ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
Electrical & Computer Engineering Department
Power Engineering Stream

Energy Conserving Electrical System Design and Performance Analysis for Commercial Buildings in Addis Ababa

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(Power Engineering)

By
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DECLARATION

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been acknowledged.

All examiners' comments are duly incorporated.

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Signature: __________________

Place: Addis Ababa

Date of submission: _________________

This thesis has been submitted for examination with my approval as a university advisor.

Dr. Getachew Bekele

Advisor's Name	Signature

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Bezawit Teshome

ABSTRACT

The electrical energy demand growth in Ethiopia has been enormous in the past few years as a result of economic development. This sharp increase in demand is expected to continue in the years to come. Therefore, in the face of increasing demand for electric energy in all sectors and the limited generation capacity problem, energy conservation has to be considered at the demand side as one of the major options to achieve a sustainable power supply system.

Next to the domestic sector, the second most energy consuming sector in Ethiopia is the commercial sector. Hence, to succeed in reducing energy consumption and in developing a sustainable energy structure, the buildings in this sector need to consider integrating sustainable energy and energy conserving strategies into their design.

This thesis work investigates the potentials for energy conservation in the commercial building sector of Addis Ababa, Ethiopia. The objective of the study is to identify and suggest the energy conserving design strategies that can reduce energy consumption of a building beyond conventional practice, making it more energy efficient and self-sufficient, with respect to its power demand. This is done by selecting best available design concepts and technologies related to energy efficiency and renewable energy resource utilization, which can be implemented for commercial buildings in Addis Ababa. Case studies are carried out on two typical commercial buildings located in the city in order to evaluate the energy consumption of conventional buildings and to select the appropriate energy conservation measures that can be taken. An energy conserving electrical system is then proposed for these two sample buildings. Annual energy saving analysis is done by comparing the energy consumption of the base case and the proposed case systems. The economical aspect of the energy conserving electrical design is also studied through the life time cost analysis. RETScreen is used as an evaluation tool in order to demonstrate the application of the strategies and to what extent it can make an impact on the energy consumption of the buildings. The thesis presents the methodology followed to design the proposed system. It also discusses the result of the annual energy saving and the life time cost analysis. Finally, based on the result of the work, suggestions are made on strategies that could help to realize energy-saving potentials, promote energy conservation, and thereby enhance energy sustainability in the nation's commercial building sector.

Key words: Energy Conservation, Energy Efficiency, Renewable Energy, Commercial Buildings, RETScreen

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

NOMENCLATURE

a	Regression coefficient
A	Ampere
AA	Addis Ababa
AC	Alternating Current
asl	Above Sea Level
b	Regression coefficient
BGH	Beer Garden Hotel
CFL	Compact Fluorescent Lamp
COE	Cost of Energy ($/kWh)
DC	Direct Current
DOD	Depth of discharge, maximum permissible depth of discharge of the battery
ECBC	Energy Conservation Building Code
ECD	Energy Conserving Design
ECS	Energy Conserving System
EED	Energy Efficient Design
EES	Energy Efficient System
EEPCo	Ethiopian Electric Power Corporation
E_L	Average daily load demand
g	Gravitational acceleration (i.e. $9.81 m/s^2$)
G_{av}	Average solar energy input per day
GDP	Gross Domestic Product
G_{on}	Extraterrestrial irradiance at normal incidence
G_{sc}	The solar constant (i.e. $1367 W/m^2$)
H	Monthly average daily global solar radiation on horizontal surface
H_0	Monthly average daily extraterrestrial solar radiation on a horizontal surface
HV	High Voltage
I	Current
ICS	Interconnected System
I_p	Current at $P_{max,}$ Maximum power current
Isc	Short-circuit current
kV	Kilovolt

kW	Kilowatt
kWh	Kilowatt hour
LTC	Life Time Cost
LTCA	Life Time Cost Analysis
LV	Low Voltage
n	Monthly average daily number of hours of bright sunshine
NASA	National Aeronautics and Space Administration
NC	Largest number of continuous cloudy days of the site
NMA	National Meteorological Agency
N	Number of daylight hours (daily hours of sunshine)
N_p	Number of modules connected in parallel, strings
N_s	Number of modules connected in series
P_{max}	Maximum Power
PSI	Peak Solar Irradiance
PV	Photovoltaic
RETScreen	Renewable Energy and Energy Efficient Technologies
SCS	Self-Contained System
TCF	Temperature Correction Factor
V_{DC}	DC Bus Voltage
V_p	Voltage at P_{max}, Maximum power voltage
YHSM	Yerga Haile Shopping Mall
YHSM1	Yerga Haile Shopping Mall - Phase 1
YHSM2	Yerga Haile Shopping Mall - Phase 2
δ	Declination angle (^{0})
ϕ	Latitude (^{0}) of an area
η	Efficiency
η_B	Battery Efficiency
η_{Inv}	Inverter Efficiency
η_{out}	Overall efficiency of the power conditioning equipment
η_{PV}	PV Efficiency
ω_s	The sunset hour angle (^{0})

CHAPTER 1
INTRODUCTION

1.1. Background

There is a huge potential for a successful use of renewable energy in Ethiopia. The sun is strong, a lot of water runs down from the highlands and several hot springs can be found easily in the giant African Rift Valley [1]. There is an immense renewable energy resource in the forms of hydropower, solar, and wind, as well as significantly untapped geothermal resources. Studies conducted indicate that Ethiopia can harvest around 60,000 MW of clean energy only from its geothermal, wind and hydropower sources [2]. It is indicated that 45,000 MW of power can be generated from hydroelectric power [3], 10,000 MW from wind energy sources [4] and around 5,000 MW from geothermal energy [5]. Located very close to the equator; between 30 and 150 degrees north; Ethiopia also enjoys abundant solar energy potential with an average solar radiation of around 5.26kWh/m^2. The values vary seasonally, from a minimum of 4.55kWh/m^2 in July to a maximum of 5.55kWh/m^2 in February and March. With location, the radiation varies even more widely between 4.25kWh/m^2 in extreme western lowland and 6.25kWh/m^2 in the Tigray regional state (northern Ethiopia) [4].

The sole power provider company in Ethiopia, Ethiopian Electric Power Corporation (EEPCo) has two electric energy supply systems. These are the Interconnected System (ICS) and the Self Contained System (SCS) [2]. The generation capacity of the power plants which are part of these two systems in the country is provided in appendix A [6]. As its main energy source, the ICS has hydro, geothermal and diesel power plants with a total capacity of 1962.2MW and the SCS has mini hydropower plants and diesel power generators allocated in various areas of the country with a total capacity of 36.67MW. Overall, the country currently has a capacity of generating 1998.87MW of electrical power [6]. As can be seen from the pie chart given below, fossil fuels account for 7.15% of the electrical power production while geothermal and hydropower plants take 0.37% and 92.49% share respectively.

Table 1.1: Installed power generation capacity in Ethiopia (MW) [6]

Source	Hydro	Diesel	Geothermal	Total
ICS	1842.6	112.3	7.3	1962.2
SCS	6.15	30.52		36.67
Total	1848.75	142.82	7.3	1998.87

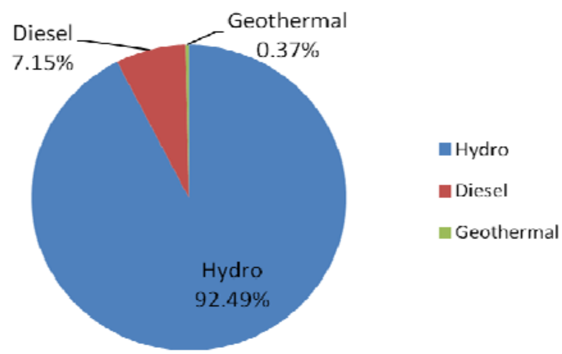

Figure 1.1: Share of installed power generation systems in Ethiopia

For the year 2010/11, the total energy production from the ICS and SCS was 4,954GWh and 26GWh respectively giving a total of 4,980GWh, out of which, 4,931GWh was from hydro, 31GWh from diesel and 18GWh was from geothermal power plants [6]. The energy production by source and system for the last 5 years is presented in the following table.

Table 1.2: Energy production by source and system (GWh) [6]

System	Source	2006/2007	2007/2008	2008/2009	2009/2010	2010/2011
ICS	**Hydro**	3260	3369	3277	3504	4922
	Diesel	10	133	381	418	14
	Geothermal	0	0	7	24	18
	Total	**3270**	**3502**	**3665**	**3946**	**4954**
SCS	**Hydro**	21	16	8	20	9
	Diesel	30	29	28	26	17
	Geothermal	0	0	0	0	0
	Total	**51**	**45**	**36**	**46**	**26**
Total	**Hydro**	3281	3385	3285	3524	4931
	Diesel	40	162	409	444	31
	Geothermal	0	0	7	24	18
	Total	**3321**	**3547**	**3701**	**3992**	**4980**

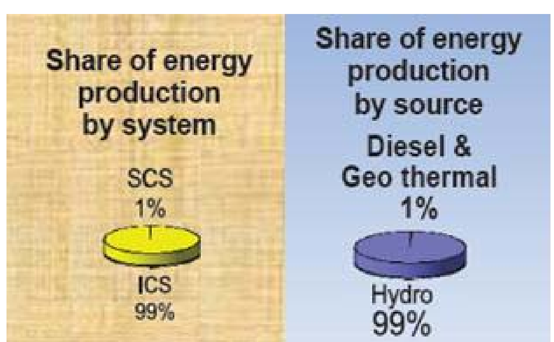

Figure 1.2: Share of energy production in Ethiopia [6]

The national power provider company, EEPCo, categorizes national energy use in five broad sectors: domestic/residential, commercial, street light, industrial LV and industrial HV [6]. The number of customers connected to the grid under these five sectors for the last five consecutive years is provided in the table below.

Table 1.3: Number of customers connected to the national grid [6]

Tariff	2006/2007	2007/2008	2008/2009	2009/2010	2010/2011
Domestic	1,207,894	1,441,304	1,576,964	1,649,062	1,652,310
Commercial	167,654	207,986	222,698	222,308	222,746
Street Light	3,056	3,060	3,260	2,690	2,695
Industrial LV	15,603	22,908	24,997	20,160	20,199
Industrial HV	196	242	216	149	149
Own Consumption	1,689	1,834	1,916	1,896	1,900
Total	**1,396,092**	**1,677,334**	**1,830,051**	**1,896,265**	**1,899,999**

The total number of customers connected to the national grid in the year 2010/2011 was 1,899,999 where the number of customers connected in the ICS and SCS was 1,811,569 and 88,431 respectively. For that same year, 222,746 of the connected customers were from the commercial sector which is around 11.72% of the total 1,899,999 customers [6].

Table 1.4: Percentage of the connected commercial customers

Year	Commercial	Total	Percentage (%)
2006/2007	167,654	1,396,092	12.01
2007/2008	207,986	1,677,334	12.40
2008/2009	222,698	1,830,051	12.17
2009/2010	222,308	1,896,265	11.72
2010/2011	222,746	1,899,999	11.72

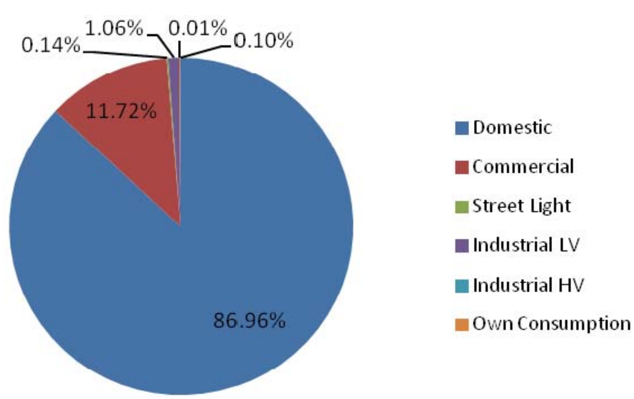

Figure 1.3: Share of sectors connected to the national grid in 2010/11

Total energy sale in the year 2010/2011 was 3,844.87GWh. In that same year, energy usage of the commercial sector was 940.33GWh which is about 24.46% of the total energy consumption. Energy usage in residential sectors, which was about 38.29% of the total energy consumption in 2010/2011, is largely controlled by individual consumers while commercial and industrial energy expenditures are determined by businesses entities and other facility managers [6].

Table 1.5: Total energy sale (GWh) [6]

Tariff	2006/2007	2007/2008	2008/2009	2009/2010	2010/2011
Domestic	1,060.31	1,029.32	1,178.10	1,190.84	1,472.25
Commercial	703.44	732.05	737.48	813.39	940.33
Street Light	48.83	42.22	22.93	26.37	29.54
Industrial LV	524.79	608.26	612.91	713.13	794.50
Industrial HV	453.04	531.39	575.03	509.56	600.66
Own Consumption	8.60	22.77	4.81	11.12	7.59
Total	**2,799.01**	**2,966.01**	**3,131.26**	**3,264.41**	**3,844.87**

Table 1.6: Percentage of energy sale to commercial customers

Year	Commercial (GWh)	Total	Percentage (%)
2006/2007	703.44	2,799.01	25.13
2007/2008	732.05	2,966.01	24.68
2008/2009	737.48	3,131.26	23.55
2009/2010	813.39	3,264.41	24.92
2010/2011	940.33	3,844.87	24.46

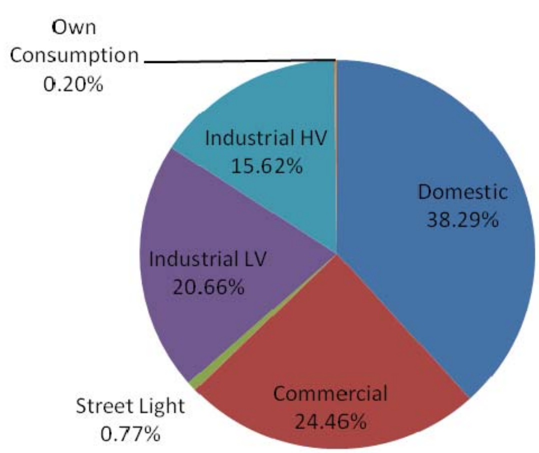

Figure 1.4: Share of energy sale between connected sectors in 2010/11

The most determinant factor of electrical energy demand growth of the connected consumers in a country is economic growth or GDP. Analysis done for Ethiopia on historical sales and GDP data for the period 1973 - 2007 revealed that the electricity demand has an elasticity of 2.15 to changes in the overall GDP. EEPCo, in its strategic plan, considers this GDP elasticity of electricity demand of 2.15 and economic growth rate of 7- 10%. Based on this elasticity estimate, if an economic growth rate of 7-10% can be achieved in the coming years, it could be translated to an electric energy demand growth rate of about 14-17% [3, 7].

In the last three consecutive years, a GDP growth of more than 10% has been achieved as a result of the recent good economic performance of the country. For the coming years, the growth is also assumed to be comparable as Ethiopia's Growth and Transformation Plan (GTP) envisages an average annual economic growth of 11 to 14.9%. This 14.9% economic growth may constitute 32% growth rate in electricity demand [3]. For instance, only on the last year about 24% increase in energy demand has been observed in Ethiopia as a result of 11% economic development [3, 7]. Consequently, there has been a common situation of limited expansion of power generation capacity facing a continuously growing energy demand for the last few years and this growth in demand is expected to continue in the years to come.

Even though potentials for a successful use of renewable energy in Ethiopia are obvious, EEPCo generates only 1998.87MW of electrical power mostly from hydro power plants and few diesel power generators, geothermal plants and mini hydros [6] (see appendix A). In order to meet the increasing energy demand, there is an aim at raising the installed power generation capacity by expanding the system. In compliance with prescribed reliability and system reserve criteria, an updated schedule for implementation of new generating plants and transmission additions is designed by EEPCo, in order to meet the projected energy demand. The generation development plan consists mainly of hydro projects. In addition, generation from wind and geothermal power plants are foreseen to compliment the hydro [7].

Another effective way of offsetting the effect of limited generation and transmission capacities is to reduce the gap between system generation and load as much as possible. This can be achieved through the implementation of well-designed energy conservation strategies, which can serve both the consumer and the power providing company. Therefore, in parallel with the generation system expansion in Ethiopia, energy conserving concepts must also be considered at the demand side of the network in order to cope with the situation of limited addition of generation capacity facing a continuously growing energy demand.

1.2. Statement of the Problem

As discussed in the previous subsection, the electrical energy demand growth in Ethiopia has been enormous in the past few years as a result of economic development and this sharp increase in demand is expected to continue in the years to come. Therefore, in order to reduce the gap between the continuously increasing demand for electric energy in all sectors and the limited generation capacity, energy conservation has to be considered at the demand side as one of the major options to achieve a sustainable power supply system in the country.

Next to the domestic sector, the second most energy consuming sector in Ethiopia is the commercial sector. Even though the commercial buildings in this sector are designed to respond to social and/or business needs of the society and inevitably have social and economic values, at the same time, their operation accounts for around 25% of the total energy consumption in Ethiopia, which is a significant portion of the nation's energy use. For instance, total energy sale in the year 2010/2011 was 3,844.87GWh and energy usage of the commercial sector was 940.33GWh which is about 24.46% of the total energy consumption [6]. In addition to this, the commercial sector is expected to be the most important electricity consumer in 2030 taking 42% of the estimated total sales [8].

Despite these facts, almost none of the commercial buildings in Ethiopia have a design that considered any kind of energy efficiency mechanism. On top of this, these buildings are totally dependent on the energy supply from the national grid except for their installed back up diesel generators. But the fact is, by following an energy conserving design process; it is possible to produce commercial buildings that use substantially less energy without compromising occupants comfort or the building's functionality. This will help in reducing the overall energy demand of the connected customers and in turn will assist in improving the electric energy access of the nation. In addition to that, the implementation of onsite power generation systems from renewable energy resources is a commitment towards preserving the environment as it makes the buildings more environmental friendly.

1.3. Objectives

The following are the objectives of this thesis work:

General objective

- To study where, when and how energy can be conserved in commercial building sector of Addis Ababa, Ethiopia and evaluate the potential for energy conservation by designing an energy efficient electrical system and onsite clean power generation system for these buildings and then by analyzing the annual energy and cost saving that can be achieved through the implementation of the proposed design strategies

Specific objectives

- To carry out case studies on sample buildings from two sectors of commercial buildings (hotel and mixed use) located in Addis Ababa, Ethiopia, by analyzing the gathered data and then creating the load profile of the buildings to demonstrate current electrical design practices in the city
- To evaluate the energy consumption of the conventional commercial buildings constructed, to assess the potential for energy saving and to select the appropriate energy conservation measures that can be implemented
- To present potential energy conserving commercial building design strategies that produce energy and cost savings over the life time of buildings
- To select and propose most energy conserving ways to design the electrical system of the sample commercial buildings using energy efficient design and renewable energy system
- To evaluate the proposed energy conserving design and present its potential energy saving through the annual energy saving analysis
- To evaluate the economical aspect and financial feasibility of the proposed energy conserving design by carrying out its life time cost analysis
- To provide a study that can be used as an input for developing and implementing national laws and energy conserving building codes that promote the development of efficient uses of energy and the use of renewable energy at the consumer level in the city of Addis Ababa

- To direct commercial building design and construction process in order to prioritize energy sustainability and guarantee a commitment to energy saving building principles
- To reinforce the commitment of commercial building owners and investors to involve in energy conservation
- To encourage the use of renewable energy technologies by consumers

1.4. Scope

In the commercial sector of Ethiopia, there is a need for increased awareness about the available energy conserving technologies, optimum mix of energy conserving strategies and their impact on the potential energy saving that can be achieved through the implementation of these measures. This thesis work of energy conserving building electrical design strives to present and justify the practices which can be used relative to energy conservation and sustainability. Case studies are carried out in specific sectors of commercial buildings by going through the electrical design and operational data of the selected sample buildings. To look in to all commercial building design process in detail and gather the proper data for all type of commercial buildings needs longer time and resource. So in order to be thorough in the research on time, this work focuses on two typical commercial buildings; hotel and mixed use building; in the urban setting of Ethiopia, Addis Ababa.

The case study provides insights into current electrical design practices in commercial buildings and highlights the level of implementation of energy conservation measures. This study demonstrates the base case energy consumption of the buildings and specifies in which areas of functions that energy demand reduction can be achieved in these buildings including the approach that can be taken to attain a better outcome.

In this thesis work, the key factors associated with the successful achievement of low energy building design are identified and formulated into a methodology. The work also prioritizes energy sustainability and guarantees a commitment to energy saving building principles in the selected sectors of commercial building. It describes most efficient and energy saving ways to design the electrical system of commercial buildings. Design evaluation is done to indicate the opportunity for strategies that can reduce energy consumption beyond conventional practice. Detailed energy analysis and discussions is also carried out to evaluate the impact of the selected energy conserving design measures for the commercial buildings.

Overall, this work provides the necessary information for implementation of an energy conserving building electrical system design. It presents a clear and comprehensive listing of potential energy saving strategies for the design of commercial buildings that could allow them to produce energy and cost savings over their life time. Therefore all investors that are planning to construct commercial buildings in Addis Ababa and also those who have already constructed one should consider the recommendations. Implementation of this work will not only save energy cost of the buildings for their life time but it will also have a huge support for the improvement of the electric energy access of the nation. Therefore, the whole nation could benefit from the application of this work.

1.5. Approach / Methodology

The key factors as well as the special requirements associated with the successful achievement of the process of energy conserving electrical design and analysis for commercial buildings are identified and formulated into a methodology. To provide high-level consideration to these key factors the methodology has been developed in the form of a step-by-step process to guide the design and analysis process. The descriptions of these process steps that provided the basis for a detailed study development are presented in this subsection. It presents the methodology followed and analytical tools that are employed throughout the study in order to realize the objectives of the thesis work.

- **Literature review and scientific research:** Books, articles, publications, simulation tools and other resources related to the thesis topic have been reviewed in order to perform this work and to be able to meet the objectives of the study.
- **Selection of sample buildings:** Two sample buildings were selected from the two commercial sectors (hotel and mixed use) of Addis Ababa, Ethiopia, to perform a case study. In choosing the sample buildings, due attention was given to identify which specific sector of the commercial building industry will most likely implement energy conserving strategies.

- **Data collection and analysis:** All the data necessary to conduct the study have been gathered through site visits, interviews, design and historical document collection. In addition to the data extracted from the design and historical documents, observations were made during the site visit and information was obtained from the interviews made with the selected buildings managers and technicians.
- **Sample case study**: Case studies are carried out to demonstrate current electrical design practices in the selected specific sectors of commercial buildings (hotel and mixed use). The data collected from the existing sample buildings is organized and manipulated by using excel spreadsheet in order to create their base case load profile. It was then analyzed to assess the potential of energy conservation and for the selection of appropriate energy conserving strategies.
- **System design**: Based on the base case load profile of the buildings, appropriate and most practical energy conserving design strategies are selected. By using the selected techniques and technologies, the base case electrical systems of the buildings were redesigned and new energy conserving electrical systems were proposed. The design was performed by considering both energy efficiency and onsite generation of power using renewable energy technologies. This work has looked into a wide range of possible influences on the energy consumption to build up a realistic profile. Excel spreadsheet is used to organize and manipulate the proposed case design data and to calculate the required inputs to RETScreen software for further analysis.
- **Saving analysis and interpretation of results**: In this thesis, by considering the user friendly interface and suitability of its tools with the study, RETScreen (Renewable-energy and Energy-efficient Technologies) Clean Energy Project Analysis Software is used to evaluate the energy consumption, and the annual energy savings of the proposed energy conserving electrical systems. The annual energy saving analysis is carried out to demonstrate the impact of the selected energy efficient and renewable energy systems on the energy use of the buildings, by comparing the energy consumption of the base case and proposed case systems. The result of the analysis summarizes the energy saved, which is the difference between the base case and the proposed case energy use, in energy unit (kWh) and also the difference as a percentage of the base case energy use (energy saved in %).

- **Life time cost analysis:** Life time cost analysis of the proposed energy conserving systems was performed by using RETScreen in order to evaluate its economical aspect and financial feasibility. The incremental initial cost and the annual cost saving associated with the implementation of the energy efficient and renewable energy technologies are considered in the analysis aiming to identify the pay-back periods of the systems.

In the proceeding chapters the above flow is exemplified through the application of the methodology to the case studies.

1.6. Organization of the Thesis

The first chapter of this thesis is an introduction presenting the background of the study, the problem to be addressed, the objectives, scope, methodology followed and organization of the thesis. This is followed by a literature review that covers/reviews topics related to this study. It provides an overview of the electrical energy use in the world and also in Ethiopia. It also presents the energy conserving strategies and technologies that are being applied for buildings around the world including the related theories. The third chapter discusses the case study carried out on the two selected buildings by going through all the collected and analyzed data and information. It also includes the solar energy resource assessment and solar radiation calculation for the city of Addis Ababa, the result of which is used in chapter 4 as an input to design the onsite power generation system for the selected buildings. Chapter four presents the energy conserving design, modeling and simulation for the selected sample commercial buildings. It also presents the annual energy saving analysis which indicates the potential saving that can be achieved by the implementation of the energy conserving design. Chapter five covers the life time cost analysis that evaluates the economical aspect and the financial feasibility of the proposed energy conserving design. The sixth and last chapter provides the conclusion of the study and some related recommendations. The thesis also includes data related to the study, attached as appendixes to be referred whenever more information and detailed data are found to be necessary. The attachments include generation capacity of power plants in Ethiopia, proposed energy conserving systems software analysis results and also incremental cost of the proposed energy conserving system components.

CHAPTER 2
LITERATURE REVIEW

Considerable efforts have been expended in developing techniques and criteria for energy conserving building electrical system design. Researches on energy conservation approaches, strategies, techniques and implementations have been documented in many publications. In the process of carrying out this thesis work, many related literatures including papers, guidelines, books, journals and those found on different websites have been reviewed and appropriate strategies and methodologies were adopted. The notes under this chapter are taken from these sources. The chapter covers topics related to the study and presents an overview of the energy conserving strategies and technologies that are being applied for buildings around the world including the concept of energy efficiency measures and appropriate renewable energy technologies. It also provides some related theories and calculation methods.

2.1. Energy Security Systems

Energy is an overwhelming need of any society. It plays an important role in the national security of any given country as a fuel to power the economic engine. However, the uneven distribution of energy supplies among countries has led to significant vulnerabilities and as a scarce resource it has been an underlying cause of political conflicts and wars. Energy security is a term for an association between national security and the availability of natural energy resources. It refers to the uninterrupted availability of energy sources at an affordable price. Long-term energy security is linked to timely investments to supply energy in line with economic developments and environmental needs. On the other hand, short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance. Currently, long term measures are being considered in the world to increase energy security by reducing dependence on any one source of imported energy, exploiting native fossil fuel or renewable energy resources, increasing the number of suppliers, and reducing overall demand through energy conservation measures. In addition to the security problem, the gathering and use of energy resources can also be harmful to local ecosystems and may have global outcomes. When producing electrical energy from the conventional energy resources through the traditional processes, the greenhouse gases leak into the atmosphere, which are very harmful to the environment. With these concerns countries have been researching new methods of creating electricity in a clean way [9, 10].

2.1.1. Sustainable Energy

Sustainable/green energy is energy that can be extracted, generated, and/or consumed without any significant negative impact to the environment. It is the provision of energy that meets the needs of the present without compromising the ability of future generations to meet their needs. Sustainable energy sources include all renewable energy sources, such as hydroelectricity, solar energy, wind energy, wave power, geothermal energy, bioenergy, and tidal power. It also includes technologies designed to improve energy efficiency. Therefore, energy efficiency and renewable energy are said to be the twin pillars of sustainable energy policy. Both strategies must be developed concurrently in order to stabilize and reduce carbon dioxide emissions. Efficient energy use is essential for slowing the energy demand growth so that rising clean energy supplies can make deep cuts in fossil fuel use. If energy use grows too rapidly, renewable energy development will chase a receding target. Likewise, unless clean energy supplies come online rapidly, slowing demand growth will only begin to reduce total carbon emissions; a reduction in the carbon content of energy sources is also needed. A sustainable energy thus requires commitments to both efficiency and renewables [9, 10].

2.1.2. Energy Conservation

Energy conservation means using less energy in a particular application and finding ways to purchase particular forms of energy at lower cost. It can be achieved through increased efficient energy use, along with decreased energy consumption from conventional energy sources. It could involve efforts made to reduce energy consumption and shifting to different energy sources of lower price and using renewable energy sources. Energy conservation is broader than energy efficiency in including active efforts to decrease energy consumption in addition to using energy more efficiently. It also facilitates the replacement of non-renewable resources with renewable energy [9, 11].

Individuals and organizations that are direct consumers of energy choose to conserve energy to reduce energy costs and promote economic security. Industrial and commercial users can also conserve energy in order to maximize profit. In addition to these reasons, as the continued reliance on and depletion of fossil-fuel resources threatens global energy security, energy conservation can play an important part in lessening climate change through reduction of emissions. Therefore, it is found to be the most economical solution to energy shortages, and a more environmentally safe alternative to increased energy production. It can result in national security, environmental quality, and human comfort [9, 11].

2.1.3. Energy Efficiency

Efficient energy use, or simply called energy efficiency, is the goal of efforts made to reduce the amount of energy required to provide products and to attain the same level of services. Improvements in energy efficiency are most often achieved by adopting a more efficient technology or production process. Reducing energy use reduces energy costs and may result in a financial cost saving to consumers if the energy savings offset any additional costs of implementing an energy efficient technology. Energy efficiency is also seen to have a national security benefit because it can be used to reduce the level of energy imports from foreign countries and may slow down the rate at which domestic energy resources are depleted. As more electricity is used, fossil-fueled power plants not only generate more electricity, but also more pollution. Therefore reducing energy use is also seen as a key solution to the problem of reducing emissions [9, 10].

2.2. Energy and Buildings

In architecture, engineering, and construction technology, the word building refers to any human-made structure used or intended for supporting or sheltering any use or continuous occupancy. Buildings serve several needs of society, primarily as shelter from weather and as general space to provide privacy, to store belongings and to comfortably live and work. Buildings come in a wide amount of shapes and functions, and have been adapted throughout history for a wide number of factors, from building materials available, to weather conditions, to specific uses and aesthetic reasons. And ever since the first cave paintings, buildings have become objects of artistic expressions. In recent years, interest in sustainable planning and practices has also become part of the design process of many new buildings. This is one part of the sustainable development concept which can be traced to the fossil fuel crisis and the environment pollution concern in the 1970s [9, 12].

2.2.1. Green Building

Green building design is a design that engages environmental considerations and brings together a vast array of practices and techniques to reduce or ultimately eliminate the impacts of new buildings on the environment and human health. In addition to minimizing environmental impact, these buildings also referred to as "sustainable", produce cost savings over their life time. The green building movement originated from the need for more energy efficient and environmental friendly construction practices and motives to building green, for its environmental, economic, and social benefits. While the practices or technologies, employed in green building are constantly evolving and may differ from region to region, there are fundamental principles that persist from which the method is derived: Siting and Structure Design Efficiency, **Energy Efficiency**, Water Efficiency, Materials Efficiency, Indoor Environmental Quality Enhancement, Operations and Maintenance Optimization, and Waste and Toxics Reduction. The essence of green building is an optimization of one or more of these principles. There are several key steps in designing sustainable buildings: specify 'green' building materials, reduce loads, optimize systems, and generate on-site renewable energy [9, 10].

2.2.2. Energy Conserving Building

By following a careful design process, it is possible to produce buildings that use substantially less energy without compromising occupant's comfort or the building’s functionality [12]. A low-energy or energy conserving building is a type of building that from design, technologies and building products uses less energy, from any source, than a traditional one. The cost of energy efficient building is generally higher due to the extra costs associated with improved building components. But in low energy buildings, as much as 80% of the operational costs can be saved through integrated design solutions. So far, around 20,000 low energy houses have been built in Europe of which approximately 17,000 in Germany and Austria alone [13].

Beyond low-energy buildings are those that use no imported energy, zero-energy buildings or even those that generate surplus, energy-plus houses. This can be achieved by a mixture of energy efficiency technologies and the use of renewable energy resources [13].

2.2.3. Importance of Building Energy Conservation

Energy use has recently become a major issue because of growing concern about the scarceness of fossil fuels and the effect of greenhouse gas emissions. Therefore, efficient use of energy is important since global energy resources are finite and power generation using fossil fuels has adverse environmental effects. With supply of fossil fuel falling and concerns for energy supply security increasing, it is essential to find ways to reduce load, increase efficiency, and utilize renewable resources in facilities of all types.

Buildings, the structure of the modern world, are significant users of energy and their energy consumption is increasing. Therefore, potential for energy savings in the building sector is large and building energy conservation is currently a high priority in many countries. In developing countries, estimates of potential energy savings for first-generation building energy coded have typically ranged from 20% to 35%, and these savings can be significant since commercial buildings can often account for 25% - 33% of the country's electricity use [14].

2.3. Energy Conserving Building Design

Commercial buildings are energy-intensive. As the building sector accounts for a significant portion of the total electrical energy consumption in the world, it is imperative that today's buildings be designed for energy efficient operation throughout its lifetime. The design and construction phase significantly determines the energy use of a building in operation and therefore some basic energy conserving strategies should be considered. These energy conserving building design techniques and technologies can be applied most easily to new buildings, but existing buildings can be adapted or "retrofitted"[13].

2.3.1. Design Considerations

Energy conserving building design technique is application specific since the amount of energy use in a building is a direct result of the climate, the building's use and the building's form. For a particular project, the specific energy conserving techniques, strategies, and mechanisms to be deployed will vary greatly depending on the following major factors [12].

