solar energy throughout the year compared to a conventional fixed-mounting system. This significant increase in energy output makes dual-axis trackers highly advantageous for maximising solar energy harvesting. (Markvart, 2000).

Active Solar Trackers

Active solar trackers have become the most widely adopted solution for capturing sunlight in PV systems. Coupled with advancements in PV manufacturing technologies, improving the performance of active solar trackers represents the most efficient approach to fully harness the abundant energy of the Sun (Juda, 2013). Active solar trackers can be classified into two main types based on the rotation of solar modules: Single-Axis Trackers (SAT) and Dual-Axis Trackers (DAT).

Single-axis trackers involve the rotation of solar PV panels around a single axis, typically aligned with the North meridian. SATs can be configured in various ways, depending on the axis's orientation relative to the ground. The specific configuration is chosen based on factors such as geographic location and tracking objectives:

- Tilted Single-Axis Tracker (TSAT)

- Horizontal Single-Axis Tracker (HSAT)

- Vertical Single-Axis Tracker (VSAT).

SATs enable solar modules to rotate between east and west directions, aligning with the changing position of the Sun throughout the day. SATs offer a favourable balance between flexibility, simplicity, and performance. Various configurations of SATs are depicted in Figure 2.4, showcasing the different ways in which the solar modules can be oriented to track the Sun's movement. These configurations allow for optimised solar energy capture and enhance the overall efficiency of the PV system.

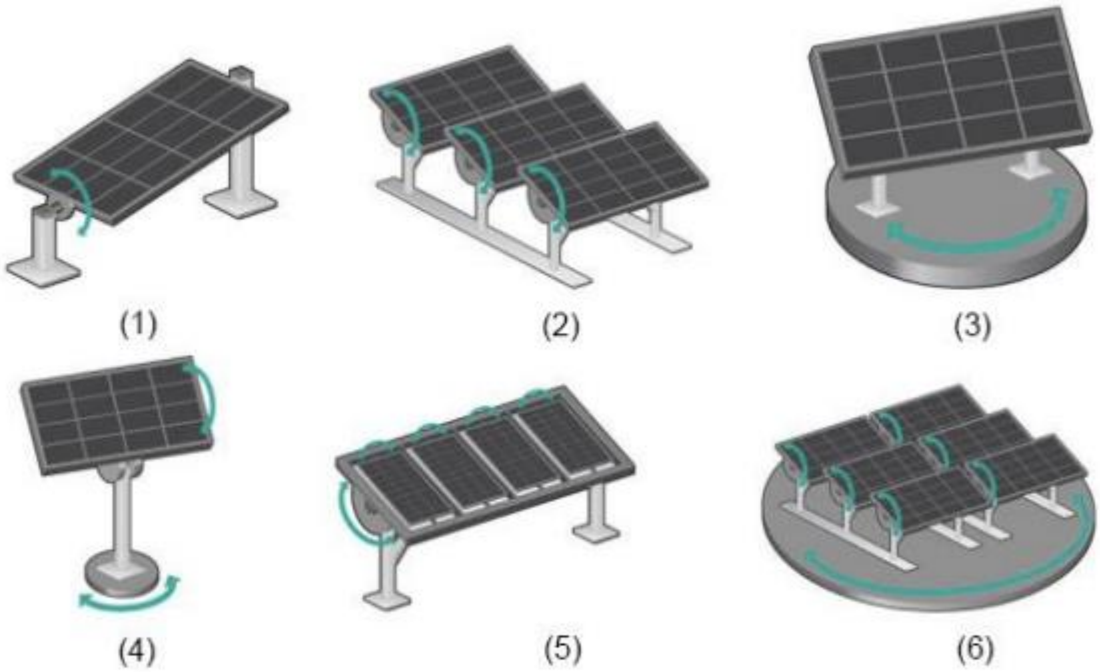

Figure 2.3 Typical Configurations for Active Solar Tracking Systems:

(1) TSAT (2) HSAT (3) VSAT (4) TTDAT (5) HDAT (6) AADAT

(Source: Juda, 2013)

DATs can be seen as an advancement over SATs, providing an extended range of movement in two separate directions. DATs offer increased flexibility in tracking the Sun's path throughout the day, optimising the solar modules' orientation for maximum energy capture. Figure 2.3 illustrates three typical configurations of dual-axis trackers, showcasing the different ways in which the solar modules can be positioned to track the Sun's movement labelled 4, 5 and 6:

- Tip-Tilt Dual-Axis Tracker (TTDAT)

- Horizontal Dual-Axis Tracker (HDAT)

- Azimuth-Altitude Dual-Axis Tracker (AADAT)

Compared to other types of mounting systems, DATs offer the broadest range of movement for solar modules. This enables the PV generator to operate at a higher efficiency for an extended duration during sunlight visibility. It is crucial to understand the concept of efficiency within the context of tracking system enhancement. In this case, efficiency refers to how effectively the tracker can optimise the utilisation of PV modules, considering a specific type of module is employed. While DATs cannot directly enhance the "radiation-to-power" efficiency of solar PV materials, these mounting systems maximise the potential of current material technologies.

The focus of this project will be the implementation of a small-scale Two-Tilt Dual-Axis Tracker (TTDAT) based on the research conducted on its structure and operation. The aim is to leverage the benefits of dual-axis tracking to enhance the performance and efficiency of the PV system, capitalising on the existing knowledge and understanding of TTDAT technology. Table 2.3 presents the advantages, performance and disadvantages of solar tracking systems available. In Table 2.4, the various types of tracking system are compared based on their investment cost and payback period.

Table 2.3 Comparison of Different Tracking Systems

Type of Solar System	Performance	Capabilities	Number of Axes	Technical Restrictions
Horizontal Single Axis Tracker (HSAT)	68 % compared to fixed panel	Less complicated, less expensive, rigid and stable. less likely to be damaged during storms	1	Occupy lot of space because they are to be arranged horizontally
Vertical Single Axis tracker (VSAT)	62 % compared to fixed panel when loss due to wind force taken into account	Less complicated, less expensive	1	Easily affected by wind force so support should be taken care
Tilted Single Axis Tracker (TSAT)	69 % compared to fixed panel	More suitable for smaller latitudes (places close to the equator)	1	Inclination should be calculated avoid shading wind loss
Polar Aligned Single Axis Tracker (PASAT)	experiments are still going on	More suitable for larger latitudes (places far to the equator)	1	In experimental stage

Table 2.3 Cont'd

Tip-Tilt Dual Axis Tracker (TTDAT)	78 % compared to fixed panel without considering the extra manufacturing cost of dual axis	Able to track the sun in both directions (east-west as well as north-south)	2	Should be attached to a long pole so wind forces will be very high
Azimuth-Altitude Dual Axis Tracker (AADAT)	82 % compared to fixed panel	More suitable for greater latitude where substantial seasonal variation in sun's height and arc	2	It's pivoting mechanism rests on the ground so occupies a large space and these are not suitable for northern climates with snow build up
Passive Tracking System	40 % compared to fixed panel	With the help of passive materials like SMA (shape memory alloy), the additional parts can be eliminated.		cost of the materials acting as actuators can be very high and availability of some materials can be difficult.

Table 2.4 Comparison of Cost of Power and Payback for Different Tracking Systems

Type of Solar Tracker	Capabilities	Technical Restrictions
Fixed solar panel	$ 2 - $ 2.4 /W depending on the panel size and region	1.5 to 3.5 years for crystalline silicon PV system
Single axis solar tracking system	$ 1.17 /W premium with respect to efficiency	3.0 years of payback cost on tracker investment
Dual axis solar tracking system	$0.36 /W premium with respect to efficiency	3.5 to 5 years of payback cost on tracker investment
Passive tracking system	$ 1.2 - 2/W depending on the tracker size and features	Approximately 5 years of payback cost

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

The chapter explains the various steps and processes taken to achieve the project objectives. An energy audit was conducted using the three levels of the ASHRAE energy audit scheme. On-site inspection and data collection from the various schools were taken. The results obtained from the auditing were used to propose a renewable energy technology.

The best solar PV system was chosen based on the initial cost of investment and a levelised cost which is relatively cheaper than purchasing energy from the national grid.

In the final part of the chapter a solar tracking prototype specifically designed for the gable roof type was developed and compared to another which remained fixed on one side of the gable roof. The following methods were used to carry out this project.

3.2 Energy Audit

3.2.1 Scope

It was observed that Senior High Schools in the study area do not use a lot of diverse electrical equipment. The most electrical appliances which were directly being used by the students are the lighting system and fans. However, inventory of all appliances including, refrigerators, televisions, lighting, air conditioning etc, were all looked at to reduce wastage where necessary.

3.2.2 Phase I: Collection of Historical Data

During an audit process, a request was made for the two-year (2019 and 2020) electricity bills. These schools had a multi-meter system, with each building unit having its own electrical meter. However, the data collected from these individual meters was incomplete, resulting in data gaps and making the analysis ambiguous. To overcome this issue, the monthly average of these meters was used as the baseline data for analysis.

It is important to note that the government is responsible for paying the electricity bills of these schools. A significant number of bills were not available at the time of the request.

Among all the schools examined, it was observed that only St. Augustine's Senior High School had substantial and reliable data recorded for analysis.

The focus was on observing patterns in energy consumption by analysing the changes and similarities in the monthly bills. However, due to incomplete and unavailable data, the analysis was limited in scope. Also, due to the COVID-19 vacations and the double tracking system, the monthly energy consumptions varied significantly as seen from St. Augustine's in Figure 3.1.

Energy Consumption Data and Cost for St. Augustine's Senior High School

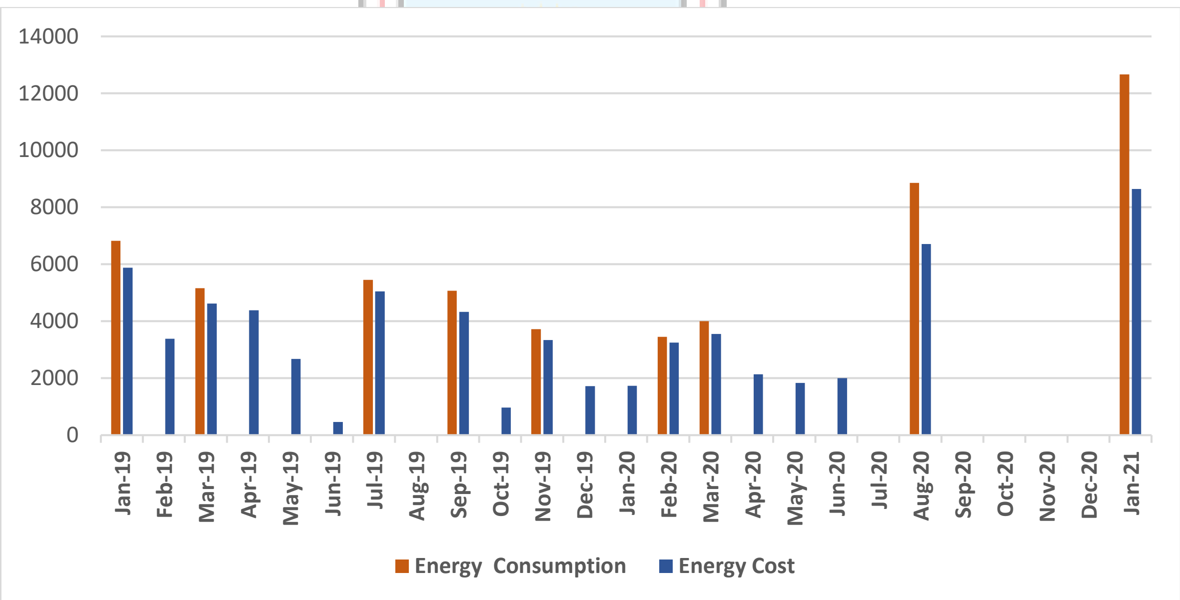

Figure 3.1 Energy Cost for Augusco from January 2019 to January 2021

3.2.3 Phase II: Walkthrough Survey

During the initial visit to the various schools, a walkthrough was conducted, excluding the staff bungalows. The walkthrough encompassed buildings such as the kitchen, administration block, classroom blocks, dormitories, canteen, clinic, and laboratories. It was noted that the student population did not impact the energy consumption in the staff bungalows, as the staff residing there were responsible for paying their own bills.

During the walkthrough, all the electrical equipment and machinery present in the schools were observed and analysed. Data from these equipment were recorded to estimate the amount of energy being consumed.

The inventory of electrical equipment was categorised into four main sections:

a. Lighting system: This included bulbs and luminaires.
b. Cooling system: Primarily consisting of air-conditioning units.
c. Refrigeration system: Including fridges and dispensers.
d. Computing system: Encompassing desktops, laptops, printers, photocopier machines, and shredders.
e. Other appliances: This category covered kitchen equipment, kettles, battery rechargers, and special machinery present in some areas.

3.2.4 Phase III: Detailed Survey

During the detailed investigation, a thorough assessment of various electrical systems was conducted. The focus was on identifying faulty appliances, inefficient gadgets, and electrical appliances with high power consumption. Calculations were performed to determine potential energy and cost savings opportunities. Appendix E provides specifics on this data collection process.

The majority of the electrical equipment used in these schools is for lighting purposes. The energy inefficiencies within the lighting system were carefully examined, and calculations were made to evaluate the feasibility of retrofitting or replacing these systems. Also, the deep freezers used to store foods in the school's canteens were very old and, in some cases, had leakages. Some fridges had been maintained over the years using crude means such as welding and placing heavy objects on the lid. These were deemed inefficient according to current standards and required replacements.

The calculations involved in determining the potential energy and cost savings achievable by upgrading to more efficient systems compared to the existing ones. This analysis aimed to provide insights into the benefits of implementing energy-saving measures and identifying opportunities for cost reduction.

Energy saving calculations and opportunities

During the analysis of the current electrical systems in the schools, the audit focused on comparing the existing lighting options, which primarily consisted of compact fluorescent light and T5 brands, with the most recent type of lamps, LEDs. LEDs are known for their energy efficiency and the potential cost savings they offer through reduced energy consumption.

LED bulbs have a longer lifespan compared to other types of lamps, with an average operating time of 40,000 to 50,000 hours, which is approximately 9 to 10 years of continuous use. This longer lifespan contributes to further cost savings by reducing the frequency of bulb replacements.

To assess the potential energy and cost savings, recording of data on energy consumption per day for the current lighting systems was made. Then calculations on the potential energy savings that could be achieved if the schools replaced their current lighting systems with LEDs. These calculations take into account the energy efficiency of LEDs and the reduced energy consumption they offer compared to the existing lighting options.

The summary of the recorded data, including energy consumption per day and the potential energy savings from replacing the current lighting systems with LEDs, can be calculated using Equation 3.1 and Equation 3.2. The detailed inventory and calculations is presented in Appendix B.

Calculations.

Energy Consumption (Daily) = Power (kW) × Time (Hours) (3.1)

Energy Cost = PURC rates × Energy Consumption. (3.2)

Energy consumption trends

Assumptions were made to determine what happens at every hour during the day. For instance, in the classroom lights and, in some cases, fans are used. It was assumed that these lights are put on from 7:00 am when learning begins to 2:00 pm when school closes. During the evenings, these lights are used for learning and are put on again for 3 hours. Such assumptions were made for offices, classrooms, kitchen dormitories etc within the facility. Appendix B displays the time series for St. Augustine's Senior High School as an example of how assumptions affected the hourly energy consumption. Appendix E presents the complete data collected from the site.

Energy consumption calculations

$$Energy\ (kW)\ =\ Power\ \times\ Time$$

Energy Consumption Per hour (kWh) = Sum of energy (*electrical appliance on*) at that hour.

Total Energy Consumption per day (kWh/day) = Sum energy consumption of entire school from hour 0 to 24.

Data on energy consumption from the electrical appliances used in the school was used to generate a load characteristics graph that depicts the pattern of energy usage throughout the day. The graph highlights the peaks and dips in electricity usage, which correspond to the maximum and minimum energy demands of the schools. Appliances such as deep freezers and fridges were assumed to be on for 24 hours during the day.

Based on the daily load profile, it was estimated that the lighting system in the schools consumes the most energy during the evenings. Although the classroom blocks are used during the day, there is an additional demand for energy at night when lights in the classrooms, corridors and compound are turned on for studying. Hence the increase in energy consumption between 7 pm and 10 pm. As a result, there is a significant decrease in energy consumption between 6 am to 9 am. During this period, the outside lights are switched off before classes begin.

Figure 3.2 provides a visual representation of the load profiles for each school.

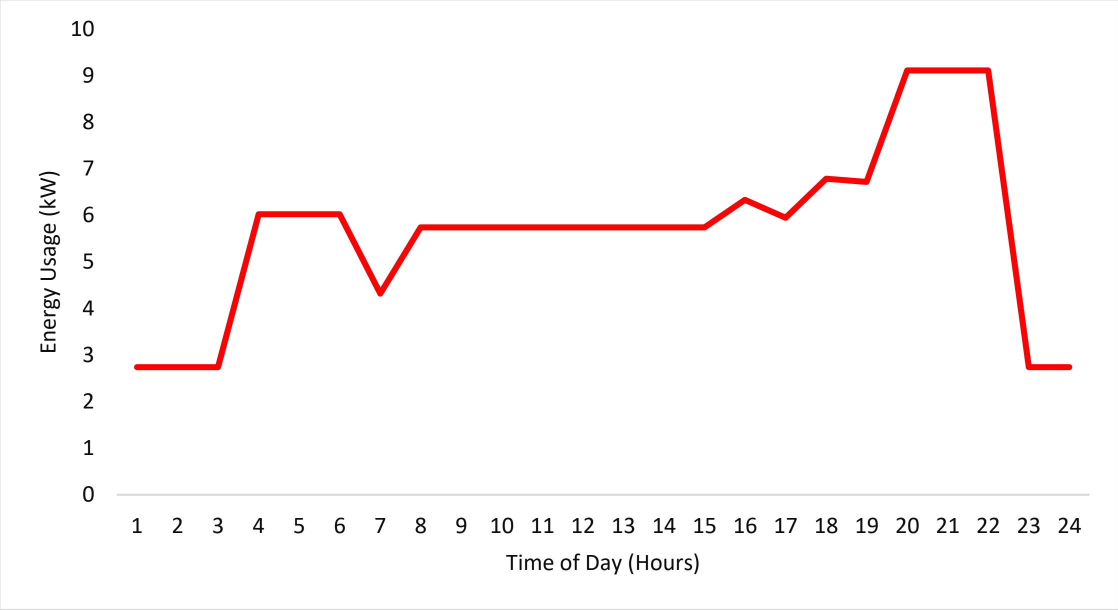

Figure 3.2 Load Characteristics of St. Augustine's Senior High School

The load profile of the schools reveals a consistent usage pattern. Between the hours of 12:00 am and 4:00 am, the energy consumption is at its lowest. Only lights on corridors and on the compounds are on at this time. Students start to wake up at 4:00 am and the energy consumption rises as the dormitory lights are added to load. As students leave the dormitories to the classroom between the hours of 7:00 am and 8:00 am, lights on the compound and in the dormitories are assumed to be turned off. However, lights in the classrooms are switched on during this period. It is around this time too that the offices are opened for teachers and management staff.

Between the hours of 9:00 am and 3:00 pm, the energy consumption is stable until students close from class. At this time, it is assumed that the transition between students moving from the classroom to the dormitories is not spontaneous. However, the power consumption remained high even in the afternoon because offices were still open until 5:00 pm.

In the evenings, the peak energy consumption is observed, with the highest consumption occurring around 10:00 pm when all lights, including outdoor lights, are in use. The lowest energy usage is recorded around after 10:00 pm when most lights in the dormitories and classrooms are turned off leaving only lights on the compounds. This pattern is generally observed in all the schools, although slight variations exist due to differences in the number of facilities and seasonal weather patterns.

LED bulbs with equivalent lux to the existing CFL lamps were used to calculate the potential savings from the LED replacements. The number of bulbs remained the same, but the wattage was reduced due to the lower energy consumption of LED bulbs compared to CFLs. For instance, at St. Augustine's Senior High School, the existing average load is calculated to be 5.2 kW, while the LED forecast is 1.43 kW. The peak load reaches a maximum of 9.1 kW (existing) and 2.3 kW (LED forecast). Based on the collected data, the average daily load is 234.30 kWh/d (existing) and 142.79 kWh/d (LED forecast).

The load profile for the other schools is presented in Figures 3.3, 3.4 and 3.5. It can be observed that the load profile is similar to that of St. Augustine's except Fiaseman SHS which had a different pattern after school hours. The sharp decline in energy usage after 5:00 pm is as a result of the number of computers and inefficient lights being used in the administration and offices of Fiasec. Hence, their usage affected the high energy consumption rate observed in Figure 3.3. Also, their dormitories were equipped with efficient lights, reducing the overall energy consumption between 3:00 am and 6:00 pm when before they leave for classes. After 3:00 pm, when the students have returned from classes, the sum total of energy being used in the offices and dormitories raises the energy consumption till 5:00 pm when the administration closes. At night, the corridor and compound lights in addition to classroom lights being used for learning raises the energy consumption to its peak till after 10:00 pm. At this time, it is assumed that all lights in the classroom and dormitories are put off. Only the lights on the compound and corridors will be on till the start of another day at 3:00 am.

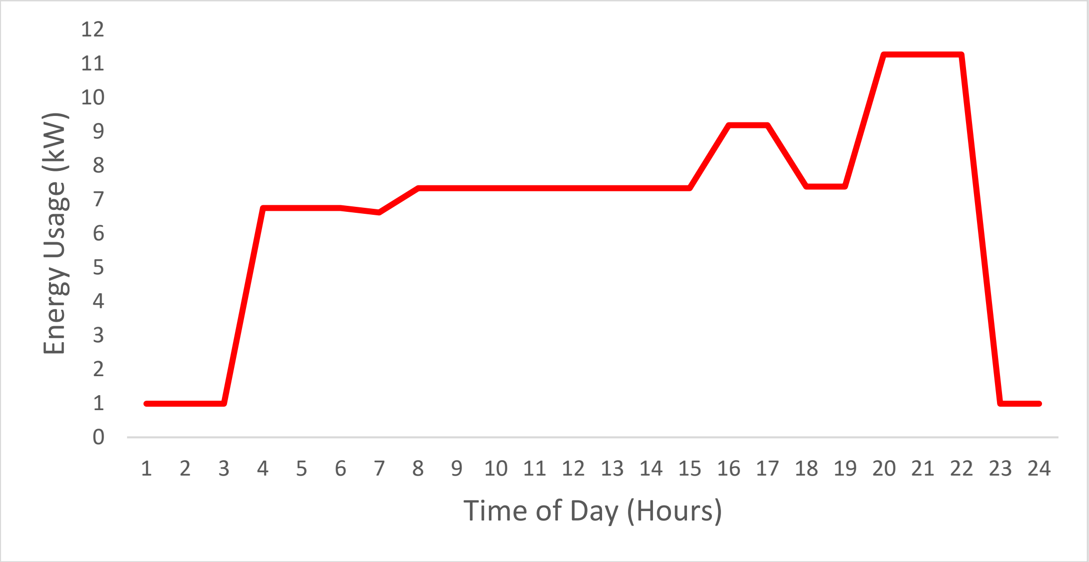

Figure 3.3 Load Characteristics of Fiaseman Senior High School

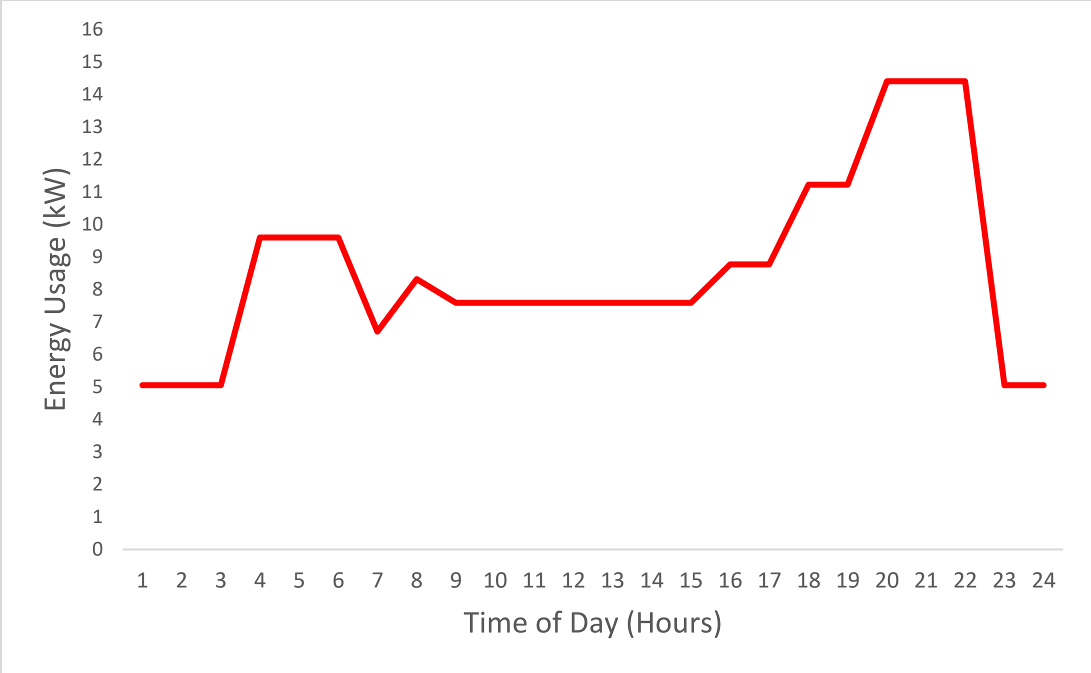

Figure 3.4 Load Characteristics of Huni Valley Senior High School

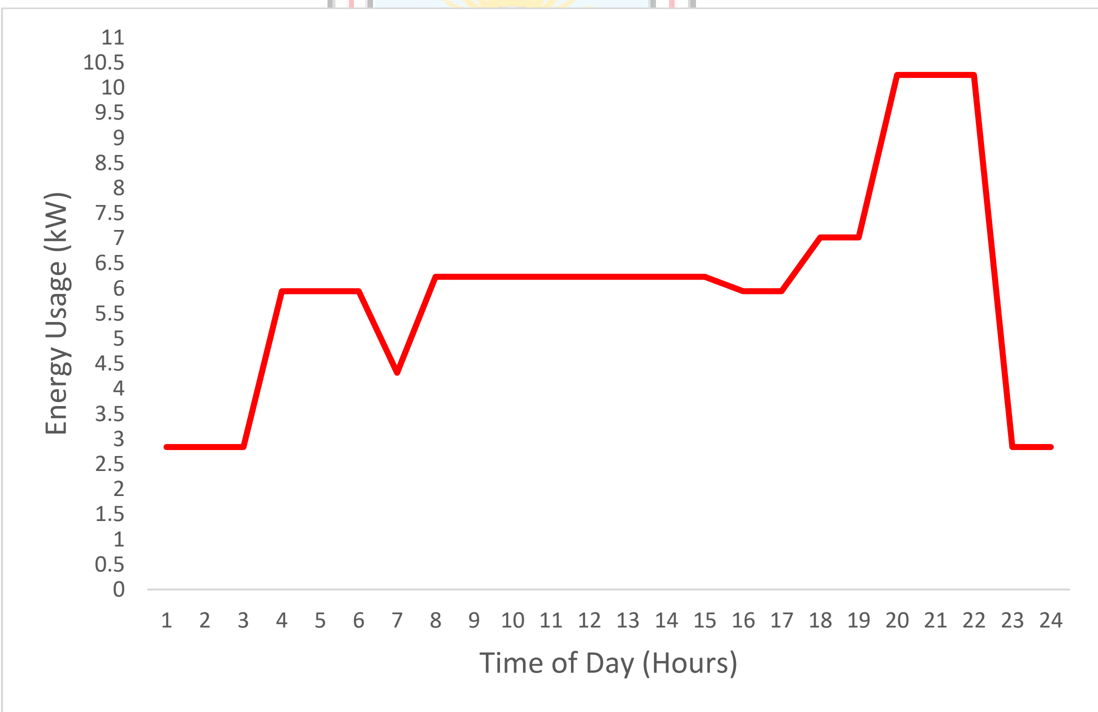

Figure 3.5 Load Characteristics of Existing System at Tarkwa Senior High School

3.3 Feasibility Study of Renewable Energy Technology Integration

3.3.1 Introduction

The possible renewable energy technologies available for exploitation at these sites were studied. Amidst solar PV, wind power, biomass, mini hydro and other sources of renewables, only solar PV was considered. The project didn't select mini hydro as an option due to its high cost and lengthy feasibility study stage. Biomass energy was also not considered due to its high emissions, and the cost of purchasing a turbine and generator unit was deemed too expensive for the project. The goal was to investigate the feasibility of using a renewable energy resource to supply part of these schools' electrical energy demands.

