Addis Ababa Institute of Technology

School of Graduate

Energy Center

Comparative Experimental Investigation between Parabolic Dish and Flat Plate Collector based solar dryer for saw dust briquette production

By: ***Hosaena Alemayehu***

Advisor: ***Dr. Solomon T/Mariam***

*Co. Advisor**: Tewodros Walle (MSc)***

A thesis submitted to the school of graduate studies of Addis Ababa university institute of Technology in partial fulfillment for the degree of masters of Science in Energy of technology

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CERTIFICATION

I, the undersigned, certify that I read and hear by recommend for the acceptance by Addis Ababa University institute of Technology, center of Energy Technology a thesis entitled “Comparative Experimental Investigation between Parabolic Dish and Flat Plate Collector based solar dryer for saw dust briquette production” This certificate used as a partial fulfillment of the requirement for the design of Masters of Science in Energy Technology.

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DECLARATION

I, Hosaena Alemayehu declare that this thesis is the result of my own work and that all source or material used for this thesis has been truly acknowledged. This thesis is submitted in partial fulfillment of the requirement for Master's Degree in Energy Technology at Addis Ababa University and to be made available at the university's Library under the role of the Library. I confidently declare that this thesis has not been submitted to any other institutions anywhere for the award of any academic degree, diploma, or certificate.

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Hosaena Alemayehu

Addis Ababa University

Addis Ababa Institute of Technology (AAiT)

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Approved by board of examiners

Dr. Solomon T/Mariam **(Chairman)**	____________________ Signature	____________________ Date
Dr. Solomon T/Mariam **(Advisor)**	____________________ Signature	____________________ Date
Dr. Kamil Dino **(Internal examiner)**	____________________ Signature	____________________ Date
Dr. Tilahun Nigussie **(External examiner)**	____________________ Signature	____________________ Date

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ABSTRACT

From different types of briquette drying technology, the open sun drying system is the most widely used, which is found in many developing countries including Ethiopia. For this type of convectional drying process, the time required to remove moisture from the product is too long. In average it requires 3 to 4 days with available sufficient solar radiation. Beside that the recent improved type solar driers (flat plate-based driers) have still inefficiency regarding to the drying time. This happened due to the low drying air temperature effect that limits the drying time and efficiency. The main objective of this project was to design, construct and test more efficient solar drier compare to the recent developed dryer type. To prove the new type of drier performance, the experiment has been done by comparing the performance of the parabolic dish based drier (PDSCD) with the Flat plate based drier (FPSCD). The comparative assessment has been done with scientific experiment using different measuring methods and tools discussed in this paper.

The experiment was conducted in the Addis Ababa Institutes of Technology compound free field area for both solar driers. The drying air temperature has been increased using concentrator collectors. ***.*** *The PDSCD and FPSCD absorber surface temperature, drying air temperature, air speed at the outlet of the drying chamber, moisture content variation, the relative humidity at ambient and inside the drying chamber were measured with unloaded and loaded setup using direct and indirect measuring methods. The amount of moisture removed from the drying chamber of PDSCD and FPSCD is 0.039 kg and 0.022 Kg respectively. The measured result indicates that performance PDSCD has a better moisture removing capacity rate than FPSCD. After analysis of the measured result, the thermal efficiency parabolic dish collector and Flat plate collector is determined 31.55% and 8.95 % respectively. And the overall drying system efficiency of the PDSCD and FPSCD is 31.55 % and 8.95 % respectively where the PDSCD has better performance than FPSCD.*

Key Words: *Solar thermal Energy, Solar dryer, parabolic dish solar collector, Drying chamber*

A NOMENCLATURE

Symbol	Description and Units
Q_{uc}	Useful energy output of the collector (W)
I_s	Absorbed solar radiation per unit area (W/m^2)
T_{1amb}	Ambient temperature (°C)
T_{abs}	Absorber temperature (°C)
CR	Concentration ratio
f	Focal length (m)
Q_{abs}	Heat Energy received by absorber (W)
T_2	Out let from collector or Inlet air temperature to the drying chamber (°C)
T_3	Out let air temperature from the drying chamber (°C)
ΔT	Temperature difference(°C)
T_{db}	Dry bulb temperature (°C)
T_{wb}	Wet bulb temperature (°C)
A_{ca}	Aperture area of the collector(m^2)
A_{cg}	Gross area of the collector (m^2)
ρ_a	Density of air at given temperature (kg/m3)
C_{pa}	Specific heat capacity of air (KJ/Kg K)
V_3	Out let air velocity from the drying chamber (m/s)
L_w	Latent heat of vaporization (kJ/kg)
m_i	Initial mass of drying item (K g)
M_f	Final moisture content (%)
M_i	Initial moisture content (%)
m_w	Mass of water evaporated (kg)

$\dot{m}_a$	Mass flow rate of air (Kg/s)
$\dot{m}_{dr}$	The average drying rate (Kg/s)
t_d	Drying time second(s)
Amb R.H	Ambient Relative Humidity (%)
Dch R.H	Drying Chamber relative Humidity (%)
Amb H.R	Ambient Humidity ratio (Kg/Kg)
Dch H.R	Drying Chamber Humidity ratio (Kg/Kg)
V_{air}	Velocity of air (m/s)
L	Local longitude (°)
A_{ca}	Aperture r area (m^2)
A_{ga}	Gross area of the collector (m^2)
$\dot{m}_a$	Mass flow rate of air (Kg/s)
h_i	Initial enthalpy of moist air (J/Kg)
h_f	Final enthalpy of moist air (J/Kg)
w_i	Initial Humidity ratio (Kg/Kg)
w_f	Final Humidity ratio (Kg/Kg)
Q_s	Solar energy incident on the Aperture area of the collect (W/m^2)
Q_{abs}	Absorbed solar energy by the collector (W/m^2))
Q_{ua}	Useful energy gained by air (W/m^2))
E_T	total useful energy received from drying air (KJ)
η_{cth}	Thermal efficiency of the collector (%)
p_{fa}	Fan power consumption (W)

B. GREEK SYMBOLS

Symbol	**Description and Units**
θ_i	The incidence angle
ρ_g	The reflection coefficient of the glass
α	Solar absorbance
τ_g	The transmittance of glazing
β	Slop
φ	Latitude (°)
γ_s	Surface azimuth angle
δ	Declination
α_s	Solar altitude angle

C. SUBSCRIPTS

P	Parabolic dish dryer
F	Flat plate dryer
f	Final
i	Initial
cth	Thermal efficiency of the collector
ca	Collector aperture area
cg	Collector gross area
abs	Absorber
amb	Ambient
db	Dry bulb
wb	Wet bulb
a	air

D. ABRIVATION

PDSCD	Parabolic Dish Solar Collector Drier
FPSCD	Flat Plate Solar Collector Drier
PDSC	Parabolic Dish Solar Collector
FPSC	Flat Plate Solar Collector
CPC	Compound Parabolic Collector
PTC	Parabolic Trough Collector
PDR	Parabolic Dish Reflector
HFC	Heliostat Field Collector
EPA	Environmental Protection Authority
ETB	Ethiopian Birr

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1 CHAPTER ONE: Introduction

1.1 Background

Biomass contains huge amounts of unutilized waste that can convert in to Energy by using different technology. Solid biofuel production is a convenient way recover the waste to energy. Before the waste becomes biofuel, it has to be modified. Very interesting possibility is to compact the modified waste in to the solid high-grade biofuel. This can be performed by compacting carbonizing and drying technologies using briquetting machine. This briquetting machine has higher advantage to modifying waste material in to highly efficient energy source [9].

In Ethiopia biomass is an important energy source which account more than 90% of total energy consumption. From the available biomass waste resource Saw dust biomass waste is available in different places of the country. Especially in many furniture factories found in urban areas. Beside to that saw dust mostly used to as fuel source for cooking purpose, but using of this waste mostly in rural area, it is not in safe way both environmentally as well as health case [6]. Briquetting technology has been introduced in this country 1980s [6] and low-pressure piston machine was installed by private individuals in first briquetting plant history. The raw-material is was primarily saw dust (60%) and the rest 40% were coffee husk and cotton-seed husk. and this briquette are sold mainly to middle-class hotels which found in Addis Ababa [6]. The equipment's which used for briquetting process are manufactured locally which includes Kiln, Hammer Mill and Hand Press Molder and solar dryer as shown in the figure below (Figure1.1) [6].

The process of briquetting starts from carbonized the Biomass wastes using a kiln then by using electric hammer mill charcoal is changed to powdered and finally briquettes are produced using manual hand press mold, which produces one "beehive" briquette at a time. For compacting process of the charcoal dust or carbonized saw dust, binding agent such as clay soil and molasses are mostly used [23]. And finally, the drying process will take place, which by putting the compacting wet briquette on the metal sheet in order to exposed to sun radiation from 3 to 4 days within in a week. This briquette manufacturing process has been done using different agricultural wastes and industry residue (biomass waste) such as Coffee husk, Cotton residue, Saw dust and Jatropha residues [29].

Figure 1-1: The open sun   honeycomb charcoal saw dust briquette drying process [23]

1.2 Statement of the problem

After the compacting process is done, the wet briquette has to be dried for better combustion process. Most of the common drying process of briquette the time requires to remove the moisture from the product is to long due to inefficient way of drying process. Most commonly used drying system in developing country including Ethiopia open sun drying system requires three to four days in average [29].

The drying time affects the overall production cost. If the production rate is slow the energy consumption is high and it can’t produce better quality briquette with requiring time. It reduces the overall revenue from the market. So, the drying rate for briquette manufacturing process has significant effect to save money and time.

The heat loss for the most commonly used open sun drying technology is high due to the wind loss and inefficient way using this system for drying wet briquettes. For open sun drying system the drying efficiency is low due to low temperature, high heat loss, and low flow rate of air and non-uniform heat distribution on the wet briquette for drying characteristics of a product.

Hence, this thesis will be focus on investigating the best way to dry the sawdust briquette by comparing the parabolic dish based drier with flat plate based solar briquette drier.

1.3 Objective:

1.3.1 General objectives

To design, construct and test the performance of parabolic dish solar collector to compare with flat plate collector for saw dust drying application.

1.3.2 Specific Objectives:

- ✓ To fabricate the parabolic dish and flat plate collector-based dryers.
- ✓ To study the significant effect and relationship among the measuring parameter such as drying air temperature, air flow speed, relative humidity and moisture content variation
- ✓ To reduce insulation consumption for PDSCD, which used to cover the absorber part by making the absorber small in size.
- ✓ To investigate the performance different between the two driers at the same input parameters such that solar incident radiation, ambient air temperature and humidity and inlet air speed.

1.4 Scope of the study

This project is going to be the final stage of demonstration the experimental model of solar energy briquette dryer. The design method, thermodynamic analysis and the construction method are covered in this paper with practical experiment analysis. The temperature generated by the solar collector and the heat transfer process review in detail in this paper. Even if this prototype is built to be flexible for trucking mechanism, the project does not include automatic solar tracking mechanism for the solar thermal system part, but for this experimental thesis, it is done manually to track the sun to whole days of sunshine with human intervention.

1.5 Significant of the project

The major significance of this project is identifying the performance difference between the two type of solar collector PDSC and FPSC. The comparative experiment is done on the constructed prototype in order to determine which type of collector is recommended for efficient solar drying processes regards to minimizing drying time.

1.6 Research Methodology

Those Methods listed below is used to achieve the objective of the project for the entire research work plan.

- **Literature survey and data collecting**

The survey concerned with identifying the observed problem in the study of previous literatures work. The type of dryers, factor affecting the performance of dryers and different type solar thermal collectors' performances are discussed in this chapter.

- **Prototype Design and Construction**

Based on the recent improved drying machine performance and the research work gap observed in the literature, the new concept solar drier design proposed to improve the overall drying time and efficiency of the drier**.** This design starts from conceptual idea with pass through mathematical modeling and end with 3D constructional model using solid work software tool with detail size and specification. The construction of the prototype is done in the mechanical workshop lab with assembling of some components of the drier.

- **Experimental Investigation**

After building the solar dryer prototype model, the experimental process has been done based on the given experimental set up. The comparative experimenting process is working with standard procedure, methods and materials.

- **Result Analysis and Interpretation**

Determine and interpret the result has been done based on the measured experimental data for both type of solar driers. Evaluating the result with thermodynamic analysis and heat transfer concepts to determine the overall efficiency of the dryers.

1.7 Project organization

Chapter 2: In the **Literature review** part the chapter explained about briquette manufacturing and drying technology in Ethiopia, and it also discussed about recent improved solar biomass dryer machines with their performance and basic drying principle and different solar collector performance.

Chapter 3: There is a review of **Solar Energy Resource and Data** in Ethiopia, specifically in the selected place Addis Ababa, the solar data and solar radiation theory is included in this study.

Chapter 4: Design and construction in these chapters the design part includes conceptual **design,** Geometrical design and mathematical modeling. Beside to that structural **construction** of the prototype and the experimental set up is discussed widely.

Chapter 5: Experimental Investigation and performance analysis of the drying system is discussed based on selected **Biomass drying** property. So that Analytical performance Analysis and the comparative Experimental Testing is the basic methodology for each parts of the solar drying system components with production system efficiency and product quality

Chapter 6: **Result and Discussion** in this chapter solar dryer efficiency with respect to PDSC and FPSC solar drying performance. The drier efficiency and drying product quality are determined through the experimental findings and observation of the result which is listed and discussed in detail in this chapter.

Chapter 8: **Conclusion and recommendation,** in this chapter**, Overall** process with drying efficiency and time saving and energy saving advantage of the machine is justified based on the observed results. And after all there are recommended points based on the result justification

2 CHAPTER TWO: Literature Review

2.1 Introduction

The continuous and rapid population growth of our world leads to the higher energy demand. To tolerate this, demand the next focus should be utilizing alternative energy source. The Biomass fuel is one of the most alternative energy resources in the world among different energy utilization methods. Briquetting technology has an advantage of converting the biomass products in to high energy density fuel source [1].

Briquetting is defined as the densification (agglomeration) of agricultural residue or waste, which used to increase the density of the fuel or decrease the moisture content. To make the briquette uniform size and shape for easy handling, transport and storage this technology is very important. "*A briquette can thus be defined as a product formed from the physic-mechanical conversion of dry, loose and tiny particle size material with or without the addition of an additive (binder) into a solid state characterized by a regular shape*" [1].

The final products of efficient briquetting machine are briquettes charcoal with different shape and sizes. The feature of this briquetting machine is pressing of materials (wastes) under high pressure and temperature without any binding material. It is very important to produce briquettes with standards given quality. Briquette quality is evaluated mainly by briquette density and calorific value.

The other important briquettes quality indicators are mechanical durability, strength and hardness. This quality of briquette comes from efficient manufacturing process which includes compacting, carbonizing, binding and drying process. Among these processes the drying system is the most common and important part of briquette production which helps to get more efficient and quality product. The most important advantages of briquette are its low sculpture content, relative freedom from dust, ease of handling, low flue gas emission and high calorific value [1].

2.2 Briquette drying Technology

Now a day's briquette manufacturing is done using different briquette manufacturing machines, but based on the production process it follows basic two steps with carbonized and non-carbonized process. Especially for carbonized briquettes drying is very important in order to get fuel efficient and quality product. The basic briquette making procedure contains the following process [15].

i. **Raw material preparation:** it is a process of collecting bio wastes to make ready for carbonization process.
ii. **Carbonizing:** Carbonizing is processes of increasing the calorific value of the briquette by adding heat energy to the biomass waste with the absence of oxygen.
iii. **Preparing the binder:** It is the process of preparing the binding chemical that used to bind the biomass waste materials due to the available in local markets, mostly Cassava starch is the recommended binder. But there are many types of binding agent such that Molasses, Coal tar, Clay, Cement and Lime [15].
iv. **Mixing process:** It used to produce uniform good quality briquettes by combining of the carbonized biomass waste with the binding chemicals.
v. **Briquetting:** It is a process of compacting the mixed bio waste before or after carbonization process is done. This is one of the major technologies which used to produce briquette by pressing the biomass waste with high- or low-pressure force in order to increase the density of the waste, since densification improves the volumetric calorific value of a fuel and reduces the cost of transport [15].
vi. **Drying:** It is a process which refers the reduction of the amount of moisture of water in biomass in order to achieve uniform moisture content in the material at the end of the drying process [32].

Briquette drying process is very essential since the briquette is wet after the compacting process is done. As the sun light potential is abundant throughout the year in many countries of our world. Sun-drying process is commonly used to dry the briquette within 3-4 day in average for efficient drying method [30]. But also, there are some trends to dry the briquette using convectional drying system such as fossil fuel [29] and electric heater [32].

To increase the quality of charcoal the moisture content has to be reduced from 50% to below 10% before sale to the market. On the briquette production process, after pressing the mixed briquette immediately the produced wet charcoal briquettes will have a moisture content of 50% and if the moisture content is above 10%, the charcoal briquette has poor quality. Poor briquette quality means that, it burns lower and lighting up takes longer time, then it discourages the customer to buy the product [14]. The Research works on briquetting making process in Nairobi Kenya shows that, sun drying system is commonly used to dry carbonized briquettes form 3 up to 4 days [31]. Even if there is a fact that biomass materials are heat sensitive it is possible to dry at relatively with high temperature exposed with in short drying time duration [27].

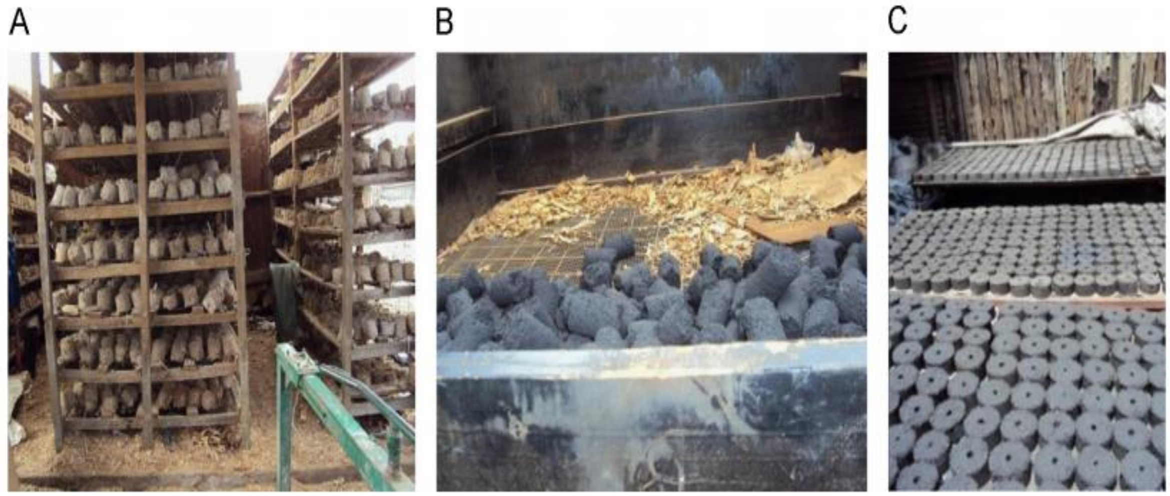

Figure 2-1: A, B, C various briquette suns drying methods [27**].**

For East African producers, drying is a critical process in briquette manufacture process. For the non-carbonized briquettes have to be dried to a moisture content of around 13% before supplying the feedstock in to briquette machine and after drying process they can be immediately packaged. For carbonized briquettes raw materials have to be dried after mixing with binding agent and mechanical pressing (molding), the finished briquettes have to be dried (to less than 10% moisture content) [13].

In Uganda drying the briquette is done using solar energy, which has favorable climate condition for sun-drying process, the most common method is laying the briquettes out on polythene or iron sheets or a wire mesh. This process can take up to 3-4 days to dry the briquettes completely. The larger companies in East Africa also used this method to produce 2,000 tons of briquettes per year, continuously using sun drying methods for finished briquettes [13]. In Ethiopia also the same briquette drying process is used for different type of agricultural and agro-industry biomass wests as discussed in chapter one.

2.3 Types of solar dryer

In August 1997, O.V. Ekechukwu and B. Norton made a comprehensive review of the various designs, details of construction and operational principles of the wide variety of solar-energy drying systems practically with realized designs figures. They classified the solar dryer based on the systematic approach. Solar-energy dryers can be indented as passive or natural-circulation solar-energy dryers and active or forced-convection solar-energy dryers (often referred to as hybrid solar dryers). And again, they categorize with in the sub group in to integral-type (direct mode), distributed-type (indirect mode) and the mixed-mode type [23].

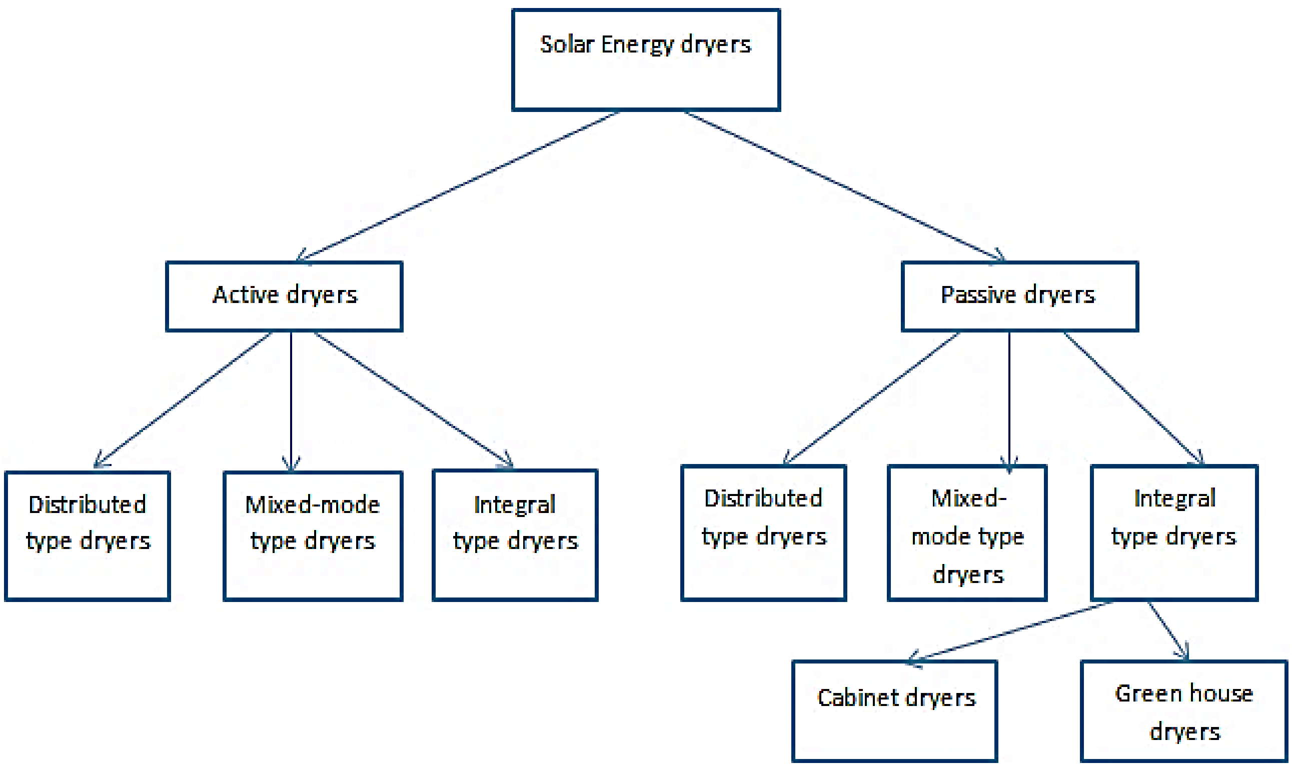

Figure 2-2: Classification solar energy dryers [23]

In general, according to their heating modes and the manner in which the solar heat is utilized Solar-energy drying systems are classified into two major groups, namely [3]: **Active solar-energy drying systems** (most types of which are often termed hybrid solar dryers); and **passive solar-energy drying systems** (conventionally termed natural-circulation solar drying systems).

Based on the variance in the design arrangement of system components and the mode of utilization of the solar heat active or passive solar drying systems can be distinct with three sub-classes they are: integral-type solar dryers, distributed-type solar dryers; and Mixed-mode solar dryers.

2.3.1 Passive solar dryer

Passive dryers are a type of dryer which do not use external power source to blow the air. Rather it uses natural air convection system to dry the biomass product.

2.3.1.1 Open sun drying system

This method is widely used in rural areas and some of urban areas but it has inherent limitations because the process is intermittent, being affected by cloudiness and unexpected rain. Therefore, the output is low and can be of very poor quality such as: high crop losses ensue from inadequate drying, fungal and insect infestation, birds and rodent encroachment and weathering effects [22]. In addition to that it leads to longer drying time where the sun's radiations are not efficiently utilized in the drying process.