2.3.1.1. Climate and Location

Climate has a major effect on building performance and energy consumption. The site-specific and seasonal nature of local climate must be considered when selecting appropriate design strategies. Therefore, without knowing the temperature, solar radiation, wind velocity, etc., it is not possible to design an energy conserving building without being wasteful.

2.3.1.2. Internal heat gains

The heat gains from building occupants, lights, and electrical equipment can be thought of as the interior climate. The heat gains anticipated from these sources should be quantified for the various spaces where they apply. In some cases, the presence of intensive and enduring internal heat gains may be a determining factor in HVAC system design.

2.3.1.3. Building size and massing

Another basic planning approach is to position all spaces that can benefit from connection to the outdoors in proximity to exterior walls. To achieve this, buildings become much narrower. Such an approach to building massing must be introduced very early in the design process. Also, recognize that not all spaces need or want to be exposed to the exterior.

2.3.1.4. Illumination requirements

The lighting needs of a building's various spaces need to be identified. Many spaces, including lobbies and circulation areas, require lighting at relatively low illumination. Such spaces are ideal candidates for daylighting. In contrast, some spaces are used for demanding tasks that require high light levels. Here the attention may shift from daylighting to a very efficient electrical lighting system which has energy efficient light fittings integrated with occupancy sensors and other efficient control techniques.

2.3.1.5. Hours of operation

Typically, on a per-square-meter basis, the most energy-intensive building types are those in continuous use. In these buildings, the balance of heating and cooling may be altered dramatically from that of a building with typical work hours. Intensive building use also increases the need for well-controlled, high-efficiency lighting systems. Hours of use can also enhance the cost effectiveness of low-energy design strategies, such as daylighting. In contrast, buildings scheduled for operations during abbreviated hours should be designed with limited use clearly in mind.

2.3.1.6. Costs for electricity

The cost for electrical energy, for most buildings is a critical factor in determining which design strategies will not only conserve energy, but will also be cost effective. In many locations, utility deregulation imposes an uncertainty on future electrical energy prices. To the greatest extent possible, the life-time benefits of various design strategies should be investigated for the range of energy-cost scenarios deemed possible.

2.3.2. Basic Energy Efficiency Principles and Technologies

During the design and development process, energy efficient buildings must have a comprehensive, integrated perspective that seeks to reduce loads. Although a single technique cannot achieve a significant energy reduction, combined techniques could do it. So many combinations should be assessed.

2.3.2.1. Climate and Site

The basic principle of building climatic design focuses on the building's response to the natural environment and how to gain the maximum benefit from the local climatic conditions. A building's location and surroundings play a key role in regulating its temperature and illumination.

The six important aspects of architectural planning which will affect thermal and energy performance of buildings are site selection, layout, shape, spacing, orientation and mutual relationship. When faced with unfavorable climatic conditions, optimal siting and site design may solve all or part of the problems. Site elements to be considered include topography (slopes, valleys, hills and their surface conditions), vegetation (plant types, mass, texture) and built forms (surrounding buildings and structures). For example, trees, landscaping, and hills can provide shade and block wind. In cooler climates, designing buildings with south-facing windows increases the amount of sun entering the building, minimizing energy use by maximizing passive solar heating. Tight building design, including energy-efficient windows, well-sealed doors, and additional thermal insulation of walls, basement slabs, and foundations can reduce heat loss by 25 to 50 percent [15].

2.3.2.2. Building Envelope

Elements of the building envelope are exterior walls, windows, roof, underground slab and foundation. And the three factors determining the heat flow across the building envelope are temperature differential, area of the building exposed and heat transmission value of the exposed area [16].

Glazing must be selected for optimal performance. Glass on south, east and west facades should be highly protective against solar heat gain, except glazing that is protected by shading devices or south-facing glazing being used for passive solar heating. Glass on north facades can be clear or lightly tinted. Consider fritted and spectrally selective glazing, tuned to use and orientation on south, east or west elevations [17].

To minimize heating, and cooling loads, effective insulation should be provided by optimally insulating the building envelope. Avoid thermal bridging in metal-framed assemblies through exterior wall, roof and floor details and components. Avoid irregular exterior building shapes, which increase surface area, resulting in unwanted heat loss. Compensate for extra surface area with additional insulation.

Air and moisture in the building envelope should be controlled by detailing the building envelope to minimize infiltration and to prevent moisture build-up within the walls due to condensation. Ensure that all internal sources of humidity are properly ventilated.

2.3.2.3. Passive Solar Design

Windows, walls, and floors can be designed to collect, store, and distribute solar energy in the form of heat in the winter and reject it in the summer. This is called passive solar design. The key is designing a passive solar to best take advantage of the local climate. General strategies for passive heating and cooling include [15, 17, 18]:

- Cold winters - maximize solar gain and reduce heat loss
- Hot summers - minimize solar gain and maximize heat removal
- Correct orientation and use of windows
- Appropriate amounts of thermal mass and insulation
- Provision for natural ventilation

And strategies for shading and sun control include:

- External projection (overhangs and side fins)
- External systems integral with the window frame or attached to the building face
- Specially treated window glass, such as heat absorbing and reflecting glass
- Internal treatments either opaque or semi-opaque, such as curtains and blinds

Installing south-facing glazing in an occupied space enables the collection of solar energy, which is partially stored in the walls, floors, and/or ceiling of the space, and later released. The functioning of the space should not be compromised by direct glare from glazed openings or by local overheating. The designer can fine tune the amount and type of glazing with glare and temperature controls, materials in the affected space, auxiliary heating, and cooling to address local climatic changes. For optimum effect, floor and wall finish materials with high heat storage capacity must be exposed to direct illumination. Dark roofs may become up to 39°C hotter than the most reflective white surfaces, and they transmit some of this additional heat inside the building. And lightly colored roofs use 40 percent less energy for cooling than buildings with darker roofs [15].

2.3.2.4. Efficient Lighting Systems

Artificial lighting is defined as illumination provided by light energy obtained from electric energy supplied to artificial light sources. Lighting is a major source of power consumption in the world. Lighting system of a building is a dominant consumer of electrical energy. Lighting systems represent one-third or more of the total electrical energy costs of a commercial building [19]. Therefore, this is an area that requires energy conservation since the effect of improvements in lighting systems will be significant. This sub section covers energy saving, highly efficient lighting design methods and the trends of the most advanced technologies for efficient lighting.

Energy efficient lighting system should ensure that illumination is not excessive and switching is provided to turn off unnecessary light. Also, take advantage of day-lighting opportunities whenever possible. The use of techniques to bring sunlight into buildings and the efficiency of artificial lighting system can contribute to saving energy. Efficient lighting system that utilizes both natural and electric sources can also provide a comfortable yet visually interesting environment for the occupants. Lighting systems introduce heat into the space and increase building cooling loads. Because lighting systems significantly impact a building's operating cost and energy performance, options for the lighting systems should be evaluated before considering strategies for a low-energy HVAC system. Strategies employed to implement such energy efficient lighting systems include [15, 19]:

- The use of energy efficient lamps and luminaries, incandescent lights are not used unless required in specialty areas
- Corridors and public spaces are designed to allow for generous amounts of natural daylight to flood the spaces, electric lighting integrated with daylight
- Lighting controls are used to regulate lighting levels according to the amount of natural daylight entering the building
- Occupancy motion sensors are used to control lighting
- Proper lighting zoning allows distinct areas within rooms to be switched on or off to match the needs of occupants
- Use of light-colored room surfaces

Daylighting

Efficient lighting design begins with daylighting; electric lighting should then be designed to maximize savings from daylighting. Therefore, to reduce the need for artificial lighting, minimize the total primary energy consumption and energy costs, daylighting techniques are the first daytime solution to employ. Efficient daylighting design should consider sky conditions, site environment, building space and form, glazing systems, etc. The techniques include [17, 19]:

- *Orienting building to optimize daylight:* through proper placement of windows and skylights. Daylighting through windows is best accomplished on façades that have a generally clear view of the sky, particularly the sky at angles of 30 degrees or more above the horizon. Create an elongated massing allowing for daylighting using north-facing and south-facing glass. An east-west elongated building with an appropriate overhang will permit effective daylighting while increasing winter solar gain through south glass and reducing the direct penetration of summer sun.

- *The use of shape form to guide daylight:* the use of architectural features that reflect light into a building. Incorporate daylight-enhancing techniques to bring light into interior spaces. Evaluate such design elements to ensure that they do not add to building heating and cooling loads. Place and size glazing apertures appropriately. Maximize daylight through location and size of windows. Place much of the façade glazing high on the wall, so that daylight penetration is deeper. Provide exterior shading devices where solar gain and direct light are undesirable.
- *Providing daylighting controls:* design appropriate daylight harvesting controls. Review alternatives for reducing electric lighting use through daylight harvesting. Continuous daylight dimming has broad occupant acceptance, especially if, in individual spaces, it is coupled with a manual dimmer that allows for adjustment for maximum intensity of the artificial light from lamps.

The complex interaction between daylight and electric lights should be studied carefully in order to achieve a desirable solution. Whenever possible, electrical lighting should be considered a supplement to natural light. When the sun goes down on buildings with long hours of operation, however, efficient electrical lighting design takes on added importance.

Energy-Efficient Lamps and Ballasts

For low light level days, non-day lighted spaces, and nighttime; the use of creative-sustainable lighting design using low-energy light sources such as compact fluorescent lamps and solid-state lighting with Light-emitting diode-LED lamps, organic light-emitting diodes, and PLED - polymer light-emitting diodes; and 'low voltage' electrical filament-Incandescent light bulbs, and compact Metal halide, Xenon and Halogen lamps, can be used [15].

Identifying and using application-specific, high-efficiency lamps and ballasts minimize the amount of electrical power required by the lighting systems, while still meeting the task-specific needs of building occupants. Recently developed energy efficient lighting equipment such as LED lamps, compact fluorescent lamps and "soft-start" electronic ballasts can be used to help cut lighting operational costs 30% to 60% while enhancing lighting quality. To achieve a quality efficient lighting environment, the equipment to satisfy both performance and aesthetical needs should be selected carefully. Lamp selection is based on efficacy (lumens per watt), color temperature, color rendering index, life and lumen maintenance, availability, switching, dimming capability, and cost [15].

Energy Efficient Lamps

Fluorescent Lamps: are about 3 to 5 times as efficient as standard incandescent lamps and can last about 10 to 20 times longer. To gain the most efficiency, use current and proven equipment technology and install fluorescent luminaires in places where they can be integrated with the architecture, available daylight, and switching or dimming controls [10, 15].

- Linear fluorescent lamps: T5HO lamps work well in luminaires that provide the general ambient lighting for a space. The long and diffuse nature of these lamps provides excellent surface lighting, and the smaller lamp diameters make for better optical performance in many luminaires. Indirect/direct linear fluorescent pendants and wall-mounted up lights are typical applications for these sources.
- Compact fluorescent lamps (CFL): are often used as simple substitutes for incandescent lamps due to their significantly longer life and better energy efficiency. Due to their small size, CFL lamps are used in recessed Luminaires, wall and ceiling mounted fixtures, and even track lighting and task lighting. The diffuse nature of the fluorescent lamp makes the CFL lamp a good choice for down lighting and wall lighting. Compact fluorescents have a typical life of about 8,000 hours [20, 21].
- Inductive fluorescent lamps: are white light sources with very good color rendering and color temperature properties. These lamps are energy efficient and offer extremely long life (over 100,000 hours) and instant-on capability. The larger, diffuse nature of these sources makes them excellent for lighting larger volumes and surfaces. They are often used in place of low- to medium-wattage high intensity discharge sources because of the instant-on capability and reduced maintenance associated with the longer lamp life.

High-Intensity Discharge Lamps (HID): are still one of the best performing and most efficient lamps for lighting large areas or great distances. Metal halide (white light) lamps are replacing high pressure sodium lamps in many outdoor applications because white light sources can be 2 to 30 times more effective in peripheral visual detection than yellow-orange sources like high pressure sodium. Typically, HID lamps do not work well with occupancy sensors because most HID lamps take a long time to start each time they are switched off. Some HID lamps are special in that they can be restarted immediately after being turned off, but if they are allowed to cool down, they will take about 15 minutes to warm up just like regular lamps. Special ballasts are available that allow the lights to be step-dimmed to 50% (or another level). These ballasts could be used with occupancy sensors and the lights would be automatically dimmed to a set level when the room is unoccupied [10, 15].

Incandescent Lamps: are still used for specialty lighting, where the warm color, controlled brightness, instant-on, and dimming capabilities of these sources is needed. However, because of their lower energy efficiency and shorter lamp life, incandescent lamps should be used carefully for lighting of specific features. Some of the most effective lighting designs balance a small quantity of incandescent lighting with a fluorescent ambient (general) lighting system. Incandescent bulbs have a typical life of 1,000 hours [10, 15].

Light Emitting Diodes, LED Lamps: is a solid-state lamp that uses light-emitting diodes (LEDs) as the source of light. High power light-emitting diodes with higher lumen output are making it possible to replace other lamps with LED lamps. LED lamps can be made interchangeable with other types of lamps. LED lamps offer long service life and high energy efficiency, but initial costs are higher than those of fluorescent lamps. LED lamps are used for both general and special-purpose lighting. Compared to fluorescent bulbs, advantages claimed for LED light bulbs are that they turn on instantly, and that lifetime is unaffected by cycling on and off, so that they are well suited for light fixtures where bulbs are often turned on and off. An LED lamp can be made dimmable over a wide range. Many LED lamps have become available as replacements for screw-in incandescent or compact fluorescent light bulbs, ranging from low-power 5–40 watt incandescent bulbs, through conventional replacement bulbs for 60 watt incandescent bulbs (typically requiring about 6 watts of power), and higher wattage bulbs, e.g., a 13-16 watt LED bulb which is about as bright as a 100W incandescent [20, 21]. These bulbs are more power-efficient than compact fluorescent bulbs and offer lifespan of 30,000 or more hours, reduced operated at a higher temperature than specified. LED light bulb can be expected to last 25–30 years under normal use. The higher purchase cost than other types may be more than offset by savings in energy and maintenance [10, 15].

Energy-Efficient Ballasts

Fluorescent Ballasts: The efficiency of fluorescent tubes with modern electronic ballasts and compact fluorescents commonly ranges from 50 to 67lum/w. Most compact fluorescents rated at 13 W or more with integral electronic ballasts achieve about 60lum/w, which is comparable to the LED bulb [15].

- Rapid start ballasts: offer a long lamp life at a reasonable cost. They have been used for years with lighting controls to provide energy savings.
- Instant start ballasts: have higher efficiency than rapid start ballasts, but lamp life is shorter, especially when the frequency of starts is increased due to the use of controls. They are often used where energy savings is the primary goal and lights are on continuously for very long periods of time.
- Program rapid start ballasts: are the best to use for energy efficiency and long lamp life. These ballasts are slightly more expensive than standard rapid start ballasts, but use a "gentler" starting method so that frequent starting lessens the reduction in rated lamp life.
- Dimming electronic ballasts: for linear fluorescent lamps usually fall into two categories. The first type has a dimming range of 5% or 10% up to 100% light output and is generally the least expensive. This ballast is commonly used when the lowest light levels are not needed, or to achieve energy savings by dimming the lights when there is plentiful daylight. The second type of ballast often referred to as an "architectural dimming ballast," is more expensive and has a dimming range of 1% to 100% light output. This ballast is used in situations where lower light levels are desired.
- Electronic high-intensity discharge ballasts (HID): for metal halide lamps are now available for most lamps up to 150 watts. These ballasts should improve lamp performance and offer a limited range of dimming to achieve some energy savings.

Luminaires

A luminaire, or light fixture, is a unit consisting lamp(s) and lamp socket(s), ballast(s), reflective material, lenses, refractors, louvers, blades, or other shielding. An efficient luminaire optimizes the system performance of each of its components. There are a few types of luminaires that offer opportunities for energy conservation in a lighting system design. Most of them are fluorescent and are easily controlled for further energy savings. Solar powered exterior circulation lighting with photovoltaic cells on each fixture or connecting to a central solar panel system, are available for gardens and outdoor lighting needs [15].

Lighting Controls

Efficient electric lighting controls are used in lighting design to achieve a high quality energy efficient lighting system. They are used as part of an efficient lighting system that integrates daylight and electric light sources to provide a comfortable and visually interesting environment for the occupants of a space. Electric lighting controls can be incorporated with daylighting to provide flexibility and energy savings. Specifying a daylight-integrated lighting control system gives the occupants control of the lighting while providing appropriate lighting levels. Lighting controls [15, 19]:

- Provide multi-zone switching for multiple use spaces by properly zoning lighting circuits and switches to optimize energy-efficient operation
- Provide multi-level switching for multiple use spaces through multi-level controls
- Incorporate time clock or energy management system controls

When electric lighting controls are used properly, energy will be saved and the life of lamps and ballasts can be extended. Lighting controls will help reduce energy by:

- Reducing the number of hours per year that the lights are on
- Allowing occupants to use controls to lower light levels and save energy
- Reducing the amount of power used during the peak demand period by automatically dimming lights or turning them off when they are not needed
- Reducing internal heat gains by cutting down lighting use, which allows for reduced HVAC system size and a reduction in the building's cooling needs

Types of Lighting Controls: Some lighting controls automatically adjust lighting levels in response to daylight availability. Other controls automatically turn lights off in response to unoccupied space. Manual switching and time clocks can also be used to control certain day-lit spaces. But the most common form of electric lighting control is the on/off "toggle" switch. The other forms of control include occupancy sensors, daylight sensors, clock switches, a variety of manual and automatic dimming devices, and centralized controls [15, 19].

Standard on/off switches and relays: can be used to turn groups of lights on and off together. If the circuiting is properly designed, creative design options can be developed with this simple tool.

Occupancy sensors: are used to turn off lights in unoccupied areas, spaces that have intermittent occupancy, such as conference rooms and storage areas. These controls serve three basic functions [22]:

- To automatically turn lights on when a room becomes occupied,
- To keep the lights on without interruption while the controlled space is occupied, and
- To turn the lights off within a preset time period after the space has been vacated.

Occupancy sensors are made with multiple activation technologies, including those that sense body heat (infrared) as well as those that detect motion (ultrasound). Some sensors employ more than one technology as a means of eliminating false signals, including passive infrared, ultrasonic, and dual technology sensors.

Passive infrared sensors (PIR): are triggered by the movement of a heat-emitting body through their field of view. They are best suited for small, enclosed spaces such as private offices, where the sensor replaces the light switch on the wall and no extra wiring is required. PIR sensors cannot "see" through opaque walls, partitions, or windows so occupants must be in direct line-of-site of the sensor.

Ultrasonic sensors: emit an inaudible sound pattern that is disrupted by any moving object altering the signal returning to the sensor. They are best suited for spaces where line-of-sight view to the occupant is not always available. This type of sensor detects very minor motion better than most infrared sensors and is often used in restrooms since the hard surfaces will reflect the sound pattern.

Dual-technology occupancy sensors: use both passive infrared and ultrasonic technologies for less risk of false triggering. Combining the technologies requires a more reliable, yet slightly larger and more expensive device.

Occupancy sensors must be located to ensure that they will not detect signals outside of the desired coverage area. They can be used in conjunction with dimming or daylight controls to keep the lights from turning completely off when a space is unoccupied, or to keep the lights off when daylight is plentiful and the room is occupied. This control scheme may be appropriate when sensors control separate groups of luminaires in a large space. The lights can be dimmed to a predetermined level in one specific area when the space is unoccupied.

Since their introduction more than 20 years ago, occupancy sensor controls for lighting systems have promised significant energy and cost savings potential in a variety of commercial lighting applications. By automatically controlling lighting to turn lights off when spaces are unoccupied, occupancy sensors controls compliment connected load reductions accomplished by lamp and ballast retrofits, giving building owners and operators additional opportunities to improve energy savings without compromising lighting service to building occupants. With typical estimated energy savings potential in from ¼ to more than ½ of lighting energy, occupancy sensors have frequently been promoted as one of the most cost effective technologies available for retrofitting commercial lighting systems [22].

Manual dimming: controls are used in conjunction with building designs that encourage entry of natural daylight. Dimming gives occupants of a space an added degree of control and satisfaction, as well as an opportunity to save energy. These dimming controls include manual hard-wired control, preset scene control, remote infrared control and remote radio frequency control.

Manual hard-wired control consists of a dimmer, connected to a single luminaire or zone which is operated by the user at the device. Preset scene dimming controls change the light level settings for multiple zones simultaneously at the press of a button. Remote control dimming is well suited for retrofit projects to minimize rewiring. Infrared and radio frequency technologies are most successful in these applications. Radio frequency controls are equipped with a sender that "talks" to other dimmer's receivers. This allows multi-zone control from a single-zone device. Personal control systems are now available that allow users to change levels of lighting, sound, heating/cooling, etc., in their own workspaces.

Light-level sensors or photo-sensors: can be used to automatically turn lights on or off, or dim them, depending on the available daylight available in the space. Daylight dimming can maintain the desired light level while providing a smooth, barely noticeable transition to or from electric lighting as daylight increases or decreases.

Clock switches: turn lights on or off for a specific period of time. They are especially useful for turning off photocell-activated exterior lighting late at night.

Centralized controls: can be used to automatically turn on, turn off, and/or dim lighting at specific times or under certain load conditions. This type of control can be used in a conference room or on a building-wide scale. Centralized control strategies can also integrate lighting controls with other building systems such as mechanical or security systems.

2.3.2.5. Efficient HVAC Systems

Heating, ventilation and air-conditioning (HVAC) systems are installed to provide occupant's comfort, health and safety. They are usually the key energy users and their design is affected by architecture features and occupant needs. To achieve optimum energy efficiency, designers should evaluate thermal comfort criteria, load calculation methods, system characteristics and equipment efficiency.

Energy efficiency of many HVAC systems and equipments has been improved gradually over the years, such as in air systems, water systems, central cooling and heating plants. The choice of which space heating or cooling technology to use in buildings can have a significant impact on energy use efficiency and carbon emissions.

Ground source heat pumps can be even more energy efficient and cost effective. Heat pumps typically use four times less electrical energy to deliver an equivalent amount of heat than a direct electrical heater does. Another advantage of a ground source heat pump is that it can be reversed in summertime and operate to cool the air by transferring heat from the building to the ground. The disadvantage is their high initial capital cost, but this is typically recouped within five to ten years as a result of lower energy use.

Advanced electronic heating and cooling systems can moderate energy consumption and improve the comfort of people in the building. Energy efficient HVAC designs now being used include [15]:

- Heat pump and heat recovery systems
- Building energy management and control systems

- Natural ventilation and natural cooling strategies

2.3.2.6. Efficient Electrical Equipments

Other building systems that consume energy include electrical appliances, lifts, escalators and other kitchen and laundry electrical equipments. Modern energy-efficient appliances, such as refrigerators, freezers, ovens, stoves, dishwashers, and clothe washers and dryers, use significantly less energy than older conventional model appliances. In addition to this, the replacement of old appliances is one of the most efficient global measures to reduce emissions of greenhouse gases.

Many countries identify energy-efficient appliances using energy input labeling. Appliance consumer products meeting independent energy efficiency testing and receiving Eco-label certification marks for reduced electrical-'natural-gas' consumption and product manufacturing carbon emission labels are preferred for use in Low-energy buildings. The eco-label certification marks of Energy Star and EKO-energy are examples [9].

2.3.3. Renewable Energy Resource Utilization

The sun is the main source of energy on the surface of the earth that can be harnessed through a variety of natural and artificial processes. Oil, coal, natural gas, and wood were originally produced by photosynthetic processes, followed by complex chemical reactions over a long period of time. Even the energy of the wind has a solar origin, since it is caused by differences in temperature in various regions of the earth.

Fossil fuels provided most of the world's energy over the past century. The continued reliance on and depletion of fossil-fuel resources threatens world energy security. In addition to this problem, as more electricity is used by utilizing fossil-fuels, the power plants not only generate more electricity, but also more pollution. These conventional energy resources are now being replaced by renewable energy resources. The consumption of renewable energy resources does not result in the depletion of resources and it is important to assure a sustainable energy source. The instable energy provision which is the major problem of the conventional energy resources can then be solved by using these renewable energy supply systems. The use of renewable energy systems also decreases environmental pollution which can be achieved by the reduction of greenhouse gas emissions due to the substitution of conventional energy resources. Therefore, "green power", electricity generated using renewable energy; helps promote energy security, achieve energy independence, lower electricity costs, and reduce pollution [9].

In addition to being part of a centralized power supply system, a renewable energy system can be used in a distributed system to generate electricity onsite and supply some or all of the electricity needs. Those in remote areas, use the electricity from these systems in place of electricity supplied to them by power providers (i.e., electric utilities). These are called stand-alone (off-grid) systems. Others connect their systems to the grid and use them to reduce the amount of conventional power supplied to them through the grid. Such grid-connected system allows the sale of any excess power produced back to the power provider.

Some of the renewable energy technologies available for use are small solar, wind, micro hydropower and hybrid electric systems. Successful stand-alone systems generally take advantage of a combination of techniques and technologies to generate reliable power, reduce costs, and minimize inconvenience. Such systems in remote locations, using a small renewable energy system that is not connected to the electricity grid, can be more cost-effective than extending a power line and connecting to the grid. But these systems are also used by energy consuming sectors that are located near the grid and wish to obtain some degree of independence from the power provider or demonstrate a commitment to non-polluting energy sources. Solar energy technologies are among the renewable energy systems that can be used for such purposes. The greatest advantage of solar energy as compared with conventional energy resources is that it is clean and can be supplied without environmental pollution. In addition to this, accelerating rural electrification, reduction of greenhouse gas emission, improving diversification and stability of energy supply are the benefits of solar energy systems.

To be able to design and implement such stand-alone renewable energy systems, the first step that needs to be taken is analysis of the availability of the respective renewable energy resources and estimation of the amount available for utilization at the specific location of system implementation.

2.3.3.1. Solar Energy Resource Assessment and Data Analysis

In countries which have no instrument for measuring the solar irradiance directly and in areas where the solar radiation data's are not available, empirical formula's can be used to estimate the average solar radiation from the hours of bright sunshine (sunshine duration) which are mainly measured by the Campbell-Stokes sunshine recorder that uses a solid glass sphere of approximately 10 cm as a lens that produces an image of the sun on the opposite surface of the sphere, and a photoelectric sunshine recorder [23].

The monthly average solar radiation (H) can then be determined from the monthly average hours of bright sunshine data, following the calculation procedure and using the related equations and basic relationships given below, which were taken from [23].

$$G_{on} = G_{sc}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right] \qquad (2.1)$$

G_{on} extraterrestrial radiation measured on the plane normal to the radiation on the Nth day of the year (W/m^2) and G_{sc} solar constant (i.e. 1367 W/m^2)

Based on the results of G_{on} obtained using equation 2.1 the total radiation incident on a horizontal surface can be calculated by

$$H_o = \frac{24 \times 3600 G_{sc}}{\pi}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right] \times \left[\cos(\phi)\cos(\delta)\sin(\omega_s) + \left(\frac{\pi\omega_s}{180}\right)\sin(\phi)\sin(\delta)\right] \qquad (2.2)$$

Where ϕ is latitude of the selected area, δ is declination angle and ω_s is the sunset hour in degrees. The daily solar radiation is measured in joules per square meter (J/m^2), however, G_{sc} is in watts per square meter (W/m^2). The declination angle which shows the angular position of the sun at solar noon with respect to the plane of the equator can be found from the equation

$$\delta = 23.45\sin\left(360\frac{284 + n}{365}\right) \qquad (2.3)$$

n is the day of the year which is a continuous function of time. It can be conventionally obtained from table 2.1 shown below.

Table 2.1: Values of n and δ for each month of the year [23]

Month	n for ith day of the month	For the average day of the month		
		Date	n, day of year	δ declination
January	i	17	17	-20.9
February	31+i	16	47	-13.0
March	59+i	16	75	-2.4
April	90+i	15	105	9.4
May	120+i	15	135	18.8
June	151+i	11	162	23.1
July	181+i	17	198	21.2
August	212+i	16	228	13.5
September	243+i	15	258	2.2
October	273+i	15	288	-9.6
November	304+i	14	318	-18.9
December	334+i	10	344	-23.0

The sunset hour angle in degrees is calculated by

$$\omega_s = \cos^{-1}(-\tan(\phi)\tan(\delta)) \qquad (2.4)$$

And the number of daylight hours is given by

$$N = \frac{2}{15} \times \omega_s \qquad (2.5)$$

The monthly average solar radiation H can then be calculated using equation 2.6.

$$\frac{H}{H_O} = a + b\frac{n}{N} \qquad (2.6)$$

Where ɑ and b are the regression coefficients (constants) dependent on the location, n is the average sunshine duration and H_o is the extraterrestrial radiation for the location which can be calculated from equation 2.2.

2.3.3.2. Solar Energy Technologies

Solar Water Heating Systems

Solar water heater uses solar collectors to preheat domestic hot water. It is composed of an array of solar collectors that include an absorber plate which heats when exposed to solar radiation. Most common among these are indirect systems that circulate a freeze-protected fluid through a closed loop and then transfer heat to potable water through a heat exchanger.

Typically roof-mounted, solar collectors should face south and tilt at an angle above horizontal, approximately equal to the latitude of the project location. This configuration will provide optimum year-round performance. The collectors should be mounted in a location that is not shaded by surrounding buildings or trees during the hours of 8 a.m. to 4 p.m. (minimum) throughout the year. To be considered effective, this strategy should yield a significant portion (50% or more) of the domestic hot water needed for day-to-day operations. Best performance will be achieved in hot climates with high solar radiation levels.

Solar Photovoltaic (PV) Systems

Photovoltaic (PV) systems are a means of directly converting radiation from the sun into electricity using a semi-conductor device without moving parts, noise, or harmful emissions.

A large majority of solar cells are made from silicon. When silicon absorbs sunlight, the energy from the sun excites some of the cell's electrons into a state where they are free to move around the entire cell. However, in solar cells, there is a separator called a junction, where two slightly different types of silicon meet. The two types of silicon are pretty much the same, except each one has a tiny percentage of other materials mixed in. The two types (called n- and p-type) of the silicon determine its electrical properties. When a random electron reaches the junction, it is accelerated across. If a wire is attached to each side of the junction, and sunlight is absorbed by the silicon, the free electrons flow from one side of the junction to the other. This flow of electrons induces a similar flow through the connected wire or the external circuit. This is electricity, electrons flowing in a single direction through conductors and this particular flow is called a DC current [24, 9].

An individual silicon solar cell is quite small, producing small watts of power. To increase the total power output from solar cells, they can be connected together to form larger units called solar modules. And the power that one module can produce is seldom enough to meet requirements of a home or a business, so the modules are linked together to form an array. The modules are usually first connected in series to obtain the desired voltage; the individual strings are then connected in parallel to allow the system to produce more current [24]. The main advantages of PV systems include:

- Reasonable conversion efficiencies

- Can be efficiently integrated in buildings, minimizing visual intrusion
- Their modularity and static character, a "solid-state" device with no moving parts
- Long lifetime and low maintenance cost

In addition to these, a solar PV system is very reliable, free in its availability and clean source of electricity that can suit a wide range of applications such as residence, industry, etc. The electricity generated can be either stored, used directly (standalone plant) or fed into a large electricity grid powered by central generation plants (grid-connected plant) or combined with one or more renewable energy sources or electricity generators more, electricity (hybrid plant). Because of all these reasons, photovoltaic energy production is recognized as an important part of the future energy generation mix which is attractive for many applications, especially in rural and remote areas of most developing countries.

PV System Components

Solar photovoltaic system (PV system) consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and means of regulating or modifying the electrical output. It includes different components that should be selected according to the system type, site, location and applications. The major components for solar PV system are PV array, solar charge controller, inverter, battery bank, auxiliary energy sources and loads or appliances [24, 9].

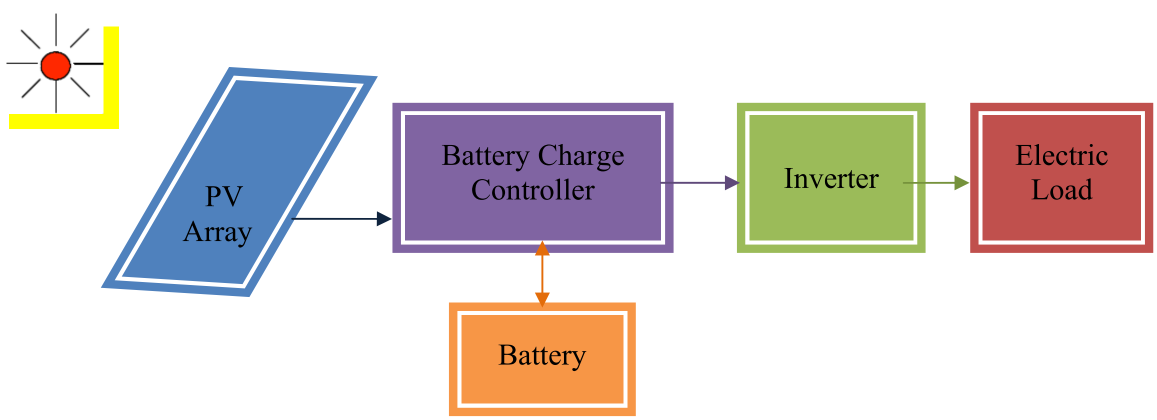

Figure 2.1: Block diagram of a PV system

The above figure shows the block diagram of a stand-alone PV system. It shows the elements needed to convert solar energy into a useable form of electric power.

PV array: Its function is to convert the sunlight directly into DC electrical power

Solar charge controller: regulates the voltage and current going from the PV panels to the battery and prevents battery overcharging and prolongs the battery life.