3.3.2 Solar PV Technology

The experiment considered two solar PV installation configurations - off-grid and grid-connected systems. The off-grid system relies solely on solar energy and requires batteries for storing excess electricity generated during the day, which can be used during cloudy days or at night. On the other hand, the grid-connected system uses a combination of solar energy and electricity from the national grid. During the day, the system primarily utilises solar energy, and any energy deficit is augmented using power from the grid, thereby eliminating the need for expensive batteries.

The schools are located in the same geographical region and the availability of sunshine throughout the year in Ghana provides a significant advantage in using solar energy. The clearness index of Tarkwa, for instance, is approximately 0.478, implying that 50 % of the time, sunlight is unobstructed, making solar energy collection feasible. Furthermore, the schools possess a substantial amount of space that can be utilised for the installation of solar PV.

Solar resources for Tarkwa

Resources for the location was downloaded via the HOMER software. From Figure 3.6, the highest solar radiations were recorded in the month of March, where on a normal day, the clearness index is 0.548. Also, the temperature variations for the location were also accessed. The graph in Figure 3.7 shows a minimum surrounding temperature in August when the rainy season is at its peak. The highest temperature of about 27.70 ^{0}C was recorded in February. Solar PV panels perform well within 15 ^{0}C to 35 ^{0}C. A table showing the solar resource data for the study area is presented in Appendix A (Table A1).

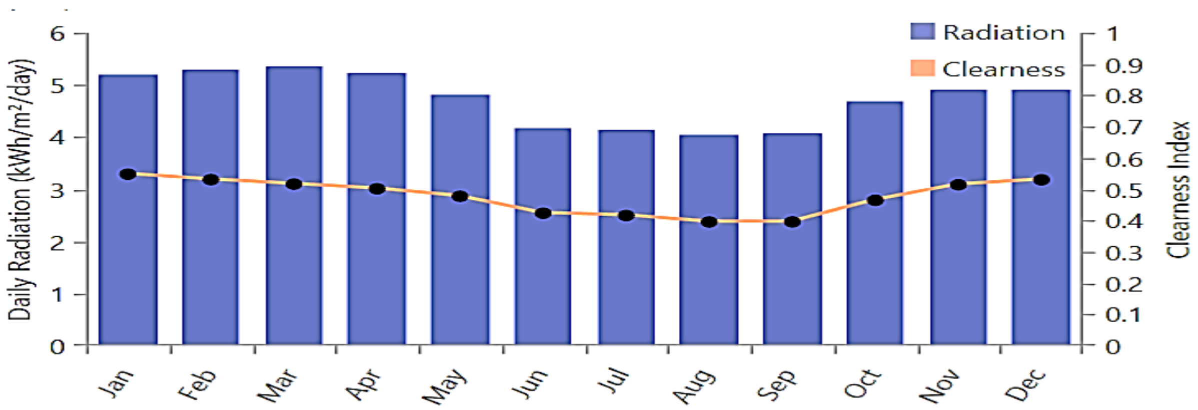

Figure 3.6 Monthly Average Solar Global Horizontal Irradiance (GHI)

(Source: NASA Surface Meteorology and Solar Energy Database)

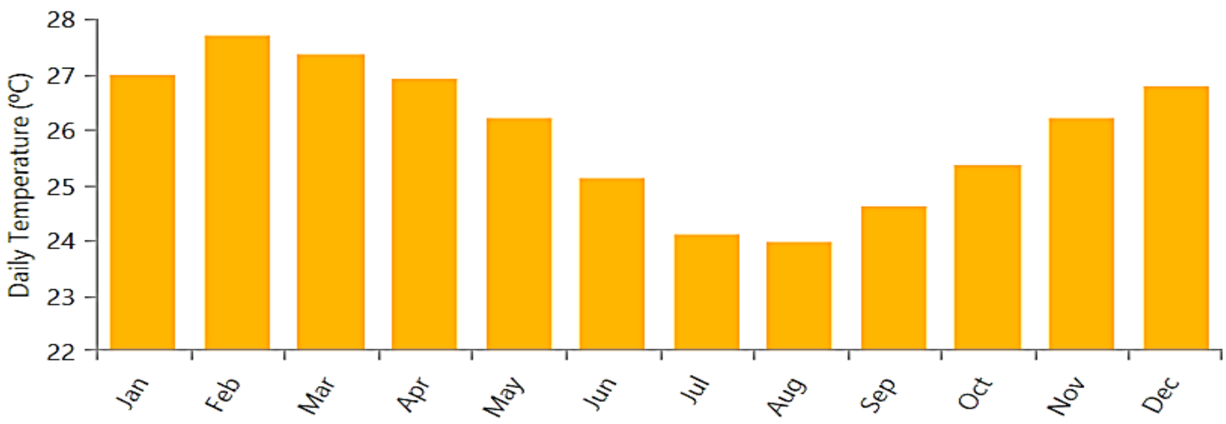

Figure 3.7 Monthly Average Temperature of Tarkwa and its Environs

(Source: NASA Surface Meteorology and Solar Energy Database)

Software simulations and calculations

The HOMER software (version 3.14.4) was used to make simulations on the most feasible combinations of components for power generation. The focus was on stand-alone solar PV, grid connected solar PV and wind power. Concurrently, calculations were made also for the cost involved in purchasing energy from the grid during the lifetime of these technologies.

Cost analysis of project

The prices of the various components chosen for the design of the solar PV system were searched from the manufacturers sites.

Battery selection

The battery type that was chosen in the HOMER software is the Generic 1kWh Lead Acid Battery. Properties of this battery are shown in Figure 3.8. The selection was based on ease of use, cost and lifespan.

The general rule is that batteries deteriorate over time as they charge and discharge. These batteries have a lifecycle of about 10 years. Due to this limitation, the batteries will require replacement during the 25 years project life. Hence using the current inflation rate of 42.63% (Public Utilities Regulatory Commision (PURC), 2023) per annum of Ghana, replacement costs were calculated by the HOMER software and integrated into the project.

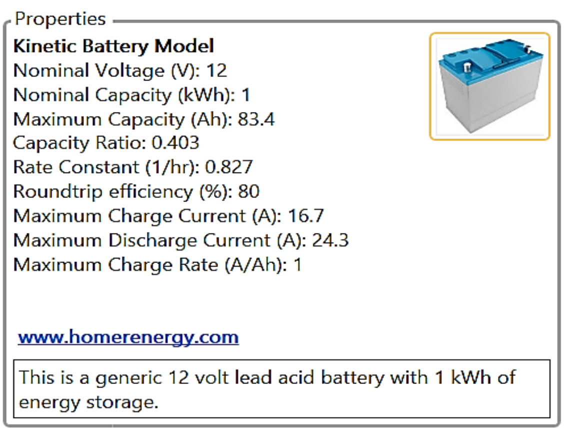

Figure 3.8 Properties of Generic 1kWh Battery

DC-AC Inverter

Inverter selection was made through the HOMER software. In order to prevent overestimation, the software was used to select and calculate the inverter's capacity. Therefore, the inverter type chosen for the project is the Leonics S-219Cp 5 kW, 240 Vdc inverter. This inverter was chosen because of its voltage capacity (240 V). The inverter has an efficiency of 96 % under normal working conditions shown in Figure 3.9.

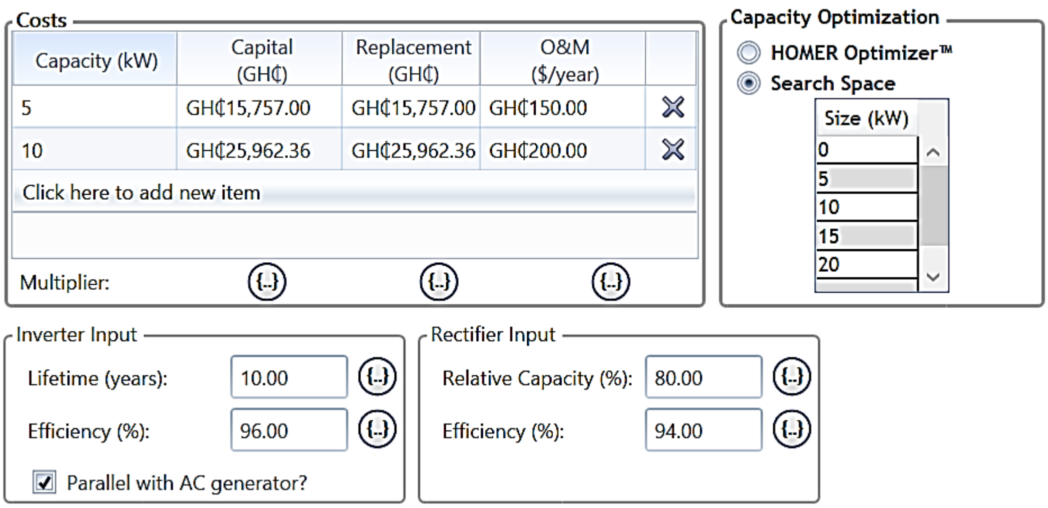

Figure 3.9 Cost and Performance Parameters of DC-AC inverter

Solar PV

The municipality's location has a good solar GHI and hence the generic 1 kW flat plate solar PV was chosen. This was chosen in the software because, it easier to make calculations with multiples of 1kW solar panels. This component has an efficiency of 13 % but the simulations and calculations yielded encouraging results. The PV array would work under an optimum temperature around 47 ^{0}C. Figure 3.10 gives information of the PV selected. The initial and replacement costs per 1 kW of this type of solar panel is shown in Figure 3.11.

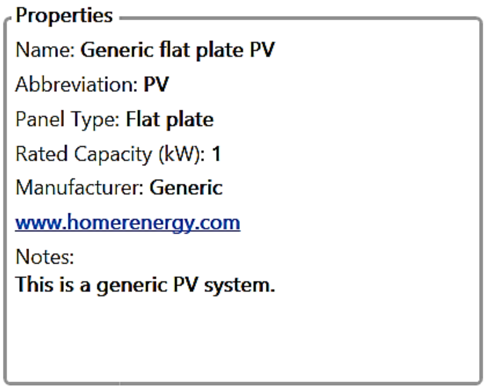

Figure 3.10 Solar PV Characteristics

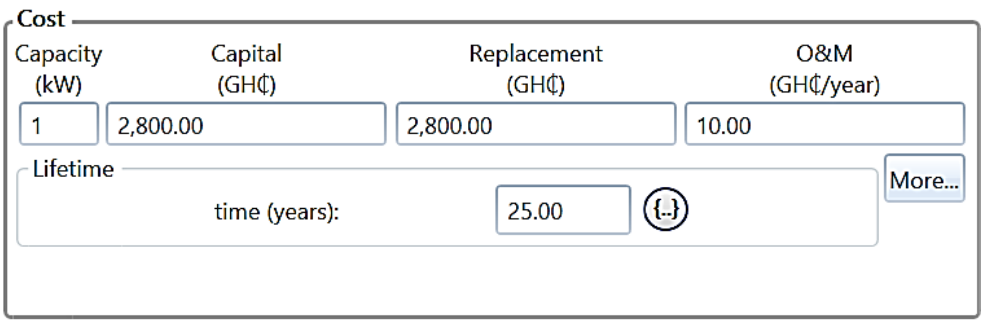

Figure 3.11 Solar PV Characteristics and Costing

Connection of components

The off-grid connection was made to disconnect the electrical system from the grid and power it solely by the energy from the PV. In the daytime, the solar PV cells produce energy which passes through the converter directly to the load and the excess energy is channelled into the batteries for charging. At night, when the sun is not available, stored energy in the batteries are released into the inverter and used to power the electrical load. The solar PV cells and the batteries being DC current sources are on the DC side of the connection with the inverter connecting the DC and AC buses. Figure 3.12 gives a pictorial description of the arrangement of the system components.

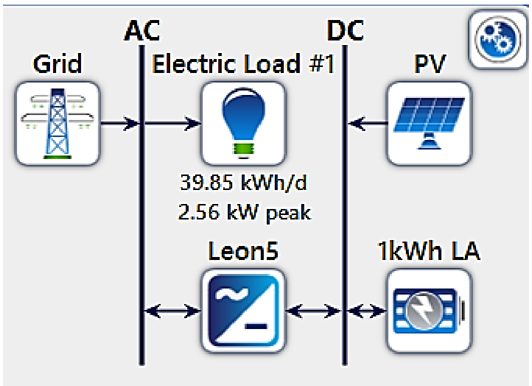

Figure 3.12 Connection of Components for the Project

The HOMER software uses the same load profile to simulate many component combinations to get the best result. In the end, the best combination is selected based on the rate of return or payback period.

3.4 Rooftop Solar Tracker

The proposal for a two-sided roof top solar tracker is considered. In this experiment, two different installations (Control and experiment) are mounted on the same roof to collect energy from the sun during the day. The control experiment is an illustration of current traditional solar installation. This experimental installation uses a solar tracker which lifts or reclines panels mounted on both sides of a gable roof as the sun moves across the sky.

3.4.1 Control Experiment

The positioning of solar panels on rooftops is usually limited to one side, as depicted in Figure 3.13. This arrangement leads to intermittent exposure to direct sunlight, resulting in reduced energy capture and output. On a sunny day, the panels achieve their peak efficiency for about five hours. However, after this period, the panels on the non-facing side receive only diffused rays, leading to a decline in energy generation.

This setup serves as the control experiment and emulates the prevailing installation method. Two fixed-position 25 W panels are mounted on one side of the roof to collect solar energy during the day. Several parameters, such as panel voltage, current, temperature, and humidity, are monitored and recorded.

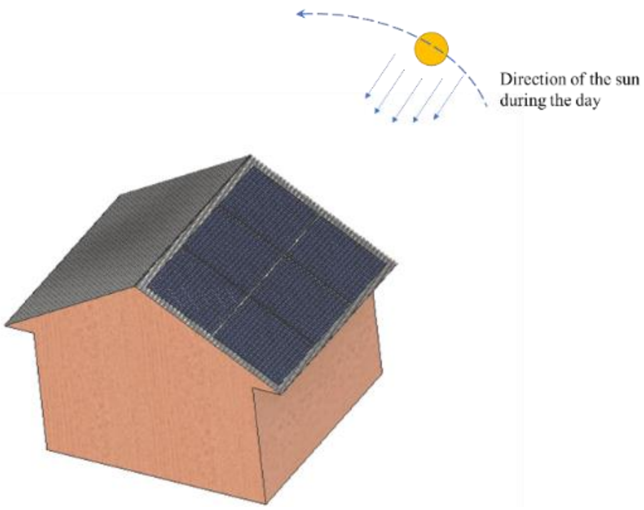

Figure 3.13 Traditional Rooftop Solar PV Installation

3.4.2 Tracking System Design.

The aim of this experiment is to improve the efficiency of solar panels mounted on rooftops. Instead of the traditional infrastructure where solar panels are mounted on only one side of the roof, this experiment involves mounting two 25 W solar panels from the same manufacturer on two sides of the roof. The panels are equipped with a mechanical system that allows them to move up or down during the day so that they are always at an angle close to 90° with the sun's rays.

The movement of each panel is controlled independently by a stepper motor connected to a bolt and nut. The nut is attached to the panel, and as the bolt rotates clockwise or anti-clockwise, the panel moves up or down respectively. In the morning, one panel is positioned at its maximum angle to collect solar energy while the other panel remains stationary. This allows both panels to receive the same amount of sunlight, as illustrated in Figure 3.14. Additionally, various parameters such as temperature, humidity, voltage, and current are measured to monitor the panels' performance.

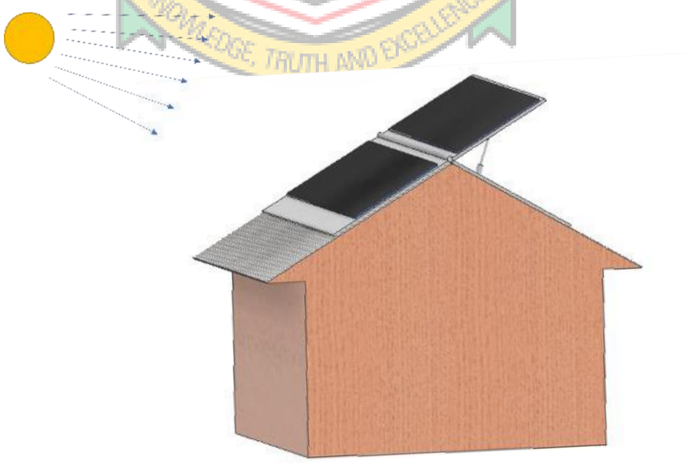

Figure 3.14 Panels on Both Sides of Roof Facing the Sun in the Morning

The panels are mounted on opposite sides of the roof and are each equipped with a stepper motor that can control their vertical orientation. As the sun moves across the sky, the panels move in the same direction to maintain a close to 90° angle with the sun's rays.

In the morning, one panel rises to assume a position which receives equal amount of sunshine as the other panel which didn't move. As the sun moves, both panels adjust their angles to follow its path. At noon, both panels reach their horizontal orientation, perpendicular to the sun's rays, as depicted in Figure 3.15. This tracking system ensures that the panels receive maximum sunlight throughout the day.

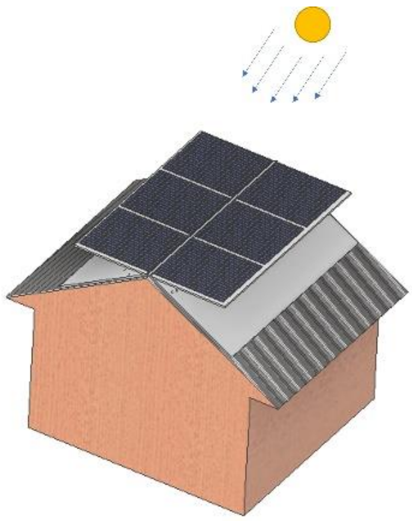

Figure 3.15 Panels on Both Sides of Roof in Horizontal Orientation to Face Direct Sunlight at Noon

During the afternoon, as the sun moves to the other side of the roof, the two panels adjust their position accordingly to face the setting sun and still receive maximum sunlight. This is depicted in Figure 3.16, where the panels are now facing in opposite directions compared to their position in the morning. The stepper motors continue to adjust the panels' angles as the sun moves until there is no more sunlight to track. This tracking system enables the panels to capture more sunlight and generate more energy compared to the fixed position panels used in the control experiment.

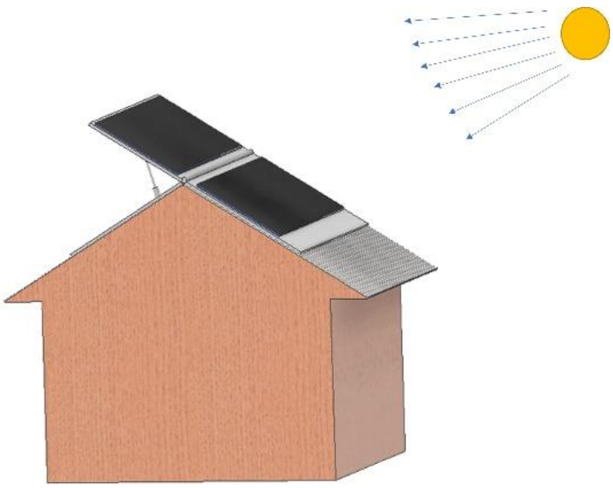

Figure 3.16 Panels on Both Sides of Roof Facing the Sun in the Afternoon

Figure 3.17 presents the fabrication of the proposed prototype. The two experiments are mounted side by side on a roof-like structure. This setup was mounted and used to collect data for analysis.

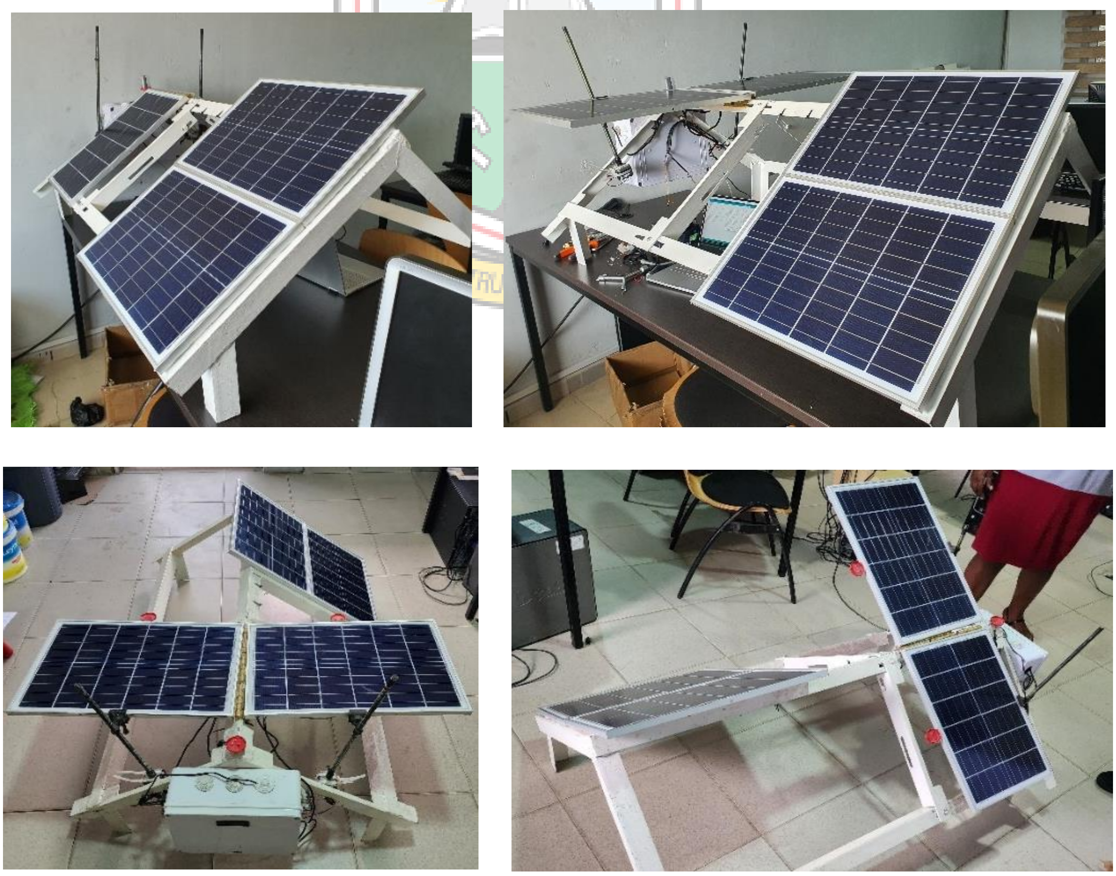

Figure 3.17 Both Systems Mounted on a Roof-like Structure

3.4.3 Component Selection

Microcontroller

To automate and gather data from the two systems, microcontrollers were utilised, which can be programmed to perform various functions. In this experiment, two Arduino Nano microcontrollers were chosen due to their compactness and user-friendliness. One of the microcontrollers was used to collect data, while the other was used to control the motor movement and light sensors to track the sun's position.