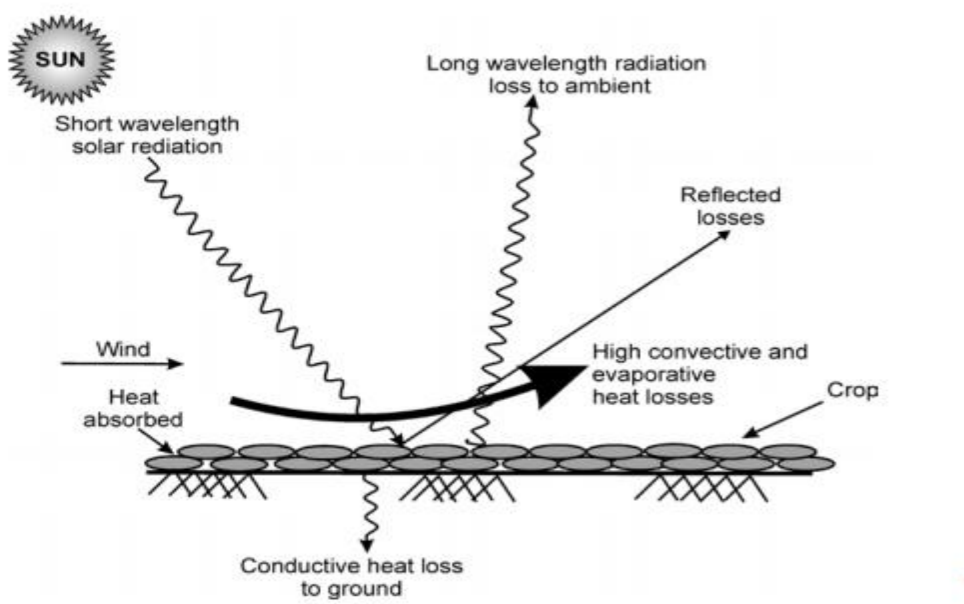

Figure 2-3: Working principle of Open sun drying [11]

2.1.1.1 Natural-circulation solar-energy crop dryers

The system operation of Natural-circulation solar-energy dryers entirely depend on solar-energy in this systems, solar-heated air is circulated through the crop with the effect of buoyancy forces or due to wind pressure, acting either singly or in combination. These dryers are often called ``passive" in order to distinguish them from systems that uses fans to force the air through the crop. There are three generic types of natural-circulation solar-energy dryers which have evolved and both retain many of the advantages of traditional open-to-sun drying. These are distributed-type natural-circulation solar-energy dryers, Integral-type natural-circulation solar-energy dryers and Mixed-mode natural-circulation solar-energy dryers they described below with comparison table based on their working principle [23].

I. Integral-type natural-circulation solar-energy dryers

The heat transfer to the dried crop is by direct radiation and convection (i.e. from heated surrounding air) and the construction and operation are simple and also it requires less maintenance. This type of drier can be operated easily at lower efficiencies due to its simplicity and less controllability of drying operations.

II. Distributed-type natural-circulation solar-energy dryers

Heat energy is transfer to the crop trough convection heat transfer mode, from pre-heated air of solar-energy collector. Components Consists of comparatively elaborate structures which requires more capital investment in materials and large running costs. It has a tendency to higher efficiency since individual components can be designed to optimal performance.

III. Mixed-mode natural-circulation solar-energy dryer

A mixed-mode natural-circulation solar-energy dryer is a combination of integral (direct) type and the distributed (indirect) type natural-circulation dryers feature and components. In this process to get the necessary heat required for the drying process, the combined action of solar radiation that directly incident on the product and pre-heated air that obtained from the solar air heater make the product to be dried effectively [8].

2.3.2 Active solar dryer

Active solar drying system uses forced-convection dryers by using motorized fans and/or pumps for air circulation. The drying process is partly depending only on solar-energy that means electrical or fossil-fuel energy is utilized for the drying process. The other feature of the Active solar drying systems is continuous drying option. If the solar-heated air is warm enough it could be used directly for the drying process otherwise the fossil-fuel fired dehydrator would be used to raise the drying air temperature to the required level. This system is important for night time drying operations or periods of low insolation levels. These active solar dryers are commonly known as ``hybrid solar dryers" which can incorporate dehydrators for supplemental heating [23].

2.3.2.1 Integral-type active solar-energy drying systems

In this solar-energy drying systems solar-energy collection unit is an integral part of the entire system, so no need of special ducting to channel the drying air in to a separate drying chamber is required. It categorized in to direct absorption dryers, solar collector-roof/collector-wall dryers and solar collector-roof/collector-wall dryers.

2.3.2.2 Distributed-type active solar-energy drying systems

It is a solar drying system in which the solar collector and drying chamber are separate units. And it has four basic components, the drying chamber; the solar air heater; the fan and/or pump; and the ducting. Conventional drying systems when the temperature increases drying efficiencies also increase until the product can withstand as high temperature.

The efficiency increased due to high-temperature distributed active solar dryers is significantly improved by high air-flow rates. But this effect depends on the size of fans and the level of insulation used and those components has to be balance for a cost-effective design [23].

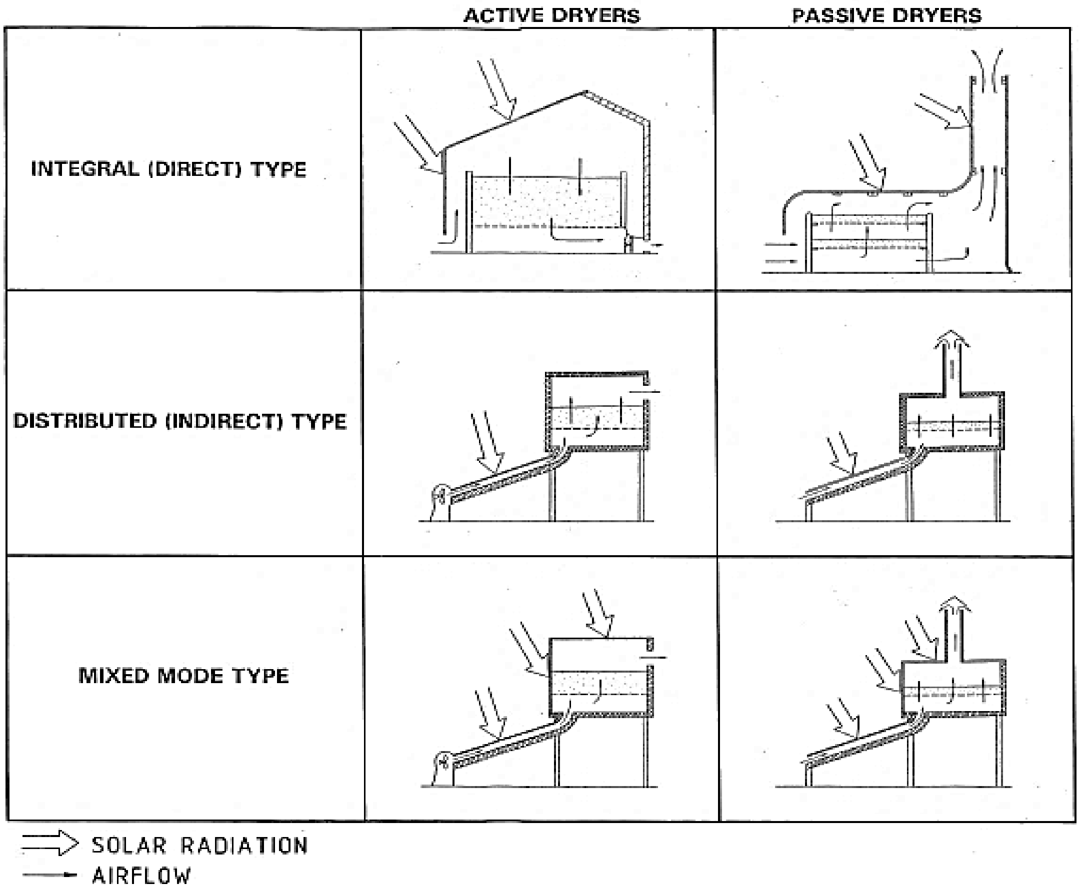

Figure 2-4: Types of Active and Passive solar energy dryer pectoral representation [23].

2.3.2.3 Mixed-mode active solar-energy dryers:

This type of dryers is a Mixed-mode design which combines some features of the integral and distributed-types. This dryer has the following components: a solar air heater, air ducting, a separate drying chamber and a fan and/or pump as in a distributed-type dryer [23].

2.4 Systematic classification of solar dryer

Based on their operating temperature range all drying systems can be classified into two main groups of high temperature dryers and low temperature dryers. But more commonly dryers are classified broadly according to their heating sources into fossil fuel dryers (more commonly known as conventional dryers) which is high temperature dryers and, Solar-energy dryers or low temperature dryer.

2.4.1 High temperature dryers

When a very fast drying process is required for briquette manufacture, high temperature dryers are necessary**.** They are usually used when the products require a short exposure to the drying air. The products are only dried to the required moisture contents and later cooled, such that, if their operating temperatures means the drying air remains in contact with the product until equilibrium moisture content is reached, serious over drying will occur [14].

There are two high temperature dryers' batch dryers and continuous-flow dryers. In batch dryers, the products are dried in a bin and subsequently moved to storage. Thus, they are usually known as batch-in-bin dryers [14].

In continuous-flow of the product, the dryer's area which the product (the briquette) flows through is a heated column under gravity power. And the biomass is exposed to heated air while it is passing at descending pattern [14].

Due to the temperature ranges prevalent in high temperature dryers, only a very few practically-realized designs of high temperature drying systems are solar-energy heated [27]. But most known designs are electricity or fossil-fuel powered machine,

2.4.2 Low temperature dryers

With constant ventilation of low temperature drying systems, the moisture content of the product is usually brought in equilibrium condition. That means they do tolerate intermittent or variable heat input. Low temperature drying is suited for long term storage systems which, enables crops to be dried in bulk [14]. This ability to accommodate intermittent heat input makes low temperature drying most appropriate for solar-energy applications. Thus, most practically-realized designs of solar-energy dryers and some conventional dryers are the low temperature type.

Generally, if forced-convection (active) solar dryers are properly designed it is proved that it is to be more effective and more controllable than the natural-circulation (passive) types. The requirement of electricity or fossil-fuel to drive fans and the use of auxiliary heating sources increase the overall operating, building and maintenance cost but still there is a chance to modify the forced-convection (active) solar dryers with low manufacturing, operating and maintenance cost by keeping the efficiency higher.

2.5 Principle of drying system

It is a drying system which a product dried in enclosed structure where the temperature of air surrounding is usually higher than the ambient temperature of the dryer. For solar drying technology it is very important to investigate basic characteristic of the dryer before using the drying system. Such indicators, which can give an overall assessment of the dryer in relation to their performance, are the drying rate and the drying efficiency.

Generally, the factors which influence the drying efficiency are the size, type of dried product, the moisture content, drying temperature, air flow and the environmental conditions such as the climate, humidity and sun light radiation.

2.5.1 Major Factors Affecting Solar drying performance

The performance of solar drier is depending on different parameters the size of drier, the drying material, seasonal variation, the geographic location where the drier is installed and the drying machine efficiency [12]. But the major factors are listed as follows.

2.5.1.1 Temperature

Temperature is the basic factor which can affect the drying process or the drying rate of the wet product. For the process of conversion, the solar radiation in to heat the solar collector is needed and also to transfer of the heat energy to the drying product with forced air convection type drier the efficient heat exchanger is required. To dry the product, the drying chamber have significant role by controlling the air flow and by protecting the heat from loss. When the drying chamber temperature is high the drying speed also increased. And this drying chamber is effective, when the surrounding ambient temperature is relatively lower that the drying chamber temperature. The temperature can be measured with thermometer [30].

2.5.1.2 Solar Irradiation

The total amount of energy that received on a collector surface and can be measured with pyrometer is the Global solar irradiance. It varies depending on the climate condition, geographical location, position of the sun, the cleanness of the sky and the day of the year. The solar irradiance is composed of three components; the direct normal, indirect and reflected solar irradiance. When the available solar irradiance is higher, the temperature is higher and that increases the drying rate [30].

2.5.1.3 Relative Humidity

It can be defined as the ratio of the maximum amount of air to the amount of water vapor in the air at the same temperature. When the surrounding air temperature is lower than the drier air, the moisture will migrate from the wet product. When the air temperature drops the relative humidity is high. So, based on this fact if the relative humidity entering the dryer is lower, the drying rate become higher and vice versa, and this usually can be measured with a hygrometer [29].

2.5.1.4 Moisture content

The moisture contain of a product depends on the type of product. The amount of moisture content of a product directly affects the drying time and also it can determine the type of solar dryer to be selected [29].

2.5.1.5 Air Mass Flow Rate

The characteristics of air flowing in and out of the drying chamber of a dryer have significant impact on the drying rate as the heat is important for drying process. Air flow rate is measured by the quantity of air that has passed through a dryer within a specified time. The air mass flow rate can be expressed as mass of air flowing through dyer in a unit time. When there are higher mass flow rates there will be good ventilation and it increases the drying efficiency of the dryer [29].

2.6 Thermal Performance of different type solar collectors

Solar collectors are a type of energy converter which converts solar radiation directly to electricity or heat by using PV (Photovoltaic) applications or for solar thermal applications respectively. Irradiation is absorbed by a solar collector concentrated as heat and then transferred to its working fluid (air, water or oil) in order to transfer the heat energy or to change the thermal energy to mechanical energy [3].

The solar thermal technologies are classified based on the concept of concentrating solar radiation, such as line concentrators and point concentrators. They used to produce steam or hot air which is currently applicable for electricity generation. Most concentrating systems use glass mirrors to get better reflective efficiency because of their very high reflectivity characteristic [10]. Currently for industrial purpose there is a trend of extracting solar energy by using solar collectors, which have sun trackers and giant mirrors in order to utilize much energy efficiently

[16]. Based on the data that found from the literature reference that from the lowest temperature range which flat plate collector generating heat energy that is below 120 °C to highest concentrating technology [16]. The collector such as PTC, Fresnel and dish concentrators which use only direct normal solar radiation have heat generating capacity above 150 °C there is a standard specification table listed below.

Table 2-1: Types of solar thermal collectors with temperature scale [16]

Motion	Collector type	Absorber type	Concentration ratio	Temperature range(°C)
Stationary	Solar pond		1	30–90
	Flat plate collector (FPC)	Flat	1	30–80
Single-axis tracking	Compound parabolic collector (CPC)	Tubular	1–5	60–240
		Tubular	5–15	60–300
	Parabolic trough collector (PTC)	Tubular	15–45	60–300
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100–1000	100–500
	Heliostat field collector (HFC)	Point	100–1500	150–2000

Therefore, from the standard table list a point concentrator's parabolic dish can generate from 100–500 °C at best efficiency level

2.7 Improved Forced air solar driers

In July 2014 T.Bhanu Prakash, and G. Satyanarayana study the performance analysis of solar drying system for drying Guntur red chili. The chili lost the moisture content from 80%w. b to 9 % w.b in 24 hr. the solar collector efficiency records at 71.4% and the overall drying system was 42.18%. This experiment done with solar radiation of 950 W/m^2 and a mass flow rate of 0.01 kg/sec. Finally, when they compare this system with Open sun drying system chili, they observed that to remove the moisture content of chili from 80% to 9 % w.b 56 hr. is required. Therefore, they found that this design has better drying efficiency than open sun drying by reducing the drying time. To this design they include air blowing system and flat plate solar collector system as shown in the figure below [31].

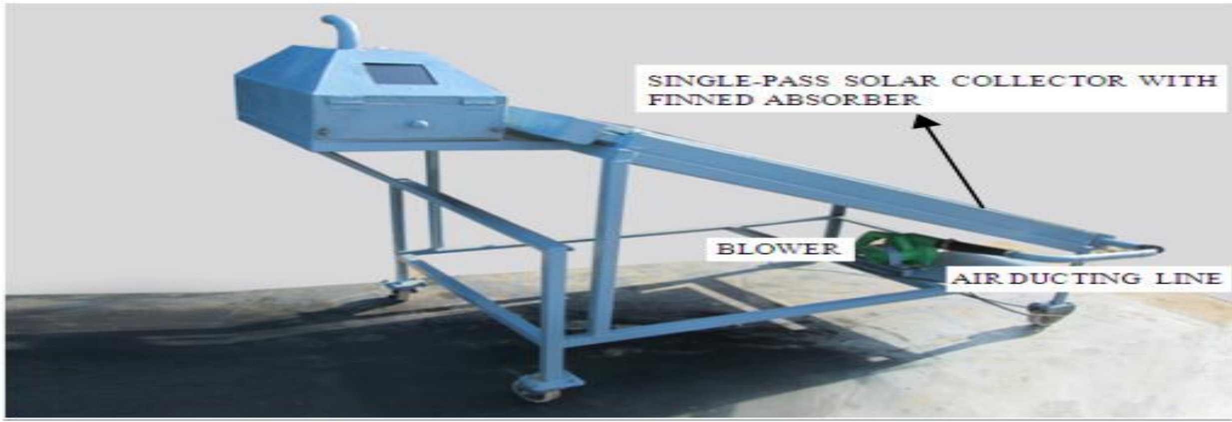

Figure 2-5: The schematic of solar drying system [31].

In 2012 Muhammad Hanif Khalil, and his friends make experimental investigation on "*Drying of Apricots Using a Proficient Dish Type Solar Air Heater*" to evaluate the performance of the air heater, which is connected to drying chamber [22]. They conduct the experiment at different flow rate and they observed that the flow rates significantly affected the efficiency of the solar air heater. The Efficiency of drier improved from 20% at the natural flow rate of 0.01kg. sec 1 to 42.6% at a high convective flow rate of 0.21 kg. sec Finally, Apricots were dried at a temperature of 45 to 50°C and humidity of 15 to 20 %. It took 13 hours to reduce moisture content from 85% to 8%. Therefore, It was concluded that solar air heaters must be operated at high flow rates to get maximum efficiency to get valuable drying of apricots [22].

Figure 2-6: The dish type solar air heater for dryer [22]

2.8 Literature summary and research gap

From review of different type of solar drier which has been discussed in this chapter, major differences between each type of dryer is observed.

For **Open sun solar dryer:** the drying time is so long requiring 3 to 4 days and it requires low cost technology to build, operation and maintenance. It has very less energy consumption to the drying process and very high heat loss to the environment due to wind effect and surface area. It is also having low efficient with rainy season which is highly affected by varying weather condition.

For **Natural convection solar dryer:** It needs more time to dry up to 2 to 3 days and requires moderate cost technology due to natural air convection system which do not use fan/air blower. The energy consumption low and high heat loss due to surface area and such system are affected by weather condition efficient only on sunny days.

For **Forced convection (Fan based) air dryer**: time require for drying is relatively low (24hr), and also the cost is relatively high due to electrical equipment's. The energy consumption and the heat loss are moderate, and it is affected by weather condition efficient on sunny days.

There is common limitation of the all solar dryer except the parabolic dish dryer system. From the limitation the main problems observed at each dryer type are:

I. Heat loss is high due to surface area of the collector is large
II. Low absorber and drying air temperature are generated.
III. Consume large size of insulation cover to minimize the heat loss.

The literatures considered about the collector type and structural design which used to increase the efficiency more and more in order to reduce the drying time. Especially for briquette production system there is not improved drying machines available to dry the wet briquette with the shortest time. This all results negative economic impact on production and supply process. For this project the main aim is not only improving drying time for drying of wet briquette process but to analyze the drying potential difference of the two type of collectors (Flat plate and parabolic dish) with the same incident radiation, air flow rate and material type as input parameter.

3 CHAPTER THREE: Solar energy resource and data

3.1 Solar Energy Resource in Ethiopia

Sun is the free gift of Energy source for the whole mankind. The solar energy can be utilized for a purpose of obtaining electric power, heating water, drying products or some other activities. In Ethiopia there is an abundant solar energy source with the annual average irradiance is estimated to be 5.2 kWh/m^2/ day with seasonal variations. The variation ranges between 4.5 kWh/m^2/day in July to 5.6 kWh /m^2/ days in February and March. In the most populous Northern, Central and Western highlands of the country the solar resource is relatively lower, but, the rift valley regions, Western and Eastern lowlands of the country receive higher annual average irradiance well above 6 kWh/m^2/day [7]. Ethiopian regions of Oromia, Amhara, west Tigray and north Southern Nations Nationalities and Peoples received the higher global solar radiation compared to regions located in the lowlands and periphery parts of the country due to their relative location, size, and elevation [7].

For making solar projects for passive and active systems, first necessary to define the intensity of solar radiation that comes to horizontal and oblique receiving surface of the particular solar system. Solar radiation recorded data is collected for every hour from October 29 to November 2 when the experimental process is conducted. The solar radiation variation at every hour of each day is shown in the below Figure 3-2.

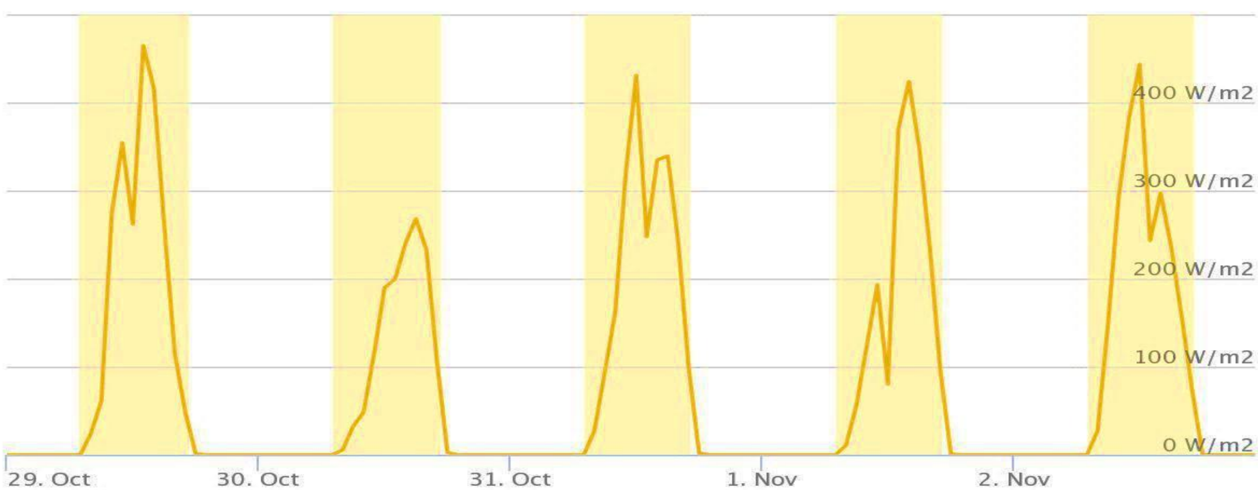

Figure 3-1: Weekly solar radiation from (Oct 29 to Nov 2, 2019) [25]

3.2 Solar radiation theory

The “radiation” is a solar energy transport process through a medium or through empty space. For this paper electromagnetic radiation is considered. And radiant energy is the energy of electromagnetic waves. Radiant power expressed as radiant energy per unit time (Wh) or joule per second (Js^{-1}). Generally, irradiation is the process in which an object is exposed to solar radiation. As a quantity it can be expressed as the incident radiant energy per unit irradiance defined as incident radiant power per unit area (W/m^2) and radiant emittance is the emerging radiant power per unit area of emitting surface [17].

3.2.1 Solar constant

It is defined as the intensity of the solar radiation hitting one square meter of the Earth. Basically, the solar constant depends on three parameters: the temperature of the Sun, the size of the Sun, and the distance between Sun and Earth [17].

3.2.2 Direct, diffuse and reflected radiation

The solar irradiance on a surface of the ground or in the atmosphere is always the sum of these three components: direct radiation and diffuse radiation the sum combination of those three parameters is called total or global irradiance [11].

$$\mathbf{I}_s = \mathbf{I_b} + \mathbf{I_d} \quad \dots (3.2)$$

Where: I_b is beam radiation, I_d is diffused radiation, I_s and is solar radiation

3.2.2.1 Direct radiation

The direct solar radiation is a component of global radiation that comes to the earth in a bright and clear day. In every spot on the earth surface the direction of the direct radiation can be found by geometry method [11].

3.2.2.2 Diffuse radiation

Every surface receives a part of solar radiation that comes to it indirectly on a brightness day, except the direct radiation and it is called the diffused solar sky radiation [33].

3.2.2.3 Reflected radiation

The radiation that reflects from surroundings is happened when the surfaces make an angle with a horizontal flat receives it is called reflected radiation [33].

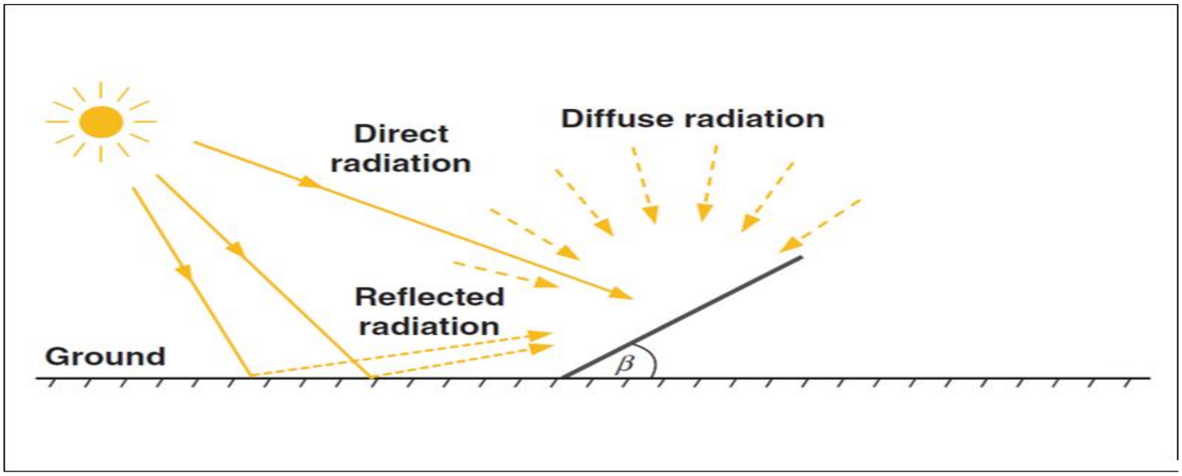

Figure 3-2: Direct, diffuse and reflected radiation on the collector surface [33]

3.2.3 Sun position relative to the collector surface

To determine the sun position relative to the collector and direction of the incident beam radiation on the surface of earth, there are important parameters need to be introduced. The position of the solar collector regarding to solar radiation can be determined by radiation factors which are listed below [11].

