ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSTITUTE OF TECHNOLOGY
CENTER OF ENERGY TECHNOLOGY

DESIGN AND SIMULATION OF GRID-TIED PHOTOVOLTAIC, THERMAL AND BIOGAS ENERGY GENERATING SYSTEMS TO POWER UNIVERSITIES IN ETHIOPIA: A CASE OF Addis Ababa UNIVERSITY, COLLAGE OF NATURAL AND COMPUTATIONAL SCIENCE

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OFADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENERGY TECHNOLOGY

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DECLARATION

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any University, and that all the source of materials used for the thesis has been duly acknowledged.

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ABSTRACT

This paper confers with a study and unfold to systematic know how on how to furnish Ethiopian universities with power using their own abundantly available renewable energy resources and to establish a project for the same purpose. In pursuance of that, it was conducted by collecting and analyzing relevant and required data like electrical energy consumption, weather and site of the targeted universities while also rendering comprehensive attention to other design standards as well as specifications of machineries. The worst case design is thoroughly regarded herein the design section for it is more convincing with respect factor of safety in the event solar radiation falls below the annual average and when there is a minimum amount of biogas resource. The simulation, optimization and sensitivity analysis of the project is dealt by renewable energy tools of HOMER software.

Foundation of the hybrid energy generating system is surfaced and actualized by making estimation of solar and biogas resource at a given site. The source data for AAUCNCSc revealed that a mean incident solar radiation of 3.66 kWh/m^2/day and a potential of about 24 tons of biogas resource per a day can be collected considering safety factor for the variation as per day to day and month to month basis. The data collected for this study further showed that the electrical energy demand of the site was 104,870 kWh in the design year (July 2012) in which a combination of the two systems are going to offset the necessity. The assessment conducted revealed that out of the total of 104,870 kWh energy needed close to 81% is furnished by and fulfilled with biogas energy generating system while the remaining 19% of it is contributed by PV/T system and yet 0.00492kWh/yr (0.00%) is found to be excess which ought to be sold to the national grid .

Pursuant to the financial analysis of HOMER, given to designed HPV/TBS and within an optimum cost of electricity (*COE*) of 0.263 $/kWh, renewable fraction (*RF*) of 1 can be obtained**.** Generally, if and when the total cost of PV/T modules, the Biogas generators and the converter are US$ 535,750.00, US$ 50,000.00 and US$ 8,000.00 respectively. The software further showed that in the emission analysis 4,172,041kg/yr of CO_2, 18,099 kg/yr SO_2 and 7,935 *NO* can be removed if this renewable design of the hybrid system is to be implanted instead of non renewable equivalent.

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ABBREVIATION

AAU	Addis Ababa University
CHP	Combined Heat and Power
CKT	Electrical Circuits of PV/T System
CNCSC	Collage of Natural and Computational Science
EEPCo	Ethiopian Electric Power Cooperation
EL	Daily Electrical Load
HOMER	Micro Power Optimization Model of Renewable Energy
HPV/TBS	Hybrid Photovoltaic Thermal and Biogas Systems
HRT	Hydraulic Retention Time
KWH	Kilo Watt Hour
NMS	Number of PV/T Modules in Series
NMT	Total Number of PV/T Modules
NREL	National Renewable Energy Laboratory
OECD	Organization for Economic Co-Operation and Development
PV/T	Integrated Photovoltaic and Thermal Modules
SWH	Solar Water Heating System
TW	Total amount of Waste

NOMENCLATURE

C	Biogas yield per unit mass of manure
E	Equation of time
E '	Amount of daily energy produced
F_m	Fraction of methane in biogas
H_b	Heat of combustion per unit volume of biogas
H_m	Heat of combustion of methane
I (t)	solar intensity at any time t
N	Number of Collectors
Psi	Maximum radiation intensity
S_d	Volumetric rate of discharge
T	Temperature
V_b	Volume of biogas
V_c	Volume of biogas collecting chamber
V_d	Volume of biomass digester
V_f	Volume of fermentation chamber
V_{gs}	Volume of gas storage chamber
Vs	Volume of sludge layer
η	Combustion efficiency of burner, gas generator

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CHAPTER ONE

1. INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Electrical energy demand is escalating and enhancing all over the world on these days. Likewise, there is also a growing awareness for renewable energy resources in Ethiopia as a result of rapidly increasing population and industrial development [13]. Owing to the stated fact, not only Ethiopia but also most countries of the globe are diverting their attention to utilize renewable energy resources in to the day to day demands of their subjects intending and in view of satisfying to the high stipulations of their increasing population, the industrial growth as well as the increasing utilization of electrical energy. There are also some limitations, like pollution and limited energy resources which must be taken into account that compelled considerable number of countries to look for alternative and substitutes. To mitigate and alleviate to any existed and potential energy related problems, establishing a system which is pollution free and economically more efficient is becoming vital. At present, the renewable energy resources like solar energy, wind energy and biogas power plants have made it possible to produce power economically, which was previously available only in big power plants [2].

1.1.1 Introduction to Biogas

It is common knowledge that biogas is a gaseous mixture of methane, carbon dioxide, hydrogen and several other gases, produced by anaerobic fermentation of organic materials such as animal and human manure, leaves, twigs grasses, industrial wastes, etc.[18]. The presence of methane in biogas lends it the property of combustibility which makes it suitable for cooking, lightning and powering prime movers. The technology for the production of biogas, by anaerobic fermentation of organic materials which are abundant, low cost and renewable in nature, is readily available. In fact, several thousand biogas plants are already in operation in many developing countries of the world. However, wide spread generation and use of it depends largely on the availability of inexpensive and appropriate plant design, which could be constructed with locally available material and skills [18,19].In view of the same, the thesis explains in detail regarding the theory of biogas production, factor affecting plant design and operation, as well as requirements and attributes which contribute to the optimization of energy generation. Moreover, design of biogas utilization devices and their operational requirements for lighting, cooking and as a fuel for prime movers have also been included. Further use of biogas for electric generation using gas engine is the core issues of this study.

1.1.2 Introduction to Photovoltaic System

In actual terms the word photovoltaic is a set of two words with different meaning has ‘photo’ to mean light whereas ‘volt’ is to mean electricity. The combined meaning of the term is a direct conversion of sunlight into electricity at an atomic level [18]. Some materials display a property known as photoelectric effect that causes them to absorb photons of light and release electrons. Electricity is produced when sunlight strikes the solar cell, causing the electrons to dislocate and move around. The dynamic effect of those electrons starts the creation of an electric current. The conversion of sunlight into electricity takes place silently and instantly [25].

1.1.3 Hybrid PV/Biogas systems

Solar energy has the benefit of having a relatively low cost and is highly abundant in various and numerous locations. On the other hand bio-energy has the advantage of flexibility, ability to store and production of thermal energy. In a location where both are highly available, it is vital and prudent to study the possibility of combining them in order to get the maximum and more efficient outcome. For that purpose and in pursuance of that the best solution can be Hybridization of PV with biogas. This is because it combines two energy sources at one that complement each other, both seasonally and diurnally which overcomes their individual drawbacks. During the day, the sun’s rays can be harnessed by PV panels and the chemical reaction inside the digester will be triggered by the heat produced during the generation of electricity by the PV panels to achieve constant base load operation [34].

Constant base load or full load plants are typically implemented as plant efficiency is maximized and unit cost of energy is minimized [13]. However, solar energy could be used to increase plant output during the day. In comparison to a biogas-only system, solar hybridization reduces biogas demand, thus improving energy security and decreasing land required for farming and storage.

What is intended by the researcher to actualize the Hybridization of PV with biogas is and its schematic representation of the system is shown in Fig. 1.1. The figure shows the main components of each of the biogas and PV systems and the flow of material as well as energy in the system [3].

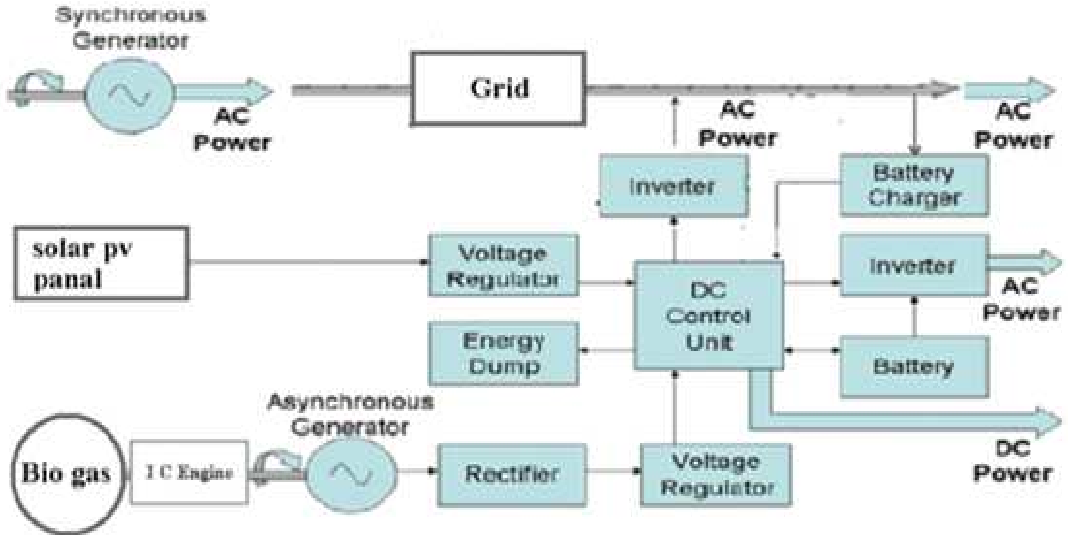


Fig.1.1 Hybrid PV and Biogas Systems [25].

As it is shown in the figure of Hybrid PV and biogas systems. The power sources are considered as double while each electric power generation process is considered separately. First, what happens during electrical power generation by PV system is examined.

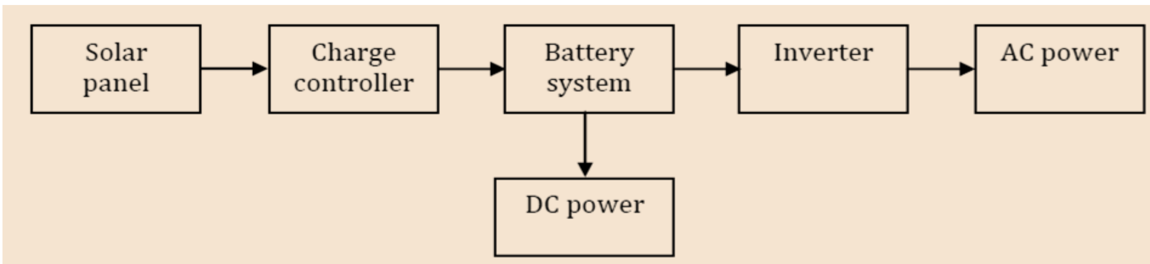


Fig.1.2 Main components of PV system [22]

The solar radiation absorbed by the PV panels could be directly converted to electrical energy (DC power); on its way a charge controller controls the uncertain voltage build up.

In a bright sunny day the solar cells produce more voltage that can lead to battery damage. A charge controller helps to maintain the balance in charging the battery.

Basically, a battery is a device that stores energy for later use. It is a combination of electrochemical cells that can store chemical energy that has the potential to be converted into electric voltage or, to put it simply; it is a device that converts chemical energy directly to electrical energy. And the last component in this circuit is inverter, solar panel generates DC electricity but most of the household and industrial appliances need AC current. The function of an inverter is to convert the DC to different AC levels. The storage device or battery is used mainly for off grid systems. For grid-tied systems just there is no need of battery or storage system since surplus generation of electricity is supplied directly to the main grid.

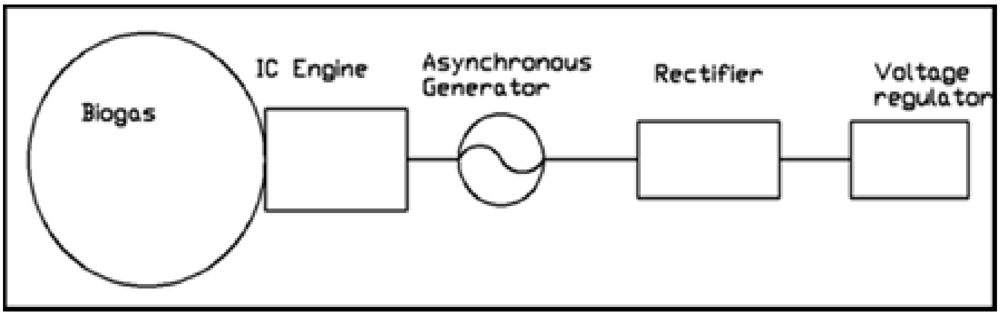


Fig.1.3 Main Components of Biogas Power Generating System [22].

In the built biogas digester a lot of reaction stages are undertaken to produce methane which can run the designed IC engine or gas engine generator set. The engine produces mechanical power (rotation), and this rotational motion will be transmitted to the electrical generator shaft with the aid of coupling and drives the electrical generator to produce electricity. The rectifier converts an alternating current (AC) to direct current (DC) to accumulate the DC outputs of both systems in one control unit (DC control unit).

1.2 STATEMENT OF THE PROBLEM

It is a fact that close to 90 % of the Ethiopian electrical energy supply is obtained from Hydropower and the demand in it is still dramatically increasing from time to time [13].
Today's major energy problem both in world wide as well as domestic is mainly attributed to the shortage and inconsistency in supply of energy required and the

environmental side effects of its sources. These problems can be mitigated or fully alleviated by deploying renewable energy schemes. When we look the energy demands of Ethiopia, given to its fast growing rate, it is facing with different energy problems including but not limited to scarcity and insecurity (interruption in supply of electricity) of electric power in different sectors. The educational sector is one of the entities to which such problems and challenges are witnessed. It is obvious that the number of universities in this country is increasing in number, which led to increment in the energy demand. On the other hand within the same path this demand cannot be met to all the universities without instability in supply because of the increment of customers in the country basis and the capacity of available energy generating plants. So these two grounds, accompanied with the need for clean energy and the accessibility of sufficient resources of both biogas and sunlight, motivated to design a hybrid PV and biogas energy generating systems to power the university, to assist the main grid of the country as well as to alleviate environmental side effects.

1.3 OBJECTIVE OF THE STUDY

1.3.1 General Objective of the Thesis

The overall objective of the study is to design a hybrid PV and biogas system for Addis Ababa University College of Natural and Computational Science (AAUCNCSc) so as to contribute in comprehensive powering the entity and ease or lessen energy consumption related environmental problems and its side effects along with simulating and optimizing the system using HOMER renewable energy software.

1.3.2 Specific objectives

Its specific objective includes the under mentioned but is not limited to it.

- Conduct a Study regarding the average monthly electricity consumption for a given or selected 1 year and the total cost incurred ;
- Proposes a PV or PV/T system specification from a given manufacturer's catalogue that includes its DC rating and evaluate the size of the system as well as the necessity of its size ;
- Conduct survey to find out the proposed and select a suitable spot for mounting the PV/T system as well as for installing biogas digester system;

- Recommend the approximate system size for the application;
- Estimate the cost of the PV or PV/T and biogas digester systems.
- Perform a financial projection of return on investment for the PV/T and biogas digester systems; and
- Design the array of PV/T systems at/on the selected site.
- Analysis of the hybrid system using Homer software.

1.4 MATERIAL AND METHODS

The research will use the following method to translate its objective in to concrete reality:

- Literature review;
- Collecting primary and secondary data which have relevance with the study;
- Design and analysis of the hybrid system manually.
- Sizing of main components of the plant.
- Selection of these components by comparing with equivalent candidates on the current market.
- Modeling and simulation of the hybrid system using Homer.

1.5 SIGNIFICANCE OF THE STUDY

According to the world bank study, only 12% the country's population is blessed to get electrical energy access in the year 2010 GC [10,11]. The growth of industrial sector accompanied with the life style of its population which is greatly reliant in using electricity augmented the problem. Ethiopia is well endowed with renewable energy resources (solar, wind, hydro and geothermal). The policy framework for household energy is set by the Ethiopian energy policy, the environmental policy and the conservation strategy of Ethiopia, which address energy conservation and energy efficiency in order to reduce the consumption of fuel wood confirms the necessity of designing and installation of energy generation system using renewable resources only.

The existing situation shows that biomass is the major resource meeting the energy needs of the Ethiopian households. It is used mainly for cooking applications on traditional three-stone open fires. As the staple food in Ethiopia’s highlands is Injera, nearly 50% of the country’s primary energy consumption is used for its preparation mostly on traditional open fire stoves, wasting more than 90% of the fuel in an unsafe and unhealthy manner. The use of biomass for energy production is not only inefficient but can have harmful effects on people's health. Smoke emission resulting from indoor cooking can lead to various respiratory diseases in poorly ventilated kitchens and goes along with a high risk of fire [12].The same is true in educational sector especially in universities. So this research is intended to show and establish a better way on how to use energy economically, alleviate any prevailing problems in the mitigation of the existing energy problems particularly focusing on universities. This is done by designing hybrid PV or PV/T and biogas system in which Ethiopia is endowed in both of the resources and the winning combination of the two is more effective than separate system [31].

1.6 SCOPE OF THE STUDY

This research aims to equip with a renewable energy to Addis Ababa University particularly Collage of Natural and Computational Science. This institution is opted because it has preferable location for the PV/T panel installation and it has paramount biogas resource which makes it simple and less expensive to construct.

1.7 STRUCTURE OF THE THESIS

This research is organized in the following manner: Chapter One deals broadly with the introducing the current electrical energy supply, bottlenecks in the supply and the negative consequences of its consequences. The theoretical background and literature reviews will be conducted on Chapter Two. The Next chapter, Chapter Three will present the data collection and data analysis. Chapter Four is dedicated to designing and selection of the equivalent component (material) which are available in the existing market in reasonable price. Modeling of the Hybrid system using HOMER and the results of the analysis along with further discussion on the results will be presented in Chapter Five. The findings of the thesis will be concluded and recommended through consideration of the results will be organized in the final chapter of the manuscript, Chapter Six.

CHAPTER TWO

2. RELEVANT LITERATURE REVIEWS AND THEORETICAL BACKGROUND

2.1 BIOGAS SYSTEMS

2.1.1 Biogas energy

It is a type of alternative fuel which can be produced from almost any type of organic waste, from old feedstock to sewage. Composed of the gases methane and carbon dioxide. Biogas is produced by the bacteria that decompose organic waste under anaerobic or oxygen-free conditions. Biogas is a carbon-neutral fuel, meaning it does not contribute to greenhouse gas levels and is a suitable replacement for natural gas, which is a fossil fuel and contributor to the greenhouse effect [2,7]. Practical applications of biogas include generating electricity for the power grid, heating, cooking and creating steam power. Biogas can be used in similar ways to natural gas in gas stoves, lamps or as fuel for engines. It consists of 50-75% methane, 25-45% carbon dioxide, 2-8% water vapour and traces of O_2 N_2, NH_3 H_2 and H_2S. Compare this with natural gas, which contains 80 to 90% methane [5]. The energy content of the gas depends mainly on its methane content. High methane content is therefore desirable. A certain carbon dioxide and water vapor content is unavoidable, but sulphur content must be minimized - particularly for use in engines. The average calorific value of biogas is about 21-23.5 MJ/m³, so that 1 m³ of biogas corresponds to 0.5-0.6 l diesel fuel or about 6 kWh[32].The biogas yield of a plant depends not only on the type of feedstock, but also on the plant design, fermentation temperature and retention time [32].

2.1.2 Planning a biogas plant

Before building a biogas plant, there are different circumstances which should be considered. For instance, the natural and agricultural conditions in the specific countries are as important as the social or the economic aspects. Failure or unsatisfactory performance of biogas units occur mostly due to planning mistakes. The consequences of such mistakes may be immediately evident or may only become apparent after several years [18]. Thorough and careful planning is, therefore, of utmost importance to eliminate mistakes before they reach irreversible stages.

As a biogas unit is an expensive investment, it should not be erected as a temporary set-up. Therefore, determining siting criteria for the stable and the biogas plant are the important initial steps of planning. Moreover, all extension-service advice concerning agricultural biogas plants must begin with an estimation of the quantitative and qualitative energy requirements of the interested party.

Then, the biogas-generating potential must be calculated on the basis of the given biomass production and compared to the energy demand. Both the energy demand and the gas generating potential, however, are variables that cannot be accurately determined in the planning phase. Sizing the plant (digester, gasholder, etc.) is the next step in the planning process. Information about the economic evaluation of a biogas plant can be found in the section on Costs and Benefits.

2.1.3 Types of biogas plants

Depending on the method of feed, the following types of plants can be distinguished [12, 18]:

- Batch plants
- Continuous plants
- Semi-batch plants

Batch plants: In this types of plant first the digesters are filled and then emptied completely after a fixed retention time. The main advantage of this plant is each design and each fermentation material is suitable for batch filling, despite such plants require high labor input. As a major disadvantage, their gas-output is not steady.

Continuous plants are fed and emptied continuously. They empty automatically through the overflow whenever new material is filled in. Therefore, the substrate must be fluid and homogeneous. Gas production is constant, and higher than in batch plants. Today, nearly all biogas plants are operating on a continuous mode [18].Concerning the construction, two main types of simple biogas plants can be differentiated:

- Fixed-dome plants
- Floating-drum plants

In developing countries, the selection of appropriate design is determined largely by the prevailing design in the region. Typical design criteria are space, existing structures, cost minimization and substrate availability. The designs of biogas plants in industrialized countries reflect a different set of conditions.

2.1.4 Working of biogas system

First of all the feed material is mixed with water in the influent collecting tank. The fermentation slurry flows through the inlet into the digester. The bacteria from the fermentation slurry are intended to produce biogas in the digester. For this purpose, they need time; time to multiply and to spread throughout the slurry. The digester must be designed in a way that only fully digested slurry can leave it. The bacteria are distributed in the slurry by stirring (with a stick or stirring facilities). The fully digested slurry leaves the digester through the outlet into the slurry storage. The biogas is collected and stored until the time of consumption in the gasholder. The gas pipe carries the biogas to the place where it is consumed by gas appliances. Condensate collected in the gas pipe is removed by a water trap.

2.1.5 Biogas - Digester types

Biogas digester is the backbone of biogas energy generating system. It is the one and the essential component where the main process of energy generation takes place. It is common practice to identify the whole system by the type of digester. The most important types of biogas plants are [11]:

1. Fixed-dome plants
2. Floating-drum plants
3. Balloon plants
4. Horizontal plants
5. Earth-pit plants
6. Ferro cement plants

Of these, the two most familiar types in developing countries are the fixed-dome plants and the floating-drum plants [28].

a. Fixed-dome plants

The costs of a fixed-dome biogas plant are relatively low. It is simple as no moving parts exist. There are also no rusting steel parts and hence a long life of the plant (20 years or more) can be expected. The plant is constructed underground, protecting it from physical damage and saving space. While the underground digester is protected from low temperatures at night and during cold seasons, sunshine and warm seasons take longer to heat up the digester. No day/night fluctuations of temperature in the digester positively influence the bacteriological processes. The construction of fixed dome plants is labor-intensive, thus creating local employment. Fixed-dome plants are not easy to build. They should only be built where construction can be supervised by experienced biogas technicians. Otherwise plants may not be gas-tight (porosity and cracks).The basic elements of a fixed dome plant (here the Nicarao Design) are shown in the figure below [11].

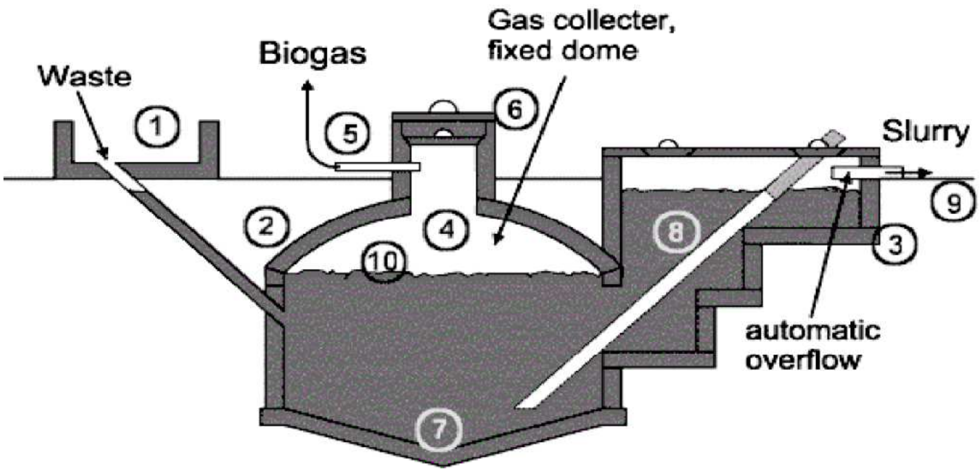


Fig. 2.1 Fixed dome biogas digester[11].