The Arduino Nano microcontroller has several analog and digital inputs, but most of the pins utilised in the experiment were analog however, the motor movement pins were digital. Figure 3.18 shows a diagram of an Arduino Nano microcontroller, including its various components.

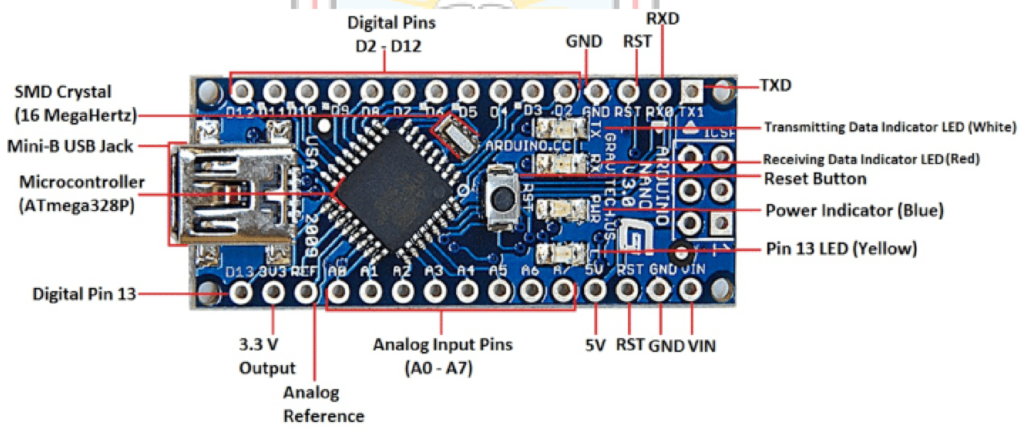

Figure 3.18 Parts of an Arduino Nano Microcontroller

Solar panel

In total, four 25 W solar panels were used for this experiment- two for each system (Control and experimental system). This selection was because the 25 W panel is light and has a small area. Details of the panel chosen is shown in Table 3.1 and Figure 3.19

Table 3.1 Details of 25 W Solar Panel Used for the Experiment

Component	**Dimension**
Weight	$2.8\ kg$
Dimension $(L \times B \times H)$	$53\ cm \times 35\ cm \times 1.7\ cm$
Current	$4.17\ A$
Voltage	$6\ V$
Short Circuit Current (I_{sc})	$4.38\ A$
Open Circuit Voltage (V_{OC})	$7.2\ V$
Power	$25\ W$
Operating Temperature	25° to 90°

Figure 3.19 Solar Panel of 25 W

Motors

The tracking system requires precision and torque, which led to the selection of two NEMA 17 stepper motors. These motors were coupled to bolts that rotated within the nut to create an up-and-down movement of the solar panels. Figure 3.20 provides a visual of the NEMA 17 stepper motor.

Figure 3.20 NEMA 17 Stepper Motor

Sensors

To collect data from the two systems, several sensors were used. For consistency, the same sensors from the same manufacturer were used in both the control system and the experiment. The ACS217 current sensor in Figure 3.21, a hall effect sensor with a sensing range of 0 A to 20 A, was selected to collect data on the maximum current output from the solar panels, which is expected to be 4.38A. Additionally, a current sensor was connected to each motor to collect electrical data from them. In total, four current sensors were used.

Figure 3.21 ACS217 Current Sensor

A voltage sensor was necessary to measure these instantaneous voltages. Two 25 V voltage sensors were used for this purpose. However, the motors were powered directly from a 12 V battery included in the tracking system installation. The B25 voltage sensor is shown in Figure 3.22.

Figure 3.22 B25 Voltage Sensor

Electrical load

To measure current, a load needs to be present in the circuit. In this experiment, three 10-ohm dropper resistors were connected in parallel to obtain an effective resistance of 3.3 ohms. This resistance was enough to obtain the maximum stated current that can be attained.

Other components

LDR: To accurately track the position of the sun, Light Dependent Resistors (LDRs) were used. The resistance of LDRs is inversely proportional to the amount of light that falls on them, meaning that as the sunlight increases, their resistances decrease. The LDRs were placed at specific points on the solar panels to detect the position of the sun. By measuring the resistance of the LDRs, the microcontroller can determine the orientation of the panels and adjust their position to maximise solar energy collection.

Button Switch: The switches were used as a safety mechanism to prevent the panels from moving beyond their intended range of motion and potentially causing damage or harm. When the panels reach the limit of their movement, they activate the switch which sends a signal to the microcontroller to stop the motors.

3.4.4 Details of Mechanical Connections

System setup

The entire structure was designed to be lightweight and portable for ease of installation and maintenance. The structure was built using aluminium angle bars with dimensions of 40 mm x 40 mm and 20 mm x 3 mm, respectively. The panels were attached to the structure using brackets made from galvanised steel strips as shown in Figure 3.23.

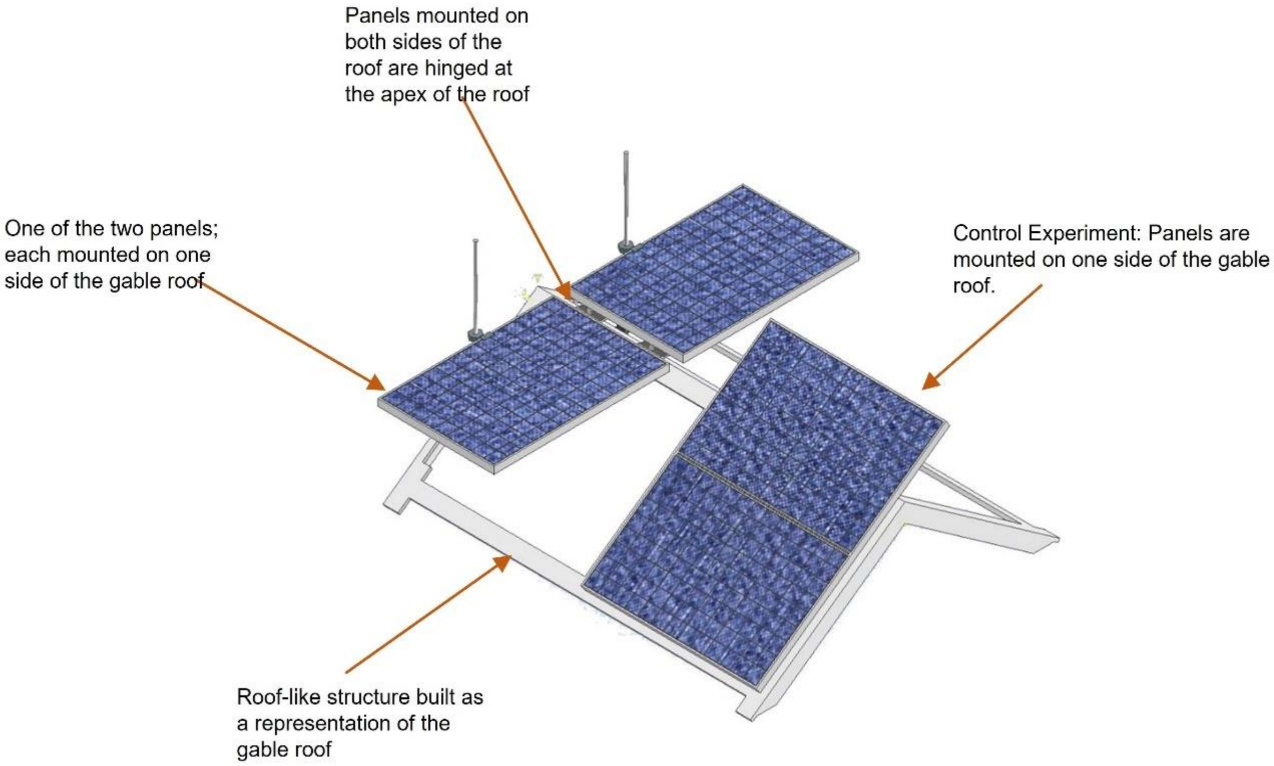

Figure 3.23 3D Model of Both Setups on the Same Roof

Hinges: The solar panels were hinged to the apex of the roof, as shown in Figure 3.25.

Clamps: To hold the solar panels firmly, clamps were designed with a bolt and nut below each solar panel. The nut was screwed tightly for a firmer grip. Each panel had one clamp. A short shaft was connected to the clamp on one end and welded to a nut on the other end. As the bolt rotated through this nut, the resulting up-and-down movement is observed on the panel. This detail is presented in Figure 3.24.

Bearings: Four bearings were used to ensure free movement of the panels and other parts of the system. As the panels move up and down, the bolt and nuts tilt slightly due to the circular movement of the panels. These slight movements were factored in the design and hence two bearings were put on each arm of the trackers.

One bearing was placed on the clamps holding the panels and another on the structure that holds the motor. These two bearings gave enough room for the tilting effect that is generated as the panels move up and down.

An exploded view of the tracking mechanism presented in Figure 3.25 shows in detail the various components and how they are arranged.

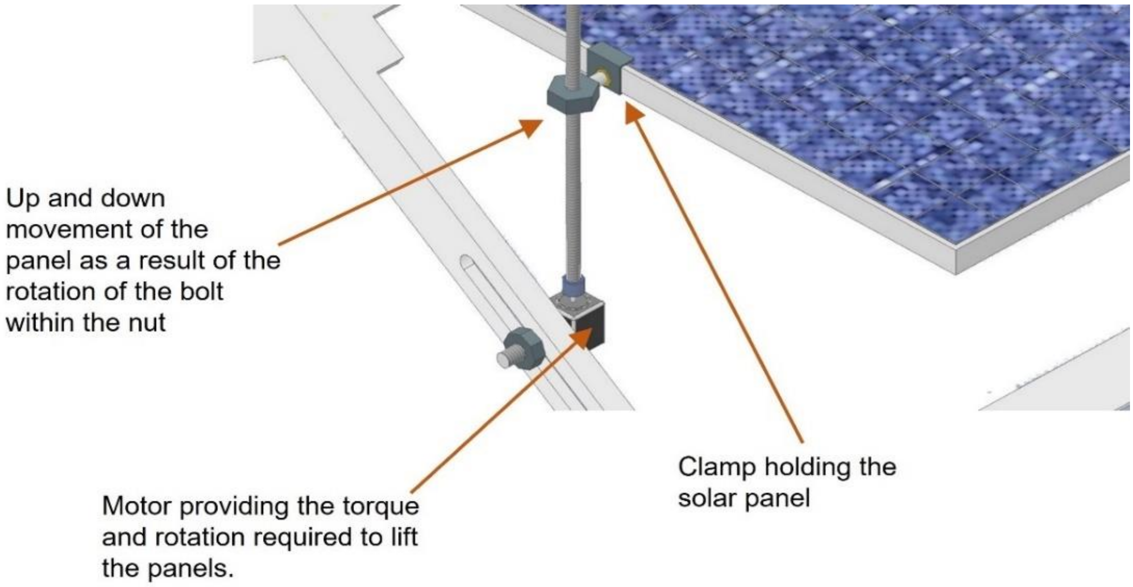

Figure 3.24 One Arm of Solar Tracking System showing the Motor, Clamp (holding the panel)

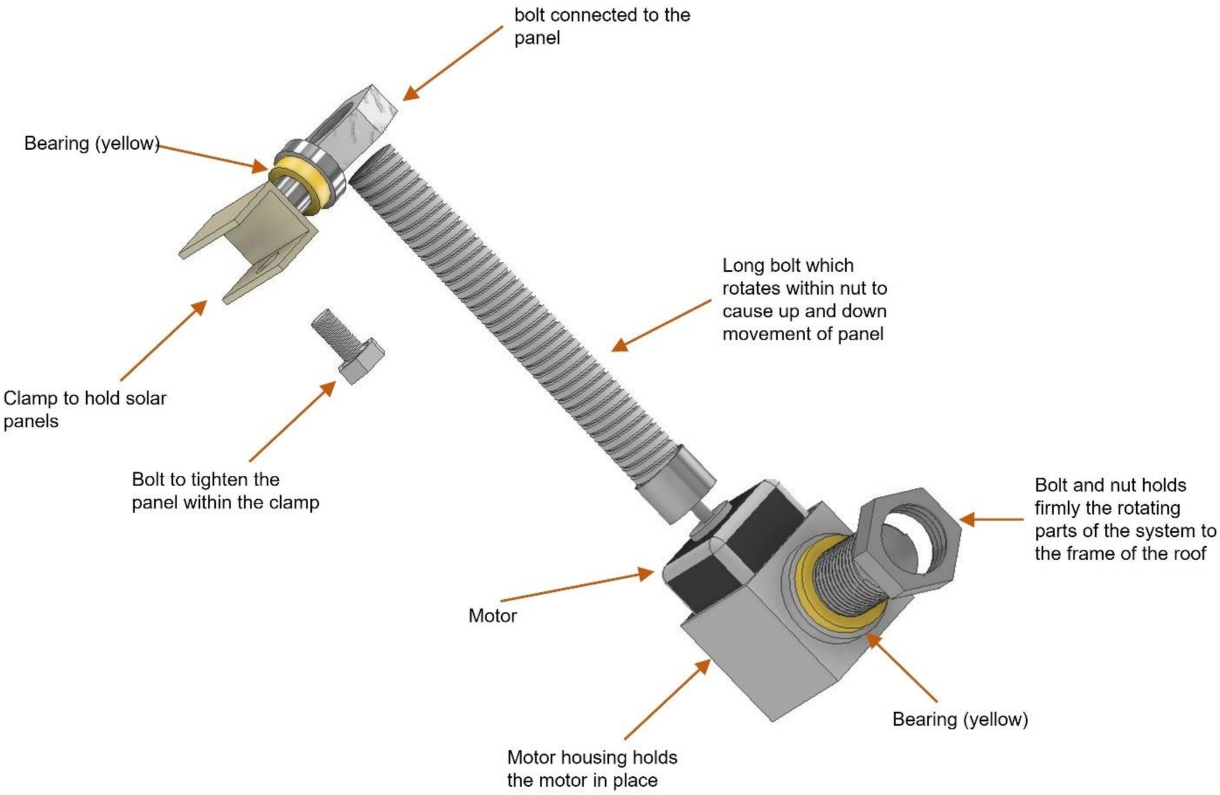

Figure 3.25 Exploded View of the Tracking Mechanism

3.4.5 Torque Required to Lift the Load

In order to select a suitable motor for the setup, the following calculations were made. The torque requirement was calculated using Equations (3.3) to (3.9) as follows:

Diameter of Screw $(D) = 12\ mm$

Coefficient of friction $(\mu) = 0.3$

Mass of panel $(M) = 2.8\ kg$

Lead distance $(L_d) = 2\ mm$

$\alpha =$ slope angle of screw

$\beta =$ Friction angle

$$\text{Velocity Ratio } (VR) = \frac{Effort\ Distance}{Load\ Distance} = \frac{\pi D}{L_d} \tag{3.3}$$

$$VR = \frac{12\pi}{2mm} = \frac{37.69}{2}$$

$$= 18.85$$

$$\text{Efficiency } (\rho) = \frac{tan\alpha}{\tan(\alpha+\beta)} \quad (3.4)$$

$$\alpha = \tan^{-1}\left(\frac{L_d}{\pi D}\right) \quad (3.5)$$

$$\alpha = \tan^{-1}\left(\frac{2}{12\pi}\right)$$

$$\alpha = \tan^{-1} 0.0531$$

$$\alpha = 3.04°$$

$$\beta = \tan^{-1}(\mu) \quad (3.6)$$

$$\beta = \tan^{-1} 0.3$$

$$\beta = 16.699°$$

$$\rho = \frac{\tan(3.04)}{\tan(3.04+16.699)}$$

$$\rho = \frac{0.0531}{0.3588}$$

$$\rho = 0.1479$$

$$Efficiency\ (\rho) = \frac{Mechanical\ Advantage\ (MA)}{Velocity\ Ratiio\ (VR)} \quad (3.7)$$

$$MA = \rho \times VR$$

$$MA = 18.85 \times 0.1479$$

$$MA = 2.788$$

$$MA = \frac{Load}{Effort} \quad (3.8)$$

$$Effort = \frac{Load}{MA}$$

$$Effort = \frac{2.8kg \times 9.81ms^{-2}}{2.788}$$

$$Effort = 9.85N$$

$$Torque = Force(Effort) \times Distance\ (Radius\ of\ screw) \quad (3.9)$$

$$Torque = 9.85N \times 0.006m$$

$$Lifting\ torque\ for\ panel\ = 0.0591Nm$$

Nema 17 stepper motors have a rated torque of $\mathbf{0.314\ Nm}$. This is the most common stepper motor available for use taking into consideration the required torque for the panel. Therefore, the Nema 17 stepper motor was selected.

3.4.6 Wiring and Connections

Details of the wiring made during the two installations are explained below.

Solar panel connection

The two panels used in each setup was connected in series so that the current remained the same and the voltage doubled. This was done for both the experiment and control system. Maximum expected system voltage is 14.12 V and current is twice the rated short circuit current. (4.17 A)

Arduino nano for data collection

One Arduino microcontroller was used exclusively for collecting data from the two systems. All voltage, current, temperature and humidity sensors for collecting data were put on this board. The connections and wiring made on this controller is presented in Figure 3.26.

A total of four current sensors were utilised in both setups. One sensor was dedicated to each system, while an additional current sensor was assigned to each stepper motor. The purpose of measuring the current from the stepper motors is to determine the power consumption of each motor during sun tracking operations.

An LCD screen was also used to display comparisons between the data being taken from the two systems.

The tracking system generated more power compared to the control system due to its ability to constantly adjust to the position of the sun, hence receiving more sunlight. This difference in power output is what makes the voltage measurements from the two systems different.

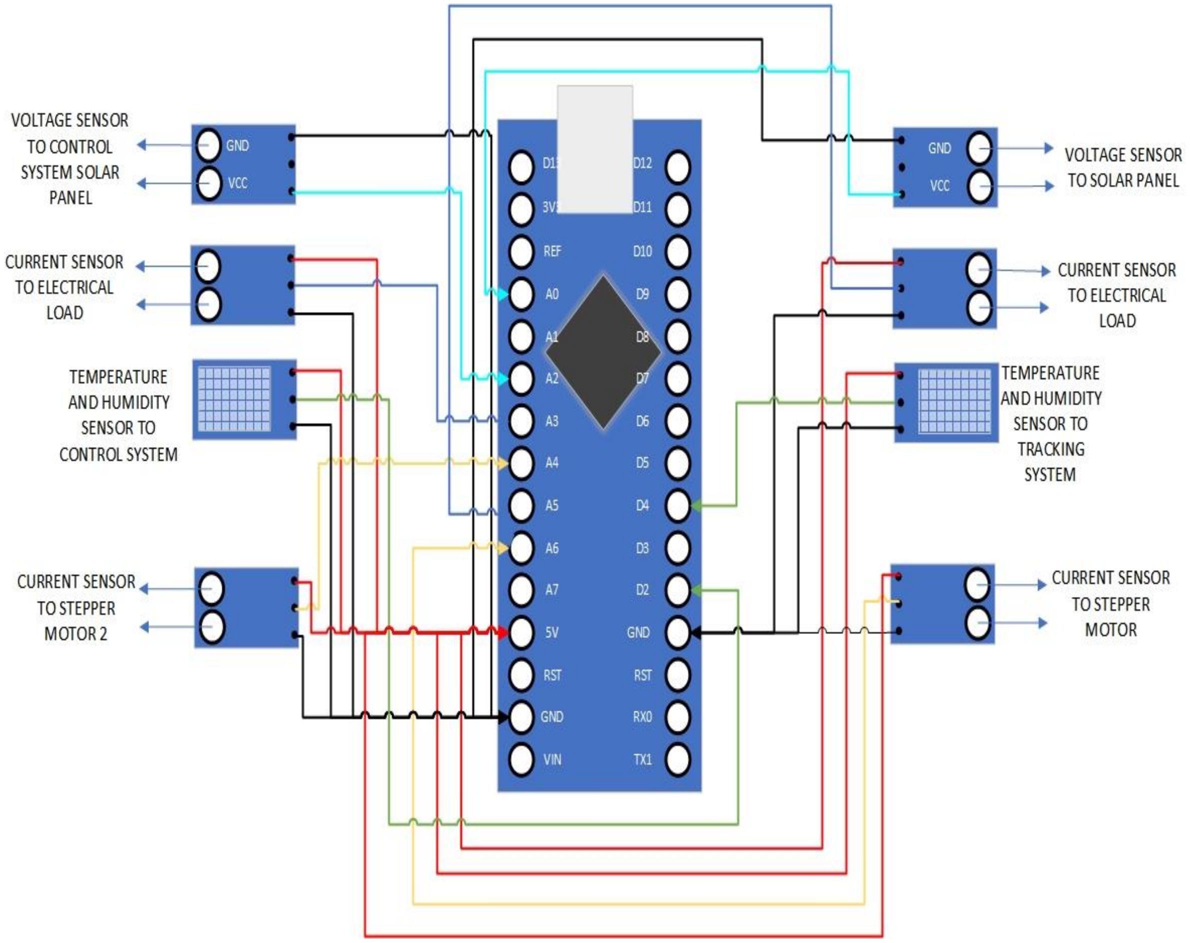

Figure 3.26 Connection of Various Components on Arduino Nano Microcontroller for Motor Movement

Arduino nano for motor movement

Two motors were used to move the panels up and down. These motors were coupled to the 12mm shaft. As the motors rotate, the shaft also rotates within the bolt. Since the motor and the shaft are fixed, the bolts are forced to move up and down. A different Arduino nano controller was programmed exclusively for this purpose. The connections for this nano controller is presented in Figure 3.27.

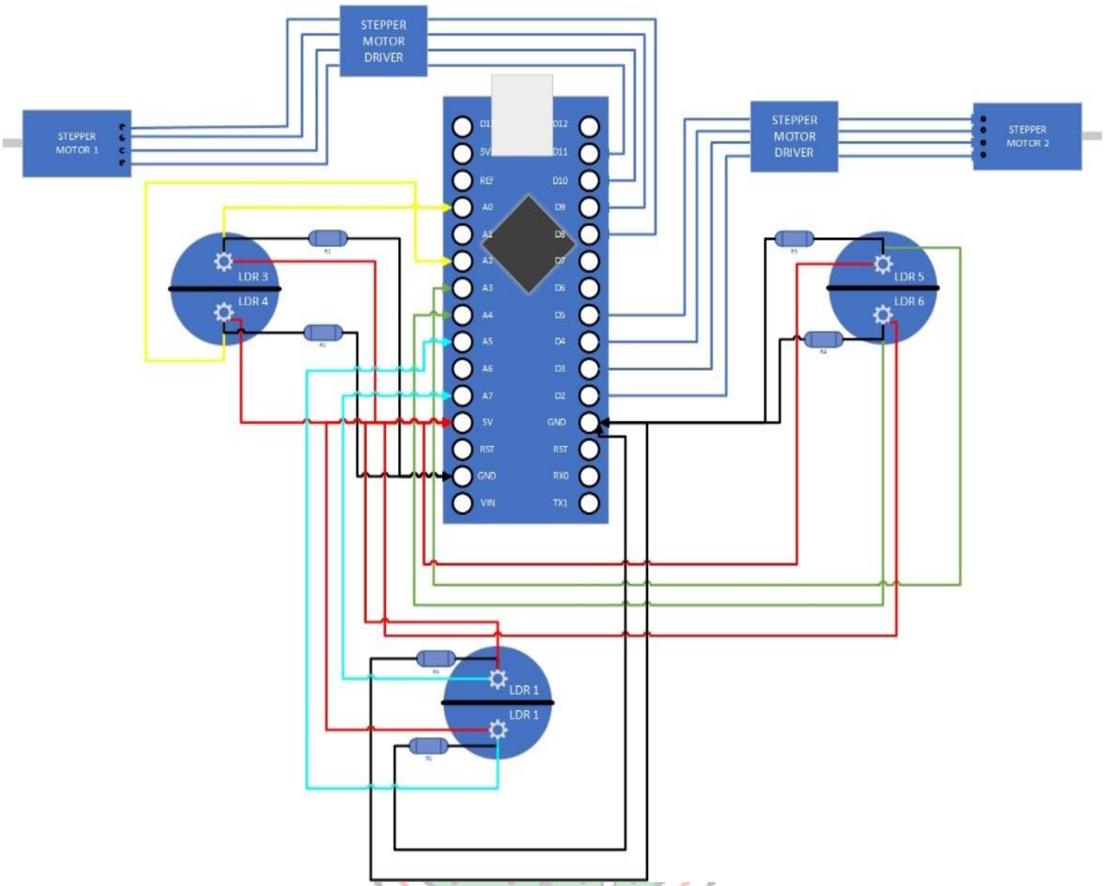

Figure 3.27 Connection of Various Components on Arduino Nano Microcontroller for Controlling the Stepper Motors

3.4.7 Arduino Programming Code

A code for data collection was written and uploaded to one microcontroller and the other microcontroller was used to automate the motor movements. This code is presented in Appendix C. Appendix D shows the code written for the movement of the stepper motors during different times of the day. One microcontroller did not have enough connections for the two codes.