3.2.4 Latitude and Longitude

Latitude (φ) is the angle measured at the center of the Earth, between the equator plane and where you are. It is expressed either north or south, and varies from 0° to 90°. Longitude (L) is used to show the location in an east or west direction, it is relative to the Greenwich meridian. The places to the east of Greenwich have longitude angles up to 180° degrees east. And for the places to the west of Greenwich have negative angles up to 180° west [11].

3.2.5 Solar azimuth angle and slope (tilt angle)

Solar azimuth Angle (γ) is between the projections of the straight line joins the site with the centers of the sun on the horizontal plane and due south. The angle of tilted surface 'β' is angle between the surface of collector and the horizontal plane. Incidence angle on a surface of tilt β and azimuth γ on the latitude φ at a time when the declination is δ and the hour angle is ω [33].

$$\cos\theta = \sin\delta \sin\varphi \cos\beta - \sin\delta \cos\varphi \sin\beta \cos\gamma + \cos\delta \cos\varphi \cos\beta \cos\omega + \cos\delta \sin\varphi \sin\beta \cos\gamma \cos\omega + \cos\delta \sin\beta \sin\gamma \sin\omega \qquad \ldots (3\text{-}1)$$

For solar collector periodic tracking throughout the year, the following which listed in table (3.1) are the recommended optimal tilt angles [24].

Table 3-1: Recommended tilt angles for optimal radiation collection of all month of the year

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ø + 25	Ø + 15°	Ø	Ø	Ø − 25°	Ø − 25°	Ø − 25°	Ø − 15°	Ø + 15°	Ø + 15°	Ø + 25°	Ø + 25°

For this project the experiment has been done on October last and November first so the probability of tilt angle is (Ø + 15° and Ø + 25°)

4 CHAPTER FOUR: Design and Construction

4.1 Conceptual design

The new type of dryer structure conceptually design based on the observation literature gap and basic drying principles. The concept initially generated after studying of major factors that influence the drying efficiency of any drier which discussed in chapter two of this paper. After understanding the main drying mechanisms main two concepts were design for this project and also due to the objective and scope of this study the prototype which built is selected using justifiable selecting mechanism. The detail conceptual designing, selecting criteria and method briefly discussed below.

4.1.1 Concept generation

The concept is generating from the requirement of high temperature air is needed to increase the drying efficiency of a dryer. This can be done by increase the temperature of the drying air and reducing the heat loss for overall drying process. Based on literature facts, by increasing the drying air temp and drying speed of air, it is possible to increases the drying rate [14,30].

For this project to increase the drying air temperature there must be efficient solar collector which can generate high temperature with the available solar radiation. The Figure 4-1 shows a drying process which enables to get a fast-drying process with high temperature drying air, that generated from solar thermal collector.

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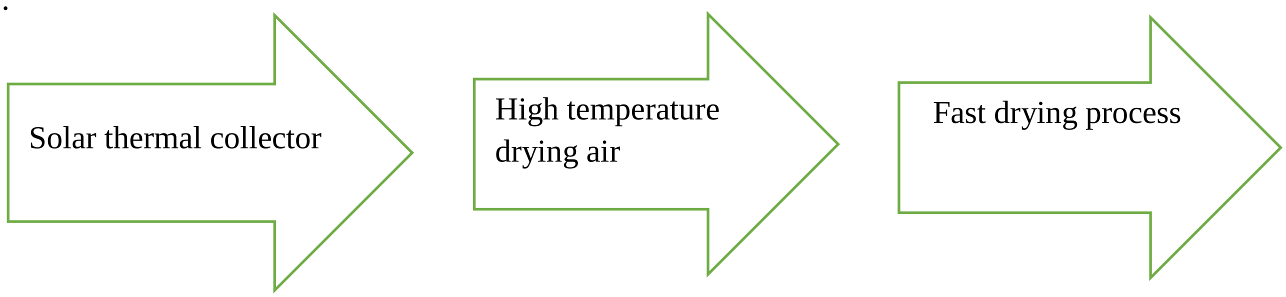

Figure 4-1: Basic theoretical assumption the drying process concept

The type of collector is the main factor which can vary the temperature range and the heat loss on the heat exchanging system. In the solar dryer process, the heat generator component is solar collector, but there are different types of collector. They classified in to two categories line concentrator and point concentrator which the classification is based on their geometrical shape and temperature generating scale. They are described in detail in this paper chapter 2 (literature review).

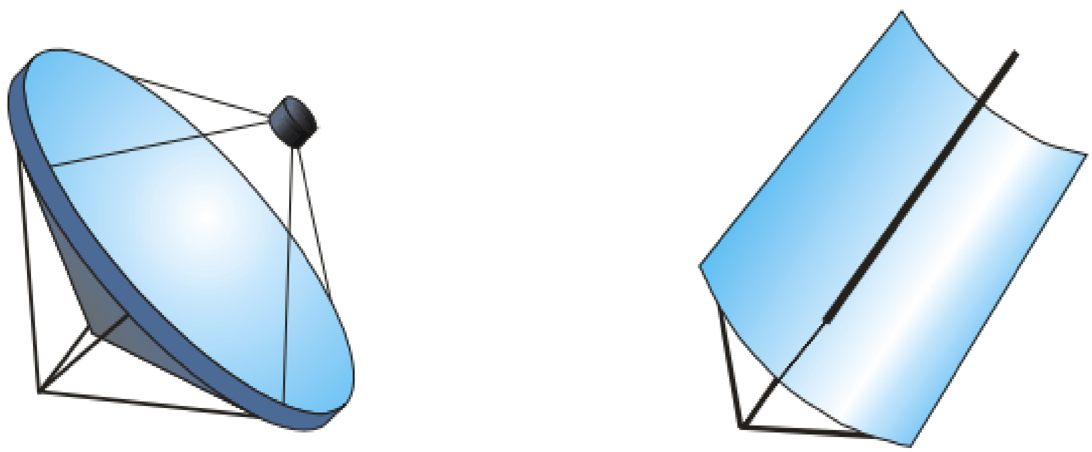

Figure 4-2: Line and point concentrator type solar collector [17]

4.1.1.1 Concept 1: Parabolic Trough collector drying system (PTSCD)

PTSCD Can generate high temperature around 300 to 500 °C for standard efficiency than the flat plate collector type. The heat loss is relatively higher than parabolic dish due to have large surface area of absorber compare to the parabolic dish absorber. But the disadvantage is having Low temperature generating capacity compare to that parabolic dish. Beside that to gate efficient parabolic trough collector it needs accurate design and construction.

4.1.1.2 Concept 2: Parabolic dish Collector drying system (PDSCD)

PDSCD have a capacity to generate high temperature from 500 to 1000 **°C** compare to that parabolic trough collector and it is possible to use well manufactured parabolic dish, this parabolic shaped satellite dish is available in the market with affordable price. The heat loss is relatively low than flat plate collector relatively due to having small surface area of absorber. To construct the reflector unit the building process somehow needs technical skill.

4.1.2 Concept selection

The concept selection method started from analyzing the whole briquette drying system with requiring parameters and overall design consideration. Preliminary designs is done using decision matrix to choose the best drying system after identifying main selected parameters that has to be considered. Main theoretical assumption behind the selection of the solar drying process is integrated with efficient solar collector and best heat exchanging system which enables the drying air temperature to be increased and reducing the heat loss for whole drying process. To achieve this, the proposed Solar thermal collector is selected by comparing the two type of concentrators based on the required parameters listed in the Table (4.1).

4.1.2.1 Preliminary design and decision matrix for collector type selection

Compression between the two concepts either using line or point Concentrated collector based on decision matric is used to select the feasible collector for this design

Table 4-1: Theoretical Justification for selecting Parameters for PDSC

Parameters	**Types of collector**	
	Parabolic trough collector	**Parabolic dish collector**
Temperature can be generated	(300 -500) **°C**	(500 -1000) **°C**
Concentration ratio	Low	High
Heat loss at absorber	High due to size	Low due to size
Size of absorber required	Large in size	Small in size
Availability and construction system	Not easily constructed	Possible to use Available PD reflector (satellite dish form)

From the above comparison table, it is observed that parabolic dish collector has higher temperature generating capacity and low heat loss effect than parabolic trough collector due to having the small size absorber comparatively.

For dryer type solar heated forced air-drying system is selected due to the objective of this project. Whereas forced air drier has an advantage of drying the product with uniform air distribution. The next step is making decision matrix to determine the collector type which can generate high temperature to heat up the forced flow air.

4.2.4 Design Description and specification

Based on the overall drying mechanism of the briquette drying machine the following design variables and specifications are considered on the fabrication process and operation of the drier.

Table 4-2: Design variables and specification to design the prototype

Design Variables	Design Specifications
Input Resource	• Saw dust briquette is selected (carbonized or not carbonized), • DC Electric power consume • Solar thermal Energy is used for drying process
Out Product	• Dried Saw dust briquette
System operation	• Solar energy collected → heat exchanged to the forced air → wet briquette drying
Solar collector Type	• Parabolic dish reflector and Aluminum plate black coated absorber with glass cove and insulation used
Heat Exchanging Component	• Blower/fan, DC electric supply unit, Aluminum plate absorber box, drying chamber
Drying chamber unit	• Small chamber made of Still metal

In general, for design of the prototype of **PDSCD** system integrated with forced air-dried system is selected. Therefore, the design and construction method are done based on the selected system components. The system components are air blowing unit (Fan), solar collecting unit ad absorbing unit, heat exchanging medium and drying chamber as shown in the below Figure 4.3.

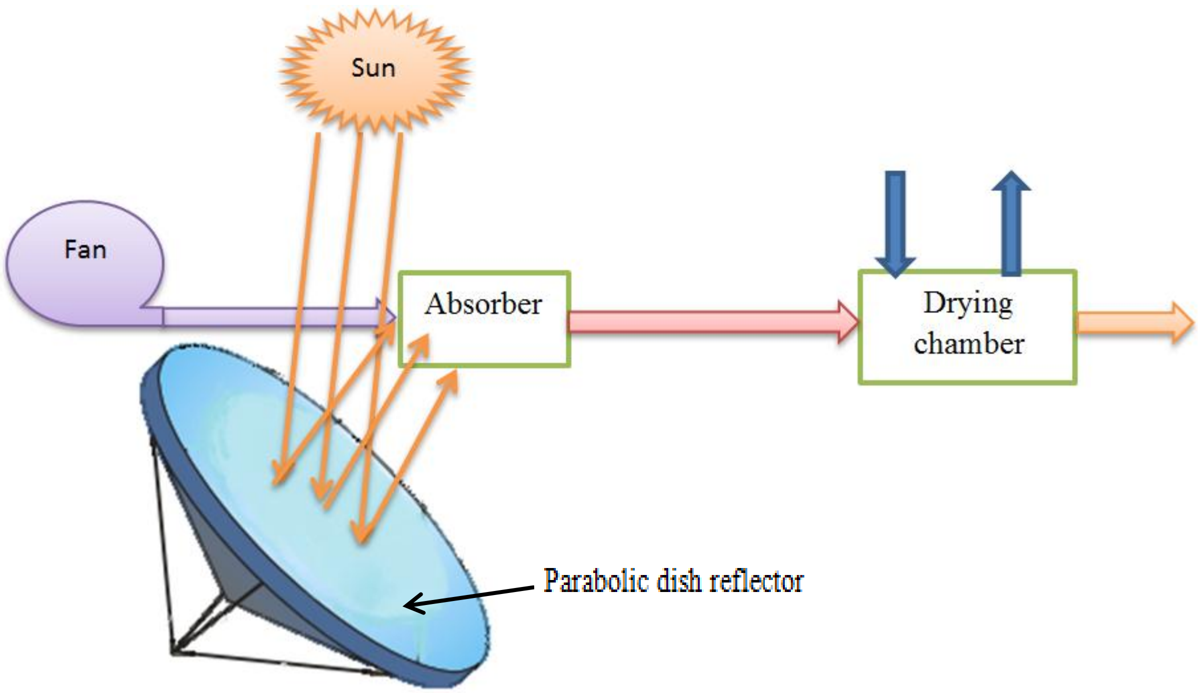

Figure 4-3: Functional Block diagram representation for design of drying system

4.2 Mathematical modeling and Geometrical design

The conceptual design is interpreted using the Analytical analysis to determine the size of the drier which needs to dry the wet product. The power consumption and the heat Energy needed can be estimated using standard mathematical formula applying for basic drying principle.

4.2.1 Mathematical Modeling of the Design

For this project to starts the design for the overall drying system with mathematical modeling the design should assume those objectives are which going to be achieved:

1. Reducing the drying time with specific selected saw dust briquette
2. Increasing the drying temperature by using parabolic dish concentrator
3. Decreasing the heat loss and size of insulation by minimizing the size of the absorber

4.2.1.1 Identify the initial required parameters

The initial design specifications are very important to determine the overall design scope and structure of the system. The initial parameters and values are listed as below.

I. Monthly average Ambient air Temperature for the experimental place = 24 ℃ [7]

II. Initial and final temperature assumed to be (24 ℃ to 50 ℃) [22]

III. Average daily solar radiation at specific selected place in every hour (514 W/m^2) [25]

IV. Average hourly ambient relative humidity and Drying Chamber R.H assumed to be (45 % and 20 % [22] respectively)

V. Initial and Final humidity ratio assumed (0.011 and 0.028) based on psychrometric analysis

VI. Initial moisture content and Final moisture content assumed (> 50% and <10%)

VII. Item to be dried, type size and mass (saw dust briquette, m_p = 100g = 0.1 kg)

4.2.1.2 Determining drying rate and mass of water vapor to be reduced

For this project the drying time is estimated to reduce less than 8hr of a day with the temperature expected in the PDSC drying chamber is around 50 ℃ [22].

The moisture content in wet briquette before drying process is commonly known that it is greater than 50 % [14]. And after drying process is undertaken the moisture should remain in the drying solid below 10 % [14].

The average drying ($\dot{m}_{dr}$) rate becomes :

$$\dot{m}_{dr} = \frac{m_w}{t_d} \qquad \dots (4\text{-}1)$$

The mass of water determined when the briquette loses the moisture from initial moisture content to final moisture content can be calculated using equation (4.1)

$$m_w = m_p \frac{(M_i - M_f)}{(100 - M_f)} = \mathbf{m_f} - \mathbf{m_i} \qquad \dots (4\text{-}2)$$

m_w = **0.045kg** is expected to loss from 100 g of wet briquette

$m_f = m_i - m_w$ = **0.056 kg** and $\dot{m}_{dr} = \frac{0.045 \text{ kg}}{7hr}$ = **0.0064 kg /hr.**

Where m_w is mass of water to evaporation, (kg), m_p is mass of the dried product, (kg), M_i is initial moisture of product, (%, wb) and M_f is final moisture of product, (%, wb),

4.2.1.3 Determine the mass flow rate of the drying air

The mass flow rate of air m_a is obtained from the equation below [2]

$$\dot{m}_a = \frac{m_{dr}}{\omega_f - \omega_i} \qquad \ldots (4\text{-}3)$$

Where: m_a = mass of air, ω_f and ω_i are the final and intial humidity ratio of air respectively.

The intial humidity ratio determined from psychrometric chart by using ambient air temperature and ambient relative humidity . $\omega_i = 0.012$ and the final H.R @ 50°C assumed to be ω_f = 0.0215

$$\dot{m}_a = \frac{0.0064 \text{ kg /hr}}{0.012} = 0.64 \text{ kg/hr}$$

4.2.1.4 Determine the energy required to remove the moisture

To calculate the amount of heat required to evaporate the water the wet briquette, it is possible determining using the following equation [2].

$$Q_{dry} = m_w L_w \qquad \ldots (4\text{-}4)$$

Where: Q_{dry} is amount of Energy required for drying process, (MJ) and L_w is heat required to evaporate 1 kg water, and it is 2260 (kJ/kg) [5].

Q_{dry} **= 101.7 (kJ)** for 100g sample briquette with evaporation of **0.045** kg water

4.2.1.5 Determine the area of collector need to trap the solar energy

The Solar radiation at 27° tilted surface is calculated 514 Wh /m^2 per hour average day.

From Psychometric chart: at the temperature T_{amb} = 24 °C h_i = 52.7 kJ/kg and at out let drying air temperature T_2 = 50 °C, h_f = 112.95 kj/kg

$$A_c I_s \eta = E_T = m_a (h_f - h_i) t_d \quad [28] \qquad \ldots (4\text{-}5)$$

E_T = 0.64 kg/h (112.9 -52.95) kJ/kg 7hr = 268.8 kJ = **74.6 Wh**

$$A_{ca} = \frac{Q_{udr}}{\eta I_S} = \frac{75 \text{ wh}}{\eta\, 514\, wh/m^2} = 0.2\, m^2$$

Where:

h = enthalpy of moist air (J/kg), A_{ca} = Aperture area of the solar collector (m^2), E_T = total useful energy received from drying air (KJ), I_s = the global radiation on the horizontal surface during drying period (kJ/m2), η = PDR efficiency is 73 % using glass mirror reflector [34].

4.2.2 Parabolic Dish reflector geometrical structure and size

Based on the conceptual design layout the parabolic dish reflector is selected from the market which is available and normally used for satellite dish receiver and modified it to the required size. This is done by fixing reflective mirror on the surface the aperture area of the dish. Before constructing the reflecting dish by assembling the squared pieces of mirror on the surface of the selected satellite dish, the design of the dish and the mirror size should be considered. This is designed based on the surface area and the rim angle of the parabolic dish. The square area of the mirror which sticks to the convex shape of the dish area is proportional with the dish structure. When the focal length is increased the area of the reflector surface increases but the mirror size should be minimizing to reduce Geometrical error. For this project 3x3cm mirror is selected to the selected parabolic dish size which the surface area is 0.28 m^2 and the focal length is 37.5 cm. the parabolic dish reflector building should consider the following point's before construction.

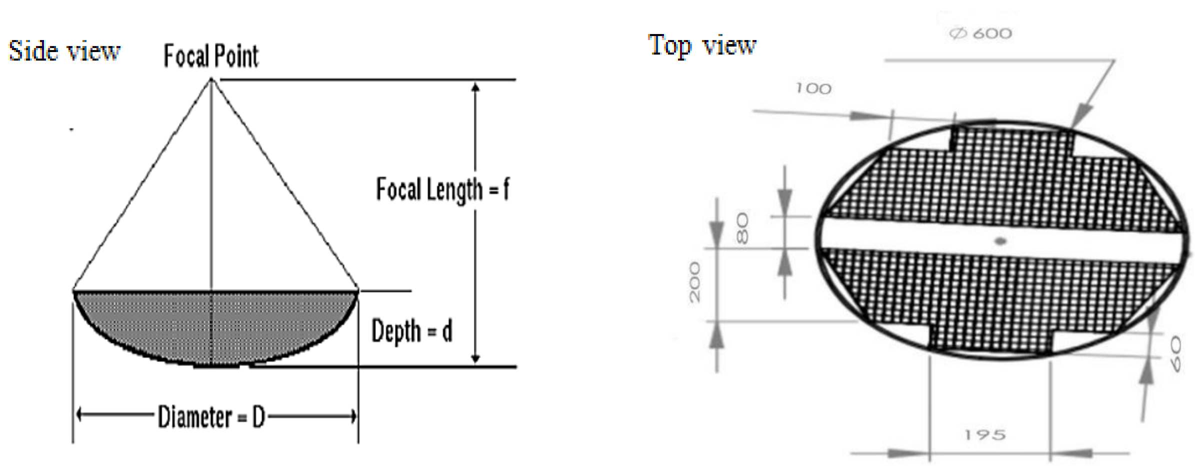

Figure 4-4: parabolic dish collector gross and aperture area

Geometrical errors result Optical collector losses from the limited reflectivity of the reflecting material type and construction error. To minimize the Geometrical errors the reflector surface should be smooth and parabolic curved, the reflective mirror weight should be lighter with perfect assembling and installation to minimize facet alignment error. Besides that, that slop of the dish (tilt angle towards the sun) is very important to truck the sun efficiently [18].

There is optical loss due to geometrical collector error was expected when the mirror is assembled with the satellite dish. The size of dish is selected from the market which has almost similar in size with the initial design concept of the collector.

4.2.2.1 Focal length

$$\mathbf{f} = \frac{\mathbf{D^2}}{\mathbf{16d}} = 0.375 \text{ m} = 37.5 \text{ cm} \qquad \dots (4\text{-}6)$$

4.2.2.2 Collector gross Area of the dish

$$\mathbf{A_{cg}} = \mathbf{3.14}\ \boldsymbol{Da^2}/\mathbf{4} = 0.283 \text{ m}^2 \qquad \dots (4\text{-}7)$$

4.2.2.3 Aperture Area of the reflector

$$\boldsymbol{A_{ca}} = A_{cg} - A_l = 0.217 \text{ m}^2 \qquad \dots (4.3)$$

$$\boldsymbol{A_l} = A_c - A_{ap} = 0.066 \text{ m}^2$$

4.2.2.4 Concentration ratio

$$\boldsymbol{CR} = \frac{\boldsymbol{A_{cg}}}{\boldsymbol{A_r}} = \frac{\mathbf{0.283}\ \boldsymbol{m^2}}{\mathbf{0.045}\ \boldsymbol{m^2}} = 6.2 \qquad \dots (4\text{-}8)$$

Where: A_{cg} is gross area of the collector , A_{ca} is Aperture area of the collector and A_r = Receiver area , Area loss (A_l) is the remaining left area on the parabolic dish part of collector surface area it is covered by non-reflective material to make the same aperture area with the FPSC to trap the of sun light radiation.

The PDSC aperture area is minimized from 0.283 m^2 to 0.217 m^2 to make equal effective sun trapping area with the FPSC. The area of the both dryer collector has almost similar size to the proposed selected area which determined in mathematical design of the model.

4.2.3 Design parameter and specification of dryers

Table 4-3: List of Design parameter and specification for both solar dryers

Components	**specification**	
Type	**FPSC**	**PDSC**
Area	0.217	0.217
Glass cover	3mm, $\boldsymbol{\tau_g}$ = 0.89	3mm, $\boldsymbol{\tau_g}$ = 0.89
Absorbance plate	Black painted aluminum (3mm, **α** = 0.87)	Black painted aluminum (3mm, **α** = 0.87)
Tilt Angle	27°	27°
Insulation cover	Fiber glass k = 0.045 W/m. k	Fiber glass k = 0.045 W/m. k
Reflector	Glass mirror	No reflector
Absorber box area	0.217 m^2	0.012 m^2
Drying chamber	Stainless steel cover with insulation	Stainless steel cover with insulation
Fan performance	2700 rpm, 12V, 2.5A, 32 W	2700 rpm, 12V, 2.5A, 32 W
Slope (Tilt angle)	Latitude + (15 - 25) = (24 - 34)	Latitude + (15 - 25) = (24 - 34)
Air passage tube	Stainless Steel (D = 2.5 cm, L= 80cm, 2mm thickness)	Stainless Stieel (D = 2.5 cm, L= 20cm, 2mm thickness)

The collector area of the PDSC and the FPSC are the same size in order to trap the sun energy with equal apertures area,

4.3 Mechanical Drawing and Construction of Driers

After selecting the conceptual design and analyze mathematical model of the system, the size of the drier is determined to sketch the overall construction design of the system. The material type and specification were selected before designing the drier. The size and the specification are listed on the Appendix (A) part of this paper. For the experimental set up of this project the two type of drier have been constructed based on the selected conceptual design. The conceptual model of the parabolic dish collector drier and the flat plate collector drier is shown below in figure.

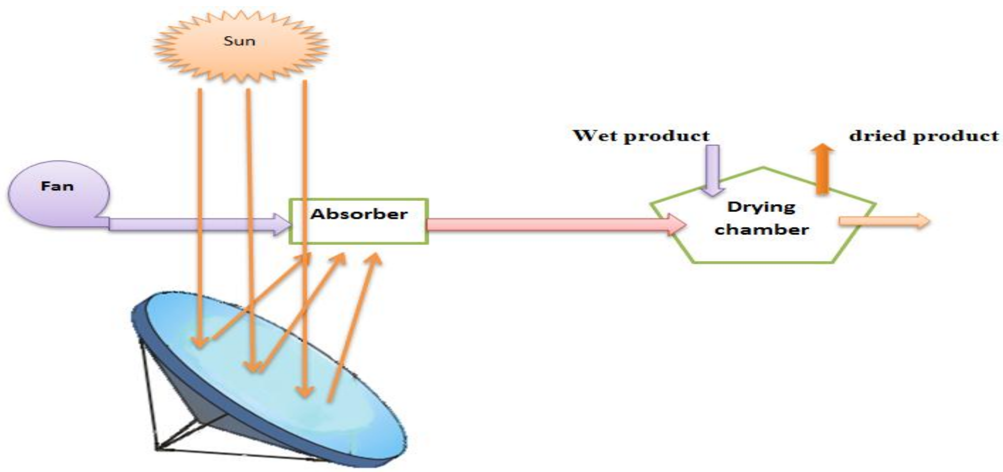

Figure 4-5: Schematic sketch for new concentrated type Parabolic Dish Collector type drier

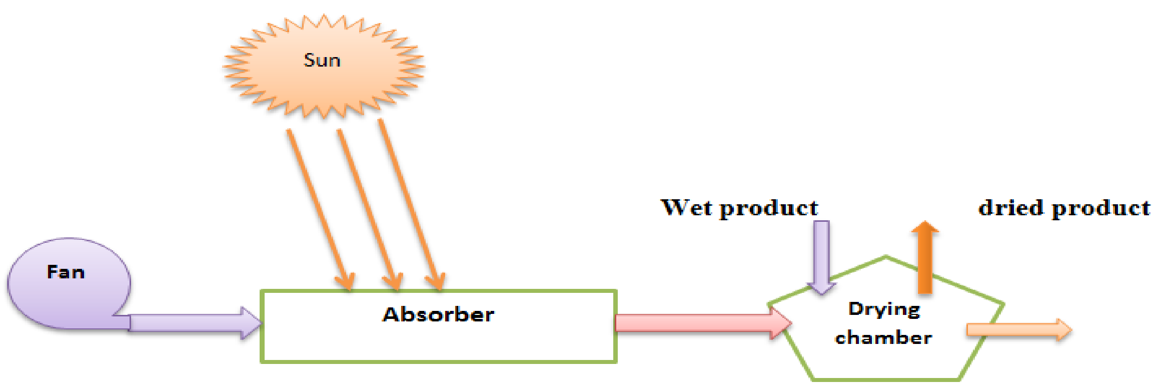

Figure 4-6: Schematic sketch for Flat Plate Collector Active drier type

4.3.1 Solid work 3D model design for PDSC and FPSC

The design of each drier type is designed using Solid work design software tools each solar drier has a number of system parts which classified based on construction and assembly unit. For construction parts the body frames the main building part of the drier. For the assembly parts each system parts such as power supply unite, Fan, drying chamber and each solar collector are constructed by modifying some kind of equipment's for this drier prototype construction purpose. The detail 2D design of each parts of the drier is found in the Appendix (A) part of the paper. 25° to 34°.