Inverter: Solar panels produce only DC current. The inverter is used to convert this DC output of PV panels in to AC to match the requirements of AC loads or to feed in to the grid.

Battery: The function of the battery is to store the excess power through the battery charge controller to provide electricity to loads when there is demand on cloudy days and at night.

Load: is electrical appliances that are connected to the solar PV system such as lights, radio, TV, computer, refrigerator, etc.

Balance of System Components: Copper wires are generally used in PV systems. When choosing the type of wire to use, the total current carrying capability of the wire must be considered. *Switches and* fuses are used in PV systems to provide over current protection when ground faults occur and switches are used to manually interrupt power in case of emergency or maintenance. Poor connections may result to losses in system efficiency, system failure, and costly repairs. System connections must be secure. To prevent against corrosion, copper conductors should be used for system connections.

PV System Design

The key factors that affect sizing of a PV system are the location of the system (solar radiation), the load size, and the operation time of the load. To design a stand-alone PV system, the following steps are followed. The calculation procedure and the related equations and basic relationships given below are taken from [25].

Definition of site, site meteorological data and weather condition: Site definition and location (latitude, longitude), weather condition and monthly average values of the global irradiance on the horizontal surface (kWh/m^2) and the annual average as well as the minimum and maximum monthly average ambient temperatures of the selected location where the PV system is going to be implemented has to be first identified.

Metrological data can be collected and used to calculate the average daily solar energy input over the year (G_{av}) on a south facing panel tilted at an angle equal to the site latitude. Or for

PV array sizing the month with the lowest solar radiation on the array plane (worst case) can also be chosen for the design.

Electrical load profile and estimation of energy requirement of the load: The next step in designing a photovoltaic system is to estimate the system load or the total power and energy consumption of all loads that need to be supplied by the solar PV system. This is achieved by listing the quantity and power demand of all loads and number of hours of use of each load per day. First, daily energy demand of each load is calculated. Then the watt hours needed for all of these loads must be added together to get the total watt hours per day, the average daily energy demand E_L of the load to be connected, which must be delivered by the PV system.

Orientation: A photovoltaic array can be mounted at a fixed angle from the horizontal. A tilt angle near the location's latitude will give the most energy annually.

Sizing of the module: Different size of PV modules will produce different amount of power. Dividing the average daily load of the design by the average daily solar radiation and the system component efficiencies yields the necessary PV array size. The efficiencies to be taken into account are inverter efficiency and battery efficiency. The size of the PV array can be calculated by the following equation:

$$\text{PV area} = \frac{E_L}{G_{av} \text{ x TCF x } \eta_{PV} \text{ x } \eta_{out}} \qquad (2.7)$$

Where,

E_L= The average daily load demand

G_{av}= Average solar energy input per day

η_{out} = Inverter efficiency (η_{Inv}) x Battery efficiency (η_B)

TCF= Temperature correction factor

η_{PV}= PV efficiency

The PV peak power required, at peak solar irradiance (PSI) of 1000 W/m^2, is thus given by:

$$\text{PV Peak power} = \text{PV area x PSI x } \eta_{PV} \qquad (2.8)$$

Module Selection: Module selection is based on the specifications provided by the manufacturer. The specification of the selected module type including its Maximum power (P_{max}), Voltage at P_{max} (V_p), Current at P_{max} (I_p) and its Short-circuit current (I_{sc}) must be identified.

Number of Modules: To calculate the number of PV panels for the system divide the PV Peak power required by the rated output watt peak of the PV modules selected.

$$Number\ of\ \mathrm{mod}ules = \frac{PV\ Peak\ Power\ \mathrm{Re}quired}{Rated\ Maximum\ Power} \tag{2.9}$$

Increasing the fractional part of the result to the next highest full number will give us the number of PV modules required and the result of the calculation is the minimum number of PV panels required to meet the power demand.

Modules Connection: The series and parallel configuration of the resulted PV array can be adjusted according to the required DC bus voltage and current, respectively.

The number of series-connected modules needed to produce the design voltage must be calculated. This calculation involves dividing the system voltage by the nominal module voltage. For stand-alone PV systems, 12-V and 24V modules are commonly used.

$$N_s = \frac{\text{system voltage}}{\text{nominal module voltage}} \tag{2.10}$$

Since this number is rarely a whole number a decision has to be to round up.

$$N_P = \frac{\text{Number of Modules}}{\text{N}_\text{S}} \tag{2.11}$$

Then, N_p strings each of N_s modules in series will be connected in parallel.

Battery Sizing: is sizing of a battery system which has the capability to meet the load demand for a given period of time, with no contribution from the photovoltaic system. This is required because the photovoltaic system must maintain a continuous energy supply at night and on cloudy days when there is little or no solar energy available. The amount of battery storage needed will depend on the load energy demand and on weather patterns at the site. Having too much energy and storage capacity will increase cost, therefore there must be a trade-off between keeping the cost low and meeting the energy demand during low-solar-energy periods.

The most commonly used batteries in PV systems are of the lead-acid type. They are rechargeable, easily maintained, inexpensive and available in different sizes and options. The maximum allowable DOD, depth of discharge depends on battery type and load profile. For a typical lead-acid battery this fraction is between 0.5 - 0.8. The storage capacity of the battery can be calculated according to the following relation:

$$Storage\ Capacity = \frac{NCxE_L}{DODx\eta_{out}} \tag{2.12}$$

$$Ampere\ H\text{our} = \frac{NCxE_L}{24VxDODx\eta_{out}} = \frac{Storage\ Capacity}{24V} \tag{2.13}$$

Therefore, taking the largest number of continuous cloudy days NC in the selected site and for a maximum depth of discharge for the battery DOD, the storage capacity can be calculated using the above formula. Then based on the result, the number of batteries required for the system can be determined.

Design of the Battery Charge Controller: Charge controllers are used in PV systems to protect the batteries from overcharge and excessive discharge. The controller in a PV system must be sized to handle the maximum current produced. The maximum current value and system voltage is the minimum needed to specify a controller. The controller selected must ensure that current does not flow from the battery to the array at night. It is required to safely charge the batteries and to maintain longer lifetime for them. It has to be capable of carrying the short circuit current of the PV array. According to standard practice, the sizing of solar charge controller is to take the short circuit current of the PV array and multiply it by 1.3. Thus, the controller will be chosen to handle current which is equal to the multiplication of the Isc of the module chosen, the number of strings and 1.3..75A and the system has 10 strings and to maintain the DC bus voltage to about 24 V. By taking the power output required to supply the load if all are functional at the same time and the voltage of the system, the charge controller must work at a maximum load current of

$$I = \frac{\text{Power out put}}{V_{DC}} \tag{2.14}$$

Design of the Inverter: An inverter is used in a system where AC power output is needed. The used inverter must be able to handle the maximum expected power of AC loads. For standalone systems the inverter must be large enough to handle the total amount of watts to be used at one time.

The inverter size should be selected to be 30% higher than the rated power of the total AC loads. The inverter must have the same nominal voltage as the battery.

2.4. Energy Management System

Engineers and researchers have carried out numerous studies and developed complex methods to improve energy efficiency in commercial buildings. And the design and construction phase is found to be critical for optimum energy consumption in buildings. But these measures should also be supplemented by energy management systems that can be performed to improve energy efficiency of commercial buildings in operation.

Modern power management systems reduce energy usage by idle appliances by turning them off or putting them into a low-energy mode after a certain time. Such building energy management systems link all of the building systems together in one centralized computer to control the whole building's lighting and power requirements. These systems provide appropriate energy management using building automation systems with the following characteristics [26]:

- Computerized monitoring and control of all major systems and equipments, these should include setback strategies for when spaces are unoccupied.
- Energy consumption monitoring and trend-logging through hourly graphs to follow the effect of operational changes and monthly graphs to analyze historical data.
- Load tracking and load anticipation capability to optimize system response to building pickup and power demand level.
- Load shedding and demand control through scheduled equipment cycling.
- Local controllers able to manage equipment operation and gather data for reporting.

The basic actions to improve energy efficiency in commercial buildings in operation can be summarized into seven groups.

Table 2.2: Actions to improve energy efficiency for commercial buildings in operation [26]

No	Action	Description	Application
1	Operational data measurement and storage	Accurate and automatic data acquisition	Detect over consumption Assess energy savings
2	Schedule different processes	Establish a diary of utilization by paying attention to the electric current contract	Utilization of the facilities adapted to the requirements of users
3	Automatic monitoring of consumption of electricity	Automatic system that alerts building managers when consumption of electricity increases	Manager focuses on repair or solving malfunctions
4	Individual in charge of energy use	Somebody is assigned responsibility for energy use	Energy use will always be considered
5	Pro-active actions to increase energy efficiency	Remote control actions enable managers to increase energy efficiency	Proper management of the premises
6	Modify premises for an easier management and lower consumption	Modify control buttons and installations of electrical panels for a better understanding and control by building users	Clear and precise control panels Adapt control buttons to real use
7	Communication between manager and users	A fixed place where managers and users can interact is necessary to have an optimal use of the facilities	Facilitate the exchange of information between managers and users

CHAPTER 3
CASE STUDY

3.1. Addis Ababa City Profile

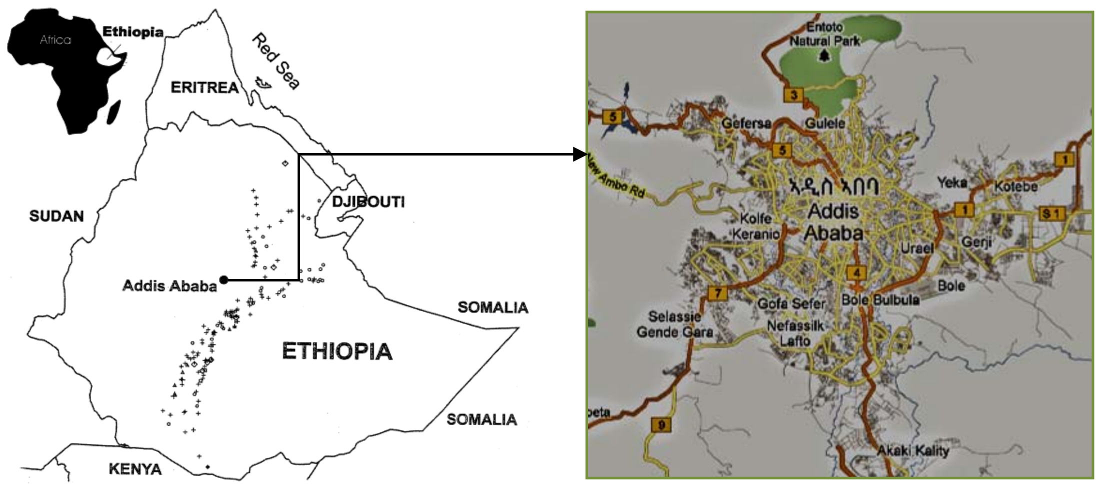

Figure 3.1: Map and location of Addis Ababa

Addis Ababa is situated almost at the centre of Ethiopia between 8055' and 9005' North Latitude and between 38040' and 38050' East Longitude, at 9°1′48″N 38°44′24″E coordinates. It lies at an altitude of 2,355 m (7,726 ft). From its lowest point at 2,326 meters (7,631 ft) asl in the southern periphery, the city rises to over 3,000 meters (9,800 ft) in the Entoto Mountains to the north. The city has a subtropical weather and possesses a complex mix of highland climate zones, with temperature differences depending on elevation and prevailing wind patterns. Its high elevation gives the city a mild and favorable climate and moderate weather conditions year-round and its position near the equator makes the temperature almost constant from month to month. The city also receives maximum precipitation in the months of July, August and September [9, 27]. The monthly average air temperature is around 20.5°C (maximum) and 16.2°C (minimum) [28].

Addis Ababa is a chartered city and the federal capital of Ethiopia. The city was founded in 1886 at the site of Filwoha hot springs by Emperor Menelik II and given the name Addis Ababa, Amharic term equivalent to “new flower” [9]. It is the largest city in the country, with a total land area of around 526.99 km^2. It has a population of more than 3 million, 3,041,002 with a density of 5770.5/km^2, according to the estimation made on July 2012 based on the results of the May 2007 national population and housing census of Ethiopia [29].

Addis Ababa is a city wooded especially with eucalyptus trees, and crossed by broad avenues. The city is the country's commercial, industrial, manufacturing, and cultural center. It is the site of an international airport, and the terminus of a railroad to the Gulf of Aden port of Djibouti. It is the location of Addis Ababa University, schools of music and art, and several research institutes. It is also the seat of the United Nations Economic Commission for Africa (UNECA) and the African Union (AU), what makes call Addis Ababa as the capital of Africa. As a result, the city is the scene of many international conferences. In many parts of the city, modern multistoried buildings stand side by side with traditional one and two-storied structures. Today, high-rise mixed use buildings dot the fronts of the main streets, giving a rather misleading impression of a well-built city. Together with a mixed or apparently well-integrated residential structure, these impressive roadside buildings often effectively mask the predominantly low standards of most housing units and residential neighborhoods.

The GDP of the whole country has been increasing every year and there have been a lot of economical developments in Addis Ababa. The city’s economy grew, on average, at rate of 8.6% annually. The service sector is the mainstay of the city’s economy. On average, it contributes about 75.4% to the city total GDP. This implies that the sector is a strategic sector with a potential to trigger the economy. In 2001 E.C, the highest electric energy consumption was exhibited in the household sector, which consumed close to 45.3% of the entire electric utilization, and followed by commercial and industrial sectors, which accounted for 31% & 23%, respectively [30].

3.2. Selection of Sample Buildings

Buildings in Addis Ababa are categorized as residential buildings, public buildings, commercial buildings and industrial buildings. Residential buildings are houses/homes or other dwelling in which people lives. Public buildings include buildings like schools, churches, mosques,… and an industrial building is a building used for industrial activities, types include brewery, factory, mining, power plant, refinery, mill,… A commercial building is a building that is used for retail or commercial use. It often combines functions, such as an office, bank, bar, coffee house, convention center, shop, store, hotel, restaurant, supermarket...

The city of Addis Ababa has recently been in a construction boom with tall buildings rising in many places. Various luxury services have also become available and the construction of commercial building has recently increased. In this thesis work, a case study is carried out on typical sample buildings from specific sectors of commercial buildings located in Addis Ababa. The purpose of conducting this case study is to provide an insight into the design and highlight the current practices and level of implementation of energy conservation measures in the electrical design of the buildings. It demonstrates the pre redesign or the base case energy consumption of the buildings and specifies in which areas of functions that energy conservation can be achieved in these buildings including the approach that can be taken to attain a better outcome. This is done by going through the electrical design and operational data of the sample buildings.

To look in to all commercial building design process in detail and gather the proper data for all type of commercial buildings needs longer time and resource. So in order to be thorough in the research within the limited time, this thesis work focuses on two typical commercial buildings in the urban setting of Ethiopia, Addis Ababa. Due to the specific nature of this study, the two prototype buildings that are considered as a representative of the commercial buildings are hotel and mixed use (shop and office) building. The hospitality and retail sectors are the fastest growing sectors in Addis Ababa as well as in Ethiopian building industry. In addition to that, these sectors are most likely in a better financial and awareness level to invest for energy conservation and energy management systems. An in-depth knowledge of the electrical system design of the sample commercial buildings is essential to outline the approach that can be taken to achieve the required outcome. Therefore, all the necessary design drawing files are collected from the consultancy office that carried out the design of the selected sample existing buildings. Actual operational data and information are also gathered through site visit to the buildings and via interviews made to the building managers. The data collected from the selected buildings is then used to evaluate the base case energy consumption of conventional buildings, to assess the potential of energy conservation and to select the appropriate energy conservation measures that can be implemented. It is also used to identify the positive trends and shortcomings in order to suggest actual and practical way for new designs. The case studies are presented in the next sub-sections of this paper.

3.3. Case Study on a Hotel Building

3.3.1. Building Description: Beer Garden Hotel Building (BGH)

Building Profile-Overview

- Location: Addis Ababa, Ethiopia
- Building type: three Star Hotel
- Total Floor Area: 3,350.46 m^2
- Project scope: Basement+Ground+6
- Number of buildings/towers - 1
- Hotel Rooms : 32
- Date of Completion: Jan, 2007 G.C.

Figure 3.2: Beer Garden Hotel Building

Building Design Type: Conventional

Occupancy

- Occupants: customers
- Occupancy Rate: average 80%, 24hrs 7 Days Service

Building Programs / Property Features

- Indoor Spaces: restaurant, kitchen, bar/lounge, steam, sauna, lobby/reception, bedrooms with bathrooms, restrooms, corridor
- Outdoor Spaces: terrace, balcony

Beer Garden Inn is a three star basement+ground+6 hotel building located in Addis Ababa, Ethiopia. It has 32 hotel bedrooms with bathrooms, indoor spaces like restaurant, kitchen, bar/lounge, steam, sauna, lobby/reception, restrooms and corridors and outdoor spaces like terrace and balcony with a total floor area of 3,350.46m^2. It gives 24hrs per day and 7 days per week service with 80% average occupancy rate [31].

3.3.2. Base Case Electrical System Design Data Analysis

Electrical power demand of this building was first analyzed based on the design. By going through the design drawings, the floor electrical plans and the details of the distribution panels, the power demand of the loads connected to the electrical system of each function in the building was calculated. The result of the calculation shows that the building has a total electrical power demand of 428.20 kW and a total power demand per total floor area of 127.8W/m^2.

Table 3.1: Electrical power end use by function - BGH

Function	Lighting	Socket Outlets	Water Heater	Sauna	Bore Hole	Laundry	Kitchen Equipments	Brewery	Chiller, Fans	Pumps	Lift Machines	Total (kW)
Power Demand (kW)	62.44	77.6	18.0	9.60	24.0	2.88	74.08	72.0	34.8	12.0	40.8	**428.2**
%	14.58	18.12	4.20	2.24	5.60	0.67	17.30	16.81	8.13	2.80	9.53	**100.0**
w/m^2	18.64	23.16	5.37	2.87	7.16	0.86	22.11	21.49	10.39	3.58	12.18	**127.8**

The percentage share of the electrical power demand for each function in the building is shown in the pie chart given below. It can be seen that the lighting system, the socket outlets and the kitchen equipments have larger share of the power demand in the building.

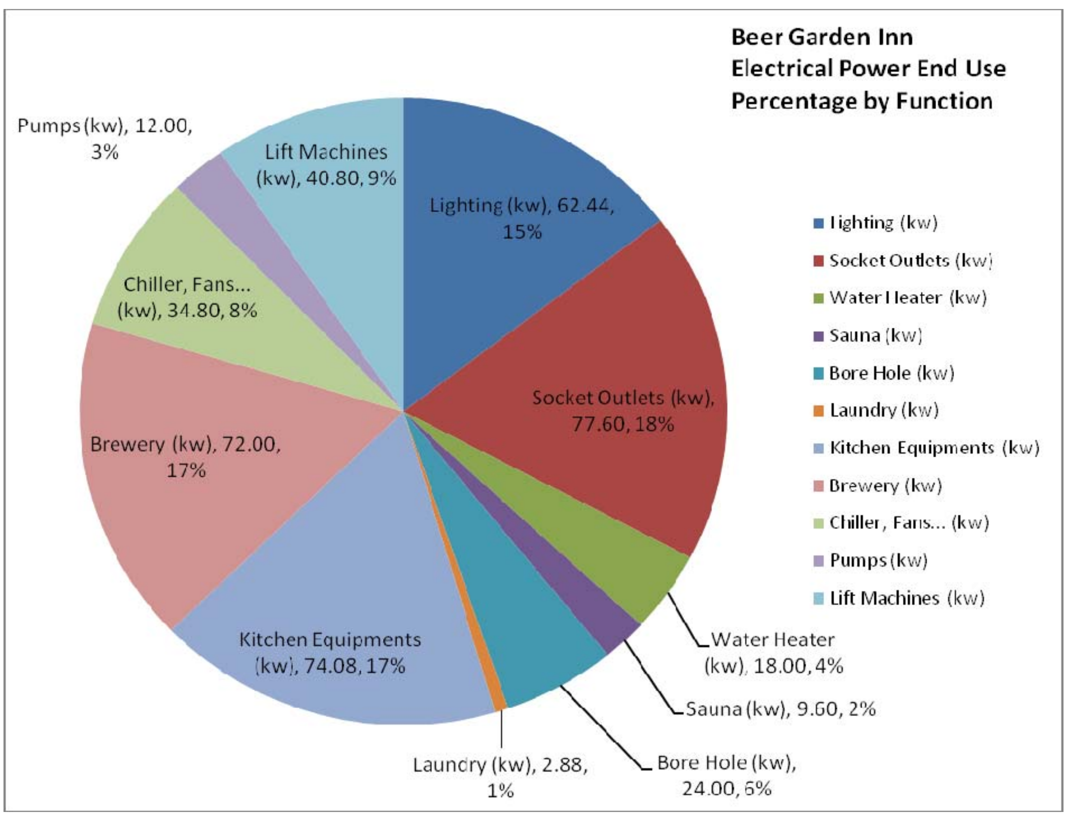

Figure 3.3: Electrical power end use percentage by function - BGH

3.3.3. Base Case Actual Load Profile

In order to create the actual load profile of the Beer Garden hotel building, its base case electrical equipment and lighting patterns are studied by using the building's electrical design and data collected during a visit of the building. Information and data like the exact power demand of some loads (in addition to the ones in the design and some replacements made) and operation hours per day (days per year) of the connected electrical loads were gathered during the site visit of the building through an interview made to the hotel manager and building electrician.

Lighting system base case identification: Using the building's floor lighting system design layouts, details of the corresponding power distribution systems and data collected during a visit of the building, the base case lighting pattern in the building was analyzed by going through all the lamps used in the lighting system of the building. The following table is prepared to show the pattern. The table indicates the types of lamps used in different areas of the building including their respective wattage and total quantity. As can be seen from the table, there are 703 different types of lamps used to light up the whole building in the base case with a total power demand of 37.42kW.

Table 3.2: Lighting system base case power demand - BGH

Area / Zone	Incandescent (60w)	Incandescent (75w)	Fluorescent (1x18w)	Fluorescent (2x18w)	Fluorescent (4x18w)	Fluorescent (1x36w)	Fluorescent (2x36w)	Compact Fluorescent (18w)	Mercury Vapor (80w)	Total	Total (kW)
Corridor	0	0	1	0	0	80	4	0	0	**85**	**3.19**
Stair	0	0	0	0	0	48	0	0	0	**48**	**1.73**
Toilet	128	0	0	0	0	0	0	0	0	**128**	**7.68**
others	86	92	1	1	4	51	111	82	14	**442**	**24.83**
Total	**214**	**92**	**2**	**1**	**4**	**179**	**115**	**82**	**14**	**703**	**37.42**
Total (kW)	**12.84**	**6.90**	**0.04**	**0.04**	**0.29**	**6.44**	**8.28**	**1.48**	**1.12**	**37.42**	

Electrical Equipments base case identification: Based on the building's electrical design and data collected during a visit of the building, quantity and load of the electrical equipments found in the building were the other parameters studied in the base case model. The Electrical equipments in the building were binned in to five categories: pumps & motors, kitchen equipment, water heater & boiler, laundry machines, guest room & others and brewery. Their respective base case load is calculated to be 55.60kW, 72.48kW, 18.00kW, 45.20kW, 87.20kW and 129.60kW.The base case electrical equipment list and their loads are presented in the following table.

Table 3.3: Electrical equipments base case power demand - BGH

Description	Quantity	Electrical load (kW)	Total load (kW)
Pumps and Motors			
Fire Pump	1	7.20	**7.20**
Domestic Pump	2	2.40	**4.80**
Goods Lift	1	12.00	**12.00**
Lift Machine	1	28.80	**28.80**
Exhaust Fans	6	0.20	**1.20**
Kitchen Equipments, Water Heater & Boiler			
Injera Mitad	1	2.40	**2.40**
Stoves	6	2.40	**14.40**
Coffee Machine	1	2.40	**2.40**
Ovens	2	4.80	**9.60**
Deep Fryer	1	14.40	**14.40**
Frying Pan	1	8.16	**8.16**
Steam cooker	1	3.60	**3.60**
Fridge	4	2.40	**9.60**
Dishwasher	1	7.92	**7.92**
Exhaust Fans	2	0.80	**1.60**
Water Heater	1	1.20	**1.20**
Boiler	1	16.80	**16.80**
Laundry machines			
Washer	1	20.00	**20.00**
Dryer	1	25.20	**25.20**
Guest Room and Others			
Televisions	40	0.20	**8.00**
Refrigerators	34	0.20	**6.80**
Sauna	1	9.60	**9.60**
Others	1	62.80	**62.80**
Brewery			
Brewery	1	72.00	**72.00**
Chiller	1	33.60	**33.60**
Borehole	1	24.00	**24.00**
Total			**408.08**

As can be seen from the above table, all the electrical equipments listed have a total power demand of 408.08kW. This brings the total actual electrical demand of the building to 445.50kW. But, as the objective of this study is to show the average saving that can be achieved by the implementation of energy conserving concepts for a commercial building, the load for the brewery will not be considered. This is because the other hotel buildings located in the city doesn't have such a system. It is found only in this building. Therefore, deducting the power demand of the brewery, which is 129.60kW, will bring the total actual power demand to 315.9kW. This value is used when carrying out the annual power saving analysis.

Table 3.4: Actual electrical power end use by function - BGH

Function	Lighting	Socket Outlets	Water Heater	Sauna	Bore Hole	Laundry	Kitchen Equip.	Brewery	Chiller, Fans	Pumps	Lift Machine	Total (kW)
Total (kW)	37.42	77.60	18.00	9.60	24.00	45.20	74.08	72.00	34.80	12.00	40.80	**445.50**
%	8.40	17.42	4.04	2.15	5.39	10.15	16.63	16.16	7.81	2.69	9.16	**100.00**

3.3.4. Base Case Annual Energy Consumption

Electric bills of 12 consecutive months (Jan- Dec, 2011 G.C) have been collected for the Beer Garden hotel building and monthly energy consumption data has been extracted from these bills. Based on these data, the total annual energy consumption of the building for that year has been calculated to be 408,640kWh for a total of 284,757.94 birr. This gives a monthly average energy consumption of 34,053.33kWh for a monthly average of 23,729.83 birr.

Table 3.5: Energy consumption data, for 2011 G.C. - BGH

Month	Amount in birr	Reading		Difference	Meter Constant	KWh/KVA
		previous	current			
January	23,914.91	9431	9640	209	160	33440
February	23,914.91	9646	9861	215	160	34400
March	23,248.38	9861	10070	209	160	33440
April	18,472.59	10070	10236	166	160	26560
May	24,025.99	10236	10452	216	160	34560
June	21,470.97	10452	10645	193	160	30880
July	19,360.30	10645	10819	174	160	27840
August	23,581.60	10819	11031	212	160	33920
September	32,024.37	11031	11319	288	160	46080
October	27,247.37	11319	11564	245	160	39200
November	20,804.44	11564	11751	187	160	29920
December	26,692.11	11751	11991	240	160	38400
Total	**284,757.94**					**408,640**
Average	**23,729.83**					**34,053.33**

The base case electrical energy consumption of the hotel building has been analyzed by calculating the base case energy consumption of the lighting system and the electrical equipments in the building. In order to do so, the following data and information were used.

- The data from the design, the base case lighting pattern and electrical equipments actual load profile analysis result
- Information and data obtained during a visit of the building, the exact power demand of some loads (in addition to the ones in the design and some replacements) and operating hours per day (days per year) of the connected electrical loads
- Building occupancy rate of 80%, and
- The total annual energy consumption data that has been extracted from the electric bills

Using all that is listed above, the base case total annual energy consumption of the building has been estimated. By multiplying the quantity of a given load by its power demand, its operating hours per day and 365 days, the annual energy consumption was calculated for each load connected to the electrical system of the building. Then to estimate the annual energy consumption of the other loads not specified in the design, which might be connected to the available socket outlets, the power demand of all the outlets was taken. And it was multiplied by 365 days and another value (operating hours per day), which was obtained through the process of trying to make the annual energy consumption taken from the bills to become 80% (occupancy rate of the building) of the total annual energy consumption that was estimated. Then the annual energy consumptions of the connected loads were added up. The result shows that, the annual electrical energy consumption of the lighting system and the equipments has been calculated to be 49,942.95kWh and 460,283.35kWh respectively. As can be seen from the table given below, all the electrical systems and equipments listed have an estimated total annual energy consumption of 510,226.30 kWh. But, for the same reason mentioned above when calculating the total actual power demand of the electrical system of the building, the annual energy consumption of the brewery will not be considered. Therefore, deducting the annual energy consumption of the brewery, which is 107,456.00 kWh, will bring the estimated total annual energy consumption to 402,770.30 kWh. And this value is used when carrying out the annual energy saving analysis.

Table 3.6: Base case lighting system annual energy consumption - BGH

Area/Zone	Electrical Load (kW)	Operating Hours per day	Annual Energy Consumption (kWh)
Corridor	3.19	8	9303.12
Stair	1.73	8	5045.76
Toilet	7.68	3	8409.60
Others	24.83	3	27184.47
Sub Total	**37.42**		**49942.95**

Table 3.7: Base case equipments annual energy consumption - BGH

Description	Quantity	Electrical load (kW)	Total load (kW)	Operating Hours per day	Annual Energy Consumption (kWh)
Pumps and Motors					
Fire Pump	1	7.20	7.20	0	0.00
Domestic Pump	2	2.40	4.80	1.32	2312.64
Goods Lift	1	12.00	12.00	4	17520.00
Lift Machine	1	28.80	28.80	8	84096.00
Exhaust Fans	6	0.20	1.20	1.5	657.00
Kitchen Equipments					
Injera Mitad	1	2.40	2.40	0	0.00
Stoves	6	2.40	14.40	7	24528.00
Coffee Machine	1	2.40	2.40	5	4380.00
Ovens	2	4.80	9.60	3	10512.00
Deep Fryer	1	14.40	14.40	2	10512.00
Frying Pan	1	8.16	8.16	3	8935.20
Steam cooker	1	3.60	3.60	3	3942.00
Fridge	4	2.40	9.60	8	28032.00
Dishwasher	1	7.92	7.92	3	8672.40
Exhaust Fans	2	0.80	1.60	7	4088.00
Water Heater	1	1.20	1.20	7	3066.00
Boiler	1	16.80	16.80	3.6	22075.20
Laundry machines					
Washer	1	20.00	20.00	5.071	37021.43
Dryer	1	25.20	25.20	5.071	46647.00
Guest Room and Others					
Televisions	40	0.20	8.00	4	11680.00
Refrigerators	34	0.20	6.80	8	19856.00
Sauna	1	9.60	9.60	0.57	2002.29
Others	1	62.80	62.80	0.1	2292.20
Brewery					
Brewery	1	72.00	72.00	1.6	42048.00
Chiller	1	33.60	33.60	8	63072.00
Borehole	1	24.00	24.00	0.27	2336.00
Sub Total			**408.08**		**460,283.35**
Total			**445.50**		**510,226.30**

3.4. Case Study on a Mixed Use Building

3.4.1. Building Description: Yerga Haile Shopping Mall (YHSM)

Building Profile - Overview

- Location: Addis Ababa, Ethiopia
- Building type: Mixed use (shop and office) building
- Total Floor Area: 10,743.3 m^2
- Project scope: 2 Basements+Ground+5
- Number of buildings – 2 (phase 1 and 2)
- Date of Completion: Phase 1 - March, 2005 G.C.
  Phase 2 - May, 2008 G.C.

Figure 3.4: Yerga Haile Shopping Mall

Building Design Type: Conventional

Occupancy

- Occupants: Customers
- Occupancy Rate: Average 100%, 12hrs 7 Days Service

Building Programs

- Indoor Spaces: shops, corridor, office space, restaurant with kitchen, restrooms
- Outdoor Spaces: terrace, balcony

Yerga Haile Mall is a mixed use 2 towers building, each with 2 basements+ground+5 floors, located in Addis Ababa, Ethiopia. It has indoor spaces like shops, corridor, office space, restaurant with kitchen, restrooms, parking and outdoor spaces like terrace and balcony with a total floor area of 10,743.3m^2. It gives 12hrs per day and 6 days per week service with 100% average occupancy rate [31].

3.4.2. Base Case Electrical System Design Data Analysis

Electrical power demand of the two mixed use buildings of the Yerga Haile Shopping Mall was analyzed based on their design. By going through the design drawings of the two buildings, the floor electrical plans and the details of the distribution panels, the power demand of each function in the buildings was calculated by using the demand of the loads connected to the electrical system of the buildings.

The result of the analysis carried out shows that the Yerga Haile phase 1 building has a total electrical power demand of 216.81kW and a total power demand per total floor Area of 31.53W/m^2.

Table 3.8: Electrical power end use by function - YHSM1

Function	Lighting	Socket Outlets	Fans	Pumps	Lift Machines	Total (kW)
Total (kW)	81.21	75.60	1.50	8.50	50.00	**216.81**
%	37.46	34.87	0.69	3.92	23.06	**100.00**
w/m^2	11.81	10.99	0.22	1.24	7.27	**31.53**

The percentage share of the electrical power demand for each function in the phase 1 building is found to be as shown in the pie chart given below. It can be seen that the lighting system, the socket outlets and the lift machines have larger share of the power demand in this building.