A fixed-dome plant comprises of a closed, dome-shaped digester with an immovable, rigid gas-holder and a displacement pit, also named 'compensation tank'. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gasholder, the gas pressure is low.

The digesters of fixed-dome plants are usually masonry structures, structures of cement and ferro-cement exist. Main parameters for the choice of material are [12]:

- Cost-effectiveness;

- Technical suitability (stability, gas- and liquid tightness);
- Availability in the region and transport costs;
- Availability of local skills for working with the particular building material.

b. Floating-drum Plants

Floating-drum plants consist of an underground digester and a moving gas-holder. The gas-holder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. The gas drum is prevented from tilting by a guiding frame. If the drum floats in a water jacket, it cannot get stuck, even in substrate with high solid content. Floating drum needs to be coated with paint in a constant interval to avoid rust. Additionally, fibrous materials will block the movement of digester. Hence, their accumulation should be avoided if possible which is difficult and costly.

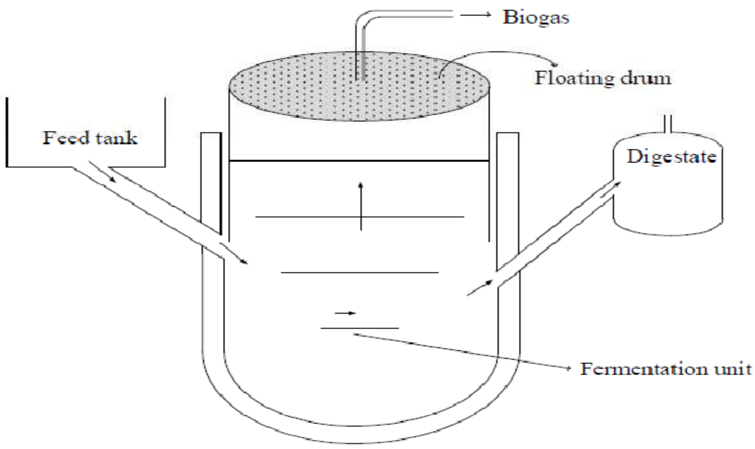


Fig. 2.1 Floating-drum biogas digester [11].

2.1.6 Selection of appropriate design

In developing countries, the design selection is determined largely be the prevailing design in the region, which, in turn takes the climatic, economic and substrate specific conditions into consideration. [12].

Typical design criteria are:

Space: determines mainly the decision if the fermenter is above-ground or underground, if it is to be constructed as an upright cylinder or as a horizontal plant.

Existing structures may be used like a liquid manure tank, an empty hall or a steel container. To reduce costs, the planner may need to adjust the design to theses existing structures.

Minimizing costs can be an important design parameter, especially when the monetary benefits are expected to be low. In this case a flexible cover of the digester is usually the cheapest solution. Minimizing costs is often opposed to maximizing gas yield.

Available substrate determines not only the size and shape of mixing pit but the digester volume (retention time), the heating and agitation devices. Agitation through gas injection is only feasible with homogenous substrate and a dry matter content below 5%. Mechanical agitation becomes problematic above 10% dry matter.

Components of Biogas Plants

- Influent collecting tank
- Inlet and outlet
- Digester
- Gasholders
- Gas pipe, valves and accessories
- Stirring facilities
- Heating systems
- Pumps
- Weak Ring

2.1.7 Digester Requirements

No matter which design is chosen, the digester (fermentation tank) must meet the following requirements [18]:

Water/gas tightness- water tightness in order to prevent seepage and the resultant threat to soil and groundwater quality; gas tightness in order to ensure proper containment of the entire biogas yield and to prevent air entering into the digester(which could result in the formation of an explosive mixture).

Insulation - if and to which extent depends on the required process temperature, the local climate and the financial means; heat loss should be minimized if outside temperatures are low, warming up of the digester should be facilitated when outside temperatures are high.

Minimum surface area - keeps cost of construction to a minimum and reduces heat losses through the vessel walls. A spherical structure has the best ratio of volume and surface area. For practical construction, a hemispherical construction with a conical floor is close to the optimum.

Structural stability - sufficient to withstand all static and dynamic loads, durable and resistant to corrosion

2.1.8 Determining the biogas production

The quantity, quality and type of biomass available for use in the biogas plant constitute the basic factor of biogas generation. The biogas incidence can and should also be calculated according to different methods applied in parallel [16, 17].

- Measuring the biomass availability
- Determining the biomass supply via pertinent-literature data
- Determining the biomass supply via regional reference data
- Determining biomass supply via user survey

It should be kept in mind that the various methods of calculation can yield quite disparate results that not only require averaging by the planner, but which are also subject to seasonal variation.

2.1.9 Biogas Utilization

If the daily amount of available dung (fresh weight) is known, gas production per day in warm tropical countries will approximately correspond to the following values [17]:

- 1 kg cattle dung 40 liters biogas
- 1 kg buffalo dung 30 liter biogas
- 1 kg pig dung 60 liter biogas
- 1 kg chicken droppings 70 liter biogas

- 1 kg human manure produces 30 liters

2.1.10 Human excrements

In most cultures, handling human excrement is loaded with taboos. Thus, if night soil is to be used in a biogas system, the toilets in question should drain directly into the system so that the night soil is fermented without pretreatment. The amount of water accompanying the night soil should be minimized by ensuring that no water taps or other external sources drain into the toilet bowls, and cleaning/flushing should be limited to rinsing out with about 0.5 - 1 liter water from a bowl [5].

2.1.11 Conditioning of biogas

Sometimes the biogas must be treated/conditioned before utilization. The predominant forms of treatment aim at removing water (Reduction of the moisture content), hydrogen sulfide (Reduction of the hydrogen-sulfide content) or carbon dioxide (Reduction of the carbon-dioxide content) from the raw gas [19].

Efficiency: The calorific efficiency of using biogas is 55% in stoves, 24% in engines, but only 3% in lamps [16]. A biogas lamp is only half as efficient as a kerosene lamp. The most efficient way of using biogas is in a heat-power combination where 88% efficiency can be reached. But this is only valid for larger installations and under the condition that the exhaust heat is used profitably.

2.2 FACTORS AFFECTING THE PERFORMANCE ANAEROBIC DIGESTER

The metabolic activity involved in microbiological methanation is dependent on the following factors [12].

2.2.1 Substrate Temperature

Anaerobic fermentation is in principle possible between 3°C and approximately 70°C. Differentiation is generally made between three temperature ranges:

- The psychrophilic temperature range lies below 20°C,
- The mesophilic temperature range between 20°C and 40°C and

- Thethermophilic temperature range above 40°C.

Minimal average temperature: The rate of bacteriological methane production increases with temperature. Since, however, the amount of free ammonia also increases with temperature; the bio-digestive performance could be inhibited or even reduced as a result. In general, unheated biogas plants perform satisfactory only where mean annual temperatures are around 20°C or above or where the average daily temperature is at least 18°C. Within the range of 20-28°C mean temperature, gas production increases over-proportionally. If the temperature of the bio-mass is below 15°C, gas production will be so low that the biogas plant is no longer economically feasible.

2.2.2 Available nutrient

In order to grow, bacteria need more than just a supply of organic substances as a source of carbon and energy. They also require certain mineral nutrients. In addition to carbon, oxygen and hydrogen, the generation of bio-mass requires an adequate supply of nitrogen, sulfur, phosphorous, potassium, calcium, magnesium and a number of trace elements such as iron, manganese, molybdenum, zinc, cobalt, selenium, tungsten, nickel etc. "Normal" substrates such as agricultural residues or municipal sewage usually contain adequate amounts of the mentioned elements. Higher concentration of any individual substance usually has an inhibitory effect, so that analyses are recommended on a case-to-case basis to determine which amount of which nutrients, if any, still needs to be added.

2.2.3 Cost efficiency

Optimizing the process parameters retention time - process temperature - substrate quality - volumetric load determine, among others, the cost efficiency of the biological processes. But as each m3 digester volume has its price, heating equipment can be costly and high quality substrates may have alternative uses, the cost-benefit optimum in biogas production is almost always below the biological optimum.

2.2.4 Substrate retention time

For liquid manure undergoing fermentation in the mesophilic temperature range, the following approximate values apply:

- Liquid cow manure: 20-30 days
- Liquid pig manure: 15-25 days
- Liquid chicken manure: 20-40 days
- Animal manure mixed with plant material: 50-80 days

If the retention time is too short, the bacteria in the digester are "washed out" faster than they can reproduce, so that the fermentation practically comes to a standstill. This problem rarely occurs in agricultural biogas systems.

2.2.5 pH value

The methane-producing bacteria live best under neutral to slightly alkaline conditions. Once the process of fermentation has stabilized under anaerobic conditions, the pH will normally take on a value of between 7 and 8.5. Due to the buffer effect of carbon dioxide-bicarbonate ($CO2$ - $HCO3-$) and ammonia ammonium ($NH3$ - $NH4+$), the pH level is rarely taken as a measure of substrate acids and/or potential biogas yield. A digester containing a high volatile-acid concentration requires a somewhat higher-than-normal pH value. If the pH value drops below 6.2, the medium will have a toxic effect on the methanogenic bacteria.

2.2.6 Nitrogen inhibition and C/N ratio

For higher pH values, even a relatively low nitrogen concentration may inhibit the process of fermentation. Noticeable inhibition occurs at a nitrogen concentration of roughly 1700 mg ammonium-nitrogen ($NH4$-N) per liter substrate. Nonetheless, given enough time, the methanogens are capable of adapting to $NH4$-N concentrations in the range of 5000-7000 mg/l substrate, the main prerequisite being that the ammonia level ($NH3$) does not exceed 200-300 mg $NH3$-N per liter substrate. The rate of ammonia dissociation in water depends on the process temperature and PH value of the substrate slurry.

2.2.7 C/N ratio

Microorganisms need both nitrogen and carbon for assimilation into their cell structures. Various experiments have shown that the metabolic activity of methanogenic bacteria can be optimized at a C/N ratio of approximately 8-20, whereby the optimum point varies from case to case, depending on the nature of the substrate.

2.3 PV SYSTEMS

2.3.1 Solar photovoltaic energy

Photovoltaic (PV) systems convert sunlight directly to electricity. They work any time the sun is shining, but more electricity is produced when the sunlight is more intense and strikes the PV or PV/T modules directly (as when rays of sunlight are perpendicular to the PV or PV/T modules) [24]. Unlike solar thermal systems for heating water, PV or PV/T does not use the sun's heat to make electricity. Instead, electrons freed by the interaction of sunlight with semiconductor materials in PV or PV/T cells are captured in an electric current.

PV or PV/T allows producing electricity without noise or air pollution from a clean, renewable resource. A PV or PV/T system never runs out of fuel, and it won't increase oil imports. Installations of photovoltaic systems have shown high growth rates around the world as shown in fig 2.2. Nevertheless, most PV or PV/T markets need considerable governmental support to reach parity with prevailing electricity supply [25].

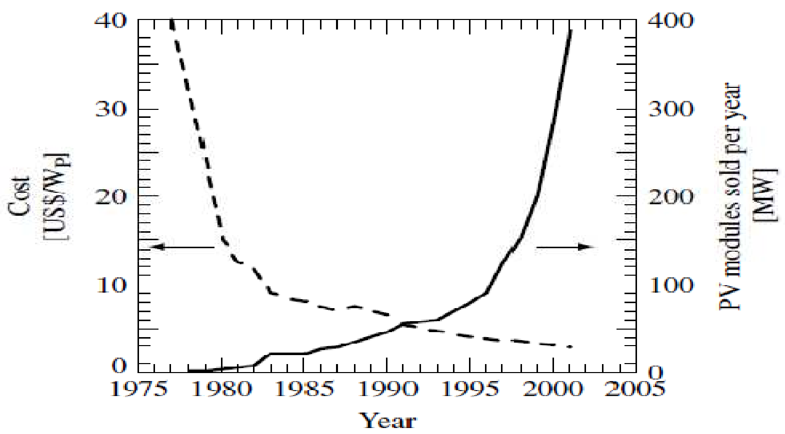


Fig. 2.2 Growth rate of PV panel demand and its cost [26]

On the other side, highly economic but still small PV or PV/T markets exist like in Ethiopia, for instance. A sustainable market development of such markets often dominated by small off-grid PV or PV/T solutions has to consider several key success factors for rural electrification. Similar success patterns have been observed around the world: adequate system design, training of installers and end-users, financing, service and institutional cooperation.

The energy demand in the world is steadily increasing and new types of energy sources must be found in order to cover the future demands, since the conventional sources are about to be emptied [23].

As one type of renewable energy source the photovoltaic (PV) cell, converts sunlight to electrical current without any form for mechanical or thermal interlink. PV cells are usually connected together to make PV modules, consisting of 72 PV cells, which generates a DC voltage between 23 Volt to 45 Volt and a typical maximum power of 160 Watt, depending on temperature and solar irradiation [25].

The electrical infrastructure around the world is based on AC voltage, with a few exceptions, with a voltage of 120 Volt or 230 Volt in the distribution grid. PV modules can therefore not be connected directly to the grid, but must be connected through an inverter. The two main tasks for the inverter are to load the PV module optimal, in order to harvest the most energy, and to inject a sinusoidal current into the grid.

2.3.2 Solar cell

The basic component of PV system is solar cell. It is basically made of p-n junction of different semiconductor materials like GaAs (Gallium Arsenide) CIGS (Copper Indium Gallium Diselenide) CdTe (Cadmium Telluride) a-Si:H (Hydrogenated amorphous silicon) which owns the property of photo electric effect. The equivalent circuit of the PV cell is shown in Fig 2. 3.

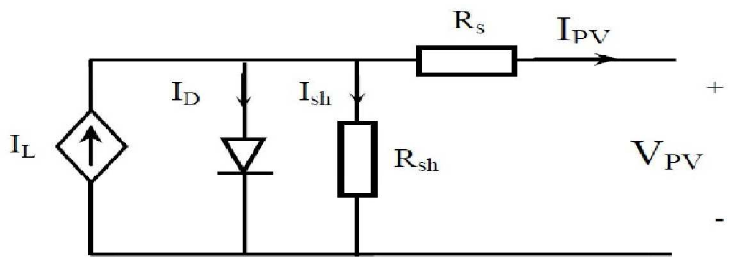


Fig. 2.3 Equivalent circuit of the PV cell

The PV curves vary with solar isolation and module temperature. Equation (1) and (2) are used to describe the characteristics of PV array.

$$I_{pv} = I_L - I_o^{\left(e^{q(V_{pv}+I_{pv}R_S)/_{AKT-1}}\right)} - \frac{V_{pv}+I_{pv}R_S}{R_{sh}} \quad 2.1$$

$$P_{pv} = V_{pv} \times I_{pv} \quad 2.2$$

Where: IPV is the PV module current (A), IL is the light generated current (A), Io is the diode saturation current, q is the charge of electron (coulomb), K is the Boltzmann's constant (j/K), A is the diode factor, T is the module temperature (K), RS is module series resistance (ohm), Rsh is module parallel resistance (ohm), VPV is the module output voltage (V), and PPV is the extracted PV power (W). (Azab., 2010).

2.3.3 Power Curve and Maximum Power Point (MPP)

In between, there is one particular combination of current and voltage, for which the power reaches a maximum(indicated with the rectangular area in Fig. 2.3. The so-called Maximum Power Point (MPP) represents the working point, at which the solar cell can deliver maximum power for a given radiation intensity. The corresponding values of VMPP and IMPP can be estimated from VOC and ISC as follows:

$$V_{MPP} = (0.75 – 0.9)\ V_{OC} \quad 2.3$$

$$I_{MPP} = (0.85 – 0.95)\ I_{SC} \quad 2.4$$

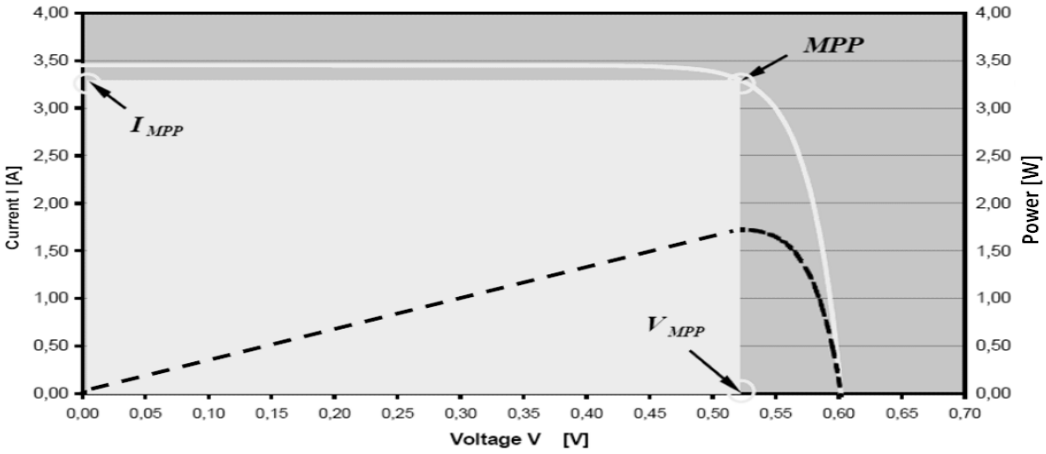


Fig. 2.3 Maximum Power Point (MPP)

2.3.4 Types of Solar Cells

According to the type of crystal, solar cells are categorized as: Monocrystalline solar cells, Polycrystalline solar cells, and Amorphous solar cells. Having efficiency in laboratory scale 24, 18 and 13 respectively. However their efficiency drops at production scale to 14 to 17, 13 to 15 and 13 5 to 7 respectively. During operation higher reduction in efficiency may happen because of different factors like installation location (shading and dirt) solar radiation intensity reduction moreover due to the heat created under the PV panels. Photovoltaics operate in a paradox–they need sunlight to generate electricity but suffer degradation in performance as they get hotter. A typical PV panel on a bright sunny day will reach temperatures in excess of 110°C. This can reduce efficiency by as much as 43% on a hot day or 0.5% for every 1°C temperature rise.

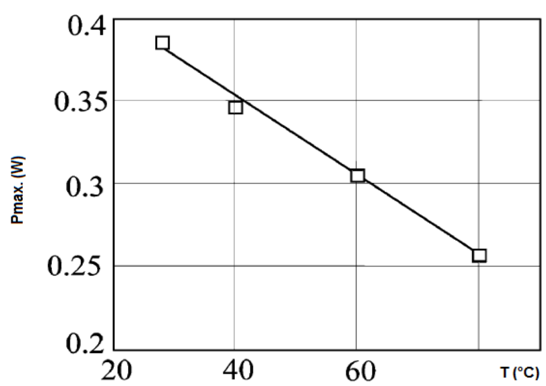


Fig. 2.4 Effect of heat generated by PV panel on power generation

Standard PV Panels typically only convert 10-15% of solar radiation into electricity and the rest is dissipated as waste heat. In this particular project it is tried to lessen this heat which can minimize efficiency of the PV system by replacing the PV only collector with equivalent Photovoltaic thermal collector (PV/T) solar collector which have thermal unit attached on it.

2.3.5 Solar energy in Ethiopia

Ethiopia is a landlocked country situated in the Horn of Africa with a population estimated at over 83 million by 2007. Its annual population growth rate of 2.5% ranks it 28th fastest growing of 229 countries in the world in terms of gross domestic product (GDP) per capita [13].

It is rated 174th of 179 and in terms of human development index it is rated 169th of 177. These numbers indicate Ethiopia as one of the poorest countries in the world. More country specific data can be found elsewhere [14]. Most Ethiopians live in rural areas (84%) and only 1% of those have access to electricity. Nevertheless, solar irradiation is well above 2000 kWh/m²/y, ranging from 1,950 – 2,600 kWh/m²/y, providing an excellent basis for PV (Figure 2.2). Due to its conditions, Ethiopia is an excellent example for most of the least developed countries in the Sunbelt; hence several results achieved for Ethiopia might be transferred to countries comprising more than 500 million people around the world [13, 14].

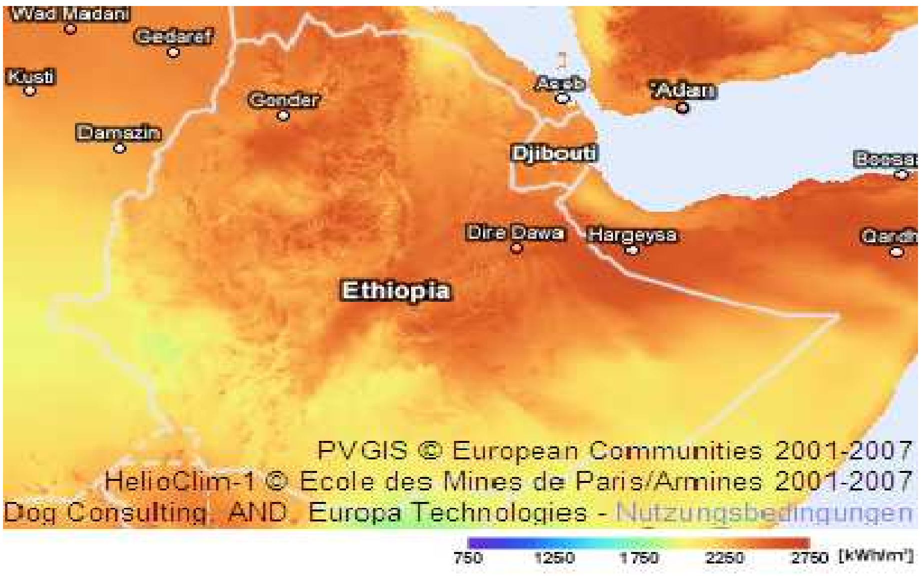


Fig. 2.5 Global irradiation incident on optimally inclined equator-oriented PV modules in Ethiopia [19].

Currently Ethiopia generates its power from its vast hydro power potential and supplemented diesel power plants. 647 MW or 89% of the installed grid connected capacity comes from hydro-electric power plants.

Economically feasible hydro-electric power potential would be up to 30 GW. Due to seasonal rainfalls the generation capacity significantly depends on the amount of rain water during the raining season. This results in power shedding during periods with low water levels. Such periods regularly force the Ethiopian Electricity Power Company (EEPCo) to cut off customers from power supply, even in the capital. Ethiopia has launched construction of several new hydro-electric power plants to prevent power shortages and meet the demand growth [13, 33].

Ethiopia exhibits excellent prerequisites for a nearly 100% renewable energy supply. Superb hydro and solar resources offer the chance of renewable energy supply in an economically, ecologically and socially sustainable way. Such as PV-hydro potentials have been already analyzed for Ethiopia and might lead to utility-scale PV power plants [13].

2.3.6 System sizing

The number of modules and the size of the battery bank, wires, controller, fuses, inverter, etc. mainly depend on the amount of power you plan to consume, and the amount of solar radiation available at your location on a daily and seasonal basis. System sizing is usually based on the maximum energy demand during the month of lowest solar radiation intensity. There are many books, manuals, and computer software packages available that detail system sizing procedures, and which provide general solar radiation data for many regions of the country, as general rule, a one kilowatt-peak capacity PV array (with single-crystalline modules), at around 100 square feet (9.3 square meters) will produce about 1 kilowatt (1,000 Watts) at solar noon on a clear sunny day.

High energy and power demands and/or a low solar resource will increase system size and costs. Sizing a PV system to operate high wattage loads such as electric space and water heaters, electric stoves, and toaster ovens will make a PV system extremely expensive. It is important to use energy efficient appliances, such as compact fluorescent lights, to reduce the electrical loads and system costs [30].

2.3.7 Site selection

The following set of fundamental questions must be answered while selecting suitable spot for installation of PV or PV/T system.