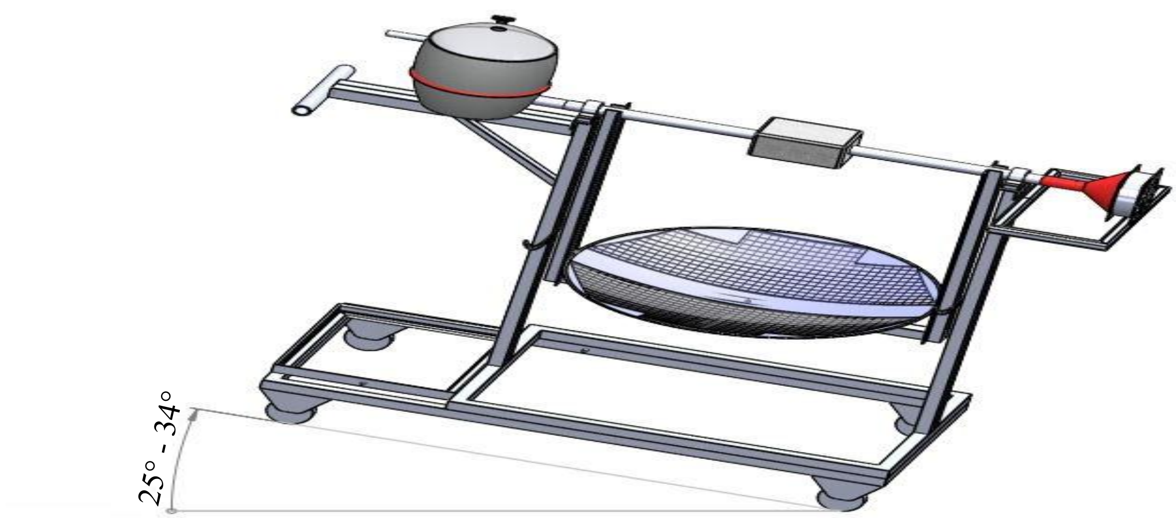

Figure 4-7: PDSCD 3D solid work constructional design

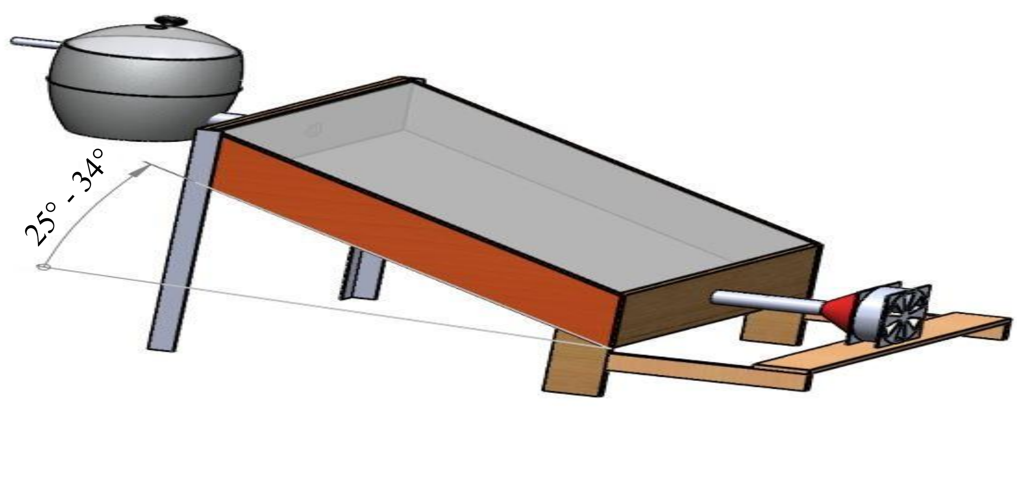

Figure 4-8: FPSCD 3D solid work costructional design

4.3.2 Parabolic dish collector construction and assembly

The construction was done in Addis Ababa university mechanical workshop. It is constructed using standard building tools such as high current welding machines, drill, hammers and a lot of hand tools which is not listed in this paper.

4.3.2.1 Parabolic dish reflector and support frame construction

This part is used for carry and supports the whole parts of the machine and it can withstand the mechanical movements and vibration of the system under its operation. The design process is done using Solid work software. Based on the design size and specification it builds in the workshop with available tools and materials. This is used to support the rotating parabolic dish and the receiver system, which attached with the lower base frame support with bolt and nuts. It also is used to support the lower parabolic dish it is used to carry and support the reflective parts (reflective sheet, metal sheet or glass mirror)

I. Fixing mirror to Parabolic dish metal sheet

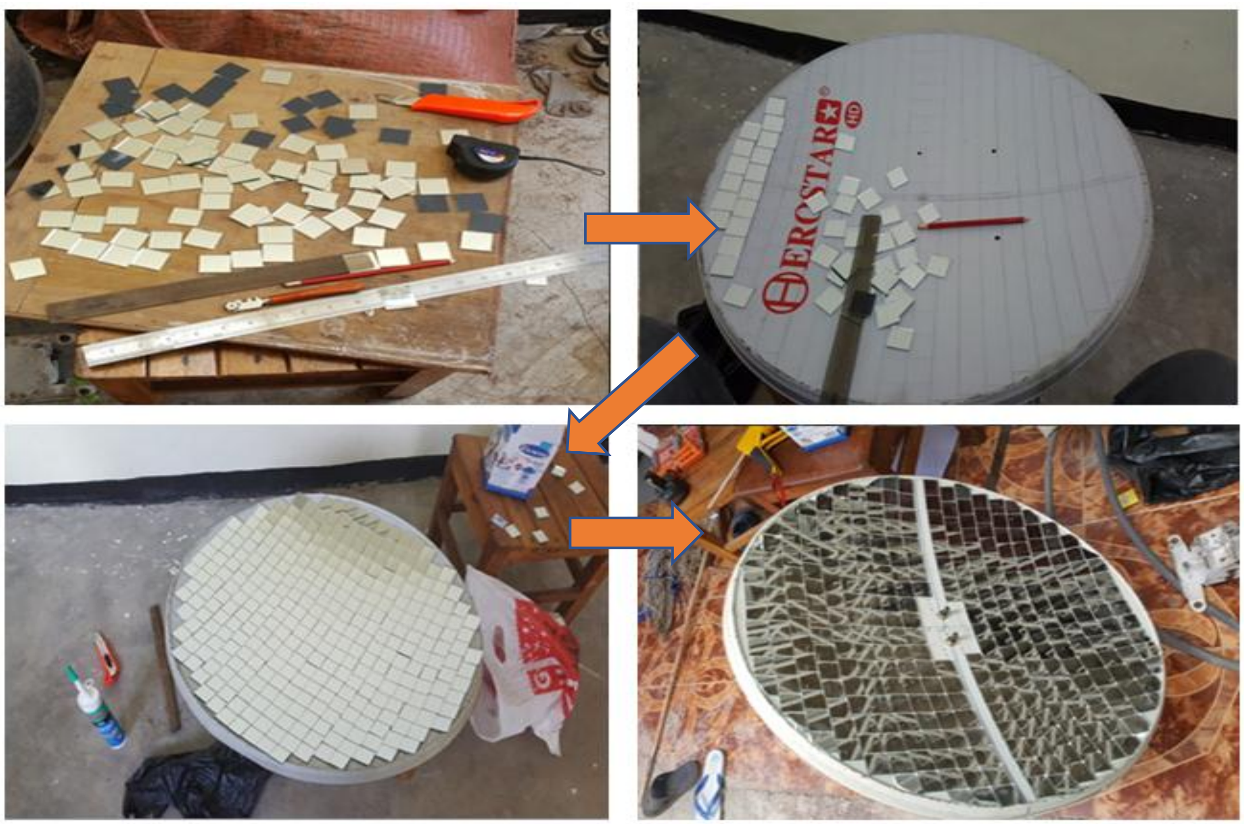

Figure 4-9: Construction of the parabolic dish reflector

The parabolic metal sheet has 3mm thickness 0.28 m^2 surface areas and 37.5 m focal point distance from the center. The Fixing process of pieces of square mirror which have 3cm by 3cm size have been done with high care of accuracy to minimize the optical error.

II. Adjust the Apertures area of the PDSC similar to FPSC Absorber area

This is done to make the PDSC aperture area is similar to the FPSC aperture area in order to treat with similar parameter on the experimental process.

Figure 4-10: Assembly of the parabolic dish reflector to the dish support unit

4.3.2.2 Absorber Unit construction and Assembly

This is done using local available materials as shown in the Figure 4-13 below and the absorber is constructed using aluminum metal sheet and plastic cover with Fiber glass insulation inside and outside the cover.

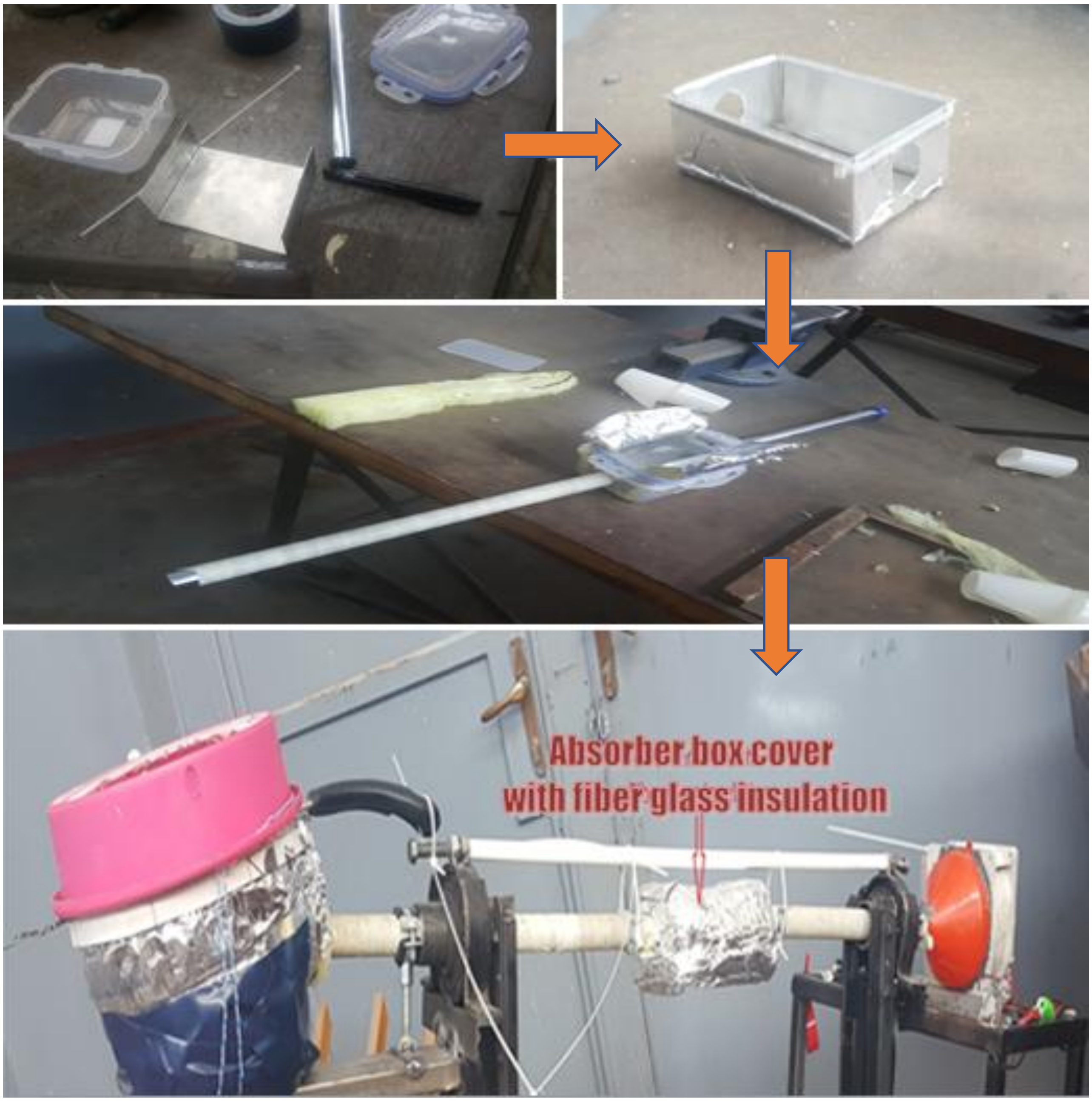

Figure 4-11: Construction and Assembly of the box absorber to the body frame

4.3.2.3 Fan and drying chamber Assembly

The Axial type Fan is connected to the inlet part of the tube which the drying air is pass through and the Drying chamber connected with at the outlet part of the tube as the shown in Figure 4-14. The Fan with Model (TA500DC computer cooling fan) is connected with DC power supply with 12V and 2.7A rating. The Drying chamber covered with Fiber glass insulation and there is wire mesh inside the drying chamber which the briquette is placed.

Figure 4-12: Fan and drying chamber assembly attached with the PDR support

4.3.3 Flat plate collector Construction and assembly

The Flat plate collector box is made from wood, aluminum metal; window glass and insulation cover with assembling of the same size drying chamber and fan with the PDSC.

Figure 4-13: Figures: fan and drying chamber Assembly

5 CHAPTER FIVE: Experimental Investigation and performance Analysis

5.1 Experimental Set up

In this paper it is important to determine the performance of the solar dryer with experimental investigation for the two types of solar collector such as parabolic dish and flat plate collector. The comparative experimental assessment is done by selecting measuring parameters and instruments with defined experimental procedure. To analyze the overall drying system and to compare the performance of each collector with respect to the selected parameter such that generated temperature, drying air Temperature and speed, Relative humidity and moisture removing capacity of the machine must be determined. To do that there is a simple method of experimental set up (unloaded and loaded set up) which is used to know the stagnation temperature at maximum possible. The overall performance of solar dryer can be calculated and analysis using fundamental thermodynamic equations. The experimental setup and the methodology are express in detail as below as shown in the Figure 5-1. There are four basic system parts of this solar drying machine. The air blowing system, the solar collector, heat exchanging medium and drying chamber.

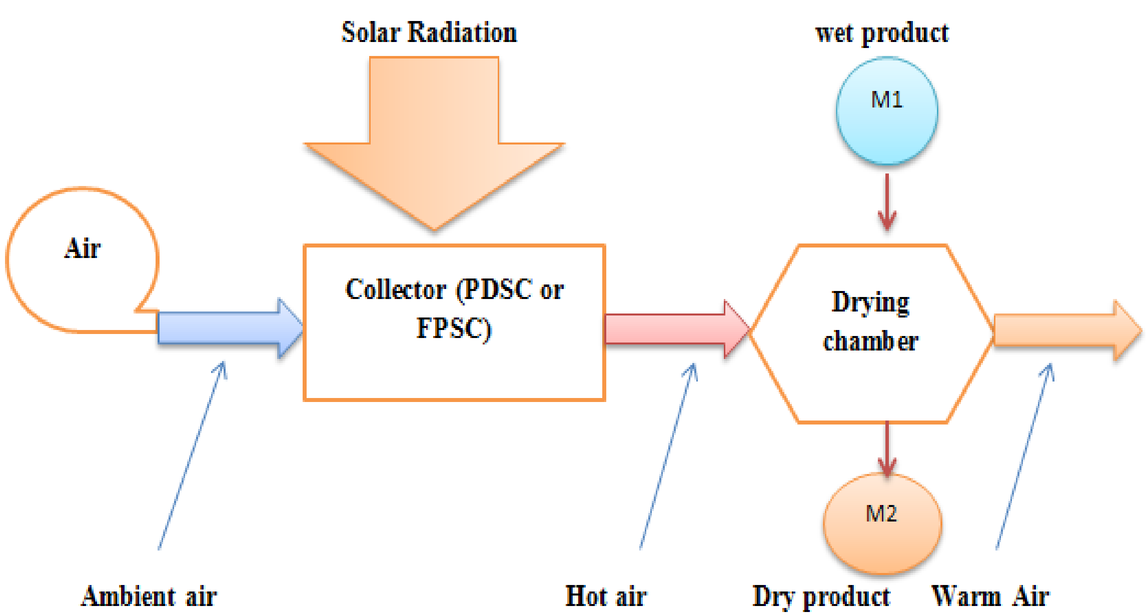

Figure 5-1: General thermal energy flow schematic diagram for (PDSC & FPSC)

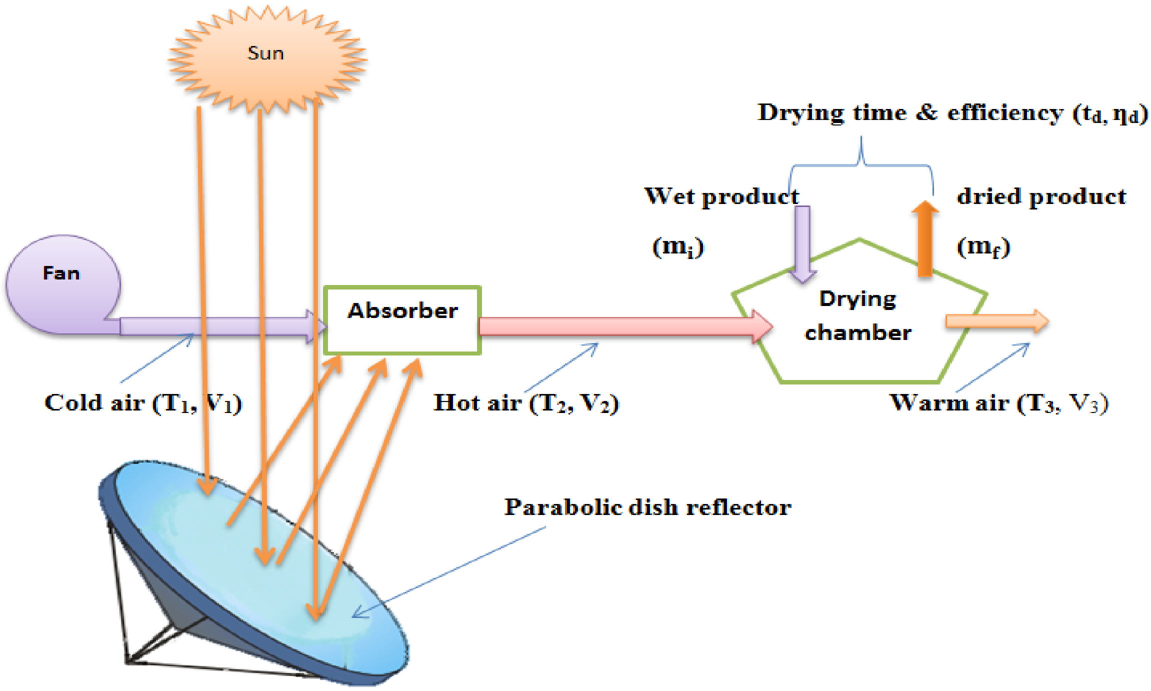

Figure 5-2: Experimental set up schematic representation of PDSCD

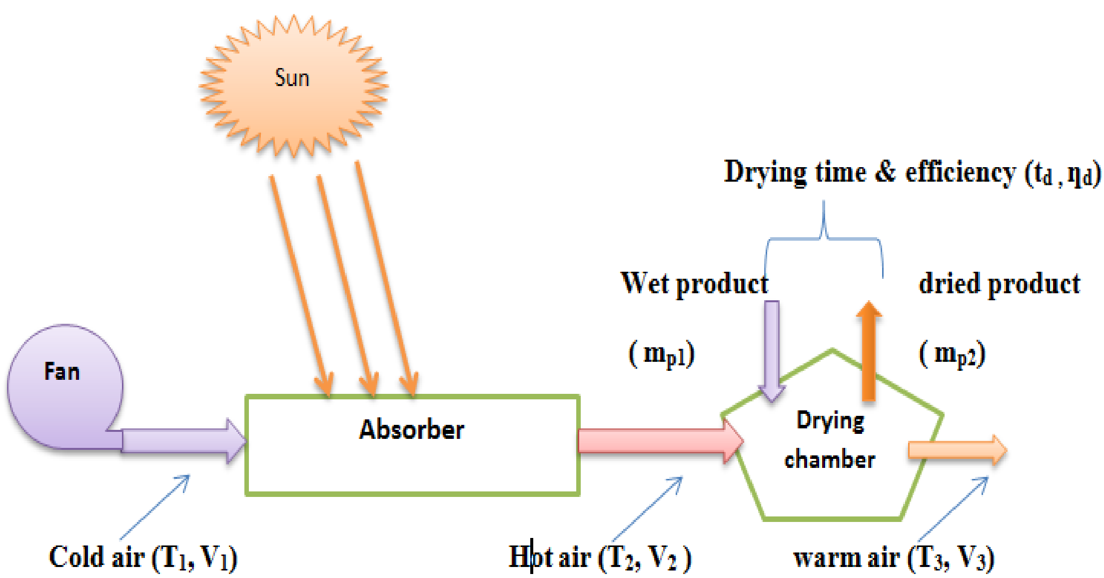

Figure 5-3: Experimental set up schematic representation of FPSCD

For the experimental processes of both solar drier the solar collectors used for Flat plate and parabolic dish collector have Aperture aria of 0.217 m^2. The air flow which comes from the environment is heated by the solar collector and the air is forced by the fan (axial type, Model A34538). They have the same input air speed and flow rate due to the fan used for those dryers are the same and identical type, which needs 32w (12 V and 2.7 A) power supplier in order to operate at full capacity.

The pocket weather measuring device has been used to measure the speed of air at the outlet of the drying chamber. For the temperature measurement part, the infrared measuring tool has been used to determine the heat at the two-absorber surface temperature. The flow air temperature at the inlet and out let of the Absorber and the drying chamber is measured using mercury glass thermometer. The wet bulb and dry bulb temperature measuring has bee also taken to determine the relative humidity and humidity ratio inside and outside of the drying chamber. The moisture content removing capacity of the drier is tested by placing the sample briquette inside the drying chamber with almost the same mass (100g). To analyze the moisture content level before and after the drying process Humidity ratio is used to determine the water vapors content at a given drying air and also the mass balance instrument is used to determine the mass difference after the drying process.

5.2 Experimental Procedure to determination of the dryer performance

For experimental work the tasks that have been done must be planned and in order to achieve better result on the experiment time. To do so the experiment has been done step by step with great care of measurement accuracy.

5.2.1 Step1: Select and adjust Test location

The location of the experiment is done at Addis Ababa with specific geographical location of (Latitude = 9.04 N and Longitude = 38.7 E) and the monthly average solar radiation at this place is 6.4 kW h/ m^2 [7]. The solar driers are placed at south faced with East – West orientation and specific tilting angle based the seasonal data.

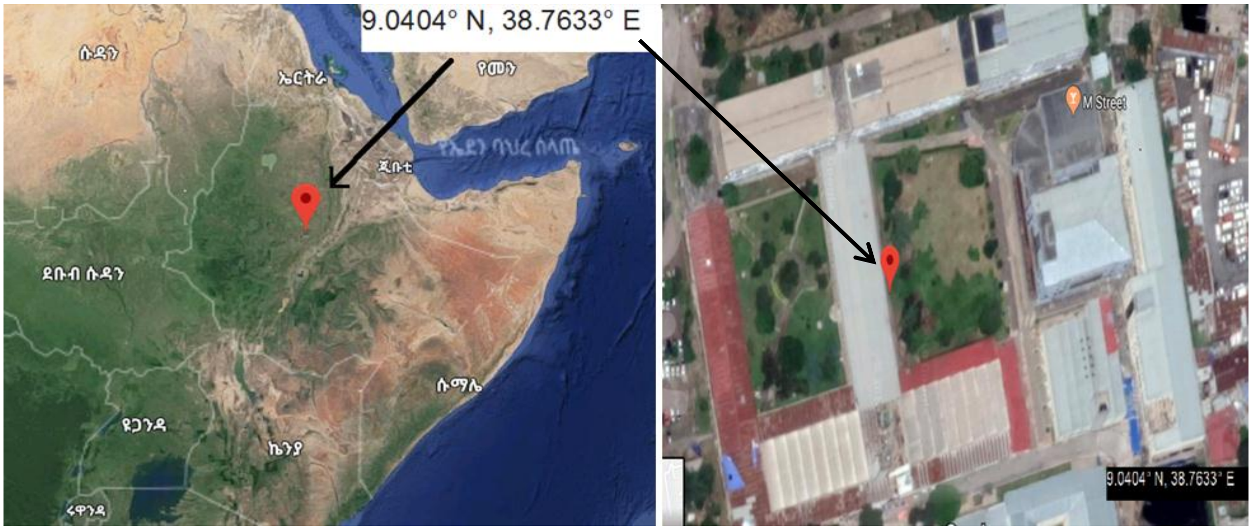

Figure 5-4: Experimental testing location from Google map

5.2.2 Step2: Determine the driers performance Unloaded with sample briquette

This is done by taking experimental Measuring without sample briquette. In this experimental process inlet and outlet air temperature, wet and dry bulb temperature, Absorber Temperature and speed of the drying air is measured. This is done for both solar drier (PDSC and FPSC) in every hour for four consecutive days using measuring instruments listed this paper.