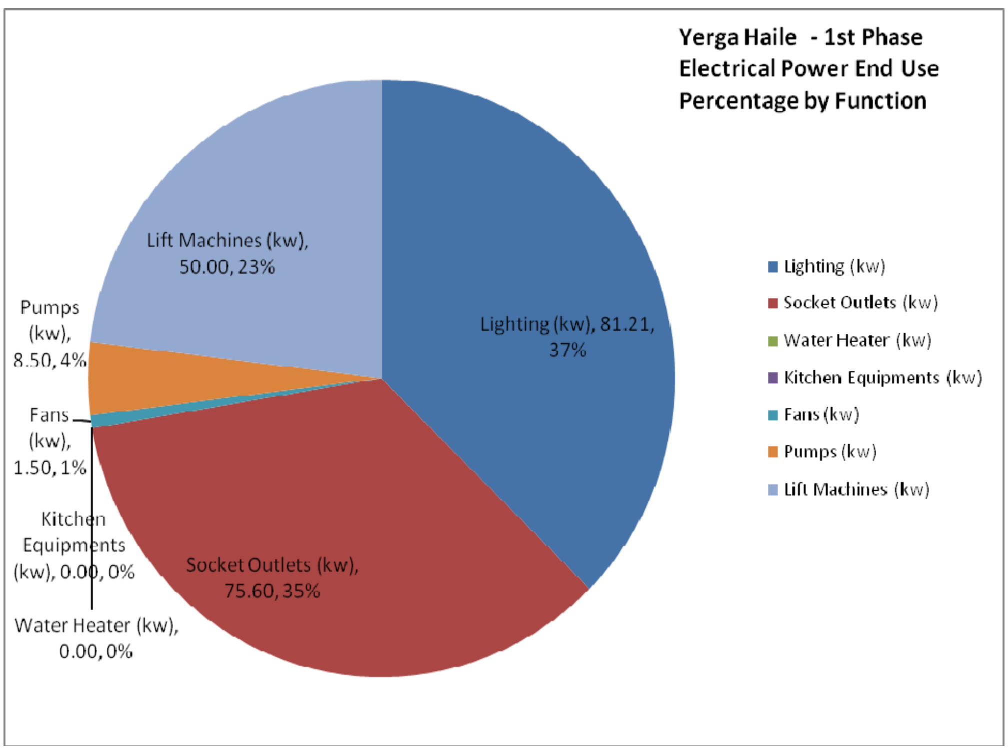

Figure 3.5: Electrical power end use percentage by function - YHSM1

And, the Yerga Haile phase 2 building has a total electrical power demand of 139.09 kW which gives a total power demand per total floor Area of 35.98W/m^2.

Table 3.9: Electrical power end use by function - YHSM2

Function	Lighting	Socket Outlets	Water Heater	Kitchen Equipments	Fans	Pumps	Total (kW)
Total (kW)	31.29	47.30	3.00	53.00	1.50	3.00	**139.09**
%	22.50	34.01	2.16	38.10	1.08	2.16	**100.00**
w/m^2	8.09	12.24	0.78	13.71	0.39	0.78	**35.98**

The percentage share of the electrical power demand for each function in the building is found to be as shown in the pie chart given below. It can be seen that the lighting system, the socket outlets and the kitchen equipments have large share of the power demand in the building.

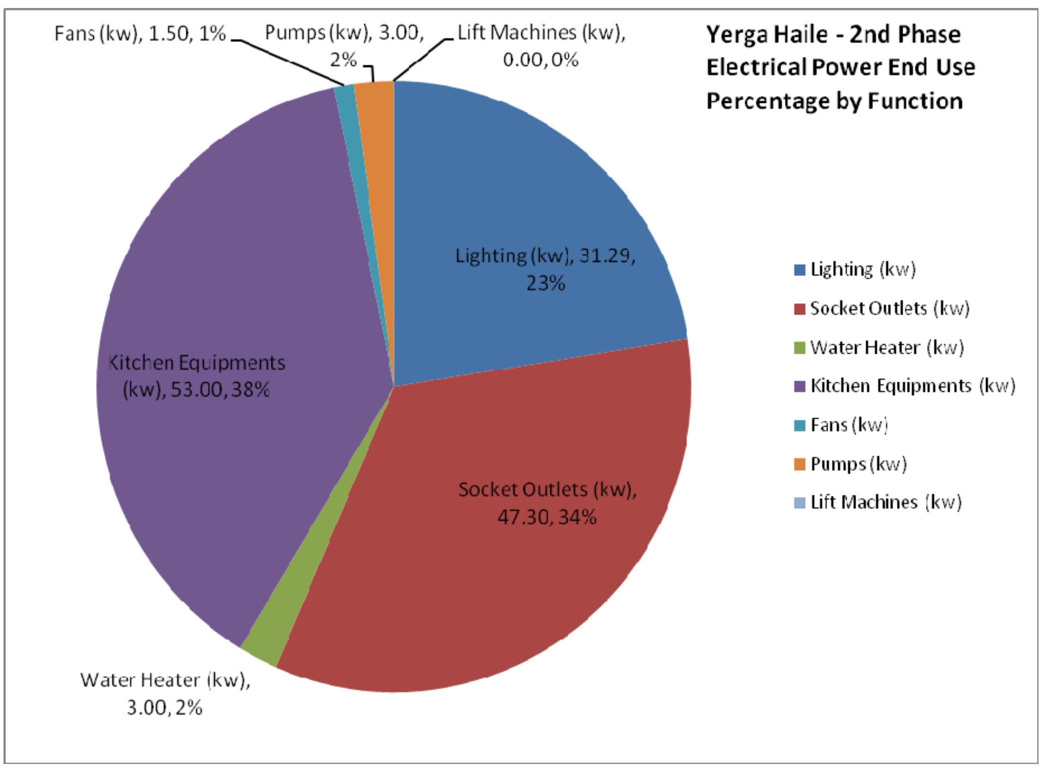

Figure 3.6: Electrical power end use percentage by function - YHSM2

The result of the design data analysis done on the electrical power demand of the two buildings of the Yerga Haile Shopping Mall shows that overall; the buildings have a total electrical power demand of 355.9kW which gives a power demand per floor area of 33.13W/m^2.

Table 3.10: Electrical power end use by function - YHSM

Function	Lighting	Socket Outlets	Water Heater	Kitchen Equipments	Fans	Pumps	Lift Machines	Total
Total (kW)	112.50	122.90	3.00	53.00	3.00	11.50	50.00	**355.90**
%	31.61	34.53	0.84	14.89	0.84	3.23	14.05	**100.00**
w/m^2	10.47	11.44	0.28	4.93	0.28	1.07	4.65	**33.13**

The percentage share of the electrical power demand for each function in the buildings is found to be as shown in the pie chart given below. It can be seen that the lighting system, the socket outlets, the lift machines and the kitchen equipments have large share of the power demand in the building.

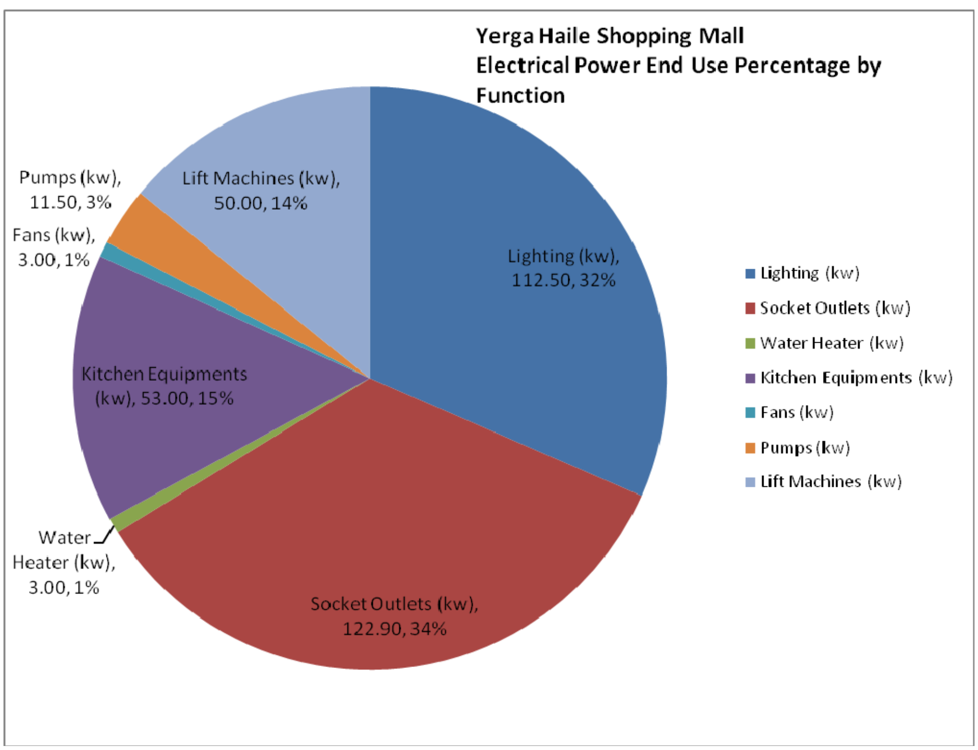

Figure 3.7: Electrical power end use percentage by function - YHSM

3.4.3. Base Case Actual Load Profile

In order to create the actual load profile of the Yerga Haile shopping mall, the base case electrical equipment and lighting patterns of both the phase 1 and phase 2 buildings are studied by using the building's electrical design and data collected during a visit of the buildings. Information and data like the exact power demand of some loads (in addition to the ones in the design and some replacements made) and operational hours per day (days per year) of the connected electrical loads were gathered during the site visit of the buildings through an interview made to the hotel manager.

Lighting system base case identification - Yerga Haile Phase 1: Based on the building's electrical design and data collected during a visit of the building, the base case lighting pattern in the building was analyzed by going through all the lamps used in the lighting system of the building and the following table is prepared to show the pattern. The table indicates the types of lamps used in different areas of the building including their respective wattage and total quantity. As can be seen from the table, there are 748 different types of lamps used to light up the phase 1 building with a total power demand of 45.58kW.

Table 3.11: Lighting system base case power demand - YHSM1

Area/Zone	**Incandescent (60w)**	**Incandescent (100w)**	**Fluorescent (1x18w)**	**Fluorescent (13w)**	**Fluorescent (1x36w)**	**Fluorescent (2x36w)**	**CFL (11w)**	**Total**	**Total (kW)**
Corridor	4	1		12	105	14	8	**144**	**5.37**
Parking						117		**117**	**8.42**
Stair					47			**47**	**1.69**
Toilet			13		12			**25**	**0.67**
Shop			1		10	213		**224**	**15.71**
Office						132		**132**	**9.50**
Bank					1	58		**59**	**4.21**
Total	**4**	**1**	**14**	**12**	**175**	**534**	**8**	**748**	**45.58**
Total (kW)	**0.24**	**0.10**	**0.25**	**0.16**	**6.30**	**38.45**	**0.09**	**45.58**	

Electrical Equipments base case identification - Yerga Haile Phase 1: Based on the building's electrical design and data collected during a visit of the building, the actual quantity and Power demand/ load of the electrical equipments found in this building were the other parameters studied in the base case model. The Electrical equipments in the building were binned in to two categories; pumps and motors and others. Their respective base case load is calculated to be 60.00kW and 75.60kW.

The base case electrical equipment list and their loads are presented in the following table.

Table 3.12: Electrical equipments base case power demand - YHSM1

Description		Quantity	Electrical load (kW)	Total load (kW)
Pumps and Motors				
	Water Pump	2	3.50	**7.00**
	Pump Sump	1	1.50	**1.50**
	Fans	1	1.50	**1.50**
	Lift Machines	2	25.00	**50.00**
Others				
	Others	1	75.60	**75.60**
Total				**135.60**

As can be seen from the above table, all the electrical equipments in this building have a total power demand of 135.6kW. This brings the total actual electrical power demand of the building to 181.18kW.

Table 3.13: Actual electrical power end use by function - YHSM1

Function	Lighting	Socket Outlets	Fans	Pumps	Lift Machines	Total (kW)
Total (kW)	45.58	75.60	1.50	8.50	50.00	**181.18**
%	25.16	41.73	0.83	4.69	27.60	**100.00**

Lighting system base case identification - Yerga Haile Phase 2: Based on the building's electrical design and data collected during a visit of the phase 2 building, the base case lighting pattern in the building was analyzed by going through all the lamps used in the lighting system of the building and the following table is prepared to show the pattern. The table indicates the types of lamps used in different areas of the building including their respective wattage and total quantity. As can be seen from the table, the result indicates that there are 416 different types of lamps used to light up the phase 2 building with a total power demand of 27.03kW.

Table 3.14: Lighting system base case power demand - YHSM2

Area/Zone	**Incandescent (60w)**	**Incandescent (100w)**	**Fluorescent (18w)**	**Fluorescent (1x36w)**	**Fluorescent (2x36w)**	**Total**	**Total (kW)**
Corridor	40	5	5	45		**95**	**4.61**
Parking				2	53	**55**	**3.89**
Stair				13		**13**	**0.47**
Shop	13				132	**145**	**10.28**
Office					82	**82**	**5.90**
Kitchen					10	**10**	**0.72**
Restaurant					16	**16**	**1.15**
Total	**53**	**5**	**5**	**60**	**293**	**416**	**27.03**
Total (kW)	**3.18**	**0.50**	**0.09**	**2.16**	**21.10**	**27.03**	

Electrical Equipments base case identification - Yerga Haile Phase 2: Similarly, based on the building's electrical design and data collected during a visit of the building, the actual quantity and power demand/ load of the electrical equipments found in this building were the other parameters studied in the base case model. The electrical equipments in the building of Yerga Haile Phase 2 were binned in to three categories; pumps and motors, kitchen equipments and others. Their respective load is calculated to be 4.50kW, 56.00kW and 47.30kW.

The base case electrical equipment list and their loads are presented in the following table.

Table 3.15: Electrical equipments base case power demand - YHSM2

Description	Quantity	Electrical load (kW)	Total load (kW)
Pumps and Motors			
Water Pump	2	1.50	**3.00**
Fans	1	1.50	**1.50**
Kitchen Equipments			
Stoves	2	12.00	**24.00**
Coffee Machine	1	4.00	**4.00**
Oven	1	25.00	**25.00**
Water Heater	2	1.50	**3.00**
Others			
Others	1	47.30	**47.30**
Total			**107.80**

As can be seen from the above table, all the electrical equipments in the building have a total power demand of 107.8kW. This brings the total actual electrical power demand of the building to 134.83kW.

Table 3.16: Actual electrical power end use by function - YHSM2

Function	Lighting	Socket Outlets	Water Heater	Kitchen Equipments	Fans	Pumps	Total (kW)
Total (kW)	27.03	47.30	3.00	53.00	1.50	3.00	**134.83**
%	20.05	35.08	2.23	39.31	1.11	2.23	**100.00**

Lighting system base case identification - Yerga Haile Shopping Mall: Based on the building's electrical design and data collected during a visit of the two buildings, the base case lighting pattern in the shopping mall was analyzed by going through all the lamps used in the lighting system of the building and the following table is prepared to show the pattern. The table indicates the types of lamps used in different areas of the building including their respective wattage and total quantity. As can be seen from the table, the resulting total base case electrical loads of the two buildings show that there are 1164 lamps used to light up the buildings with a total power demand of 72.61kW.

Table 3.17: Lighting system base case power demand - YHSM

Area/Zone	Incandescent (60w)	Incandescent (100w)	Fluorescent (1x18w)	Fluorescent (13w)	Fluorescent (18w)	Fluorescent (1x36w)	Fluorescent (2x36w)	CFL (11w)	Total	Total (kW)
Corridor	44	6	0	12	5	150	14	8	**239**	**9.98**
Parking	0	0	0	0	0	2	170	0	**172**	**12.31**
Stair	0	0	0	0	0	60	0	0	**60**	**2.16**
Toilet	0	0	13	0	0	12	0	0	**25**	**0.67**
Shop	13	0	1	0	0	10	345	0	**369**	**26.00**
Office	0	0	0	0	0	0	214	0	**214**	**15.41**
Bank	0	0	0	0	0	1	58	0	**59**	**4.21**
Kitchen	0	0	0	0	0	0	10	0	**10**	**0.72**
Restaurant	0	0	0	0	0	0	16	0	**16**	**1.15**
Total	**57**	**6**	**14**	**12**	**5**	**235**	**827**	**8**	**1164**	**72.61**
Total (kW)	**3.42**	**0.60**	**0.25**	**0.16**	**0.09**	**8.46**	**59.54**	**0.09**	**72.61**	

Electrical Equipments base case identification - Yerga Haile Shopping Mall: Similarly, based on the building's electrical design and data collected during a visit of the building, the actual quantity and power demand/ load of the electrical equipments found in this building were the other parameters studied in the base case model.

The electrical equipments in the building of Yerga Haile shopping mall were binned in to three categories; pumps and motors, kitchen equipments and others. Their respective load is calculated to be 64.50kW, 56.00kW and 122.90kW.

The base case electrical equipment list and their loads are presented in the following table. As can be seen from the table, all the electrical equipments in the building have a total power demand of 243.40kW.

Table 3.18: Electrical equipments base case power demand - YHSM

Description		Quantity	Electrical load (kW)	Total load (kW)
Pumps and Motors				
	Water Pump	2	3.50	**7.00**
	Pump Sump	1	1.50	**1.50**
	Fans	2	1.50	**3.00**
	Lift Machines	2	25.00	**50.00**
	Water Pump	2	1.50	**3.00**
Kitchen Equipments				
	Stoves	2	12.00	**24.00**
	Coffee Machine	1	4.00	**4.00**
	Oven	1	25.00	**25.00**
	Water Heater	2	1.50	**3.00**
Others				
	Others	1	122.90	**122.90**
Total				**243.40**

The total base case electrical loads in the two Yerga Haile buildings were binned in to seven categories. Electrical loads in each category were studied in the base case model. The loads are presented in the following table and the total actual electric power demand of the two buildings is found to be 316.01kW.

Table 3.19: Actual electrical power end use by function - YHSM

Function	Lighting	Socket Outlets	Water Heater	Kitchen Equipments	Fans	Pumps	Lift Machines	Total (kW)
Total (kW)	72.61	122.90	3.00	53.00	3.00	11.50	50.00	**316.01**
%	22.98	38.89	0.95	16.77	0.95	3.64	15.82	**100.00**

3.4.4. Base Case Annual Energy Consumption

Electric bills of 12 consecutive months (Jan- Dec, 2011 G.C) have been collected for the Yerga Haile shopping mall and monthly energy consumption data has been extracted from these bills. Based on these data, the total annual energy consumption of the building for that year has been calculated to be 451,120kWh for a total of 316,736.71 birr. This gives a monthly average energy consumption of 37,593.33kWh for a monthly average of 26,394.73 birr.

Table 3.20: Energy consumption data, for 2011 G.C. - YHSM

Month	Amount in birr	Reading		Difference	Meter Constant	KWh/KVA
		previous	current			
January	24,520.00	8829	9270	441	80	35280
February **March**	53,222.97	9270	10220	950	80	76000
April	26,735.69	10220	10700	480	80	38400
May	16,147.14	10700	10978	278	80	22240
June	34,579.35	10978	11590	612	80	48960
July	27,117.75	11590	12085	495	80	39600
August **September**	52,463.66	12085	13027	942	80	75360
October	27,831.68	13027	13496	469	80	37520
November	27,492.84	13496	13990	494	80	39520
December	26,625.63	13990	14468	478	80	38240
Total	**316,736.71**					**451,120.00**
Average	**26,394.73**					**37,593.33**

The base case energy consumption of the two buildings has been analyzed by calculating the base case electrical energy consumption of the lighting system and the electrical equipments in the building. In order to do so, the following data and information were used.

- The data from the design, the base case lighting pattern and electrical equipments actual load profile analysis result
- Information and data obtained during a visit of the building, the exact power demand of some loads (in addition to the ones in the design and some replacements) and operating hours per day (days per year) of the connected electrical loads
- Building occupancy rate of 98%, and
- The total annual energy consumption data that has been extracted from the electric bills

Using all that is listed above, the base case total annual energy consumption of the buildings has been estimated. By multiplying the quantity of a given load by its power demand, its operating hours per day and 365 days, the annual energy consumption was calculated for each load connected to the electrical system of the building. Then to estimate the annual energy consumption of the other loads not specified in the design, which might be connected to the available socket outlets, the power demand of all the outlets was taken. And it was multiplied by 365 days and another value (operating hours per day), which was obtained through the process of trying to make the annual energy consumption taken from the bills to become 98% (occupancy rate of the building) of the total annual energy consumption that was estimated. Then the annual energy consumptions of the connected loads were added up.

Following this procedure, the base case energy consumption of the lighting system and the equipments of the two buildings have been calculated and the results are presented in the following tables.

Table 3.21: Base case lighting system annual energy consumption - YHSM1

Lighting			
Area/Zone	**Electrical Load (kW)**	**Operating Hours per day**	**Annual Energy Consumption (kWh)**
Corridor	5.37	10	19607.80
Parking	8.42	10	30747.60
Stair	1.69	3	1852.74
Toilet	0.67	10	2430.90
Shop	15.71	10	57356.10
Office	9.50	8	27751.68
Bank	4.21	8	12299.04
Sub Total	**45.58**		**152045.86**

Table 3.22: Base case equipments annual energy consumption - YHSM1

Description	**Quantity**	**Electrical load (kW)**	**Total load (kW)**	**Operating Hours per day**	**Annual Energy Consumption (kWh)**
Pumps and Motors					
Water Pump	2	3.50	7.00	0.6	1533.00
Pump Sump	1	1.50	1.50	1	547.50
Fans	1	1.50	1.50	2	1095.00
Lift Machines	2	25.00	50.00	8	146000.00
Others					
Others	1	75.60	75.60	0.1	2759.40
Sub Total			**135.60**		**151934.90**
Total			**181.18**		**303980.76**

The annual electrical energy consumption of the lighting system and the equipments for the phase 1 building has been calculated to be 152,045.86kWh and 151,934.90kWh respectively. As can be seen from the above table, all the electrical systems and equipments listed for the Yerga Haile phase 1 building have a total annual energy consumption of 303,980.76 kWh.

Similarly, the base case annual electrical energy consumption of the lighting system and the equipments for the phase 2 building have been calculated to be 91,772.68kWh and 64,798.45kWh respectively. And the table below shows that, all the electrical systems and equipments listed for the Yerga Haile phase 2 building have a total annual energy consumption of 156,571.13 kWh.

Table 3.23: Base case lighting system annual energy consumption - YHSM2

Lighting			
Area/Zone	**Electrical Load (kW)**	**Operating Hours per day**	**Annual Energy Consumption (kWh)**
Corridor	4.61	10	16826.50
Parking	3.89	10	14191.20
Stair	0.47	3	512.46
Shop	10.28	10	37536.60
Office	5.90	8	17239.68
Kitchen	0.72	8	2102.40
Restaurant	1.15	8	3363.84
Sub Total	**27.03**		**91772.68**

Table 3.24: Base case equipments annual energy consumption - YHSM2

Description	**Quantity**	**Electrical load (kW)**	**Total load (kW)**	**Operating Hours per day**	**Annual Energy Consumption (kWh)**
Pumps and Moters					
Water Pump	2	1.50	3.00	0.6	657.00
Fans	1	1.50	1.50	2	1095.00
Kitchen Equipments					
Stoves	2	12.00	24.00	4	35040.00
Coffee Machine	1	4.00	4.00	8	11680.00
Oven	1	25.00	25.00	1	9125.00
Water Heater	2	1.50	3.00	5	5475.00
Others					
Others	1	47.30	47.30	0.1	1726.45
Sub Total			**107.80**		**64798.45**
Total			**134.83**		**156571.13**

The total base case annual electrical energy consumption of the lighting system and the equipments for the Yerga Haile Shopping Mall has been calculated to be 243,818.54kWh and 216,733.35kWh respectively. And as can be seen from the table given below, the estimated total annual energy consumption of Yerga Haile Shopping Mall shows that, all the electrical systems and equipments listed for the building have a total annual energy consumption of 460,551.89kWh.

Table 3.25: Base case lighting system annual energy consumption - YHSM

Lighting			
Area/Zone	**Electrical Load (kW)**	**Operating Hours per day**	**Annual Energy Consumption (kWh)**
Corridor	9.98	10	36434.30
Parking	12.31	10	44938.80
Stair	2.16	3	2365.20
Toilet	0.67	10	2430.90
Shop	26.00	10	94892.70
Office	15.41	8	44991.36
Bank	4.21	8	12299.04
Kitchen	0.72	8	2102.40
Restaurant	1.15	8	3363.84
Sub Total	**72.61**		**243,818.54**

Table 3.26: Base case equipments annual energy consumption - YHSM

Description	**Quantity**	**Electrical load (kW)**	**Total load (kW)**	**Operating Hours per day**	**Annual Energy Consumption (kWh)**
Pumps and Moters					
Water Pump	2	3.50	**7.00**	0.6	1533.00
Pump Sump	1	1.50	**1.50**	1	547.50
Fans	2	1.50	**3.00**	2	2190.00
Lift Machines	2	25.00	**50.00**	8	146000.00
Water Pump	2	1.50	**3.00**	0.6	657.00
Kitchen Equipments					
Stoves	2	12.00	**24.00**	4	35040.00
Coffee Machine	1	4.00	**4.00**	8	11680.00
Oven	1	25.00	**25.00**	1	9125.00
Water Heater	2	1.50	**3.00**	5	5475.00
Others					
Others	1	122.90	**122.90**	0.1	4485.85
Sub Total			**243.40**		**216,733.35**

Total			**316.01**		**460,551.89**

3.5. Solar Radiation Intensity of Addis Ababa

3.5.1. Solar Energy Resource Assessment

The assessment of the solar radiation potential for the city of Addis Ababa is done by taking data from different sources. These sources include National Metrological Agency of Ethiopia, NASA Surface meteorology and Solar Energy, and the RETScreen weather database. The data available at the National Metrological Agency of Ethiopia, Addis Ababa was the monthly average sunshine duration per day for the past consecutive eleven years (2001G.C. to 2011G.C.). The sunshine duration data taken from the agency is shown in the table below.

Table 3.27: Monthly average sunshine duration data for Addis Ababa

Source: National Meteorological Agency of Ethiopia												
Element: Monthly average sunshine hour (in hours/day)								**Station:** Addis Ababa				
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2001	7.7	9.0	5.0	8.8	5.6	3.7	2.4	2.0	5.5	7.7	9.3	8.9
2002	6.6	9.2	7.1	8.4	6.1	2.9	8.5	2.8	4.7	9.5	9.5	5.8
2003	7.9	9.0	8.2	6.1	8.4	4.7	1.6	2.9	4.1	9.7	9.0	8.3
2004	7.5	8.7	7.7	6.0	7.8	4.6	2.2	2.4	4.9	7.4	8.7	8.2
2005	7.3	9.2	7.9	6.4	5.6	4.7	2.4	3.8	4.9	8.1	8.7	9.4
2006	9.0	8.5	6.7	6.2	7.0	4.7	2.5	2.4	4.4	7.2	8.8	7.6
2007	8.0	8.0	8.7	6.6	6.6	4.2	2.5	2.7	3.8	8.4	9.0	9.4
2008	8.9	9.8	10.2	8.6	7.1	4.5	3.2	2.9	4.9	7.8	8.3	9.7
2009	8.5	9.6	9.2	7.7	8.6	6.9	2.3	4.2	5.5	7.2	9.3	5.8
2010	8.5	4.5	6.5	5.4	4.3	4.4	2.9	2.2	4.4	8.4	8.3	8.5
2011	9.0	9.6	7.4	7.5	6.0	5.2	3.1	3.3	4.1	9.4	6.8	9.5

3.5.2. Calculation of Average Solar Radiation Intensity

The monthly average sunshine duration data taken from the National Metrological agency of Ethiopia, Addis Ababa is analyzed using mathematical approach to get the solar radiation intensity. There are two regression coefficients a and b which are required to calculate average solar radiation (H) by using equation 2.6. The value of these coefficients varies with location, and hence the appropriate values for the selected site which is Addis Ababa are taken to be 0.25 and 0.60 for ɑ and b respectively [32]. Therefore, the monthly average solar radiation is then calculated using the values of the regression coefficients and H_o which is calculated using equation 2.2. The calculation result obtained for the year 2011 is as shown on the table below. The symbols given on this table represent the measured and calculated values which are used to analyze the extraterrestrial radiation (H_o) and the solar radiation (H) for the location.

Table 3.28: Monthly average solar radiation of Addis Ababa for the year 2011

Month	ϕ in deg	ϕ in rad	N (n)	δ in deg	δ in rad	ω_s in rad	ω_s in deg	N_s in deg	N_s in rad	G_{sc} in W/m^2	H_O in MJ/m^2	n	H in MJ/m^2	H in KW/m^2
January	9.023	0.157	17	-20.90	-0.365	1.510	86.523	11.536	0.201	1367	32.464	9.0	23.312	6.476
February	9.023	0.157	47	-13.00	-0.227	1.534	87.899	11.720	0.205	1367	35.222	9.6	26.116	7.255
March	9.023	0.157	75	-2.40	-0.042	1.564	89.618	11.949	0.209	1367	37.896	7.4	23.555	6.543
April	9.023	0.157	105	9.40	0.164	1.597	91.506	12.201	0.213	1367	39.388	7.5	24.374	6.771
May	9.023	0.157	135	18.80	0.328	1.625	93.099	12.413	0.217	1367	39.416	6.0	21.285	5.913
June	9.023	0.157	162	23.10	0.403	1.639	93.884	12.518	0.218	1367	39.086	5.2	19.513	5.420
July	9.023	0.157	198	21.20	0.370	1.632	93.531	12.471	0.218	1367	39.258	3.1	15.670	4.353
August	9.023	0.157	228	13.15	0.230	1.608	92.126	12.283	0.214	1367	39.524	3.3	16.252	4.514
September	9.023	0.157	258	2.20	0.038	1.577	90.349	12.047	0.210	1367	38.668	4.1	17.563	4.879
October	9.023	0.157	288	-9.60	-0.168	1.544	88.461	11.795	0.206	1367	36.212	9.4	26.369	7.325
November	9.023	0.157	318	-18.90	-0.330	1.516	86.883	11.584	0.202	1367	33.221	6.8	20.006	5.557
December	9.023	0.157	344	-23.00	-0.401	1.503	86.135	11.485	0.200	1367	31.628	9.5	23.605	6.557

The symbol n represents the measured sunshine duration and ϕ represents the latitude angle of the area (Addis Ababa). The symbols δ and ω_s represent the calculated values of the declination angle and the sunset angle which are obtained using equations 2.3 and 2.4 respectively. And N is calculated using equation 2.5. All these values are then taken to calculate the extraterrestrial radiation (H_o) and the solar radiation (H) using equation 2.2 and 2.6. In the same manner the monthly average solar radiation for the previous ten years is calculated using the hours of bright sunshine data collected. The monthly solar radiation data for each month of the 11 years and monthly and annual average solar radiation in MJ/m^2 of Addis Ababa are shown on table 3.29. The values specified in this table are then converted in to KWh/m^2 using the conversion relation 1MJ is equal to 277.78Wh. Finally, the monthly and annual average solar radiation of the site (in KWh/m^2) is obtained for the eleven years and these values are presented on table 3.30.