Code for solar tracking

Using LDRs (Light Dependent Resistors) to track the sun's position is a common method used in solar tracking systems. LDRs are inexpensive and easy to use sensors that change resistance depending on the amount of light that falls on them. By placing two Light Dependent Resistors (LDRs) side by side and separating them with an opaque barrier, we can detect a notable change in their readings when the sun shines on one side of the LDRs. This change in reading can be utilised to determine the position of the sun. By using this information, we can adjust the position of the solar panel accordingly to maximise its exposure to sunlight and optimise energy generation.

In the morning, when the sun's intensity is felt on one side of the roof more than the other, the fixed LDR detects the position of the sun, and this information is used by the microcontroller to pause movement. This ensures that the solar panel moves only when necessary, reducing unnecessary wear and tear on the system and increasing its efficiency.

3.4.8 Data Collection from Experiment

It is imperative to collect data generated by the two systems. The difference in the data collected represents the effectiveness of one system over the other. To get the instant power generated by each system, the voltage and current readings collected from the sensors are used in Equation 3.10;

$$Power = Voltage \times Current \tag{3.10}$$

The total power collected from each system during the day is obtained by summing all the instantaneous power collected at various points during the day and compared. A 15 second interval was used to collect the power from sunrise to sunset for each system.

An example of the table used in the comparison is shown in Table 3.14

Table 3.14 Sample of Recorded Data from the Two Experiments

TIME	TRACKING SYSTEM							FIXED SYSTEM			PERCENTAGE DIFFERENCE IN POWER
	SOLAR PANELS			MOTOR			EFFECTIVE POWER				
	VOLTAGE (V)	CURRENT (A)	POWER (W)	VOLTAGE (v)	CURRENT (A)	POWER		VOLTAGE	CURRENT	POWER	
6:00:00 AM											
6:00:15 AM											
6:00:30 AM											
6:00:45 AM											
6:01:00 AM											
6:01:15 AM											
6:01:30 AM											
6:01:45 AM											
6:02:00 AM											
6:02:15 AM											

The effective power from the tracking system is obtained by finding the difference in power generated and the power used to rotate the motor.

$$Effective\ Power = Power\ obtained\ from\ panels - Power\ used\ to\ rotate\ motor \quad (3.11)$$

This effective power is compared to the power from the stationary system. The percentage difference is calculated using Equation 3.12.

$$Percentage\ Difference = \frac{Effective\ Power - Power\ from\ Fixed\ System}{Power\ from\ Fixed\ System} \times 100 \quad (3.12)$$

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter focuses on presenting the results and findings of the study, specifically addressing the three levels of energy efficiency improvement outlined in the research objectives. It acknowledges the influence of the assumptions made in the chosen methodology and proceeds to provide a detailed explanation of the results achieved for each objective.

4.2 Energy Audit

The audit process involved three phases; Historical Billing Data Collection, Walkthrough Survey and Detailed Survey. The data collected revealed findings that led to recommendations for energy-saving opportunities. The information gathered from each school is presented as follows.

The sample result for St. Augustine's College is presented in Table 4.1.

Details of the inventory of appliances and their energy calculations is in Appendix E.

Current PURC rate for electricity per kilowatt = GH₵ 1.1572 (Public Utilities Regulatory Commision (PURC), 2020).

Table 4.1 Energy and Cost Savings Calculations based on Data Collected (Augusco)

Item	Energy (kW)	Cost (GH₵)
Total calculated daily consumption (Current System)	243.617	281.92
Total calculated daily consumption (Proposed Replacement)	135.373	156.65
Calculated Daily Energy Savings	108.244	125.26
Percentage Savings	**44.43%**	

Table 4.2 Comparing Calculated Energy Consumption to Actual Energy Consumption on Electricity Bills for (Augusco)

Item	Energy (kW)	Cost (GH₵)
Actual average monthly consumption (from school's ECG bills)	6,132.79	7,096.94
Calculated monthly consumption (Current appliances being used in the school)	5,846.81	6,766.00
Difference between calculated consumption and Actual Consumption	285.98	330.94
Accuracy in Calculations and Assumptions	**94.34 %**	
Assumed monthly consumption (Proposed Replacement)	3,248.94	3,759.71
Expected Monthly savings from LED replacements	**2,597.87**	**3,006.28**

As presented in Table 4.2, there is a difference of 4.66 % between the actual average monthly consumption on the electricity bills and the calculated energy consumption using the assumptions made. This indicates that the calculated energy consumption is close to the actual day-to-day running of the school, with an accuracy level of 95.34 %. This suggests that the assumptions used in the calculations provide a reasonably accurate estimate of the school's daily energy consumption. The summary of data from the four schools is shown in Table 4.3

Table 4.3 Summary of Data Collected from the Four Schools;

School	CFL Lights	T5 Lights	Existing LED	Fans	Air Conditioner	Computers	Deep Freezers	Fridges
Augusco	237	36	32	131	2	26	2	0
Hunivas	281	44	70	159	3	37	3	1
Fiasec	298	7	60	111	2	30	3	1
Tarsco	366	36	32	91	5	33	4	1

From the results presented in Table 4.3, it was initially expected that Hunivalley Senior High School, with the highest number of existing LED lights, would have the lowest energy consumption. However, the total energy consumption is influenced not only by the number of appliances but also by their usage patterns and their locations within the school. It was observed that the hours of use for each appliance and their specific placement within the facility had a significant impact on the overall energy consumption. For instance, even if an appliance is highly efficient, its contribution to the energy consumption of the facility would be minimal if it is rarely used. Therefore, it is the combination of appliance efficiency, hours of use, and their respective locations that collectively determine the total energy consumption of the facility.

The details and usage pattern of all appliances four the schools are presented in Appendix E which includes other appliances such as televisions, printers, photocopiers etc.

4.2.1 Summary of Energy Savings Observed in each School

Similar calculations were made for each school and the results are summarised in Table 4.4. The percentage decrease in energy consumption is observed in each school.

Table 4.4 Summary of Energy Saving Opportunities

School	Energy Consumption (kWh/Day)		Energy Cost (GH₵/Day)		Expected Savings		Percentage Decrease (%)
	Existing System	Proposed Replacements	Existing System	Proposed Replacements	Energy (kWh/Day)	Cost (GH₵/Day)	
Augusco	243.617	135.373	281.92	156.65	**108.245**	**125.26**	**44.43**
Hunivas	405.865	246.765	475.23	285.56	**159.100**	**184.11**	**39.20**
Fiasec	329.987	199.307	381.86	230.64	**130.681**	**151.23**	**39.60**
Tarsco	416.662	217.495	482.17	251.69	**199.167**	**230.48**	**47.80**

4.2.1 Cost Analysis

The investment in an efficient lighting system and other appliances incurs an initial cost, which often discourages managers from making the decision. However, a cost analysis for one of the schools, Augusco, is presented in Table 4.5. This table provides information on the number of bulbs which needs replacement, the initial cost of replacement, and the payback period for such an investment, considering the daily calculated savings.

Total Number of Inefficient Appliance Requiring Replacement, x

Price Per New Efficient Appliance, y

Total Cost of New Appliances to be Introduced $= x \times y$ (4.1)

Calculated Daily Cost Savings, z

$$\text{Payback Period} = \frac{Total\ Cost\ of\ New\ Appliance\ to\ be\ Introduced}{Calculated\ Daily\ Cost\ Savings} \quad (4.2)$$

Table 4.5 Cost of Suggested Replacements of Appliances (Augusco)

Appliance	Suggested Replacements	Unit Price (GH₵)	Total Cost of Replacement (GH₵)
CFL	237	42	9,954
T5	36	65	2,340
Table Top Fridge	0	1,450	0
Deep Freezer	3	3,000	9,000
Total			**21,294.00**

The total cost of replacing the non-efficient appliances was calculated as GH¢ 28,195.00. If the calculated energy savings per day is GH¢ 125.26, then the payback period is calculated using Equation 4.2.

$$Payback\ Period = \frac{21{,}294.00}{125.26}$$

$$= 169.99\ days$$

The payback period for the investment in purchasing these efficient appliances is 170 days. This implies that within less than a year, the amount invested in acquiring these appliances will be recovered through the savings generated from the reduced energy consumption.

The summary for the cost analysis in the other schools is presented in Table 4.6.

Table 4.6 Payback Period Calculations

School	Total Cost of Proposed Replacements (GH₵)	Daily Cost Savings (GH₵)	Payback Period (Days)
Augusco	21,294.00	125.26	**169.99**
Hunivas	25,112.00	184.11	**136.39**
Fiasec	23,421.00	151.23	**154.88**
Tarsco	29,712.00	234.59	**126.66**

4.3 Renewable Energy Technology Integration

Renewable energy technologies such as the off-grid solar PV and hybrid PV were assessed, the most viable option was selected. The comparison involved considering factors such as the initial cost of installation, maintenance requirements, energy production potential, and environmental impact. Comparisons made were put under these categories;

a. Project with the least present cost
b. Project with the least emissions
c. Project with a good Levelised Cost of Electricity (LCOE)
d. Project with a good payback period

Calculations for the best renewable energy system was made and compared to purchasing power from the grid over 25 years. The details of the simulations and calculations made for St. Augustine's Senior High School is presented as follows:

4.3.1 Purchasing Energy from the Grid

Based on the current energy sales in Ghana of 1.1572 GH₵/kW (Public Utilities Regulatory Commision (PURC), 2023), the amount of electricity that would be purchased over a 25-year period was calculated using the HOMER software, taking inflation into consideration. This was done to estimate the potential cost savings that could be achieved by implementing the proposed renewable energy system. The calculations took into account the projected increase in electricity prices over the 25-year period.

In this system, energy is being bought from the utility company, hence no energy generation on site. Assuming a constant load, the price of energy purchases equals GH₵ 3,912,121.00 for 25 years. This is the amount required to supply the 13,403 kWh/yr load. The details of the cost which will be incurred from grid purchases are shown in Figure 4.1.

Production	kWh/yr	%
Grid Purchases	13,403	100
Total	13,403	100

Figure 4.1 Energy Demand from the Grid per Year

4.3.2 Standalone Photovoltaic System

Battery

During the day, the batteries were charged directly by the solar PV, and at night they were discharged. The project was designed to have a 3-day autonomy, meaning that for 3 days in the year, there would be no sunshine consequently no battery charging.

Quantity	Value	Units
Batteries	88.0	qty.
String Size	4.00	batteries
Strings in Parallel	22.0	strings
Bus Voltage	48.0	V

Figure 4.2 Quantity and Connection of Battery Selected (Standalone PV)

Quantity	Value	Units
Average Energy Cost	0	GH₵/kWh
Energy In	7,860	kWh/yr
Energy Out	6,299	kWh/yr
Storage Depletion	12.4	kWh/yr
Losses	1,573	kWh/yr
Annual Throughput	7,042	kWh/yr

Figure 4.3 Energy Output of Battery for Standalone PV Installation

Generic Flat Plate PV

According to the analysis from HOMER, the required capacity of the PV system was found to be 60.2 kW, which could be achieved by installing 61 units of 1 kW Generic Flat Plate PVs. As the batteries will be charged directly from the PV during daylight hours, the system needs to produce excess electricity to meet the load requirements. The expected mean energy output was calculated to be 230 kWh/d, and the total annual production from the solar PV system was estimated to be 83,780 kWh/yr, as illustrated in Figure 4.4.

Quantity	Value	Units
Rated Capacity	60.2	kW
Mean Output	9.56	kW
Mean Output	230	kWh/d
Capacity Factor	15.9	%
Total Production	83,780	kWh/yr

Figure 4.4 Generic Flat Plate PV Energy Production for Standalone PV

Inverter

Based on the selected inverter with an efficiency of 94 %, the HOMER software determined a capacity of 2.55 kW. Details of the inverter capacity and output is shown in Figure 4.5.

Quantity	Inverter	Rectifier	Units
Capacity	2.55	2.04	kW
Mean Output	1.53	0	kW
Minimum Output	0.703	0	kW
Maximum Output	2.32	0	kW
Capacity Factor	60.0	0	%

Figure 4.5 Inverter Capacity and Power Output Potential for Standalone PV

The inverter works all year (8760 hrs/yr) with an output energy potential of 13,393 kWh/yr. The details of the energy output potential is observed in Figure 4.6.

Quantity	Inverter	Rectifier	Units
Hours of Operation	8,760	0	hrs/yr
Energy Out	13,393	0	kWh/yr
Energy In	13,951	0	kWh/yr
Losses	558	0	kWh/yr

Figure 4.6 Energy Output Potential of Leonics Inverter for Standalone PV

Costing and payback period of standalone Photovoltaic System

The project is expected to last for 25 years after which all the components especially the solar PV needs replacement. During this 25-year period however, some components like the battery and inverter is replaced and require maintenance from time to time. Using the current inflation rate of 42.63 % (Public Utilities Regulatory Commision (PURC), 2023) and discount rate of 23.83 % (Bank of Ghana, 2021), the software results are shown in Figure 4.7.

Component	Capital (GH₵)	Replacement (GH₵)	O&M (GH₵)	Fuel (GH₵)	Salvage (GH₵)	Total (GH₵)
Generic 1kWh Lead Acid	GH₵264,000.00	GH₵5,539,962.28	GH₵221,968.30	GH₵0.00	-GH₵4,512,981.22	GH₵1,512,949.35
Generic flat plate PV	GH₵168,513.88	GH₵0.00	GH₵151,804.95	GH₵0.00	GH₵0.00	GH₵320,318.83
Leonics S-219Cp 5kW	GH₵2,557.05	GH₵0.00	-GH₵8,494.51	GH₵0.00	GH₵0.00	-GH₵5,937.46
System	GH₵435,070.93	GH₵5,539,962.28	GH₵365,278.73	GH₵0.00	-GH₵4,512,981.22	GH₵1,827,330.72

Figure 4.7 Detailed Cost of Components for Standalone Solar PV

Some components such as the batteries and inverters can be sold or used after 25 years. This resale value is labelled in Figure 4.7 as the salvage value.

Total NPC:	GH₵1,827,331.00
Levelized COE:	GH₵0.5405
Operating Cost:	GH₵5,519.66

Figure 4.8 Cost of Electricity for Standalone Solar PV

It can be observed from figure 4.8 that the cost of electricity (GH₵ 0.5405) for the standalone system is less than half for the grid purchases (GH₵ 1.1572) for the same period. The total net present cost (NPC) is the total amount needed to install and maintain the system for 25 years.

4.3.3 Grid Connected Photovoltaic System

Similar simulations were made for the grid connected PV system as in the standalone system. In this setup, no batteries were required. The backup power was the grid power. Summary of the output of components are presented below.

Inverter

The same inverter chosen for the off-grid PV system was selected for the hybrid system also. This inverter only converts Direct Current (DC) from the panels to Alternating Currents (AC) needed to power the electrical appliances. Its capacity was less than that of the off-grid system because no battery charging was required. The capacity selected by the HOMER software was 1.86 kW shown in Figure 4.9.

Quantity	Inverter	Rectifier	Units
Capacity	1.86	1.49	kW
Mean Output	0.812	0	kW
Minimum Output	0	0	kW
Maximum Output	1.86	0	kW
Capacity Factor	43.8	0	%

Figure 4.9 Inverter Capacity and Power Output Potential for Grid Connected PV

From Figure 4.10, the inverter has an annual operation hours of 4,380 and a total energy output of 7,112 kWh/yr using it's 94 % efficiency.

Quantity	Inverter	Rectifier	Units
Hours of Operation	4,380	0	hrs/yr
Energy Out	7,112	0	kWh/yr
Energy In	7,408	0	kWh/yr
Losses	296	0	kWh/yr

Figure 4.10 Energy Output Potential of Leonics Inverter for Grid Connected PV

Solar PV

Since, the solar panels are not going to charge batteries for periods when there is no sunlight, it is observed that the number of solar panels needed for this installation is about half the number needed for the off-grid installation. 32.2 kW was selected which means about 33 of the 1 kW panels can be used with a total production of 44,757 kWh/yr shown in Figure 4.11.

Quantity	Value	Units
Rated Capacity	32.2	kW
Mean Output	5.11	kW
Mean Output	123	kWh/d
Capacity Factor	15.9	%
Total Production	44,757	kWh/yr

Figure 4.11 Generic Flat Plate PV Energy Production for Grid Connected PV

Grid Purchases

As a replacement for batteries the grid purchases for the year is shown in Figure 4.12.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge GH₵	Demand Charge GH ₵
January	532	0	532	2	GH₵615.55	GH₵0
February	479	0	479	2	GH₵554.81	GH₵0
March	536	0	536	2	GH₵620.48	GH₵0
April	505	0	505	2	GH₵584.88	GH₵0
May	526	0	526	2	GH₵608.47	GH₵0
June	519	0	519	2	GH₵600.70	GH₵0
July	541	0	541	2	GH₵625.56	GH₵0
August	540	0	540	2	GH₵624.93	GH₵0
September	533	0	533	2	GH₵616.26	GH₵0
October	532	0	532	2	GH₵615.39	GH₵0
November	516	0	516	2	GH₵597.17	GH₵0
December	532	0	532	2	GH₵615.57	GH₵0
Annual	6,291	0	6,291	2	GH₵7,279.76	GH₵0

Figure 4.12 Monthly Grid Purchases for Grid Connected PV

Costing and Payback Period

In this system, there is no salvage amount since the solar panels are expected to expire after 25 years. The total grid purchases for the 25 years is labelled under operations and maintenance (O & M) to be GH₵ 1,835,368.06. The total initial capital cost for this system is GH₵ 91,120.99.

Component	Capital (GH₵)	Replacement (GH₵)	O&M (GH₵)	Fuel (GH₵)	Salvage (GH₵)	Total (GH₵)
Generic flat plate PV	GH₵90,022.48	GH₵0.00	GH₵81,096.33	GH₵0.00	GH₵0.00	GH₵171,118.80
Grid	GH₵0.00	GH₵0.00	GH₵1,835,368.06	GH₵0.00	GH₵0.00	GH₵1,835,368.06
Leonics S-219Cp 5kW	GH₵1,098.51	GH₵0.00	-GH₵21,633.67	GH₵0.00	GH₵0.00	-GH₵20,535.16
System	GH₵91,120.99	GH₵0.00	GH₵1,894,830.71	GH₵0.00	GH₵0.00	GH₵1,985,951.70

Figure 4.13 Detailed Cost of Components for Grid Connected PV

With GH₵ 0.5874 per kW Cost of Electricity (COE), this system has an advantage over purchasing energy from the grid which costs GH₵ 1.1572 per kW. The total cost for the system for the 25 years was calculated as GH₵ 1,985,952.00 as presented in Figure 4.13.

Total NPC:	GH₵1,985,952.00
Levelized COE:	GH₵0.5874
Operating Cost:	GH₵7,512.11

Figure 4.14 Cost of Electricity for Grid Connected PV

4.3.4 Selection of Best System

Project with the least present cost

Purchasing energy from the grid does not require any start-up cost and hence is left out of this comparison. The winning project under this category was the grid-connected solar technology which had a total initial cost of GH₵ 91,120.99 and a total project cost of GH₵ 1,985,952.00 due which includes grid purchases over 25 years and inflation on replacing components.

Project with the least emission.

It is assumed that solar PV technology has no emissions. Hence any of the two technologies can be selected under this assessment category.

Project with a good Levelised Cost of Electricity (LCOE).

The LCOE refers to the price at which energy can be sold per kW for the lifespan of the project in order to break even at the end of the project. The lower the NPC, the more attractive the project is. This LCOE also affects the payback period of the project. Looking at the summary of the technologies, standalone solar PV technology had the lowest LCOE (0.5405 GH₵/kW) as compared to grid-connected solar PV (0.5874 GH₵/kW) and grid purchases (1.1572 GH₵/kW).

Project with a good payback period

The grid-connected solar PV system is preferred due to its cost advantages. It eliminates the need for battery purchases, reducing initial investment costs. In contrast, the standalone PV system requires batteries, making it more expensive upfront. Although the standalone system has a lower LCOE, its high startup cost makes it less attractive for Senior High Schools. Overall, the grid-connected system is more practical and cost-effective, with the grid serving as a backup power source. A summary of the findings in the case of St. Augustine’s Senior high School is indicated in Table 4.7.

St. Augustine's Senior High School

Peak Energy Consumption: 2.32 kW

Energy Consumption Per day: 36.72 kWh/day

Table 4.7 Summary of Renewable Energy Project Costs and Expectations (Augusco)

SYSTEM	Initial Capital	Total Cost (GH₵)	Levelised Cost of Electricity (GH₵)	Payback Period (Years)	Remarks
Grid Connected PV	91,120.99	1,985,951.70	0.5874	12.75	Feasible
Standalone PV	435,070.93	1,827,330.72	0.5405	11.68	Initial investment too high for SHS
Purchasing Energy from the Grid		3,912,120.63	1.1572	25	Base Case

From Table 4.7, the results from the calculations indicate that in order to recover costs, the electricity generated from grid connected solar PV system should be sold at 0.5874 GH₵/kWh. Therefore, if electricity is sold at a price of 1.1572 GH₵/kWh, the project could break even within the 13th year of its 25-year lifespan, and profits can be earned for the remaining 12 years.

Similar calculations have been made for the other schools, and summaries of these calculations are presented in Tables 4.8 to 4.10.

Hunivalley Senior High School

Peak Energy Consumption: 4.40 kW

Energy Consumption Per day: 64.06 kWh/day

Table 4.8 Summary of Renewable Energy Project Costs and Expectations (Hunivas)

SYSTEM	Initial Capital	Total Cost (GH₵)	Levelised Cost of Electricity (GH₵/kWh)	Payback Period (Years)	Remarks
Grid Connected PV	154,269.90	3,966,245.56	0.6725	14.53	Feasible
Standalone PV	749,126.74	3,480,479.52	0.5901	12.75	Initial investment too high for SHS
Purchasing Energy from the Grid		6,824,903.26	1.1572	25	Base Case

Tarkwa Senior High School

Peak Energy Consumption: 7.22 kW

Energy Consumption Per day: 104.22 kWh/d

Table 4.9 Summary of Renewable Energy Project Costs and Expectations (Tarsco)

SYSTEM	Initial Capital	Total Cost (GH₵)	Levelised Cost of Electricity (GH₵/kWh)	Payback Period (Years)	Remarks
Grid Connected PV	186,415.03	7,040,299.58	0.7337	15.85	Feasible
Standalone PV	1,290,890.57	6,361,051.61	0.6635	14.33	Initial investment too high for SHS
Purchasing Energy from the Grid		11,103,730.32	1.1572	25	Base Case

Fiaseman Senior High School (FIASEC)

Peak Energy Consumption: 5.27 kW

Energy Consumption Per day: 71.24 kWh/d

Table 4.10 Summary of Renewable Energy Project Costs and Expectations (Fiasec)

SYSTEM	Initial Capital	Total Cost (GH₵)	Levelised Cost of Electricity (GH₵/kWh)	Payback Period (Years)	Remarks
Grid Connected PV	146,978.12	5,218,901.09	0.812	17.54	Feasible
Standalone PV	929,830.14	4,591,680.33	0.7007	15.14	Initial investment too high for SHS
Grid Electricity		7,589,854.00	1.1572	25	Base Case

4.4 Data from Solar Tracking System

The data for the graph in Figure 4.14 was collected daily from 6:00 am to 6:30 pm, using a 15-second interval for data collection. The average of the daily data collection was calculated and plotted in the graph presented in Figure 4.14. It's important to note that the graph represents the average of the data collected over a period of 31 days.