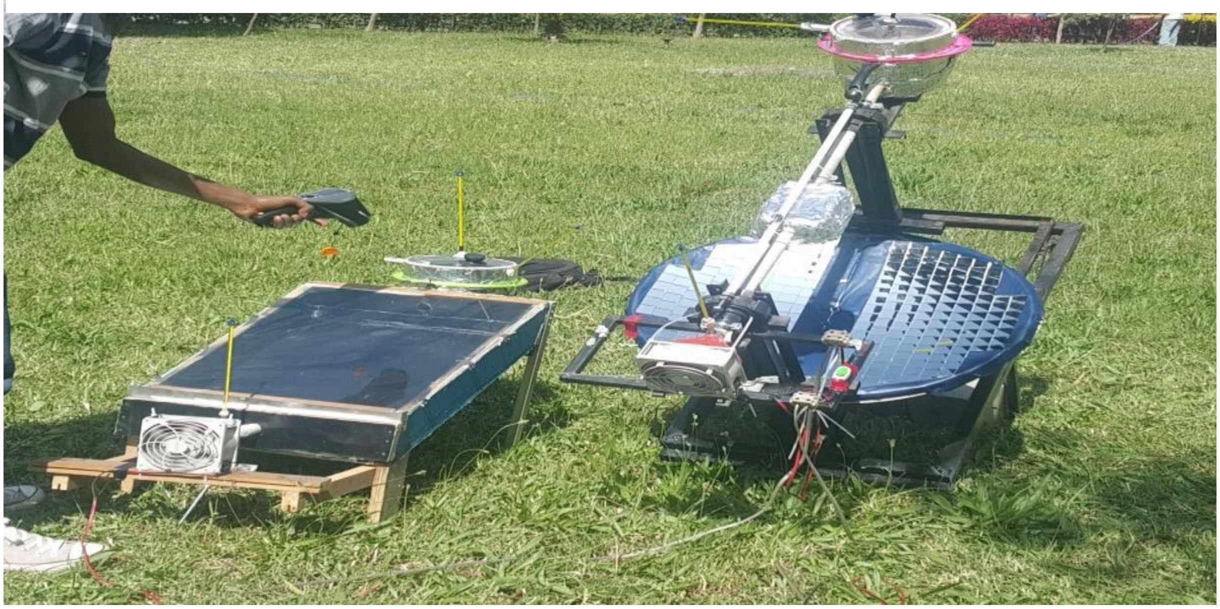

Figure 5-5: PDSC and FPSC Experimental dryers on the Testing process

5.2.3 Step 3: Determine the driers performance Loaded with sample briquette

In this experiment also the inlet and outlet air temperature, wet and dry bulb temperature absorber plate temperature and air flow rate are measured. Beside that the sample briquette mass measured before entering and after exiting the drying chamber, this is done to determine the moisture loss of the sample briquette. The Relative humidity and Humidity ratio measurement is done to determine the performance of the driers respect to the amount of water vapors loose from the product. Before Testing the drying performance of the driers in the presence of the sample wet saw dust. There are mainly two processes have been undertaking for the preparing of saw dust briquette.

5.2.3.1 Prepare the wet briquette to Loaded in the drying chamber

For this drying experiment the saw dust briquette is selected. Preparing process of the sample was starting by mixing the dry saw dust with water and molasses (which used as a binding agent) the molasses used to make the saw dust more compacted due to the sticky property of the agent.

Figure 5-6: Process of saw dust briquette molding for preparing to drying experiment

Then compaction process is done using hydraulic press and molding equipment's with 200 bar high pressure compacting force. This is done in the workshop using available materials and tools.

5.2.3.2 Measure the moisture removed from the briquette

To measure moisture removing capacity of the dryer it is possible to use those two methods. They are identifying inlet and out let humidity ratio to determine how much moisture is removed from the moist air or determining the water vapor removed by measuring the mass of the briquette before and after drying.

I. Moisture content determination Using Humidity ratio Concept

Humidity ratio of moist air can be expressed as the mass of water vapor in the humid air to the mass of dry air. Humidity Ratio Expressed by mass as the ratio between actual mass of water vapor presents in moist air to mass of the dry air.

$$H.R = \mathbf{m_w} / \mathbf{m_a} \qquad \dots (5\text{-}1)$$

Where: H.R is humidity ratio (Kg water/Kg dry air), m_w is mass of water vapor, m_a is mass of dry air

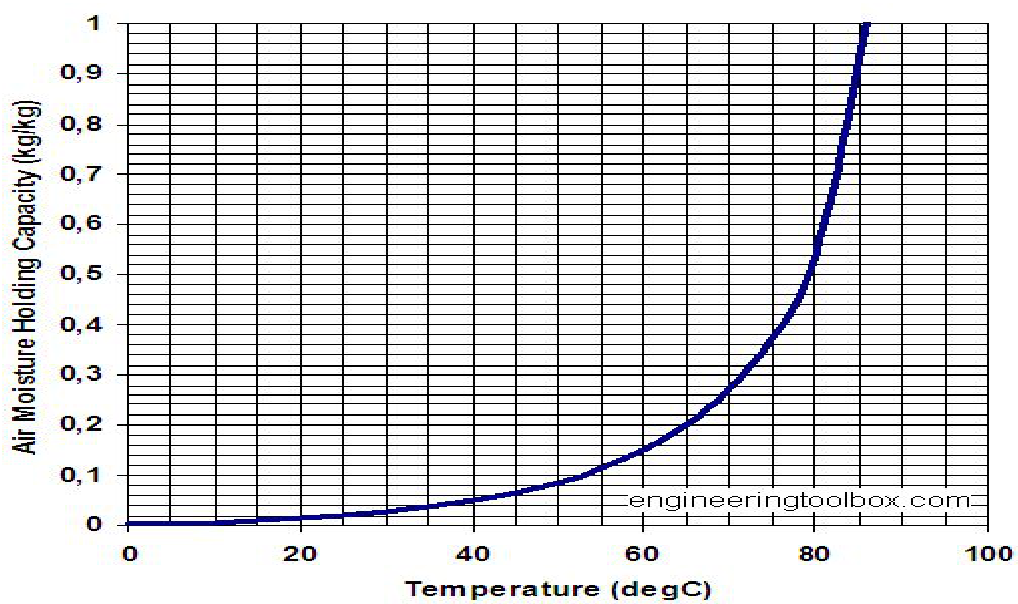

Figure 5-7: Psychometric chart and graphical explanation for humidity ratio variation [5]

By using wet and dry bulb thermometer it is possible to measure the air temperature directly and it used to determine Relative humidity, humidity ratio, dew point, density and specific volume with indirectly measurement method. As shown in Figure 5-7 above, at higher temperature the humidity ratio increases as well, this indicates the moisture holding capacity of air also increased with the increasing of humidity ratio.

II. Mass difference before and after drying using mass balance

This is done after preparing the wet molded sample briquette and by using additional instrument mass balance measurements, the mass of briquettes measured before and after drying process to determine how much moisture content is removed from the sample briquette after 7hr drying time.

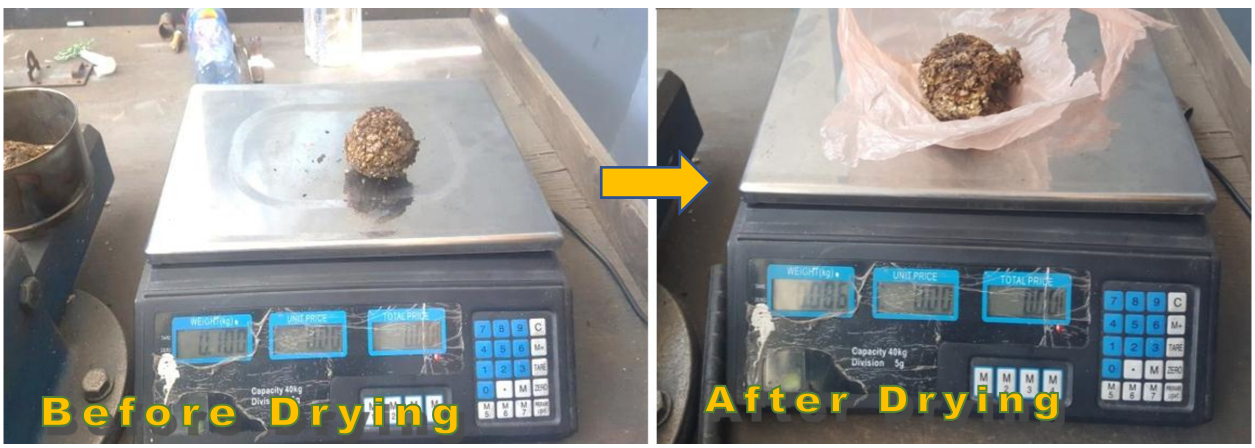

Figure 5-8: Measurement of mass of a sample briquette before and after drying

5.2.4 Step 4: collect and analyzed measured data

This was doing to determine each collector performance and to investigate the overall drying performance effect based on the selected measuring parameters

The experimental measuring result recorded from each hour time interval of testing process for five consecutive days. This helps to understand the interaction among the selected parameter such as solar radiation, absorber Temperature, flow air Temperature, speed of air, Relative humidity and humidity ratio at each solar dryer.

Each day of hourly measured data was taking with Direct and Indirect method of measurement with the Unloaded and loaded of wet briquette in the drying chamber. Each day’s hourly recorded data is listed on the Appendix (B) of this paper. The unloaded data which was taking for four consecutive days is for the purpose of two checking the consistent performance of the constructed drier from the experiment analysis. So, based on the tested experimental data both drier give Good performances that enable to take experimental test with loading the wet saw dust product in drying chamber on both dryers. Therefore, based on the collected data indicate on each day of experimenting the driers show identical performance respect to the selected measuring parameters.

5.2.4.1 Unloaded with briquette Average Hourly measured data

For all 4 days experiment of drier without the wet sawdust loaded, each measured parameter is similar with the next day result (Appendix B), so it is possible to take the average data for all 4 days unloaded hourly recorded measurement data result to analyses the performance of the driers

Table 5-1: Direct hourly Four days Average experimental data for PDSC &FPSC

Day (1 to 4)	**Direct hourly Average data**		**Unloaded set up (Oct 29 to Nov 1,2018)**					
Time Interval	**Solar radiation and Ambient Temp**		**PDSC (Temperature and speed of air)**			**FPSC (Temperature and speed of air)**		
	$\mathbf{I_s}$	$\mathbf{T_{1amb}}$	$\mathbf{T_{abs.P}}$	$\mathbf{T_{2.P}}$	$\mathbf{V_{3.P}}$	$\mathbf{T_{abs.F}}$	$\mathbf{T_{2.F}}$	$\mathbf{V_{3.F}}$
Units	**W/m2**	**°C**	**°C**	**°C**	m/s	**°C**	**°C**	m/s
9:00 AM	273.7	22	73.0	55	1.2	44	36	0.57
10:00 AM	413	24	80.8	58	1.275	46	39	0.62
11:00 AM	560	25	89.3	61	1.35	50	42	0.7
12:00 AM	603.5	27	96.9	65	1.5	54	45	0.75
1:00 PM	550	28	92.5	64	1.475	52	44	0.72
2:00 PM	464	26	89.9	65	1.5	51	44	0.75
3:00 PM	531.2	26	88.0	62	1.375	53	45	0.75
4:00 PM	355	24	78.7	57	1.225	49	41	0.65
Average	**468.8**	**25**	**86.1**	**61**	**1.36**	**50**	**42**	**0.69**
Maximum	603.5	28	96.9	65	1.5	54	45	0.75
Minimum	273.7	22	73.0	55	1.2	44	36	0.57

Table 5-2: Indirect hourly Four days Average Experimental data for PDSC &FPSC

Indirect hourly Average data						**Unloaded set up (Oct 29 to Nov 1,2018)**				
Day 1-4						**For PDSC**				
Time Interval	**Ambient Solar data, Relative humidity, Humidity ratio & temperature**					**Wet & dry bulb air Temp**		**Psychometric chart result**		
	I_s	$Amb\ R.H$	T_{1db}	T_{wb}	**H. R**	$T_{3\ Wb.P}$	$T_{3\ Db.P}$	$Dch\ R.H.P$	ρ_a	**H. R**
Units	**(W/m2)**	**(%)**	℃	℃	Kg/Kg	℃	℃	**(%)**	Kg/m^3	Kg/Kg
9:00 AM	273.75	51.75	22	15	0.0116	31	55	21.5	0.79	0.0293
10:00 AM	413	47.25	24	15	0.0118	31	58	18	0.78	0.0286
11:00 AM	560	43.5	25	16	0.0121	30	61	14.25	0.77	0.0253
12:00 AM	603.5	40.25	27	15	0.0106	32	65	13	0.77	0.028
1:00 PM	550	38.25	28	17	0.0121	31	64	13	0.77	0.0269
2:00 PM	464	37.75	26	15	0.0108	33	65	14	0.76	0.0308
3:00 PM	531.25	39	26	16	0.0111	33	62	17.25	0.77	0.0329
4:00 PM	355	39.75	24	14	0.01	32	57	20.5	0.78	0.0306
Average	**468.8**	**42.18**	**25**	**15**	**0.0113**	**32**	**61**	**16.43**	**0.77**	**0.0291**
Maximum	603.5	51.75	28	17	0.0121	33	65	21.5	0.79	0.0329
Minimum	273.75	37.75	22	14	0.01	30	55	13	0.76	0.0253

Indirect hourly data						**Unloaded setup (Oct 29 to Nov 1,2018)**				
Day 1-4						**For FPSC**				
Time Interval	**Ambient Solar data, Relative humidity, Humidity ratio & temperature**					**Wet & dry bulb air Temp**		**Psychometric chart result**		
Units	I_s	$Amb\ R.H$	T_{1db}	T_{1wb}	**H. R**	$T_{3\ Wb.F}$	$T_{3\ Db.F}$	$Dch\ R.H.F$	ρ_a	**H. R**
	(W/m2)	**(%)**	℃	℃	Kg/Kg	℃	℃	**(%)**	Kg/m3	Kg/Kg
9:00 AM	273.75	51	22	15	0.0116	23	36.5	36.25	0.84	0.0187
10:00 AM	413	47	24	15	0.0118	22	39.5	25.75	0.83	0.0156
11:00 AM	560	43	25	16	0.0121	21	42.2	18.75	0.83	0.0131
12:00 AM	603.5	40	27	15	0.0106	23	45.5	17.5	0.82	0.0145
1:00 PM	550	38	28	17	0.0121	23	44.7	18.75	0.82	0.0148
2:00 PM	464	37	26	15	0.0108	22	44	19.75	0.82	0.0146
3:00 PM	531.2	39	26	16	0.0111	24	45.2	21.75	0.82	0.0175
4:00 PM	355	39	24	14	0.01	23	41	26.5	0.83	0.0173
Average	**468.8**	**42**	**25**	**15.9**	**0.0113**	**22**	**42.3**	**23.12**	**0.82**	**0.0158**
Maximum	603.5	51	28	17	0.0121	24	45.5	36.25	0.84	0.0187
Minimum	273.7	37	22	14	0.01	21	36.5	17.5	0.82	0.0131

5.2.4.2 Loaded with briquette Average Hourly measured data

Table 5-3: 5th Day Direct hourly measured data for PDSC & FPSC

Day 5	**(Nov 2, 2018)**		**Loaded with briquette in the drying chamber**				
Time Interval	**Solar data and Ambient temperature**		**PDSC (Temperature, velocity of air and moisture removed)**				
Parameters	I_s	T_{1amb}	$T_{abs.P}$	$T_{3Db.P}$	$T_{2air.P}$	$V_{3\ air.P}$	$M_{p.P}$
Units	W/m2	°C	°C	°C	°C	m/s	(kg)
9:00 AM	418	24	76	45	56	0.9	0.105
10:00 AM	609	26	91	54	62	1.2	x
11:00 AM	751	29	102	59	66	1.3	x
12:00 AM	833	32	112	63	70	1.4	x
1:00 PM	761	30	109	64	70	1.4	x
2:00 PM	396	26	76	53	58	1.2	x
3:00 PM	433	25	78	56	60	1.2	x
4:00 PM	279	23	70	54	55	1.2	0.066
Average	**560**	**26**	**89**	**56**	**62**	**1.2**	**0.0855**
Maximum	833	32	112	64	70	1.4	0.105
Minimum	279	23	70	45	55	0.9	0.066

Day 5			**Loaded with briquette**				
Time Interval	**Solar data and Ambient temperature**		**FPSC (Temperature, velocity of air and moisture removed)**				
Parameters	**Ins**	T_{1amb}	$T_{2.P}$	$T_{3Db.F}$	$T_{abs.P}$	$V_{3\ air.F}$	$M_{p.F}$
Units	W/m2	**°C**	**°C**	**°C**	**°C°**	m/s	**kg**
9:00 AM	418	24	45	39	48	0.6	0.108
10:00 AM	609	26	52	41	50	0.7	x
11:00 AM	751	29	56	48	56	0.8	x
12:00 AM	833	32	58	52	62	0.9	x
1:00 PM	761	30	57	53	60	0.9	x
2:00 PM	396	26	41	39	52	0.6	x
3:00 PM	433	25	46	42	50	0.7	x
4:00 PM	279	23	40	35	46	0.6	0.086
Average	**560**	**26**	**49**	**43**	**53**	**0.7**	**0.097**
Maximum	833	32	58	53	62	0.9	0.108
Minimum	279	23	40	35	46	0.6	0.086

Table 5-4: 5th Day Indirect hourly measured data for PDSC & FPSC

Indirect measured hourly data	**Loaded set up with briquette in the drying chamber**									
Day 5 (Nov 2, 2018)	**PDSC**									
Time Interval	**Ambient Solar data, relative humidity air Temperature and humidity ratio**					**Wet & dry bulb air Temp**			**Psychometric chart result**	
Parameters	**Is**	**Am R.H**	T_{1db}	T_{1wb}	**H. R**	T_{3WbP}	T_{3DbP}	**DC R.H. P**	ρ_a	**H. R**
Units	W/m2	(%)	°C	°C	Kg/Kg	℃	℃	(%)	Kg/m3	Kg/Kg
9:00 AM	418	46	24	15	0.0115	38	45	66	0.8	0.0564
10:00 AM	609	42	26	16	0.0118	40	54	45	0.78	0.0606
11:00 AM	751	37	29	17	0.0124	40	59	34	0.77	0.0584
12:00 AM	833	34	32	19	0.0136	41	63	30	0.76	0.061
1:00 PM	761	33	30	19	0.014	40	64	26	0.76	0.0561
2:00 PM	396	35	26	15	0.0098	36	53	36	0.79	0.0453
3:00 PM	433	41	25	15	0.0108	32	56	22	0.79	0.0312
4:00 PM	279	39	23	13	0.0091	30	54	21	0.79	0.0265
Average	**560**	**38.3**	**26.8**	**16**	**0.0116**	**37.1**	**56**	**35**	**0.78**	**0.0494**
Maximum	833	46	32	19	0.014	41	64	66	0.8	0.061
Minimum	279	33	23	13	0.0091	30	45	21	0.76	0.0265

Indirect hourly data	**Loaded set up with briquette in the drying chamber**									
Day 5 (Nov 2, 2018)						**FPSC**				
Time Interval	**Ambient Solar data, relative humidity air Temperature and humidity ratio**					**Wet & dry bulb air Temp**			**Psychometric chart result**	
Parameters	**Is**	**Amb R.H**	T_{1db}	T_{1wb}	**H. R**	T_{3WbF}	T_{3DbF}	**DC R.H. F**	ρ_a	**H. R**
Units	(W/m2)	(%)	°C	°C	Kg/Kg	℃	℃	(%)	Kg/m3	Kg/Kg
9:00 AM	418	46	24	15	0.0115	31	39	59	0.83	0.0357
10:00 AM	609	42	26	16	0.0118	31	41	52	0.82	0.0348
11:00 AM	751	37	29	17	0.0124	33	48	39	0.8	0.0376
12:00 AM	833	34	32	19	0.0136	36	52	38	0.79	0.0457
1:00 PM	761	33	30	19	0.014	37	53	39	0.78	0.0489
2:00 PM	396	35	26	15	0.0098	29	44	36	0.82	0.0282
3:00 PM	433	41	25	15	0.0108	28	42	38	0.82	0.0266
4:00 PM	279	39	23	13	0.0091	25	36	44	0.84	0.0224
Average	**560**	**38**	**26**	**16.5**	**0.0116**	**31**	**44**	**43**	**0.81**	**0.0349**
Maximum	833	46	32	19	0.014	37	53	59	0.84	0.0489
Minimum	279	33	23	13	0.0091	25	36	36	0.78	0.0224

5.3 Instrumentation and Measurement method

The Experimental Data was collected by direct measuring of the required parameter using Standard Instruments and indirectly determine using, recorded data, different software's tools and scientific mechanism. The measurement methodology using different type of instrumentation has been done with two experimental set up, unloaded and loaded of sample briquette method.

The experimental measurement taking **Unloaded** of sample briquette is the main part of experiment which used to determine the performance of the driers between PDSCD and FPSCD. The experimental process was done without adding sample briquette on the drying chamber for four days **(29/10/18 - 2/11/18).**

The other experimental measurement taking **with the loaded** of sample briquette is done to prove which drier types give the best result in the presence of sample briquette. And the experiment is done by adding sample briquette on the drying chamber for one day **(2/11/18)**. For Parabolic dish collector Solar drier with **0.105 g** added in the chamber, and for Flat plate collector solar drier with **0.108 g** added in the chamber.

For PDSCD and FPSCD the experimental measurement has been taken by direct and indirect measurement. **Direct measurement** is the measuring method of experimental data which directly collected from the measuring instruments such as Temperature measurement and air speed measurement. For **Indirect measurement** method the data is not directly determined from instruments rather that by using the primary direct measured data, the secondary data is possible to determine with indirect ways. For this method Relative humidity, Humidity ratio and Insolation determination is identified using Psychrometric chart and online software recorded data access.

5.3.1 Temperature measurement

The Temperature variation trough out a day at different parts of the solar driers was measured using standard instruments. The testing parameters are Absorber surface temperature, air temperature at the inlet and outlet of the absorber and the drying chamber.

Instruments: 8 Mercury glass thermometers is used which can measure from 0 -300 degree of the air Temperature and Infrared Temperature measurement (surface Temperature) is used to measure the air and the surface temperature of the drier parts.

Figure 5-9: Laboratory thermometer and Infrared Temperature measurement device

5.3.2 Drying Air velocity measurement

The heated air speed that out from the drying chamber with loaded briquette and with unloaded condition is slightly different for both types of dryer (FPSC & PDSC**) Instrument:** for air velocity measurement Digital pocket Weather meter (Kestrel 3500) is used directly to measure speed of air.

Figure 5-10: Digital pocket Weather meter (Kestrel 3500)

5.3.3 Relative Humidity measurement

To determine the relative humidity of air at a given place using wet and dry bulb thermometer Psychometrics analysis of the system is very important. Psychometrics is the part of science which studying the thermodynamic properties of moist air. And also, it used to determine the amount of moisture vapor in the air varies quite significantly under different conditions

It can be used to predict changes in the environment when the amount of heat and/or moisture in the air changes. The use of psychometric analysis is also important to determine the volume flow rates of air to be pushed into the ducting system and the sizing of the major system components [2].