Table 3.29: Monthly and annual average solar radiation of Addis Ababa (MJ/m²)

Month	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average
January	21.117	19.260	21.455	20.779	20.442	23.312	21.623	23.143	22.468	22.468	23.312	**21.762**
February	25.034	25.395	25.034	24.494	25.395	24.133	23.231	26.477	26.116	16.920	26.116	**24.395**
March	18.988	22.984	25.078	24.126	24.507	22.223	26.029	28.883	26.981	21.843	23.555	**24.109**
April	26.893	26.118	21.663	21.469	22.244	21.856	22.631	26.505	24.762	20.307	24.374	**23.529**
May	20.523	21.476	25.858	24.715	20.523	23.191	22.429	23.381	26.239	18.047	21.285	**22.515**
June	16.703	15.204	18.577	18.389	18.577	18.577	17.640	18.202	22.698	18.015	19.513	**18.372**
July	14.348	25.869	12.837	13.970	14.348	14.537	14.537	15.859	14.159	15.292	15.670	**15.584**
August	13.742	15.286	15.480	14.514	17.217	14.514	15.093	15.480	17.989	14.128	16.252	**15.427**
September	20.260	18.719	17.563	19.104	19.104	18.141	16.986	19.104	20.260	18.141	17.563	**18.631**
October	23.237	26.553	26.922	22.685	23.974	22.316	24.527	23.422	22.316	24.527	26.369	**24.259**
November	24.307	24.651	23.791	23.275	23.275	23.447	23.791	22.586	24.307	22.586	20.006	**23.275**
December	22.613	17.491	21.622	21.457	23.440	20.465	23.440	23.935	17.491	21.952	23.605	**21.592**
Average	**20.647**	**21.584**	**21.323**	**20.748**	**21.087**	**20.559**	**20.996**	**22.248**	**22.149**	**19.519**	**21.468**	**21.121**

Table 3.30: Monthly and annual average solar radiation of Addis Ababa (KWh/m²)

Month	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average
January	5.866	5.350	5.960	5.772	5.678	6.476	6.007	6.429	6.241	6.241	6.476	**6.045**
February	6.954	7.054	6.954	6.804	7.054	6.704	6.453	7.355	7.255	4.700	7.255	**6.776**
March	5.275	6.385	6.966	6.702	6.807	6.173	7.230	8.023	7.495	6.067	6.543	**6.697**
April	7.470	7.255	6.017	5.964	6.179	6.071	6.286	7.363	6.878	5.641	6.771	**6.536**
May	5.701	5.966	7.183	6.865	5.701	6.442	6.230	6.495	7.289	5.013	5.913	**6.254**
June	4.640	4.223	5.160	5.108	5.160	5.160	4.900	5.056	6.305	5.004	5.420	**5.103**
July	3.986	7.186	3.566	3.881	3.986	4.038	4.038	4.405	3.933	4.248	4.353	**4.329**
August	3.817	4.246	4.300	4.032	4.783	4.032	4.193	4.300	4.997	3.925	4.514	**4.285**
September	5.628	5.200	4.879	5.307	5.307	5.039	4.718	5.307	5.628	5.039	4.879	**5.175**
October	6.455	7.376	7.478	6.301	6.660	6.199	6.813	6.506	6.199	6.813	7.325	**6.739**
November	6.752	6.848	6.609	6.465	6.465	6.513	6.609	6.274	6.752	6.274	5.557	**6.465**
December	6.282	4.859	6.006	5.960	6.511	5.685	6.511	6.649	4.859	6.098	6.557	**5.998**
Average	**5.735**	**5.996**	**5.923**	**5.763**	**5.858**	**5.711**	**5.832**	**6.180**	**6.153**	**5.422**	**5.964**	**5.867**

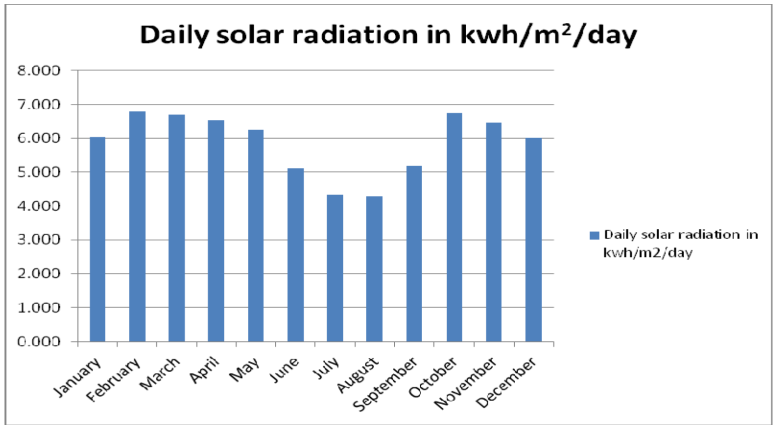

Figure 3.8: Monthly average daily solar radiation of Addis Ababa (in kWh/m^2/day)

As can be seen on the above tables and also from the graph which was prepared by an excel sheet using the calculation result, the monthly average solar radiation is maximum on February with a value of 6.78 KWh/m^2 and minimum on July and August with a value of 4.33 KWh/m^2 and 4.29 KWh/m^2, and this is because of the reason that July and August are the months of the rainy season in Addis. The annual average solar radiation of the city of Addis Ababa based on the calculation is 5.87 KWh/m^2, and this value indicates that the area has good potential for the implementation of photovoltaic (PV) system to provide power for some portion of the electrical load of a building located in the city. The monthly average daily solar radiation value calculated by using the sunshine hour data collected from the National Meteorological Agency office is used to design the solar photovoltaic systems.

Table 3.31: Average solar radiation of Addis Ababa in KWh/m^2[28, 33]

Source	**NASA [28]**	**RETScreen [33]**	**NMA**
Month	**Daily solar radiation** (kWh/m^2/d)	**Daily solar radiation** (kWh/m^2/d)	**Daily solar radiation** (kWh/m^2/d)
January	6.18	5.48	6.04
February	6.59	5.47	6.78
March	6.52	5.64	6.70
April	6.48	5.27	6.54
May	6.42	5.17	6.25
June	5.86	4.47	5.10
July	5.15	3.77	4.33
August	5.18	3.73	4.29
September	5.84	4.5	5.18
October	6.4	5.47	6.74
November	6.31	5.65	6.47
December	6.11	5.27	6.00
Annual Average	**6.09**	**4.99**	**5.87**

CHAPTER 4

ENERGY CONSERVING ELECTRICAL SYSTEM DESIGN AND ANNUAL ENERGY SAVING ANALYSIS

4.1. System Analysis Softwares /Tools

4.1.1. RETScreen

The Renewable-energy and Energy-efficient Technologies, Clean Energy Project Analysis Software (usually shortened to RETScreen) is a decision support tool developed in 1996 with contributions from government, industry, and academia by Natural Resources Canada, a department of the government of Canada. This subsection gives a general description of the software as obtained from its official website [33].

The RETScreen is a Microsoft Excel-based free software package that can be used to evaluate the energy production and savings, costs, emission reductions, financial viability, and risk for various types of ‘Renewable-energy and Energy-efficient Technologies’ (RETs). It is used to determine the technical feasibility, financial feasibility and environmental suitability of clean energy projects, which includes renewable energy technologies and a wide range of energy efficiency options. The software can be applied to any energy-system, ranging from individual projects to global applications.

The RETScreen can be used to evaluate various types of Energy Efficiency Measures Projects. It can investigate the viability of energy efficiency improvements in a wide range of residential, commercial, institutional buildings, hospitals and industrial facilities, from single-family homes and apartment complexes, to office, mixed use and hotel buildings. The software can be used to assess projects incorporating a variety of energy efficiency measures associated with building envelope, ventilation, lights, electrical equipment, hot water, pumps, fans, motors, process electricity, process heat, process steam, steam losses, heat recovery, compressed air, refrigeration, and more. It is useful for both new construction and retrofits. Whole facilities can be modeled, or sub-systems and rooms can be studied individually. The RETScreen can also be used to evaluate various types of Power Projects. It permits analysis of a wide range of renewable and conventional (fossil) fuels (which can be used in parallel), including wind; hydro; solar; landfill gas; biomass; bagasse; biodiesel; biogas; hydrogen; natural gas; oil/diesel; coal; municipal waste, etc. The tool consists of standardized and integrated renewable energy project analysis software that can be used world-wide to evaluate the energy production, life time costs and greenhouse gas emission reductions for various types of renewable energy technologies and it can incorporate energy efficiency measures relatively easily.

Fundamental to RETScreen is a comparison between a ‘base case’, typically the conventional technology, and a ‘proposed case’ which is typically the clean energy technology. The software is ultimately not concerned with the absolute costs, but rather the costs of the proposed case that are in excess of those for the base case. Typically, the costs will not be the same for the base case and the proposed case: the proposed case will have higher initial costs and lower annual costs (i.e. savings).

In addition to the software, the tool includes: product, weather and cost databases; an online manual. It integrates a number of databases to assist the site assessor, including a global database of climatic conditions obtained from 4,700 ground-based stations and NASA's satellite data.

RETScreen requires the use of Microsoft Excel 2000 or higher and Microsoft Windows 2000 or higher. Each RETScreen renewable energy technology model is developed within an individual Microsoft Excel spreadsheet "Workbook" files. The Workbook file is in-turn composed of a series of worksheets.

4.1.2. Microsoft Office Excel (Spread Sheet)

Spreadsheet applications (sometimes simply referred as *spreadsheets*) are computer programs that let one create and manipulate spreadsheets electronically. A spreadsheet is a computer application that simulates a paper accounting worksheet. It is a grid that organizes data into multiple cells usually in a two-dimensional matrix or grid called sheet consisting of rows and columns. The names of the cells are called *labels*. Each cell might contain alphanumeric text, numeric values or formulas. The user can define what type of data is in each cell and how different cells depend on one another. The relationships between cells are called *formulas*. Formulas say how to mechanically compute new values from existing values. A formula defines how the content of that cell is to be calculated from the contents of any other cell (or combination of cells) each time any cell is updated. Each value can have a predefined relationship to the other values. Once the cells and the formulas for linking them together is defined, the data can be entered. Spreadsheets are frequently used because of their ability to re-calculate the entire sheet automatically after a change to a single cell is made. Selected values can be modified to see how all the other values change accordingly. This enables the study of various what-if scenarios [9].

Various tools for programming sheets, visualizing data, remotely connecting sheets, displaying cells dependencies, etc. are commonly provided. Many spreadsheet applications permit charts or graphs to be generated from specified groups of cells which are dynamically re-built as cell contents change. The generated graphic component can either be embedded within the current sheet or added as a separate object.

Most spreadsheet applications are multidimensional, meaning that one spreadsheet can be liked to another. A three-dimensional spreadsheet, for example, is like a stack of spreadsheets all connected by formulas. A change made in one spreadsheet automatically affects other spreadsheets. Now there are a number of spreadsheet applications on the market, Microsoft Excel being among the most famous. Starting in the mid-1990s continuing through the present, Excel has dominated the commercial electronic spreadsheet market.

Microsoft Excel is a proprietary commercial spreadsheet application written and distributed by Microsoft. It has the basic features of all spreadsheets, using a grid of cells arranged in numbered rows and letter-named columns to organize data manipulations like arithmetic operations. It has a battery of supplied functions to answer statistical, engineering and financial needs. In addition, it can display data as line graphs, and charts, and with a very limited three-dimensional graphical display.

4.2. Energy Conserving Design and Power Saving Analysis

4.2.1. Energy Conserving Design Considerations

The base case electrical system of two sample commercial buildings located in Addis Ababa, which are Beer Garden Hotel and Yerga Haile Shopping Mall were studied. Based on the collected data and information, the base case electrical power demands of these buildings were analyzed. The actual load profile of the buildings was created and their annual energy consumption was also estimated. The results are presented in the previous chapter.

In this chapter, the two commercial buildings are taken for more detailed study. As part of this thesis work, a redesign for the electrical system of the two buildings is carried out to come up with the proposed case energy conserving electrical system. And the annual energy saving analysis of the system is performed by comparing the resulting energy consumption of the proposed design with that of the base case design.

Energy conserving building electrical system design strategies, energy efficient and renewable energy technologies, considered while redesigning the electrical systems of the buildings and working on the proposed case energy conserving systems include the following.

4.2.1.1 Energy Efficient Design Technique and Technology Applications

Although a single technique for energy conservation might not achieve a significant energy reduction, combined techniques could do it. Therefore, many combinations were assessed. The design techniques and technologies considered while preparing the proposed energy conserving system are provided below.

The energy performance of a lighting system is influenced by a number of factors. These typically include the illumination level required for the type of space being lit, the lamp and fixture type selected, the luminous efficacy and electricity load of the lamp, the total number of fixtures installed, and finally, the operating hours of the lamps. Putting these in mind, the following lighting energy efficiency measures are used to design the proposed system.

- The use of energy efficient LED lamps, by replacing the previous power consuming incandescent and fluorescent lamps with an equivalent LED lamps (with the same lumen output but of lower power/energy consumption)
- The use of energy efficient CFL lamps for lighting, by replacing the previous power consuming incandescent and fluorescent lamps with an equivalent CFL lamps (with the same lumen output but of lower power/energy consumption)

Table 4.1: Equivalent energy efficient lamps for incandescent lamps [20]

Minimum light output	Electrical power consumption		
Light Output Lumens (lm)	**LEDs (W)**	**CFLs (W)**	**Incandescent (W)**
450	4	9	40
800	6	13	60
1100	9	18	75
1600	16	24	100
2600	25	42	150

Table 4.2: Equivalent energy efficient lamps for fluorescent lamps [34]

Fluorescent lights (W)	18	25	36	45	60	70	72	95
Fluorescent replacement equivalent LED tube lights (W)	7	9	14	18	22	26	29	36

- Using energy efficient lighting control systems for the lighting circuits located in the public or common spaces, automatic control of the lighting in common areas, as nobody feels responsible for these areas, energy is mostly wasted,
- Motion detectors in toilets,
- Public lighting circuits controlled by the level of daylight using a luminosity sensor for effective use of daylight during the day through better controls,
- A combined presence of a detector and photocell integrated into public space lighting system which allows the electric lights to be on only when the space is occupied and when daylight levels are inadequate.

The energy consumption of appliances (or plug in loads) and other electrical equipment is influenced by a number of factors. These typically include the number of hours that the equipment is operating and the electricity load of the equipment itself. The electrical appliances and equipment energy efficiency measure taken is:

- The replacement of conventional appliances by energy-efficient ones, using energy star equipments where ever possible, as energy star labeled buildings on average use 35% less energy and generate 35% fewer greenhouse gas emissions [35].

Table 4.3: Percentage savings of energy star electrical equipments [35]

No.	Description of Equipment	Saving of Energy Stars than standard models
1	Dishwashers	10% more energy efficient
2	Clothes Washers	use about 37% less energy
3	Commercial Dishwashers	25 % more energy efficient
4	Commercial Clothes Washers	37% more efficient
5	Refrigerators	20% more energy efficient
6	Kitchen Equipment	25 % more energy efficient
7	Fans, Ventilating	use about 60% less energy
8	Televisions	over 40% more energy efficient
9	solar water heating system	cuts annual hot water costs in half, 50%

4.2.1.2 Renewable Energy Technology Applications

Heat, solar water heater: the energy performance of a hot water system is influenced by a number of factors. These typically include the amount of hot water used on a daily basis by the application or facility under consideration (flow rate), the duration of each use of hot water, the end-use water temperature required, as well as the supply temperature of the water available, and the use of a heat recovery device. The hot water system energy efficiency measure taken is:

- The use of efficient solar water heater system to cover the hot water requirement of the building

Power, solar photovoltaic: the energy performance of a photovoltaic system is influenced by a number of factors. These may include resource and design elements such as the amount of solar radiation hitting the solar PV panel, the panel type, power capacity, area, efficiency, nominal operating cell temperature and temperature coefficient, as well as the solar tracking mode (i.e. fixed, one-axis, azimuth or two-axis tracker), the slope and the azimuth (physical orientation) of the collector. Other factors include the use of an inverter to transform the DC output to AC for systems that include AC loads or a grid-connection. And the energy performance will also be influenced by the battery days of autonomy, voltage, efficiency, maximum depth of discharge, temperature and capacity, as well as the charge controller efficiency. In order to meet some part of the building's power demand:

- On site generation of electrical power by using solar photovoltaic technology is considered with an optimized arrangement of solar PV panels on the roof and with the maximum possible number of panels for a higher total power and energy

The energy efficient building design techniques and renewable energy technologies that are mentioned above are used to redesign the original electrical system of the two sample buildings and create the proposed case energy conserving electrical system design. RETScreen is then used for assessing the technical and financial feasibility of the implementation of the proposed energy conserving electrical design by analyzing the systems through a comparison between the 'base case', which is the conventional system, and the 'proposed case' which is the energy conserving system. The software is used to model the lighting system, the electrical equipments and the hot water system in order to evaluate the energy use and savings, costs and financial viability for the lighting, electrical equipment and hot water energy efficiency measures taken. And the photovoltaic power was also modeled to evaluate the energy production and savings, costs, and financial viability, to determine if a PV system is cost-effective alternative to use within the building.

4.2.2. Energy Conserving Design for the Hotel Building

By considering the energy efficient and renewable energy technologies that are mentioned in the previous sub section the base case electrical system of the Beer Garden hotel building was redesigned and an energy conserving electrical design was proposed.

4.2.2.1. Energy Efficient System Design And Power Saving Analysis

- From the initial design which is the base case, there are incandescent and fluorescent lamps of different wattage used. In this case the total power demand of the lighting system is 37.42kW. In order to decrease the power demand and energy consumption of the lighting system in the building, replacement of the incandescent and fluorescent lamps in use by equivalent energy efficient lamps like LED and CFL lamps was proposed. To do so, the spaces in the building were divided in to 4 categories namely corridor, stairs, toilet and others. From the initial design which is the base case, there are 214 60w incandescent, 92 75w incandescent, 2 1x18w fluorescent, 1 2x18w fluorescent, 4 4x18w fluorescent, 179 1x36w fluorescent, 115 2x36w fluorescent, 82 18w CFL and 14 80w Incandescent lamps used to light up these 4 categories. In this case the power demand is 3.19kW, 1.73kW, 7.68kW and 24.83kW for the 4 categories respectively giving a total of 37.42kW.

- In the proposed case, the energy efficient LED lamps used to replace the above mentioned lamps include 86 6w for 60w incandescent, 92 9w for 75w incandescent, 14 10w for 80w incandescent, 2 7w for 1x18w fluorescent, 1 14w for 2x18w fluorescent, 179 14w for 1x36w fluorescent, 115 29w for 2x36w fluorescent and 4 29w for 4x18w fluorescent. And 128 13w energy efficient CFL lamps are used to replace 60w incandescent lamps. In this case the power demand is 1.27kW, 0.69kW, 1.66kW and 7.03kW for the 4 categories respectively giving a total of 10.66kW. This result in a power saving of 1.91kW, 1.04kW, 6.02kW and 17.80kW for the 4 categories respectively giving a total power saving of 26.76kW which is about 71.52% of the base case lighting system power demand.

Table 4.4: Proposed energy efficient light fitting replacements- BGH

		Incandescent (60w)	Incandescent (60w)	Incandescent (75w)	Fluorescent (1x18w)	Fluorescent (2x18w)	Fluorescent (4x18w)	Fluorescent (1x36w)	Fluorescent (2x36w)	Compact Fluorescent (18w)	Mercury Vapor (80w)	Total
Base Case	**Fitting Type**											
	Wattage (W)	60	60	75	18	36	72	36	72	18	80	
	No of Fittings	128	86	92	2	1	4	179	115	82	14	**703**
	Total (kw)	**7.68**	**5.16**	**6.90**	**0.04**	**0.04**	**0.29**	**6.44**	**8.28**	**1.48**	**1.12**	**37.42**
Proposed Case	**Equivalent Fitting Type**	**CFL**	**LED**	**LED**	**LED**	**LED**	**LED**	**LED**	**LED**	**CFL**	**LED**	
	Wattage (W)	13	6	9	7	14	29	14	29	18	10	
	No of Fittings	128	86	92	2	1	4	179	115	82	14	**703**
	Total (kw)	**1.66**	**0.52**	**0.83**	**0.01**	**0.01**	**0.12**	**2.58**	**3.31**	**1.48**	**0.14**	**10.66**
Power Saving (kw)		**6.02**	**4.64**	**6.07**	**0.02**	**0.02**	**0.17**	**3.87**	**4.97**	**0.00**	**0.98**	**26.76**

Table 4.5: Power saving of proposed lighting pattern - BGH

Area/Zone	Base Case (kW)	Proposed Case (kW)	Power Saving (kW)
Corridor	3.19	1.27	1.91
Stair	1.73	0.69	1.04
Toilet	7.68	1.66	6.02
others	24.83	7.03	17.80
Total	**37.42**	**10.66**	**26.76**

- In the base case scenario all of the lighting circuits in the building are controlled by a standard manual on and off switches. In the proposed energy efficient design the application of better control systems are suggested. The use of energy efficient lighting control systems, an occupancy sensor + photo sensor + dimmer for the lighting system of the corridor and an occupancy sensor for the lighting circuits of the toilet and the stair case will reduce the power consumption of the systems by 25% and 35% respectively by reducing the unnecessary operational hours and lumen outputs of the lamps. As a result, the base case power demand of the 4 categories corridor, stairs, toilet and others which is 1.27kW, 0.69kW, 1.66kW and 7.03kW respectively giving a total of 10.66kW is reduced to 0.96kW, 0.45kW, 1.08kW and 7.03kW respectively giving a total of 9.51kW. This result in a power saving of 0.32kW, 0.24kW, 0.58kW and 0kW giving a total power saving of 1.14kW.

Table 4.6: Power saving of proposed lighting control system - BGH

Area/Zone	Lightning (kW)	Base Case Control System	Proposed Case Control System	Total (KW)	Power Saving (kW)
Corridor	1.27	Toggle Switch	Occupancy Sensor + Photo sensor + Dimmer	0.96	0.32
Stair	0.69	Toggle Switch	Occupancy Sensor	0.45	0.24
Toilet	1.66	Toggle Switch	Occupancy Sensor	1.08	0.58
others	7.03	Toggle Switch	-	7.03	0.00
Total	**10.66**	**-**	**-**	**9.51**	**1.14**

- The power saving of the proposed lighting control system brings the total power saving of the energy efficient lighting system design from the base case 37.42kW to the proposed case 9.51kW with a total power saving of 27.91kW which is about 74.57% of the base case lighting system power demand.

Table 4.7: Total power saving of proposed lighting system - BGH

Description	Base Case (kW)	Proposed Case Power Saving (kW)			Proposed Case Total Power (kW)	Percentage Power Saving (%)
		Efficient Lamp	Efficient Control	Total Power Saving (kW)		
Lighting	37.42	26.76	1.14	27.91	9.51	74.57

- In the base case condition, four solar water heater systems are installed on the roof for covering the hot water requirement of the building. This system has a backup centralized electrical water heater system which requires about 18kW of power. The solar heater can at least save about 40% of the power demand. But the use of an energy star qualified solar water heating system can cut hot water costs in half, and is generally designed for use with an electric back-up water heater. Therefore with this replacement in the proposed case, the solar heater can at least save 50% of the power demand of the backup electrical water heater system which is equal to 9kW.

Table 4.8: Power saving of proposed water heating system - BGH

Description	Quantity	Base Case Power Consumption (kW)	Base Case Solar Heater Share (kW)	Total Power (kW)	Proposed Case Solar Heater Share (kW)	Power Saving (kW)
Water Heater	1	1.20	0.00	1.20	0.60	0.60
Boiler	1	16.80	6.72	10.08	8.40	8.40
Total		**18.00**	**6.72**	**11.28**	**9.00**	**9.00**

- In the proposed energy efficient case energy star equipments are to be used wherever possible. The most energy efficient products were selected among energy star products and these appliances are used instead of the base case equipments. From the replacements of conventional model equipments in the base case with a total power consumption of 198.08kW, a total power saving of 42.04 kW has been achieved by giving a total power consumption of 156.04kW in the proposed case.

Table 4.9: Power saving of proposed equipments and appliances - BGH

Description	Base Case Power Consumption (kW)	Proposed Case Power Saving (%)	Proposed Case Power Demand (kW)	Power Saving (kW)
Laundry	45.20	0.37	28.48	16.72
Kitchen Equipments	62.88	0.25	47.16	15.72
Fans	2.80	0.60	1.12	1.68
Fridge	9.60	0.35	6.24	3.36
Televisions	8.00	0.40	4.80	3.20
Refrigerators	6.80	0.20	5.44	1.36
Others	62.80	0.00	62.80	0.00
Total	**198.08**		**156.04**	**42.04**

The following table gives a detailed description of the changes made on the original design with all the necessary information and also the resulting power saving that can be achieved by the implementation of the proposed energy efficient design techniques and technologies.

Table 4.10: Power saving of proposed energy efficient design - BGH

Function	Conventional Design Power Demand (kW)	Power Saving (kW)	Efficient Design Power Demand (kW)
Lighting	37.42	27.91	9.51
Hot Water	18.00	9.00	9.00
Other Equipments	198.08	42.04	156.04
Sauna	9.60		9.60
Pumps	12.00		12.00
Lift Machines	40.80		40.80
Total	**315.90**	**78.95**	**236.95**

After these changes are made on the original design by the proposed energy efficient design techniques and technologies, the resulting power saving that can be achieved is analyzed. From a total of 315.90 kW of conventional design power demand a reduction to 236.95kW is achieved. This shows a power saving of 24.99% which is equal to 78.95kW.77

Table 4.11: Power saving analysis of the energy efficient system - BGH

Total power demand of base case electrical system (kW)	**315.90**
Total power demand of proposed case energy efficient system (kW)	**236.95**
Power saving of proposed case energy efficient system (kW)	**78.95**
Percentage power saving of proposed case energy efficient system (%)	**24.99**

4.2.2.2. Onsite Power Generation Using Solar PV System

- In the proposed case, photovoltaic system is considered in order to meet some part of the building's power demand. Photovoltaic power model was used to evaluate the energy production and savings, costs, and financial viability and to determine if a photovoltaic (PV) system is cost-effective alternative to use within the building. But before that, the required PV system is designed.

  A model of the PV power supply system to be considered is prepared to be as shown in the figure below.

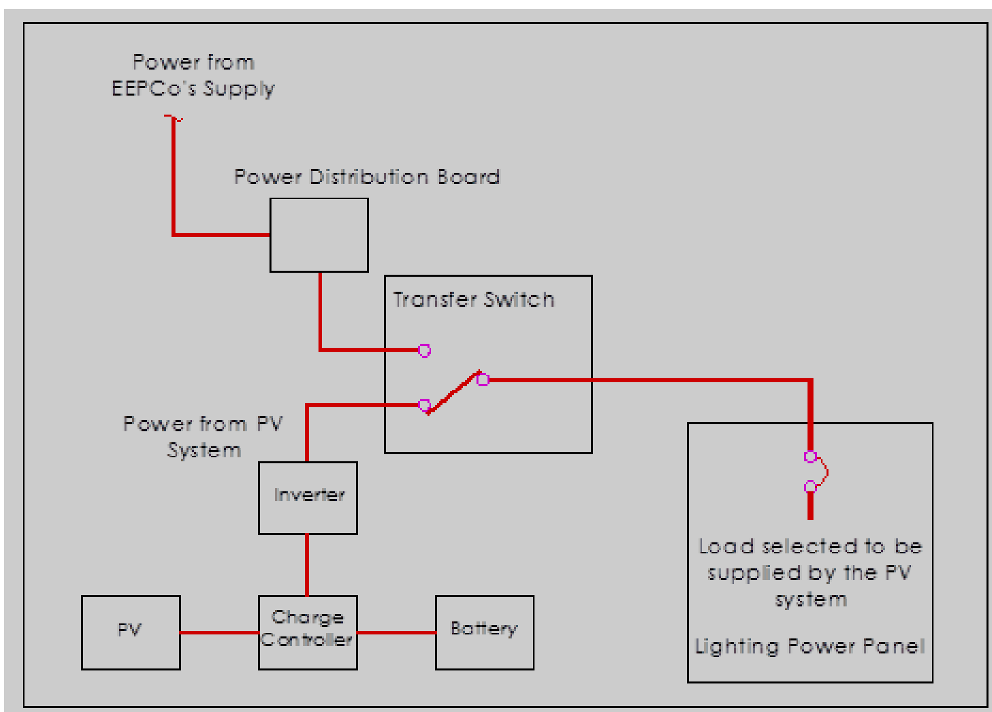

Figure 4.1: PV system power supply model

The calculation procedure and the related equations and basic relationships presented in section 2.3.3.2 were used to design the PV system. In order to do so, the following steps were followed. First, part of the building's lighting system, corridor and stair lighting, is selected to be supplied by the PV system.

The Average Daily Solar Energy: By using the data obtained from the National Meteorological Agency shown in section 3.5.1, the average solar radiation intensity for the city of Addis Ababa was calculated as provided in section 3.5.2 of this paper. The result of the calculation shows that the annual average solar radiation of the city of Addis Ababa is 5.87 KWh/m^2. By entering this in to RETScreen, the average daily solar radiation (G_{av}) on a south facing panel tilted at an angle equal to the site latitude 9.02^0 is found to be 5.97kWh/m^2/day.

Orientation: The photovoltaic array can be mounted at a fixed angle from the horizontal. As presented in section 2.3.3.2, a tilt angle near the location's latitude, in this case 9.02^0, will give the most energy annually.

The Average Daily Load Demand: According to base case information, power demand, daily and annual electricity consumption of the selected lighting system are calculated to be 4.91kW, 39.312kWh and 14.349MWh respectively. After the energy efficient design, power demand, daily and annual electricity consumptions of this lighting system is reduced to 1.41kW, 11.241kWh and 4.103MWh respectively. Therefore, the average daily load demand E_L of the lighting system to be supplied by the PV system can be taken to be 11,240.64Wh/day. Based on this data, PV system calculations were carried out. In this context, the first step was calculation of PV peak power required to deliver the energy.

Sizing of the module: The size of the PV array for this study can be calculated by using equation 2.7. For the considered location, which has a monthly average air temperature of around 20.5°C [28], the temperature correction factor (TCF) can be taken to be 0.8 [25]. Assuming η_{PV} = 12% = 0.12, and η_{out} = 0.85 x 0.9 = 0.765 [37],

$$\text{PV area} = \frac{11240.64}{5970 \text{ x } 0.8 \text{ x } 0.12 \text{ x } 0.765} = 25.64m^2$$

The PV peak power required, at peak solar irradiance (PSI) of 1000 W/m^2, is thus calculated using equation 2.8.

$$\text{PV Peak power} = 25.64\text{m}^2 \times 1000\text{w/m}^2 \times 0.12 = 3076.56\text{W}_\text{P}$$

Module Selection: BP 275, 75-Watt peak Mono-crystalline Photovoltaic Module was selected from the RETScreen database to calculate the number of modules required. The selected module has the following specifications [36] at standard conditions (i.e., 1000 W/m^2 & 25^{o}C).

Maximum power (P_{max})	75W_P
Voltage at P_{max}(V_p)	17.0V
Current at P_{max}(I_p)	4.45A
Short-circuit current (Isc)	4.75A

Number of Modules: To calculate the number of PV panels for the system using equation 2.9

$$Number\ of\ \text{mod}ules = \frac{3076.56Wp}{75Wp} = 41.02 \approx 42$$

Increasing the fractional part of the result to the next highest full number, that will be the number of PV modules required and the result of the calculation is the minimum number of PV panels required to meet the power demand. Thus, 42 modules are used to supply the required energy for the selected system.

Modules Connection: The series and parallel configuration of the resulted PV array can be adjusted according to the required DC bus voltage and current, respectively.

Based on equation 2.10, the number of series-connected modules needed to produce the design voltage is calculated using the nominal module voltage and the system voltage or DC bus voltage which is chosen to be 24 V,

$$N_s = \frac{24V}{17.0V} = 1.412$$

Since this number is rarely a whole number a decision has to be to round up. Then 2 modules will be connected in series. And now by using equation 2.11,

$N_P = \dfrac{42}{2} = 21$, and 21 strings each of 2 modules in series will be connected in parallel.

Battery Sizing: Taking the largest number of continuous cloudy days NC in the selected site to be about 1 day and for a maximum depth of discharge for the battery DOD of 0.8, the storage capacity of the battery can be calculated according to equation 2.12 and 2.13 and the storage capacity becomes 18367.06 Wh. Since, the selected DC bus voltage is 24 V, then the required Ampere-hours of the battery = 18367.06/24 = 765.29 Ah,

$Ampere\ Hour = \frac{1x11240.64}{24Vx0.8x0.765} = 765.29Ah$, Then 4*215Ah=860Ah can be used.

Design of the Battery Charge Controller: sizing of solar charge controller is to take the short circuit current of the PV array and multiply it by 1.3. Thus, in this case a module with an Isc of 4.75A has been chosen and the system has 21 strings. Therefore, the controller will be chosen to handle **4.75A x 21 x 1.3 = 129.675A** and to maintain the DC bus voltage to about 24 V. So the charge controller should be rated 132A at 24V.

The power output required if all lights are on at the same time is 1405.08W and the voltage of the system is 24V. So, using equation 2.14, the charge controller must work at a maximum load current of

$$\mathrm{I} = \frac{1405.08W}{24V} = 58.55 \approx 63A$$

Design of the Inverter: The inverter to be used must be able to handle the maximum expected power of AC loads. The inverter size should be 20-30% bigger than the total watt of load connected. Therefore, it can be selected as 30% higher than the rated power of the total loads. Thus the rated power of the inverter becomes = 1405.08W + (0.3 x 1405.08W) = 1826.60 W. The inverter must have the same nominal voltage as the battery. The specifications of the required inverter will be 2000W, 24 VDC, 220 VAC, and 50 Hz.

Table 4.12: PV system design calculation results and input to the software - BGH

Description	Value
G_{av} (Wh/m^2/day)	5970
E_L (Wh/day)	11,240.64 Wh/day
PV area (m^2)	25.64 m^2
PV Peak Power (W_P)	3,076.56 W_P
No of modules required	42
Approximate value of N_s x N_p	2 x 21
Battery Size	4*215Ah=860Ah
Charge Controller	132A at 24V
Inverter	2000 W, 24 VDC, 220 VAC, and 50 Hz

Taking the data obtained from the above calculation, those values required by the software in order to simulate and analyze the designed PV system are entered in to the RETScreen. 42 of the selected modules are used and 27m^2 roof area is needed for the establishment of the PV panels in order to meet the required electricity load. The output of the RETScreen PV system analysis is provided in appendix B-2.

Table 4.13: On-site power generation and supply using PV system - BGH

Lighting -Area/Zone	Base Case Lighting Load (kW)	Proposed Case Power Saving (kW)
Corridor	0.956	0.956
Stair	0.449	0.449
Total	**1.405**	**1.405**

4.2.2.3. Overall Power Saving Analysis

The overall power saving analysis for the energy conserving design is carried out considering saving of both the energy efficient design and the onsite power generating PV system. The result shows that the power demand of this building reduced from 315.9kW to 235.55kW giving a percentage power saving of 25.44% which is equal to 80.35kW.

Table 4.14: Overall power saving analysis of the energy conserving design - BGH

Total power demand of base case electrical system (kW)	**315.90**
Total power demand of proposed case energy conserving system (kW)	**235.55**
Total power saving of proposed case energy conserving system (kW)	**80.35**
Percentage power saving of proposed case energy conserving system (%)	**25.44**

4.2.3. Energy Conserving Design for the Mixed Use Building

By following the same procedure used for the hotel building and by considering similar energy conserving building design techniques and technologies the base case electrical system of the Yerga Haile shopping mall was redesigned and an energy conserving design was proposed. The design was carried out independently for the phase 1 and the phase 2 buildings. Then the result was summarized for the whole shopping mall.

4.2.3.1. Energy Efficient System Design and Power Saving Analysis

Yerga Haile Phase 1

By considering the energy efficient building design techniques and technologies that are mentioned in the previous sub section the original electrical system of the Yerga Haile Phase 1 building was redesigned as follows.