- Is the installation site free from shading by nearby trees, buildings or other obstructions?
- Can the PV or PV/T system be oriented for good performance?
- Does the roof or property have enough area to accommodate the solar array?
- If the array will be roof-mounted, what kind of roof is it and what is its condition?

The specific site where a PV or PV/T system will be located plays a crucial role in the design and performance of the system. The amount of power generated by a solar cell depends upon the intensity of sunlight striking it, and the amount of available sunlight varies with latitude, climate, and local conditions, such as the presence of trees [26].

There are three factors responsible for variations in the amount and quality of sunlight reaching the Earth. First, the Earth is round. Second, it revolves around the sun in an elliptical orbit. Third, the Earth rotates on a tilted axis. As the Earth is round, sunlight strikes its surface at differing angles ranging from 0o (just above the horizon) to 90o (when the sun is directly overhead). When the sun's rays are perpendicular to the surface of the Earth, they transmit the most energy. When the sun is low in the sky and its rays are at a very low angle, they must pass through a longer portion of the atmosphere, making the sunlight scattered, diffuse, and reducing its energy [23].

a. ***Shading***

Photovoltaic arrays are adversely affected by shading. Even small shadows, such as the shadow of a single branch of a leafless tree can significantly reduce the power output of a solar module. Shading from the building itself due to vents, attic fans, skylights, gables or overhangs – must also be avoided [20, 29].

b. Orientation

In northern latitudes, by conventional wisdom PV modules are ideally oriented towards true south. But the tilt or orientation of a roof does not need to be perfect because solar modules produce 95 percent of their full power when within 20 degrees of the sun's direction. Roofs that face east or west may also be acceptable. Flat roofs work well because the PV modules can be mounted on frames and tilted up toward true south. Optimum orientation can be influenced by typical local weather patterns [29].

c. Tilt

An increased tilt favors power output in the winter and a decreased tilt favors output in the summer. Nevertheless, it is recommended that modules be installed at the same pitch as a sloping roof, whatever that slope is, primarily for aesthetic reasons, but also because the tilt is very forgiving [29].

d. Roof Types

For roof-mounted systems, typically composition shingles are easiest to work with and slate and tile roofs are the most difficult. Nevertheless, it is possible to install PV or PV/T modules on all roof types. If the roof will need replacing within 5 to 10 years, it should be replaced at the time the PV or PV/T system is installed to avoid the cost of removing and reinstalling the PV or PV/T system. Building integrated PV or PV/T (BIPV) modules, which can be integrated into the roof itself, might be considered for new construction or for an older roof in need of replacing. While BIPV products currently have a premium price, costs are expected to decrease [16, 29].

2.3.8 Panel selection

The heart of a photovoltaic system is the solar module. Module costs typically represents only 40-60% of total PV system cost and the rest is accounted by inverter, PV array support, electrical cabling and installation [22].

Many photovoltaic cells are wired together by the manufacturer to produce a solar module. When installed at a site, solar modules are wired together in series to form strings. Strings of modules are connected in parallel to form an array.

a Module Types

Rigid flat framed modules are currently most common and most of these are composed of silicon. Silicon cells have atomic structures that are single-crystalline (Mono-crystalline), poly-crystalline (multi-crystalline) or amorphous (thin film silicon). Other cell materials used in solar modules are cadmium telluride (CdTe, commonly pronounced “CadTel”) and copper indium diselenide (CIS). Some modules are manufactured using combinations of these materials. An example is a thin film of amorphous silicon deposited onto a substrate of single-crystalline silicon.

b Building Integrated Photovoltaic Products

PV or PV/T technology has been integrated into roofing tiles, flexible roofing shingles, roofing membranes; adhesive laminates for metal standing-seam roofs, windows, and other building integrated photovoltaic (BIPV) products. BIPV modules are generally more expensive than rigid flat modules, but are anticipated to eventually reduce overall costs of a PV system because of their dual purpose [27].

2.4 SOLAR THERMAL SYSTEMS

Solar thermal energy can be interpreted as direct conversion of the energy from solar radiation to useful thermal energy. The heat is generated by the absorption of sun’s ray through a dark coated material, called absorber. The absorber actually is a system of pipes filled up with a heat transfer medium and the medium flows to the collector to collect the heat from sun’s ray and goes back to the hot water store. In some systems, heat exchanger is used to extract heat from the water-glycol mixture that is circulated in a closed circuit; is called an indirect system. Other systems, in which pure water is used as the heat transfer medium, are called drain back systems. Use of water entails a requirement for sealed paths and protection against corrosion, just as in thermal solar collectors. Using the sun’s energy to heat water is not a new idea [28].

2.3.9 PV/T collectors

PV/T collector is a combination of photovoltaic (PV) and solar thermal (T) components/systems which produce both electricity and heat from one integrated component. PV systems turn on average less than 20% of the sunlight into electricity. The remainder is turned into heat. Utilizing this untapped energy is the general concept for hybrid systems. By circulating a fluid, which will extract heat from the PV modules, module temperature is decreased and hence, performance of the PV modules increases. Furthermore, in cases where heating is required, extracted heat from the PV modules serves as a second benefit along with the increased performance of the PV module. Domestic hot water heating, air heating in ventilation systems, pool heating can be counted among these cases, where combining a Photovoltaic and Thermal collector makes most sense in terms of efficiency and performance [31, 32].

Another advantage of combining the photovoltaic and thermal system is that total area requirement of a PV/T collector is around 40% less (IEA, 2007) compared to photovoltaic and thermal collectors with the same total capacity. In cases where available area is limited and maximum utilization of the available space is desired, PV/T collectors shine as the better alternative. It is also suggested that PV/T collectors are aesthetically more appealing compared to a combination of thermal and photovoltaic collectors [25, 22].

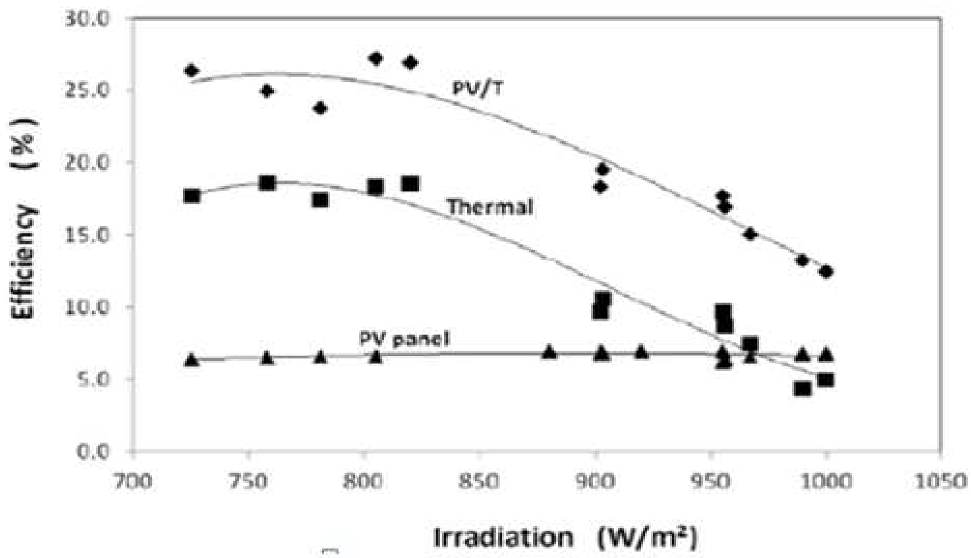
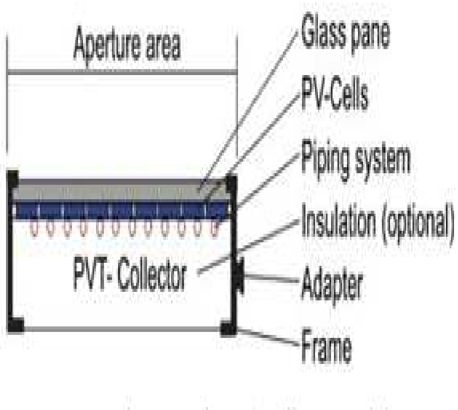


Fig 2.6 Efficiency of the PV/T and thermal units at different irradiation and water flow rate 0.17 ml/s [32].

2.3.10 Demonstration of the System

Solar energy can be made useful by photovoltaic cells which generate electric power directly. Solar thermal panels can be utilized to produce heat energy [4]. A system is suggested to convert a large portion of this energy into electric energy. The hybridization of the two schemes provides distinct advantages as far as cost, the small demand of the land area and installation are concerned [5]. The main drawback of the system is that the overall efficiency of the combined system will be smaller than that of standalone system. A simple diagram describing a basic structure is shown in fig. 2.3[6]. The thermal part consists of transparent plastic layers having cellular inner walls and working medium is made circular. Under the plastic layers, silicon photovoltaic cells are joined and insulated thermally. The sunlight enters through the plastic layers and the working medium produces electricity in the solar cells. The heat energy is absorbed by both working medium and plastic layers. Thermal insulation is present under the silicon layer. To increase the system operating temperature, an additional glazing cover is necessary (like that of the usual solar thermal collectors), but it results in a decrease of the PV module electrical output from the additional absorption of the solar radiation.Fig.2.3 shows the cross section of the two basic PV/T module designs, one without (PV/T UNGLAZED) and a second with the additional glazing (PV/T GLAZED). These systems use flat heat exchanger with pipes for the circulation of water and have also thermal insulation to avoid thermal losses from the non-illuminated system side.



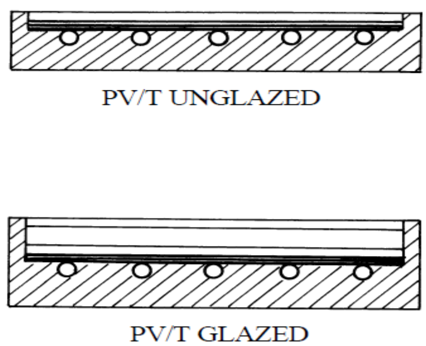


Fig. 2.7 Cross section of the PV/T experimental models [23].

2.3.11 PV/T solar collector types

There are several types of PV/T collectors and they are classified with respect to the fluid used, shape of the collector and whether it's integrated into a building or not. Furthermore, existence of glazing on the collector is another factor that distinguishes a PV/T collector's characteristics.

Liquid type PV/T collectors, air type PV/T collectors, concentrating PV/T collectors and building integrated PV/T collectors are the four different types of PV/T collectors [22]. For simplicity, here the two main types of PV/T collectors will be discussed.

2.3.12 Liquid type flat PV/T collectors

In this type of PV/T collectors, water or a mixture of water (i.e. water-ethylene-glycol) is circulated through the collector to extract heat from it. Using a liquid-PV/T collector is advantageous if there is a demand for hot water. Flat structure allows convenient integration on a building, usually rooftops. Furthermore, hot water may be stored in an external tank for a period of time. Its drawback is mainly leakages. However, these can be prevented by robust construction and by using water-ethylene-glycol mixture [30, 31].

PV/T collectors may either be glazed or unglazed. An extra layer of glass on top of the photovoltaic cells results in less heat losses and greater thermal performance, whereby reducing electrical performance by some extent due to the reason that photovoltaic cells perform worse in higher temperatures. Unglazed liquid type flat – PV/T collectors have higher electrical performance and lower thermal performance compared to glazed ones because of greater heat losses and resulting lower operating temperatures. It can be stated that in order to achieve higher thermal performance, glazed- and for higher electrical performance, unglazed liquid type flat PV/T collectors will be the correct choice.

Below, a figure representing a liquid type Flat – PV/T collector and two commercial collectors, one glazed and the other unglazed, can be observed.

Parts and Components

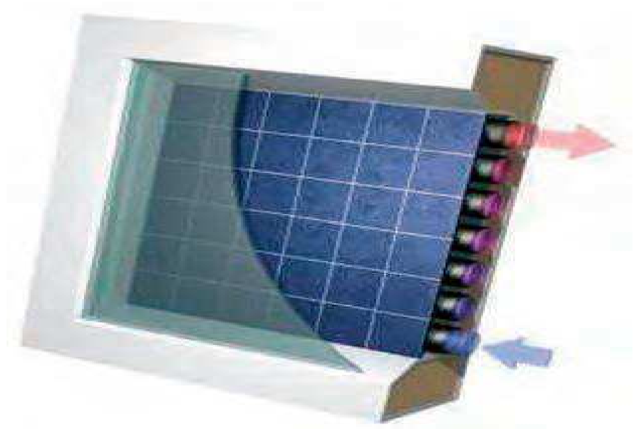


Fig.2.8 Liquid type Flat – PV/T collector

2.3.13 Solar reflectors

Considering PV/T solar systems installed on horizontal building roof they are usually placed in parallel rows, keeping a distance from one row to the other in order to avoid PV module shading. It is suggested to place stationary flat diffuse reflectors, as shown in Fig. 2.5 from the higher part of the modules of one row to the lower part of the modules of the next row. This installation increases solar input on the PV modules almost all year resulting in an increase of electrical and thermal output of the PV/T systems. The suggested diffuse reflectors don’t contribute to electrical efficiency drop, as they provide an almost uniform distribution of reflected solar radiation on PV module surface [29].

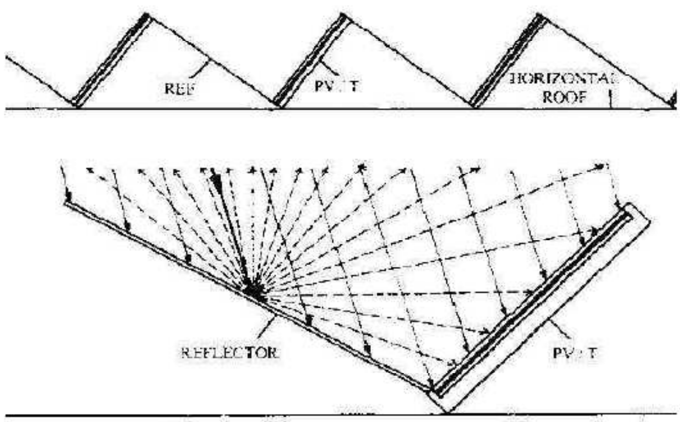


Fig.2.9 PV/T reflector

CHAPTER THREE

3. DATA COLLECTION AND ANALYSIS

All the data used in the analysis of the project are discussed in this section. The data required throughout this can be categorized as: local metrological data, load profile of the study location and project site related data such as available area for installation of system components, number of population, number of cafeterias and lounges.

3.1 GATHERED DATA SETS

3.1.1 Load assessment

The energy demand in the university can be categorized in to household load and industrial loads. Household loads include lightings in class rooms, library, dormitory, offices, fans, air conditioners and others. The industrial loads are the consumptions of energy by variety of machineries and equipment of laboratories, workshops, kitchens, water pumps and others. The monthly consumption of the university is given in Table 3.1.

3.1.2 Consumption (load data)

Table 3.1: Monthly electrical consumption of the University data for the year 2012GC

Month	Energy Consumption [KWh]	Cost [Birr]
January	100,883.00	77,602.31
February	102,644.00	78,956.92
March	79,955.00	61,503.85
April	96,566.00	74,281.54
May	100,800.00	77,538.46
June	102,666.00	78,973.85
July	104,870.00	80,669.23
August	66,395.00	51,073.08
September	116,232.00	89,409.23

October	86,425.00	66,480.77
November	79,976.00	61,520.00
December	96,574.00	74,287.69
Total	1,133,986	872,296.9

(Source: Addis Ababa University 6 Kilo Campus)

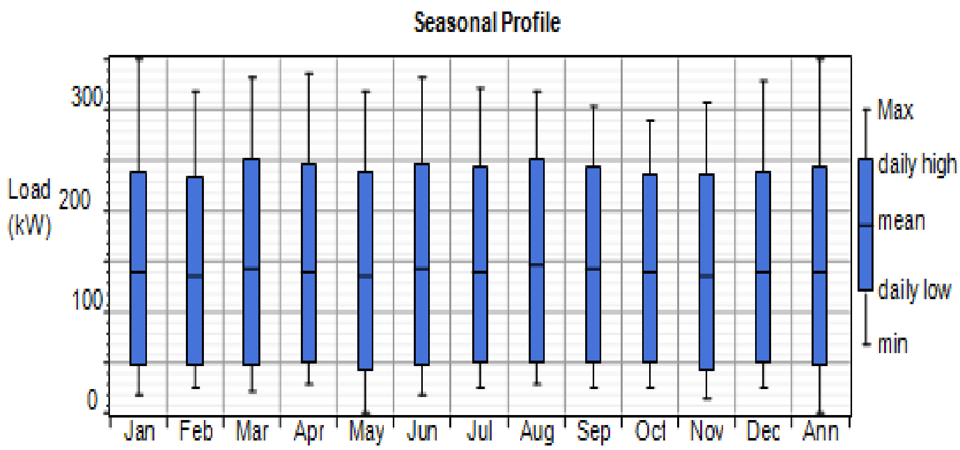


Fig.3.1 Monthly energy consumption (*Source: Homer software*)

As it can be clearly seen from the above figures, the monthly energy consumed by the institution uneven from month to month. In the month September the maximum amount of electrical energy was consumed where as the minimum load was in the month of August. From observation made on September, as it is the start of winter in Ethiopia, the institution admits a large number of new (fresh) students as it is the starting time of teaching learning. Contrarily on August some of the students leave the campus residence by different reasons like withdrawal, re admissions and even by complete dismissal. So since the main consumer of the electrical energy is the institution dwellers particularly students the variation in their number can directly affect both the generation and consumption of the electrical energy as the university is concerned.

Fig.3.2 Daily energy consumption profile (*source: homer software result*)

Figure 3.2 is the result of the homer software using the monthly energy consumption in which homer prorates to hourly basis. From the figure it can be pronounced that the minimum power requirement in a specific day lies in the time interval of 1am to 4am and 12pm to 3pm this ensues because most of the populations in the campus are passive at those times. Unlike to this, in the time gap of 6am to 12 am and 5pm to 11 am the maximum amount of load come about since most of the kitchen activities are done now moreover students are highly engaged on laboratory works also.

3.2 RENEWABLE ENERGY RESOURCE DATA

3.2.1 Biomass resources

Table 3.2 the average amount of waste collected from the five cafeterias each month of a year

Month	Amount of Waste Collected(ton)	Remarks
January	63.00	Normal Teaching Learning Actives
February	57.20	Normal Teaching Learning Actives
March	56.50	Normal Teaching Learning Actives
April	56.00	Easter Holiday
May	60.00	Normal Teaching Learning Actives
Jun	33.00	(Only MSc and Summer Students are to be had in the campus)

July	24.00	(Only MSc and Summer Students are to be had in the campus)
August	20.00	Decrease in the Number of Staffs available inside the Campus
September	18.00	Normal Teaching Learning Actives
October	57.23	Normal Teaching Learning Actives
November	57.00	Normal Teaching Learning Actives
December	57.50	Charismas Holiday(Ethiopians)
Sum	559.43	
Average	46.62	

(Source: Direct Interview From Cafeteria Managers And Internet Exploration For Related Case Studies [14].)

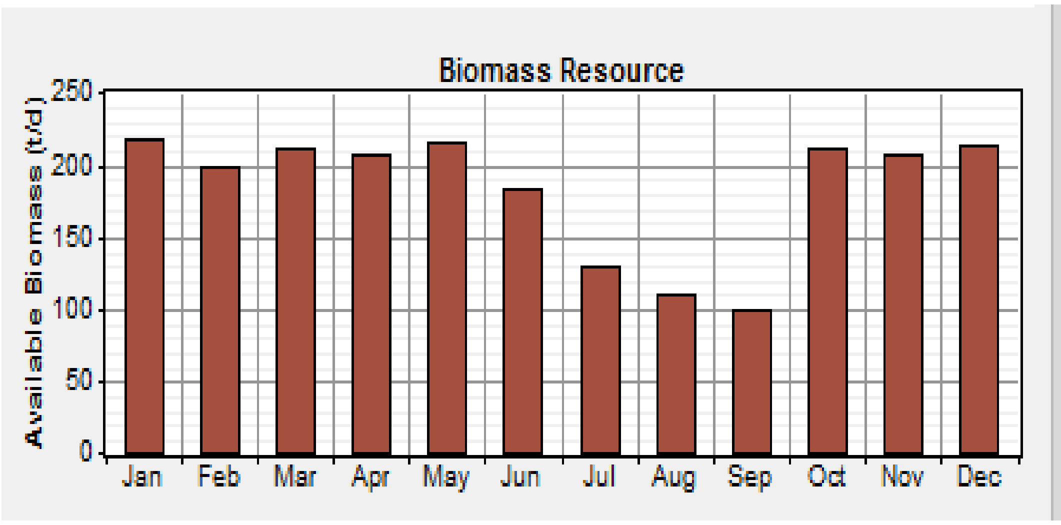


Fig.3.3 Total Biomass Resource (*Source: Homer Software)*

Although there is no readymade recorded data for the amount of available biomass resource from the kitchen and cafeterias for this study direct site survey information and related studies from published papers were used useful to have reasonable assumptions. One of the biomass resources is the populations in the campus. The gross number of population including other staff than students can be estimated as 6200 as per the information obtain from the institution registrar. But for this study about half of the figure (3,500) populations are considered to be technically active to deliver the biomass resources (human manure and urine) from the total amount of people living and working in the university. These peoples are as well supposed to be served by the cafeterias available in the campus yard.

3.2.2 Meteorological data

The metro data retrieved and recorded for this thesis are using the instrument called Pyranometer SP-Lite and CMP3.This device can record variety of weather related data items at once. For this particular paper the most necessary data like relative humidity, wind speed, ambient temperature and solar radiation of Addis Ababa are collected which are recorded for each fifteen minutes interval. About 35,000 data sets are collected for each items discussed above of the year 2012 GC taking it as a design year which is random selection since there is no significant yearly changes of these items. Since analyzing the 35,000 data is too difficult it is reasonable to select the design month more conveniently the design day (July 25,2012GC).