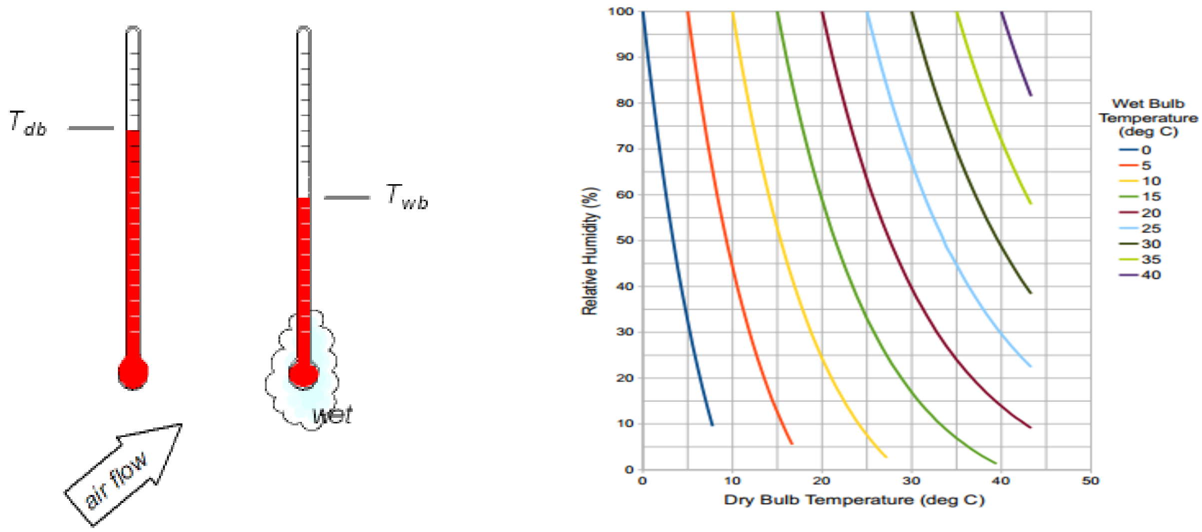

Figure 5-11: Dry and wet bulb temperature measurement and R.H with temperature graph [5]

Instrument: Dry bulb thermometer and wet bulb thermometer can be used to determine the relative humidity (R.H) of air. For this experiment the External (ambient) relative humidity is collected from recorded weather data and the internal relative humidity inside the drying chamber is determine using wet and dry bulb thermometer. The wet bulb thermometer is made by attaching the wick on the bulb part of thermometer. The wick has been made from a piece of socks to suck the water from the small water container. After measuring the wet bulb and dry bulb temperature variance at a given interval of time, The R.H and H.R and other parameters such as Dew point, Enthalpy and air density can be determine using Psychometric chart or Psychometric software tool which is available online internet service [26]. The Ambient relative humidity also measured using handmade hygrometer which shows in the figure (5-12).

Figure 5-12: wet and dry bulb Thermometer on the drying chamber

5.3.4 Solar Radiation data recording methods collecting materials

For solar radiation the data recording of direct solar radiation data is collected from the trusted site “metoblue” which is available at internet online access [25]. The software interface is showed in the Appendix of this paper.

Table 5-5: Five Days Hourly Solar Radiation and External Relative Humidity

	Solar Radiation data (W/m^2) (Oct 29 to Nov 2)				
Days	1	2	3	4	5
Time Interval	S. R	S. R	S. R	S. R	S. R
9:00 Am	394	299	161	241	418
10:00 Am	609	501	202	340	609
11:00 Am	749	671	270	550	751
12:00 Am	765	698	387	564	833
1:00 pm	558	523	483	636	761
2:00 pm	330	384	417	725	396
3:00 pm	520	404	485	716	433
4:00 pm	218	310	347	545	279
Average	**517.8**	**473.7**	**344**	**539.6**	**560**
Maximum	765	698	485	725	833
Minimum	218	299	161	241	279

5.3.5 Moisture content Measurement unit (mass balance)

In the 5th day experimental setup the moisture content of the loaded briquette (wet briquette) put in to the drying chamber and after drying for 7 hr of a day. By analyzing the mass difference, it is possible to test how much moisture is removed.

Instrument: Digital Mass balance (mass difference) is an instrument which used to measure the mass of any object which weighted from 5 g to 40 Kg. The mass if each briquette sample was measured before and after the experiment.

Figure 5-13: Digital Mass balance Instrument for sample briquette measurement

6 CHAPTER SIX: Result and Discussion

6.1 Assessment of measured result for Unloaded and loaded test

Based on the direct and indirect way of experimental measured result, the performance of both collectors has been evaluated. For all five consecutive days the absorber surface temperature, the air temperature at the inlet ad out let, external and internal relative humidity and drying air velocity were measured. The all days recorded data list are located in the Appendix B. Based on the four consecutive days unloaded testing result the average values are taken to analyze the measured data. In the 5^{th} day the sample 0.001 kg wet briquette was loaded in to both drying chambers to evaluate the performance.

The experimental measurement using selected measuring parameter has been done for both solar drier with unloaded and loaded of briquette set up. The average of 7hr drying time data is selected to evaluate all parameter measured for the whole drying process of five continuative days.

6.1.1 Solar radiation incident captured on collector Aperture area

The aperture area of both parabolic dish and Flat plate solar collector area is **0.217 m^2**. For both PDSC and FPSC Unloaded with briquette Four days average data the average solar radiation ($\mathbf{I_s}$) is the same for both collector which is 468.8 W/m^2**.** And for Loaded briquette experimental set up average solar radiation is 560 W/m^2. Hence: solar Energy collected on the aperture area of collector is calculated as $Q_s = I_s A_c$ and when they were Unloaded and Loaded these values have been **101.7 W** and **121.52 W** respectively**.**

6.1.2 Temperature Variations measured result

PDSC and Unloaded: the average collector inlet to outlet air temperature and absorber surface temperature measured result are 25 **°C, 61 °C and 86 °C** respectively.

PDSC and Loaded: the average collector inlet to outlet, drying chamber outlet air temperature and absorber surface temperature measured result are 26.8 **°C, 62 °C, 56 °C and 89 °C** respectively.

FPSC and Unloaded: the average collector inlet and, outlet air temperature and absorber surface temperature measured result are **25 °C, 42.3 °C and 50.1 °C** respectively.

FPSC and Loaded: The average the average inlet, outlet air and absorber surface temperature measured result are **26.8 °C, 49 °C, 43.6 °C and 53 °C** respectively.

The parabolic dish based solar drier have high absorber temperature **(85 to 90 °C)** as compared to the Flat plate collector-based drier which reads **(50 to 55°C)**. The temperature difference between the two driers is around **35 °C.**

6.1.3 Air flow speed variation measured result

The speed of air has been measured using weather meter hand tools at the outlet of drying chamber.

For PDSC: The average air speed at the outlet of drying chamber measured result with **Unloaded and Loaded** test setup was **1.36** $^{\mathbf{m}}/_{\mathbf{s}}$ and was **1.22** $^{\mathbf{m}}/_{\mathbf{s}}$ respectively, and The difference is almost **0.14** $^{\mathbf{m}}/_{\mathbf{s}}$ However the result indicates that speed of air reduced at the load of wet briquette set up due to the dropping of out let temperature and blocks restriction of the air flow inside the drying chamber.

For FPSC: The average air speed measured result with **Unloaded and Loaded** experimental setup at the outlet of the drying chamber was **0.6** $^{\mathbf{m}}/_{\mathbf{s}}$ and 0.7 $^{\mathbf{m}}/_{\mathbf{s}}$ respectively and the difference between the loaded and unloaded effect of air speed was **0.15** $^{\mathbf{m}}/_{\mathbf{s}}$ **.**

The air speed measured value is different between the two drier types. This result indicates that the PDSC have high hot air speed than FPSC.

6.1.4 Relative humidity Variation measured result

The relative humidity of air at the ambient and inside the drying chamber was measured indirectly using wet and dry bulb temperature difference with psychometric chart analysis for loaded and unloaded experimental setup.

For PDSC: The relative humidity measured average value at ambient and inside the drying chambers for **unloaded** experimental set up are **42.1 %,** and **16.4%** respectively. And for **Loaded** with briquette the average measure value ambient and inside the drying chamber are **38.3 %,** and **35 %** respectively.

For FPSC: The relative humidity measured average value at ambient and inside the drying chambers for **unloaded** experimental set up are **42.1 %** and 23.12 **%** and For **Loaded** with briquette the average data for External and Internal Relative humidity shows that **38.3 %**, and **43.12 %** respectively. From Observation of experimental result of relative humidity inside the drying chamber of both drier Unloaded with briquette chamber have less humidity than the loaded one. When comparing internal Relative humidity between PDSC and FPSC at each drying chamber shows the PDSC drying chamber is more humid than FPSC. The difference average range is around (15 to 20 %).

6.1.5 Moisture removed from the sample briquette

- **For PDSC and Loaded:** The moisture removed from the briquette is equal to **0.039 kg** it is directly measured using mass balance. (m_i = 0.105 kg and m_f = 0.066)

  $M_w = m_i - m_f$ = 0.105 - 0.066 = **0.039 kg** and $\dot{m}_{dr} = \frac{m_w}{t_d} = \frac{\mathbf{0.039kg}}{\mathbf{7hr}}$ = **0.0056 kg/hr.**

- **For FPSC and Loaded**: The moisture removed from the briquette is equal to **0.022 kg** it is directly measured using mass balance measurement. Temperature variation with Relative Humidity. (m_i = 0.108 kg and 0.086)
- $M_w = m_i - m_f$ = 0.108 - 0.086 = **0.022 kg and** $\dot{m}_{dr} = \frac{m_w}{t_d} = \frac{\mathbf{0.022\ kg}}{\mathbf{7hr}}$ = **0.0031 kg/hr.**

Table 6-1: Measured result summarized data for PDSC and FPSC

	PDSC			**FPSC**		
Measuring parameters	**Unloaded**	**Loaded**	**Average**	**Unloaded**	**Loaded**	**Average**
$\mathbf{T_{abs}}$ **(plate Temperature)**	86.17 °C	89.2°C	87.6 °C	42.34 °C	49.3 °C	45.82 °C
$\mathbf{T_{1\ amb}}$ **(air temperature)**	25°C	26°C	25.5°C	25°C	26°C	25.5°C
$\mathbf{T_2}$ **(air temperature)**	61°C	62 °C	61.5 °C	50 °C	49 °C	49.5 °C
$\mathbf{T_3}$ **(air temperature)**	61 °C	56 °C	58.5 °C	50 °C	43 °C	46.5 °C
$\mathbf{V_3}$ **(out let air speed)**	1.3 m/s	1.2 m/s	1.25m/s	0.6 m/s	0.7 m/s	0.65 m/s
Amb Relative humidity	42.1 %	38.3 %	40.2 %	42.1 %	38.3 %	40.2 %
Dch Relative humidity	16.4%	35 %	25.7%	23.12 %	43.12 %	33.12%
Moisture removed	-	0.039 kg	-	-	0.022 Kg	-

The above recorded measured data shows the performance difference between the two types of drier on the selected test parameters.

6.2 Determination of measured results with correlation between parameters

The measured parameters such that, temperature, relative humidity, air speed and moisture content which indicate the drying performance of the dryer is analyzed with comparative assessment to determine the significant effect of result variation among the selected parameters.

6.2.1 Variation of Temperature and Relative Humidity with time

From the result as shown in the Figure 6-1 and 6-2 when the air Temperature increases the relative humidity of air reduces for both PDSC and FPSC. However, the variation is higher for PDSC than FPSC. This indicates the drying capacity of PDSC is significantly high than FPSC.

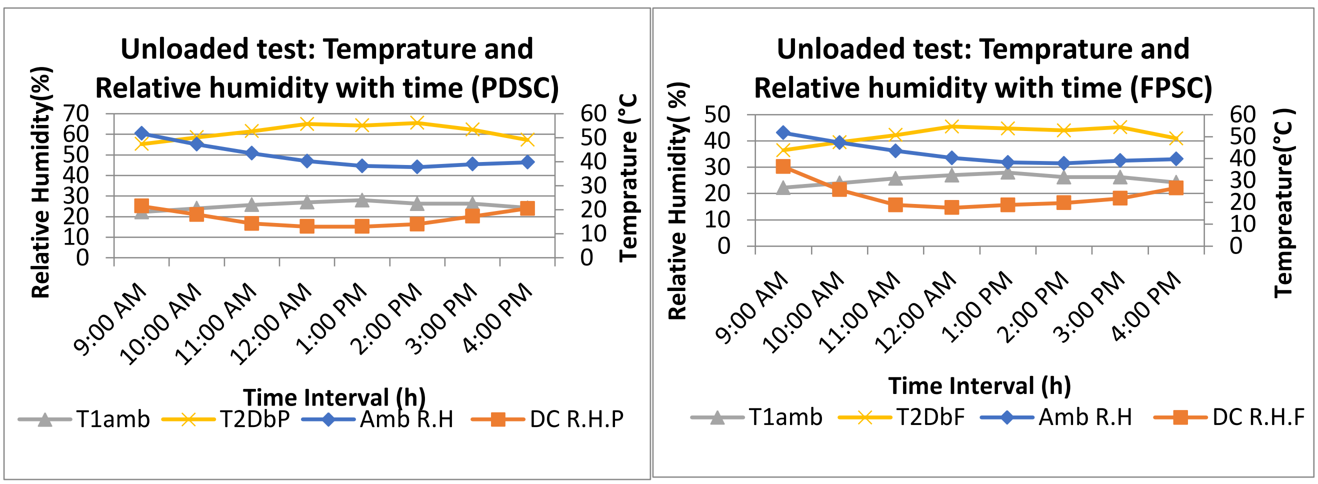

Figure 6-1: Plotted graph for Temperature with Time with Humidity relation

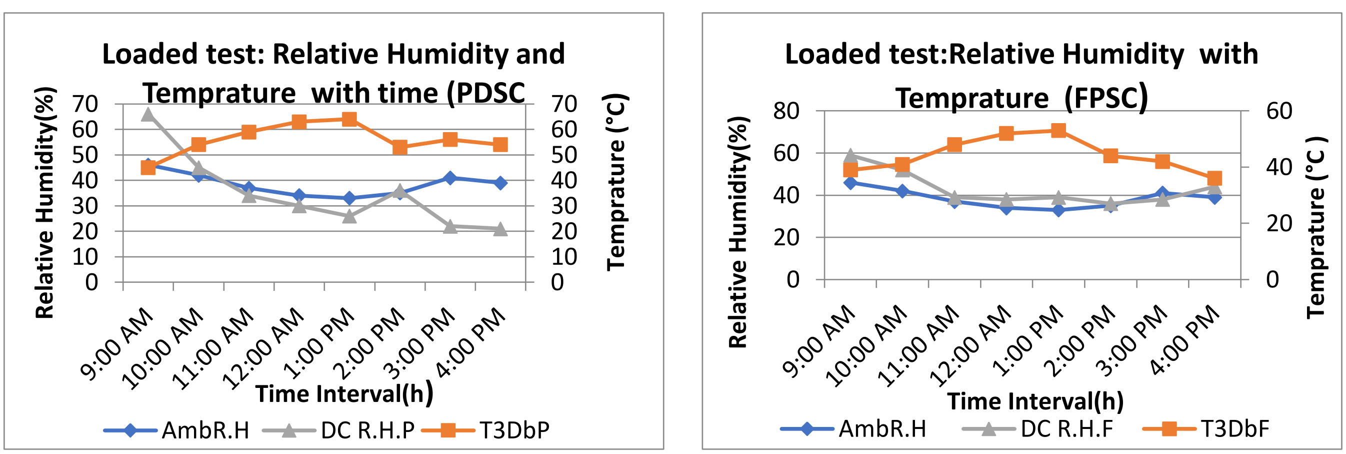

Figure 6-2: 5th Day average plotted data for relative humidity with temperature

6.2.2 Variation of Relative Humidity and Solar radiation with time

As the solar radiation increases hourly the external and internal relative humidity decreases with different level of variation. For both driers drying chamber internal relative humidity is always less than external humidity based on the experimental result found. The relative result determined for unloaded and loaded test relation with solar radiation is described in graphical representation in Figure 6-3 and 6-4.

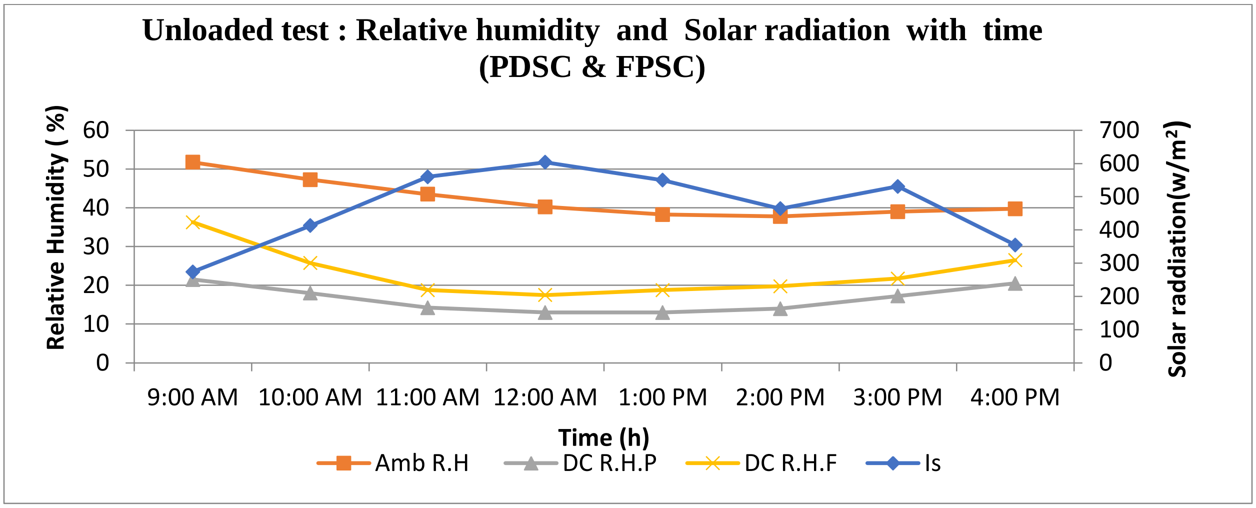

Figure 6-3: Unloaded test Plotted graph for Relative humidity and Insolation variation

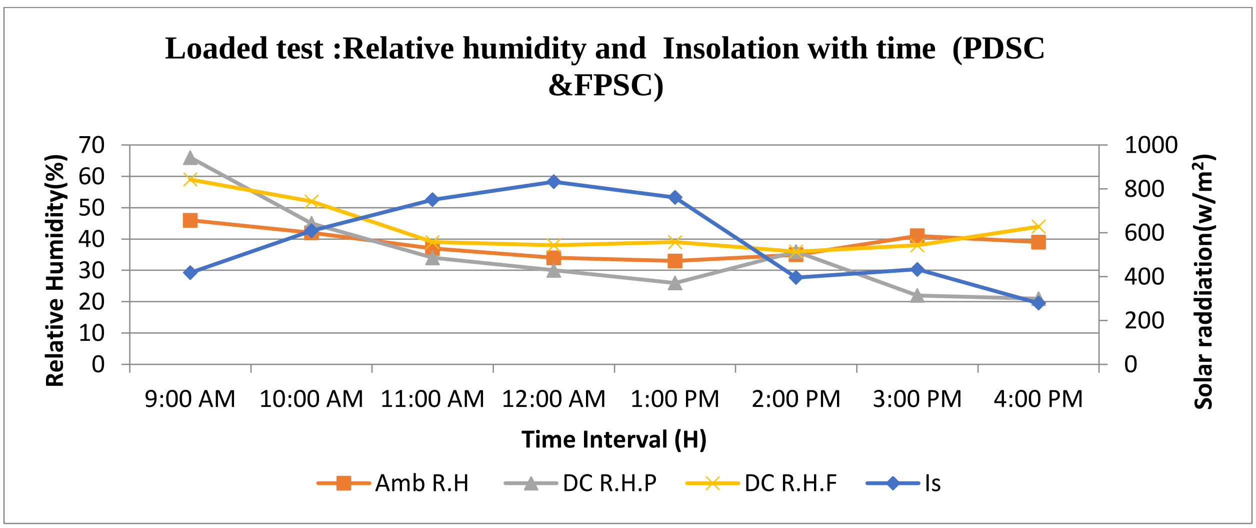

Figure 6-4: Loaded test plotted graph for Relative humidity and Insolation with time

6.2.3 Variations of Temperature and Solar radiation with Time

The variation of temperature with solar radiation is given in Figure 6-5 and 6-6 for both drier unloaded and loaded test. When solar radiation increases the absorber temperature and the air temperature increases which flow across the solar collector.

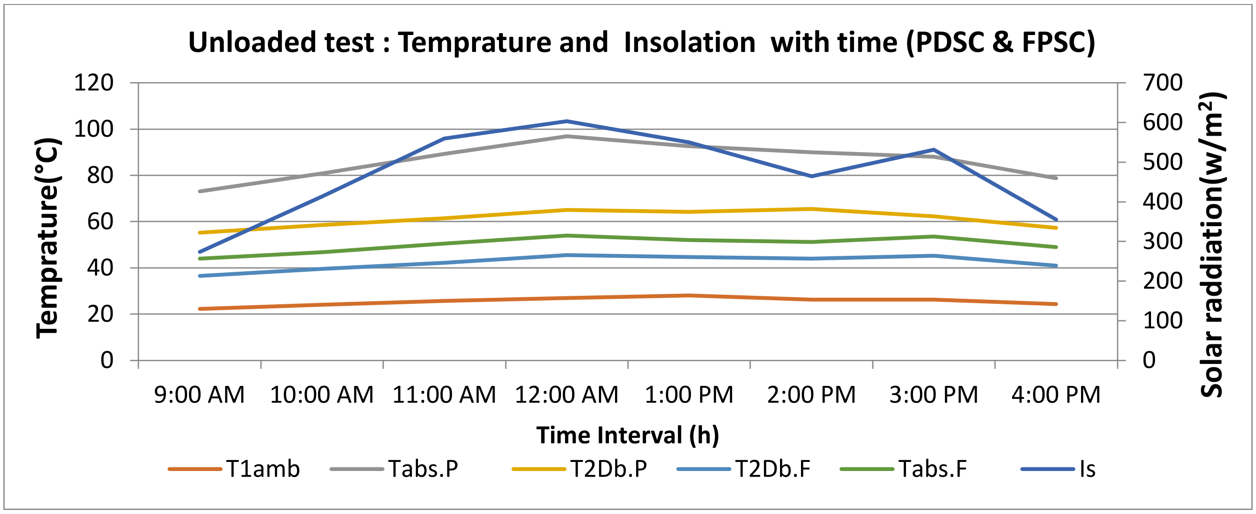

Figure 6-5: 1-4 Days average data plotted graph for Insolation vs. Temperature variation

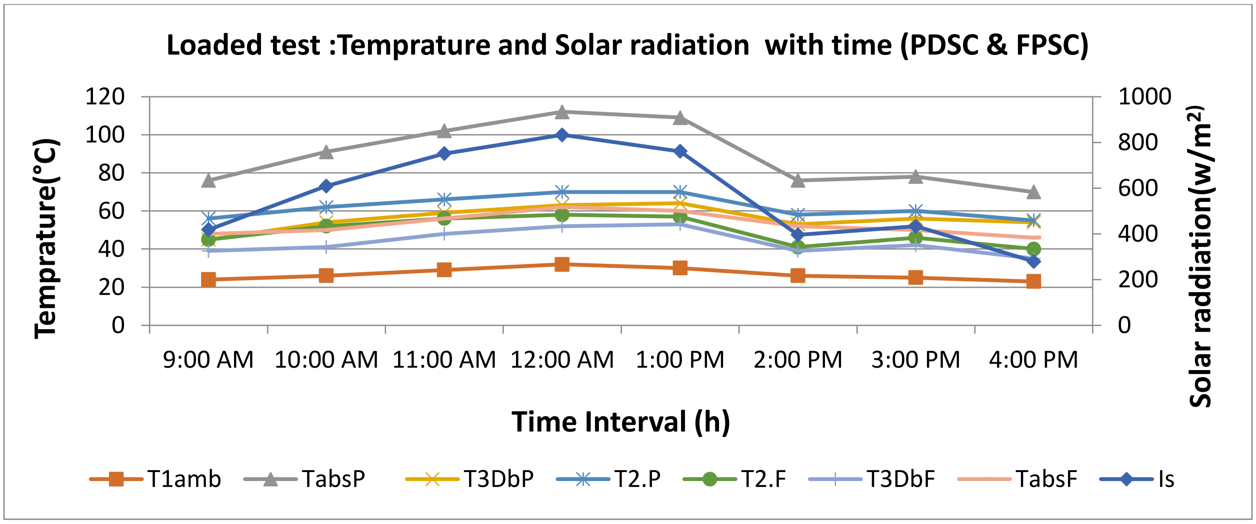

Figure 6-6: 5th day average data plotted graph for Insolation and Temperature variation

6.2.4 Variations of Air flow Speed variation and Temperature with time

The air flow speed at high temperature faster than the lower temperature relatively. Based on this fact the air speed at the outlet of drying chamber of PDSC is significantly higher than FPSC. This variation shows in Figure 6-7 and 6-8 below.

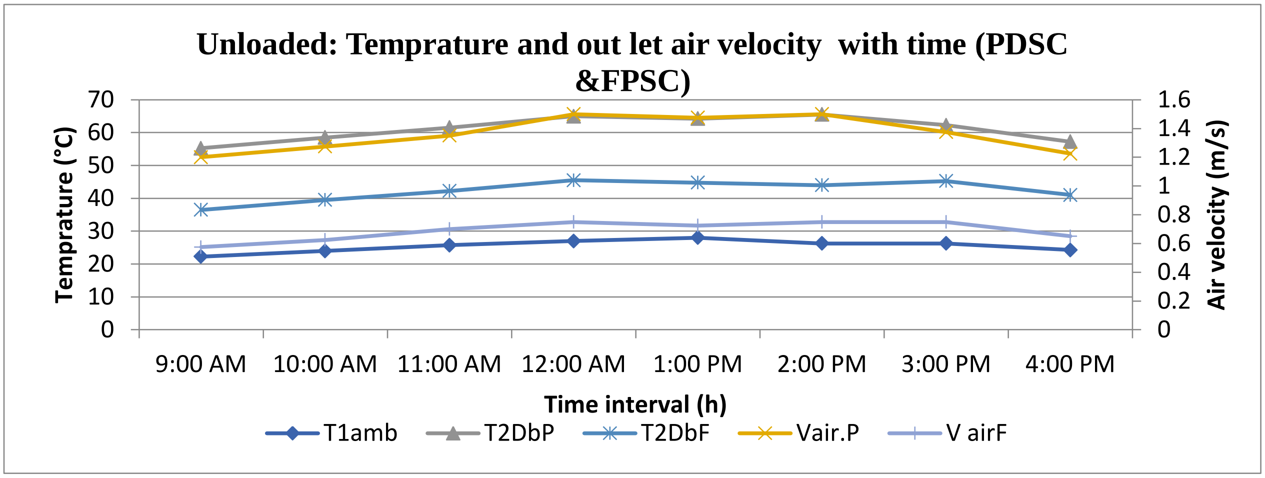

Figure 6-7: 4 days average data plots for temperature vs. air velocity variation

The other factor is the overall area of the collector and the drying chamber where the air pass flow when the outlet area of the air become narrow the air velocity become high from general theory and facts.