- From the initial design which is the base case, there are incandescent and fluorescent lamps used to light up these spaces. In order to decrease the power demand and energy consumption of the lighting system in the building, replacement of the lamps in use by equivalent energy efficient lamps like LED and CFL lamps were proposed. To do so, the spaces in the building were divided in to 7 categories namely corridor, parking, stairs, toilet, shop, office and bank. From the initial design which is the base case, there are 4 60w incandescent, 1 100w incandescent, 14 1x18w fluorescent, 12 13w fluorescent, 175 1x36w fluorescent, 534 2x36w fluorescent and 8 11w CFL lamps used to light up these 7 categories. In this case the power demand is 5.37kW, 8.42kW, 1.69kW, 0.67kW, 15.71kW, 9.5kW and 4.21kW for the 7 categories respectively giving a total of 45.58kW.
- In the proposed case, the energy efficient LED lamps used to replace the above mentioned lamps include 14 7w for 1x18w fluorescent, 12 5w for 13w fluorescent, 175 14w for 1x36w fluorescent and 534 29w for 2x36w fluorescent. Similarly, 4 13w and 1 24w energy efficient CFL lamps are used to replace 60w and 100w incandescent lamps. In this case the power demand is 2.14kW, 3.37kW, 0.68kW, 0.27kW, 6.29kW, 3.80kW and 1.68kW for the 7 categories respectively giving a total of 18.23kW. This result in a power saving of 3.23kW, 5.05kW, 1.02kW, 0.40kW, 9.43kW, 5.70kW and 2.53kW for the 7 categories respectively giving a total power saving of 27.36kW which is about 60.02% of the base case lighting power demand.

Table 4.15: Proposed energy efficient light fitting replacements - YHSM1

	Fitting Type	Incandescent (60w)	Incandescent (100w)	Fluorescent (1x18w)	Fluorescent (13w)	Fluorescent (1x36w)	Fluorescent (2x36w)	Compact Fluorescent (11w)	Total
Base Case	**Wattage (W)**	60	100	18	13	36	72	11	
	No of Fittings	4	1	14	12	175	534	8	**748**
	Total (kw)	**0.24**	**0.10**	**0.25**	**0.16**	**6.30**	**38.45**	**0.09**	**45.58**
Proposed Case	**Equivalent Fitting Type**	**CFL Lamp**	**CFL Lamp**	**LED Lamp**	**LED Lamp**	**LED Lamp**	**LED Lamp**	**CFL Lamp**	
	Wattage (W)	13	24	7	5	14	29	11	
	No of Fittings	4	1	14	12	175	534	8	**748**
	Total (kw)	**0.05**	**0.02**	**0.10**	**0.06**	**2.52**	**15.38**	**0.09**	**18.23**
Power Saving (kw)		**0.19**	**0.08**	**0.15**	**0.09**	**3.78**	**23.07**	**0.00**	**27.36**

Table 4.16: Power saving of proposed lighting pattern - YHSM1

Area/Zone	Base Case (kW)	Proposed Case (kW)	Power Saving (kW)
Corridor	5.37	2.14	3.23
Parking	8.42	3.37	5.05
Stair	1.69	0.68	1.02
Toilet	0.67	0.27	0.40
Shop	15.71	6.29	9.43
Office	9.50	3.80	5.70
Bank	4.21	1.68	2.53
Total	**45.58**	**18.23**	**27.36**

- In the base case scenario all of the lighting circuits in the building are controlled by a standard manual on and off switches. In the proposed energy efficient design the application of better control systems are suggested. The use of energy efficient lighting control systems, an occupancy sensor + photo sensor+ dimmer for the lighting system of the corridor, shop, office and bank and an occupancy sensor for the lighting circuits of the parking, toilet and the stair case will reduce the power consumption of the systems by 25% and 35% respectively by reducing the unnecessary operational hours and lumen outputs of the lamps. As a result, the base case power demand of the 7 categories corridor, parking, stairs, toilet, shop, office and bank which is 2.14kW, 3.37kW, 0.68kW, 0.27kW, 6.29kW, 3.80kW and 1.68kW respectively giving a total of 18.23kW is reduced to 1.61kW, 2.19kW, 0.44kW, 0.17kW, 4.71kW, 2.85kW and 1.26kW respectively giving a total of 13.24kW. This result in a power saving of 0.54kW, 1.18kW, 0.24kW, 0.09kW, 1.57kW, 0.95kW and 0.42kW giving a total power saving of 4.99kW.

Table 4.17: Power saving of proposed lighting control system - YHSM1

Area/Zone	Lightning (kW)	Base Case Control System	Proposed Case Control System	Total (KW)	Power Saving (kW)
Corridor	2.14	Toggle Switch	Occupancy Sensor + Photo sensor+ Dimmer	1.61	0.54
Parking	3.37	Toggle Switch	Occupancy Sensor	2.19	1.18
Stair	0.68	Toggle Switch	Occupancy Sensor	0.44	0.24
Toilet	0.27	Toggle Switch	Occupancy Sensor	0.17	0.09
Shop	6.29	Toggle Switch	Occupancy Sensor + Photo sensor+ Dimmer	4.71	1.57
Office	3.80	Toggle Switch	Occupancy Sensor + Photo sensor+ Dimmer	2.85	0.95
Bank	1.68	Toggle Switch	Occupancy Sensor + Photo sensor+ Dimmer	1.26	0.42
Total	**18.23**	**-**	**-**	**13.24**	**4.99**

- This value brings the total power saving of the energy efficient lighting system design from the base case 45.58kW to the proposed case 13.24kW with a total power saving of 32.35kW which is about 70.96% of the base case lighting system power demand.

Table 4.18: Total power saving of proposed lighting system - YHSM1

Description	Base Case (kW)	Proposed Case Power Saving (kW)			Proposed Case Total Power (kW)	Percentage Power Saving (%)
		Efficient Lamp	Efficient Control	Total Power Saving (kW)		
Lighting	45.58	27.36	4.99	32.35	13.24	70.96

- In the proposed energy efficient case energy star equipments are to be used wherever possible. The most energy efficient products were selected among energy star products and these appliances are used instead of the base case equipments. From the replacements of conventional model equipments in the base case with a total power consumption of 77.10kW, a total power saving of 0.90kW has been achieved by giving a total power consumption of 76.20kW in the proposed case.

Table 4.19: Power saving of proposed equipments and appliances - YHSM1

Description	Base Case Power Consumption (kW)	Proposed Case Power Saving (%)	Proposed Case Total Power (kW)	Power Saving (kW)
Fans	1.50	0.60	0.60	0.90
Others	75.60	0.00	75.60	0.00
Total	**77.1**		**76.2**	**0.9**

The following tables give a detailed description of the changes made on the original design with all the necessary information and also the resulting power saving that can be achieved by the implementation of the proposed energy efficient design techniques and technologies.

Table 4.20: Power saving of proposed energy efficient design - YHSM1

Function	Conventional Design Power Demand (kW)	Power Saving (kW)	Efficient Design Power Demand (kW)
Lighting	45.58	32.35	13.24
Other Equipments	77.10	0.90	76.20
Pumps	8.50		8.50
Lift Machines	50.00		50.00
Total	**181.18**	**33.25**	**147.94**

After the application of the proposed energy efficient design techniques and technologies, the resulting power saving that can be achieved is analyzed. From a total of 181.18kW of conventional design power demand for the functions listed in the following table a power demand a reduction to 147.94kW is attained. This shows a power saving of 33.25kW after the redesign which results in a percentage power saving of 18.35%.

Table 4.21: Power saving analysis of the energy efficient system - YHSM1

Total power demand of base case electrical system (kW)	**181.18**
Total power demand of proposed case energy efficient system (kW)	**147.94**
Power saving of proposed case energy efficient system (kW)	**33.25**
Percentage power saving of proposed case energy efficient system (%)	**18.35**

Yerga Haile Phase 2

The procedure followed to design the energy efficient system for the phase 2 building was similar to the one used for the phase 1 building. By considering the energy efficient building design techniques and technologies that are mentioned in the previous sub section the original electrical system of the Yerga Haile Phase 2 building was redesigned as follows.

- In the initial design which is the base case, there are incandescent and fluorescent lamps used. In order to decrease the power demand and energy consumption of the lighting system in the building, replacement of the lamps in use by equivalent energy efficient lamps like LED and CFL lamps were proposed. To do so, the spaces in the building were divided in to 7 categories namely corridor, parking, stairs, shop, office, kitchen and restaurant. From the initial design which is the base case, there are 53 60w incandescent, 5 100w incandescent, 5 18w fluorescent, 60 1x36w fluorescent and 293 2x36w fluorescent lamps used to light up these 7 categories. In this case the power demand is 4.61kW, 3.89kW, 0.47kW, 10.28kW, 5.90kW, 0.72kW and 1.15kW for the 7 categories respectively giving a total of 27.03kW.
- In the proposed case, the energy efficient LED lamps used to replace the above mentioned lamps include 5 7w for 18w fluorescent, 60 14w for 1x36w fluorescent and 293 29w for 2x36w fluorescent. Similarly, 53 13w and 5 24w energy efficient CFL lamps are used to replace 60w and 100w incandescent lamps. In this case the power demand is 1.32kW, 1.56kW, 0.19kW, 3.97kW, 2.36kW, 0.29kW and 0.46kW for the 7 categories respectively giving a total of 10.15kW. This result in a power saving of 3.29kW, 2.33kW, 0.28kW,

6.31kW, 3.54kW, 0.43kW and 0.69kW for the 7 categories respectively giving a total power saving of 16.88kW which is about 62.45% of the base case lighting system power demand.

Table 4.22: Proposed energy efficient light fitting replacements - YHSM2

	Fitting Type	Incandescent (60w)	Incandescent (100w)	Fluorescent (18w)	Fluorescent (1x36w)	Fluorescent (2x36w)	Total
Base Case	Wattage (W)	60	100	18	36	72	
	No of Fittings	53	5	5	60	293	**416**
	Total (kw)	**3.18**	**0.50**	**0.09**	**2.16**	**21.10**	**27.03**
Proposed Case	Equivalent Fitting Type	**CFL Lamp**	**CFL Lamp**	**LED Lamp**	**LED Lamp**	**LED Lamp**	
	Wattage (W)	13	24	7	14	29	
	No of Fittings	53	5	5	60	293	**416**
	Total (kw)	**0.69**	**0.12**	**0.04**	**0.86**	**8.44**	**10.15**
Power Saving (kw)		**2.49**	**0.38**	**0.05**	**1.30**	**12.66**	**16.88**

Table 4.23: Power saving of proposed lighting pattern - YHSM2

Area/Zone	Base Case (kW)	Proposed Case (kW)	Power Saving (kW)
Corridor	4.61	1.32	3.29
Parking	3.89	1.56	2.33
Stair	0.47	0.19	0.28
Shop	10.28	3.97	6.31
Office	5.90	2.36	3.54
Kitchen	0.72	0.29	0.43
Restaurant	1.15	0.46	0.69
Total	**27.03**	**10.15**	**16.88**

- In the base case scenario all of the lighting circuits in the building are controlled by a standard manual on and off switches. In the proposed energy efficient design the application of better control systems are suggested. The use of energy efficient lighting control systems, an occupancy sensor + photo sensor + dimmer for the lighting system of the corridor, shop, office kitchen and restaurant and an occupancy sensor for the lighting circuits of the parking and the stair case will reduce the power consumption of the systems by 25% and 35% respectively by reducing the unnecessary operational hours and lumen outputs of the lamps. As a result, the base case power demand of the 7 categories corridor, parking, stairs, shop, office, kitchen and restaurant which is 1.32kW, 1.56kW, 0.19kW, 3.97kW, 2.36kW, 0.29kW and 0.46kW respectively giving a total of 10.15kW is reduced to 0.99kW, 1.01kW, 0.12kW, 2.98kW, 1.77kW, 0.22kW and 0.35kW respectively giving a total of 7.44kW. This result in a power saving of 0.33kW, 0.54kW, 0.07kW, 0.99kW, 0.59kW, 0.07kW and 0.12kW giving a total power saving of 2.71kW.

Table 4.24: Power saving of proposed lighting control system - YHSM2

Area/Zone	Lightning (kW)	Base Case Control System	Proposed Case Control System	Total (KW)	Power Saving (kW)
Corridor	1.32	Toggle Switch	Occupancy Sensor + Photosensor+ Dimmer	0.99	0.33
Parking	1.56	Toggle Switch	Occupancy Sensor	1.01	0.54
Stair	0.19	Toggle Switch	Occupancy Sensor	0.12	0.07
Shop	3.97	Toggle Switch	Occupancy Sensor + Photosensor+ Dimmer	2.98	0.99
Office	2.36	Toggle Switch	Occupancy Sensor + Photo sensor+ Dimmer	1.77	0.59
Kitchen	0.29	Toggle Switch	Occupancy Sensor + Photo sensor+ Dimmer	0.22	0.07
Restaurant	0.46	Toggle Switch	Occupancy Sensor + Photo sensor+ Dimmer	0.35	0.12
Total	**10.15**	**-**	**-**	**7.44**	**2.71**

- This value brings the total power saving of the energy efficient lighting system design from the base case 27.03kW to the proposed case 7.44kW with a total power saving of 19.59kW which is about 72.48% of the base case lighting system power demand.

Table 4.25: Total power saving of proposed lighting system - YHSM2

Description	Base Case (kW)	Proposed Case Power Saving (kW)			Proposed Case Total Power (kW)	Percentage Power Saving (%)
		Efficient Lamp	Efficient Control	Total Power Saving (kW)		
Lighting	27.03	16.88	2.71	19.59	7.44	72.48

- In the proposed energy efficient case energy star equipments are to be used wherever possible. The most energy efficient products were selected among energy star products and these appliances are used instead of the base case equipments. From the replacements of conventional model equipments in the base case with a total power consumption of 104.80kW, a total power saving of 14.15kW has been achieved by giving a total power consumption of 90.65kW in the proposed case.

Table 4.26: Power saving of proposed equipments and appliances - YHSM2

Description	Base Case Power Consumption (kW)	Proposed Case Power Saving (%)	Proposed Case Total Power (kW)	Power Saving (kW)
Water Heater	3.00	0.00	3.00	0.00
Kitchen Equipments	53.00	0.25	39.75	13.25
Fans	1.50	0.60	0.60	0.90
Others	47.30	0.00	47.30	0.00
Total	**104.8**		**90.65**	**14.15**

The following tables give a detailed description of the changes made on the original design with all the necessary information and also the resulting power saving that can be achieved by the implementation of the proposed energy efficient design techniques and technologies.

Table 4.27: Power saving of proposed energy efficient design - YHSM2

Function	Conventional Design Power Demand (kW)	Power Saving (kW)	Efficient Design Power Demand (kW)
Lighting	27.03	19.59	7.44
Other Equipments	104.80	14.15	90.65
Pumps	3.00		3.00
Lift Machines	0.00		0.00
Total	**134.83**	**33.74**	**101.09**

After the redesign of the system using the proposed energy efficient design techniques and technologies, the resulting power saving that can be achieved is analyzed. From a total of 134.83kW of conventional design power demand for the functions listed in the following table a power demand a reduction to 101.09kW is achieved. This shows a power saving of 33.74kW after the redesign which results in a percentage power saving of 25.02%.

Table 4.28: Power saving analysis of the energy efficient system - YHSM2

Total power demand of base case electrical system (kW)	**134.83**
Total power demand of proposed case energy efficient system (kW)	**101.09**
Power saving of proposed case energy efficient system (kW)	**33.74**
Percentage power saving of proposed case energy efficient system (%)	**25.02**

Yerga Haile Shopping Mall – Total

In the base case design of the Yerga Haile shopping mall, there are incandescent and fluorescent lamps used to light up the building. In order to decrease the power demand and energy consumption of the lighting system, replacement of the lamps in use by equivalent energy efficient lamps like LED and CFL lamps were proposed. To do so, the spaces in the building were divided in to 9 categories namely corridor, parking, stairs, shop, toilet, office, bank, kitchen and restaurant. The replacements made result in a total power saving of 44.24kW which is about 60.93% of the base case lighting system power demand, 72.61kW.

Table 4.29: Power saving of proposed lighting patterns - YHSM

Area/Zone	Base Case (kW)	Proposed Case (kW)	Power Saving (kW)
Corridor	9.98	3.47	6.52
Parking	12.31	4.92	7.39
Stair	2.16	0.86	1.30
Toilet	0.67	0.27	0.40
Shop	26.00	10.26	15.74
Office	15.41	6.16	9.24
Bank	4.21	1.68	2.53
Kitchen	0.72	0.29	0.43
Restaurant	1.15	0.46	0.69
Total	**72.61**	**28.37**	**44.24**

- In the base case scenario all of the lighting circuits in the building are controlled by a standard manual on and off switches. In the proposed energy efficient design the application of better control systems are suggested. The use of energy efficient lighting control systems resulted in a total power saving of 7.70kW.

Table 4.30: Power saving of proposed lighting control system - YHSM

Area/Zone	Lightning (kW)	Current Control System	Efficient Control System	Total (KW)	Power Saving (kW)
Corridor	3.47	Toggle Switch	Occupancy Sensor + Photo sensor+ Dimmer	2.60	0.87
Parking	4.92	Toggle Switch	Occupancy Sensor	3.20	1.72
Stair	0.86	Toggle Switch	Occupancy Sensor	0.56	0.30
Toilet	0.27	Toggle Switch	Occupancy Sensor	0.17	0.09
Shop	10.26	Toggle Switch	Occupancy Sensor + Photo sensor+ Dimmer	7.69	2.56
Office	6.16	Toggle Switch	Occupancy Sensor + Photo sensor+ Dimmer	4.62	1.54
Bank	1.68	Toggle Switch	Occupancy Sensor + Photo sensor+ Dimmer	1.26	0.42
Kitchen	0.29	Toggle Switch	Occupancy Sensor + Photo sensor+ Dimmer	0.22	0.07
Restaurant	0.46	Toggle Switch	Occupancy Sensor + Photo sensor+ Dimmer	0.35	0.12
Total	**28.37**	**-**	**-**	**20.67**	**7.70**

- This value brings the total power saving of the energy efficient lighting system design from the base case 72.61kW to the proposed case 20.67kW with a total power saving of 51.94kW which is about 71.53% of the base case lighting system power demand.

Table 4.31: Overall power saving of proposed lighting system - YHSM

Description	Base Case (kW)	Proposed Case Power Saving (kW)			Proposed Case Total Power (kW)	Percentage Power Saving (%)
		Efficient Lamp	Efficient Control	Total Power Saving (kW)		
Lighting	72.61	44.24	7.70	51.94	20.67	71.53

- In the proposed energy efficient case energy star equipments are to be used instead of the base case equipments wherever possible. From the replacements of conventional model equipments in the base case with a total power consumption of 181.9kW, a total power saving of 15.05kW has been achieved by giving a total power consumption of 166.85kW in the proposed case.

Table 4.32: Power saving of proposed equipments and appliances - YHSM

Description	Base Case Power Consumption (kW)	Proposed Case Power Saving (%)	Proposed Case Total Power (kW)	Power Saving (kW)
Water Heater	3.00	0.00	3.00	0.00
Kitchen Equipments	53.00	0.25	39.75	13.25
Fans	3.00	0.60	1.20	1.80
Others	122.90	0.00	122.90	0.00
Total	**181.9**		**166.85**	**15.05**

The following tables give a detailed description of the functions where the changes are made on the original design and also the resulting power saving that can be achieved by the implementation of the proposed energy efficient design techniques and technologies.

Table 4.33: Power saving of proposed energy efficient design by function - YHSM

Function	Conventional Design Power Demand (kW)	Power Saving (kW)	Efficient Design Power Demand (kW)
Lighting	72.61	51.94	20.67
Other Equipments	181.90	15.05	166.85
Pumps	11.50	0.00	11.50
Lift Machines	50.00	0.00	50.00
Total	**316.01**	**66.99**	**249.02**

From a total of 316.01 kW of base case design power demand for the functions listed in the above table a power demand reduction to 249.02 kW is achieved for the two mixed use buildings through the application of the energy efficient design techniques and technologies. This shows a power saving of 66.99 kW after the redesign which results in a percentage power saving of 21.20%.

Table 4.34: Power saving analysis of the energy efficient system - YHSM

Total power demand of base case electrical system (kW)	**316.01**
Total power demand of proposed case energy efficient system (kW)	**249.02**
Power saving of proposed case energy efficient system (kW)	**66.99**
Percentage power saving of proposed case energy efficient system (%)	**21.20**

4.2.3.2. Onsite Power Generation Using Solar PV System

- In the proposed case, photovoltaic system is considered in order to meet some part of the two buildings power demand. Photovoltaic Power Model was used to evaluate the energy production and savings, costs, and financial viability and to determine if a photovoltaic (PV) system is cost-effective alternative to use within the buildings. But before that, the PV system was designed for the two buildings independently.

Yerga Haile Phase 1

First, part of the building's lighting system, corridor and parking lighting system of the building, is selected to be supplied by the PV system. According to base case information, power demand, daily and annual electricity consumption of the selected lighting system are calculated to be 13.8kW, 137.96kWh and 50.355MWh respectively. After the energy efficient design, power demand, daily and annual electricity consumptions of this lighting system is reduced to 3.8kW, 37.96kWh and 13.857MWh respectively. Therefore, the average daily load demand E_L of the lighting system to be supplied by the PV system can be taken to be 37,964.4Wh/day. Based on this data, PV system calculations were carried out. In this context, the required PV system is designed following the same procedure used to design the one for the hotel building. The following result was obtained.

Table 4.35: PV system design calculation results and input to the software - YHSM1

Description	Value
G_{av} (Wh/m^2/day)	5970
E_L (Wh/day)	37,964.4Wh/day
PV area (m^2)	86.59m^2
PV Peak Power (W_P)	10,390.84W_P
No of modules required	140
Approximate value of N_s x N_p	2 x 70

Battery Size	12*215Ah=2580
Charge Controller	450A at 24V
Inverter	5000W, 24 V_{DC}, 220 V_{AC}, and 50 Hz

Taking the data obtained from the above calculation, those values required by the software in order to simulate and analyze the designed PV system are entered in to the RETScreen. 140 of the selected modules are used and 90m^2 roof area is needed for the establishment of the PV panels in order to meet the required electricity load.

Table 4.36: On-site power generation and supply using PV system - YHSM1

Lighting -Area/Zone	Base Case Lighting Load (kW)	Proposed Case Power Saving (kW)
Corridor	1.606	1.606
Parking	2.190	2.190
Total	**3.796**	**3.796**

Yerga Haile Phase 2

First, part of the building's lighting system, corridor and parking lighting system of the building is selected to be supplied by the PV system. According to base case information, power demand, daily and annual electricity consumptions of the selected lighting system are calculated to be 8.50kW, 84.98kWh and 31.018MWh respectively. After the energy efficient design, power demand, daily and annual electricity consumptions of this lighting system is reduced to 2.0kW, 20.04kWh and 7.314MWh respectively. Therefore, the average daily load demand EL of the lighting system to be supplied by the PV system can be taken to be 20,038.8Wh/day. Based on this data, PV system calculations were carried out. In this context, the required PV system is designed following the same procedure used to design the one for the hotel building. The following result was obtained.

Table 4.37: PV system design calculation results and input to the software - YHSM2

Description	Value
G_{av} (Wh/m^2/day)	5970
E_L (Wh/day)	20,038.8Wh/day
PV area (m^2)	45.71m^2
PV Peak Power (W_P)	5,484.61W_P
No of modules required	74
Approximate value of N_s x N_p	2 x 37
Battery Size	7*215Ah=1505
Charge Controller	250A at 24V
Inverter	2700W, 24 V_{DC}, 220 V_{AC}, and 50 Hz

Taking the data obtained from the above calculation, those values required by the software in order to simulate and analyze the designed PV system are entered in to the RETScreen. 74 of the selected modules are used and 48m2 roof area is needed for the establishment of the PV panels in order to meet the required electricity load.

Table 4.38: On-site power generation and supply using PV system - YHSM2

Lighting -Area/Zone	Base Case Lighting Load (kW)	Proposed Case Power Saving (kW)
Corridor	0.993	0.993
Parking	1.011	1.011
Total	**2.004**	**2.004**

Yerga Haile Shopping Mall – Total

The output of the RETScreen PV system analysis is provided in appendix C-2.

Table 4.39: On-site power generation and supply using PV system - YHSM

Lighting -Area/Zone	Base Case Lighting Load (kW)	Proposed Case Power Saving (kW)
Corridor	2.599	2.599
Parking	3.201	3.201
Total	**5.800**	**5.800**

4.2.3.3. Overall Power Saving Analysis

Yerga Haile Phase 1: The power saving analysis for the energy conserving design is carried out considering saving of both the energy efficient design and the onsite power generating PV system. The result shows that the power demand of this building reduced from 181.18kW to 144.14kW giving a percentage power saving of 20.44% which is equal to 37.04kW.

Yerga Haile Phase 2: The power saving analysis for the energy conserving design is carried out considering saving of both the energy efficient design and the onsite power generating PV system. The result shows that the power demand of this building reduced from 134.83kW to 99.08kW giving a percentage power saving of 26.51% which is equal to 35.74kW.

Yerga Haile Shopping Mall: The overall power saving analysis for the energy conserving design is carried out considering both the energy efficient design and the PV system. The result shows that the power demand of this building reduced from 316.01kW to 243.22kW giving a percentage power saving of 23.03% which is equal to 72.79kW.

Table 4.40: Overall power saving analysis of the energy conserving design - YHSM

Total power demand of base case electrical system (kW)	**316.01**
Total power demand of proposed case energy conserving system (kW)	**243.22**
Total power saving of proposed case energy conserving system (kW)	**72.79**
Percentage power saving of proposed case energy conserving system (%)	**23.03**

4.3. Annual Energy Consumption and Saving Analysis

In the previous sub section, the base case electrical systems of the two sample commercial buildings were redesigned by using energy efficient electrical system design techniques and renewable energy technologies and an energy conserving electrical design was proposed. After the redesign of the electrical systems of the buildings, the power saving of the proposed energy conserving electrical systems were also analyzed by manipulating the base case and proposed case power demand data using an excel spreadsheet.

The next step is the evaluation and analysis of the annual energy consumption and annual energy saving of the proposed energy conserving electrical systems designed for the two sample commercial buildings, which is carried out by using both excel spreadsheet and RETScreen analysis software.

4.3.1. Inputs to the software

Excel spreadsheet is used to calculate the annual energy consumption and annual energy saving of the proposed energy conserving electrical systems by following the same procedure that was followed to estimate the base case annual energy consumption of the buildings electrical system. It is carried out by manipulating the proposed case power demand and the operating hour's data of the loads in the energy efficient electrical system. The annual energy supply of the proposed PV system was also taken in to consideration.

RETScreen is used to model the lighting system, the electrical equipments and the hot water system in order to evaluate the energy use and savings, costs and financial viability of the lighting, electrical equipment and hot water energy efficiency measures taken.

The software is used for assessing the technical and financial feasibility of the proposed energy conserving electrical design by analyzing the system through a comparison between the ‘base case’, which is the conventional system, and the ‘proposed case’ which is the energy conserving system. The base case and the proposed case power demand of each function in the electrical systems were used as an input to the RETScreen software in order to analyze the annual energy consumption and annual energy saving of the proposed energy conserving design.

Inputs to the software to analyze the annual energy consumption and annual energy saving of the energy efficient systems include the following.

- The base case and proposed case power demand of
  - → lighting system of each area/zone
  - → each electrical equipment, appliances pumps, lift machines and funs
  - → hot water system
- The base case and proposed case operating hours per day of
  - → lighting system of each area/zone
  - → each electrical equipment, appliances pumps, lift machines and funs
  - → hot water system
- Quantity of each type of electrical equipment
- Electricity rate or energy cost in $/mwh
- Incremental initial cost of each proposed system
- Total floor area of the building
- Historical total annual energy consumption of the building

And the RETScreen software photovoltaic power model was also used to evaluate the energy production and savings, costs, and financial viability, and to determine if a PV system is cost-effective alternative to use within the building. In order to do so, the following were used as an input to the software.

- Type of PV module, manufacturer, model and power capacity (the same one chosen and used to design the PV system), selected from the database of the software
- Number of modules based on the required PV area, as obtained from the PV system design calculation result
- Solar tracking mode and slope of the PV panel
- One year data of monthly average daily solar radiation on a horizontal surface in kwh/m^2/day

- Base case load characteristics of the electrical system to be supplied by the PV power
- Proposed case end use energy efficiency measures
- Proposed case load characteristics of the electrical system to be supplied by the PV
- Efficiency of inverter and other parts of the PV system
- Base case electricity rate or energy cost in $/mwh
- Incremental initial cost of each proposed system

This section presents the result of the annual energy consumption and annual energy saving analysis carried out for the proposed energy efficient system, PV power generation system and the overall energy conserving systems for the two sample commercial buildings.

4.3.2. Annual Saving Analysis for the Hotel Building

The annual energy saving analysis of the proposed energy efficient design is carried out for the hotel building. The result shows that a saving of 36.96MWh, a reduction from 49.943MWh to 12.983MWh is obtained from the lighting system and a saving of 82.6997MWh, a reduction from 352.827 to 270.128MWh is obtained from the rest of the electrical system in the building. This brings the total annual energy consumption from 402.77MWh to 283.111MWh saving 29.71% which is 119.6598MWh of energy per year. The output of the RETScreen energy efficient system analysis is provided in appendix B-1.

Table 4.41: Annual energy saving of proposed energy efficient lighting- BGH

Area/Zone	Operating Hours per day	Base Case Electrical Load (kW)	Proposed Case Electrical Load (kW)	Power Saving (kW)	Base Case Annual Energy Consumption (kWh)	Proposed Case Annual Energy Consumption (kWh)	Annual Energy Saving (kWh)
Corridor	8	3.19	0.96	2.23	9303.12	2790.94	6512.18
Stair	8	1.73	0.45	1.28	5045.76	1311.90	3733.86
Toilet	3	7.68	1.08	6.60	8409.60	1184.35	7225.25
others	3	24.83	7.03	17.80	27184.47	7695.66	19488.81
Sub Total		**37.42**	**9.51**	**27.91**	**49942.95**	**12982.85**	**36960.10**

Table 4.42: Annual energy saving of proposed energy efficient equipments - BGH

Description	Quantity	load (kW)	Operating Hours per day	Base Case Electrical Load (kW)	Proposed Case Electrical Load (kW)	Power Saving (kW)	Base Case Annual Energy Consumption (kWh)	Proposed Case Annual Energy Consumption (kWh)	Annual Energy Saving (kWh)
Pumps and Motors									
Fire Pump	1	7.20	0	7.2	7.2	0	0.00	0.00	0.00
Domestic Pump	2	2.40	1.32	4.8	4.8	0	2312.64	2312.64	0.00
Goods Lift	1	12.00	4	12	12	0	17520.00	17520.00	0.00
Lift Machine	1	28.80	8	28.8	28.8	0	84096.00	84096.00	0.00
Exhaust Fans	6	0.20	1.5	1.2	0.48	0.72	657.00	262.80	394.20
Kitchen Equipments									
Injera Mitad	1	2.40	0	2.4	1.8	0.6	0.00	0.00	0.00
Stoves	6	2.40	7	14.4	10.8	3.6	24528.00	18396.00	6132.00
Coffee Machine	1	2.40	5	2.4	1.8	0.6	4380.00	3285.00	1095.00
Ovens	2	4.80	3	9.6	7.2	2.4	10512.00	7884.00	2628.00
Deep Fryer	1	14.40	2	14.4	10.8	3.6	10512.00	7884.00	2628.00
Frying Pan	1	8.16	3	8.16	6.12	2.04	8935.20	6701.40	2233.80
Steam cooker	1	3.60	3	3.6	2.7	0.9	3942.00	2956.50	985.50
Fridge	4	2.40	8	9.6	6.24	3.36	28032.00	18220.80	9811.20
Dishwasher	1	7.92	3	7.92	5.94	1.98	8672.40	6504.30	2168.10
Exhaust Fans	2	0.80	7	1.6	0.64	0.96	4088.00	1635.20	2452.80
Water Heater	1	1.20	7	1.2	0.6	0.6	3066.00	1533.00	1533.00
Boiler	1	16.80	3.6	16.8	8.4	8.4	22075.20	11037.60	11037.60
Laundry machines									
Washer	1	20.00	5.07	20	12.6	7.4	37021.43	23323.50	13697.93
Dryer	1	25.20	5.07	25.2	15.876	9.324	46647.00	29387.61	17259.39
Guest Room and Others									
Televisions	40	0.20	4	8	4.8	3.2	11680.00	7008.00	4672.00
Refrigerators	34	0.20	8	6.8	5.44	1.36	19856.00	15884.80	3971.20
Sauna	1	9.60	0.57	9.6	9.6	0	2002.29	2002.29	0.00
Others	1	62.80	0.1	62.8	62.8	0	2292.20	2292.20	0.00
Sub Total				**278.48**	**227.44**	**51.04**	**352827.35**	**270127.64**	**82699.72**
Total				**315.90**	**236.95**	**78.95**	**402770.30**	**283110.48**	**119659.8**
%						**24.99**			**29.709**

In addition to the energy saving of the proposed energy efficient system, the implementation of the proposed PV system can save 4102.83kWh of energy annually resulting in a reduction of the overall annual energy consumption from 402.770MWh to 279.008MWh. This increases the overall annual energy saving of the proposed energy conserving system to 123.763MWh which is equal to 30.728% of the base case electrical system annual energy consumption. The output of the RETScreen overall energy conserving system analysis is provided in appendix B-3.