Table 3.3 Metrological data of the year 2012GC

Time(min)	RH(%)	V_w(m/s)	T_a(^oC)	I(W/m^2)	Time(min)	RH(%)	V_w(m/s)	T_a(^oC)	I(W/m^2)
12:00:00 AM	88.5	0.86	14.2	0.5	06:00:00 AM	90	1.32	13.8	0.6
12:15:00 AM	89.1	0.21	13.9	0.5	06:15:00 AM	90	1.1	13.8	0.7
12:30:00 AM	90	0.06	13.4	0.5	06:30:00 AM	90	5.81	13.2	0.9
12:45:00 AM	90	0.6	13.3	0.5	06:45:00 AM	90	2.34	11.5	2.7
01:00:00 AM	90	0.64	13	0.4	07:00:00 AM	90	1.23	11.5	6.3
01:15:00 AM	90	0.06	12.8	0.5	07:15:00 AM	90	0.47	11.5	9.2
01:30:00 AM	90	0.4	12.5	0.5	07:30:00 AM	90	1.77	11.5	14.7
01:45:00 AM	90	0.06	12.5	0.5	07:45:00 AM	90	2.13	11.7	33.3
02:00:00 AM	90	0.55	12.7	0.5	08:00:00 AM	90	1.54	11.8	68.8
02:15:00 AM	90	0.7	12.7	0.5	08:15:00 AM	90	1.5	12	86.5
02:30:00 AM	90	2.68	12.7	0.5	08:30:00 AM	90	2.98	12	70.9
02:45:00 AM	90	0.68	12.7	0.5	08:45:00 AM	90	1.5	12.2	78
03:00:00 AM	90	0.65	13.2	0.5	09:00:00 AM	90	1.3	12.3	114.8
03:15:00 AM	90	3.3	13.5	0.6	09:15:00 AM	90	1.61	12.7	156.7
03:30:00 AM	90	1.57	13.5	0.5	09:30:00 AM	90	2.15	13.1	201.7
03:45:00 AM	90	0.91	13.4	0.5	09:45:00 AM	90	2.77	13.2	210.9
04:00:00 AM	90	1.36	13.5	0.5	10:00:00 AM	90	2.02	13.4	163

04:15:00 AM	90	2.96	13.6	0.5	10:15:00 AM	90	1.87	13.6	181.8
04:30:00 AM	90	2.61	13.5	0.5	10:30:00 AM	90	3.38	14.1	220.2
04:45:00 AM	90	2.46	13.5	0.5	10:45:00 AM	90	4.08	14.8	372.9
05:00:00 AM	90	2.69	13.6	0.5	11:00:00 AM	90	4.86	15.8	469.6
05:15:00 AM	90	2.99	13.6	0.5	11:15:00 AM	90	5.86	16.5	596.1
05:30:00 AM	90	3.48	13.7	0.5	11:30:00 AM	90	5.39	16.7	565
05:45:00 AM	90	2	13.8	0.5	11:45:00 AM	90	4.92	17.1	381.2
12:00:00 PM	90	4.07	16.7	330.8	06:00:00 PM	90	1.42	19.1	108.5
12:15:00 PM	90	4.01	17.7	499.6	06:15:00 PM	90	2	18.2	38.3
12:30:00 PM	90	5.55	17.8	338.2	06:30:00 PM	90	0.84	17.7	16
12:45:00 PM	90	5.63	18.6	802.6	06:45:00 PM	90	0.06	17.4	2.3
01:00:00 PM	90	4.91	19.8	199.9	07:00:00 PM	90	0.33	17.2	0.7
01:15:00 PM	90	6.25	19.2	303.2	07:15:00 PM	90	0.67	17.2	0.6
01:30:00 PM	90	5.23	19.6	355.3	07:30:00 PM	90	3.92	16.8	0.5
01:45:00 PM	90	6.33	19.6	426.7	07:45:00 PM	90	3.24	16.3	0.5
02:00:00 PM	90	4.74	18.8	205.2	08:00:00 PM	90	0.06	15.9	0.5
02:15:00 PM	90	5.65	18.9	200.7	08:15:00 PM	90	0.41	15.7	0.5
02:30:00 PM	90	4.32	18.4	104.2	08:30:00 PM	90	0.2	15.6	0.6
02:45:00 PM	90	3.79	18.3	101.8	08:45:00 PM	90	0.06	15.5	0.5
03:00:00 PM	90	5.78	17.7	73.4	09:00:00 PM	90	0.06	15.2	0.5
03:15:00 PM	90	4.97	16.4	79.2	09:15:00 PM	90	2.17	15.7	0.6
03:30:00 PM	90	5.39	16	65.7	09:30:00 PM	90	3.02	16.1	0.5
03:45:00 PM	90	3.46	15.9	67.2	09:45:00 PM	90	6.19	16	0.5
04:00:00 PM	90	3.23	15.6	66.7	10:00:00 PM	90	6.68	14.9	0.5
04:15:00 PM	90	2.63	15.7	53	10:15:00 PM	90	0.42	14.5	0.5
04:30:00 PM	90	1.02	15.8	50.2	10:30:00 PM	90	2.17	14.1	0.5
04:45:00 PM	90	0.61	16.1	61.6	10:45:00 PM	90	1.3	13.7	0.5
05:00:00 PM	90	2.31	16.6	94.1	11:00:00 PM	90	0.06	13.4	0.5
05:15:00 PM	90	1.65	17.1	110	11:15:00 PM	90	0.06	13.5	0.5
05:30:00 PM	90	2.17	17.6	110.9	11:30:00 PM	90	0.06	12.9	0.5
05:45:00 PM	90	1.98	18.1	131.9	11:45:00 PM	90	0.83	13.6	0.5

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d
January	5.48	5.87
February	5.47	5.70
March	5.64	5.71
April	5.27	5.19
May	5.17	4.99
June	4.47	4.29
July	3.77	3.66
August	3.73	3.66
September	4.50	4.50
October	5.47	5.64
November	5.65	6.02
December	5.27	5.68
Annual	**4.99**	**5.07**

Annual solar radiation - horizontal	MWh/m²	1.82
Annual solar radiation - tilted	MWh/m²	1.85

Fig. 3.4 Weather Data of Study Site *(Source: Ret Screen Software Help)*

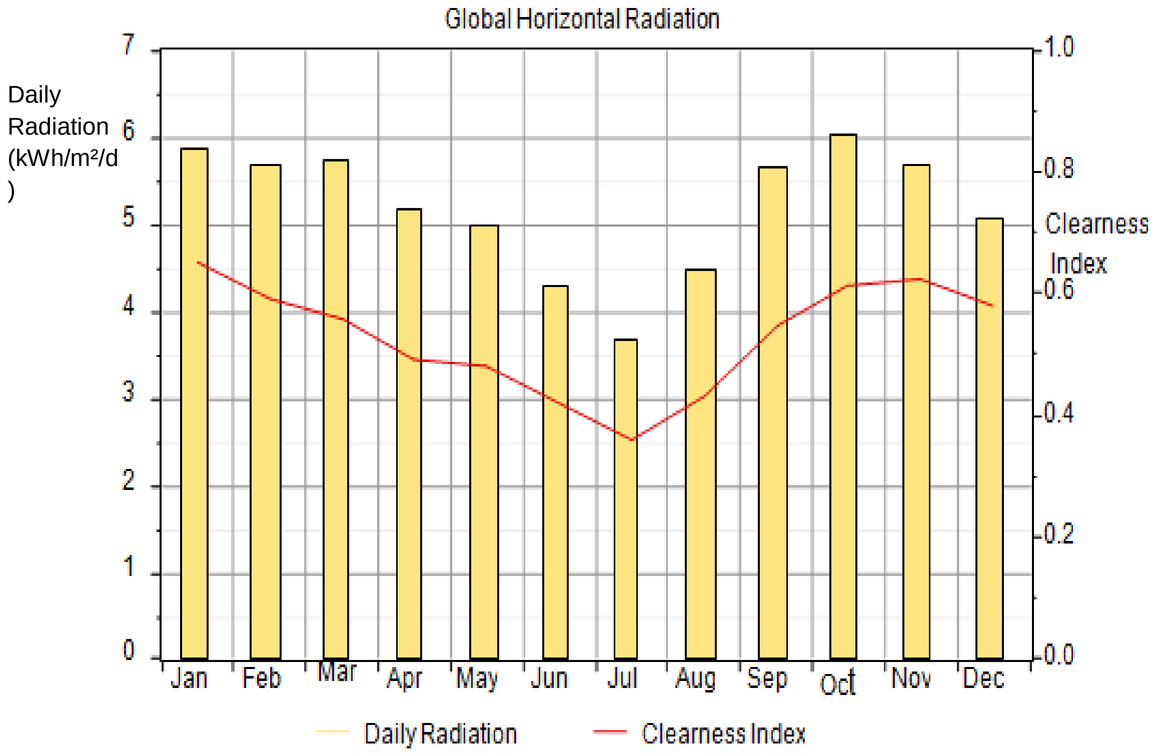


Fig.3.5 Global Monthly Solar Radiation of the Study Site (*Source: Homer Software analysis result*)

3.2.3 Data from different Literatures and International Scientific Journals

Table 3.4 Facts and Figures About Biogas

Unit Quantity of Biogas and Methane	Correspondence with other fuel
1 m^3 Biogas	5.0 – 7.5 KWh total energy content
1 m^3 Biogas	50 – 75 % methane content
1 m^3 Biogas	1.9-3.2 KWhel
1 m^3 Biogas	~ 0.6 liters oil equivalent
1m^3 Methane	9.97 KWh total energy content
1m^3 Methane	3.3 – 4.3 KWhel
1m^3 Methane	1 liter oil equivalent
CHP Electrical Efficiencies	33 – 45%
CHP Thermal Efficiency	35 - 56 %
CHP Total Efficiency	85 – 90%

(*Source: Giz Module 5: Basic Design Parameters For Anaerobic Digestion (Ad) / Biogas Power Plants (Bruno Wilhelm)*

CHAPTER FOUR

4. DESIGN AND SYSTEM SIZING

4.1 HYBID BIOGAS AND PV/T SYSTEM SIZING

This section discusses about the details of the process while going through a complete Biogas and PV/T systems designs for Addis Ababa University Collage of Natural Science (AAUCNCSc). It describes how each step of the methodology described in the previous section is implemented starting with identification of DC equivalent demand, determining the type and the size of gas engine, generator, water pump, PV/T module, inverter, gas pipe, pipes valves, accessories and other on grid system components by comparing from different trusted manufacturers or suppliers available on the current market.

Assumptions based on Literatures

1. 1 kg of human excreta =0.078m^3 of biogas [4])
2. Gas production rate from food waste = 0.05 m^3/kg [4]
3. Retention time = 40 days, selected because pre heating is considered in the project.
4. Ratio of manure and water 1:1dilution
5. Heat content of methane= 38.13 MJ/m^3
6. A cubic meter of methane has an energy value of about 10 kilowatts- hours (9.97 kWh). Therefore, biogas with a content of 55 % methane has an energy value of about 5.5 kWh per cubic meter [33].

4.1.1 Estimation of Energy Generated from Biogas System.

Amount of Biogas obtained from waste of kitchen and cafeterias' leftover food

From the data collected, the five cafeterias can produce about an average of 1.503 ton each day. From the total amount waste collected, 70% of it is biodegradable and the remaining is non-biodegradable which accounts 30%. Therefore, the total mass of biodegradable solid wastes (peel of potatoes, onion, can sugar, oaf, etc) per month can be calculated as follows:

$$\text{Total mass of biodegradable waste} = 0.7\times 46{,}619 \text{ kg/month}$$

$$= 32{,}633.358 \text{ kg/month}$$

$$=1{,}052.7 \text{ kg/day}$$

and the total mass of non-biodegradable waste:

= 0.3x46, 619 kg/month

=13,985.7 kg/month then the daily average

= 466.2 kg/day

Daily volumetric flow rate (S_d) in cubic meter per month

$$S_d = \frac{Total\ mass\ of\ biodegradable\ waste}{Density\ of\ food\ waste} \quad 4.1$$

$$= \frac{32{,}633.358\text{kg/month}}{1160\text{kg}/m^3}$$

= 28.136 m^3/month thus the daily average will be

= 0.94 m^3/day

4.1.2 Amount biogas obtained from human manure (toilets)

A. Amount of biogas generated from human manure

The number of effective population living in the campus is estimated as=3,500

The amount of manure per day (d) =1 kg/day/adult as American Journal of Energy Engineering 2014; 2([14]: 16-22 19 and 0.4 kg/day between 10 to 15 ages but it are obvious that university students in Ethiopia are usually above 17 years old. Therefore, the total amount of human waste per day=1×3,500=3,500 kg/day.

$$S_d = \frac{Total\ mass\ of\ manure\ waste}{Density\ of\ human\ waste} \quad 4.2$$

$$= \frac{3{,}500kg/day}{1000kg/m^3}$$

=3.5 m^3/day

B. The amount of biogas generated from human urine

Amount of urine per person per day=1.L/day = 0.001m3.Therefore, the total amount of urine waste per day=1L×3,500=3,500 L/day =3.5 m3/day

C. Total amount of waste collected (TW) (m^3)

TW=Waste obtained from food + Waste obtained from urine + Waste obtained from human manure = 0.94 m^3/day+3.5 m^3/day+3.5 m^3/day

= 7.94 m^3/day

From past experience the inhabitants of the campus flash water at the end of toilet use. The consequence of this action makes the substrate (biogas resource) wet. As a result, applying one to one dilution ratio is reasonable to achieve the required solid concentration that accounts 8%. Therefore, 4.44m^3/day of water is supposed to be added in the solid substrate so as to obtain 1 to 1 dilution. Therefore, volume of the daily charge (S_d) =12.38m^3/day.

Note that as per the design, hot water is expected to be delivered to the all the toilets throughout the campus so as to be flashed at the end of use. The hot water helps the bacterial regeneration in the biogas digester which can enhance higher yield of biogas fuel. This mechanism (hot water flashing) is proposed because the surrounding temperature of the selected site is too low to have optimum digestion.

The volume of the digester (slurry) (VD) is defined as the product of the volume of the daily charge (S_d) and hydraulic retention time (HRT).The volume of digester = Total waste per day × retention time/ density of waste in one retention time.

$$Hydraulic\ retention\ [day] = \frac{Fill\ volume\ of\ digester[m^3]}{Substrate\ input[m^3/day]} \quad 4.3$$

$$V_D = S_d \times HRT$$

$$= 12.38 m^3/day \times 40\ days$$

$$= 495.2\ m^3$$

Total amount Biogas produced

Gas produced from food waste per day = amount of food waste per day × its gas production rate

= 1,052.7 kg/day × 0.05

= 52.6 m^3/day

Gas from human waste per day = No of population × waste per day × its gas production

= 3,500×1 kg/day × 0.078

= 273 m^3

Gas produced from total waste per day = 52.6 m3+273 m3

$= 325.6\ m^3/day$

4.1.3 The amount of electrical energy produced from the biogas resource

The energy available from a biogas digester is given by [4]:

$$E = \eta \times H_b \times V_b \qquad 4.4$$

Where η is the combustion efficiency of burners, boilers, generators etc. (~ 60%).In this thesis, the biogas generator (Gen-Set) HGGM1250 Googol Brand is selected depending on the result of optimization result of homer software which owns an efficiency of 42 % H_b is the heat of combustion per unit volume biogas (22.5 MJ m^{-3} at 10 cm water gauge pressure, 0.01 atmosphere) and V_b is the volume of biogas. Alternatively:

$$E = \eta \times H_m \times f_m \times V_b \qquad 4.5$$

where H_m is the heat of combustion of methane(38.13MJ/m3,28MJkg-3, at STP) the two constants are used alternatively as per the formula or designer requires and fm is the fraction of methane in the biogas. As from the digester, f should be between 0.5 and 0.7, but increase fm to nearly 1.0. From the manual (mathematical) analysis performed above 288.38m^3 volume of biogas is obtained daily basis.

The volume of biogas is given by:

$$V = c \times m_o \qquad 4.6$$

Where **c** is the biogas yield per unit dry mass of whole input (0.2 – 0.4m3 kg-1) and mo is the mass of dry input.

From the above equation (4.5) the amount of energy produced daily will be:

$$E = 0.42 \times 38.13 MJ/m^3 \times 0.65 \times 325.6\ m^3$$

$$= 3{,}389.32 MJ$$

1kWh=3.6MJ which implies 3,389.32MJ equals to be $\mathbf{941.5 kWh.}$

4.2 DESIGN AND SIZING OF BIOGAS DIGESTER

Among the various types of digesters discussed on the literature review section, in this section fixed dome Nicarao a continuous feed (displacement) digester is selected, because it is plant are relatively cheap. It is simple no rusting steel parts and hence a long life of the plant (25 years or more) and the construction is underground which can save space and maintain digester temperature [12]. After selecting the type of digester, the retention time, which is a key parameter in determining digester size, is chosen to maximize the percentage of production of biogas. From standard practice of biogas digester design Sixty days is chosen as the minimum amount of time for sufficient bacterial action but in case of bio digesters with pre heating system lower retention time can make enhanced biodegradation [14].

The basic elements of a fixed dome plant are shown in the figure below.

Cross-section of a digester:

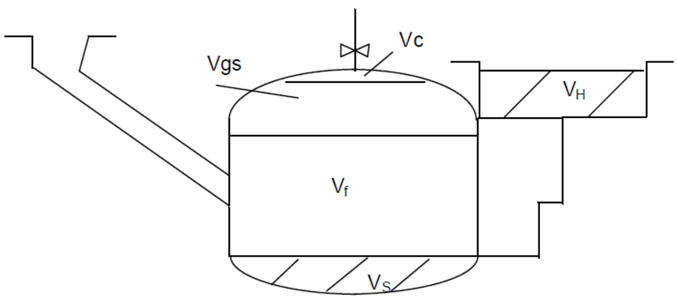


Fig.4.1 Basic elements of a fixed dome plant[62].

a) Volume of gas collecting chamber = V_c

b) Volume of gas storage chamber = V_{gs}

c) Volume of fermentation chamber = V_f

d) Volume of hydraulic chamber = V_H

e) Volume of sludge layer = V_s

Total volume of digester $V = V_c + V_{gs} + V_f + V_s$

Geometrical dimensions of the cylindrical shaped biogas digester body:

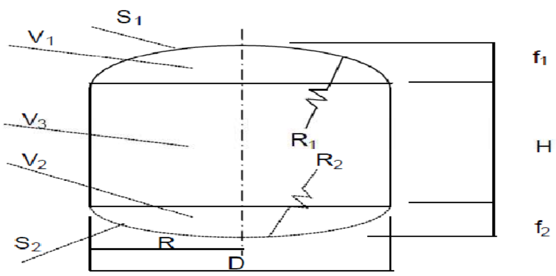


Fig.4.2 Cylindrical shaped biogas digester body [32]

For structure stability and efficient performance, fixed dome digester is expressed by the following correlation [7, 8].

From the previous calculation the total volume of the digester is obtained to be 492.8m^3 So from this stand point the size of different parts of the biomass digester can be calculated as follows.

The following formulas are obtained from the above standard assumption.

$$V_c = 0.05V = 24.64m^3 \quad 4.7$$

$$V_s = 0.15V = 73.92m^3 \quad 4.8$$

$$V_{gs} + V_f = 80\%V,\ V_f = 0.8V - V_g \quad 4.9$$

$$Vgs = V_H \quad 4.10$$

V_{gs}=1/2(V_{gs}+ V_f+ Vs)K=1/2(Vgs+[0.8V-Vgs] +Vs)K from equation (4.3),2Vgs=(0.8V+0.15V)K=(0.95V)K where K =0.4 for Ethiopia[13].

Therefore,

V_{gs}=99.23m^3=V_h

V_f=295.01m^3

4.3 GEN-SET SIZING AND SELECTION

Sizing and selection of Gas engine-generator set (Gen-Set)is a one of the fundamental procedures while going through the design and feasibility study of biogas energy generation.

The biogas generator is supposed to work about 6 hours of a day with a minimum power capacity of 418.3 kW. So it can be sound if we purchase a biogas generator with a capacity of 500 kW and efficiency of more than 35 percent to have safe design. In this respect about ten biogas generators has been selected and compared. Among the ten suppliers of biogas generator one of them has been filtered for analysis with the help of Homer software by considering the cost, efficiency and availability of relevant information or specification on online search.

Googol (JTA3240SG2) is the best fits with respect to its power capacity, cost and availability. The detail specification and comparison table of this appliance and other contestants are attached at the end of the thesis (Annex B-1)to be used as a reference during purchase. All the other components' dimensions and specification are left to be calculated during construction based the selected site condition counting different modifications.

Per the above detail analysis, the total electrical energy consumption of the university on the selected design month is 104870kWh per month which is equivalent to 3,382.9kWh per day. Since only less than half of the energy requirement of the institution is met by biogas energy to encompass sufficient and persistent electrical energy in the campus additional energy generating system has to be considered. In this respect PV system is the best option as it is available in integrated form with thermal collectors system (PV/T). The availability of the two collector systems in compact form is required because they can have a win- win combination with the biogas generating system. While the working fluid; water circulates through the pipes of the PV/T modules, it can extract the undesired heat generated under it. The efficiency of the PV or PV/T module is rises significantly due to the removal of heat. Unlike to its miserable effect on to the PV/T system, the heat energy is crucial for biogas digesters especially for sites like ours, because it facilitates biochemical reaction which leads to more rate of biogas generation.

Hence a PV/T system which can generate a minimum of 938.7kWh and more because the plant is intended to supply (sell)power to the main grid during excess generation and buy if there exist deficiency. Assume that the total electrical energy demand of the institution is to be fulfilled by energy generated from the PV/T system only. That is considering the biogas generating system as a backup (auxiliary). The sizing of all the components of the system depends on this basic hypothesis.

4.4 SOLAR-THERMAL (PV/T) SYSTEM SIZING

4.4.1 Power Consumption Demand

At this stage the total watt-hrs per day for the load and the total watt-hrs per day needed from the PV Module are calculated [2].

A. Total watt-hrs per day for the load: On the design month, July 2012, 104,870kWh of electricity has been consumed [2]. The total watt-hrs per day for the design month is 104,870kWh /31days = 3,382.9 kWh/day.

B. Total watt-hrs per day needed from the PV Module: All the previous power consumption was in terms of alternating current (AC) electricity but a PV array produces only direct current (DC) electricity. So an inverter is assumed to be used to convert the DC to AC. Thus the total W-hrs needed per day for the load is the total W-hrs from the PV module (DC equivalent demand) reduced by the inverter efficiency [2].

The selected inverter efficiency is 98.7% .Therefore, DC equivalent energy demand (DC kWh) = AC kWh / ηInverter

$$\text{DC kWh} = \frac{3382.9 \text{ kWh/day}}{0.987} = 3{,}427.5 \text{kWh/day}$$

4.4.2 PV/T array sizing

To find out the sizing of PV array, the total peak watt produced needs to be known. The peak watt (WP) produced depends on size of the PV module and radiation of site location. The radiation of site location is expressed under a term called Sun-Hrs. Sun hours is defined as the equivalent number of hours per day, with solar irradiance equaling 1,000 W/m^2, which gives the same energy received from sunrise to sundown. Sun hours only make sense because PV panel power output is rated with a radiation level of 1,000W/m^2 [3].

To calculate the total peak watt needed from the PV array we divide the monthly average daily consumption in plane of PV array by the sun hrs per day of that specific month. The sun hrs per day of a month is calculated as follows, for the design month:

Sun hrs/day = Monthly average daily radiation in plane of PV array (kWh/m^2/day) / 1kWper m^2

July sun hrs/day = 3.66 kWh/m^2/day / 1 kW per m^2

July sun hrs/day = 3.66 hr/day

Therefore the total peak watt needed from the PV array for the month of July is:

Total peak watt needed from the PV array = 3,427.5kWh/day / 3.66 hr per day

Total peak watt needed from the PV array = 936.5kW

It can be seen that the month of July demands the highest kW power. The total peak watt power is increased by 20% [4] to account for miscellaneous losses due to the presence of dirt on the modules, mismatch and wiring losses. Thus the total Peak watt power from the PV array = 936.5kW× 1.2

Total peak watt needed from the PV array = 1,123.8 kW

4.4.3 Inverter sizing

As discussed in the sub section power consumption demand an inverter is used in the system where AC power output is needed. The input rating of the inverter should never be lower than the total watt of the load [2].

In this analysis since it was difficult to go through the nature of every load on the site higher value of loading factor, 0.85 is considered (or it's assumed that 85% of the load operates at a time.)

Thus the inverter size is:

Inverter size(kW) = Total peak watt needed from the PV array ×0.85

= 1,123.8 kW×0.85

= 955.23 kW or greater

4.5 SYSTEM COMPONENT SELECTION, SITE CONDITION AND POWER CIRCUIT ARRANGEMENT

This section tries to make the above design practical by using items (PV/T modules, Inverters and other accessories) that are both technically competent and cost effective. Also an attempt has been made on how to arrange the items described above in a workable circuit by considering the available area on the site.

Thus first we put the items considered for comparison in a summary table considering the most important technical and cost parameters. Then we put the site condition (available space on the site for our consideration) according to my visit on the site. Finally we compare and choose the most competent combination of items and power circuits depending on price and efficiency of items and available useful area on the site. Therefore the items considered with the summarized technical and cost parameters and the observed site conditions will be discussed hereafter.

4.5.1 PV /T Modules

I tried to look in to different brands of PV/T modules, all being most reputed ones as PV/T technology is still on the rise and I choose to use those items that are well proven. For many suppliers of PV/T modules some of which are summarized below are considered and compared for this thesis depend on the following criteria:

Efficiency--- Best efficiency modules are chosen for the set system volume
Price or cost --- Wide range of price values are considered to allow flexibility Rated voltage --- a voltage level that fits the system voltage is considered
Short Circuit current --- A short circuit current level that fits the available charge controller is considered
The summarized table can be put as follows. Detail technical data sheets and cost references for all brands are attached on Appendix A.
It can clearly be seen that the brands selected give a wide range in terms of efficiency, price, watt per module and other important parameters. But since we are in the constraint of space for installation it would be logical to select a PV/T module having higher efficiency and reasonable price. Therefore SYFD of model SYFD-250W efficiency

18.5% and price range of 0.65 - 0.75 USD PV/T modules is selected for this project. The detail specification of this Module is attached on the Annex B-1.