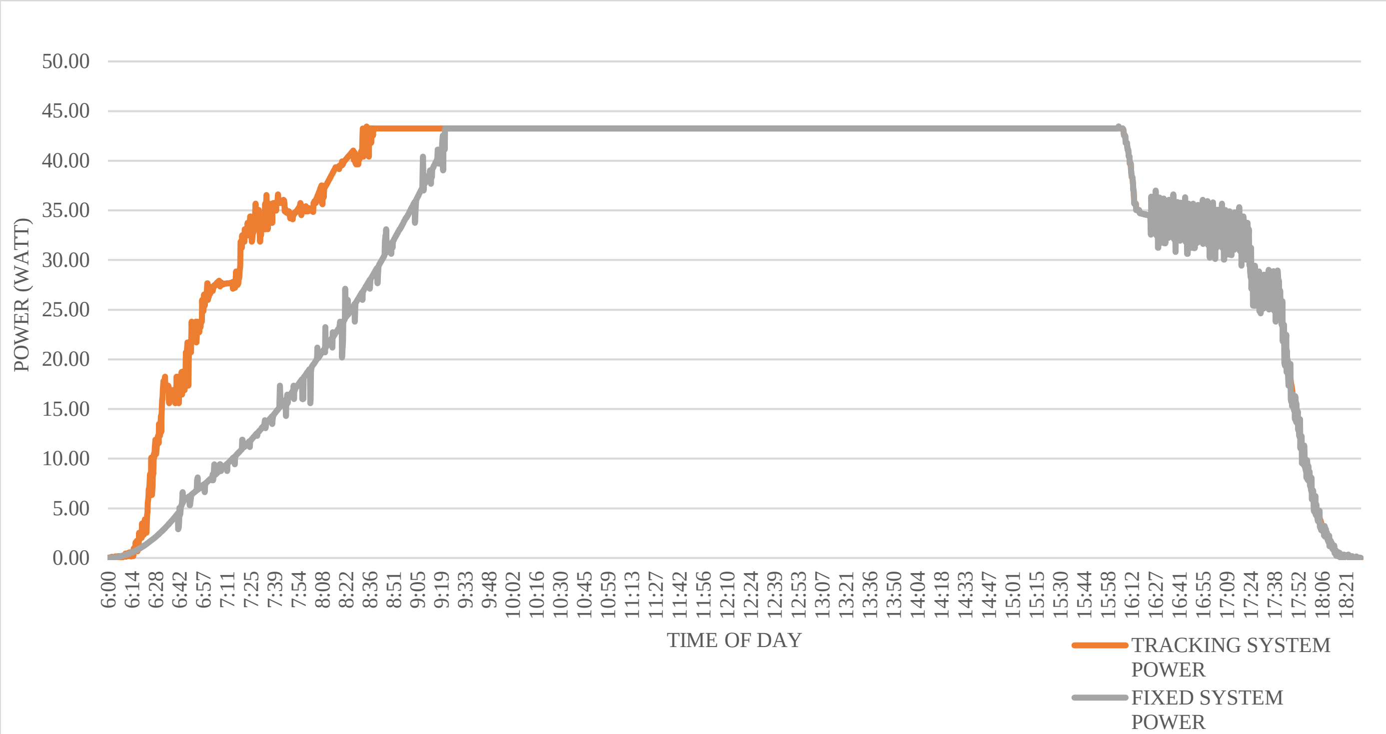

Figure 4.14 Energy Distribution for the two Systems during the Day

The tracking system used in the study was observed to collect more power from the sun for approximately three hours during the day compared to the stationary system. This observation is evident in Figure 4.14, which depicts the data regarding the energy collected by both systems.

After about 9:00 am, both the tracking system and the stationary system collected a similar amount of energy from the sun until sunset. This indicates that once the sun reaches a certain angle or intensity, both systems are equally effective in capturing solar energy.

It is important to note that on cloudy mornings, there was no significant difference in the amount of sunshine received by the two systems. Cloud cover tends to diffuse sunlight and reduce the intensity, making it less distinguishable between the tracking and stationary systems. Therefore, during cloudy conditions, the advantages of the tracking system in terms of collecting more energy were not as prominent.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS.

5.1 Introduction

This chapter presents summary of findings, conclusions and recommendations of the study. Energy efficiency and sustainability is a crucial issue in Ghana as the country relies on thermal power for 64 % of its energy mix. With the expected surge in electricity demand and fuel prices, there is an urgent need to reduce energy wastage in the system or find alternative energy sources that are renewable.

Amidst line losses, electricity theft, technical losses, dilapidated infrastructure and other problems facing Ghana's electricity supply system, Demand Side Management and solar tracking mechanisms are the two main efficiency measures adopted in this research work.

5.2 Summary of Findings

Energy audit, that was conducted in the four schools indicated losses in the use of electricity. After subjecting the energy use of these schools to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards for energy auditing, the following results were obtained.

i. St. Augustine's College (AUGUSCO) with an existing load of 243.617 kWh/day saw a 44.43 % in energy reduction.

ii. Tarkwa Senior High School (TARSCO) already had an efficient lighting system with most of their lights already changed to LED. This affected their energy cost positively. However, the active use of their computer lab had a big toll on their daily energy consumption with 11.6 % of their total consumption coming from the use active of the computer laboratory. Their daily consumption of 429.293 kWh was the highest among all the four schools.

iii. 39.60 % reduction in energy was realised in the case of Fiaseman Senior High School (FIASEC), their total energy consumption was about 329.98 kWh/day.

iv. For the case of Huni-Valley Senior High School (HUNIVAS), the school uses an estimated 405.865 kWh/day of electricity. Although a small school, with the least population and small facilities they had the most inefficient lighting system with a lot of incandescent bulbs. After subjecting their energy usage to the ASHRAE standards 39.20 % of energy was saved.

On the average, more than 40 % of energy savings was observed in the four schools. This result was obtained by retrofitting the current lighting system to LED lights only and recommending new deep freezers for their kitchens.

After analysing the calculations conducted in the HOMER software, it was determined that the off-grid solar PV system had the most favourable results, with an average payback period of 13 years. However, due to the high initial cost of investment associated with this system, the grid-connected solar PV system was ultimately chosen as the preferred option. The grid-connected system has an average payback period of 15 years but offers a lower initial cost of investment. Considering these factors, the hybrid system emerged as a potentially better investment choice for these schools.

To optimise the effectiveness of the solar system, the proposed design which installed solar panels on both sides of the gable roof was developed with tracking system. The gable roof infrastructure which are predominant in our Senior High Schools benefit from this new design.

5.3 Conclusions

Here are the major outcomes of the research:

i. Senior high schools in and around Tarkwa typically consume between 250 kWh/day to 400 kWh/day of electricity on average.

ii. All four schools in the study had LED lights already installed, with Hunivas having the highest number (70 LED lights) due to the recent construction of a modern classroom block. Fiaseman Senior High School, Tarkwa Senior High School, and St. Augustine's Senior High School followed in descending order in terms of the number of LED lights already installed, with 60, 32, and 32 respectively. However, it is important to note that the number of LED lights does not necessarily reflect the efficiency of their daily consumption. The total load and energy efficiency were affected by factors such as the specific location of these bulbs within the schools and the number of hours they were used.

iii. The proposed use of LED bulbs, change of old and inefficient deep freezers and the old table top fridge alone resulted in a significant reduction in energy usage in St. Augustine's Senior High School, with a maximum percentage decrease of 44.43 %. Hunivas saved 39.20 %, Fiasec saved 39.60 %, and Tarsco saved 47.80 %.

iv. Using the cost savings expected from replacing these systems, the average payback period for the cost of purchasing these efficient appliances is within 150 days for the schools.

v. The Grid-Connected Solar Photovoltaic System is the most efficient renewable energy technology for the Senior High Schools in Tarkwa. This system offers a cost-effective solution for Senior High Schools, as it requires the least initial investment compared to other alternatives. Also, the geographical location of Tarkwa, with a high rainfall expectancy, makes off-grid a viable choice. This affordability coupled with high rainfall pattern in Tarkwa makes it a viable option for educational institutions operating on limited budgets.

vi. The proposed renewable energy systems for each school had an average payback period of about 15 years and can provide approximately 10 years of free electricity. With expected increases in electricity tariffs, this payback period is expected to reduce.

vii. Rooftop solar tracking is a feasible option for Senior High Schools in the area with gable roofing systems.

viii. The research conducted successfully demonstrated that the developed solar tracking system achieved an impressive 31.1 % increase in solar power generation compared to the conventional installation limited to one side of the gable roof.

ix. The utilisation of efficient solar tracking systems results in increased energy collection, leading to a significant reduction in the required number of solar panels for energy generation.

5.4 Recommendations

Based on the findings of this research, the following recommendations are made:

i. It is recommended that the government implements a policy of regular energy auditing for Senior High Schools. This will help to identify energy inefficiencies and suggest appropriate energy-saving measures that can be implemented. Thus, schools can save on energy costs and reduce their carbon footprint, which is in line with the country's Sustainable Development Goal (SDG) of reducing carbon emission to the global standard.

ii. It is also recommended that Senior High Schools should promote sustainable transportation practices, reduce waste energy generation, and implementing green procurement policies such as purchasing from suppliers who have interests in sustainable environmental practices.

iii. The Ghanaian government should also continue to promote and incentivise the use of renewable energy sources, such as solar, wind, and hydropower, to reduce the country's reliance on fossil fuels and achieve its climate goals.

By implementing these recommendations, Ghana can make significant progress towards a more sustainable future while also reducing energy costs and improving energy security for its citizens. ,

5.5 Further Research Opportunities

Future works that can be done in this research area includes

i. Optimisation of the proposed tracking system. Further studies should be conducted to assess the long-term reliability and durability of the solar tracker system under different conditions and configurations.

ii. Investigate the potential of other renewable energy sources such as biomass in these schools.

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APPENDIX A

TABLE A1 Electricity Tariffs for Ghana From 2018 TO 2022

Customer Category	Power Consumption (kWh)	Old Tariff (2018) (GHp/kWh)	New Tariff (2022) (GHp/kWh)
Residential	0 - 30	32.606	41.9065
	31 - 300	65.4161	89.0422
	301 - 600	84.8974	115.5595
	601+	94.3304	128.3995
Non-Residential	0 - 300	79.7943	83.1552
	301 - 600	84.9097	89.1552
	601+	133.9765	133.0919
Special Load Tariff (SLT)	Low Voltage - LV	104.7303	132.6125
	Medium Voltage - MV	79.5167	100.6863
	High Voltage - HV	83.4562	105.6746
	High Voltage - Steel Companies	53.5688	74.5315
	High Voltage - HV Mines	263.9705	263.9705

(Source: Energy Commission, 2022)

TABLE A2 Solar Resource of Tarkwa and its Environs

Month	Clearness Index	Daily Radiation ($kWH/m^2/day$)	Monthly Average Temperature (ºC)
January	0.548	5.19	26.990
February	0.531	5.3	27.700
March	0.516	5.37	27.370
April	0.502	5.22	26.900
May	0.477	4.82	26.220
June	0.423	4.17	25.130
July	0.416	4.13	24.100
August	0.395	4.04	23.950
September	0.396	4.09	24.620
October	0.464	4.67	25.340
November	0.514	4.91	26.210
December	0.530	4.91	26.770

(Source: NASA Surface meteorology and Solar Energy Database)

APPENDIX B

HOURLY ENERGY CONSUMPTION FOR EACH SCHOOL

Table B1. Estimated Hours of Usage for Electrical Appliances and the Total Estimated Hourly Consumption for Augusco.

Location			Total Consumption				Total Hourly Energy Usage																							
			Old System		Replacement																									
			Current Lights	Others	LED	Others	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Main Classroom Block		Basement	0.27	0	0.063	0								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1									
	First Floor	Classroom 1	0.18	0.96	0.042	0.96								0	0	0	0	0	0	0	0					0	0	0		
		Classroom 2	0.18	0.96	0.042	0.96								0	0	0	0	0	0	0	0					0	0	0		
		Classroom 3	0.18	0.96	0.042	0.96								0	0	0	0	0	0	0	0					0	0	0		
		Classroom 4	0.18	0.96	0.042	0.96								0	0	0	0	0	0	0	0					0	0	0		
		Classroom 5	0.18	0.96	0.042	0.96								0	0	0	0	0	0	0	0					0	0	0		
		Classroom 6	0.18	0.96	0.042	0.96								0	0	0	0	0	0	0	0					0	0	0		
		Chaplaincy Office	0.09	0.96	0.021	0.96								0	0	0	0	0	0	0	0	0	0							
	Second Floor	ICT Lab 1	0.09	2.96	0.021	2.96								0	0	0	0	0	0	0	0									
		ICT Lab 2	0.09	0.96	0.021	0.96								0	0	0	0	0	0	0	0									
		Classroom 7	0.18	0.96	0.042	0.96								0	0	0	0	0	0	0	0					0	0	0		
		Classroom 8	0.18	0.96	0.042	0.96								0	0	0	0	0	0	0	0					0	0	0		
		Classroom 9	0.18	0.96	0.042	0.96								0	0	0	0	0	0	0	0					0	0	0		
		Classroom 10	0.18	0.96	0.042	0.96								0	0	0	0	0	0	0	0					0	0	0		
	Third Floor	Library	0.09	0.96	0.021	0.96								0	0	0	0	0	0	0	0									
		Classroom 11	0	0.96	0	0.96								0	0	0	0	0	0	0	0					0	0	0		
		Classroom 12	0.09	0.96	0.021	0.96								0	0	0	0	0	0	0	0					0	0	0		
		Classroom 13	0.09	0.96	0.021	0.96								0	0	0	0	0	0	0	0					0	0	0		
		Classroom 14	0.18	0.96	0.042	0.96								0	0	0	0	0	0	0	0					0	0	0		
Mini Classroom		Snr. House Master	0.064	0.6	0.036	0.6								0	0	0	0	0	0	0	0	0	0	0						
		Classroom 1	0.192	0.96	0.108	0.96								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1				0.1	0.1	0.1		
		Classroom 2	0.192	0.96	0.108	0.96								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1				0.1	0.1	0.1		
		Clinic	0.154	1.92	0.057	1.92								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					
Administration		Chemistry Lab	0.256	4.32	0.144	4.32								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1							
		Office	0.032	0.48	0.018	0.48								0	0	0	0	0	0	0	0	0	0							
		House Mistress	0.045	0.48	0.0105	0.48								0	0	0	0	0	0	0	0	0	0							
		Physics Lab	0.192	1.44	0.108	1.44								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1							
		Secretariat	0.09	8.46	0.021	8.46								0	0	0	0	0	0	0	0	0	0							
		Headmaster	0.09	0.96	0.021	0.96								0	0	0	0	0	0	0	0	0	0							
		Asst. Head Academics	0.045	0.48	0.0105	0.48								0	0	0	0	0	0	0	0	0	0							
		Store Room	0.032	0.48	0.018	0.48								0	0	0	0	0	0	0	0	0	0							
		Staff Room	0.218	2.28	0.093	2.28								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1							
		Head's Office	0.045	0	0.0105	0								0	0	0	0	0	0	0	0	0	0							
		Old Office	0.135	1.44	0.0315	1.44								0	0	0	0	0	0	0	0	0	0							
		Accountant	0.135	1.44	0.0315	1.44								0	0	0	0	0	0	0	0	0	0							

Table B1 (Cont'd)

New Block	CLASSROOM 1	0	0.96	0	0.96								0	0	0	0	0	0	0	0	0				0	0	0		
	CLASSROOM 2	0	0.96	0	0.96								0	0	0	0	0	0	0	0	0				0	0	0		
	CLASSROOM 3	0	0.96	0	0.96								0	0	0	0	0	0	0	0	0				0	0	0		
	CLASSROOM 4	0	0.96	0	0.96								0	0	0	0	0	0	0	0	0				0	0	0		
	CLASSROOM 5	0	0.96	0	0.96								0	0	0	0	0	0	0	0	0				0	0	0		
	CLASSROOM 6	0	0.96	0	0.96								0	0	0	0	0	0	0	0	0				0	0	0		
	BULBS AROUND	0.54	0	0.126	0	0.1	0.1	0.1	0.1	0.1	0.1												0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Entrance	0.36	0	0.084	0	0.1	0.1	0.1	0.1	0.1	0.1												0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Kitchen	0.315	28.8	0.0735	28.8	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Chapel	0.27	0	0.063	0																								
	Dining Hall	0.54	4.32	0.126	4.32																		0.1	0.1	0.1	0.1	0.1		
BOYS DORMITORY	Room 1	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
	Room 2	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
	Room 3	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
	Room 4	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
	Room 5	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
	Room 6	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
	Room 7	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
	Room 8	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
	Prefects Room 1	0.09	1.2	0.021	1.2				0	0	0	0									0	0	0	0	0	0	0		
	Prefects Room 2	0.09	1.2	0.021	1.2				0	0	0	0									0	0	0	0	0	0	0		
	KVIP Toilet	0.045	0	0.0105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Bathroom	0.09	0	0.021	0				0	0	0	0									0	0	0	0	0	0	0		
	Corridors	0.084	0	0.084	0	0.1	0.1	0.1	0.1	0.1	0.1												0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Outside	0.36	0	0.084	0	0.1	0.1	0.1	0.1	0.1	0.1												0.1	0.1	0.1	0.1	0.1	0.1	0.1
	KVIP Toilet	0.225	0	0.0525	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
GIRLS DORMITORY	Corridors	0.36	0	0.084	0	0.1	0.1	0.1	0.1	0.1	0.1												0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Room 1	0.18	0.24	0.042	0.24				0	0	0	0									0	0	0	0	0	0	0		
	Room 2	0.18	0.24	0.042	0.24				0	0	0	0									0	0	0	0	0	0	0		
	Room 3	0.18	0.24	0.042	0.24				0	0	0	0									0	0	0	0	0	0	0		
	Room 4	0.18	0.24	0.042	0.24				0	0	0	0									0	0	0	0	0	0	0		
	Room 5	0.18	0.24	0.042	0.24				0	0	0	0									0	0	0	0	0	0	0		
	Room 6	0.18	0.24	0.042	0.24				0	0	0	0									0	0	0	0	0	0	0		
	Room 7	0.18	0.24	0.042	0.24				0	0	0	0									0	0	0	0	0	0	0		
	Room 8	0.18	0.24	0.042	0.24				0	0	0	0									0	0	0	0	0	0	0		
	Prefects Room	0.045	0.12	0.0105	0.12				0	0	0	0									0	0	0	0	0	0	0		
	Sockets	0	0	0	0																								
	Bathroom	0.09	0	0.021	0				0	0	0	0									0	0	0	0	0	0	0		
	KVIP Toilet	0.18	0	0.042	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WC	0.27	0	0.063	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table B2. Estimated Hours of Usage for Electrical Appliances and the Total Estimated Hourly Consumption for Hunivas.

Location			Total Consumption: Old System – Current Lights	Old System – Others	Replacement – LED	Replacement – Others	Total Hourly Energy Usage: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
New Classroom Block	Basement	Exams Office	0.072	1.7	0.072	1.7								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1							
		3 Arts 1	0.072	1.2	0.072	1.2								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					0.1	0.1	0.1		
		3 Arts 2	0.072	1.2	0.072	1.2								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					0.1	0.1	0.1		
		3 Arts 3	0.072	1.2	0.072	1.2								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					0.1	0.1	0.1		
		3 Arts 4	0.072	1.2	0.072	1.2								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					0.1	0.1	0.1		
		Corridor	0.27	0	0.27	0	0.3	0.3	0.3	0.3	0.3	0.3												0.3	0.3	0.3	0.3	0.3	0.3	0.3
	1st Floor	3 Business 1	0.18	1.2	0.042	1.2								0	0	0	0	0	0	0	0					0	0	0		
		3 Business 2	0.072	1.2	0.072	1.2								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					0.1	0.1	0.1		
		H. Econs 3	0.072	1.2	0.072	1.2								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					0.1	0.1	0.1		
		H. Econs 2	0.072	1.2	0.072	1.2								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					0.1	0.1	0.1		
		H. Econs 1	0.072	1.2	0.072	1.2								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					0.1	0.1	0.1		
		Empty Class	0.072	1.2	0.072	1.2																								
		Corridor	0.27	0	0.27	0	0.3	0.3	0.3	0.3	0.3	0.3												0.3	0.3	0.3	0.3	0.3	0.3	0.3
Administration	Basement	Asst. Head Acad.	0.09	3.5	0.021	3.5								0	0	0	0	0	0	0	0	0	0							
		Typing Office	0.09	3.6	0.021	3.6								0	0	0	0	0	0	0	0	0	0							
		Accounts	0.09	7.4	0.021	7.4								0	0	0	0	0	0	0	0	0	0							
		Headmaster	0.18	11.525	0.042	11.525								0	0	0	0	0	0	0	0	0	0							
		Staff	0.18	1.2	0.042	1.2								0	0	0	0	0	0	0	0	0	0							
		General Office	0.09	2.06	0.021	2.06								0	0	0	0	0	0	0	0	0	0							
		Corridor	0.18	0	0.042	0	0	0	0	0	0	0												0	0	0	0	0	0	0
		Stores	0.18	1.2	0.042	1.2								0	0	0	0	0	0	0	0	0	0							
		Accountant	0.045	0.6	0.0105	0.6								0	0	0	0	0	0	0	0	0	0							
	1st Floor	Snr. Hse. Master	0.09	0.6	0.021	0.6								0	0	0	0	0	0	0	0	0	0							
		Lab/Library	0.192	2.88	0.108	2.88								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1							
		Computer Lab	0.36	5.3	0.084	5.3								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1							

Table B2 (Cont'd)

OLD CLASSROOM BLOCK	Basement	1st Class	0.18	0	0.042	0								0	0	0	0	0	0	0	0					0	0	0		
		2nd Class	0.18	0	0.042	0								0	0	0	0	0	0	0	0					0	0	0		
		3rd Class	0.18	0	0.042	0								0	0	0	0	0	0	0	0					0	0	0		
		4th Class	0.18	0	0.042	0								0	0	0	0	0	0	0	0					0	0	0		
		5th Class	0.18	0	0.042	0								0	0	0	0	0	0	0	0					0	0	0		
		6th Class	0.18	0	0.042	0								0	0	0	0	0	0	0	0					0	0	0		
		Prefects Room	0.045	1.2	0.0105	1.2				0	0	0	0									0	0	0	0	0	0	0		
	Corridor		0.321	0	0.1065	0	0.1	0.1	0.1	0.1	0.1	0.1												0.1	0.1	0.1	0.1	0.1	0.1	0.1
	1st Floor	1st Class	0.18	0	0.042	0								0	0	0	0	0	0	0	0					0	0	0		
		2nd CLass	0.18	0	0.042	0								0	0	0	0	0	0	0	0					0	0	0		
		Room 1	0.18	0	0.042	0				0	0	0	0									0	0	0	0	0	0	0		
		Room 2	0.18	0	0.042	0				0	0	0	0									0	0	0	0	0	0	0		
		Room 3	0.18	0	0.042	0				0	0	0	0									0	0	0	0	0	0	0		
		Room 4	0.18	0	0.042	0				0	0	0	0									0	0	0	0	0	0	0		
		Prefects	0.045	1.2	0.0105	1.2				0	0	0	0									0	0	0	0	0	0	0		
	Corridor		0.321	0	0.1065	0	0.1	0.1	0.1	0.1	0.1	0.1												0.1	0.1	0.1	0.1	0.1	0.1	0.1
	2nd Floor	Room 1	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 2	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 3	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 4	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 5	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 6	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Prefects	0.045	1.2	0.0105	1.2				0	0	0	0									0	0	0	0	0	0	0		
	Corridor		0.321	0	0.1065	0	0.1	0.1	0.1	0.1	0.1	0.1												0.1	0.1	0.1	0.1	0.1	0.1	0.1
			0	0	0	0																								
Science Block	Basment	CHEM LAB	0.384	2.4	0.216	2.4								0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2							
		PHY LAB	0.384	2.4	0.216	2.4								0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2							
	CORRIDOR		0.16	0	0.09	0	0.1	0.1	0.1	0.1	0.1	0.1												0.1	0.1	0.1	0.1	0.1	0.1	0.1
	1st FLoor	2 AGRIC	0.09	0	0.021	0								0	0	0	0	0	0	0	0					0	0	0		
		3 SCI	0.36	4.8	0.084	4.8								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					0.1	0.1	0.1		
		BIO LAB	0.36	3.6	0.084	3.6								0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1							
	CORRIDOR		0.27	0	0.063	0	0.1	0.1	0.1	0.1	0.1	0.1												0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Clinic Block	1st Class	0.18	1.2	0.042	1.2								0	0	0	0	0	0	0	0					0	0	0		
		2nd Class	0.18	1.2	0.042	1.2								0	0	0	0	0	0	0	0					0	0	0		
		3rd Class	0.18	1.2	0.042	1.2								0	0	0	0	0	0	0	0					0	0	0		
		4th Class	0.18	1.2	0.042	1.2								0	0	0	0	0	0	0	0					0	0	0		
		Male Ward	0.045	1.2	0.0105	1.2							0	0	0	0	0	0	0	0	0	0	0	0	0					
		Dispensary	0.045	0.6	0.0105	0.6							0	0	0	0	0	0	0	0	0	0	0	0	0					
		Female Ward	0.045	1.2	0.0105	1.2							0	0	0	0	0	0	0	0	0	0	0	0	0					
		Dispensary	0.045	0.6	0.0105	0.6							0	0	0	0	0	0	0	0	0	0	0	0	0					
		Assembly	0.72	2.52	0.168	2.52							0.2	0.2										0.2	0.2	0.2	0.2	0.2		
		Dining Hall	0.72	2.52	0.168	2.52							0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2		
		Choke Lights in Dh	2.4	0	0.6	0	0.6	0.6	0.6	0.6	0.6	0.6												0.6	0.6	0.6	0.6	0.6	0.6	0.6
		Kitchen	0.54	44.64	0.126	44.64	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		PREV. GIRLS DORM	0.45	14.4	0.105	14.4				0.1	0.1	0.1	0.1									0.1	0.1	0.1	0.1	0.1	0.1	0.1		

Table B2 (Cont'd)

Girls Dormmimtory	House 1	Room 1	0.09	2.4	0.021	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 2	0.09	2.4	0.021	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 3	0.09	2.4	0.021	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 4	0.09	2.4	0.021	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 5	0.09	2.4	0.021	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 6	0.09	2.4	0.021	2.4				0	0	0	0									0	0	0	0	0	0	0		
	House 2	Room 1	0.09	2.4	0.021	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 2	0.09	2.4	0.021	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 3	0.09	2.4	0.021	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 4	0.09	2.4	0.021	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 5	0.09	2.4	0.021	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 6	0.09	2.4	0.021	2.4				0	0	0	0									0	0	0	0	0	0	0		
	House 3 & 4	Room 1	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 2	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 3	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 4	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 5	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		
		Room 6	0.18	2.4	0.042	2.4				0	0	0	0									0	0	0	0	0	0	0		

Table B3. Estimated Hours of Usage for Electrical Appliances and the Total Estimated Hourly Consumption for Fiasec.