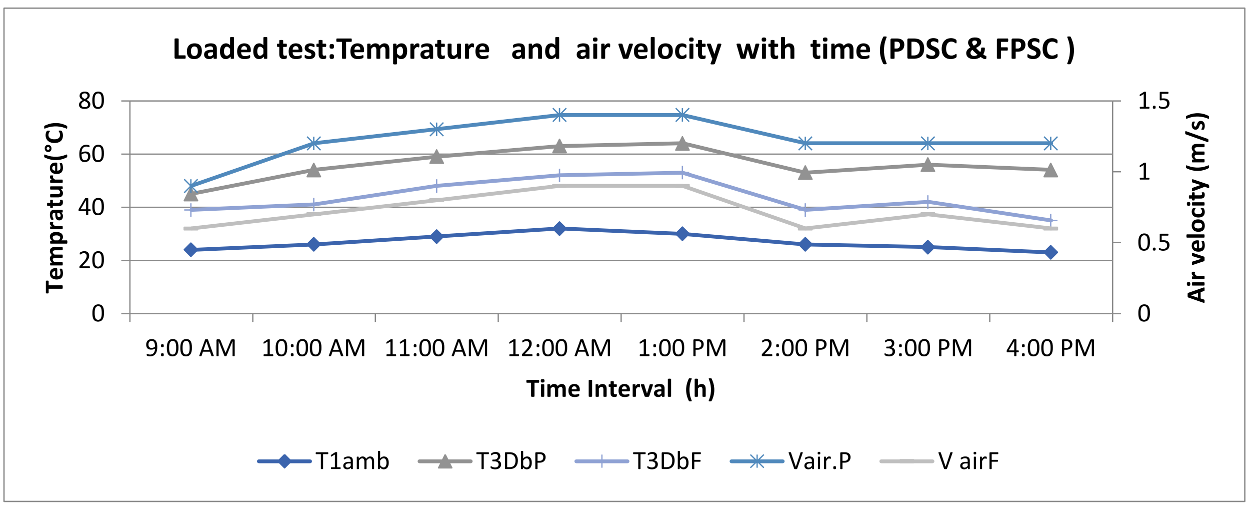

Figure 6-8: Loaded setup plotted graph for temperature and air velocity variation

6.2.5 Variation of air Speed and Relative Humidity with time

When the air temperature increases in the drying chamber the relative humidity reduced and the air velocity increases and also when air temperature drops humidity increases and the air velocity drops. The variation of Relative humidity and air velocity with time are observe differently with loaded and unloaded set up as show in the Figure 6-9.

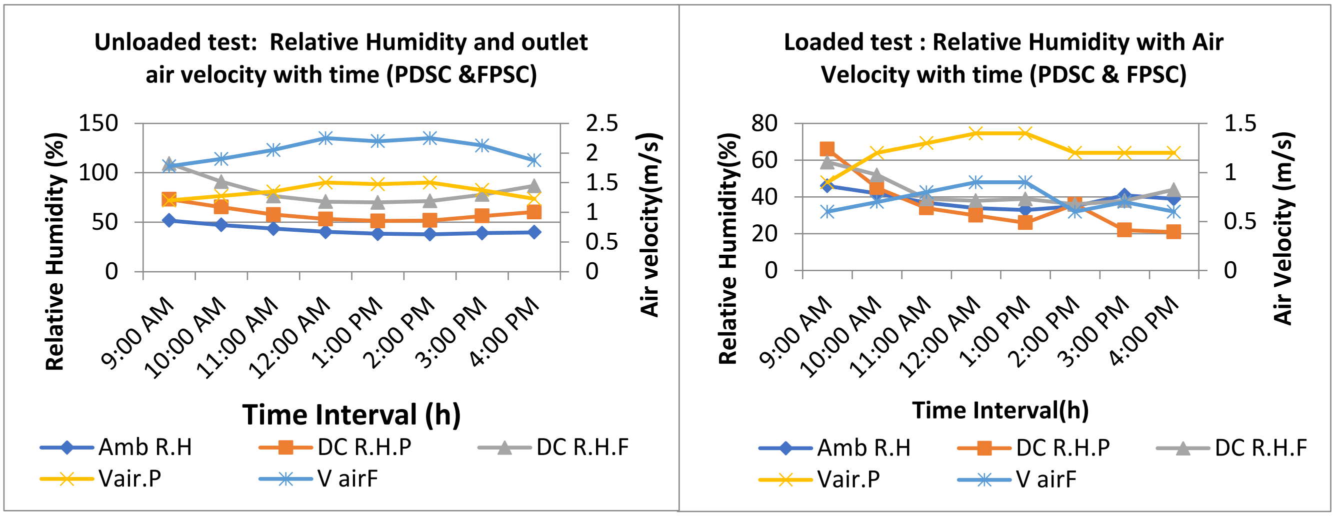

Figure 6-9: 4 days' average and 5th day measuring result of relative humidity and velocity with

6.2.6 Variation of Humidity ratio variation with time

From the graph below in Figure 6-10 shows the humidity ratio in drying chamber is higher than the ambient for both solar driers, but the humidity ratio variation for unloaded set up have constant range with the consecutive drying duration of time. For loaded set up the humidity ratio drops with increasing drying time. From overall result comparison the PDSC still have higher humidity ratio than the FPSC at each drying chamber for both experimental setups. In general, this result indicate there is a moisture difference at the inlet and out let of the dryer which approves the dryer have a performance of removing a water vapor from the moisturized air.

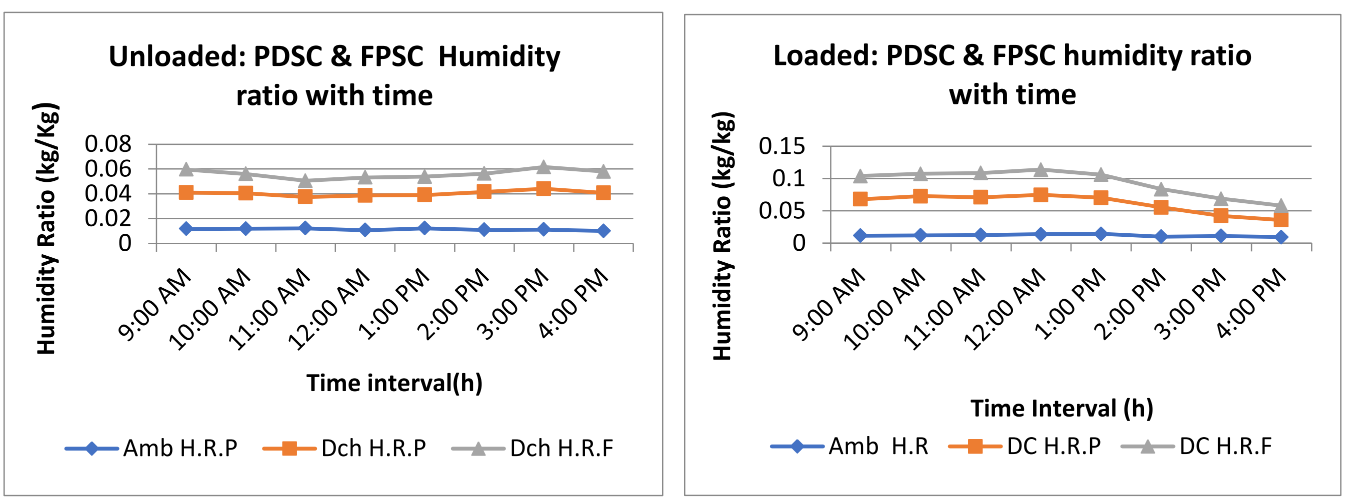

Figure 6-10: 4 days' average and 5th day measuring result of humidity ratio with time

6.3 Result analysis based on heat transfer concept of the driers

The experimental result has shown that the performance of PDSC is higher than the FPSC. This result comes from the effect of increasing to Absorber temperature, drying air temperature and less relative humidity inside the PDSC drying chamber. To analyze the Energy transfer magnitude from the solar Energy absorbing unit to drying chamber heat Energy utilization process the following concepts must be analyzed.

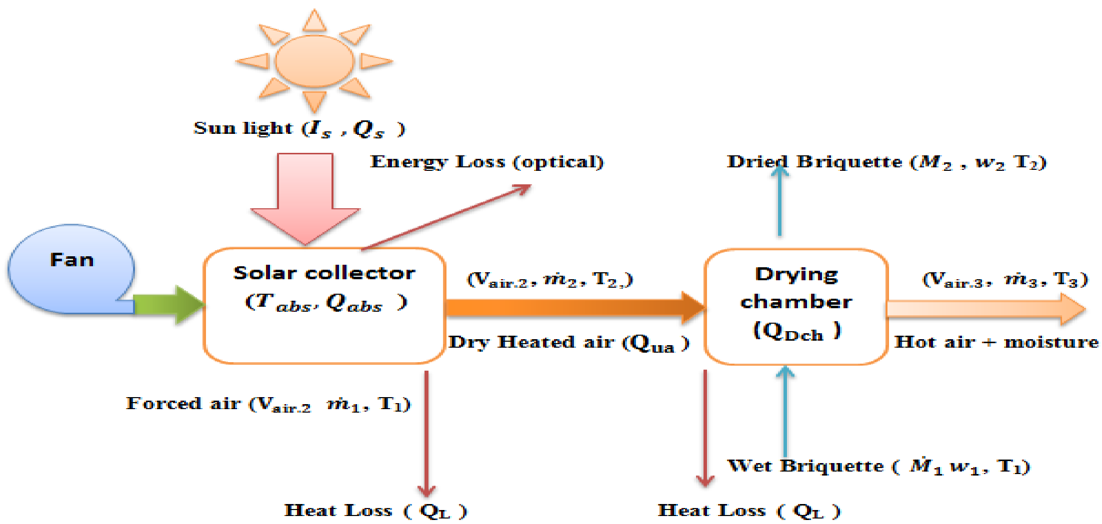

Figure 6-11: Schematic diagram of drying system process

In the solar drying system heat energy is transfer from the FPC to the drying chamber trough conduction, convection and radiation heat transfer modes. This heat exchanging system performance has a great impact on the drying efficiency. It can be evaluated by using the heat transfer analysis concepts based on the measuring values. Such overall drying system heat transfer flow and mathematical equation is described below in detail.

6.3.1 Useful Energy at the Collector

To determine the Energy collected by the absorber of the two dryer types, it is very important considering optical and thermal losses of the collector. The optical loss and thermal loss are mainly depending on the collector optical efficiency and thermal loss is linked to the absorber material type and insulation cover to protect the loss.

For this study The PDSC used reflective mirror for the concentrated reflecting dish and glass cover for absorbing part and FPSC uses window glass for which can transmit the radiation with higher transmittance efficiency. To protect the thermal loss for both absorber fiber glass insulation was used to cover the absorber unit.

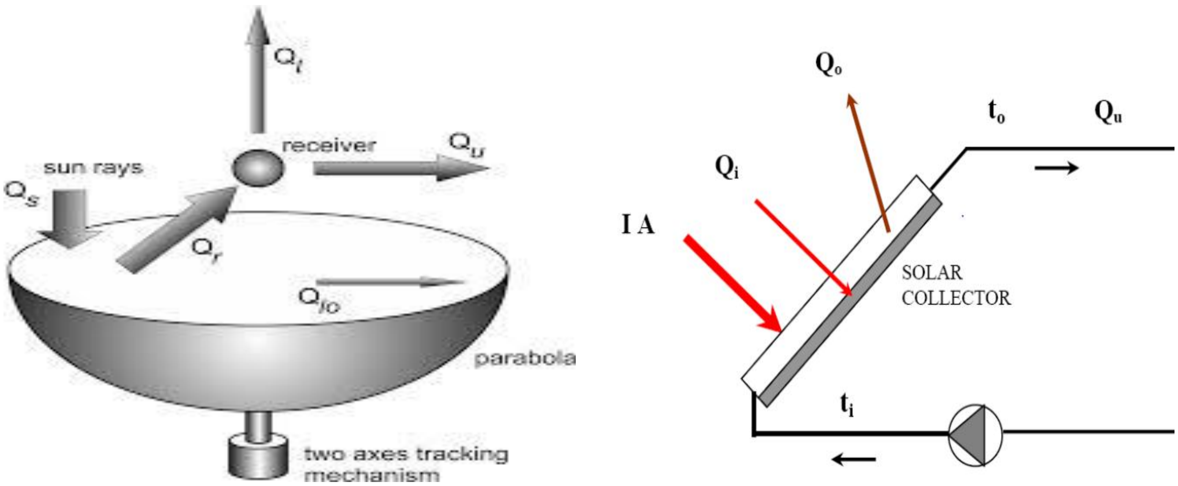

Figure 6-12: Thermal Energy flow diagram for parabolic dish and Flat plate collector [33]

To determine net heat gain by the Collector (useful Energy gain by the collector) equation (6.1) can be used as discussed below [20].

$$\mathbf{Q_{uc}} = \mathbf{I_s A_{ap}} \eta_{opt} - \mathbf{A_{abs} U_L (T_{abs} - T_{1amb})} \qquad \dots (6\text{-}1)$$

$$\mathbf{Q_{uc}} = \mathbf{Q_{abs}} - \mathbf{Q_{lt}} \qquad \dots (6\text{-}2)$$

$$\mathbf{Q_{abs}} = \mathbf{Q_s \eta_o} = \mathbf{A_{abs} I_s} \eta_{opt} \qquad \dots (6\text{-}3)$$

Hence $Q_s = A_{abs} I_s$ and $Q_{tl} = Q_{rad} + Q_{conv} + Q_{cond}$

Assume that no heat loss is considered $Q_{lt} = 0$, due to the insulation cover for both absorber surface of the drier.

Where: Q_s is solar energy incident on the Aperture area of the collect, Q_{tl} is thermal loss, $\boldsymbol{\eta_{opt}}$ and is optical efficiency

To determine the energy loss on the collector due to the optical loss it is possible to use optical efficiency of the materials to calculate the overall solar energy collected by the absorber.

6.3.1.1 Useful Energy collected by PDSC

Heat energy collected by the absorber of the PDSC can be calculated using equation (6.4). The optical Efficiency of the parabolic dish collector is a combination of parabolic dish reflector and flat plate absorbing box (6.6). For this prototype un-etched glass is used to cover the absorber. It has a good transmittance of solar radiation. The transmittance of un-etched glass can be determined based on the tilt angle of the incident solar radiation [4]. The tilt angle for this experiment is adjusted at 27^0 from the horizontal surface.

Table 6-2: Transmittance of the glass varies by incidence angle

Angle of tilt	20^0	27^0	40^0
Transmittance	0.894	-	0.903

By interpolation it is possible to find the exact transmission of the glass (τ_g) = 0.89

The absorber box with window glass transmittance ($\boldsymbol{\tau_g}$) and black painted aluminum absorber plate absorbance ($\boldsymbol{\alpha}$) is 0.89 [19] and 0.87 [5] respectively.

$$\mathbf{Q_{abs.P}} = \boldsymbol{I_s A_{c.p}} \eta_{\boldsymbol{opt.p}} \quad \dots (6\text{-}4)$$

$$\eta_{\boldsymbol{opt.p}} = \boldsymbol{\rho_m \tau_g \alpha \gamma} = \underline{0.73} \quad \dots (6\text{-}5)$$

Where: ρ_m : is reflectance of mirror glass = 0.95 [8], A_c: Is Aperture Area of collector

$A_{c.p} = A_{c.F} = \mathbf{0.217\ m^2}$, γ : Intercept factor = 1 [19]

6.3.1.2 Useful Energy collected by FPSC

Heat energy collected by the absorber of the FPSC can be calculated using equation (6.6). And the optical efficiency of window glass is calculated as in equation (6.7).

$$\mathbf{Q_{abs.F}} = \boldsymbol{I_b A_{c.F}} \eta_{\boldsymbol{opt.F}} \quad \dots (6\text{-}6)$$

$$\eta_{\boldsymbol{opt.F}} = \boldsymbol{\tau_g \alpha} = 0.89 * 0.87 = \underline{0.77} \quad \dots (6\text{-}7)$$

Where: $\eta_{\boldsymbol{opt.F}}$ optical efficiency of window glass

6.3.2 Useful energy Gain by Air at the collector

The heat Energy transfers from the black painted aluminum absorber to the forced flowed air by convection heat transfer process. The useful energy at the collector can be calculated as [20]:

$$Q_{ua} = m_a C_{pa} (\Delta T_{air}) \quad , \ \Delta T_{air} = T_{abs} - T_{1amb} \qquad \dots (6\text{-}8)$$

To determine Useful Heat Energy gained by for the PDSC and FPSC the Equation (6.10) and (6.11) used to find the magnitude of the heat transfer rate of the air flow respectively

PDSC based drier: This equation can be used to calculate heat energy gain by the air

$$\mathbf{Q_{ua.P}} = \boldsymbol{m_{a.p} C_{pa} \left(T_{abs.P} - T_{1amb}\right)} \qquad \dots (6\text{-}9)$$

FPSC based drier: This equation can be used to calculate heat energy gain bay air

$$\mathbf{Q_{ua.F}} = \boldsymbol{m_{a.F} C_{pa} \left(T_{abs.F} - T_{1amb}\right)} \qquad \dots (6\text{-}10)$$

Where: C_{pa} Is Specific heat of air for PDSC and FPSC is the same = 1.0049 kJ/kg, $T_{2\,out.P}$ Is Temperature of air at the out let of collector PDSC, $T_{2\,out.F}$ Is Temperature of air at the out let of collector FPSC, T_{1in} Is Temperature of at the Inlet of collector (Ambient temperature) the same for both collector and $\dot{m}_{ap}$ Is mass flow rate the heated air at PDSC and $\dot{m}_{aF}$ is at FPSC.

$$\dot{m}_a = \rho_a A_t V_{3\,air} \qquad \dots (6\text{-}11)$$

Where: ρ_a is density of air at specific temperature of each hour measurement or at average result temperature result and A_t the area of a tube which air passing trough

It is found from the Psychometric chart at a specific value of Relative humidity and drying air temperature for each hour measurement.

- **For Unloaded average result:** The Specific heat of air for PDSC ($\mathbf{C_{pa}}$) = at average temperature of 43.32 ℃ = 1.0049 kJ/kg (300 to 325 k) and C_{pa} at a temperature of 33.9 ℃ (300 to 325 k) for FPSC = 1.0049 kJ/kg
- **For Loaded for Loaded result:** C_{pa} = at 41.4 ℃ (300 to 325 K) = 1.0049 kJ/kg for PDSC and C_{pa} = at 35.2 ℃ = 1.0049 kJ/kg (300 K to 325 K) for FPSC

For both absorber specific heat of air C_{pa} = 1.0049 k j/kg and Area of the outlet tube A_t = 0.0009 m^2

6.3.1 Useful energy utilized in the drying chamber

To calculate the amount of heat required for drying process, it is possible to use the following equation discussed below [21].

$$\mathbf{Q_{dry} = M_w L_w} \qquad \dots \text{(6-12)}$$

Where: Q_{dry} is amount of heat utilized for drying process, (MJ) and L_w Is heat required to evaporate 1 kg water, and it is 2260 (kJ/kg) [5], M_w Is mass of the water evaporated

When the drying chamber is insulated and no heat loss occurred the heat energy became balance

$$\dot{m}_a C_{pa} (T_3 - T_2) = M_w L_w$$

$$\boldsymbol{Q_{dry} = M_w L_w} \qquad \dots \text{(6-13)}$$

$$\mathbf{M_w = m_i - m_f} \qquad \dots \text{(6-14)}$$

Where: M_w= Mass of water evaporated from the briquette and Q_{dry} = the heat required to evaporate a fluid at the drying chamber, T_2 and T_3 are inlet and out let air temperature from drying chamber,

For PDSCD the energy required to evaporate the water from the drying briquette can be calculated as:

$\boldsymbol{Q_{dry.P}} = M_w * L_w$ = 0.039 kg * *2256 kJ/kg* = ***87.984 kJ*** = $\frac{87984\ j}{7 * 3600\ S}$ **= 3.4 j/s = 12.5 kJ /h**

For FPSCD the energy required to evaporate the water from the drying briquette can be calculated as:

$\boldsymbol{Q_{dry.F}}$= $M_w * L_w$ = 0.022 kg * *2256 kJ/kg* = ***49.632 kJ*** = $\frac{49632\ j}{7 * 3600\ S}$ = **1.96 J/s = 7.09 kJ /h**

6.3.1.1 To Determination of moisture content removed by PDSC and FPSC

For PDSC $\%M_{wb} = \frac{m_i - m_f}{m_i} 100\%$ = **37.1%**

For FPSC $\%M_{wb} = \frac{m_i - m_f}{m_i} 100\%$ = **20.3%**

Where m_i = initial mass of the sample (wet saw dust), m_f = final mass of the sample (dry saw dust), A_c = Effective Area of Collector, I_b = Solar Insolation t = Time of Drying = 3600 s

6.3.1.2 Power consumption of DC fan can be calculated

p_f = v*I = 12 v * 2.7 A = 32W

Table 6-3: Average of the hourly averages data for Unloaded and loaded briquette Test

$A_{c.p}$ = $A_{c.p}$ = 0.217 m^2, $\eta_{opt.p}$ =0.73, $\eta_{opt.F}$ =0.77, $C_{Pa.P}$ = 1.0049 kJ/kg K

For Parabolic Dish Solar Collector (PDSC)

Type	I_s	$\eta_{opt.p}$	$\dot{m}_{air.P}$	ΔT_{air}	M_w	L_w	$Q_{abs.P}$	$Q_{ua.P}$	$Q_{dry.P}$
Units	(W/m2)		Kg/h	℃	kg	*kJ/kg*	w	J/s(wh)	J/s
Unloaded	468.8	0.73	3.7188	35.7			74.264	**37.255**	
Loaded	560	0.73	3.366	29.1	0.039	2256	88.70	**25.2**	**3.4**

For Flat Plate Solar Collector (FPSC)

Type	I_s	$\eta_{opt.F}$	$\dot{m}_{air.P}$	ΔT_{air}	M_w	L_w	$Q_{abs.P}$	$Q_{ua.P}$	$Q_{dry.F}$
Units	(W/m2)		Kg/h	℃	kg	*kJ/kg*	w	J/s(wh)	J/s
Unloaded	468.8	0.77	2.012	16.8			78.333	**9.6**	
Loaded	560	0.77	3.368	16.7	0.022	2256	93.57	**8.3**	**1.96**

6.3.2 Determination on efficiency of the drying system

The energy gain by air and the sample drier product with respect to the input Energy calculated using efficiency analysis. The total over all drying efficiency is determined by the output product heat utilization to the input energy to the solar collector.

7.2.3.1 Collector Thermal efficiency

To analyze collector thermal efficiency for both drier the heat loss is neglected due to the absorber is covered by insulator. Thermal efficiency can be calculated by dividing the output heat energy gain by the air to the input solar radiation to the absorber.

For both solar collectors the thermal efficiency of the collector expressed as:

$$\mathbf{Q_{abs}} = \mathbf{Q_{.s}} \eta_{opt} = I_b A_{c.P} \eta_{opt} \qquad \dots (6\text{-}15)$$

$$Q_{.s} = I_b A_c \qquad \text{… (6-16)}$$

$$Q_{ua} = m_a C_{pa} (T_{abs} - T_{1amb}) \qquad \text{… (6-17)}$$

By Using equation (6.16 and 6.17) collector thermal efficiency for both dryers calculated as:

$$\eta_{cth} = \frac{Q_{ua}}{Q_{.s}} \qquad \text{… (6-18)}$$

Hence, For PDSC $\quad Q_{abs.P} = I_b A_{c.P}\, \eta_{opt.P} = Q_{.s}\, \eta_{opt.P}$ and

For FPSC $\quad Q_{abs.F} = I_b A_{c.F}\, \eta_{opt.F} = Q_{.s}\, \eta_{opt.F}$

Where: m_a = mass of air, C_{pa} = Specific heat of heat I_b = Solar Insolation, η_{opt} is optical efficiency, T_{abs} is absorber surface temperature, T_{1amb} is ambient temperature

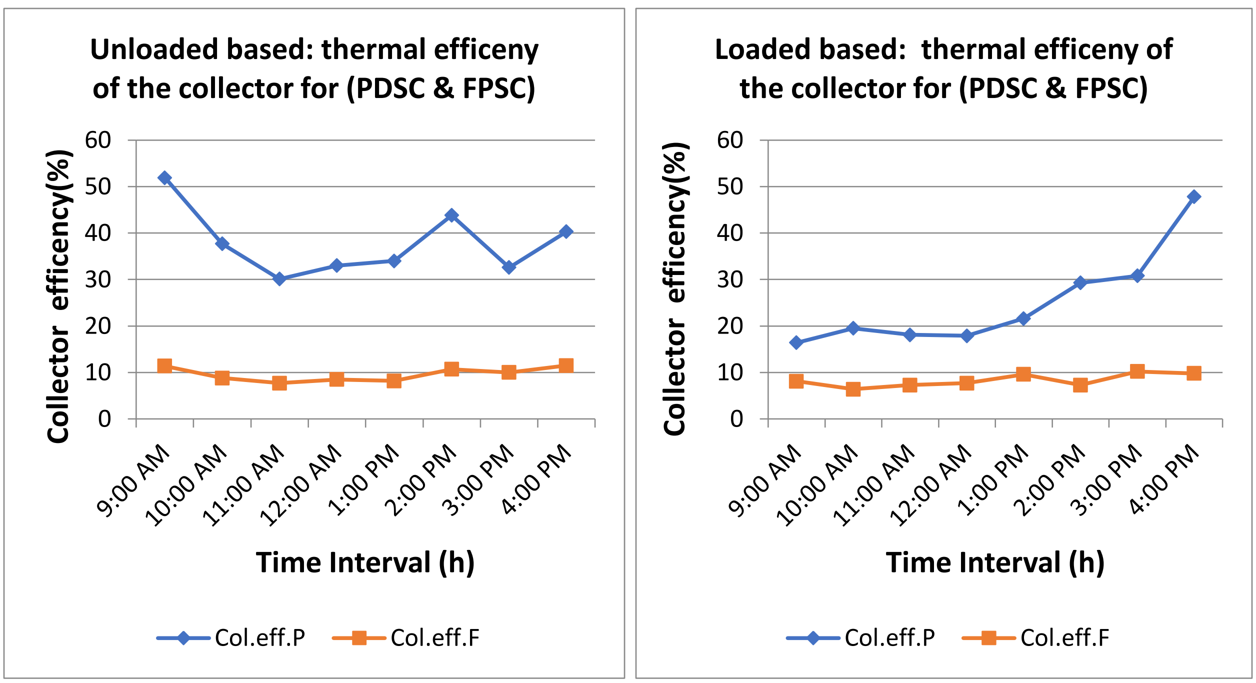

Figure 6-13: Plotted graph for Collector thermal Efficiency with time for (PDSC & FPSC)

In the above figure (6-13) the plated graph shows the Thermal efficiency of PDSC have better thermal efficiency than the FPSC for both loaded and Unloaded experimental setup.