4.5.2 Inverter selection

The following ten brands of on grid inverters are compared with respect to different criteria. All the inverter Works in the Temperature range of -25 to 60oC (Annex B-3)

4.5.3 Site conditions

A site visit was conducted to identify suitable areas for implementation of the project inside the college of Natural Science facility. The criterion's used to select a suitable spot are:

- A place not occupied or planned to be used for other purposes
- A flat surface on the roof or ground
- An inclined plane facing south perpendicularly
- A place with no or little amount of shading
- A place owing Optimum space for both the biogas and PV systems so as to minimize wiring and piping costs

Accordingly only few suitable spots were identified inside the college of Natural Science because most of the roofs don't face south rather 600 up to 1500 apart from south. All areas on the ground are few in terms of area and already occupied for car parking and recreational area filled with plantations producing significant shading.

4.6 THEORETICAL AND PRACTICAL MEASUREMENT OF USABLE AREA

From direct survey of the project site there is about 7,200 m2area comfortable for installation of PV/T system both on roof top and on the ground.

In general three spots have been identified to be suitable for our project with a total area of 7,200m^2 The details are put as follows:

I. On the roof of lecture hall and toilet =1,600 m^2
II. On the roof of NBH 1 building=2,000 m^2

III. Marshal building fresh man(statics dept sinet)=1,000 m^2

IV. Free space in front of Marshal building =1,800 m^2

V. free space(car parking) in front of NBH building and straight to it=800m^2

Total free area for installation = **7,200 m^2**

So the amount covenant size of the site is the main constraint to select components and the system at all. In the previous section a PV/T module SYFD-250W which takes less area(1.6 m^2) , higher efficiency (18.5%)and higher cost (0.7/watt)was selected by considering that scarcity of installation area.

Fig.4.3 Sample photos of selected useful dimensions of the site

4.6.1 Power circuit arrangement

In this section we will discuss how items selection and circuit configuration is done on a step by step basis. For college of Natural Science since the area we have is very limited we picked PV/T Modules with high efficiency and relatively high price in combination with moderate efficiency and lower area coverage. From the PV/T modules listed in the above section, SFYD with model SYFD-250W having efficiency of 18.5% is selected for this particular project. I expect the gain in efficiency to compensate part of the cost increment we incurred from other brands.

4.6.2 Sizing of PV/T Modules

The number of PV modules is determined from the following expression

$$No\ modules = \frac{PVpeak\ power}{Peak\ power\ of\ the\ module} \quad 4.11$$

$$Where\quad PV_{peak}\ power = PV_{area} \times PSI \times \eta_{pv} \quad 4.12$$

$$PV_{area} = \frac{EL}{Gin \times \eta pv \times TCF \times \eta out} \quad 4.13$$

Where $Gin -$ monthly average daily radiation in plane of PV array

ηout -the grid side (output side of the inverter)

TCF - temperature and irradiation correction factor.

EL- Daily Electrical energy consumption of the site (kWh)

PSI-is the maximum radiation intensity taken to be 1000W/m^2 and the peak power of the selected module is 250Wp [25].

$$\text{PV area} = \frac{\frac{3{,}758.78\text{kWh}}{\text{day}}}{\frac{\frac{3.66\text{kWh}}{m^2}}{\text{day}} \times 0.185 \times 0.94 \times 0.92}$$

$$= 6{,}597.5\ \text{m}^2$$

$$\text{PVpeak power} = \text{PVarea} \times \text{PSI} \times \eta_{pv}$$

$$= 5{,}937.2\ \text{m}^2 \times 1000\text{W/m}^2 \times 0.18$$

$$= 1{,}187.5\text{kW}$$

Now it is simple to calculate the total number of modules in the system

$$Total\ No\ modules\ (NMt) = \frac{PVpeak\ power}{Peak\ power\ of\ the\ module} \quad 4.14$$

$$= 1068790.0\ \text{W} / 250\ \text{W}$$

$$\text{NMt} = 4275.16$$

$$= 4{,}275\text{modules}$$

Therefore, NMt = 4275PV/T Modules

No of modules in parallel (NM_P) is equal to maximum in put current into the inverter divided by maximum current of the module at its peak power.

$$NMp = \frac{I_{max}}{I_m} \qquad 4.15$$

$$= \frac{1{,}200\text{A}}{8.14\text{A}}$$

= 147.4; 147 modules can be taken in parallel

No of modules in series implies that the division of the peak power (Pp) of the system by the product of η_{inv},V_m,NMp and I_m.

$$\text{NMs} = \frac{\text{Pp}}{\eta\text{inv}\times\text{Vm}\times\text{NMp}\times\text{Im}} \qquad 4.16$$

$$= \frac{1{,}232{,}400\text{W}}{0.987\times30.72\text{V}\times147\times8.14\text{A}}$$

= 33.87

So, 34 modules (strings) can be considered in series.

The next step is to identify the number of circuits required to implement on grid PV system for AAUCNCSc with a total capacity of 1,123.8kW

Note: A circuit is one complete set of on grid PV/T power generating system components such as PV array, inverter and others that converts the sun energy to AC electric power.

Then the amount of watt power to be supplied by one circuit is identified:

Wp from one ckt = Wp of PV/T module × $N_{\underline{O}}$ of parallel array in a ckt
Wp from one ckt = 250W ×147 = 36750W=36.75kW
N$\underline{o}$ of ckts for the project = DC equivalent demand/ Wp from one ckt
N$\underline{o}$ of ckts for the project = 1,123.8 kW/ 36.75kW = 30.58
An approximate value of 31 is taken as a working value.
Inverter size kW = Total watt power from one PV array ckt × 0.85
= 36.75 kW×0.85
= 31.24 kW (a single inverter capacity)

Total area required for one circuit is then calculated by adding areas of the PV/T array area for one circuit and are of inverters one circuit and multiplying the result by 1.1 to include the area for thermal system components and pumps. PV/T array area for one ckt = Wp from one ckt/ conversion efficiency of the PV/T module (in w/m2)

PV array area for one ckt = 36750W/(185W/m^2) = 198.65m^2

Total Area per ckt with inverter = (198.65m^2) ×1.1=218.5 m^2

Total Project area = Area per ckt × No of Ckts

198.65m2×31

= 6,158m^2

4.7 THERMAL SYSTEM ANALYSIS

The PV panels receive energy from the solar irradiance, converts some of it into electricity through the PV effect and the rest is transformed into heat. The objective of attaching the thermal panel underneath the PV cell is to remove as much heat as possible in order to increase the efficiency. The heat extracted from the PV panels must be reused using thermal systems. Hereunder the undesired heat energy obtained from the PV panels will be mainly used for heating water, which in advance can be used as an input for the designed biogas digester.

To recap, the hot water, as per this paper, is used for the following purposes in the campus residence.

1. As an input in the biomass digester: uses to speed up biochemical reaction.
2. For use in the cafeterias: to be as an input in different cooking and boiling processes.
3. For residential use: that is for any kind of home use like washing, shower and others related purposes.

4.7.1 Thermal energy demand

Estimated load calculation

Load calculation is necessary for the service hot water (with or without storage) models.

The actual load is calculated as the energy required heating up mains water to the specified hot water temperature. If Vl is the required amount of water and Th is the required hot water temperature, both specified by the user, then the energy required Qload is expressed as:

$$Q_{load}= C_p \rho V_l(T_h - T_c) \quad 4.17$$

Where;

Cp is the heat capacitance of water (4,200 (J/kg)/ºC), ρ its density (1 kg/L), and T_c is the cold (mains) water temperature. Q_{load} is prorated by the number of days the system is used per week.

Before starting the mathematical analysis, the amount of thermal energy demanded by each division mentioned above is estimated as follows: First the amount of thermal energy demanded by the biomass generator is calculated depending on the amount of water required for dilution of the biomass slurry each day as per the design of biomass system. From the information developed on the section of biogas design the amount of water required to have 1:1 dilution ratio is about 6.94 m^3/day.

Second category of consumer is that of cafeterias. There are about five cafeterias and lounges in the campus in which the thermal energy consumption mainly concentrates for cooking, which is the daily activity about three times a day. It is too difficult to state the exact consumed amount each day because of the variability in number of consumers each day. For this study assumptions are made from similar paper works and observation taking the number of population in the university residence. As it was taken in the section of data analysis and design sections the number of active populations are about 3,500.So from the previous works [28], for preparation of meal per person, about 4.5 liters of water is required each day. From this amount, if half of it is assumed to be required as hot and the remaining as it is, 2.25 liters of hot water is to be demanded each day for one person. Therefore the total amount of hot water require in a day can be assumed to be 7,875 liter. At last the amount of hot water required for residential use is mainly for showering which is expected to be 20litres per person per day [32]. So 15,000.00 liter of hot water is required for showering each day considering that in average a person takes shower in 3 days interval and half of the population wants cold water instead of the hot one. Finally, it can be clearly known that the daily demand volume of hot water on the design site is the sum of the three: 29.815 m^3 per day.

4.8 THERMAL MODELING

Before starting thermal modeling, it is reasonable to discuss about factors affecting thermal energy production from the PV/T panels. Those factors are categorized in to two, natural (environmental) and manmade or design point of view. Here in this paper, the natural factors are mainly discussed because those have significant effects on the output of both the thermal likewise the electrical energy production of the hybrid system.

4.8.1 Environmental Variables

A number of environmental variables have to be calculated from the weather data supplied by the user (or copied from the RETScreen Online Weather Database). The values to compute are the monthly average daily irradiance in the plane of the solar collector, used to calculate collector efficiency and solar energy collected; Cold water temperature, used to determine the heating load the system has to meet.

4.8.2 Solar Radiation

Solar radiation is an electromagnetic wave emitted by the Sun's surface that originates in the bulk of the Sun where fusion reactions convert hydrogen atoms into helium. Solar energy is quite simply the energy produced directly by the sun and collected elsewhere, normally the Earth. The electromagnetic radiation (including visible light, infra-red light, and ultra-violet radiation) streams out into space in all directions. Only a very small fraction of the total radiation produced reaches the Earth. The radiation that does reach the Earth is the indirect source of nearly every type of energy used today [26].

The potential amount of radiation that can reach the surface is determined by its location and time of the year. Due to differences in the position of the sun, the potential radiation differs at various latitudes and in different seasons. The actual solar radiation reaching the evaporating surface depends on the turbidity of the atmosphere and the presence of clouds which reflect and absorb major parts of the radiation [29].

Radiation reaching the Earth's surface is altered by a number of factors, namely the inclination of the Earth's axis and the atmosphere that causes both absorption and reflection (albedo) of part of the incoming radiation.

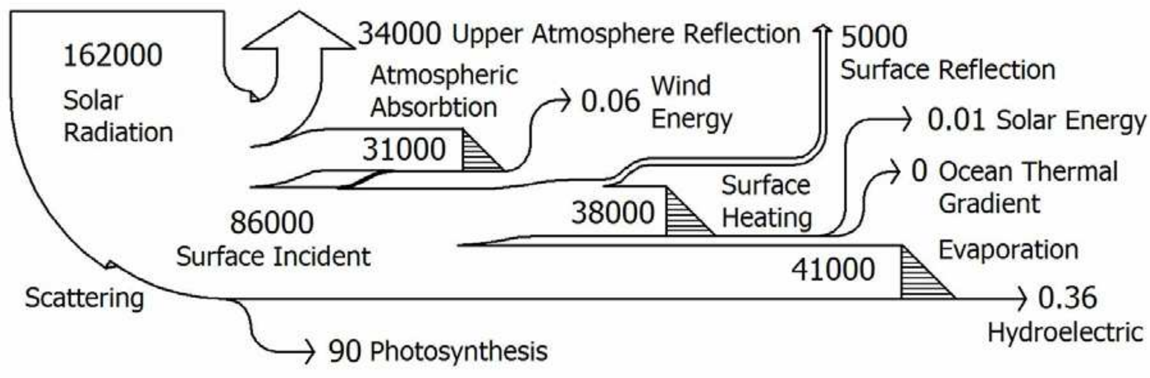


Fig.4.4 Solar radiation exergy flow diagram (units in TW). Shaded surfaces represent natural exergy destruction; arrows represent human use for energy services [31].

Solar radiation can be divided into two components: beam or direct radiation, which is radiated from the sun to earth surface directly, and diffuse radiation, which is reflected and/or scattered by small matter in the atmosphere such as clouds or water drops, then to the earth surface.

4.8.3 Earth-Sun angles

Solar Time

In solar energy study there is an important distinction between standard time and solar time. Solar time is a time based on the apparent angular motion of the sun across the sky, with solar noon the time with the sun crosses the meridian of the observer Standard time is described on longitudes and is dependent on the standard meridian for each country. The relation between solar time and standard time in min is given by [33].

$$Solar\ time = Standard\ time + 4(L_{st} - L_{Loc}) + E \qquad 4.17$$

Where: - Lst is the standard meridian for the local time zone (GMT+3, for Addis Ababa) Lloc is the longitude of the location in question (38"42', for Addis Ababa)

E is equation of time in minutes, accounts for the small irregularities in day length that occur due to the Earth's elliptical path around the sun. The equation of time used here, in minutes, comes from Spencer (as cited by Iqbal, 1983):(-4.8minute for 25th July, i.e the design day)

$$E=229.2(0.000075+0.001868CosB-0.032077SinB-0.014615Cos2B-0.04089Sin2B) \quad 4.18$$

The equation of time as a function of each day of the year is shown in Figure 4.5, minimum and maximum irregularities occurs at February 18 and maximum at June 2 respectively[25].

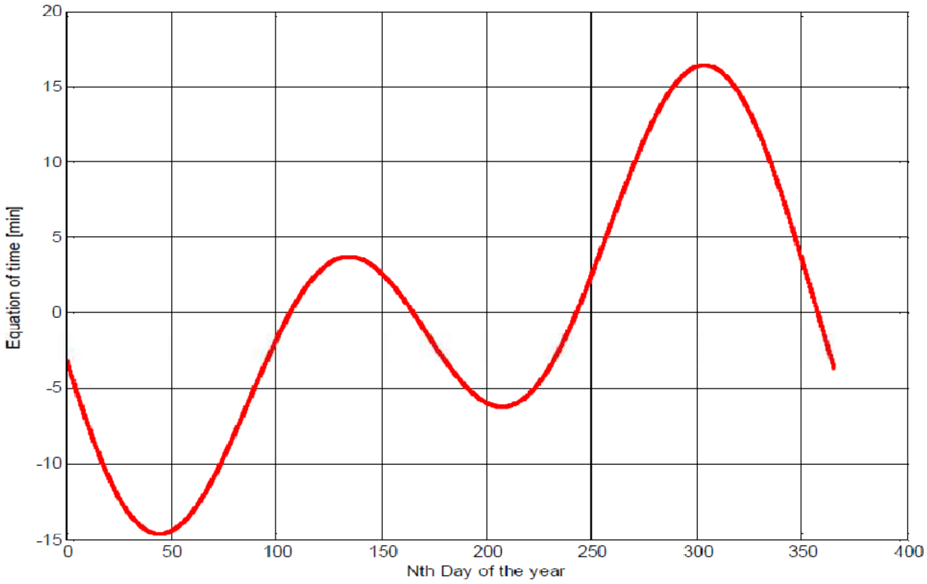


Fig.4.5 Equation of time E in minutes as a function of day of the year

Hour Angle (ω)

One of the most important solar angle used to illustrate the earth's revolution with reference to its polar axis is the hour angle (ω).Hour angle can be described as the angular distance measured between the meridian of the viewer and the meridian whose plane enclose the sun as shown in the Figure 2.6. When the sun gets to its highest point in the sky or when it becomes overhead, the hour angle becomes zero at solar noon (12:00). The hour angle increases by 15 degrees every hour.

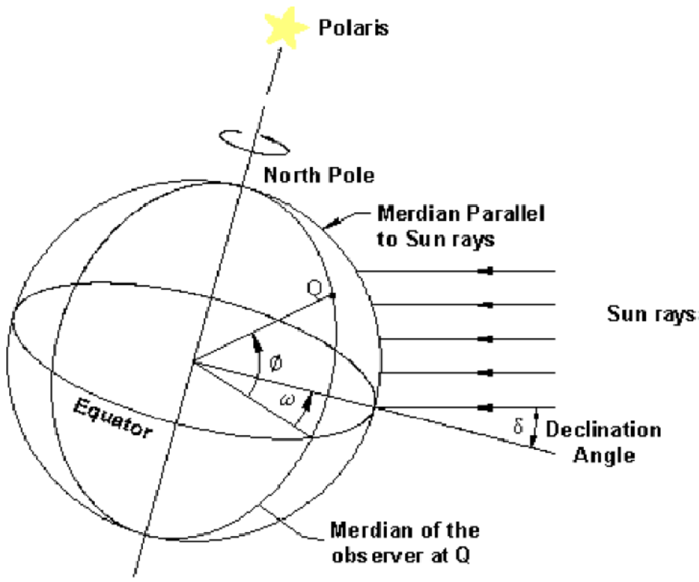


Fig.4.6 Solar angles on the earth globe [4]

Hour angle is given by the following equation.

$$\omega = (ST-12) \times 15^0 \qquad 4.19$$

Where: ST is solar time

Declination Angle (δ)

In the earth's globe, the plane that comprises the earth's equator is called the equatorial plane.

The declination angel can be known by pinching a line between the center of the earth and the sun. The angle between the pinched line and the earth's equatorial plane is called the declination angle (δ) as shown in Figure4.6. The earth's equatorial plane will inclined 23.45oto a line pinched between the earth and sun, when the earth's northern part of earth's revolving axis is liable toward the sun which is around June 21.During this time it is observed that the noontime sun is at its maximum point in the sky and the declination angle (δ) attain positive 23.45^o.These condition called summer solstice which tells the beginning of summer in the Northern Hemisphere.

$$\delta = 23.45 \sin\left(360\frac{284+N}{365}\right) \qquad 4.20$$

Since July is selected as a design month, the number of day in this month is 15 from the standard table which is attached on the appendix(C-1).

So the result of mathematical analysis shows that the declination angle for Addis Ababa is 21.2o.Variation of declination with day of the year is shown in Figure 4.7.

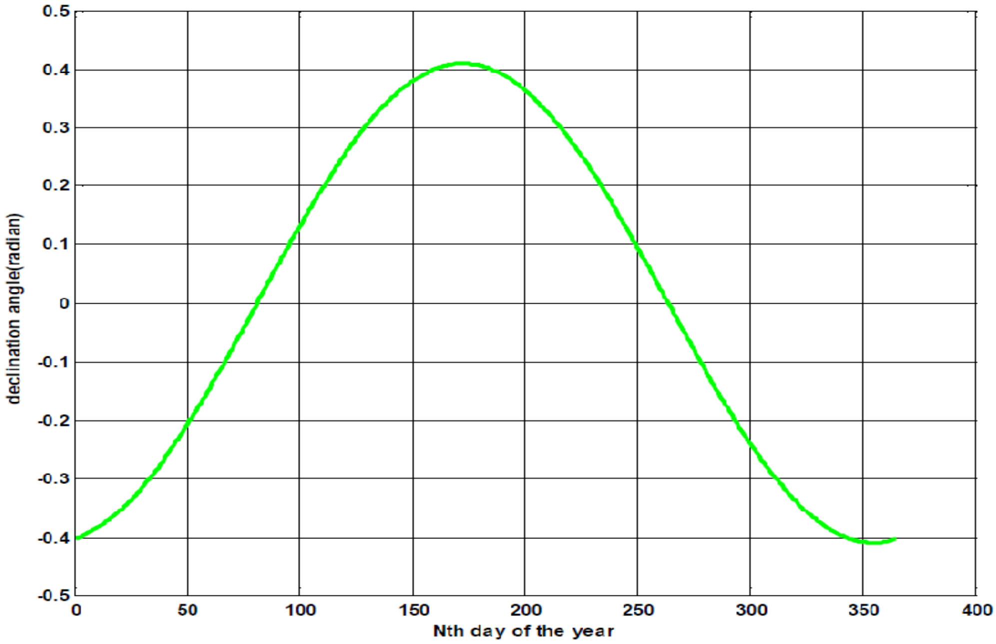


Fig.4.7 Declination angle as a function of day of the year

Solar altitude angle (α)

The angle specified between the ray from the sun and a horizontal plane enclose the viewer is named as solar altitude angle. The equation for the solar altitude angle (α) is given in Equation (4.21) below.

$$Sin\underline{\alpha} = sin\underline{\alpha} sin\phi + cos\delta cos\omega cos\phi \qquad 4.21$$

The sun's altitude can be illustrated in terms of the solar zenith angle (θz), which is basically the complement of the solar altitude angle.

$$\theta_z = 90° - \alpha \text{ (degrees)} \qquad 4.22$$

This gives the equation for the solar altitude angle to be

$$Cos\ \theta_z = Sin\delta Sin\phi + Cos\delta cos\omega cos\phi \qquad 4.23$$

Additionally, because of the sun-earth angle concept, the solar radiation received at the earth's surface varies on hourly, daily, or monthly basis. Hourly variation is due to the motion of the sun from east to west, and also due to the presence of clouds, whereas daily variation and monthly (seasonal) variation is due to the position of the sun. Longitude and latitude give the location of a place on the earth's surface. The sun comes overhead twice a year in the tropical belt. Ethiopia is in the equatorial region which is probably the most favorable region for solar energy. According to the findings of this work, disregarding the rainy season, July and August, the average daily duration of sunshine is approximately 8-10 hours [27].

Solar radiation, known as extraterrestrial radiation, H_0, on a horizontal plane outside the atmosphere, is given by equation 4.24.

$$H_0=\frac{24\times3600}{\pi}G_{sc}\left(1+0.033cos\frac{360N}{365}\right)\left(cos\emptyset cos\delta sin\Omega_s+\frac{\pi\Omega_s}{180}sin\emptyset sin\delta\right) \quad 4.24$$

Where:

G_{sc}=Solar Constant=1376W/m^2

N= the day of the year

δ= monthly mean solar declination, degrees

Ω_s= sun set hour angle, degrees

∅= latitude of location, degrees

H_o= monthly mean daily extraterrestrial radiation on horizontal surface, MJ/m^2.day

Then, average daily radiation is then broken down into hourly values. This is done with the formula from collares-pereira and rabl for global irradiance.

$$\bar{I}=\bar{H}\left[\frac{\pi}{24}\frac{Cos\omega-Cos\Omega_S}{sin\Omega_S-\frac{\pi}{180}\Omega_S\times cos\Omega_S}\right] \quad 4.25$$

Where:

$\bar{I}$= hourly mean total radiation on horizontal surface, MJ/m^2.h

$\bar{H}$= monthly mean daily total radiation on horizontal surface, MJ/m^2.h.day

Ω = hour angle, degrees

Since the sun advances fifteen degrees in one hour the hour angle can be express as:

Ω = 15 Degrees X (Time - 12)

Ω_s = Sunset hour angle give as

Ω_s= Cos-1[-tan ∅ tan δ]

The maximum possible sunshine hour is given as:

$$N=\frac{2}{15}\times\Omega_S \qquad 4.26$$

4.8.4 Estimation of Ambient Temperature

The ambient temperature can be estimated by using the sinusoidal ambient temperature model which is based on the variation of maximum and minimum ambient temperatures in a day [ketjoy, 1999].

$$T_{a(t)}=\left[(T_{max}+T_{min})(T_{max}-T_{min})Sin\left(\frac{2\pi}{24}St\right)\right] \qquad 4.27$$

Where:

$T_{a(t)}$ = ambient temperature at time, t

T_{max} = maximum ambient temperature of the day

T_{min} = minimum ambient temperature of the day

St = h – 9

H = considered time in unit of hour

The result of the above calculations of angular location of the selected site is summarized in the following table.