Location			Total Consumption				Total Hourly Energy Usage																							
			Old System		Replacement																									
			Current Lights	Others	LED	Others	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Basement	Classroom 1	0.036		0.036									0	0	0	0	0	0	0	0					0	0	0		
		Classroom 2	0.036		0.036									0	0	0	0	0	0	0	0					0	0	0		
		Classroom 3	0.036		0.036									0	0	0	0	0	0	0	0					0	0	0		
		Classroom 4	0.09		0.021									0	0	0	0	0	0	0	0	0	0							
		Classroom 5	0.036		0.036									0	0	0	0	0	0	0	0					0	0	0		
		Classroom 6	0.036		0.036									0	0	0	0	0	0	0	0					0	0	0		
			0		0																									
	1st Floor	Classroom 6	0.09		0.021									0	0	0	0	0	0	0	0									
		Classroom 7	0.09		0.021									0	0	0	0	0	0	0	0									
		Classroom 8	0.09		0.021									0	0	0	0	0	0	0	0					0	0	0		
		Classroom 9	0.09		0.021									0	0	0	0	0	0	0	0					0	0	0		
		Classroom 10	0.09		0.021									0	0	0	0	0	0	0	0					0	0	0		

Table B3 (Cont'd)

		Chemistry Lab	0.36		0									0	0	0	0	0	0	0	0	0	0							
		Biology Lab	0.36		0									0	0	0	0	0	0	0	0	0	0							
		Physics Lab	0.36		0									0	0	0	0	0	0	0	0	0	0							
	Labs	Home Econs Dept.	0.225		0.0525									0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1							
		Clothing Dept.	0.072		0.072									0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1							
		E-Learning	0.072		0.072									0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1							
		Computer Lab	0.334		0.099									0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1							
			0		0																									
		Corridor	0		0		0	0	0	0	0	0												0	0	0	0	0	0	0
		Classroom 1	0.036		0.036									0	0	0	0	0	0	0	0	0	0			0	0	0		
		Classroom 2	0.036		0.036									0	0	0	0	0	0	0	0	0	0			0	0	0		
		Classroom 3	0.036		0.036									0	0	0	0	0	0	0	0	0	0			0	0	0		
		Classroom 4	0.054		0.054									0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1			0.1	0.1	0.1		
		Store Room	0.045		0.0105									0	0	0	0	0	0	0	0	0	0							
		Wash Room	0.045		0.0105									0	0	0	0	0	0	0	0	0	0							
	Classroom Block 2	Administration	0.077		0.0285									0	0	0	0	0	0	0	0	0	0							
		Headmaster	0.09		0.021									0	0	0	0	0	0	0	0	0	0							
		Asst. Head 1	0.045		0.0105									0	0	0	0	0	0	0	0	0	0							
		Asst. Head 2	0.045		0.0105									0	0	0	0	0	0	0	0	0	0							
		Conference Room	0.045		0.0105									0	0	0	0	0	0	0	0	0	0							
		Typing Room	0.018		0.018									0	0	0	0	0	0	0	0	0	0							
		Library	0.128		0.072									0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1							
		Classroom 5	0.036		0.036									0	0	0	0	0	0	0	0					0	0	0		
			0		0																									
		Classroom 1	0.18		0.042									0	0	0	0	0	0	0	0					0	0	0		
		Classroom 2	0.18		0.042									0	0	0	0	0	0	0	0					0	0	0		
		Classroom 3	0.18		0.042									0	0	0	0	0	0	0	0					0	0	0		
	Block 3	Classroom 4	0.18		0.042									0	0	0	0	0	0	0	0					0	0	0		
		Classroom 5	0.18		0.042									0	0	0	0	0	0	0	0					0	0	0		
		Classroom 6	0.18		0.042									0	0	0	0	0	0	0	0					0	0	0		
		Classroom 7	0.18		0.042									0	0	0	0	0	0	0	0					0	0	0		
			0		0																									
		CLASSROOM 1	0.18		0.042									0	0	0	0	0	0	0	0					0	0	0		
		CLASSROOM 2	0.18		0.042									0	0	0	0	0	0	0	0					0	0	0		
	Basement	CLASSROOM 3	0.18		0.042									0	0	0	0	0	0	0	0					0	0	0		
		CLASSROOM 4	0.18		0.042									0	0	0	0	0	0	0	0					0	0	0		
BLOCK 4		CLASSROOM 5	0.18		0.042									0	0	0	0	0	0	0	0					0	0	0		
		CLASSROOM 1	0.216		0.078									0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					0.1	0.1	0.1		
		CLASSROOM 2	0.216		0.078									0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					0.1	0.1	0.1		
	1st Floor	CLASSROOM 3	0.216		0.078									0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					0.1	0.1	0.1		
		CLASSROOM 4	0.216		0.078									0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					0.1	0.1	0.1		
		CLASSROOM 5	0.216		0.078									0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1					0.1	0.1	0.1		

Table B3 (Cont'd)

		Kitchen	0.315		0.0735		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
			0		0																									
		Summer hut	0.135		0.0315		0	0	0	0	0	0												0	0	0	0	0	0	0
		Staff Room	0.108		0.108																									
		Dining Hall	0.63		0.147																			0.1	0.1	0.1	0.1	0.1		
			0		0																									
	Boys Dormitory	Room 1	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 2	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 3	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 4	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 5	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 6	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 7	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 8	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 9	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 10	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 11	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 12	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 13	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		BATHROOM	0.225		0.0525		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
			0		0																									
Girls Dormitory	Old Block	Room 1	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 2	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 3	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 4	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 5	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 6	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 7	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 8	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 9	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 10	0.18		0.042		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Bathroom	0.225		0.0525																									
	New Block	Room 1	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 2	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 3	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 4	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 5	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 6	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 7	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 8	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 9	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Room 10	0.18		0.042					0	0	0	0										0	0	0	0	0	0	0	
		Bathroom'	0.135		0.0315		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B4. Estimated Hours of Usage for Electrical Appliances and the Total Estimated Hourly Consumption for Tarsco.

Location		Total Consumption				Total Hourly Energy Usage																							
		Old System		Replacement																									
		Current Lights	Others	LED	Others	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Main Classroom Block 1st Floor	Basmeent	0.27	0	0.063	0								0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063					0.063	0.063	0.063		
	Classroom 1	0.18	0	0.042	0								0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042					0.042	0.042	0.042		
	Classroom 2	0.18	0	0.042	0								0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042					0.042	0.042	0.042		
	Classroom 3	0.18	0	0.042	0								0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042					0.042	0.042	0.042		
	Classroom 4	0.18	0	0.042	0								0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042					0.042	0.042	0.042		
	Classroom 5	0.18	0	0.042	0								0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042					0.042	0.042	0.042		
	Classroom 6	0.18	0	0.042	0								0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042					0.042	0.042	0.042		
	Chaplaincy Office	0.09	0	0.021	0								0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021							
		0	0	0	0																								
Main Classroom Block 2nd Floor	ICT Lab 1	0.09	22.84	0.021	22.84								0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021							
	ICT Lab 2	0.09	24.24	0.021	24.24								0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021							
	Classroom 7	0.18	0	0.042	0								0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042					0.042	0.042	0.042		
	Classroom 8	0.18	0	0.042	0								0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042					0.042	0.042	0.042		
	Classroom 9	0.18	0	0.042	0								0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042					0.042	0.042	0.042		
	Classroom 10	0.18	0	0.042	0								0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042					0.042	0.042	0.042		
		0	0	0	0																								
Main Classroom Bl	Library	0.09	0	0.021	0								0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021							
	Classrooom 11	0.072	0	0.072	0								0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072					0.072	0.072	0.072		
	Classrooom 12	0.126	0	0.057	0								0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057					0.057	0.057	0.057		
	Classrooom 13	0.126	0	0.057	0								0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057					0.057	0.057	0.057		
	Classrooom 14	0.18	0	0.042	0								0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042					0.042	0.042	0.042		
		0	0	0	0																								
Mini Clssroom Block	Snr. Hse. Master	0.064	0	0.036	0							0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036				
	Classroom 1	0.192	1.2	0.108	1.2								0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108					0.108	0.108	0.108		
	Classroom 2	0.192	1.2	0.108	1.2								0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108					0.108	0.108	0.108		
	Clinic	0.154	0	0.057	0								0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057					
		0	0	0	0																								
Administration	Chemeistry Lab	0.256	3.36	0.144	3.36								0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144							
	Office	0.032	0.84	0.018	0.84								0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018							
	House Mistress	0.045	0.84	0.0105	0.84							0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011				
	Physics Lab	0.192	6.86	0.108	6.86								0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108							
	Secretariat	0.09	2.84	0.021	2.84								0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021							
	Headmaster	0.09	17.88	0.021	17.88								0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021							
	Asst. Head 1	0.045	2.34	0.0105	2.34								0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011							
	Store Room	0.032	0.84	0.018	0.84								0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018							
	Staff Room	0.218	1.68	0.093	1.68								0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093							
	Washroom	0.045	0	0.0105	0								0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011							
	Old Office	0.135	0.84	0.0315	0.84								0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032							
	Accountant	0.135	2.94	0.0315	2.94								0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032							

Table B4 (Cont'd)

New Block	Classrooms 1	0.072	2.4	0.072	2.4								0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072					0.072	0.072	0.072	
	Classrooms 2	0.072	2.4	0.072	2.4								0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072					0.072	0.072	0.072	
	Classrooms 3	0.072	2.4	0.072	2.4								0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072					0.072	0.072	0.072	
	Classrooms 4	0.072	2.4	0.072	2.4								0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072					0.072	0.072	0.072	
	Classrooms 5	0.072	2.4	0.072	2.4								0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072					0.072	0.072	0.072	
	Classrooms 6	0.072	0	0.072	0								0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072					0.072	0.072	0.072	
	Outside Lighting	0.54	0	0.126	0	0.126	0.126	0.126	0.126	0.126	0.126												0.126	0.126	0.126	0.126	0.126	0.126
		0	0	0	0																							
	Entrance	0.36	0	0.084	0	0.084	0.084	0.084	0.084	0.084	0.084												0.084	0.084	0.084	0.084	0.084	0.084
	Kitchen	0.315	28.8	0.0735	28.8	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074
	Chapel	0.27	0	0.063	0																		0.063	0.063	0.063	0.063	0.063	
	Dining Hall	0.54	0	0.126	0																		0.126	0.126	0.126	0.126	0.126	
		0	0	0	0																							
Boys Dormitory	Room 1	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Room 2	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Room 3	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Room 4	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Room 5	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Room 6	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Room 7	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Room 8	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Prefects Room 1	0.09	1.2	0.021	1.2				0.021	0.021	0.021	0.021									0.021	0.021	0.021	0.021	0.021	0.021	0.021	
	Prefects Room 2	0.09	1.2	0.021	1.2				0.021	0.021	0.021	0.021									0.021	0.021	0.021	0.021	0.021	0.021	0.021	
	KVIP Toilets	0.045	0	0.0105	0	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
	Bathroom	0.09	0	0.021	0	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
	Corridor	0.36	0	0.084	0	0.084	0.084	0.084	0.084	0.084	0.084												0.084	0.084	0.084	0.084	0.084	0.084
	Compund Lights	0.36	0	0.084	0	0.084	0.084	0.084	0.084	0.084	0.084												0.084	0.084	0.084	0.084	0.084	0.084
		0	0	0	0																							
	3 Cubicles Washroom	0.225	0	0.0525	0	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
		0	0	0	0																							
	Corridors	0.36	0	0.084	0	0.084	0.084	0.084	0.084	0.084	0.084												0.084	0.084	0.084	0.084	0.084	0.084
	Room 1	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Room 2	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Room 3	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Room 4	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Room 5	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Room 6	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Room 7	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032	
	Room 8	0.18	1.2	0.042	1.2				0.042	0.042	0.042	0.042									0.042	0.042	0.042	0.042	0.042	0.042	0.042	
	Prefects Room	0.045	1.2	0.0105	1.2				0.011	0.011	0.011	0.011									0.011	0.011	0.011	0.011	0.011	0.011	0.011	
	Sockets	0	0	0	0																							
	Bathroom	0.09	0	0.021	0	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
	KVIP	0.18	0	0.042	0	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
	Washroom	0.27	0	0.063	0	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063

Table B4 (Cont'd)

Girls Dormitory 1	Corridors	0.36	0	0.084	0	0.084	0.084	0.084	0.084	0.084	0.084												0.084	0.084	0.084	0.084	0.084	0.084	0.084
	Room 1	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 2	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 3	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 4	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 5	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 6	0.18	1.2	0.042	1.2				0.042	0.042	0.042	0.042									0.042	0.042	0.042	0.042	0.042	0.042	0.042		
	Room 7	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 8	0.18	1.2	0.042	1.2				0.042	0.042	0.042	0.042									0.042	0.042	0.042	0.042	0.042	0.042	0.042		
	Prefects Room	0.045	1.2	0.0105	1.2				0.011	0.011	0.011	0.011									0.011	0.011	0.011	0.011	0.011	0.011	0.011		
	Sockets	0	0	0	0																								
	Bathroom	0.09	0	0.021	0	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
	Washroom	0.18	0	0.042	0	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
	Washroom	0.27	0	0.063	0	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
		0	0	0	0																								
Girls Dormitory 2	Corridors	0.36	0	0.084	0	0.084	0.084	0.084	0.084	0.084	0.084												0.084	0.084	0.084	0.084	0.084	0.084	0.084
	Room 1	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 2	0.18	1.2	0.042	1.2				0.042	0.042	0.042	0.042									0.042	0.042	0.042	0.042	0.042	0.042	0.042		
	Room 3	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 4	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 5	0.18	1.2	0.042	1.2				0.042	0.042	0.042	0.042									0.042	0.042	0.042	0.042	0.042	0.042	0.042		
	Room 6	0.18	1.2	0.042	1.2				0.042	0.042	0.042	0.042									0.042	0.042	0.042	0.042	0.042	0.042	0.042		
	Room 7	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 8	0.18	1.2	0.042	1.2				0.042	0.042	0.042	0.042									0.042	0.042	0.042	0.042	0.042	0.042	0.042		
	Prefects Room	0.045	1.2	0.0105	1.2				0.011	0.011	0.011	0.011									0.011	0.011	0.011	0.011	0.011	0.011	0.011		
	Sockests	0	0	0	0																								
	Bathroom	0.09	0	0.021	0	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
	KVIP	0.18	0	0.042	0	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
	Washroom	0.27	0	0.063	0	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
		0	0	0	0																								
Girls Dormitory 3	Corridors	0.36	0	0.084	0	0.084	0.084	0.084	0.084	0.084	0.084												0.084	0.084	0.084	0.084	0.084	0.084	0.084
	Room 1	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 2	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 3	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 4	0.18	1.2	0.042	1.2				0.042	0.042	0.042	0.042									0.042	0.042	0.042	0.042	0.042	0.042	0.042		
	Room 5	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 6	0.18	1.2	0.042	1.2				0.042	0.042	0.042	0.042									0.042	0.042	0.042	0.042	0.042	0.042	0.042		
	Room 7	0.135	1.2	0.0315	1.2				0.032	0.032	0.032	0.032									0.032	0.032	0.032	0.032	0.032	0.032	0.032		
	Room 8	0.18	1.2	0.042	1.2				0.042	0.042	0.042	0.042									0.042	0.042	0.042	0.042	0.042	0.042	0.042		
	Prefects Room	0.045	1.2	0.0105	1.2				0.011	0.011	0.011	0.011									0.011	0.011	0.011	0.011	0.011	0.011	0.011		
	Sockests	0	0	0	0																								
	Bathroom	0.09	0	0.021	0	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
	KVIP	0.18	0	0.042	0	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
	Washroom	0.27	0	0.063	0	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063

APPENDIX C

PROGRAMMNG CODE FOR DATA COLLECTION USING ARDUINO NANO MICROCONTROLLER

```
#include <Wire.h>

#include <LiquidCrystal_I2C.h>

#include <DHT.h>

// Define analog input

#define VOLTAGE_IN_PIN A0

#define VOLTAGE_IN_PIN2 A2

#define CURRENT_IN_PIN A3

#define CURRENT_IN_PIN2 A6

 // Set the LCD address to 0x27 for a 16 chars and 2-line display

LiquidCrystal_I2C lcd(0x27, 16, 2);

//Constants

#define DHTPIN 2     // what pin we're connected to

#define DHTPIN2 4     // what pin we're connected to

#define DHTTYPE DHT22   // DHT 22  (AM2302)

DHT dht(DHTPIN, DHTTYPE); //// Initialise DHT sensor for normal 16 mhz Arduino

DHT dht2(DHTPIN2, DHTTYPE);

//Variables

int chk;

//int sensorPin1 = A1; //LDR 1 sensor
```

APPENDIX C (Cont'd)

```
//int sensorPin2= A7;  //LDR 2 sensor

float sensorValue ; // variable to store the value coming from the sensor

float sensorValue1;

//int offset = 20; // set the correction offset value of voltage sensor

float temp; //Stores temperature value

float temp2; //Stores temperature value


// Floats for ADC voltage & Input voltage

float adc_voltage = 0.0;

float in_voltage = 0.0;


float adc_voltage1 = 0.0;

float in_voltage1 = 0.0;


// Floats for resistor values in divider (in ohms)

float R1 = 30000.0;

float R2 = 7500.0;


// Float for Reference Voltage

float ref_voltage = 5.0;

float voltage, voltage1;
```

APPENDIX C (Cont'd)

```
// Integer for ADC value
int adc_value = 0; int adc_value1 = 0;

const float VCC   = 5.0;// supply voltage is from 4.5 to 5.5V. Normally 5V.
const int model = 2;   // enter the model number (see below)

float cutOffLimit = 1.01;// set the current which below that value, doesn't matter. Or set 0.5
float sensitivity[] ={
          0.185,// for ACS712ELCTR-05B-T
          0.100,// for ACS712ELCTR-20A-T
          0.066// for ACS712ELCTR-30A-T  };

//const float QOV =   0.5 * VCC;// set quiescent Output voltage of 0.5V
float test_current1;// internal variable for voltage
float test_current2;//

void setup()
{
  Serial.begin(9600);
  dht.begin();
  dht2.begin();
  lcd.begin();;// initialise the LCD
```

```
  lcd.backlight();// Turn on the blacklight and print a message.
}
  int count=0;
void loop()
{
 //Read data and store it to variables hum and temp
//    hum = dht.readHumidity();
      temp= dht.readTemperature();


 //Read data and store it to variables hum and temp
//    hum2 = dht2.readHumidity();
      temp2= dht2.readTemperature();


// Read the Analog Input for voltage
    adc_value = analogRead(A0);
    adc_value1 = analogRead(A2);


// Determine voltage at ADC input
   adc_voltage  = (adc_value * ref_voltage) / 1024.0;
   adc_voltage1  = (adc_value1 * ref_voltage) / 1024.0;


// Calculate voltage at divider input
   voltage = adc_voltage / (R2/(R1+R2)) ;
```

APPENDIX C (Cont'd)

```
 voltage1 = adc_voltage1 / (R2/(R1+R2)) ;


//ACS712 Current Sensor
  float AcsValue=0.0, Samples = 0.0, AvgAcs=0., current1=0.0;
  float AcsValue1=0.0, Samples1 = 0.0, AvgAcs1=0., current2=0.0;


  for (int x=0; x<150; x++){ //get 150 samples
    AcsValue = analogRead (A3); // Read sensor values
    AcsValue1 = analogRead (A6);


    Samples = Samples +AcsValue; //Add samples
    Samples1 = Samples1 +AcsValue1; //Add samples
    delay (3); // let ADC settle before next sample (3ms)
      }
  AvgAcs=Samples/150.0; //Taking Average of Samples
  AvgAcs1=Samples1/150.0; //Taking Average of Samples
  // ((AvgAcs*(5.0/1024)) is converting the read voltage in 0 - 5 volts
  // 2.5 offset
  // 0.100v (100mV) is the rise in output voltage when 1A current flows at input


  current1= (2.5-(AvgAcs*(5.0/1024.0)) )/0.100;
```

APPENDIX C (Cont'd)

```
  current2= (2.5-(AvgAcs1*(5.0/1024.0)) )/0.100;


float power_factor = (voltage/6); //comparing voltage with expected total of 6V

float power_factor1 = (voltage1/6);

float power  = ((sensorValue/1024.0)*50)* power_factor; //(50 Watt / analog read limit) * LDR
reading

float power1 = ((sensorValue1/1024.0)*50)* power_factor1;

float efficiency = ((voltage-voltage1)/voltage1)*100;

    Serial.print("Temp 1: ");

    Serial.print(temp);

    Serial.print(",  ");

    Serial.print("Temp 2: ");

    Serial.print(temp2);

    Serial.println(",");

// Print results to Serial Monitor to 2 decimal places

    Serial.print("Voltage1 = ");

    Serial.print(voltage, 2);

    Serial.print(",  ");

    Serial.print("Voltage2 = ");

    Serial.print(voltage1, 2);

    Serial.println(",");

//  Serial.print("Current 1: ");
```

APPENDIX C (Cont'd)

```
//    Serial.print(current1, 4); // print the current with 2 decimal places
//    Serial.print(",  ");
//    Serial.print("Current 2: ");
//    Serial.print(current2, 4); // print the current with 2 decimal places
//    Serial.println(",");
        Serial.print("POWER 1 = ");
    Serial.println(power); //prints the values coming from the sensor on the screen
    Serial.print("POWER 2 = ");
    Serial.println(power1);
    Serial.println();
    Serial.println(" ");
    Serial.print("EFFICIENCY = ");
    Serial.println(efficiency); //prints the values coming from the sensor on the screen
    lcd.setCursor(0,0);
  lcd.print("SOLAR TRACKER");
  lcd.setCursor(0,17);
  lcd.print("by OFFEI DANIEL");
  delay(2000);
  lcd.clear();
  lcd.setCursor(0,0);
  lcd.print("TEMP 1: "+String(temp)+"*C");
  lcd.setCursor(0,17);
```

APPENDIX C (Cont'd)

```
 lcd.print("TEMP 2: "+String(temp2)+"*C");
   delay(5000);
 lcd.clear();
 lcd.setCursor(0,0);
 lcd.print("VOLT 1: "+String(voltage)+"V");
 lcd.setCursor(0,17);
 lcd.print("VOLT 2: "+String(voltage1)+"V");
   delay(5000); //Dalay 5 sec.
 lcd.clear();
 lcd.setCursor(0,0);
 lcd.print("POWER 1: "+String(power)+"W");
 lcd.setCursor(0,17);
 lcd.print("POWER 2: "+String(power1)+"W");
   delay(5000); //Dalay 5 sec.
 lcd.clear();
 lcd.setCursor(0,0);
lcd.print("EFFICIENCY");
 lcd.setCursor(0,17);
 lcd.print(String(efficiency)+"%");
   delay(5000); //Dalay 5 sec.
}
```