Table 4.43: Annual energy saving of proposed on-site power generation system - BGH

Lighting					
Area/Zone	**Operating Hours per day**	**Base Case Electrical Load (kW)**	**Proposed Case Power Saving (kW)**	**Base Case Annual Energy Consumption (kWh)**	**Proposed Case Annual Energy Saving (kWh)**
Corridor	8	0.96	0.96	2790.94	2790.94
Stair	8	0.45	0.45	1311.90	1311.90
Sub Total		**1.41**	**1.41**	**4102.83**	**4102.83**

Table 4.44: Annual energy saving of proposed energy conserving design - BGH

Description	**Base Case Electrical Load (kW)**	**Proposed Case Electrical Load (kW)**	**Power Saving (kW)**	**Base Case Annual Energy Consumption (kWh)**	**Proposed Case Annual Energy Consumption (kWh)**	**Annual Energy Saving (kWh)**
Total	**315.90**	**235.55**	**80.35**	**402770.30**	**279007.65**	**123762.66**
%			**25.437**			**30.728**

4.3.3. Annual Saving Analysis for the Mixed Use Building

The annual energy saving analysis of the proposed energy efficient design has been carried out for the phase 1 building. The result shows that a saving of 107.853MWh is obtained from the lighting system and a saving of 0.657MWh is obtained from the rest of the electrical system in the building. This brings the total annual energy consumption from 303.981MWh to 195.471MWh saving 108.510MWh of energy which is 35.7% of the total.

Similarly, the result of the annual energy saving analysis carried out for the proposed energy efficient design of the phase 2 building shows that a saving of 66.644MWh is obtained from the lighting system and a saving of 14.618MWh is obtained from the rest of the electrical system. This brings the total annual energy consumption from 156.571MWh to 75.309MWh saving 81.262MWh of energy which is 51.9% of the total.

The total annual energy saving of the energy efficient design for the two buildings is

189.772MWh, which is equal to 41.21% of the base case annual energy consumption of the buildings. This shows a reduction of the annual energy consumption from 460.552MWh to 270.78MWh. The output of the RETScreen energy efficient system analysis is provided in appendix C-1.

Table 4.45: Annual energy saving of proposed energy efficient lighting - YHSM

Area/Zone	Operating Hours per day	Base Case Electrical Load (kW)	Proposed Case Electrical Load (kW)	Power Saving (kW)	Base Case Annual Energy Consumption (kWh)	Proposed Case Annual Energy Consumption (kWh)	Annual Energy Saving (kWh)
Corridor	10	9.98	2.60	7.38	36434.30	9487.08	26947.22
Parking	10	12.31	3.20	9.11	44938.80	11684.09	33254.71
Stair	3	2.16	0.56	1.60	2365.20	614.95	1750.25
Toilet	10	0.67	0.17	0.49	2430.90	632.03	1798.87
Shop	10	26.00	7.69	18.31	94892.70	28076.35	66816.35
Office	8	15.41	4.62	10.79	44991.36	13497.41	31493.95
Bank	8	4.21	1.26	2.95	12299.04	3689.71	8609.33
Kitchen	8	0.72	0.22	0.50	2102.40	630.72	1471.68
Restaurant	8	1.15	0.35	0.81	3363.84	1009.15	2354.69
Sub Total		**72.61**	**20.67**	**51.94**	**243818.54**	**69321.49**	**174497.05**

Table 4.46: Annual energy saving of proposed energy efficient equipments - YHSM

Description	Quantity	Electrical load (kW)	Operating Hours per day	Base Case Electrical Load (kW)	Proposed Case Electrical Load (kW)	Power Saving (kW)	Base Case Annual Energy Consumption (kWh)	Proposed Case Annual Energy Consumption (kWh)	Annual Energy Saving (kWh)
Pumps and Motors									
Water Pump	2	3.50	0.6	7	7	0	1533	1533	0
Pump Sump	1	1.50	1	1.5	1.5	0	547.5	547.5	0
Fans	2	1.50	2	3	1.2	1.8	2190	876	1314
Lift	2	25.00	8	50	50	0	146000	146000	0
Water Pump	2	1.50	0.6	3	3	0	657	657	0
Kitchen Equipments									
Stoves	2	12.00	4	24	18	6	35040	26280	8760
Coffee Machine	1	4.00	8	4	3	1	11680	8760	2920
Oven	1	25.00	1	25	18.75	6.25	9125	6843.75	2281.25
Water Heater	2	1.50	5	3	3	0	5475	5475	0
Others									
Others	1	122.90	0.1	122.9	122.9	0	4485.85	4485.85	0
Sub Total				**243.40**	**228.35**	**15.05**	**216733.35**	**201458.10**	**15275.25**

Total		**316.01**	**249.02**	**66.99**	**460551.89**	**270779.59**	**189772.30**
%				**21.197**			**41.205**

The proposed PV system for the phase 1 building increased the annual energy saving of the proposed energy conserving system to 122.367MWh which is equal to 40.255% of the base case annual energy consumption of the building. This shows a reduction of the total annual energy consumption from 303.981MWh to 181.614MWh.

Similarly, through the proposed PV system to the phase 2 building the annual energy saving of the proposed energy conserving system is increased to 56.57%, which is equal to 88.576MWh of energy saving that resulted from a reduction of the total annual energy consumption from 156.571MWh to 67.995MWh.

The overall annual energy saving analysis was carried out for the two buildings by considering both the proposed energy efficient and PV systems. It shows that, the proposed PV systems resulted in a reduction of the total annual energy consumption from 460.552MWh to 249.608MWh, increasing the total annual energy saving of the proposed energy conserving system to 210.944MWh, which is equal to 45.8% of the base case annual energy consumption of the buildings. The output of the RETScreen overall energy conserving system analysis is provided in appendix C-3.

Table 4.47: Annual energy saving of proposed on-site power generation system - YHSM

Lighting					
Area/Zone	**Operating Hours per day**	**Base Case Electrical Load (kW)**	**Proposed Case Power Saving (kW)**	**Base Case Annual Energy Consumption (kWh)**	**Proposed Case Annual Energy Saving (kWh)**
Corridor	10	2.60	2.60	9487.08	9487.08
Parking	10	3.20	3.20	11684.09	11684.09
Sub Total		**5.80**	**5.80**	**21171.17**	**21171.17**

Table 4.48: Annual energy saving of proposed energy conserving design - YHSM

Description	**Base Case Electrical Load (kW)**	**Proposed Case Electrical Load (kW)**	**Power Saving (kW)**	**Base Case Annual Energy Consumption (kWh)**	**Proposed Case Annual Energy Consumption (kWh)**	**Annual Energy Saving (kWh)**
Total	**316.01**	**243.22**	**72.79**	**460551.89**	**249608.43**	**210943.46**
%			**23.033**			**45.802**

CHAPTER 5

LIFE TIME COST ANALYSIS

The life time cost analysis of the proposed energy conserving electrical systems is carried out for both of the sample hotel and mixed use buildings. The analysis has been done using RETScreen in order to determine the financial feasibility of the proposed energy efficient system, the PV system and the overall energy conserving system.

5.1. Inputs to the Software

As mentioned in the background of this paper, subsection 1.1, the national power provider company, EEPCo, categorizes national energy use in five broad sectors: domestic/residential, commercial, street light, industrial LV and industrial HV [6]. The electricity charges (rates) vary according to these different categories/sectors of users. There are also different tariff blocks within each user category. The "general/commercial" category includes government offices, private offices, international organizations, embassies, and most business sectors excluding industries [37]. The current energy tariff rates for this category are shown in the following table.

Table 5.1: EEPCo's current energy tariff for commercial sector [37]

No.	Tariff Category and block ID	Monthly Consumption in kWh	Rate in birr	Rate in USD
1	General (Commercial) Sector			
1.1	First Block	First 50 kW	0.6088 birr/kWh	0.0346$/ kWh
1.2	Second Block	Above 50 kWh	0.6943 birr/kWh	0.0394$/ kWh

For the commercial sector, the current average EEPCo tariff including monthly service fees is 0.69birr/kWh [38]. Dividing this value by the exchange rate of January 24, 2012, which was equal to 17.6101birr/USD [39] gives the energy rate in $/kWh, 0.0392$/kWh (≈0.04$/kWh). This same energy cost value of 0.04$/kWh was obtained after a calculation was carried out to get the annual average electrical energy cost rate for the two buildings, based on the data that has been extracted from their respective electric bills. The calculation was done by dividing the total annual cost of electrical energy paid to the corresponding total annual energy consumption of the buildings. The value obtained in birr/kWh was then converted to $/kWh using the exchange rate given before. For example, the total annual electrical energy cost of the Beer Garden hotel building paid for the year 2010/11, which is 284,757.94birr divided by the annual total energy consumption of the building for that same year, 408640kWh gives 0.6968birr/kWh. By dividing this value by the exchange rate, which was equal to 17.6101birr/USD gives the energy rate in $/kWh, 0.0396$/kWh (≈0.04$/kWh). The same calculation was done for the Yerga Haile shopping mall to find the annual average energy rate resulting in a value equal to the one found for the hotel building. Therefore, to execute the life time cost analysis of the proposed systems by using RETScreen, an average electricity rate of $40/MWh has been taken as an input to the software.

Fundamental to RETScreen is a comparison between a 'base case', typically the conventional technology, and a 'proposed case' which is typically the clean energy technology. The software is not concerned with the absolute costs, but rather the costs of the proposed case that are in excess of those for the base case (the incremental initial costs of the proposed systems). Typically, the costs will not be the same for the base case and the proposed case: the proposed case will have higher initial costs and lower annual costs (i.e. savings).

When calculating the incremental initial cost of the proposed energy conserving system, costs of the components associated with both the base case and the proposed case systems were assessed and different prices were examined. The incremental cost of the proposed energy efficient system components and the costs of the PV system components used when calculating the initial cost of the system are attached in appendix D [25, 34, 35, 40-48]. These values were used as an input to the software in order to carry out the financial feasibility of the proposed energy conserving system. The results of the life time cost analysis of the proposed energy conserving electrical systems carried out for both of the sample hotel and mixed use buildings are discussed in the next subsections. The outputs of the RETScreen software are also provided, including the financial feasibility of the proposed energy efficient system, the PV system and the overall energy conserving system.

Table 5.2: Summary of energy cost saving analysis result

Building	**Energy rate $/ MWh**	**Base case**		**Proposed case**		**Fuel cost savings**		
		Annual Energy consumption (MWh)	**Annual Energy cost ($)**	**Annual Energy consumption (MWh)**	**Annual Energy cost ($)**	**Annual Energy saving (MWh)**	**Annual Energy saving (%)**	**Annual Energy cost savings**
BGH	40.0	402.8	16,110	279.0	11,160	123.8	30.7%	$ 4,950
YHSM1	40.0	304.0	12,159	181.6	7,265	122.4	40.3%	$ 4,895
YHSM2	40.0	156.6	6,263	68.0	2,720	88.6	56.6%	$ 3,543
YHSM	40.0	460.6	18,422	249.6	9,984	210.9	45.8%,	$ 8,438

5.2. Life Time Cost Analysis for the Hotel Building

The proposed energy efficient system for this building brings with it an additional cost which is around $33,190. At the same time the implementation of this system will bring annual cost saving of $4,786 by decreasing the annual energy cost from $16,110 to $11,324. The result of the financial analysis shows that this proposed system has a payback period of 6.3yrs. The output of the RETScreen financial analysis for the energy efficient system is provided in appendix B-1.

And the proposed PV system has an additional cost of around $13,802. This system will bring annual energy cost saving of $574. The result of the financial analysis shows that this proposed system has a payback period of 18.7yrs. The output of the RETScreen financial analysis for the PV system is provided in appendix B-2.

The overall proposed energy conserving system for this building brings with it an additional cost of $40,023. At the same time the implementation of this system will bring annual cost saving of $4,950 by decreasing the annual energy cost from $16,110 to $11,160. The result of the financial analysis shows that this proposed system has a payback period of 7.3yrs. The output of the RETScreen financial analysis for the energy conserving system is provided in appendix B-3.

Table 5.3: Summary of the LTCA result for the proposed system - BGH

	Additional Cost of the Proposed System ($)	Annual Energy Cost ($)		Annual Energy Cost Saving ($)	Payback Period (yrs)
		Base Case System	Proposed Case System		
Hotel Building					
Proposed Energy Efficient System	33,190	16,110	11,324	4,786	6.3
Proposed PV System	13,802	574	0	574	18.7
Overall Proposed Energy Conserving System	40,023	16,110	11,160	4,950	7.3

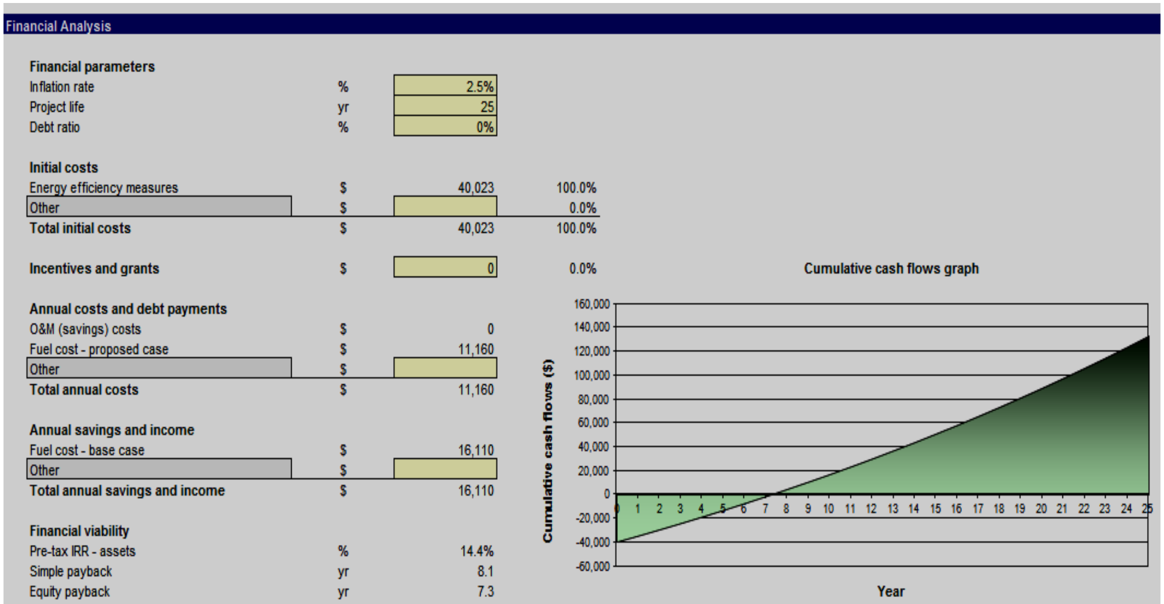

Figure 5.1: Overall financial analysis result for the energy conserving system - BGH

5.3. Life Time Cost Analysis for the Mixed Use Building

The proposed energy efficient system for the phase 1 building brings with it an additional cost which is around $58,770. At the same time the implementation of this system will bring annual cost saving of $4,340 by decreasing the annual energy cost from $12,159 to $7,819. Based on the result of the financial analysis carried out, this proposed system has a payback period of 11.6yrs. Similarly, the proposed energy efficient system for the phase 2 building brings with it an additional cost which is around $32,615. At the same time the implementation of this system will bring annual cost saving of $3,251 by decreasing the annual energy cost from $6,263 to $3,012. Based on the financial analysis result, this proposed system has a payback period of 8.9yrs. The overall proposed energy efficient system for the mixed use building brings with it an additional cost which is around $91,385. At the same time the implementation of this system will bring annual cost saving of $7,591 by decreasing the annual energy cost from $18,422 to $10,831. The result of the financial analysis shows that this proposed system has a payback period of 10.4yrs. The output of the RETScreen financial analysis for the energy efficient system is provided in appendix C-1.

And the proposed PV system for the phase 1 building has an additional cost of $38,098. This system will bring annual energy cost saving of $2,014. Based on the result of the financial analysis carried out, this proposed system has a payback period of 15.4yrs. Similarly the proposed PV system for the phase 2 building has an additional cost of $19,012. This system will bring annual energy cost saving of $1,241. Based on the financial analysis result, this proposed system has a payback period of 12.9yrs. The proposed PV systems for the two buildings of the Yerga Haile shopping mall have an additional cost of $57,110. This system will bring annual energy cost saving of $3,255. The result of the financial analysis shows that this proposed system has a payback period of 14.4yrs. The output of the RETScreen financial analysis for the PV system is provided in appendix C-2.

The overall proposed energy conserving system for the phase 1 building has an additional cost of $79,537. At the same time, this system will bring annual cost saving of $4,895 by decreasing the annual energy cost from $12,159 to $7,265. Based on the result of the financial analysis carried out, this proposed system has a payback period of 13.5yrs. The overall proposed energy conserving system for the phase 2 building has an additional cost of $43,893. At the same time, this system will bring annual cost saving of $3,543 by decreasing the annual energy cost from $6,263 to $2,720. Based on the financial analysis result, this proposed system has a payback period of 10.7yrs. The overall proposed energy conserving system for the two buildings of the Yerga Haile shopping mall has an additional cost of $123,430. At the same time, this system will bring annual cost saving of $8,438 by decreasing the annual energy cost from $18,422 to $9,984. The result of the financial analysis shows that this proposed system has a payback period of 12.4yrs. The output of the RETScreen financial analysis for the energy conserving system is provided in appendix C-3.

Table 5.4: Summary of the LTCA result for the proposed system - YHSM

	Additional Cost of the Proposed System ($)	**Annual Energy Cost ($)**		**Annual Energy Cost Saving ($)**	**Payback Period (yrs)**
		Base Case System	**Proposed Case System**		
Mixed Use Building-Phase 1					
Proposed Energy Efficient System	58,770	12,159	7,819	4,340	11.6
Proposed PV System	38,098	2,014	0	2,014	15.4
Overall Proposed Energy Conserving System	**79,537**	**12,159**	**7,265**	**4,895**	**13.5**

Mixed Use Building-Phase 2					
Proposed Energy Efficient System	32,615	6,263	3,012	3,251	8.9
Proposed PV System	19,012	1,241	0	1,241	12.9
Overall Proposed Energy Conserving System	**43,893**	**6,263**	**2,720**	**3,543**	**10.7**
Mixed Use Building					
Proposed Energy Efficient System	91,385	18,422	10,831	7,591	10.4
Proposed PV System	57,110	3,255	0	3,255	14.4
Overall Proposed Energy Conserving System	**123,430**	**18,422**	**9,984**	**8,438**	**12.4**

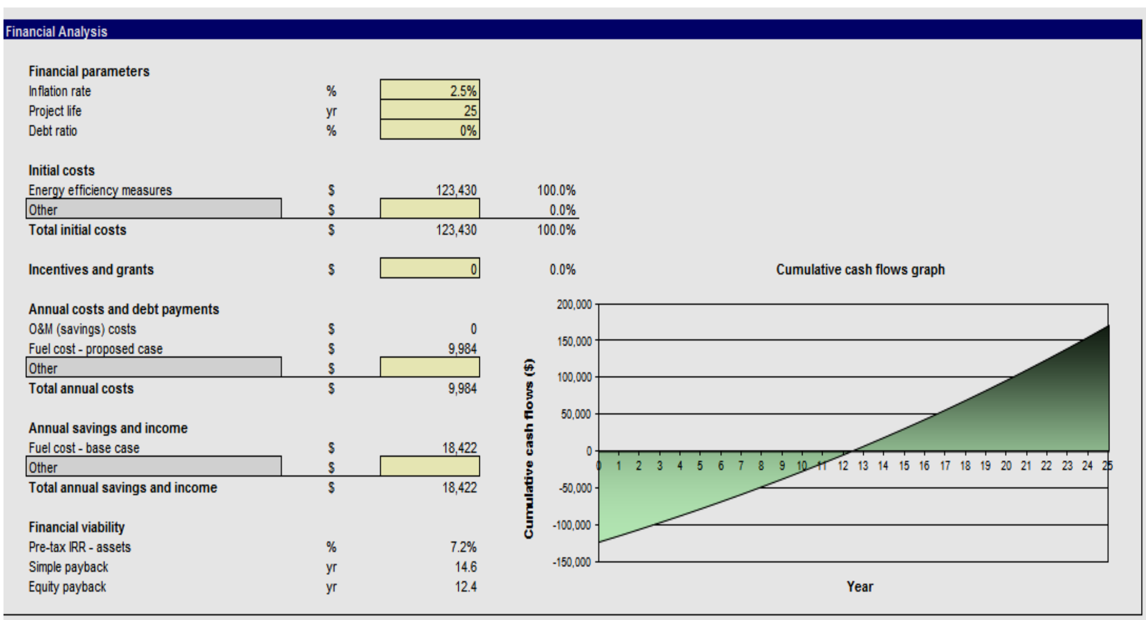

Figure 5.2: Overall financial analysis result for the energy conserving system – YHSM

CHAPTER 6
CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The operation of commercial buildings accounts for up to 25% of the total energy consumption in Ethiopia, which is a significant portion of the nation's energy use. This figure indicates that the potential for energy savings in the building sector is large. In this thesis work the key factors associated with the successful achievement of energy conserving building design are identified and evaluated through a case study. Even in a conservative application, the results of this study show that for commercial buildings in Addis Ababa, it is technically and economically realistic to reduce annual energy consumption by 25% - 50%, depending on the type of the commercial building considered, or even more if optimum mixes of energy efficient design strategies are implemented. The results indicate that the saving in the annual energy consumption of the proposed overall energy conserving system can increase even more to 30% - 55% through the implementation of an onsite power generating PV system.

The study also points out that energy conserving buildings cost at first but yield much more over the entire life of the buildings as a result of savings in money that comes from the efficient use of energy and the use of the energy supply from the PV system. The result of the financial analysis indicates that the proposed energy efficient systems have a payback period of 6 to 12 years depending on the type of building considered. And this study makes it apparent that there are constraints in the technology of onsite energy generation sector in Ethiopia. Even for the available technology the price becomes an uphill battle to apply in the desired intensity. The financial analysis done for the proposed PV systems shows that it has a payback period of 12 to 19 years based on the size of the system proposed and the load it is required to supply. But the result of the life time cost analysis carried out to the overall proposed energy conserving system shows that the payback period of the whole system will be reduced to 7 to 14 years period of time. This proves that, in conjunction with the onsite generation system, considering energy efficiency concepts as much as possible will increase the saving and shortens the payback period of the whole energy conserving system. So, the preference is just between the knowledge of up-front or initial cost of the energy conserving system vs. its life-time cost.

With concerns for energy supply security and environmental problems increasing, it has become essential to create a sustainable environment to live in by finding ways to reduce load, increase efficiency and utilize renewable energy resources. This is not only a matter of choice but it's also a matter of insuring a better world for this and the upcoming generation. Hence, to succeed in developing a sustainable and energy conscious society, the energy performance of the sectors connected to the national grid of the country will always need to be improved as energy conserving technologies improve. And creating sustainable environment starts with constructing sustainable buildings to work or live in.

Even though sustainable energy and energy conserving building design technology is still not yet matured technology sector in the world, there is better awareness, knowledge, finance and technology for the implementation of such concepts in the developed nations compared to developing nations. But this doesn't mean that developing countries should do nothing to conserve energy, rather should do more. For buildings of Addis Ababa, attempt to incorporate such concepts will give them big jump to the future science and technology race. In addition to the financial benefits, it will provide them a competitive edge and a big leap to attain sustainability.

When energy is saved in commercial buildings by using energy conserving electrical system design strategies, it can be used for a school, a clinic or a factory which couldn't have access to electricity due to the power supply shortage in the country. Therefore, the implementation of such concepts will not only save energy cost of the buildings for their life time but it will also have a huge support for the improvement of the electric energy access of the nation. In simple words energy conservation is of national concern as it is a fundamental way of reducing poverty and a means to get one step closer to become a developed nation with better living condition for all citizens.

6.2. Recommendation

The saving or the reduction of annual energy consumption proved by this study to be technically and economically feasible for commercial buildings, by the implementation of energy conserving electrical system design strategies, will considerably increase even more if energy management systems are applied when the buildings are operational.

Energy conserving buildings will be best implemented in an integrated fashion wherein owners, designers and contractors commit from the onset to work together and follow the principles while designing and construction their projects. These will enable them to take a collaborative, thoughtful and deliberate approach when addressing such critical energy conservation issues.

Energy conservation is the least expensive source of energy available today. When every consumer conserves energy, the national power providing utility can have enough energy available to meet the needs of all users at peak hours without building and operating a new power plant just to cover the demand over that portion of the day. Hence, incentive programs for saving energy should be considered by the national power provider, as it is profitable to the company while improving national energy security. For these same reasons, the government should also consider developing and realizing different incentive programs that can encourage investors in implementing energy conserving concepts while designing and constructing commercial buildings in the country.

To stop wasteful use of energy by the consumers and bridge the power demand-supply gap in Ethiopia, the government should enact an energy conservation act with provisions related to the enforcement of Energy Conservation Building Codes (ECBC) for efficient use of energy in commercial buildings. The development of such codes is necessary to introduce a level of awareness for energy conservation and benchmark energy consumption levels in large commercial buildings as these codes set the minimum energy efficiency standards for design and construction of a building. These codes can be developed by participation of all stakeholders including architects, engineers, building product manufacturers, and concerned organizations. It should be prepared to ensure that the compliance processes are as simple, clear, and easy to use as possible by adopting proven techniques and best practices appropriately to suit the country's conditions. The government should take measures to ensure proper dissemination of information about ECBC compliance procedures while making it consumer friendly. It also must commit to identify appropriate methods of encouraging compliance, including monetary awards, publicity awards, building energy labels, and technical assistance.

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APPENDICES

Appendix A
Generation Capacity of Power Plants in Ethiopia

Appendix A: Generation Capacity of Power Plants in Ethiopia

		Capacity(MW)				
ICS		**Hydro**	**Diesel**	**Geothermal**	**Total**	**In-service Date**
1	Koka	43.2	-	-	43.2	1960
2	Awash II	32	-	-	32	1966
3	Awash III	32	-	-	32	1971
4	Finach	134	-	-	134	1973/2003
5	Melka Wakena	153	-	-	153	1988
6	Tis-Abay I	11.4	-	-	11.4	1964
7	Tis-Abay II	73	-	-	73	2001
8	Gilgel Gibe	184	-	-	184	2004
9	Aluto Langano	-	-	7.3	7.3	1999
10	Kaliti	-	14	-	14	2004
11	Dire Dawa	-	38	-	38	2004
12	Awash 7 killo	-	35	-	35	2004
13	Tekeze	300	-	-	300	Oct-09
14	Gilgel Gibe II	420	-	-	420	Jan-10
15	Beles	460	-	-	460	May-10
16	Alemaya	-	2.3	-	2.3	1958
17	Dire Dawa (MU)	-	4.5	-	4.5	1965
18	Adigrat	-	2.5	-	2.5	1992,93,95
19	Axum	-	3.2	-	3.2	1975,92
20	Adwa	-	3	-	3	1998
21	Mekelle	-	5.7	-	5.7	1984,91,93
22	Shire	-	0.8	-	0.8	1975,91'95
23	Jimma	-	1.1	-	1.1	
24	Nekempt	-	1.1	-	1.1	1984
25	Ghimbi	-	1.1	-	1.1	1962,84
	ICS Sub Total	**1842.60**	**112.30**	**7.30**	**1962.20**	
SCS						
1	Yadot	0.35	-	-	0.35	-
2	Sor	5	-	-	5	-
3	Dembi	0.8	-	-	0.8	-
4	Isolated diesel power plants	-	30.52	-	30.52	-
	SCS Sub Total	**6.15**	**30.52**	**0.00**	**36.67**	-
Total		**1848.75**	**142.82**	**7.30**	**1998.87**	**-**

Appendix B
Beer Garden Hotel Building:
Proposed System Analysis Result
(RETScreen Outputs)

Natural Resources Canada / Ressources naturelles Canada

Canada

RETScreen® International

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Clean Energy Project Analysis Software

Project information

See project database

Project name	Beer Garden Hotel - Energy Efficiency
Project location	Addis Ababa, Ethiopia
Prepared for	
Prepared by	Bezawit Teshome
Project type	Energy efficiency measures
Facility type	Commercial
Analysis type	Method 1
Heating value reference	Lower heating value (LHV)
Show settings	☐

Site reference conditions

Select climate data location

Climate data location	Addis Ababa
Show data	☐

Complete Energy Model sheet

RETScreen4 2010-09-22

NRCan/CanmetENERGY

RETScreen Energy Model - Energy efficiency measures project

Fuels & schedules

☑ Show data

Fuel			Fuel type 1	Fuel type 2	Fuel type 3	Fuel type 4	Fuel type 5	Fuel type 6
Fuel type			Electricity					
Fuel consumption - unit			MWh					
Fuel rate - unit			$/kWh					
Fuel rate			0.040					

Schedule	Unit		Schedule 1	Schedule 2	Schedule 3	Schedule 4	Schedule 5	Schedule 6
Description			24/7					
				Occupied	Occupied	Occupied	Occupied	Occupied
Temperature - space heating	°C							
Temperature - space cooling	°C							
Temperature - unoccupied	+/-°C							
Occupancy rate - daily			h/d					
Monday			24					
Tuesday			24					
Wednesday			24					
Thursday			24					
Friday			24					
Saturday			24					
Sunday			24					
Occupancy rate - annual	h/yr		8,760					
	%		100%					
Heating/cooling changeover temperature	°C	16.0						
Length of heating season	d	179						
Length of cooling season	d	186						

Facility characteristics

☑ Show data

Show: Fuel saved	Heating MWh	Cooling MWh	Electricity MWh	Incremental initial costs $	Fuel cost savings $	Incremental O&M savings $	Simple payback yr	Include measure? ☐
Heating system								
Cooling system								
Building envelope								
Ventilation								
Lights								
Corridor Lighting	-	-	7	4,392	260	0	16.9	☑
Stair Lighting	-	-	4	2,577	149	0	17.3	☑
Toilet Lighting	-	-	7	2,446	289	0	8.5	☑
Others	-	-	19	16,289	780	0	20.9	☑
Electrical equipment								
Kitchen Equipments	-	-	18	2,550	715	0	3.6	☑
Refrigerators	-	-	14	2,020	551	0	3.7	☑
Laundry Machines	-	-	31	516	1,238	0	0.4	☑
Lifts	-	-	0	0	0	0	-	☑
Others	-	-	17	2,400	690	0	3.5	☑
Hot water								
Pumps								
Domestic Pump	-	-	0	0	0	0	-	☑
Fans								
Exaust Fans	-	-	0	0	16	0	0.0	☑
Kitchen Fan	-	-	2	0	98	0	0.0	☑
Motors								
Process steam								
Heat recovery								
Compressed air								
Refrigeration								
Other								
Total	0	0	120	33,190	4,786	0	6.93	

Summary

☑ Show data

	Fuel		Base case		Proposed case		Fuel cost savings	
Fuel type	Fuel consumption - unit	Fuel rate	Fuel consumption	Fuel cost	Fuel consumption	Fuel cost	Fuel saved	Fuel cost savings
Electricity	MWh	$ 40.000	402.8	$ 16,110	283.1	$ 11,324	119.7	$ 4,786

Project verification Fuel type	Fuel consumption - unit	Fuel consumption - historical	Fuel consumption Base case	Fuel consumption - variance
Electricity	MWh	301.2	402.8	25%

Energy	Heating MWh	Cooling MWh	Electricity MWh	Total MWh
Energy - base case			403	403
Energy - proposed case			283	283
Energy saved			120	120
Energy saved - %			29.7%	29.7%

Benchmark		
Energy unit	kWh	
Reference unit	m²	3,350

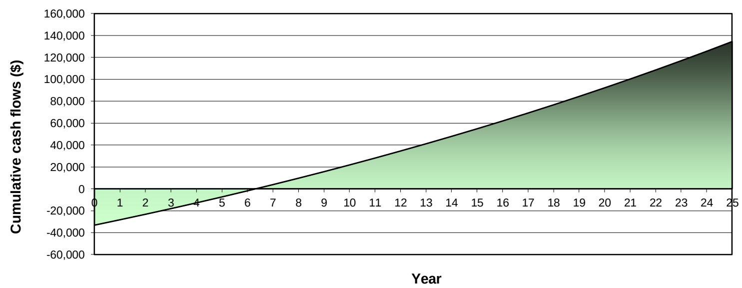
Benchmark Energy	Heating kWh/m²	Cooling kWh/m²	Electricity kWh/m²	Total kWh/m²
Energy - base case			120.2	120.2
Energy - proposed case			84.5	84.5
Energy saved			35.7	35.7

☐ Emission Analysis

Financial Analysis

Financial parameters			
Inflation rate	%	2.5%	
Project life	yr	25	
Debt ratio	%	0%	
Initial costs			
Energy efficiency measures	$	33,190	100.0%
Other	$		0.0%
Total initial costs	$	33,190	100.0%
Incentives and grants	$	0	0.0%
Annual costs and debt payments			
O&M (savings) costs	$	0	
Fuel cost - proposed case	$	11,324	
Other	$		
Total annual costs	$	11,324	
Annual savings and income			
Fuel cost - base case	$	16,110	
Other	$		
Total annual savings and income	$	16,110	
Financial viability			
Pre-tax IRR - assets	%	16.7%	
Simple payback	yr	6.9	
Equity payback	yr	6.3	

Cumulative cash flows graph



RETScreen® International
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Clean Energy Project Analysis Software