Table 4.1 Summary of Solar Geometry Calculations

Quantity	Simplified Expressions(results)	Conditions
Local Solar time(Lst)	Lt+1.783	Et=-5 ,N=198
Solar Declination (**δ**)	21.2^o	-----------------
Solar Altitude(A)	A=Sin-1[0.05657+0.9208cosω]	Φ =9"02'
Hour Angle(Ω)	Ω = 15^{o}x(Lt-12)	Ω varies with respect to Lt of the site
Sunset Hour Angle(Ω_s)	Cos-1[-tan Φ tan Δ]=93.5^o	

Hourly Solar Radiation(I_t)	=162.97(Cos ω +0.061)	Varies with respect to Ω

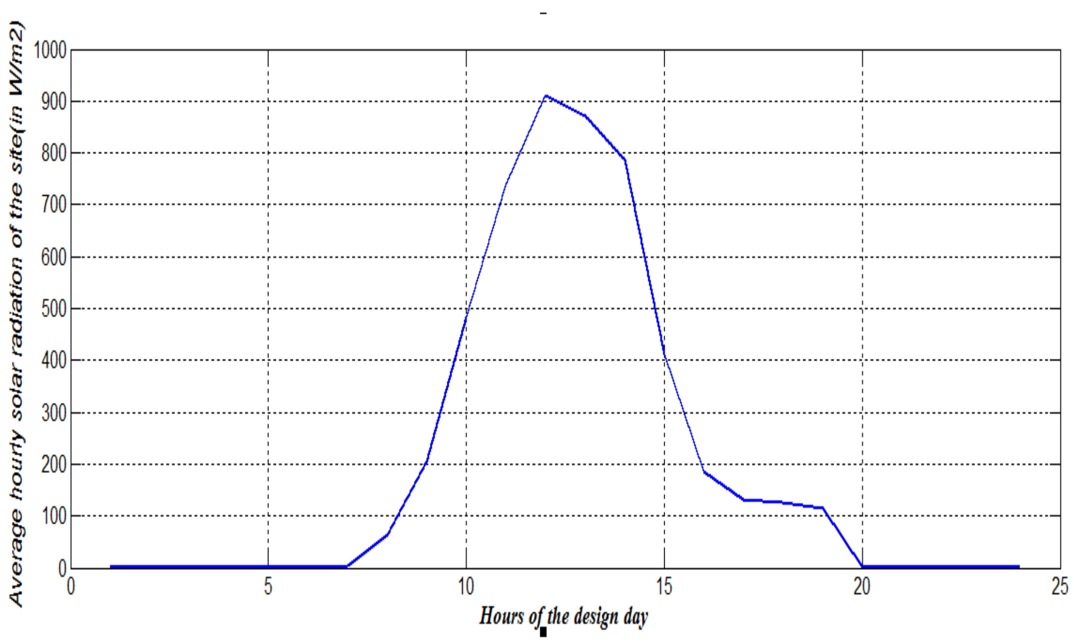
4.8.5 Thermal Modeling of Hybrid PV/T Water Collector

The following subjects are supposed to be addressed in this subtopic

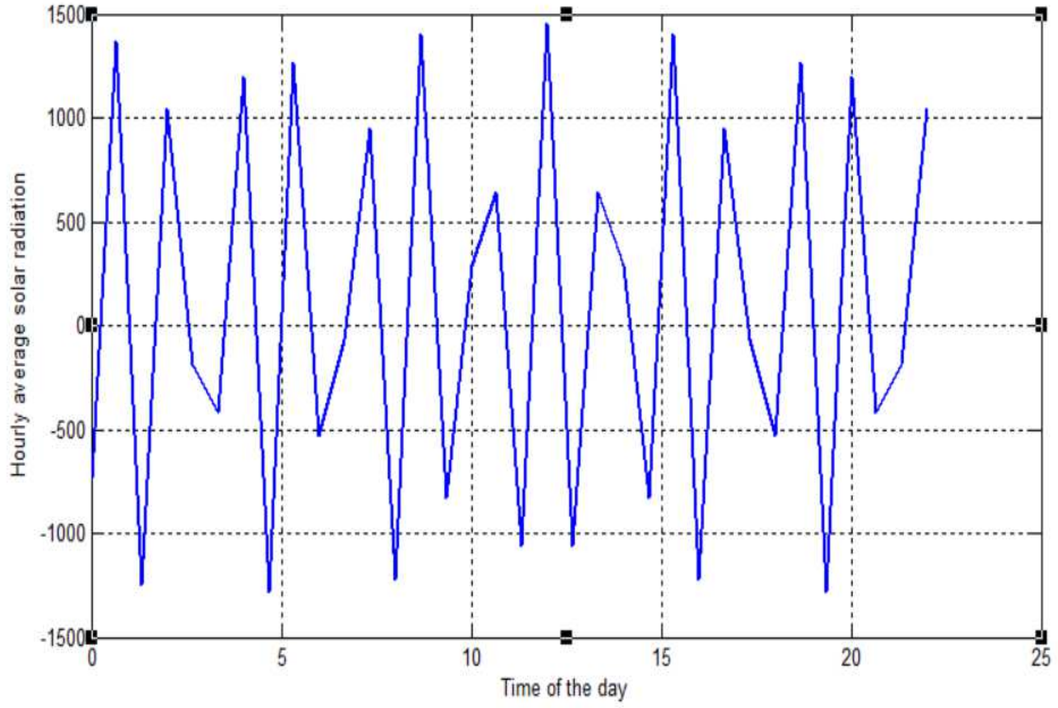
- Evaluation of solar radiation and ambient temperature
- Comparison of the metrological data with the mathematical formulae.
- Formulation of the data obtained from metro station for both hourly average solar radiation and ambient temperature of the study site using mat lab software by curve fitting method.
- Calculating the amount of thermal output, electrical output and the outlet temperature of N^{th} PV/T collector using mat lab software.
- Summarizing the overall working of the solar thermal system

The following consecutive plots are obtained by inserting variables in the result of the previous summary table(4.1).sequences of calculations are done regarding the site geographical locations as an input.

A. Comparison Hourly Variation of Average Solar Radiation



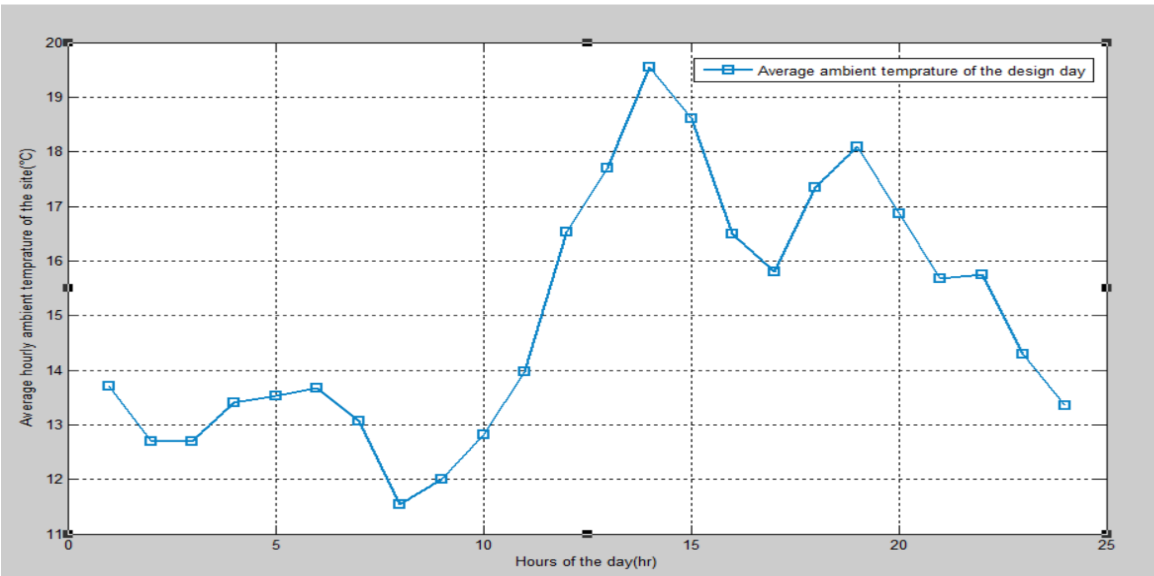
(a)



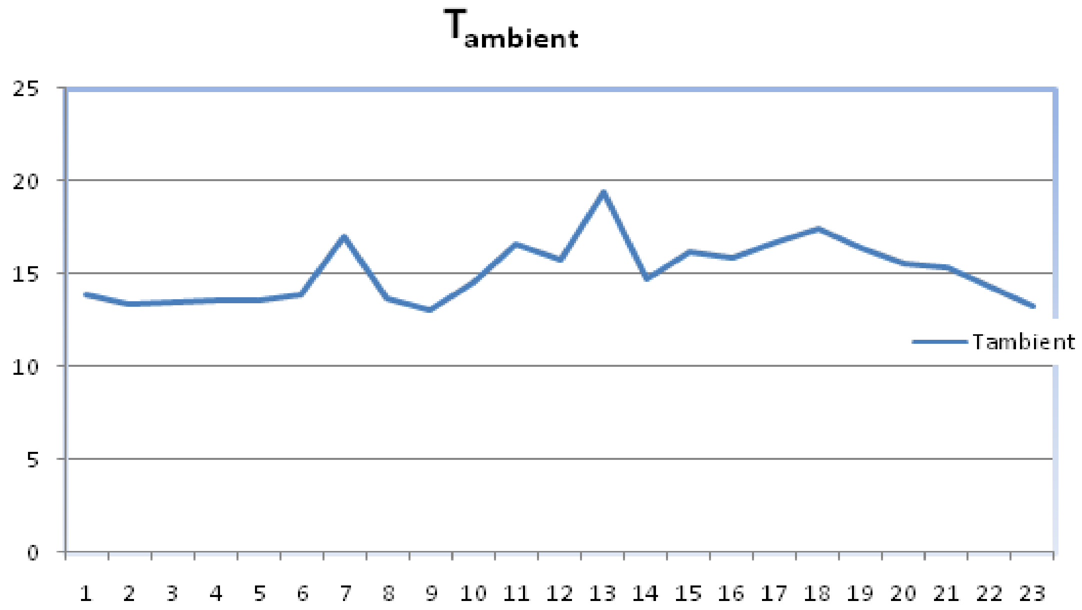
(b)

Fig.4.8 The variation of solar radiation computed hourly for one day a) shows the hourly average solar radiation from metrological data b) shows the deviation on the ground of the standard formulas and the geographical location of the site.

B. Comparison variation of hourly average ambient temperature



(a)



(b)

Fig.4.9 Variability of ambient temperature in the 24 hours of a day, from metrological data and standard formulas respectively

C. Formulation of metrological data using Mat lab curve fitting methods

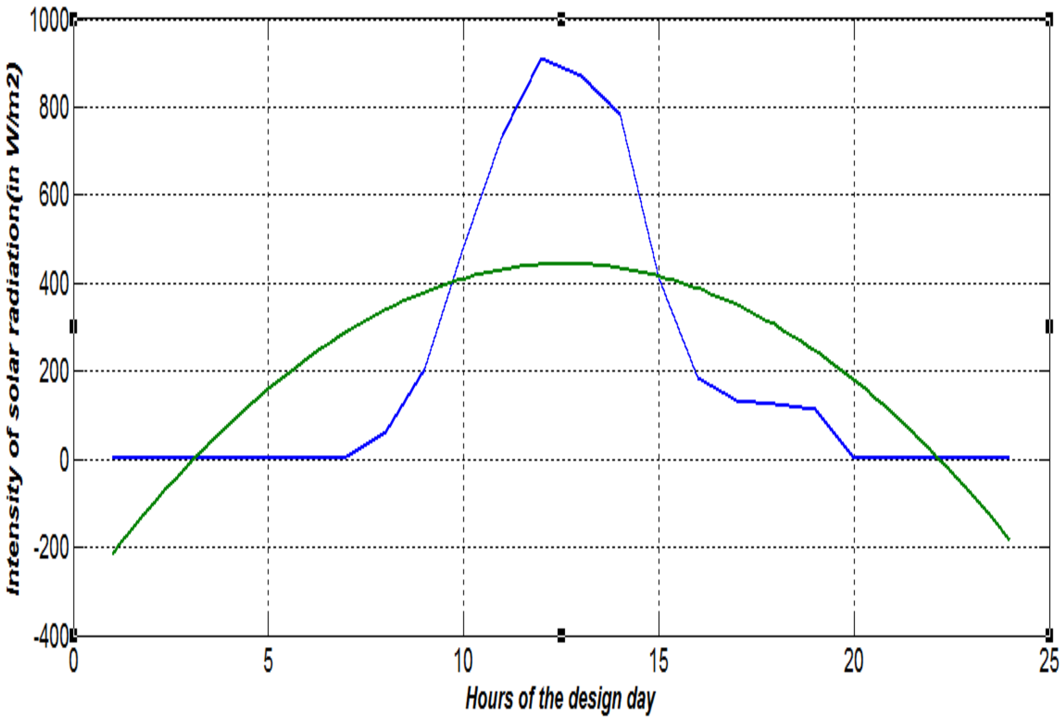


Fig.4.10 Standardization metrological solar radiation data using Matlab

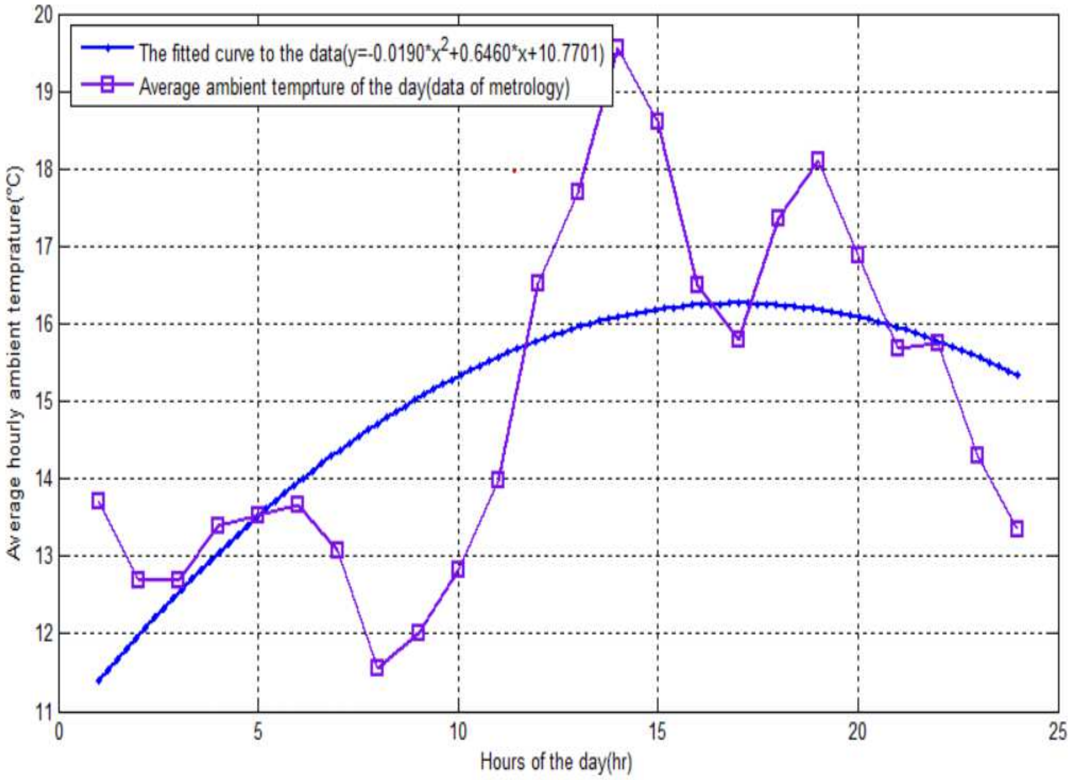


Fig.4.11 Standardization of metrological ambient temperature data using Matlab.

4.9 THERMAL AND ELECTRICAL OUTPUTS

Following Dubey And Tiwari [34], For N identical collectors partially covered by pv modules connected in series, the outlet fluid temperature at the end of nth collector can be given as,

$$T_{foN}=\frac{AF_R A(\alpha T)}{\dot{m}C_F}\left(\frac{1-K_K{}^N}{1-K_K}\right)I(t)+\frac{AF_R U_L}{\dot{m}C_F}\left(\frac{1-K_K{}^N}{1-K_K}\right)T_{a(t)}+T_F K_K{}^N \qquad 4.28$$

Where, $\boldsymbol{I_{(t)}=-4.86t^2+122.89t-332.69}$

$\boldsymbol{T_{a(t)}=-0.0190t^2+0.6460t+10.7701}$

$$K_k=\frac{F' A_M U_L}{\dot{m}_F C_F} \qquad 4.29$$

Note the parametric values to calculate k_k are give on the annexc-2.

4.9.1 Electrical Output

The electrical output generated by proposed hybrid photovoltaic thermal biogas can be evaluated by the following expression

$$E_{daily} = \sum_{i=1}^{n} \eta_m I_i A_m \times N \qquad 4.30$$

Where, $\eta_m = \eta_{mo}[1\text{-B}(\dot{T}_f - T_a)]$, $\dot{T}_f = \frac{T_{foN}+T_{fi}}{2}$

η_{mo} =0.12 and β=0.0045

4.9.2 Thermal Output

The rate of thermal energy available from the proposed hybrid photovoltaic thermal biogas plant can be obtained as:

$$\mathring{q}_u = \mathring{m}_f \mathring{C}_f (T_{foN} - T_{fi}) \qquad 4.31$$

For a set of design and climatic parameters, outlet temperature of nth collector and slurry temperature has been calculated using MATLAB software.

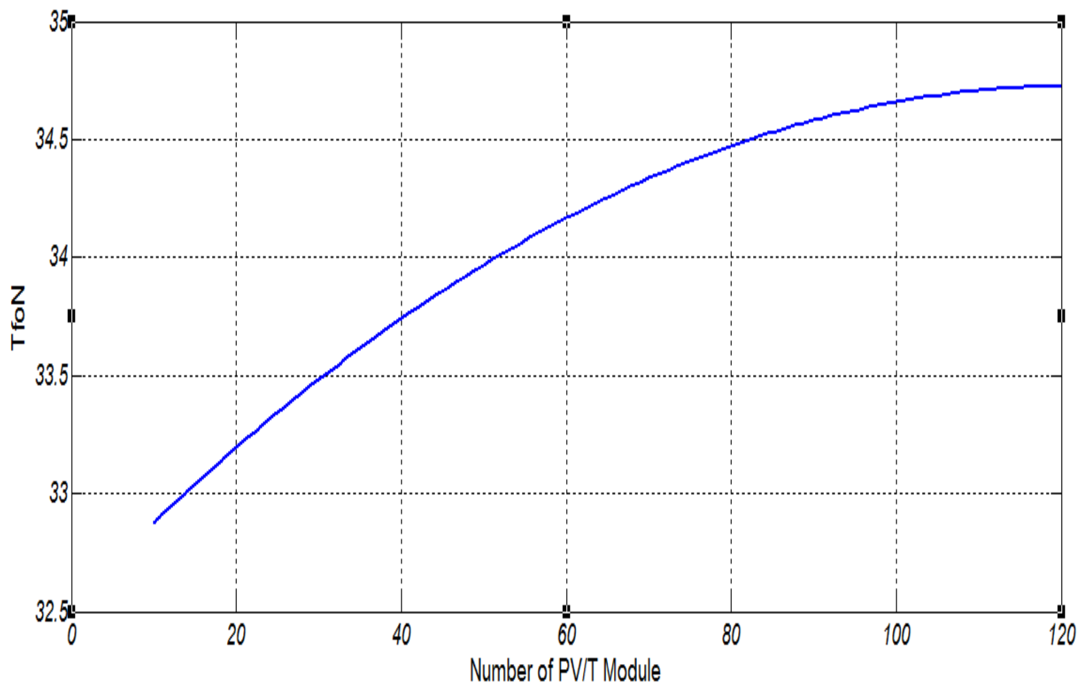


Fig.4.12 The outlet temperature of N^{th} PV/T Collector using Matlab Software

4.10 RESULT AND DISCUSSION

Hourly variation of solar intensity on the PV/T collectors has been calculated by using Liu and Jordan formula and compared with the collected metrological data. The metrological weather data has been further manipulated using MATLAB software so as to reach on standard governing equation for further analysis and modeling of the system. As it can be observed from plots of the data, the hourly variation of both solar radiation and ambient temperature seems to be down ward parabolas. Depending on this hypothesis and from the previous works like [65] the quadratic polynomial function of the form (Ax^2+Bx+C) is considered to fit the data collected. The analysis is made with the help MATLAB software and ($I_{(t)}=-4.86t^2+122.89t-332.69$) and ($T_{a(t)}=-0.0190t^2+0.6460t+10.7701$) are obtained for solar radiation and ambient temperature of the design day 25^{th} July 2014GC respectively as shown on figure 4.10 and 4.12.

Fig. 4.9 shows the variation of solar intensity and ambient air temperature with time. Fig.4.12 gives the variation of outlet temperature from N^{th} collector and slurry temperature during 24 hours period of day and night. The coefficients heat transfer and other standard values are attached on the appendix 4.28 .this figure shows that peak slurry temperature also increases with increase of number of collectors due to increase of thermal energy provided by PV/T collectors to the slurry. It is observed that there is not much variation in peak slurry temperature (T_{amax}) after 100 numbers of collectors and hence the optimum number of collectors for a design and climatic parameters under consideration is about 100.

The energy production can be categorized in to two thermal and electrical. Both the electrical and thermal energy generation from PV/T collectors are influenced by the initial and final (outlet) temperature of the fluid (water in this case)

4.11 WATER PUMP SIZING AND SELECTION

4.11.1 Water Pump Selection

A centrifugal type of water pump of brand Dellent CPM and model CPM-100 having maximum head of 16 meter, maximum discharge of 70 l/min and capacity of 0.25 kW is selected for this specific project. The basic criteria to select this pump from varieties in the market are as follows:

It has optimum head which confidentially balance our requirement. As per the analysis made some of the selected site for installation are on the roof of three and / or four story buildings. In order to transport the water above this story roof, a pump with higher capacity is a must. Based on the information obtained from civil engineers and architects, buildings constructed for teaching/learning purposes (universities') may have 1.75 to 2 meters height on each floor. So taking the maximum value for safe design in to consideration the four story building can have 8 to 10 meters including the balancing structure made to fix the PV/T panels. Therefore, the Dellent CPM pump can fit in all aspects of the requirements set as per the design.

4.11.2 Water pump energy consumption

The following basic analyses are made to estimate the energy demand of the selected pump.

Discharge (l/min) = required volume of water per one day/hours the pump is busy (hr/day)
hours the pump is busy (hr/day) =required volume of water per one day/ discharge (l/min)

= 29.815 m^3/day/70 l/min, 1 day=24 hrs and 1m^3= 1000 liter

= 7.1556 hrs per a day

So, the amount of electrical energy consumed per day is estimated as = capacity of the selected pump× estimated working hours of the day

= 0.25kw×7.1556 hrs/day

= 1.7889 kWhr/day or 55.4559kwhrs/month (the number of days in design month, July=31)

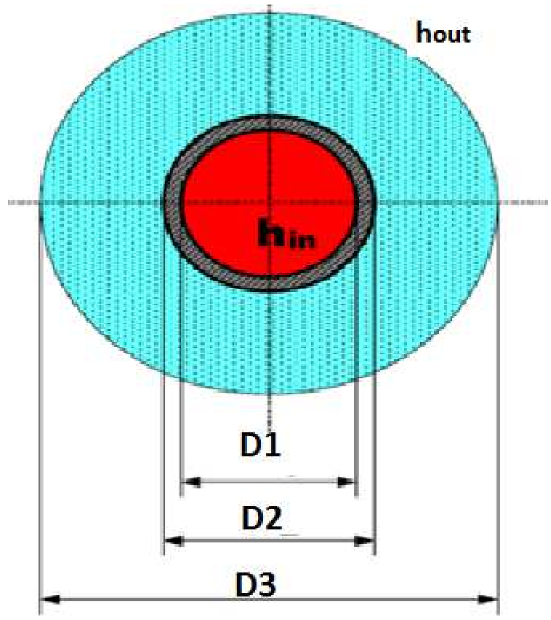
Table 4.2 Monthly electrical energy consumption of the pump CPM-100

Month	Energy Consumption (In KWh)	Cost (Birr)	Month	Energy Consumption (In KWh)	Cost (Birr)
January	55.46	42.6	July	55.5	42.6
February	51.9	39.9	August	55.5	42.6
March	55.5	42.6	September	53.7	41.3
April	53.7	41.3	October	55.5	42.6
May	55.5	42.6	November	53.7	41.3
June	53.7	41.3	December	55.5	42.7

4.12 HEAT TRANSFER IN PIPES

The water which absorbed heat from the underneath of the PV/T panels will be transported through pipes to biogas digesters and utility areas wherein there exist heat transfer from the pipes to the air (environment) surrounding them. Generally the heat may be transferred in three different modes: conduction transfer of heat as a result of molecular motion and the subsequent transfer of kinetic energy. This is predominant in solid materials and in static fluids. Convection the flow of heat as a result of macroscopic movement of matter from a hot to a cool region and radiation transfer of energy in the form of rays or waves or particles.