APPENDIX D

MICROCONTROLLER CODE FOR TRACKING THE SUN

```
#include <Stepper.h>
const int stepsPerRevolution = 200;  // change this to fit the number of steps per revolution
// for your motor
int POSITION;
int TIME;
int PERIOD ;
int i;
int switch1 = 12; //DIGITAL PIN FOR BUTTON SWITCH 1 & 2
int switch2 = 6;
int pin1 ;
int pin2 ;
int UP = stepsPerRevolution;
int DOWN = -stepsPerRevolution;
int STAY = 0 * stepsPerRevolution;
int sensorPin1 = A0; // select the input pin for LDR
int sensorPin2 = A2;

int LDR1 ;
int LDR2 ;
// initialise the stepper library on pins 2 to 5 & 8 to 11:
Stepper myStepper1(stepsPerRevolution, 2, 3, 4, 5);
Stepper myStepper2(stepsPerRevolution, 11, 10, 9, 8);

void CHECK_PERIOD()
{
  LDR1 = analogRead(sensorPin1); // read the value from the sensor
  LDR2 = analogRead(sensorPin2);
  int TIME_OF_DAY = LDR1 + LDR2;
```

APPENDIX D (Cont'd)

```
int TIME;
if (TIME_OF_DAY > 200)
{    TIME = 1; //Day Time  }
else if (TIME_OF_DAY < 200)
{    TIME = 0; //Night  }
//  int difference = LDR1 - LDR2;
if (TIME = 0) // NIGHT
{    PERIOD = 0;  }
else if (TIME = 1) // DAY
{    if ((LDR1 - LDR2) > 30)
  {      PERIOD = 1; //MORNING    }
  else if (-30 < (LDR1 - LDR2) && (LDR1 - LDR2) < 30)
  {      PERIOD = 2; //NOON    }
  else if ( (LDR2 - LDR1) > 30 )
  {      PERIOD = 3; //AFTERNOON    }
}
Serial.print ("LDR1: ");
Serial.println (LDR1);
Serial.print ("LDR2: ");
Serial.println (LDR2);
Serial.print ("difference: ");
Serial.println (LDR1 - LDR2);
Serial.print ("TIME OF DAY: ");
Serial.println (TIME_OF_DAY);
Serial.print ("TIME: ");
Serial.println (TIME);
Serial.print ("PERIOD: ");
Serial.println (PERIOD);
Serial.print ("POSITION: ");
Serial.println (POSITION);
```

APPENDIX D (Cont'd)

```
}
void RESET_POSITION()
{
 for (int i = 0; digitalRead (switch1) == LOW; i++)
 {
  pin1 = digitalRead (switch1);
  myStepper1.step(DOWN);
  Serial.print("PIN 1 STATUS: ");
  Serial.println(pin1);
  Serial.print ("STEPPER 1 DOWN RESET = ");
  Serial.println (i);
  if (digitalRead (switch1) == HIGH)
  {
   Serial.println("End of STEPPER 1 reset");
  }
  digitalRead (switch1);
 }
 for (int j = 0; digitalRead (switch2) == LOW; j++)
 {
  pin2 = digitalRead (switch2);
  myStepper2.step(DOWN);
  Serial.print("PIN 2 STATUS: ");
  Serial.println(pin2);
  Serial.print ("STEPPER 2 DOWN RESET = ");
  Serial.println (j);
  if (digitalRead (switch2) == HIGH)
  {
   Serial.println("End of STEPPER 2 reset");
  }
  digitalRead (switch2) }
```

APPENDIX D (Cont'd)

```
POSITION = 0; //FOLDED POSITION
  delay (3000);
}

void STARTING_POSITION()
{
  CHECK_PERIOD();
  if (TIME = 1)
  {
    if (PERIOD == 1)
    {
      for (int x = 0; x < 193; x++)
      {
        myStepper1.step(STAY);
        //      delay (2000);
        myStepper2.step(UP);
        Serial.print ("stepper 2 UP (START): ");
        Serial.println (x);
      }
      POSITION = 1;
    }
    else if (PERIOD == 2)
    {
      for (int x = 0; x < 97; x++)
      {
        myStepper1.step(UP);
        Serial.print ("stepper 1 UP (START): ");
        Serial.println (x);
        //      delay (00);
```

APPENDIX D (Cont'd)

```
        myStepper2.step(UP);
        Serial.print ("stepper 2 UP (START): ");
        Serial.println (x);
      }
      POSITION = 2;
    }

    else if (PERIOD == 3)
    {
      for (int x = 0; x < 193; x++)
      {
        myStepper1.step(UP);
        Serial.print ("stepper 1 UP (START): ");
        Serial.println (x);

        //     delay (2000);
        myStepper2.step(STAY);
        Serial.println ("stepper 2 STAY (START): ");
      }
      POSITION = 3;
    }
  }
  else if (TIME = 0)
  {
    {
      RESET_POSITION();
    }
  }
}
```

APPENDIX D (Cont'd)

```
void CHANGE_POSITION()
{
 CHECK_PERIOD();
 while (POSITION == 0) // FOLDED
 {
  Serial.println ("STAGE ONE");
  if (TIME == 0) // NIGHT
  {
   RESET_POSITION();
   CHECK_PERIOD();
  }

  else if (TIME == 1) // DAY
  {
   if (PERIOD == 1)
   {
    myStepper1.step(STAY);
    Serial.println ("stepper 1 STAY (CHANGE MORN): ");
    delay (2000);
    for (int x = 0; x < 193; x++)
    {
     myStepper2.step(UP);
     Serial.print ("stepper 2 UP (CHANGE MORN): ");
     Serial.println (x);
     if (x == 192)
     {
      POSITION = 1;
     }
    }
    //  delay(500);
```

APPENDIX D (Cont'd)

```
    }
    CHECK_PERIOD();
  }
  CHECK_PERIOD();
}

while (POSITION == 1) //MORNING
{
  Serial.println ("STAGE TWO");
  if (TIME == 0) // NIGHT
  {
    RESET_POSITION();
    CHECK_PERIOD();
  }

  else if (TIME == 1) // DAY
  {
    if (PERIOD == 1) //MORNING
    {
      for (int x = 0; PERIOD == 1; x++)
      {
        myStepper1.step(STAY);
        delay (2000);
        Serial.println ("stepper 1 STAY (MORN): ");
        myStepper2.step(STAY);
        Serial.println ("stepper 2 STAY (MORN): ");
        if (PERIOD != 1)
        {
          Serial.println ("TIME TO CHANGE POSITION");
        }
```

APPENDIX D (Cont'd)

```
        //  delay(500);
        CHECK_PERIOD();
        POSITION = 1;
      }
    }

    else if (PERIOD == 2) // NOON
    {
     for (int y = 0; y < 97; y++)
      {
        myStepper1.step(UP);
        Serial.print ("stepper 1 UP (CHANGE NOON): ");
        Serial.println (y);
        myStepper2.step(DOWN);
        Serial.print ("stepper 2 DOWN (CHANGE NOON): ");
        Serial.println (y);
        if (y == 96)
        {
          POSITION = 2;
        }
        //  delay(500);
      }
    }
    CHECK_PERIOD();
  }

 }
 CHECK_PERIOD();
 while (POSITION == 2)
 {
```

APPENDIX D (Cont'd)

```
Serial.println ("STAGE THREE");
if (TIME == 0)
{
 RESET_POSITION();
 CHECK_PERIOD();
}
else if (TIME == 1)
{
 CHECK_PERIOD();
 if (PERIOD == 2) //NOON
 {
  for (int x = 0; PERIOD == 2; x++)
  {
   myStepper1.step(STAY);
   Serial.println ("stepper 1 STAY (NOON): ");
   delay (2000);
   myStepper2.step(STAY);
   Serial.println ("stepper 2 STAY (NOON): ");
   POSITION = 2;
   if (PERIOD != 2)
   {
    Serial.println ("TIME TO CHANGE POSITION");
   }
   //  delay(500);
   CHECK_PERIOD();
  }
 }

 else if (PERIOD == 3) // AFTERNOON
 {
```

APPENDIX D (Cont'd)

```
    CHECK_PERIOD();
    for (int z = 0; z < 97; z++)
    {
     myStepper1.step(UP);
     Serial.print ("stepper 1 UP (CHANGE AFTERNOON): ");
     Serial.println (z);
     POSITION = 3;

     myStepper2.step(DOWN);
     Serial.print ("stepper 2 DOWN (CHANGE AFTERNOON): ");
     Serial.println (z);
     POSITION = 3;
     if (z == 96)
     {
      POSITION = 3;
     }
     //  delay(500);
    }

    CHECK_PERIOD();
   }
  }
 }
 while (POSITION == 3)
 {
  Serial.println ("STAGE FOUR");
  CHECK_PERIOD();
  if (TIME = 0)
  {
   RESET_POSITION();
```

APPENDIX D (Cont'd)

```
   CHECK_PERIOD();
  }
  else if (TIME = 1)
  {
   CHECK_PERIOD();
   if (PERIOD = 3) //AFTERNOON
   {
    for (int x = 0; PERIOD == 3; x++)
    {
     myStepper1.step(STAY);
     Serial.println ("stepper 1 STAY (AFTERNOON): ");
     delay (2000);
     myStepper2.step(STAY);
     Serial.println ("stepper 2 STAY (AFTERNOON): ");
     POSITION = 3;
     if (PERIOD != 3)
     {
      Serial.println ("TIME TO CHANGE POSITION");
     }
     //  delay(500);
     CHECK_PERIOD();
    }
   }
   else if (TIME = 0) // AFTERNOON
   {
    RESET_POSITION;
    CHECK_PERIOD();
   }
  }
 }
```

APPENDIX D (Cont'd)

```
}
void setup()
{
  delay (5000);
  pinMode (switch1, INPUT);
  pinMode (switch2, INPUT);
  // set the speed at 200 rpm:
  myStepper1.setSpeed(60);
  myStepper2.setSpeed(60);
  // initialise the serial port:
  Serial.begin(9600);
  RESET_POSITION();
  STARTING_POSITION();
  delay (3000);
}
void loop ()
{
  CHANGE_POSITION();
}
```

APPENDIX E

Table E1 Inventory of Electrical Appliances Collected at St. Augustine's Senior High School.

		Location	Total Consumption: Old System: Current Lights	Total Consumption: Old System: Others	Total Consumption: Replacement: LED	Total Consumption: Replacement: Others	CFL Bulbs: CFL Bulbs (45 W): Qty	CFL Bulbs: CFL Bulbs (45 W): Power (kW)	CFL Bulbs: LED Replacment (10.5 PHILIPS): Qty	CFL Bulbs: LED Replacment (10.5 PHILIPS): Power (kW)	T5 Lights: T5 (32 W): Qty	T5 Lights: T5 (32 W): Power (kW)	T5 Lights: Replacement (18 W PHILIPS): Qty	T5 Lights: Replacement (18 W PHILIPS): Power (kW)	Existing LED (18W LED): Qty	Existing LED (18W LED): Power (kW)	Fans: Qty.	Fans: Hours of Use	Fans: Power (0.12kW)	Fridge: Qty.	Fridge: Hours of Use	Fridge: Power (0.6kW)	Fridge (replacement): Qty.	Fridge (replacement): Hours of Use	Fridge (replacement): Power (0.4kW)	Printer: Qty.	Printer: Hours of Use	Printer: Power (0.5W)	Television: Qty.	Television: Hours of Use	Television: Power (0.045kW)
Main Classroom Block		Basement	0.27	0	0.063	0	6	0.27	6	0.063		0		0		0	0		0			0			0			0			0
	First Floor	Classroom 1	0.18	0.96	0.042	0.96	4	0.18	4	0.042		0		0		0	2	4	0.96			0			0			0			0
		Classroom 2	0.18	0.96	0.042	0.96	4	0.18	4	0.042		0		0		0	2	4	0.96			0			0			0			0
		Classroom 3	0.18	0.96	0.042	0.96	4	0.18	4	0.042		0		0		0	2	4	0.96			0			0			0			0
		Classroom 4	0.18	0.96	0.042	0.96	4	0.18	4	0.042		0		0		0	2	4	0.96			0			0			0			0
		Classroom 5	0.18	0.96	0.042	0.96	4	0.18	4	0.042		0		0		0	2	4	0.96			0			0			0			0
		Classroom 6	0.18	0.96	0.042	0.96	4	0.18	4	0.042		0		0		0	2	4	0.96			0			0			0			0
		Chaplaincy Office	0.09	0.96	0.021	0.96	2	0.09	2	0.021		0		0		0	1	8	0.96			0			0			0			0
								0		0		0		0		0	0		0			0			0			0			0
	Second Floor	ICT Lab 1	0.09	2.96	0.021	2.96	2	0.09	2	0.021		0		0		0	2	4	0.96			0			0	2	2	2			0
		ICT Lab 2	0.09	0.96	0.021	0.96	2	0.09	2	0.021		0		0		0	2	4	0.96			0			0			0			0
		Classroom 7	0.18	0.96	0.042	0.96	4	0.18	4	0.042		0		0		0	2	4	0.96			0			0			0			0
		Classroom 8	0.18	0.96	0.042	0.96	4	0.18	4	0.042		0		0		0	2	4	0.96			0			0			0			0
		Classroom 9	0.18	0.96	0.042	0.96	4	0.18	4	0.042		0		0		0	2	4	0.96			0			0			0			0
		Classroom 10	0.18	0.96	0.042	0.96	4	0.18	4	0.042		0		0		0	2	4	0.96			0			0			0			0
								0		0		0		0		0	0		0			0			0			0			0
	Third Floor	Library	0.09	0.96	0.021	0.96	2	0.09	2	0.021		0		0		0	2	4	0.96			0			0			0			0
		Classroom 11	0	0.96	0	0.96		0		0		0		0	4	0.072	2	4	0.96			0			0			0			0
		Classroom 12	0.09	0.96	0.021	0.96	2	0.09	2	0.021		0		0	2	0.036	2	4	0.96			0			0			0			0
		Classroom 13	0.09	0.96	0.021	0.96	2	0.09	2	0.021		0		0	2	0.036	2	4	0.96			0			0			0			0
		Classroom 14	0.18	0.96	0.042	0.96	4	0.18	4	0.042		0		0		0	2	4	0.96			0			0			0			0
								0		0		0		0		0	0		0			0			0			0			0
Mini Classroom		Snr. House Master	0.064	0.6	0.036	0.6		0		0	2	0.064	2	0.036		0	1	5	0.6			0			0			0			0
		Classroom 1	0.192	0.96	0.108	0.96		0		0	6	0.192	6	0.108		0	2	4	0.96			0			0			0			0
		Classroom 2	0.192	0.96	0.108	0.96		0		0	6	0.192	6	0.108		0	2	4	0.96			0			0			0			0
		Clinic	0.154	1.92	0.057	1.92	2	0.09	2	0.021	2	0.064	2	0.036		0	4	4	1.92			0			0			0			0
								0		0		0		0		0			0			0			0			0			0
Administration		Chemistry Lab	0.256	4.32	0.144	4.32		0		0	8	0.256	8	0.144		0	9	4	4.32			0			0			0			0
		Office	0.032	0.48	0.018	0.48		0		0	1	0.032	1	0.018		0	1	4	0.48			0			0			0			0
		House Mistress	0.045	0.48	0.0105	0.48	1	0.045	1	0.0105		0		0		0	1	4	0.48			0			0			0			0
		Physics Lab	0.192	1.44	0.108	1.44		0		0	6	0.192	6	0.108		0	3	4	1.44			0			0			0			0
		Secretariat	0.09	8.46	0.021	8.46	2	0.09	2	0.021		0		0		0	2	4	0.96			0			0	5	3	7.5			0
		Headmaster	0.09	0.96	0.021	0.96	2	0.09	2	0.021		0		0		0	2	4	0.96			0			0			0			0
		Asst. Head Academics	0.045	0.48	0.0105	0.48	1	0.045	1	0.0105		0		0		0	1	4	0.48			0			0			0			0
		Store Room	0.032	0.48	0.018	0.48		0		0	1	0.032	1	0.018		0	1	4	0.48			0			0			0			0
		Staff Room	0.218	2.28	0.093	2.28	2	0.09	2	0.021	4	0.128	4	0.072		0	2	8	1.92			0			0			0	1	8	0.36
		Head's Office	0.045	0	0.0105	0	1	0.045	1	0.0105		0		0		0		4	0			0			0			0			0
		Old Office	0.135	1.44	0.0315	1.44	3	0.135	3	0.0315		0		0		0	3	4	1.44			0			0			0			0
		Accountant	0.135	1.44	0.0315	1.44	3	0.135	3	0.0315		0		0		0	3	4	1.44			0			0			0			0

Table E1 (Cont'd)

New Block	CLASSROOM 1	0	0.96	0	0.96		0		0		0	0	4	0.072	2	4	0.96			0			0	0	0
	CLASSROOM 2	0	0.96	0	0.96		0		0		0	0	4	0.072	2	4	0.96			0			0	0	0
	CLASSROOM 3	0	0.96	0	0.96		0		0		0	0	4	0.072	2	4	0.96			0			0	0	0
	CLASSROOM 4	0	0.96	0	0.96		0		0		0	0	4	0.072	2	4	0.96			0			0	0	0
	CLASSROOM 5	0	0.96	0	0.96		0		0		0	0	4	0.072	2	4	0.96			0			0	0	0
	CLASSROOM 6	0	0.96	0	0.96		0		0		0	0	4	0.072	2	4	0.96			0			0	0	0
	BULBS AROUND	0.54	0	0.126	0	12	0.54	12	0.126		0	0		0		4	0			0			0	0	0
							0		0		0	0		0			0			0			0	0	0
	Entrance	0.36	0	0.084	0	8	0.36	8	0.084		0	0		0			0			0			0	0	0
							0		0		0	0		0			0			0			0	0	0
							0		0		0	0		0			0			0			0	0	0
	Kitchen	0.315	28.8	0.0735	28.8	7	0.315	7	0.0735		0	0		0		12	0	2	24	28.8	2	24	19.2	0	0
							0		0		0	0		0			0			0			0	0	0
	Chapel	0.27	0	0.063	0	6	0.27	6	0.063		0	0		0		4	0			0			0	0	0
							0		0		0	0		0			0			0			0	0	0
	Dining Hall	0.54	4.32	0.126	4.32	12	0.54	12	0.126		0	0		0	12	3	4.32			0			0	0	0
							0		0		0	0		0			0			0			0	0	0
Boys Dormitory	Room 1	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0	0		0	2	10	2.4			0			0	0	0
	Room 2	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0	0		0	2	10	2.4			0			0	0	0
	Room 3	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0	0		0	2	10	2.4			0			0	0	0
	Room 4	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0	0		0	2	10	2.4			0			0	0	0
	Room 5	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0	0		0	2	10	2.4			0			0	0	0
	Room 6	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0	0		0	2	10	2.4			0			0	0	0
	Room 7	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0	0		0	2	10	2.4			0			0	0	0
	Room 8	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0	0		0	2	10	2.4			0			0	0	0
	Prefects Room 1	0.09	1.2	0.021	1.2	2	0.09	2	0.021		0	0		0	1	10	1.2			0			0	0	0
	Prefects Room 2	0.09	1.2	0.021	1.2	2	0.09	2	0.021		0	0		0	1	10	1.2			0			0	0	0
	KVIP Toilet	0.045	0	0.0105	0	1	0.045	1	0.0105		0	0		0						0			0	0	0
	Bathroom	0.09	0	0.021	0	2	0.09	2	0.021		0	0		0						0			0	0	0
	Corridors	0.084	0	0.084	0	0.08	0.084	8	0.084		0	0		0						0			0	0	0
	Outside	0.36	0	0.084	0	8	0.36	8	0.084		0	0		0						0			0	0	0
							0		0		0	0		0						0			0	0	0
	KVIP Toilet	0.225	0	0.0525	0	5	0.225	5	0.0525		0	0		0						0			0	0	0
							0		0		0	0		0						0			0	0	0
Girls Dormitory	Corridors	0.36	0	0.084	0	8	0.36	8	0.084		0	0		0						0			0	0	0
	Room 1	0.18	0.24	0.042	0.24	4	0.18	4	0.042		0	0		0	2	10	0.24			0			0	0	0
	Room 2	0.18	0.24	0.042	0.24	4	0.18	4	0.042		0	0		0	2	10	0.24			0			0	0	0
	Room 3	0.18	0.24	0.042	0.24	4	0.18	4	0.042		0	0		0	2	10	0.24			0			0	0	0
	Room 4	0.18	0.24	0.042	0.24	4	0.18	4	0.042		0	0		0	2	10	0.24			0			0	0	0
	Room 5	0.18	0.24	0.042	0.24	4	0.18	4	0.042		0	0		0	2	10	0.24			0			0	0	0
	Room 6	0.18	0.24	0.042	0.24	4	0.18	4	0.042		0	0		0	2	10	0.24			0			0	0	0
	Room 7	0.18	0.24	0.042	0.24	4	0.18	4	0.042		0	0		0	2	10	0.24			0			0	0	0
	Room 8	0.18	0.24	0.042	0.24	4	0.18	4	0.042		0	0		0	2	10	0.24			0			0	0	0
	Prefects Room	0.045	0.12	0.0105	0.12	1	0.045	1	0.0105		0	0		0	1	10	0.12			0			0	0	0
	Sockets	0	0	0	0		0		0		0	0		0						0			0	0	0
	Bathroom	0.09	0	0.021	0	2	0.09	2	0.021		0	0		0						0			0	0	0
	KVIP Toilet	0.18	0	0.042	0	4	0.18	4	0.042		0	0		0						0			0	0	0
	WC	0.27	0	0.063	0	6	0.27	6	0.063		0	0		0						0			0	0	0
						No. of Bulbs		237		No. of Bulbs	36														

Table E2 Inventory of Electrical Appliances Collected at Huni-Valley Senior High School.

Location			Total Consumption: Old System – Current Lights	Old System – Others	Replacement – LED	Replacement – Others	CFL Bulbs: CFL Bulbs (0.045 kW) QTY	CFL Bulbs (0.045 kW) Power (kW)	CFL Bulbs: LED Replacment (0.0105kW) QTY	LED Replacment Power (kW)	T5 Lights: T5 (32 W) QTY	T5 (32 W) Power (kW)	T5 Lights: LED Relacement (18 W) QTY	LED Relacement Power (kW)	Existing LED (18W LED) QTY	Existing LED Power (kW)	Fans (0.12 kW) Qty.	Fans HoU	Fans Power
New Classroom Block	Basement	Exams Office	0.072	1.7	0.072	1.7		0		0		0	4	0.072		0	2	5	1.2
		3 Arts 1	0.072	1.2	0.072	1.2		0		0		0	4	0.072		0	2	5	1.2
		3 Arts 2	0.072	1.2	0.072	1.2		0		0		0	4	0.072		0	2	5	1.2
		3 Arts 3	0.072	1.2	0.072	1.2		0		0		0	4	0.072		0	2	5	1.2
		3 Arts 4	0.072	1.2	0.072	1.2		0		0		0	4	0.072		0	2	5	1.2
		Corridor	0.27	0	0.27	0		0		0		0	15	0.27		0			
	1st Floor	3 Business 1	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	2	5	1.2
		3 Business 2	0.072	1.2	0.072	1.2		0		0		0	4	0.072		0	2	5	1.2
		H. Econs 3	0.072	1.2	0.072	1.2		0		0		0	4	0.072		0	2	5	1.2
		H. Econs 2	0.072	1.2	0.072	1.2		0		0		0	4	0.072		0	2	5	1.2
		H. Econs 1	0.072	1.2	0.072	1.2		0		0		0	4	0.072		0	2	5	1.2
		Empty Class	0.072	1.2	0.072	1.2		0		0		0	4	0.072		0	2	5	1.2
		Corridor	0.27	0	0.27	0		0		0		0	15	0.27		0			
								0		0		0		0		0			
Administration	Basement	Asst. Head Acad.	0.09	3.5	0.021	3.5	2	0.09	2	0.021		0		0		0	1	5	0.6
		Typing Office	0.09	3.6	0.021	3.6	2	0.09	2	0.021		0		0		0	1	5	0.6
		Accounts	0.09	7.4	0.021	7.4	2	0.09	2	0.021		0		0		0	1	5	0.6
		Headmaster	0.18	11.525	0.042	11.525	4	0.18	4	0.042		0		0		0	2	5	1.2
		Staff	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	2	5	1.2
		General Office	0.09	2.06	0.021	2.06	2	0.09	2	0.021		0		0		0	1	6	0.72
		Corridor	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0			
		Stores	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	2	5	1.2
		Accountant	0.045	0.6	0.0105	0.6	1	0.045	1	0.0105		0		0		0	1	5	0.6
	1st Floor	Snr. Hse. Master	0.09	0.6	0.021	0.6	2	0.09	2	0.021		0		0		0	1	5	0.6
		Lab/Library	0.192	2.88	0.108	2.88		0		0	6	0.192		0	6	0.108	3	8	2.88
		Computer Lab	0.36	5.3	0.084	5.3	8	0.36	8	0.084		0		0		0	8	5	4.8
								0		0		0		0		0			
Old Classrom Block	Basement	1st Class	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0			
		2nd Class	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0			
		3rd Class	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0			
		4th Class	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0			
		5th Class	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0			
		6th Class	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0			
		Prefects Room	0.045	1.2	0.0105	1.2	1	0.045	1	0.0105		0		0		0	1	10	1.2
	Corridor		0.321	0	0.1065	0	5	0.225	5	0.0525	3	0.096		0	3	0.054			
	1st Floor	1st Class	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0			
		2nd CLass	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0			
		Room 1	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0			
		Room 2	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0			
		Room 3	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0			
		Room 4	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0			
		Prefects	0.045	1.2	0.0105	1.2	1	0.045	1	0.0105		0		0		0	1	10	1.2
	Corridor		0.321	0	0.1065	0	5	0.225	5	0.0525	3	0.096		0	3	0.054			
	2nd Floor	Room 1	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0		0		0	2	10	2.4
		Room 2	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0		0		0	2	10	2.4
		Room 3	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0		0		0	2	10	2.4
		Room 4	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0		0		0	2	10	2.4
		Room 5	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0		0		0	2	10	2.4
		Room 6	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0		0		0	2	10	2.4
		Prefects	0.045	1.2	0.0105	1.2	1	0.045	1	0.0105		0		0		0	1	10	1.2
	Corridor		0.321	0	0.1065	0	5	0.225	5	0.0525	3	0.096		0	3	0.054			