Project information

See project database

Project name	Beer Garden Hotel - PV System
Project location	Addis Ababa, Ethiopia
Prepared for	
Prepared by	Bezawit Teshome
Project type	Power
Technology	Photovoltaic
Grid type	Isolated-grid & internal load
Analysis type	Method 1
Heating value reference	Lower heating value (LHV)
Show settings	☐

Site reference conditions

Select climate data location

Climate data location	Addis Ababa
Show data	☑

	Unit	Climate data location	Project location
Latitude	˚N	9.0	9.0
Longitude	˚E	38.7	38.7
Elevation	m	2,324	2,324
Heating design temperature	°C	10.2	
Cooling design temperature	°C	25.0	
Earth temperature amplitude	°C	15.7	

Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January		15.9	63.0%	6.04	77.4	3.1	22.4	65	183
February		16.4	66.0%	6.78	77.4	2.6	24.4	45	179
March		17.9	66.0%	6.70	77.3	3.1	25.6	3	245
April		17.6	71.0%	6.54	0.0	3.6	24.1	12	228
May		17.8	67.0%	6.25	0.0	3.1	21.8	6	242
June		16.6	74.0%	5.10	0.0	2.6	18.6	42	198
July		15.0	83.0%	4.33	77.2	2.1	16.9	93	155
August		15.0	85.0%	4.29	77.3	2.1	16.8	93	155
September		15.6	79.0%	5.18	77.2	2.6	17.3	72	168
October		15.8	69.0%	6.74	77.3	3.6	17.8	68	180
November		15.2	66.0%	6.47	77.4	4.1	19.3	84	156
December		15.6	69.0%	6.00	77.5	3.6	20.5	74	174
Annual		16.2	71.5%	5.86	58.1	3.0	20.4	658	2,262
Measured at	m					10.0	0.0		

NASA UNEP GEF reeep

Complete Load & Network sheet

RETScreen4 2010-09-22 NRCan/CanmetENERGY

RETScreen Load & Network Design - Power project

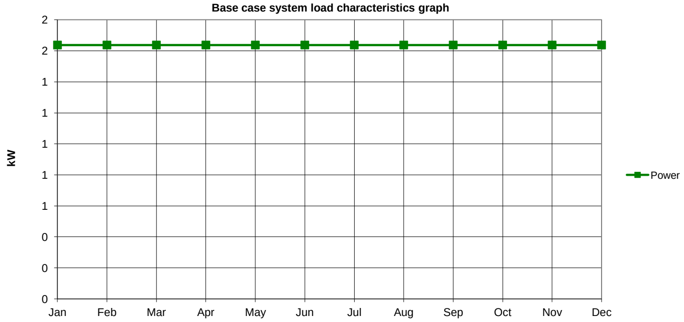
Power project	Unit	
Base case power system		
Grid type		Isolated-grid & internal load
Peak load - isolated-grid	kW	
Minimum load - isolated-grid	kW	5

Base case load characteristics

Month	Power gross average load kW
January	2
February	2
March	2
April	2
May	2
June	2
July	2
August	2
September	2
October	2
November	2
December	2

System peak electricity load over max monthly average		0.0%
Peak load - annual		2
Electricity	MWh	14
Electricity rate - base case	$/kWh	0.040
Total electricity cost		$ 574

Base case system load characteristics graph

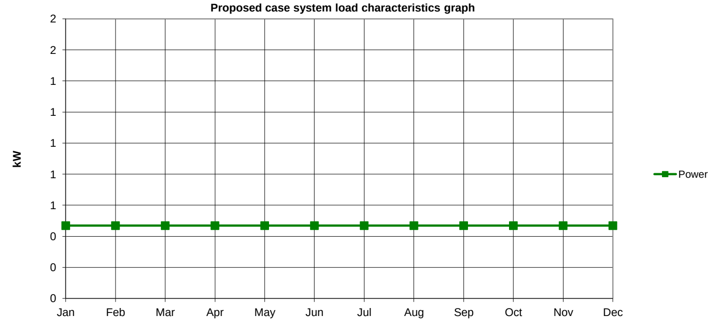


Proposed case load characteristics

Month	Power net average load kW
January	0
February	0
March	0
April	0
May	0
June	0
July	0
August	0
September	0
October	0
November	0
December	0

Peak load - annual 0

Proposed case system load characteristics graph



Proposed case energy efficiency measures

End-use energy efficiency measures	%	71%
Net peak electricity load	kW	0
Net electricity	MWh	4

Proposed case load and energy		Power
System peak load	kW	0
System energy	MWh	4

RETScreen Energy Model - Power project

☐ Show alternative units

Proposed case power system

Incremental initial costs

Technology		Photovoltaic
Analysis type		○ Method 1
		⦿ Method 2

Resource assessment

Solar tracking mode		Fixed
Slope	°	9.0
Azimuth	°	0.0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	6.04	6.51	0.0	0.011
February	6.78	7.12	0.0	0.011
March	6.70	6.80	0.0	0.011
April	6.54	6.43	0.0	0.011
May	6.25	6.00	0.0	0.010
June	5.10	4.87	0.0	0.008
July	4.33	4.18	0.0	0.007
August	4.29	4.20	0.0	0.007
September	5.18	5.18	0.0	0.009
October	6.74	7.00	0.0	0.012
November	6.47	6.95	0.0	0.011
December	6.00	6.53	0.0	0.011
Annu	**5.86**	**5.97**	**0.00**	**0.120**

Annual solar radiation - horizontal	MWh/m²	2.14
Annual solar radiation - tilted	MWh/m²	2.18

Photovoltaic

Type		mono-Si		
Power capacity	kW	3.15	$ 3,465	*See product database*
Manufacturer		BP Solar		
Model		mono-Si - BP 275 U	42 unit(s)	
Efficiency	%	11.6%		
Nominal operating cell temperature	°C	45		
Temperature coefficient	% / °C	0.40%		
Solar collector area	m²	27		
Miscellaneous losses	%	0.0%		

Inverter

Efficiency	%	76.5%
Capacity	kW	2.0
Miscellaneous losses	%	15.0%

Summary

Capacity factor	%	15.3%
Electricity delivered to load	MWh	4.103
Electricity exported to grid	MWh	0.120
Electricity rate - base case	$/MWh	40.00
Fuel rate - proposed case power system	$/MWh	0.00
Electricity rate - proposed case	$/MWh	0.00

Operating strategy	Electricity delivered to load MWh	Electricity exported to grid MWh	Remaining electricity required MWh	Power system fuel MWh	Operating profit (loss) $	Efficiency %
Full power capacity output	**4**	**0**	**0**	**0**	**164**	**-**
Power load following	4	0	0	0	164	-

Select operating strategy: Full power capacity output

☐ Emission Analysis

Financial Analysis

Financial parameters

Inflation rate	%	2.5%
Project life	yr	25
Debt ratio	%	0%

Initial costs

Power system	$	3,465	25.1%
Other	$	10,337	74.9%
Total initial costs	$	13,802	100.0%
Incentives and grants	$	0	0.0%

Annual costs and debt payments

O&M (savings) costs	$	0
Fuel cost - proposed case	$	0
	$	
Total annual costs	$	0

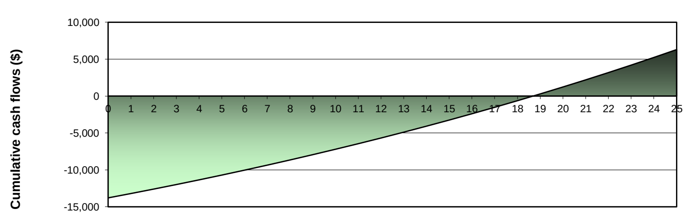
Annual savings and income

Fuel cost - base case	$	574
	$	
Total annual savings and income	$	574

Financial viability

Pre-tax IRR - assets	%	2.8%
Simple payback	yr	24.0
Equity payback	yr	18.7

Cumulative cash flows graph



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Canada

RETScreen® International

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Clean Energy Project Analysis Software

Project information

See project database

Project name	Beer Garden Hotel - Overall Energy Conservation
Project location	Addis Ababa, Ethiopia
Prepared for	
Prepared by	Bezawit Teshome
Project type	Energy efficiency measures
Facility type	Commercial
Analysis type	Method 1
Heating value reference	Lower heating value (LHV)
Show settings	☐

Site reference conditions

Select climate data location

Climate data location	Addis Ababa
Show data	☐

Complete Energy Model sheet

RETScreen4 2010-09-22

NRCan/CanmetENERGY

RETScreen Energy Model - Energy efficiency measures project

Fuels & schedules ☑ Show data

Fuel		Fuel type 1	Fuel type 2	Fuel type 3	Fuel type 4	Fuel type 5	Fuel type 6
Fuel type		Electricity					
Fuel consumption - unit		MWh					
Fuel rate - unit		$/kWh					
Fuel rate		0.040					

Schedule	Unit		Schedule 1	Schedule 2	Schedule 3	Schedule 4	Schedule 5	Schedule 6
Description			24/7					
				Occupied	Occupied	Occupied	Occupied	Occupied
Temperature - space heating	°C							
Temperature - space cooling	°C							
Temperature - unoccupied	+/-°C							
Occupancy rate - daily			h/d					
Monday			24					
Tuesday			24					
Wednesday			24					
Thursday			24					
Friday			24					
Saturday			24					
Sunday			24					
Occupancy rate - annual	h/yr		8,760					
	%		100%					
Heating/cooling changeover temperature	°C	16.0						
Length of heating season	d	179						
Length of cooling season	d	186						

Facility characteristics ☑ Show data

Show: Fuel saved	Heating MWh	Cooling MWh	Electricity MWh	Incremental initial costs $	Fuel cost savings $	Incremental O&M savings $	Simple payback yr	Include measure? ☐
Heating system								
Cooling system								
Building envelope								
Ventilation								
Lights								
Corridor Lighting	-	-	9	9,040	372	0	24.3	☑
Stair Lighting	-	-	5	4,762	202	0	23.6	☑
Toilet Lighting	-	-	7	2,446	289	0	8.5	☑
Others	-	-	19	16,289	780	0	20.9	☑
Electrical equipment								
Kitchen Equipments	-	-	18	2,550	715	0	3.6	☑
Refrigerators	-	-	14	2,020	551	0	3.7	☑
Laundry Machines	-	-	31	516	1,238	0	0.4	☑
Lifts	-	-	0	0	0	0	-	☑
Others	-	-	17	2,400	690	0	3.5	☑
Hot water								
Pumps								
Domestic Pump	-	-	0	0	0	0	-	☑
Fans								
Exaust Fans	-	-	0	0	16	0	0.0	☑
Kitchen Fan	-	-	2	0	98	0	0.0	☑
Motors								
Process steam								
Heat recovery								
Compressed air								
Refrigeration								
Other								
Total	0	0	124	40,023	4,950	0	8.08	

Summary ☑ Show data

	Fuel		Base case		Proposed case		Fuel cost savings	
Fuel type	Fuel consumption - unit	Fuel rate	Fuel consumption	Fuel cost	Fuel consumption	Fuel cost	Fuel saved	Fuel cost savings
Electricity	MWh	$ 40.000	402.8	$ 16,110	279.0	$ 11,160	123.8	$ 4,950

Project verification Fuel type	Fuel consumption - unit	Fuel consumption - historical	Fuel consumption Base case	Fuel consumption - variance
Electricity	MWh	301.2	402.8	25%

Energy	Heating MWh	Cooling MWh	Electricity MWh	Total MWh
Energy - base case			403	403
Energy - proposed case			279	279
Energy saved			124	124
Energy saved - %			30.7%	30.7%

Benchmark		
Energy unit	kWh	
Reference unit	m²	3,350

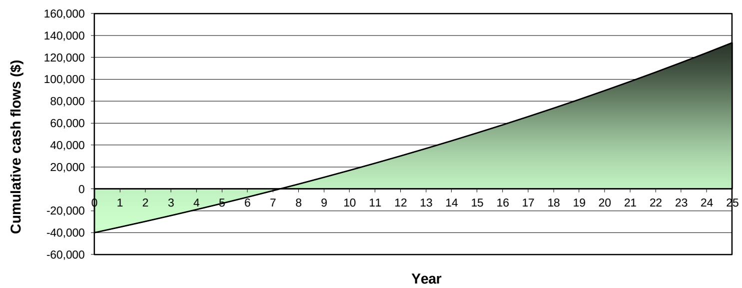
Benchmark Energy	Heating kWh/m²	Cooling kWh/m²	Electricity kWh/m²	Total kWh/m²
Energy - base case			120.2	120.2
Energy - proposed case			83.3	83.3
Energy saved			36.9	36.9

☐ **Emission Analysis**

Financial Analysis

Financial parameters			
Inflation rate	%	2.5%	
Project life	yr	25	
Debt ratio	%	0%	
Initial costs			
Energy efficiency measures	$	40,023	100.0%
Other	$		0.0%
Total initial costs	$	40,023	100.0%
Incentives and grants	$	0	0.0%
Annual costs and debt payments			
O&M (savings) costs	$	0	
Fuel cost - proposed case	$	11,160	
Other	$		
Total annual costs	$	11,160	
Annual savings and income			
Fuel cost - base case	$	16,110	
Other	$		
Total annual savings and income	$	16,110	
Financial viability			
Pre-tax IRR - assets	%	14.4%	
Simple payback	yr	8.1	
Equity payback	yr	7.3	

Cumulative cash flows graph



Appendix C
Yerga Haile Shopping Mall:
Proposed System Analysis Result
(RETScreen Outputs)

RETScreen® International

www.retscreen.net

Clean Energy Project Analysis Software

Project information

See project database

Project name	Yerga Haile Shopping Mall - Energy Efficiency
Project location	Addis Ababa, Ethiopia
Prepared for	
Prepared by	Bezawit Teshome
Project type	Energy efficiency measures
Facility type	Commercial
Analysis type	Method 1
Heating value reference	Lower heating value (LHV)
Show settings	☐

Site reference conditions

Select climate data location

Climate data location	Addis Ababa
Show data	☐

Complete Energy Model sheet

RETScreen Energy Model - Energy efficiency measures project

Fuels & schedules

☑ Show data

Fuel	Fuel type 1	Fuel type 2	Fuel type 3	Fuel type 4	Fuel type 5	Fuel type 6
Fuel type	Electricity					
Fuel consumption - unit	MWh					
Fuel rate - unit	$/kWh					
Fuel rate	0.040					

Schedule	Unit		Schedule 1	Schedule 2	Schedule 3	Schedule 4	Schedule 5	Schedule 6
Description			24/7					
				Occupied	Occupied	Occupied	Occupied	Occupied
Temperature - space heating	°C							
Temperature - space cooling	°C							
Temperature - unoccupied	+/-°C							
Occupancy rate - daily			h/d					
Monday			24					
Tuesday			24					
Wednesday			24					
Thursday			24					
Friday			24					
Saturday			24					
Sunday			24					
Occupancy rate - annual	h/yr		8,760					
	%		100%					
Heating/cooling changeover temperature	°C	16.0						
Length of heating season	d	179						
Length of cooling season	d	186						

Facility characteristics

☑ Show data

Show:	Heating	Cooling	Electricity	Incremental initial costs	Fuel cost savings	Incremental O&M savings	Simple payback	Include measure?
Fuel saved	MWh	MWh	MWh	$	$	$	yr	☐
Heating system								
Cooling system								
Building envelope								
Ventilation								
Lights								
Corridor Lighting	-	-	27	10,193	1,078	0	9.5	☑
Parking Lighting	-	-	33	14,872	1,330	0	11.2	☑
Stair Lighting	-	-	2	4,029	70	0	57.6	☑
Shop and Toilet Lighting	-	-	69	35,125	2,745	0	12.8	☑
Office, Bank, Kitchen and Restaurant	-	-	44	27,166	1,757	0	15.5	☑
Electrical equipment								
Kitchen Equipments	-	-	14	0	558	0	0.0	☑
Water Heater	-	-	0	0	0	0	-	☑
Others	-	-	0	0	0	0	-	☑
Lifts	-	-	0	0	0	0	-	☑
Hot water								
Pumps								
Water Pump	-	-	0	0	0	0	-	☑
Water Pump	-	-	0	0	0	0	-	☑
Pump Sump	-	-	0	0	0	0	-	☑
Fans								
Fans	-	-	1	0	53	0	0.0	☑
Motors								
Process steam								
Heat recovery								
Compressed air								
Refrigeration								
Other								
Total	0	0	190	91,385	7,591	0	12.04	

Summary

☑ Show data

	Fuel		Base case		Proposed case		Fuel cost savings	
Fuel type	Fuel consumption - unit	Fuel rate	Fuel consumption	Fuel cost	Fuel consumption	Fuel cost	Fuel saved	Fuel cost savings
Electricity	MWh	$ 40.000	460.6	$ 18,422	270.8	$ 10,831	189.8	$ 7,591

Project verification Fuel type	Fuel consumption - unit	Fuel consumption - historical	Fuel consumption Base case	Fuel consumption - variance
Electricity	MWh	451.1	460.6	2%

Energy	Heating MWh	Cooling MWh	Electricity MWh	Total MWh
Energy - base case			461	461
Energy - proposed case			271	271
Energy saved			190	190
Energy saved - %			41.2%	41.2%

Benchmark		
Energy unit	kWh	
Reference unit	m²	10,743

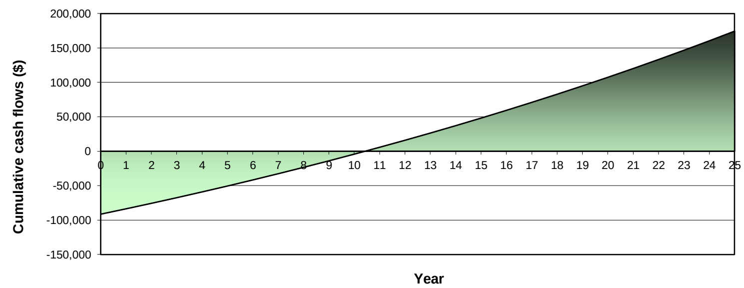
Benchmark Energy	Heating kWh/m²	Cooling kWh/m²	Electricity kWh/m²	Total kWh/m²
Energy - base case			42.9	42.9
Energy - proposed case			25.2	25.2
Energy saved			17.7	17.7

☐ Emission Analysis

Financial Analysis

Financial parameters			
Inflation rate	%	2.5%	
Project life	yr	25	
Debt ratio	%	0%	
Initial costs			
Energy efficiency measures	$	91,385	100.0%
Other	$		0.0%
Total initial costs	$	91,385	100.0%
Incentives and grants	$	0	0.0%
Annual costs and debt payments			
O&M (savings) costs	$	0	
Fuel cost - proposed case	$	10,831	
Other	$		
Total annual costs	$	10,831	
Annual savings and income			
Fuel cost - base case	$	18,422	
Other	$		
Total annual savings and income	$	18,422	
Financial viability			
Pre-tax IRR - assets	%	9.3%	
Simple payback	yr	12.0	
Equity payback	yr	10.4	

Cumulative cash flows graph



Project information

See project database

Project name	Yerga Haile Shopping Mall - PV System
Project location	Addis Ababa, Ethiopia
Prepared for	
Prepared by	Bezawit Teshome
Project type	Power
Technology	Photovoltaic
Grid type	Isolated-grid & internal load
Analysis type	Method 1
Heating value reference	Lower heating value (LHV)
Show settings	☐

Site reference conditions

Select climate data location

Climate data location	Addis Ababa
Show data	☑

	Unit	Climate data location	Project location
Latitude	˚N	9.0	9.0
Longitude	˚E	38.7	38.7
Elevation	m	2,324	2,324
Heating design temperature	°C	10.2	
Cooling design temperature	°C	25.0	
Earth temperature amplitude	°C	15.7	

Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January		15.9	63.0%	6.04	77.4	3.1	22.4	65	183
February		16.4	66.0%	6.78	77.4	2.6	24.4	45	179
March		17.9	66.0%	6.70	77.3	3.1	25.6	3	245
April		17.6	71.0%	6.54	0.0	3.6	24.1	12	228
May		17.8	67.0%	6.25	0.0	3.1	21.8	6	242
June		16.6	74.0%	5.10	0.0	2.6	18.6	42	198
July		15.0	83.0%	4.33	77.2	2.1	16.9	93	155
August		15.0	85.0%	4.29	77.3	2.1	16.8	93	155
September		15.6	79.0%	5.18	77.2	2.6	17.3	72	168
October		15.8	69.0%	6.74	77.3	3.6	17.8	68	180
November		15.2	66.0%	6.47	77.4	4.1	19.3	84	156
December		15.6	69.0%	6.00	77.5	3.6	20.5	74	174
Annual		16.2	71.5%	5.86	58.1	3.0	20.4	658	2,262
Measured at	m					10.0	0.0		

Complete Load & Network sheet

RETScreen Load & Network Design - Power project

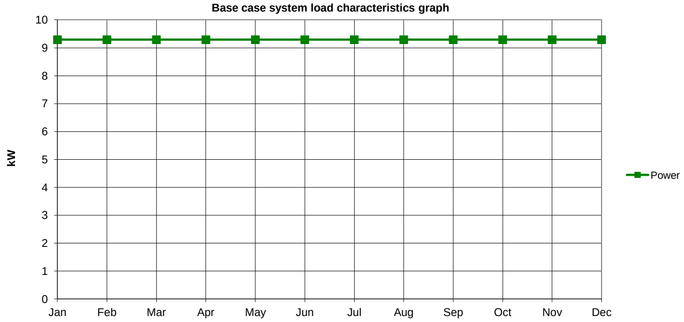
Power project	Unit	
Base case power system		
Grid type		Isolated-grid & internal load
Peak load - isolated-grid	kW	
Minimum load - isolated-grid	kW	6

Base case load characteristics

Month	Power gross average load kW
January	9
February	9
March	9
April	9
May	9
June	9
July	9
August	9
September	9
October	9
November	9
December	9

System peak electricity load over max monthly average		0.0%
Peak load - annual		9
Electricity	MWh	81
Electricity rate - base case	$/kWh	0.040
Total electricity cost		$ 3,255

Base case system load characteristics graph



Proposed case energy efficiency measures

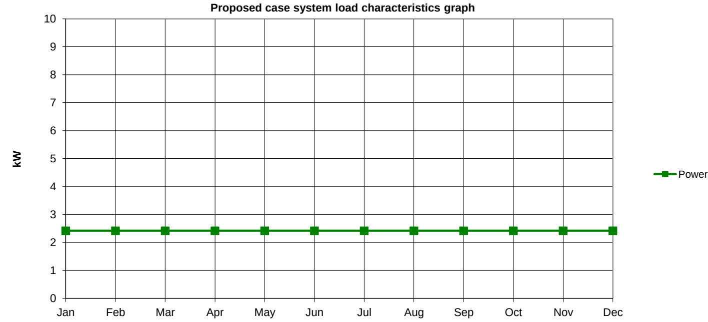
End-use energy efficiency measures	%	74%
Net peak electricity load	kW	2
Net electricity	MWh	21

Proposed case load characteristics

Month	Power net average load kW
January	2
February	2
March	2
April	2
May	2
June	2
July	2
August	2
September	2
October	2
November	2
December	2

Peak load - annual 2

Proposed case system load characteristics graph



Proposed case load and energy		Power
System peak load	kW	2
System energy	MWh	21

RETScreen Energy Model - Power project

☐ Show alternative units

Proposed case power system

Incremental initial costs

Technology: Photovoltaic

Analysis type:
- ○ Method 1
- ⦿ Method 2

Resource assessment

Solar tracking mode		Fixed
Slope	°	9.0
Azimuth	°	0.0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	6.04	6.51	0.0	0.032
February	6.78	7.12	0.0	0.031
March	6.70	6.80	0.0	0.033
April	6.54	6.43	0.0	0.030
May	6.25	6.00	0.0	0.029
June	5.10	4.87	0.0	0.023
July	4.33	4.18	0.0	0.021
August	4.29	4.20	0.0	0.021
September	5.18	5.18	0.0	0.025
October	6.74	7.00	0.0	0.034
November	6.47	6.95	0.0	0.033
December	6.00	6.53	0.0	0.032
Annı	**5.86**	**5.97**	**0.00**	**0.344**

Annual solar radiation - horizontal	MWh/m²	2.14
Annual solar radiation - tilted	MWh/m²	2.18

Photovoltaic

Type		mono-Si	
Power capacity	kW	16.05	$ 17,655 — *See product database*
Manufacturer		BP Solar	
Model		mono-Si - BP 275 U	214 unit(s)
Efficiency	%	11.6%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	138	
Miscellaneous losses	%	0.0%	

Inverter

Efficiency	%	76.5%
Capacity	kW	2.0
Miscellaneous losses	%	15.0%

Summary

Capacity factor	%	15.3%
Electricity delivered to load	MWh	21.171
Electricity exported to grid	MWh	0.344
Electricity rate - base case	$/MWh	40.00
Fuel rate - proposed case power system	$/MWh	0.00
Electricity rate - proposed case	$/MWh	40.00

Operating strategy	Electricity delivered to load MWh	Electricity exported to grid MWh	Remaining electricity required MWh	Power system fuel MWh	Operating profit (loss) $	Efficiency %
Full power capacity output	**21**	**0**	**0**	**0**	**847**	**-**
Power load following	21	0	0	0	847	-

Select operating strategy: Full power capacity output

☐ Emission Analysis

Financial Analysis

Financial parameters

Inflation rate	%	2.5%
Project life	yr	25
Debt ratio	%	0%

Initial costs

Power system	$	17,655	30.9%
Other	$	39,455	69.1%
Total initial costs	$	57,110	100.0%
Incentives and grants	$	0	0.0%

Annual costs and debt payments

O&M (savings) costs	$	0
Fuel cost - proposed case	$	0
	$	
Total annual costs	$	0

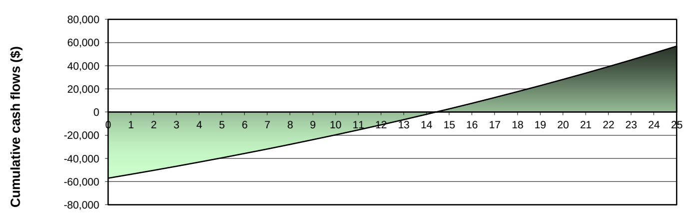
Annual savings and income

Fuel cost - base case	$	3,255
	$	
Total annual savings and income	$	3,255

Financial viability

Pre-tax IRR - assets	%	5.5%
Simple payback	yr	17.5
Equity payback	yr	14.4

Cumulative cash flows graph



Year

RETScreen® International

www.retscreen.net

Clean Energy Project Analysis Software

Project information

See project database

Project name	Yerga Haile Shopping Mall - Overall Energy Conservation
Project location	Addis Ababa, Ethiopia
Prepared for	
Prepared by	Bezawit Teshome
Project type	Energy efficiency measures
Facility type	Commercial
Analysis type	Method 1
Heating value reference	Lower heating value (LHV)
Show settings	☐

Site reference conditions

Select climate data location

Climate data location	Addis Ababa
Show data	☐

Complete Energy Model sheet

RETScreen4 2010-09-22

NRCan/CanmetENERGY

RETScreen Energy Model - Energy efficiency measures project

Fuels & schedules ☑ Show data

Fuel			Fuel type 1	Fuel type 2	Fuel type 3	Fuel type 4	Fuel type 5	Fuel type 6
Fuel type			Electricity					
Fuel consumption - unit			MWh					
Fuel rate - unit			$/kWh					
Fuel rate			0.040					

Schedule	Unit		Schedule 1	Schedule 2	Schedule 3	Schedule 4	Schedule 5	Schedule 6
Description			24/7					
				Occupied	Occupied	Occupied	Occupied	Occupied
Temperature - space heating	°C							
Temperature - space cooling	°C							
Temperature - unoccupied	+/-°C							
Occupancy rate - daily			h/d					
Monday			24					
Tuesday			24					
Wednesday			24					
Thursday			24					
Friday			24					
Saturday			24					
Sunday			24					
Occupancy rate - annual	h/yr		8,760					
	%		100%					
Heating/cooling changeover temperature	°C	16.0						
Length of heating season	d	179						
Length of cooling season	d	186						

Facility characteristics ☑ Show data

Show:	Heating	Cooling	Electricity	Incremental initial costs	Fuel cost savings	Incremental O&M savings	Simple payback	Include measure?
Fuel saved	MWh	MWh	MWh	$	$	$	yr	☐
Heating system								
Cooling system								
Building envelope								
Ventilation								
Lights								
Corridor Lighting	-	-	36	26,215	1,457	0	18.0	☑
Parking Lighting	-	-	45	30,895	1,798	0	17.2	☑
Stair Lighting	-	-	2	4,029	70	0	57.6	☑
Shop and Toilet Lighting	-	-	69	35,125	2,745	0	12.8	☑
Office, Bank, Kitchen and Restaurant	-	-	44	27,166	1,757	0	15.5	☑
Electrical equipment								
Kitchen Equipments	-	-	14	0	558	0	0.0	☑
Water Heater	-	-	0	0	0	0	-	☑
Others	-	-	0	0	0	0	-	☑
Lifts	-	-	0	0	0	0	-	☑
Hot water								
Pumps								
Water Pump	-	-	0	0	0	0	-	☑
Water Pump	-	-	0	0	0	0	-	☑
Pump Sump	-	-	0	0	0	0	-	☑
Fans								
Fans	-	-	1	0	53	0	0.0	☑
Motors								
Process steam								
Heat recovery								
Compressed air								
Refrigeration								
Other								
Total	0	0	211	123,430	8,438	0	14.63	

Summary ☑ Show data

	Fuel		Base case		Proposed case		Fuel cost savings	
Fuel type	Fuel consumption - unit	Fuel rate	Fuel consumption	Fuel cost	Fuel consumption	Fuel cost	Fuel saved	Fuel cost savings
Electricity	MWh	$ 40.000	460.6	$ 18,422	249.6	$ 9,984	210.9	$ 8,438

Project verification Fuel type	Fuel consumption - unit	Fuel consumption - historical	Fuel consumption Base case	Fuel consumption - variance
Electricity	MWh	451.1	460.6	2%

Energy	Heating MWh	Cooling MWh	Electricity MWh	Total MWh
Energy - base case			461	461
Energy - proposed case			250	250
Energy saved			211	211
Energy saved - %			45.8%	45.8%

Benchmark		
Energy unit	kWh	
Reference unit	m²	10,743

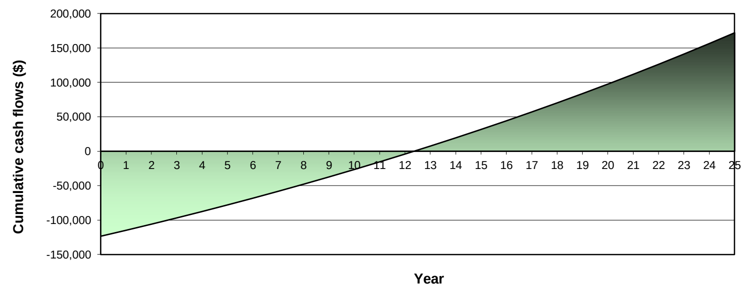
Benchmark Energy	Heating kWh/m²	Cooling kWh/m²	Electricity kWh/m²	Total kWh/m²
Energy - base case			42.9	42.9
Energy - proposed case			23.2	23.2
Energy saved			19.6	19.6

☐ Emission Analysis

Financial Analysis

Financial parameters			
Inflation rate	%	2.5%	
Project life	yr	25	
Debt ratio	%	0%	
Initial costs			
Energy efficiency measures	$	123,430	100.0%
Other	$		0.0%
Total initial costs	$	123,430	100.0%
Incentives and grants	$	0	0.0%
Annual costs and debt payments			
O&M (savings) costs	$	0	
Fuel cost - proposed case	$	9,984	
Other	$		
Total annual costs	$	9,984	
Annual savings and income			
Fuel cost - base case	$	18,422	
Other	$		
Total annual savings and income	$	18,422	
Financial viability			
Pre-tax IRR - assets	%	7.2%	
Simple payback	yr	14.6	
Equity payback	yr	12.4	

Cumulative cash flows graph



Appendix D
Incremental Cost of the Proposed Energy Conserving System Components

Appendix D: Incremental Cost of the Proposed Energy Conserving System Components

Base Case		Proposed Case		Additional Cost Per Unit (in USD)
Light Fitting Type	Wattage (W)	Light Fitting Type	Wattage (W)	
Incandescent	60	Equivalent CFL Lamp	13	4.27
Incandescent	100	Equivalent CFL Lamp	24	10.96
Incandescent	60	Equivalent LED Lamp	6	16.9
Incandescent	75	Equivalent LED Lamp	9	27.47
Fluorescent	1x18	Equivalent LED Lamp	7	32.17
Fluorescent	2x18	Equivalent LED Lamp	14	64.34
Fluorescent	4x18	Equivalent LED Lamp	29	128.68
Fluorescent	1x36	Equivalent LED Lamp	14	41.82
Fluorescent	2x36	Equivalent LED Lamp	29	83.64
Mercury Vapor	80	Equivalent LED Lamp	10	20.01
Fluorescent	13	Equivalent LED Lamp	5	34.55

Proposed Efficient Lighting Control System	Cost Per Unit (in USD)
Occupancy Sensor + Photo sensor + Dimmer	39.99
Occupancy Sensor	37.99

Proposed Efficient Equipments and Appliances	Additional Cost Per Unit (in USD)
Deep Fryer	260
Frying Pan	260
steam cooker	1500
Fridge	250
dishwasher	530
Washer	258
Dryer	258
Televisions	60
Refrigerators	30

Item	PV $\$/W_P$	Battery $/Ah	Charger $/A	Inverter $/W	Installation - % of PV cost	M&O/Year - % of PV cost
Cost	1.1	1.15	5.878	0.831	10%	2%