Any surface which is hotter than its surroundings will lose heat. The heat loss depends on many factors, but the surface temperature and its size are dominant. Putting the insulation on a hot surface will reduce the external surface temperature. By insulation, the surface will increase on circular pipes or vessels, but the relative effect of temperature reduction will be much greater and heat loss will be reduced.



$$U=\frac{1}{\frac{D_3\times ln\left(\frac{D_3}{D_2}\right)}{2\times k_{insulation}}+\frac{1}{h_{out}}} \quad 4.32$$

Where, h_{in}- amount of heat inside the pipe

H_{out}- amount of heat outside the pipe

$K_{insulation}$ is the thermal conductivities of insulation

Heat loss per one meter of insulated pipe is:

$$\frac{Q}{L}=\Pi\times D_3\times U\times(T_{In}-T_{out}) \quad 4.33$$

CHAPTER FIVE

5. SIMULATION AND OPTIMIZATION

5.1 INTRODUCTION

The homer micro power optimization model is a computer model developed by the U.S. national renewable energy laboratory (NREL) to assist in the design of micro power systems and to facilitate the comparison of power generation technologies in a wide range of applications. Homer models a power system's physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life span. Homer allows the modeler to compare many different design options based on their technical and economic merits. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs. A micro power system is a system that generates electricity, and possibly heat, to serve a nearby load. Such a system may employ any combination of electrical generation and storage technologies and may be grid-connected or autonomous, meaning separate from any transmission grid.

Homer performs three principal tasks: simulation, optimization, and sensitivity analysis. In the simulation process, homer models the performance of a particular micro power system configuration each hour of the year to determine its technical feasibility and life-cycle cost. In the optimization process, homer simulates many different system configurations in search of the one that satisfies the technical constraints at the lowest life-cycle cost. In the sensitivity analysis process, homer performs multiple optimizations under a range of input assumptions to gauge the effects of uncertainty or changes in the model inputs. Optimization determines the optimal value of the variables over which the system designer has control such as the mix of components that make up the system and the size or quantity of each. Sensitivity analysis helps assess the effects of uncertainty or changes in the variables over which the designer has no control, such as the average wind speed or the future fuel price [30].

5.2 ABOUT THE DESIGN SITE

Addis Ababa, a capital of Ethiopia is the largest city of the country with population of 3,384,569 according to the 2007 census. The city is geographically located at located at coordinates: 9°1′48″N 38°44′24″E. It has a subtropical highland climate with temperature differences of up to 10 °C (18 °F). The high elevation moderates temperatures year-round, and the city's position near the equator means that temperatures are very constant from month to month.

The highland climate regions are characterized by dry winters. During this season the daily maximum temperatures are usually not more than 23 °C (73 °F), and the night-time minimum temperatures can drop to freezing. The short rainy season is from February to May. During this period, the difference between the daytime maximum temperatures and the night-time minimum temperatures is not as great as during other times of the year, with minimum temperatures in the range of 10–15 °C (50–59 °F). At this time of the year the city experiences warm temperatures and a pleasant rainfall. The long wet season is from June to mid-September; it is the major winter season of the country. This period coincides with summer, but the temperatures are much lower than at other times of year due to the frequent rain and hail and the abundance of cloud cover and fewer hours of sunshine. This time of the year is characterized by dark, chilly and wet days and nights. Autumn which follows is a transitional period between the wet and dry seasons. In history the highest record temperature was 32 °C (90 °F) August 27, 1996, while the lowest record temperature was 0 °C (32 °F) on November 23, 1999 [13,14,20, &30].

5.2.1 College of Natural and Computational Sciences (CNACSc)

CNACSc is one of the main numbers of branches of AAU. It was establishment before 50 years through various stages of development. Currently, the college comprises eight departments, two schools, two institutes, and three multidisciplinary programs offering undergraduate and postgraduate degrees. The collage is occupied by different buildings like dormitories, libraries student cafeterias, staff cafeterias different lounges class rooms in which the total population which comprises students, lecturers of with different titles, security guards and other staffs dwelling inside the campus is estimated to be around 6,200 [33].

Fig.5.1 Site Plan of CNACSC

Studies show that variety of renewable energy resources like solar, wind, biomass and others are available in Addis Ababa as a city and in CNACSC as project site. From these the two resources solar and biomass are potentially abundant and their combination has promising output. The average solar radiation on the horizontal surface is 5.69 kWh/m²/day and on average 198.7 tons of biomass resources can be collected each month.

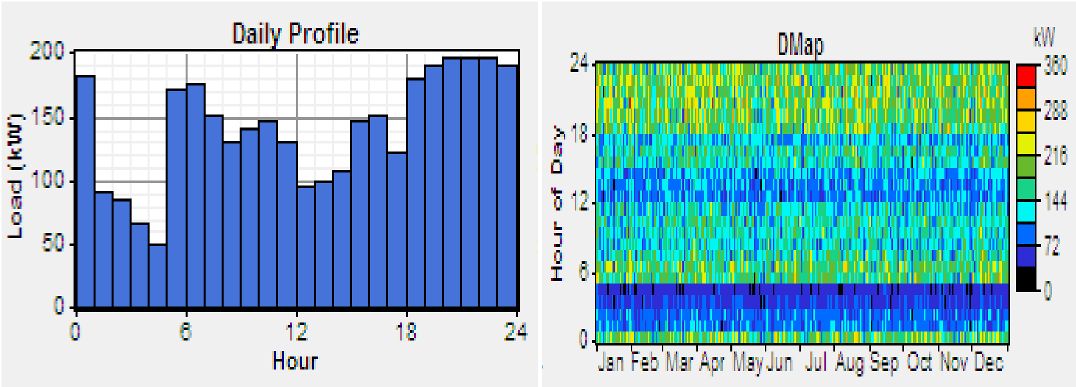
The other main reason in favor of the two renewable resource as a couple, is the side effect that setback the energy generation of the one (solar PV system) can be the remedy to the existing shortcoming the remaining. Moreover, they require less space compared to the others in that the solar (PV/T) modules can be integrated with the existing buildings likewise underground construction is possible for the biogas digester which can cause greater result by keeping the digester temperature higher. The tariff of electricity in Ethiopia is 0.567 birr/kW (equivalent to 0.0263 us $/kW) at the moment, which is much cheaper than the average international price (which is why export of surplus electricity is feasible), but the EEPCo is very willing to have a stable supply so that it is open to flexible negotiations on the conditions, including the tariff [30, 33 & 34]

5.3 SIMULATION USING HOMER SOFTWARE

5.3.1 Load Profile and Design of Hybrid System

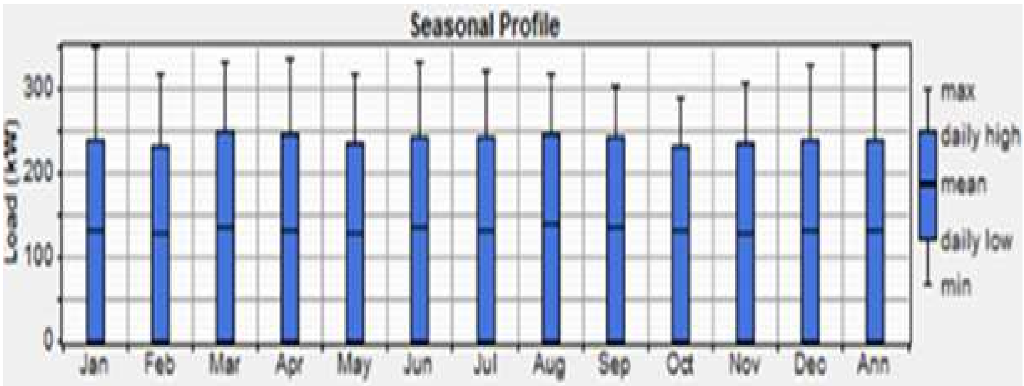
In the design of renewable energy systems before the execution of the design on to the ground simulation is a bridge to clarify and imagine what will happen in the future in each hour or minute or second of the coming years. One of the basic requirements in the simulation of renewable energy is the electrical energy consumption or load profile the design site. The load can be in any form or type such as electrical, thermal or deferrable, continuous in any form which can necessarily be served by electrical energy as an input. In this thesis since two systems are going to be analyzed as one, the load profile mainly focuses on the electrical load which is consumed by the dwellers, the thermal load which is supposed to be consumed by the biogas digester and the deferrable load which is intended to be in use by pumps and other un specified machines in which the consumption is not regular or continuous. As it is tried to cite in the subsequent sections the main purpose of integrating the PV/T system with a system that generates biogas is to have optimum temperature of the substrate in the biogas digester so the thermal load here is not served by the electrical energy directly instead the water is heated by the by product of the PV system when it circulates through the pipes inside the PV/T panel. Therefore in this section of simulation the thermal load is not going to be analyzed.

The primary load or energy consumption pattern usually varies daily and monthly of the year. The following figure (fig.5.2) shows the load profile of the design month and it is assumed to be same throughout the year since worst case design method is pursued. The homer simulates the operation of a hybrid system by making energy balance calculations for every 8760hours in a year [32]. The annual peak load is considered as 349 kW with primary energy of 3.4 MWh/day in the project area. Figure 5.3 shows how the load varies in each months of a year.

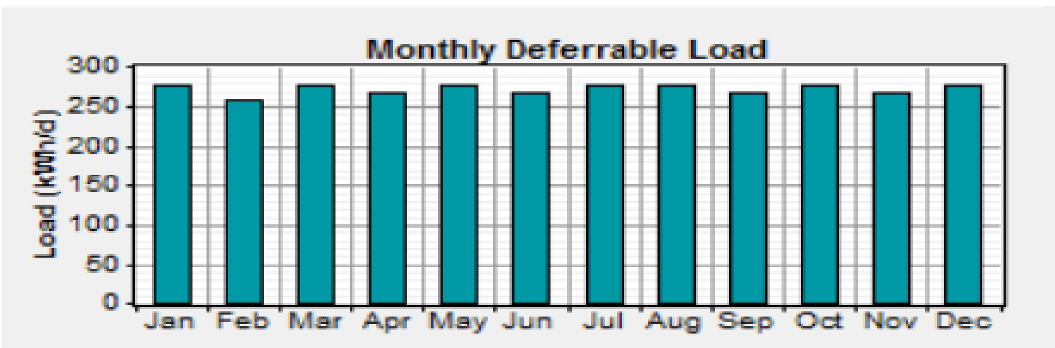


	Baseline	Scaled
Average (kWh/d)	3,355	3,355
Average (kW)	140	140
Peak (kW)	349	349
Load factor	0.400	0.400

Fig.5.2 Daily Load Profile of the Projected Hybrid System



(a)



(b)

Fig.5.3 Monthly Electrical load profile (a) Primary (b) Deferrable

The hybrid system consists of solar PV/T and biogas generator with the total power generation capacity of 2.1MW. The simulation components diagram which is generated by homer software is shown on the following figure (skeleton).

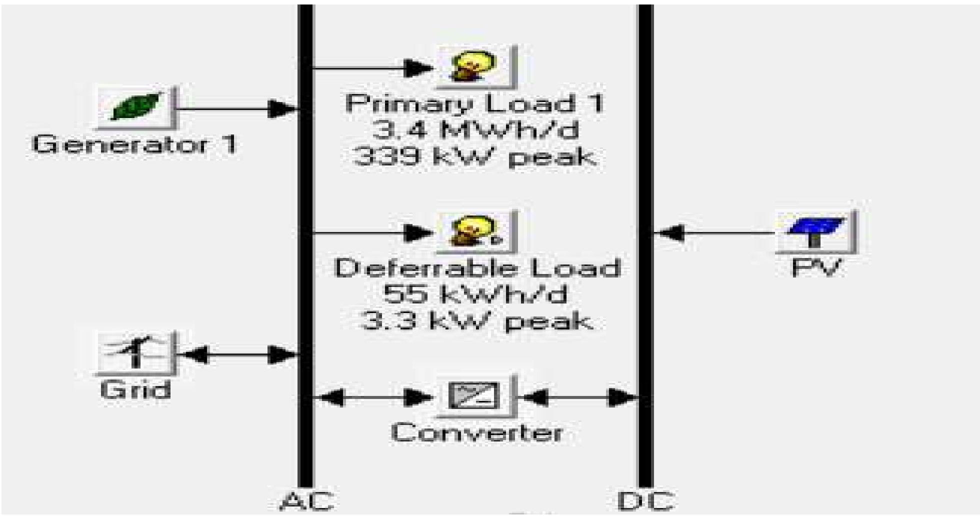


Fig.5.4 Schematic Represents the Load and Components Selected

From figure 5.4, it can be observed that the biomass generator and the PV/T panels feed electrical power to the AC and DC buses and the converter is used to alter the dc electrical power generated by the PV/T panel into the desirable ac electrical power which can be feed to the ac bus. The grid here uses in two fashions one it can take (purchase) the generated power from the plant when there is excess generation of power than needed, likewise the grid may serve as power wholesaler when there exist energy demand from the consumer side, in this case the university. The capacity of buying and selling of power both from the grid and consumer is determined with the help of net metering system.

Another basic requirement as an input for simulation using homer is cost of system components. These costs include the initial or purchasing cost of components; the homer provides simulation results of hybrid system for optimal system design according to the sensitivity analysis [32]. This software presents the optimized results categorically for different sensitivity parameters like amount of solar radiation and biomass resources. The resources which are required for optimal system design are long term global solar radiation data, available biomass resource, load profile of the selected area, technical specifications and cost of the proposed hybrid system, constraints, controls, type of load dispatch strategy and others. The latitude and longitude of the selected area are considered as 9°1′48″N and 38°44′24″E respectively with annual average wind speed of 3.02 m/s, average solar radiation of 5.2 kWh/m2/day. The following figures fig.5.5, 5.6 and 5.7 represent the categorized optimization result, the overall optimization and the sensitivity analysis respectively.

The homer simulates all the systems in their respective search space for each of the sensitivity values. In this paper various optimized model of hybrid system are designed by the simulation software for a variation of solar radiation of the selected site, and price deviation of biomass resource.

As it has been described above the designed inverter is about 955.23kW and more, so a couple of 500kW grid tie EA500KTL inverters with the capital cost of about 4,000.00USD each including all other costs is the most suitable per the comparison result of this thesis. The inversion efficiency of this particular inverter is also tremendously high (98.7%) when compared to the other brands. The detail all the inverters considered as candidate for selection are prepared at the end of the manuscript (annexes).

The second item of the system is biogas engine generator set. About ten generators have been selected for the comparison purpose as it is shown on the annex A-2.From those gen-sets HGGM1250 model is considered for the simulation because this generator matches with the size of the designed generator as shown on the design and sizing of biogas plant section.

As it is discussed above 1 kW, SYFD-250W PV/T panel is considered for the simulation. The price of 1kW PV/T panel is about 700 USD [19].the total cost of one kilowatt PV/T panel is 1500 USD including all other costs in addition to the price of the module. Here the labor cost and the O&M costs are given per an hour so as the laborer is assumed to work for eight working hours, an average of 15 consecutive days and the O&M is considered for one year or 8760 hours.

Replacement costs, the cost incurred for operating and maintaining during failure of the installed system and other miscellaneous costs like labors for installation, mounting, wiring, materials for additional fittings etc.

Per the online survey of the current market, different components of the energy generating system, plenty of sizes with variety costs are considered and compared on the criteria such as cost, size (dimension), efficiency, capacity and reputation, simplicity of operation and maintenance. The following summary of basic components the hybrid system (PV/T module, biogas generator and inverter) which can take the share of the lion in the consideration of system's initial and other costs which are supposed to be incurred during installation of the system are summarized in the following successive tables to make the task of simulation simple.

Table 5.1Cost Breakdown for 1kW Model SYFD-250W PV/T Panel

Parameter		Unit Of Measurement	Value
Capital Cost		USD	700.00
Replacement Cost		USD	500.00
Operation and Maintenance Cost		USD/h	0.000899
Life Time		Years	20
Others	Mounting Hardware Cost	USD	5.00
	Labor cost to fit	USD/h	1.5

As it is discussed above 1 kW, SYFD-250W PV/T panel is considered for the simulation. The price of 1kW PV/T panel is about 700 USD [19].The total cost of one kilowatt PV/T panel is 1500USD including all other costs in addition to the price of the module. Here the labor cost and the O&M costs are given per an hour so as the laborer is assumed to work for eight working hours, an average of 15 consecutive days and the O&M is considered for one year or 8760 hours.

Table 5.2 Cost Breakdown for 1000 HGGM1250 Biogas Generator

Parameter	Unit Of Measurement	Value
Capital Cost	USD	50,000.00
Replacement Cost	USD	40,000.00
Operation And Maintenance Cost	USD/h	0.098
Life Time	Years	15
Others (Wiring, Mounting Hardware, Installation)	USD/h	2.5

The second item of the system is biogas engine generator set. About ten generator have been selected for the comparison purpose as it is shown on the AnnexA-2.From those gen-sets HGGM1250 model is considered for the simulation because this generator matches with the size of the designed generator as shown on the design and sizing of biogas plant section.

Table 5.3 Cost Breakdown for 500kW grid-tie EA500KTL Inverter

Parameter	Unit of Measurement	Value
Capital Cost	USD	3,000.00
Replacement Cost	USD	2,200.00
Operation And Maintenance Cost	USD/h	$5.7*10^{-4}$
Life Time	Years	15
Others (Wiring, Mounting Hardware, Installation)	USD/h	1.27

As it has been described above the designed inverter is about 955.23kW and more, so a couple of 500kW grid tie EA500KTL inverters with the capital cost of about 4,000.00USD each including all other costs is the most suitable per the comparison result of this thesis. The inversion efficiency of this particular inverter is also tremendously high (98.7%) when compared to the other brands. The detail all the inverters considered as candidate for selection are prepared at the end of the manuscript (Annexes).

Table 5.4 Dellent SCM Centrifugal Water Pumps and Steel Pipes

Parameter	Unit of Measurement	Value
Capital Cost	USD	5×60=300.00
Replacement Cost	USD	200.00
Operation and Maintenance Cost	USD/h	1*10-4
Installation and Mounting Labor Cost	USD/h	0.5

5.4 DISCUSSION ON THE SIMULATION RESULT AND OUTPUT ANALYSIS

The homer provides simulation results of hybrid system for optimal system design according to the sensitivity analysis [32]. This software presents the optimized results categorically for different sensitivity parameters like amount of solar radiation and biomass resources. The resources which are required for optimal system design are long term global solar radiation data, available biomass resource, load profile of the selected area, technical specifications and cost of the proposed hybrid system, constraints, controls, type of load dispatch strategy and others. The latitude and longitude of the selected area are considered as 9°1′48″N and 38°44′24″E respectively with annual average wind speed of 3.02 m/s, average solar radiation of 5.2 kWh/m^2/day. The following figures, fig.5.5, 5.6 and 5.7 represent the categorized optimization result, the overall optimization and the sensitivity analysis respectively.

The HOMER simulates all the systems in their respective search space for each of the sensitivity values. In this paper various optimized model of hybrid system are designed by the simulation software for a variation of solar radiation of the selected site, and price deviation of biomass resource.

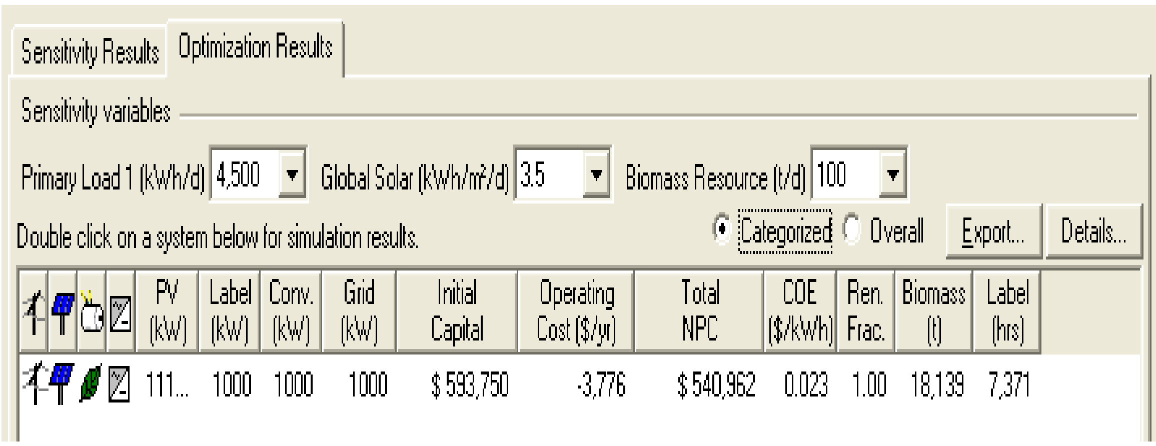


Fig.5.5 Categorized Optimization Result of the Hybrid System

PV (kW)	Label (kW)	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biomass (t)	Label (hrs)
111...	1000	1000	1000	$ 593,750	-138,738	$ -1,179,787	-0.074	1.00	18,866	7,866
106...	1000	1000	1000	$ 806,125	-135,808	$ -929,959	-0.058	1.00	19,062	7,949
111...	25	1000	1000	$ 548,855	-5,315	$ 480,911	0.030	0.66		0
111...	30	1000	1000	$ 549,250	-5,321	$ 481,234	0.030	0.66		0
111...	800	1000	1000	$ 868,750	-19,330	$ 621,651	0.039	0.85	5,683	2,876
106...	25	1000	1000	$ 761,230	-1,112	$ 747,020	0.047	0.65		0
106...	30	1000	1000	$ 761,625	-1,117	$ 747,343	0.047	0.65		0
106...	800	1000	1000	$ 1,081,125	-15,222	$ 886,535	0.056	0.85	5,790	2,930
136...	1000	1000	1000	$ 4,066,240	-116,776	$ 2,573,453	0.162	1.00	17,812	7,411
136...	25	1000	1000	$ 4,021,345	10,312	$ 4,153,162	0.261	0.71		0
136...	30	1000	1000	$ 4,021,740	10,306	$ 4,153,486	0.261	0.71		0
136...	800	1000	1000	$ 4,341,240	-3,415	$ 4,297,591	0.270	0.85	5,150	2,606

Fig.5.6 Overall Optimization Result of the Hybrid System

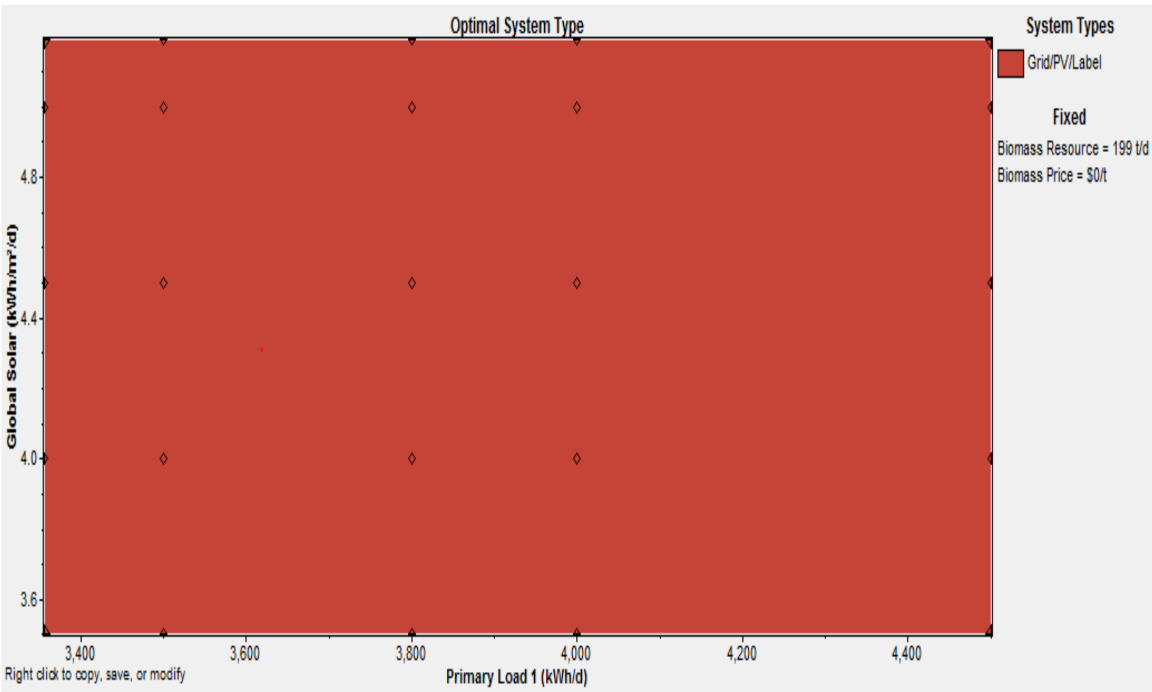


Fig.5.7 Overall sensitivity analysis result of the Hybrid system

The sensitivity analysis has been made with sensitivity variables solar radiation(5.19,5.0,4.5,4.0, 3.5 and kWh/m^2/d), variation in biomass resource potential availability(199,190,170,150,100 t/d) (0.00,0.15,0.18,0.20,0.25), and cost of biomass(if any)(0.00,0.5,0.75,1.0 and 1.5 $/t).