Location	AC (1.2 kW) Qty	AC HoU	AC Power	Deskop(0.3 kW) Qty.	Deskop HoU	Deskop Power	Printer (0.5 kW) Qty	Printer HoU	Printer Power	Photocopier (0.5 kW) Qty.	Photocopier HoU	Photocopier Power	TV (0.045 W) Qty	TV HoU	TV Power	Fridge (0.6 kW) Qty.	Fridge HoU	Fridge Power	Fridge Replacement (.4 Qty	Fridge Replacement HoU	Fridge Replacement Power
Exams Office										1	1	0.5									
Asst. Head Acad.				1	8	2.4				1	1	0.5									
Typing Office				2	5	3															
Accounts				3	7	6.3	1	1	0.5							TT			TT		
Headmaster	1	***					1	1	0.5				1	5	0.225	1	24	9.6	1	24	6
General Office				1	***		1	1	0.5				1	7	0.84						
Corridor (Administration)													CRT								
Computer Lab	2	***		23	***		1	1	0.5												

Table E2 (Cont’d)

Science Block	Basment	Chemistry Lab	0.384	2.4	0.216	2.4		0		0	12	0.384		0	12	0.216	4	5	2.4								
		Physics Lab	0.384	2.4	0.216	2.4		0		0	12	0.384		0	12	0.216	4	5	2.4								
	Corridor		0.16	0	0.09	0		0		0	5	0.16		0	5	0.09											
	1st FLoor	2 Agric	0.09	0	0.021	0	2	0.09	2	0.021		0		0		0											
		3 Science	0.36	4.8	0.084	4.8	8	0.36	8	0.084		0		0		0	8	5	4.8								
		Biology Lab	0.36	3.6	0.084	3.6	8	0.36	8	0.084		0		0		0	6	5	3.6								
	Corridor		0.27	0	0.063	0	6	0.27	6	0.063		0		0		0											
								0		0		0		0		0											
	Clinic Block	1st Class	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	2	5	1.2								
		2nd Class	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	2	5	1.2								
		3rd Class	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	2	5	1.2								
		4th Class	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	2	5	1.2								
		Male Ward	0.045	1.2	0.0105	1.2	1	0.045	1	0.0105		0		0		0	2	5	1.2								
		Dispensary	0.045	0.6	0.0105	0.6	1	0.045	1	0.0105		0		0		0	1	5	0.6								
		Female Ward	0.045	1.2	0.0105	1.2	1	0.045	1	0.0105		0		0		0	2	5	1.2								
		Dispensary	0.045	0.6	0.0105	0.6	1	0.045	1	0.0105		0		0		0	1	5	0.6								
								0		0		0		0		0											
		Assembly	0.72	2.52	0.168	2.52	16	0.72	16	0.168		0		0		0	7	3	2.52								
		Dining Hall	0.72	2.52	0.168	2.52	16	0.72	16	0.168		0		0		0	7	3	2.52								
		Choke Lights in Dh	2.4	0	0.6	0	6	2.4	6	0.6		0		0		0											
		Kitchen	0.54	44.64	0.126	44.64	12	0.54	12	0.126		0		0		0	1	12	1.44			3	24	43.2	3	24	28.8
		PREV. GIRLS DORM	0.45	14.4	0.105	14.4	10	0.45	10	0.105		0		0		0	12	10	14.4								
								0		0		0		0		0											
Girls Dormmimtory	House 1	Room 1	0.09	2.4	0.021	2.4	2	0.09	2	0.021		0		0		0	2	10	2.4								
		Room 2	0.09	2.4	0.021	2.4	2	0.09	2	0.021		0		0		0	2	10	2.4								
		Room 3	0.09	2.4	0.021	2.4	2	0.09	2	0.021		0		0		0	2	10	2.4								
		Room 4	0.09	2.4	0.021	2.4	2	0.09	2	0.021		0		0		0	2	10	2.4								
		Room 5	0.09	2.4	0.021	2.4	2	0.09	2	0.021		0		0		0	2	10	2.4								
		Room 6	0.09	2.4	0.021	2.4	2	0.09	2	0.021		0		0		0	2	10	2.4								
	House 2	Room 1	0.09	2.4	0.021	2.4	2	0.09	2	0.021		0		0		0	2	10	2.4								
		Room 2	0.09	2.4	0.021	2.4	2	0.09	2	0.021		0		0		0	2	10	2.4								
		Room 3	0.09	2.4	0.021	2.4	2	0.09	2	0.021		0		0		0	2	10	2.4								
		Room 4	0.09	2.4	0.021	2.4	2	0.09	2	0.021		0		0		0	2	10	2.4								
		Room 5	0.09	2.4	0.021	2.4	2	0.09	2	0.021		0		0		0	2	10	2.4								
		Room 6	0.09	2.4	0.021	2.4	2	0.09	2	0.021		0		0		0	2	10	2.4								
	House 3 & 4	Room 1	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0		0		0	2	10	2.4								
		Room 2	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0		0		0	2	10	2.4								
		Room 3	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0		0		0	2	10	2.4								
		Room 4	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0		0		0	2	10	2.4								
		Room 5	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0		0		0	2	10	2.4								
		Room 6	0.18	2.4	0.042	2.4	4	0.18	4	0.042		0		0		0	2	10	2.4								
									281				70		44		159			3	30						

Table E3 Inventory of Electrical Appliances Collected at Fiaseman Senior High School.

	Location	Total Consumption: Old System – Current Lights	Old System – Others	Replacement – LED	Replacement – Others	CFL Bulbs (0.045 kW) QTY	CFL Power (kW)	LED Replacment QTY	LED Power (kW)	T5 (32 W) QTY	T5 Power (kW)	LED Relacement QTY	LED Power (kW)	Existing LED (18W LED) QTY	Existing LED Power (kW)
Basement	Classroom 1	0.036		0.036			0		0		0		0	2	0.036
	Classroom 2	0.036		0.036			0		0		0		0	2	0.036
	Classroom 3	0.036		0.036			0		0		0		0	2	0.036
	Classroom 4	0.09		0.021		2	0.09	2	0.021		0		0		0
	Classroom 5	0.036		0.036			0		0		0		0	2	0.036
	Classroom 6	0.036		0.036			0		0		0		0	2	0.036
		0		0											
1st Floor	Classroom 6	0.09		0.021		2	0.09	2	0.021		0		0		0
	Classroom 7	0.09		0.021		2	0.09	2	0.021		0		0		0
	Classroom 8	0.09		0.021		2	0.09	2	0.021		0		0		0
	Classroom 9	0.09		0.021		2	0.09	2	0.021		0		0		0
	Classroom 10	0.09		0.021		2	0.09	2	0.021		0		0		0
		0		0			0		0		0		0		0
	Chemistry Lab	0.36		0		8	0.36	8							
	Biology Lab	0.36		0		8	0.36	8							
	Physics Lab	0.36		0		8	0.36	8							
Labs	Home Econs Dept.	0.225		0.0525		5	0.225	5	0.0525		0		0		0
	Clothing Dept.	0.072		0.072			0		0		0		0	4	0.072
	E-Learning	0.072		0.072			0		0		0		0	4	0.072
	Computer Lab	0.334		0.099		6	0.27	6	0.063	2	0.064	2	0.036		0
		0		0											
	CORRIDOR	0		0		6		6							
Classroom Block 2	Classroom 1	0.036		0.036			0		0		0		0	2	0.036
	Classroom 2	0.036		0.036			0		0		0		0	2	0.036
	Classroom 3	0.036		0.036			0		0		0		0	2	0.036
	Classroom 4	0.054		0.054			0		0		0		0	3	0.054
	Store Room	0.045		0.0105		1	0.045	1	0.0105		0		0		0
	Wash Room	0.045		0.0105		1	0.045	1	0.0105		0		0		0
	Administration	0.077		0.0285		1	0.045	1	0.0105	1	0.032	1	0.018		0
	Headmaster	0.09		0.021		2	0.09	2	0.021		0		0		0
	Asst. Head 1	0.045		0.0105		1	0.045	1	0.0105		0		0		0
	Asst. Head 2	0.045		0.0105		1	0.045	1	0.0105		0		0		0
	Conference Room	0.045		0.0105		1	0.045	1	0.0105		0		0		0
	Typing Room	0.018		0.018			0		0		0		0	1	0.018
	Library	0.128		0.072			0		0	4	0.128	4	0.072		0
	Classroom 5	0.036		0.036			0		0		0		0	2	0.036
		0		0			0		0						
Block 3	Classroom 1	0.18		0.042		4	0.18	4	0.042						
	Classroom 2	0.18		0.042		4	0.18	4	0.042						
	Classroom 3	0.18		0.042		4	0.18	4	0.042						
	Classroom 4	0.18		0.042		4	0.18	4	0.042						
	Classroom 5	0.18		0.042		4	0.18	4	0.042						
	Classroom 6	0.18		0.042		4	0.18	4	0.042						
	Classroom 7	0.18		0.042		4	0.18	4	0.042						
		0		0			0		0						
Block 4 Basement	CLASSROOM 1	0.18		0.042		4	0.18	4	0.042					2	
	CLASSROOM 2	0.18		0.042		4	0.18	4	0.042					2	
	CLASSROOM 3	0.18		0.042		4	0.18	4	0.042					2	
	CLASSROOM 4	0.18		0.042		4	0.18	4	0.042					2	
	CLASSROOM 5	0.18		0.042		4	0.18	4	0.042					2	
Block 4 1st Floor	CLASSROOM 1	0.216		0.078		4	0.18	4	0.042		0		0	2	0.036
	CLASSROOM 2	0.216		0.078		4	0.18	4	0.042		0		0	2	0.036
	CLASSROOM 3	0.216		0.078		4	0.18	4	0.042		0		0	2	0.036
	CLASSROOM 4	0.216		0.078		4	0.18	4	0.042		0		0	2	0.036
	CLASSROOM 5	0.216		0.078		4	0.18	4	0.042		0		0	2	0.036
		0		0			0		0		0		0		0
	Kitchen	0.315		0.0735		7	0.315	7	0.0735		0		0		0
		0		0			0		0		0		0		0
	Summer hut	0.135		0.0315		3	0.135	3	0.0315					4	
	Staff Room	0.108		0.108			0		0		0		0	6	0.108
	Dining Hall	0.63		0.147		14	0.63	14	0.147		0		0		0

Location	Fans (0.12 kW) Qty.	Fans HoU	Fans Power	AC (1.2 kW) Qty	AC HoU	AC Power	Deskop(0.3 kW) Qty.	Deskop HoU	Deskop Power	Printer (0.5 kW) Qty	Printer HoU	Printer Power	Photocopier (0.5 kW) Qty.	Photocopier HoU	Photocopier Power	TV (0.045 W) Qty	TV HoU	TV Power	Fridge (0.6 kW) Qty.	Fridge HoU	Fridge Power	Fridge Replacement (.4 W) Qty	Fridge Replacement HoU	Fridge Replacement Power
Chemistry Lab	4	5	2.4																					
Biology Lab	4	5	2.4																					
Physics Lab	4	5	2.4																					
Home Econs Dept.	6	5	3.6																					
Clothing Dept.	6	5	3.6																					
E-Learning	4	5	2.4	1	4	4.8	26	***																
Computer Lab	6	5	3.6										1	1	0.5									
Administration	2	7	1.68																					
Headmaster	2	7	1.68	1	4	4.8	1	10	3										TT			TT		
Asst. Head 1	1	7	0.84				1	5	1.5	1	1	0.5							1	24	6	1	24	6
Asst. Head 2	1	10	1.2																					
Conference Room	2	2	0.48																					
Typing Room	1	3	0.36				2	4	2.4	1	1	0.5												
Library	4	5	2.4																					
Block 3 Classroom 1	2	10	2.4																					
Block 3 Classroom 2	2	10	2.4																					
Block 3 Classroom 3	2	10	2.4																					
Block 3 Classroom 4	2	10	2.4																					
Block 3 Classroom 5	2	10	2.4																					
Block 3 Classroom 6	2	10	2.4																					
Block 3 Classroom 7	2	10	2.4																					
Kitchen	2	13	3.12																3	24	43.2	3	24	28.8
Staff Room	2	5	1.2																					

Table E3 (Cont’d)

Boys Dormitory	Room 1	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 2	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 3	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 4	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 5	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 6	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 7	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 8	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 9	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 10	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 11	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 12	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 13	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	BATHROOM	0.225		0.0525		5	0.225	5	0.0525														
		0		0			0		0														
Old Block	Room 1	0.18		0.042		4	0.18	4	0.042														
	Room 2	0.18		0.042		4	0.18	4	0.042														
	Room 3	0.18		0.042		4	0.18	4	0.042														
	Room 4	0.18		0.042		4	0.18	4	0.042														
	Room 5	0.18		0.042		4	0.18	4	0.042														
	Room 6	0.18		0.042		4	0.18	4	0.042														
	Room 7	0.18		0.042		4	0.18	4	0.042														
	Room 8	0.18		0.042		4	0.18	4	0.042														
	Room 9	0.18		0.042		4	0.18	4	0.042														
	Room 10	0.18		0.042		4	0.18	4	0.042														
	Bathroom	0.225		0.0525		5	0.225	5	0.0525														
New Block	Room 1	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 2	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 3	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 4	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 5	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 6	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 7	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 8	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 9	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Room 10	0.18		0.042		4	0.18	4	0.042	0		0		0	2	10	2.4						
	Bathroom'	0.135		0.0315		3	0.135	3	0.0315	0		0		0									
								298			7		60		111			2	30	2	1	0	4	4

Table E4 Inventory of Electrical Appliances Collected at Tarkwa Senior High School.

	Location	Total Consumption				CFL Bulbs				T5 Lights				Existing LED (18W LED)	
		Old System		Replacement		CFL Bulbs (0.045		LED Replacment		T5 (32 W)		LED Relacement (18			
		Current Lights	Others	LED	Others	QTY	Power (kW)	QTY	Power (kW)	QTY	Power (kW)	QTY	Power (kW)	QTY	Power (kW)
Main Classroom Block 1st Floor	Basmeent	0.27	0	0.063	0	6	0.27	6	0.063		0		0		0
	Classroom 1	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0
	Classroom 2	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0
	Classroom 3	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0
	Classroom 4	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0
	Classroom 5	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0
	Classroom 6	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0
	Chaplaincy Office	0.09	0	0.021	0	2	0.09	2	0.021		0		0		0
		0	0	0	0		0		0		0		0		0
Main Classroom Block 2nd Floor	ICT Lab 1	0.09	22.84	0.021	22.84	2	0.09	2	0.021		0		0		0
	ICT Lab 2	0.09	24.24	0.021	24.24	2	0.09	2	0.021		0		0		0
	Classroom 7	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0
	Classroom 8	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0
	Classroom 9	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0
	Classroom 10	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0
		0	0	0	0		0		0		0		0		0
Main Classroom Bl	Library	0.09	0	0.021	0	2	0.09	2	0.021		0		0		0
	Classrooom 11	0.072	0	0.072	0		0		0		0		0	4	0.072
	Classrooom 12	0.126	0	0.057	0	2	0.09	2	0.021		0		0	2	0.036
	Classrooom 13	0.126	0	0.057	0	2	0.09	2	0.021		0		0	2	0.036
	Classrooom 14	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0
		0	0	0	0		0		0		0		0		0
Mini Clssroom Block	Snr. Hse. Master	0.064	0	0.036	0		0		0	2	0.064	2	0.036		0
	Classroom 1	0.192	1.2	0.108	1.2		0		0	6	0.192	6	0.108		0
	Classroom 2	0.192	1.2	0.108	1.2		0		0	6	0.192	6	0.108		0
	Clinic	0.154	0	0.057	0	2	0.09	2	0.021	2	0.064	2	0.036		0
		0	0	0	0		0		0		0		0		0
Administration	Chemeistry Lab	0.256	3.36	0.144	3.36		0		0	8	0.256	8	0.144		0
	Office	0.032	0.84	0.018	0.84		0		0	1	0.032	1	0.018		0
	House Mistress	0.045	0.84	0.0105	0.84	1	0.045	1	0.0105		0		0		0
	Physics Lab	0.192	6.86	0.108	6.86		0		0	6	0.192	6	0.108		0
	Secretariat	0.09	2.84	0.021	2.84	2	0.09	2	0.021		0		0		0
	Headmaster	0.09	17.88	0.021	17.88	2	0.09	2	0.021		0		0		0
	Asst. Head 1	0.045	2.34	0.0105	2.34	1	0.045	1	0.0105		0		0		0
	Store Room	0.032	0.84	0.018	0.84		0		0	1	0.032	1	0.018		0
	Staff Room	0.218	1.68	0.093	1.68	2	0.09	2	0.021	4	0.128	4	0.072		0
	Washroom	0.045	0	0.0105	0	1	0.045	1	0.0105		0		0		0
	Old Office	0.135	0.84	0.0315	0.84	3	0.135	3	0.0315		0		0		0
	Accountant	0.135	2.94	0.0315	2.94	3	0.135	3	0.0315		0		0		0
		0	0	0	0		0		0		0		0		0
New Block	Classrooms 1	0.072	2.4	0.072	2.4		0		0		0		0	4	0.072
	Classrooms 2	0.072	2.4	0.072	2.4		0		0		0		0	4	0.072
	Classrooms 3	0.072	2.4	0.072	2.4		0		0		0		0	4	0.072
	Classrooms 4	0.072	2.4	0.072	2.4		0		0		0		0	4	0.072
	Classrooms 5	0.072	2.4	0.072	2.4		0		0		0		0	4	0.072
	Classrooms 6	0.072	0	0.072	0		0		0		0		0	4	0.072
	Outside Lighting	0.54	0	0.126	0	12	0.54	12	0.126		0		0		0
		0	0	0	0		0		0		0		0		0
	Entrance	0.36	0	0.084	0	8	0.36	8	0.084		0		0		0
	Kitchen	0.315	28.8	0.0735	28.8	7	0.315	7	0.0735		0		0		0
	Chapel	0.27	0	0.063	0	6	0.27	6	0.063		0		0		0
	Dining Hall	0.54	0	0.126	0	12	0.54	12	0.126		0		0		0

Location	Fans (0.12 kW)			AC (1.2 kW)			Deskop(0.3 kW)			Printer (0.5 kW)			Photocopier (0.5 kW)			TV (0.045 W)			Fridge (0.6 kW)			Fridge Replacement (.4 W)		
	Qty.	HoU	Power	Qty	HoU	Power	Qty.	HoU	Power	Qty	HoU	Power	Qty.	HoU	Power	Qty	HoU	Power	Qty.	HoU	Power	Qty	HoU	Power
Basmeent																								
Classroom 1																								
Classroom 2																								
Classroom 3																								
Classroom 4																								
Classroom 5																								
Classroom 6																								
Chaplaincy Office																								
ICT Lab 1	6	2	1.44	2	2	4.8	13	4	15.6				2	1	1									
ICT Lab 2	6	2	1.44	2	2	4.8	15	4	18															
Classroom 7									0															
Classroom 8									0															
Classroom 9									0															
Classroom 10									0															
									0															
Library									0															
Classrooom 11									0															
Classrooom 12									0															
Classrooom 13									0															
Classrooom 14									0															
									0															
Snr. Hse. Master									0															
Classroom 1	2	5	1.2						0															
Classroom 2	2	5	1.2						0															
Clinic									0															
									0															
Chemeistry Lab	4	7	3.36						0															
Office	1	7	0.84						0															
House Mistress	1	7	0.84						0															
Physics Lab	4	7	3.36				1	10	3	1	1	0.5												
Secretariat	1	7	0.84				1	5	1.5	1	1	0.5							TT					
Headmaster	2	7	1.68	1	5	6	1	10	3										1	24	7.2			
Asst. Head 1	1	7	0.84				1	5	1.5															
Store Room	1	7	0.84																					
Staff Room	2	7	1.68																					
Washroom																								
Old Office	1	7	0.84																					
Accountant	1	7	0.84				1	7	2.1															
Classrooms 1	2	10	2.4																					
Classrooms 2	2	10	2.4																					
Classrooms 3	2	10	2.4																					
Classrooms 4	2	10	2.4																					
Classrooms 5	2	10	2.4																					
Classrooms 6																								
Outside Lighting																								
Entrance																								
Kitchen																					4	24	28.8			
Chapel																								
Dining Hall																								

Table E4 (Cont’d)

Boys Dormitory	Room 1	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 2	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 3	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 4	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 5	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 6	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 7	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 8	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Prefects Room 1	0.09	1.2	0.021	1.2	2	0.09	2	0.021		0		0		0	1	10	1.2																			
	Prefects Room 2	0.09	1.2	0.021	1.2	2	0.09	2	0.021		0		0		0	1	10	1.2																			
	KVIP Toilets	0.045	0	0.0105	0	1	0.045	1	0.0105		0		0		0																						
	Bathroom	0.09	0	0.021	0	2	0.09	2	0.021		0		0		0																						
	Corridor	0.36	0	0.084	0	8	0.36	8	0.084		0		0		0																						
	Compund Lights	0.36	0	0.084	0	8	0.36	8	0.084		0		0		0																						
		0	0	0	0		0		0		0		0		0																						
	3 Cubicles Washroom	0.225	0	0.0525	0	5	0.225	5	0.0525		0		0		0																						
		0	0	0	0		0		0		0		0		0																						
	Corridors	0.36	0	0.084	0	8	0.36	8	0.084		0		0		0																						
	Room 1	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 2	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 3	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 4	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 5	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 6	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 7	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 8	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	1	10	1.2																			
	Prefects Room	0.045	1.2	0.0105	1.2	1	0.045	1	0.0105		0		0		0	1	10	1.2																			
	Bathroom	0.09	0	0.021	0	2	0.09	2	0.021		0		0		0																						
	KVIP	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0																						
	Washroom	0.27	0	0.063	0	6	0.27	6	0.063		0		0		0																						
		0	0	0	0																																
Girls Dormitory 1	Corridors	0.36	0	0.084	0	8	0.36	8	0.084		0		0		0																						
	Room 1	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 2	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 3	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 4	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 5	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 6	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	1	10	1.2																			
	Room 7	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 8	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	1	10	1.2																			
	Prefects Room	0.045	1.2	0.0105	1.2	1	0.045	1	0.0105		0		0		0	1	10	1.2																			
	Sockets	0	0	0	0		0		0		0		0		0																						
	Bathroom	0.09	0	0.021	0	2	0.09	2	0.021		0		0		0																						
	Washroom	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0																						
	Washroom	0.27	0	0.063	0	6	0.27	6	0.063		0		0		0																						
		0	0	0	0																																
Girls Dormitory 2	Corridors	0.36	0	0.084	0	8	0.36	8	0.084		0		0		0																						
	Room 1	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 2	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	1	10	1.2																			
	Room 3	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 4	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 5	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	1	10	1.2																			
	Room 6	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	1	10	1.2																			
	Room 7	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 8	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	1	10	1.2																			
	Prefects Room	0.045	1.2	0.0105	1.2	1	0.045	1	0.0105		0		0		0	1	10	1.2																			
	Sockests	0	0	0	0		0		0		0		0		0																						
	Bathroom	0.09	0	0.021	0	2	0.09	2	0.021		0		0		0																						
	KVIP	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0																						
	Washroom	0.27	0	0.063	0	6	0.27	6	0.063		0		0		0																						
		0	0	0	0																																
Girls Dormitory 3	Corridors	0.36	0	0.084	0	8	0.36	8	0.084		0		0		0																						
	Room 1	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 2	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 3	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 4	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	1	10	1.2																			
	Room 5	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 6	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	1	10	1.2																			
	Room 7	0.135	1.2	0.0315	1.2	3	0.135	3	0.0315		0		0		0	1	10	1.2																			
	Room 8	0.18	1.2	0.042	1.2	4	0.18	4	0.042		0		0		0	1	10	1.2																			
	Prefects Room	0.045	1.2	0.0105	1.2	1	0.045	1	0.0105		0		0		0	1	10	1.2																			
	Sockests	0	0	0	0		0		0		0		0		0																						
	Bathroom	0.09	0	0.021	0	2	0.09	2	0.021		0		0		0																						
	KVIP	0.18	0	0.042	0	4	0.18	4	0.042		0		0		0																						
	Washroom	0.27	0	0.063	0	6	0.27	6	0.063		0		0		0																						
	TOTALS	0		0																																	
								366				36		32	0.576	91	601	88.44	5			33			2			2			0			5			0	

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