A total of 876 sensitivity cases are examined for each hybrid system configuration. The first two columns indicate the amount and variability of renewable resources solar and biomass respectively. The third and fourth shows biomass feedstock price estimation and its carbon content. Interest rate and project life are indicated in the next columns five and six. The columns seven to ten indicates the presence of grid, solar PV, biogas generator, and converter, respectively. The fifteenth, sixteenth seventeenth, eighteenth, nineteenth, and twentieth columns show initial capital cost, operating cost, net present cost (*NPC*), cost of electricity (*COE*, *US$/kWh*) and renewable energy fraction. Except the columns of biomass carbon content interest rate and project life the results optimization and sensitivity analysis are same.

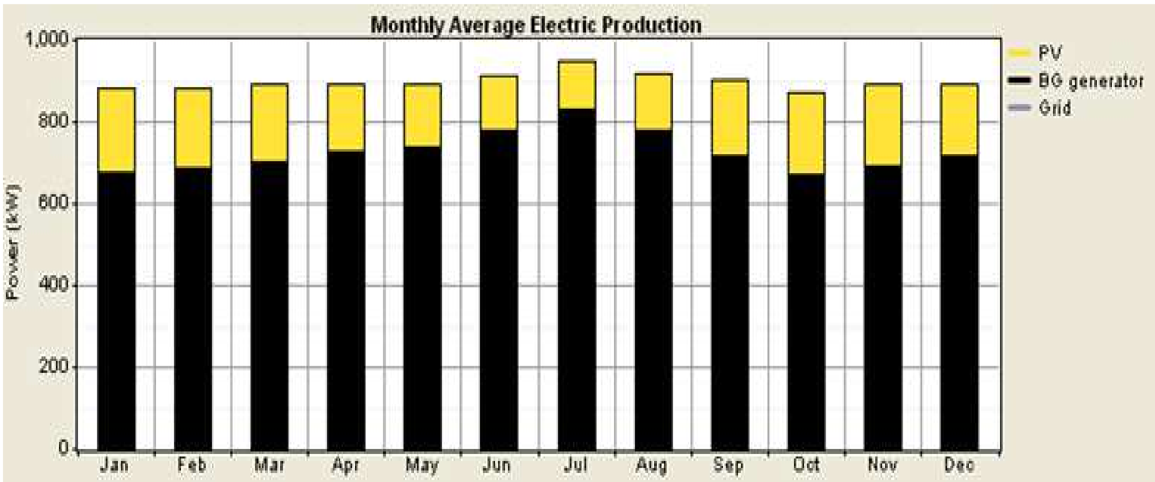
According to the simulated results, the hybrid system comprised of 1,111.5 kW PV array, a 1000kW biogas based generator and addition to 1000 kW converters is found to be the most feasible system with a minimum total net present cost (NPC) of 540,962.00US$, *COE* of 0.023 $/kWh and a renewable energy fraction of 1.00 which is shown in fig.5.9. Figure 5.9 shows simulation results of generated electricity by PV, biomass generator and the grid excess electricity after meeting local load demand, un-met load, capacity shortage and renewable fraction for the most economically feasible system applicable for the projected area. According to the simulation results the un-met load is 0.00 kWh and excess electricity generation is about 0.0492 kWh/yr almost zero. This excess electricity is about 0.0 % of the total generated electricity from the designed hybrid system. The minimal excess electricity is obtained because the plant sells most of the generated electricity to the national grid.

Figure 5.8 represents the emission of different gases during electricity generation from the projected hybrid. Here since both the energy generating systems have renewable nature with 1.00 renewable fractions, it is reasonable to observe insignificant amount of air pollutants. Moreover negative emission values for carbon dioxide, sulpher and nitrogen oxides shows promising combination of the two renewable energy generating systems regarding environmental conservation. Contrarily 103kg/yr carbon monoxide and insignificant amount of particulate matter including un burnt hydrocarbons are expected per a year because there is no system as efficient as 100%.

Pollutant	Emissions (kg/yr)
Carbon dioxide	-4,172,041
Carbon monoxide	103
Unburned hydrocarbons	11.4
Particulate matter	7.74
Sulfur dioxide	-18,099
Nitrogen oxides	-7,935

Fig.5.8 Emission Analysis of the Hybrid System

Fig.5.9 shows the biogas generator and the PV generator energy production shares. As per the simulation result the PV generator contribution is about 19% and the remaining 81 % of electrical energy is contributed by the biogas generator. Likewise from the energy generated by both the PV and biogas generator 16% is allocated to meet the ac load of the consumption and 84% is going to be sold to the national grid.



Cost Summary | Cash Flow | Electrical | PV | Label | Converter | Grid | Emissions | Hourly Data

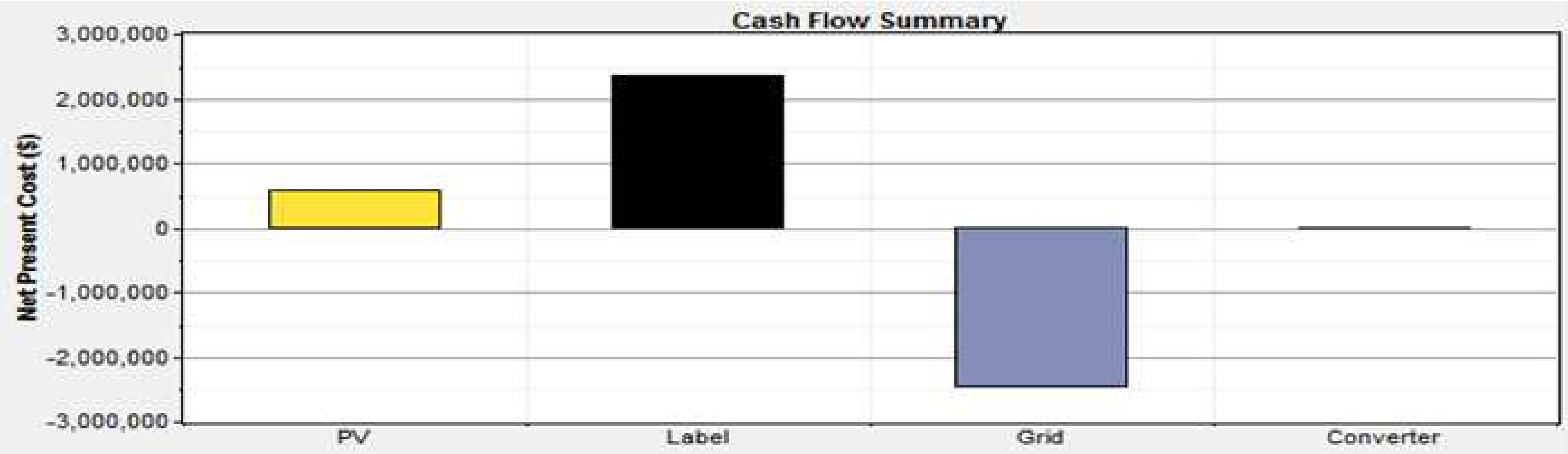
Production	kWh/yr	%
PV array	1,502,685	19
BG generator	6,367,021	81
Grid purchases	0	0
Total	7,869,706	100

Consumption	kWh/yr	%
AC primary load	1,224,575	16
Deferrable load	19,941	0
Grid sales	6,605,656	84
Total	7,850,172	100

Quantity	kWh/yr	%
Excess electricity	0.00492	0.00
Unmet electric load	0.00	0.00
Capacity shortage	0.00	0.00

Quantity	Value
Renewable fraction	1.00

Fig.5.9 Simulation Results of Generated Electricity from Hybrid System



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	535,750	159,093	140	0	-93,135	601,848
BG generator	50,000	264,594	2,061,172	0	-8,286	2,367,481
Grid	0	0	-2,438,861	0	0	-2,438,861
Converter	8,000	3,044	70	0	-618	10,495
System	593,750	426,731	-377,479	0	-102,039	540,962

Fig.5.10 Overall Cost Summary of the Projected Hybrid System

Fig.5.10 describes the overall cost summary of the plant components and the system. As it is clearly shown on the figure the costs are mainly concentrate on PV, biogas generator and converter. As negative costs are returns, the cost expend on the grid is negative implies 2,438,861US$ profit is attained from the power sold to the main grid. The initial capital cost of PV, the biogas generators and the converter are US$535,750.00, US$50,000.00 and US$ 8,000.00 respectively. The total initial capital of the system is therefore, the sum of the initial capital cost of the components which is 593,750.00US$.

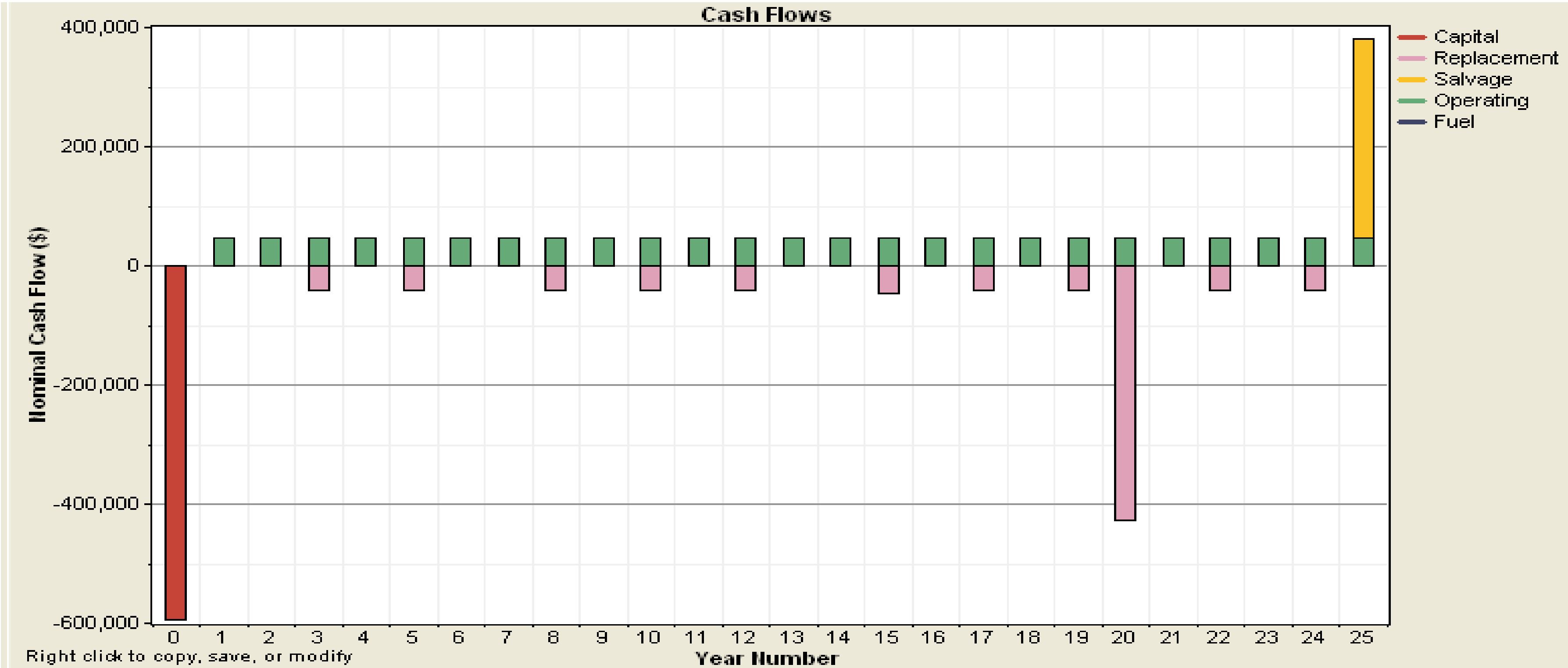


Fig.5.11 Cash Flow of the Hybrid System

The figure 5.10 presents the cash flow summary according to the net present value whereas the figure 5.11 represents the cash flow summary according to the annualized cost of the overall system. Basically figure 5.10 and 5.11 represents the overall cost summary of the projected hybrid system which is essential for economic feasibility of any system. The operating cost, fuel cost and levelized cost of electricity generation are also included in the simulation result.

Fig.5.12 Payback period of the proposed Hybrid system

Fig.5.12 shows the simple payback period of the designed system. It is one of the key indicators of financial viability. It is the number of years required for the initial cost of the project to be paid for out of annual savings. The payback period of this particular project is 24.9 years which is almost at the end of the life span of the project. The payback period analysis here is done without considering incentives for renewable design. and without exempting government tax.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATION

6.1 CONCLUSIONS

The electricity generation of Ethiopia greatly relies on conventional fuel sources despite the base case system in the country is hydropower which is too expensive to install dams that can power all over the country. The existence of sufficient water source for power generation is also unanswered challenge. On the other hand, there is insignificant use and little awareness of renewable sources for electricity generation even if the country is blessed with renewable sources like solar, wind and biogas which can be utilized as an alternate means for large scale electricity generation. Given to the stated fact and in order to provide electricity in the off-grid remote and rural areas, decentralized or grid interactive hybrid electricity generation system can be a suitable option. In view of that, the study in hand focused and paid a due attention about the design and cost analysis of a 3.1 MW hybrid power system with utilization of local renewable resources integrating with the national grid. The monthly average solar radiation varies from 3.66 to 5.87 kWh/m^2/day whereas the average annual wind speed varies from 3.1 to 4.1 m/s of the selected location for the hybrid system. Like most rural areas of Ethiopia the selected location for hybrid system has ample resources of biogas and sufficient solar radiation which can be utilized for electricity generation. There is a high amount of potential availability of biogas resource in universities. In AAUCNCSC about 559.43 tons biomass per year can be collected only from cafeterias found in the campus. In addition to this about a volume of 10 m^3 biomass resources can be obtained each day from toilets. Generally about 7556,231kWh/yr electrical energy can be harnessed from the total biomass resource. This can cover about 87% percent of energy demand of the site. The remaining need is met by the integral of photovoltaic and thermal systems. This grid tied hybrid system is designed to be properly used and suitably function for areas where the annual average energy demand is considered as 3,176 kWh/d with peak load demand of 349 kW and load factor of 0.379. The initial cost of the PV and Biogas systems is around 593,750 US$ with unit energy selling price to be 0.023$/kWh. Hence the payback period as per simulation result is around 24.9 years. Even if there is no financial frame of reference for payback period to categorize a design/installation of any system to be economically viable and infeasible the exaggerated number shows the considered hybrid system is not feasible or economical . The main cause of letdown of the project is high cost of PV panels, biogas engine generator and other main components in addition the minimal electricity tariff of the country which is subsidized by the government.

6.2 RECOMMENDATIONS AND FURTHER WORKS

In the research being conducted hybrid PV/T and biogas systems are being considered and studied. As it can be easily observed the thermal integration with the photovoltaic modules has a better merit in extracting the undesired heat generated in the PV modules. The thermal system uses water as a cooling agent which has dual function both in cooling (remove the unwanted heat) and heating water for both biomass in the digester and hot water for kitchen use, shower as well as for other home use functions. But based on what I have learned from the research being conducted I have learned that more amount of energy can be collected from solar radiation if V-type reflectors is used incorporated with the PV/T collector and thereby I strongly recommend the same given to its profit and benefit.

Unfortunately due to high initial cost of the hybrid system the return from the investment is too late when compared to other systems, so considering the biogas system only for heating purpose in which the institution is also in need of it for different activities will be other option. Likewise using this project can be useful in order to provide electricity in the off-grid remote and rural areas, since remote rural areas of the country are unluckily failed to be connected with the national grid due to the high expansion cost of transmissions and partly due to failures to the distribution network of national grid system.

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ANNEXES

Annex A: Tables

Annex A-1: Standard Biomass Digesters dimensions

For volume	For geometrical dimensions
$Vc \leq 5\%\ V$ $Vs \leq 15\%\ V$ $Vgs + V_f = 80\%\ V$ $Vgs = V_H$ $Vgs = 0.5\ (Vgs + V_f + Vs)\ K$ Where K = Gas production rate per m^3 digester volume per day. For Bangladesh $K = 0.4\ m^3/m^3d$.	$D=1.3078 \times V^{1/3}$ $V_1=0.0827\ D^3$ $V_2 = 0.05011\ D^3$ $V_3 = 0.3142\ D^3$ $R_1= 0.725\ D$ $R_2= 1.0625\ D$ $f_1 = D/5$ $f_2 = D/8$ $S_1 = 0.911\ D^2$ $S_2 = 0.8345\ D^2$

Annex A-2: Comparison of different Biogas Gen-Set Brands

SN	Brand Name	Model	Rated Power (KW)	Rated Voltage(V)	Rated Current(A)	Cost($)	Speed (RPM)
1	Yuchai	30gf	30	380/220	54	5,500	1500
2	High Tech	Ht4100d	25	400/230	38	5,105	1500
3	Googol	Jta3240sg2	800	480v Adjustable	1481	325,000	1200
4	Googol	Hggm1250	1000	415/240	1739	50000	1500
5	Vovac	Vr120gfz	120	400	216	30000	1800

Annex A-3: Comparison of different PV/T Modules Brands

No	PV/T Module Manufacturer	Model	Module Watt Power(W)	Frame Area(m^2	Efficiency (%)	Vmp (V)	Isc (A)	Material
1	Sekisui	MWPVT-200	200	2.00	20.40	54.70	6.46	Monocrystalline Silicon
2	SYFD	SYFD-200W	200	1.20	>18.50	45.36	5.71	Monocrystalline Silicon
3	SUNTECH	KPV215M-60	260	1.64	15.62	38.1	9.14	Monocrystalline Silicon
4	Millennium Electric	MIL-PV-320W	320	2.32	14.2	44.2	9.94	Monocrystiline texture and antireflective
5	SYFD	SYFD-250W	250	1.6	>18.00	30.72	8.52	Monocrystalline Silicon

Annex. B Manufacturer Specification Hybrid System Components

Annex B .1 Specification of SYFD-250W PV/T Module

Maximum Power (Wp)	250Wp
Maximum Power Voltage (V)	37.80
Maximum Power Current (A)	5.29
Open Circuit Voltage (A)	45.36
Short Circuit Current (A)	5.71
Cell Efficiency (%)	18.50%
Number of Cells (pcs)	72(6×12)
Size of Cell (mm)	125×125
Size of Module (mm)	1580×808×35
Weight Per Piece (kg)	16
Junction Box Type	PV-JB001(TUV)
Frame (Material,Corners,Etc)	Aluminum
Temperature Range	-40---+85

Standard Test Conditions:1000W/M2 Am1.5 25'c

Annex B.2 Specification of HGGM1250 Googol Brand Gen-Set

Specifications

800kW 1000KVA Biogas Engine Electric Generator for Sale 60hz
Jta3240sg2 Gas Engine 12 Cylinders V Type
Alternator Marathon

800kW 1000kVA Biogas Engine Electric Generator for Sale 60hz

Engine Model		JTA3240SG2
Rating Speed	RPM	1200
Frequency	Hz	60
Generator Output (Cop)	kW	800
Power Factor		0.8
Gas Engine Parameter		
Engine Output (Cop)	kW	842
Air Ratio	Λ	1.7
Configuration		12 Vee
Displacement	L	53.1
Bore	mm	170
Stroke	mm	195
Compression Ratio		12:1
Piston Speed	m/s	7.8
Number of Flywheel Teeth		218
Fly wheel House Size		SAE00-21
System Parameter		
Oil Capacity	L	180
Max. Allowed Oil Temperature	°C	110
Oil Pressure Warning	kPa	300
Oil Pressure Shutdown	kPa	200
Coolant Capacity For Engine	L	100
Max. Coolant Warning Temperature	°C	93
Max. Coolant Shutdown Temperature	°C	97
Max. Intercooler Outlet Temperature	°C	40.5
Flow of Coolant Pump (JW)	m^3/h	39
Flow of Coolant Pump (Liter)	m^3/h	36
Max. Exhaust Temperature	°C	453

Exhaust Flow	kg/h	4370
Exhaust Flange Diameter	mm	1×250
Charging Alternator Capacity	A	55
Starting Voltage	V	24
Thermal Balance		
JW Coolant Heat	±8% kW	422
CAC Intercooler Heat	±8% kW	67
Exhaust Heat up to 120°C	±8% kW	442
Energy Input	kW	1956
Electrical Efficiency	%	40.9
Mechanical Efficiency	%	42.9
Thermal Efficiency	%	44.2
Total Efficiency	%	85.1
Gas Consumption	MJ/kWh	8.80
Generator Parameter		
Generator Model		MX-800-6
Generator Prime Output	kW	880
Generator Efficiency @ 0.8pf		95.3%
Genset Dimension		
Length	Mm	4500
Width	Mm	1600
Height	Mm	2200
Genset Weight	Kg	10500

Annex B .3 Specification East Brand Inverter of Model EA500KTL

Technical Data	EA500KTL
Max Dc Voltage	900Vdc
MPPT Voltage Range	450~820Vdc
Max Dc Power	550kWp
Max Input Current	1200A

Nominal Ac Power	500kW
Nominal Ac Voltage	220 Vac
Nominal Frequency	50hz/60hz
Power Factor	0.9(Lagging)~0.99(Leading)
Max Efficiency	98.7%
Net/Gross Weight	2000kg/2100kg

Annex B .4 CPM Centrifugal Water Pump.

Fob Price Us $ 20 - 80 / Piece

- Place of Origin: Zhejiang, China (Mainland)
- Brand Name: Hanghai CPM Centrifugal Water Pump
- Model Number: CPM Series Centrifugal Water Pump
- Theory: Centrifugal Pump
- Structure: Single-Stage Pump
- Usage: Water
- Power: Electric
- Standard or Nonstandard: Standard
- Fuel: Electric

Working Conditions

Max Temperature of fluid up to +80°C

Max Pressure 10bar,

Max Ambient Temperature up to 40°C

Type	Power		Q.max (L/min)	H.max(M)	Pipe dia	L×W×H(mm)	N.W (Kg)
	Hp	kW					
CPM-100	0.33	0.25	70	16	1"×1"	310×170×235	8.9

Annex C

Annex C-1: Standard Parametric Values.

Parameters	Values
U_T	66 $Wm^{-2}K^{-1}$
U_t	9.24 $Wm^{-2}K^{-1}$
U_{tT}	8.1028 $Wm^{-2}K^{-1}$
K_G	0.033 $Wm^{-1}K^{-1}$
K_T	0.033 $Wm^{-1}K^{-1}$
K_{abs}	204 $Wm^{-1}K^{-1}$
L_G	0.003 m
L_T	0.0005 m
h_o	57.75 $Wm^{-1}K^{-1}$
$h_{c\alpha}$	45 $Wm^{-1}K^{-1}$
h_{fi}	300 $Wm^{-1}K^{-1}$
h_T	500 $Wm^{-1}K^{-1}$
α_{sc}	0.70 – 0.85
α_p	0.8
η_{sc}	0.09
β_{sc}	0.9
τ_g	0.95
$\dot{m}$	0.01 kg/s
C_f	4190 $Jkg^{-1}K^{-1}$