Based on the result value that gate from the experiment the two dryers perform difference is shown in the above Table 6-3.

Table 6-4: Summary of experimental result for average Collector Thermal Efficiency

Unloaded Experimental set up daily Average result								
Day (1 to 4)	**PDSC**				**FPSC**			
Time Interval	$Q_{s.P}$	$Q_{abs.P}$	$Q_{ua.P}$	$\eta_{cth.P}$	$Q_{s.F}$	$Q_{abs.F}$	$Q_{ua.F}$	$\eta_{cth.F}$
Units	Wh	Wh	Wh	%	Wh	Wh	Wh	%
Average **Daily Sum**	101.70 813	74.2	37.25	37.9	101.7 813	78.333	9.55	9.6
Loaded Experimental set up daily Average result								
Day (5)	**PDSC**				**FPSC**			
Time Interval	$Q_{s.P}$	$Q_{abs.P}$	$Q_{ua.P}$	$\eta_{cth.P}$	$Q_{s.F}$	$Q_{abs.F}$	$Q_{ua.F}$	$\eta_{cth.F}$
Units	Wh	Wh	Wh	%	Wh	Wh	Wh	%
Average **Daily Sum**	121.4 971.9	88.70	27.7	25.2	121.4 971.9	93.57	9.961	8.3
Loaded and Unloaded average Result		**81.45**	**37.25**	**31.55**		**85.95**	**9.75**	**8.95**

The Energy absorbed by the flat plate collector is slightly greater than the parabolic dish collector due to it have better optical efficiency than the dish-based collector. However, the net heat gain by the drying air in the PDSC drying chamber has higher heat energy than FPSC. This is happened due to the temperature generating performance of the collector. The increasing of drying air temperature affects the efficiency of the collector become high and the overall drying efficiency of the drier also increases.

6.3.3 Drying chamber efficiency

It can be described as the ratio of difference between the drying chamber inlet and outlet temperature to the difference between the drying chamber inlet and ambient temperature [28].

$$\eta_{DC} = \frac{(T_3 - T_2)}{(T_{1amb} - T_2)} \quad \ldots (6\text{-}19)$$

Table 6-5: Drying chamber efficiency calculation with Unloaded and loaded set up

Average result	**PDSC**				**FPSC**			
measured parameters	T_{1amb}	T_2	T_3	$\eta_{DC.P}$	T_{1amb}	T_2	T_3	$\eta_{DC.F}$
units	℃	℃	℃	**%**	℃	℃	℃	**%**
Unloaded	25.5	61.2	61.2	**0**	25.5	42.3	42.3	**0**
Loaded	26.88	62.12	56	**17.4**	26.88	49.38	43.63	**25.6**

For the drying process the flat plate collector drying chamber is more efficient to dry the saw dust compare to the parabolic dish drying chamber which hold the same size and weight sample briquette. This is due to the hot drying air loss at the PDSCD drying chamber is greater than the FPSCD one. The wet briquette sample product amount must be more than two briquettes to make The PDSCD drying chamber is efficient for overall drying process. The temperature difference between inlet and out let (T_2 and T_3) of PDSCD and FPSCD drying air at the both drying chambers is 6.12 ℃ . It indicates the wet briquette consume heat energy which enables too dry with the given temperature. The temperature range at the FPSCD is enough to dry the briquette with the same rate to the PDSC, but the air velocity variation on two drying chambers increase the drying rate and moisture removing capacity for the PDSCD than the FPSC.

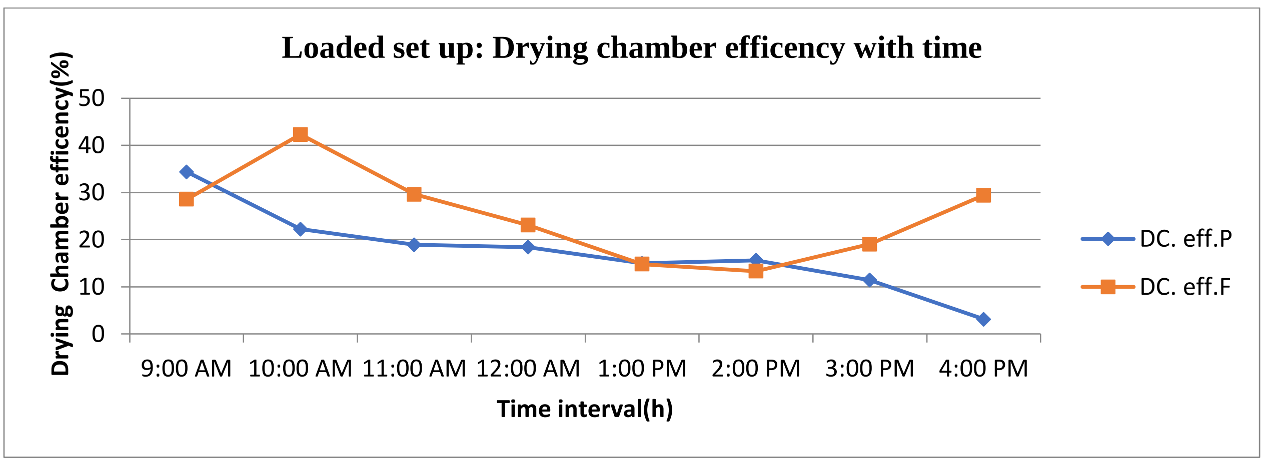

Figure 6-14: Drying chamber efficiency regarding with time in loaded setup

Therefore, to make efficient drying chamber for PDSCD the drying product size or quantity must be increased to utilize the heat energy efficiently that influence the overall drying efficiency of drier maximized.

6.3.4 Over all drying efficiency the Dryers

Total drying efficiency of the dryers can be calculated using the below formula

For PDSC & FPSC $$\eta_{Dry} = \frac{L_w M_{w.}}{t\, I_s A_c \ + p_f} = \frac{Q_{Dry}}{t\, I_s A_{c.P} + p_{fa}} \quad \ldots (6\text{-}20)$$

Where: Q_{Dry} = Energy utilized for drying, L_w = Latent heat of Vaporization of water (*2256 kJ/kg)* and, $M_{w.}$ = mass of the water vapor removed p_f = fan power consumption, t = time interval of the drying duration

Table 6-6: Over all drying efficiency the for both Dryers

Day (5)	**PDSC Loaded**					**FPSC Loaded**				
parameters	I_s	$Q_{Dry.P}$	$A_{ca\,P}$	P_{fa}	$\eta_{Dry.F}$	I_s	$Q_{Dry.F}$	$A_{ca\,P}$	P_{fa}	$\eta_{Dry.F}$
Units	w/m^2	Wh	m^2	W	%	w/m^2	Wh	m^2	W	%
Time interval (1hrs)	560	24.44	0.217	32	15.9	560	13.79	0.217	32	8.9

For both unloaded and loaded with sample briquette experimental work the result found from the measuring result that has been taking using direct and indirect methods has showed the different result. The results measured based on the selected parameters shows the performance variation between FPSC and PDSC. And the heat transfer analysis and efficiency calculation also determine which drier have better performance regarding to comparing parameter.

7 CHAPTER EIGHT: Conclusion and Recommendation

7.1 Conclusion

Making efficient solar dryer is used to increase the drying rate with producing better quality product. In this paper the new type PDSCD was design and manufactured with the purpose of increasing the drying efficiency by increasing the drying air temperature. To test the performance of each dryer the comparative experimental test has been used between the PDSCD and FPSCD. This starts from selecting constant parameters such as collector area, solar input energy, and input forced air flow rate. To determine the performance of the driers, unloaded and loaded experimental setup was used and direct and indirect measurement has been taken. The measurement was taking for five consecutive days for every hour using standard measuring tools and instruments. The experimental evaluation was done based on the selected parameters such as absorber and drying air temperature, air flow speed, relative humidity variation inside the drying chamber humidity ratio and finally moisture removing rate on sample product.

The absorber plate temperature of PDSC is higher than FPSC in average 30 to 40 °C gap. The higher absorber temperature gives the higher air temperature, so the drying air temperature flow through the absorber of PDSC is greater than the FPSC. The PDSCD Average drying air temperature at out let with unloaded and loaded setup measured 61°C and 56°C respectively, whereas the Flat Plate Solar Collector drying air temperature at outlet is 50 °C and 43 °C. The air temperature varies with 10 °C gap in average between each drier. The loaded and unloaded average air speed at the outlet of the drying chamber is 1.25 m/s, which is higher than the Flat Plate solar collector that measured 0.65 m/s. The relative humidity measured at the drying chamber of PDSCD is 16.4 % for unloaded and 35 % for loaded set up, whereas for FPSCD it measured 23 % for unloaded and 43.3 % in loaded set up. Hence the ambient relative humidity for both drier measured 42.1% and 38.3% for unloaded and loaded set up respectively. The humidity ratio of the exhaust air at PDSCD is higher than FPSCD type. However, the Average relative humidity of PDSCD in the drying chamber is less than FPSCD. The heat energy transferring efficiency on the collector of PDSC is higher than FPSC. It approved by the greater air temperature measured at the PDSC outlet.

The increasing of air temperature affects the density air which flow through the absorber. The speed of the air also linked with the size of absorber box area. When absorber surface area is large and having high density of the viscosity of air increases and it reduces the speed of drying air and vice versa to small size absorber plate.

The parabolic dish drier can dryer the saw dust quickly than Flat plate drier due to having high speed and drying air temperature, but The PDSC drying chamber get less humidity and high humidity ratio variation relative with FPSC drying chamber. Due to this effect the PDSCD lose more moisture form the briquette than the FPSCD. The Drying rate calculated at PDSCD and FPSCD is 0.0056 kg/hr. and 0.0031 kg/hr. respectively. The moisture content of the briquette reduced to 13% with in 7hr in the drying chamber of PDSCD. This result shows that the drying time require to reduce the moisture from the briquette using PDSCD is better than the dryer listed in the literature which requires 13 hr to dry Apricots using a proficient dish type solar air heater [22].

The overall result analysis shows that the thermal energy absorbed by the absorber using PDSC is 81.482 W and FPSC is 85.95 W, whereas the useful heat Energy gained by the air at PDSC (32.48 W) is higher than FPSC (9.75 W). The average Thermal efficiency of PDSC and FPSC is 31.5 % and 8.9 % respectively. The overall drying efficiency of PDSC is 15.9 %, which is comparatively higher than the FPSC calculated as 8.7 %.

In general, from this experiment the PDSC is proven that it has high performance to drying saw dust briquette than the FPSC driers. However, the PDSCD has overall efficiency of 15.9 % which is less than from the literatures works on drying of apricots using a proficient dish type solar air heater that having 42.6% efficiency. The PDSCD have less efficiency compare to the previous work. This is happened due to the high air flow rate effect at the outlet of drying chamber that increases the heat loss at selected sample briquette.

The total cost which invested for making each prototype is relatively low and different. But when each dryer compares, the PDSCD costs 3419.17 ETB and FPSCD costs 1662 ETB, which listed in detail at the Appendix F. Therefore, the PDSCD construction cost is higher than the FPSCD ones due to using metal for the frame body construction.

7.2 Recommendation and Future Work

From this experimental result the PDSC type drier is proven that it has a potential to dry more than one briquette sample in a given duration of time. From the result the drying efficiency is low because of loss of hot air at the outlet of the drying chamber. The drying efficiency can be increased using large size drying chamber which capable of holding much briquette in it. This drier is more effective with automatic trucking system, so by using low cost trucking system it is possible getting better efficiency on drying regarding to minimizing the drying time. So, the following points are important suggestion for future work and further research.

i. By regulating the air speed, it is possible to increase the heat energy gained by the air and for low speed of air it is highly efficient to gate the hot air flow to the drying chamber. To absorb the heat energy from the absorber surface efficiently there must be optimum velocity of air. Otherwise by some blocking for the air flow inside the absorber we can limit the air flow and increasing the drying air temperature.

ii. For this experimental works of prototype building the cost of PDSCD is relatively high due to using metal but it is possible by using wood to reduce the overall cost

iii. The new concept recommended design is expected to increase the drying efficiency of the dryer without adding extra size collector and fan but by modifying drying chamber. By combining the FPSC and PDSC driers it is possible to made new type PDSC with flat plate dryer chamber for better performance.

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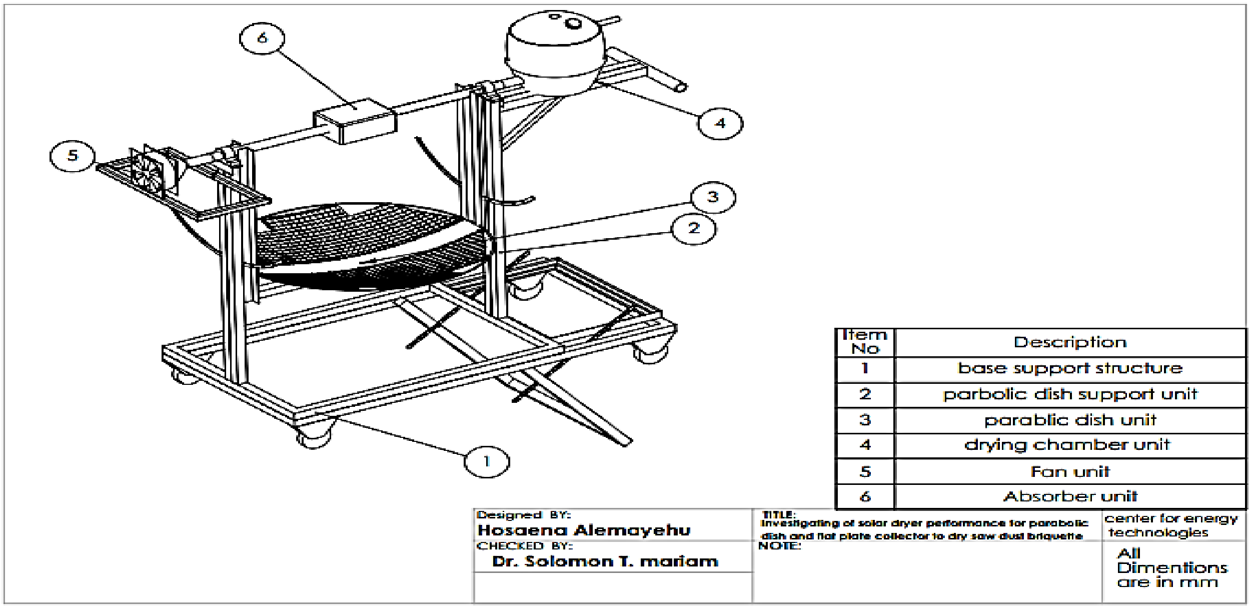
8.1 APPEDIX

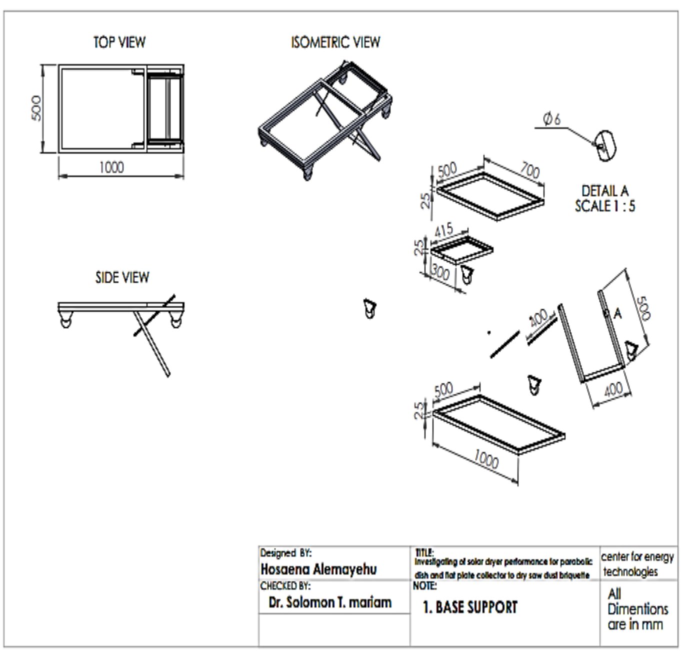
8.2 Appendix A: Solid work sketch of PDSC & FPSC

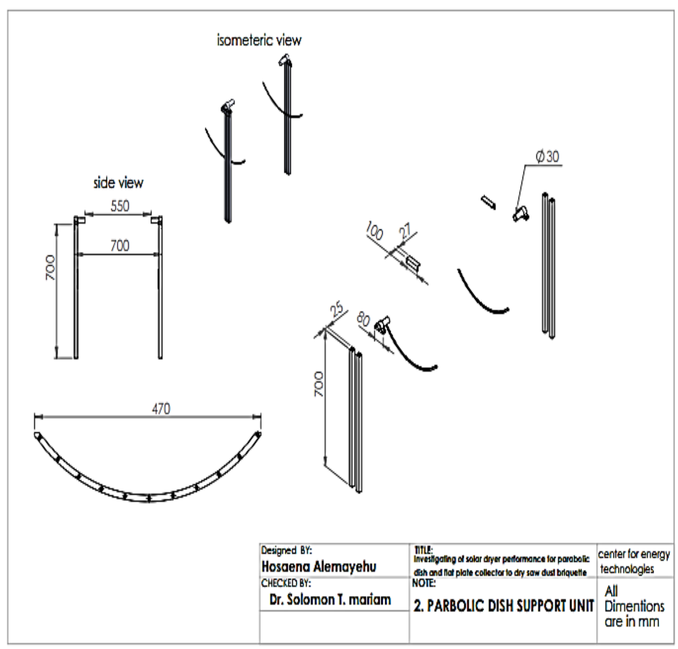
1.1 Parabolic Dish drier Design



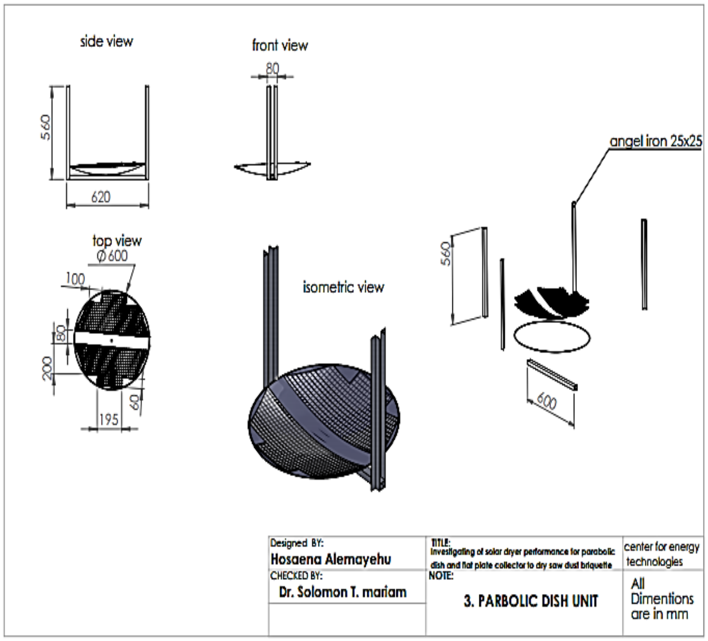
Part 1: Base support unit

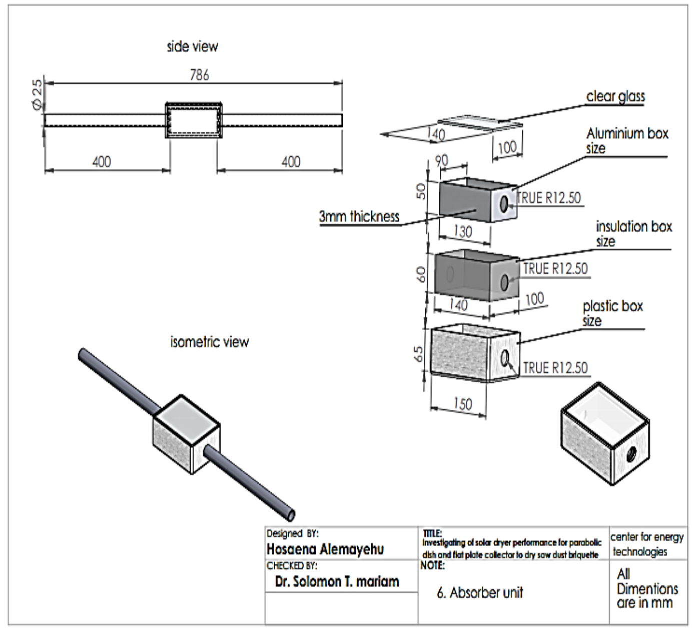
Part 2: Parabolic dish support unit



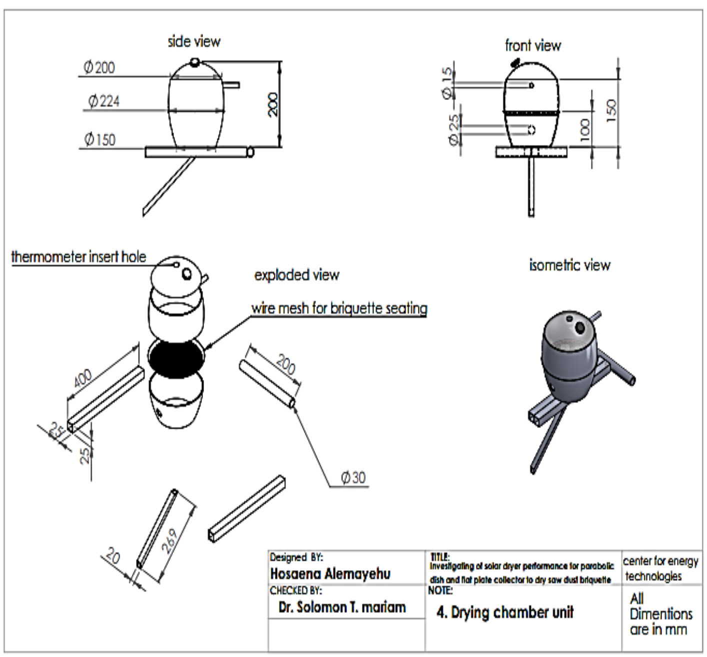


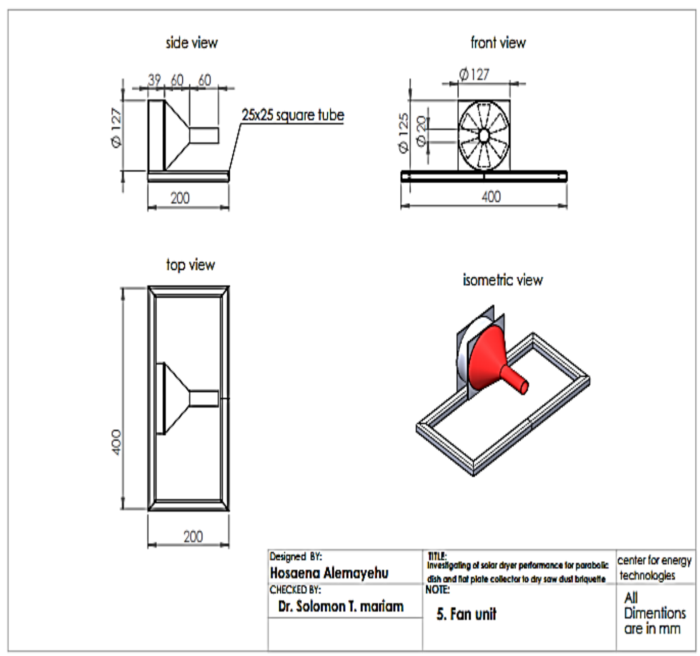
Part 3: Parabolic dish reflector unit **Part 4: Absorber box Unit**



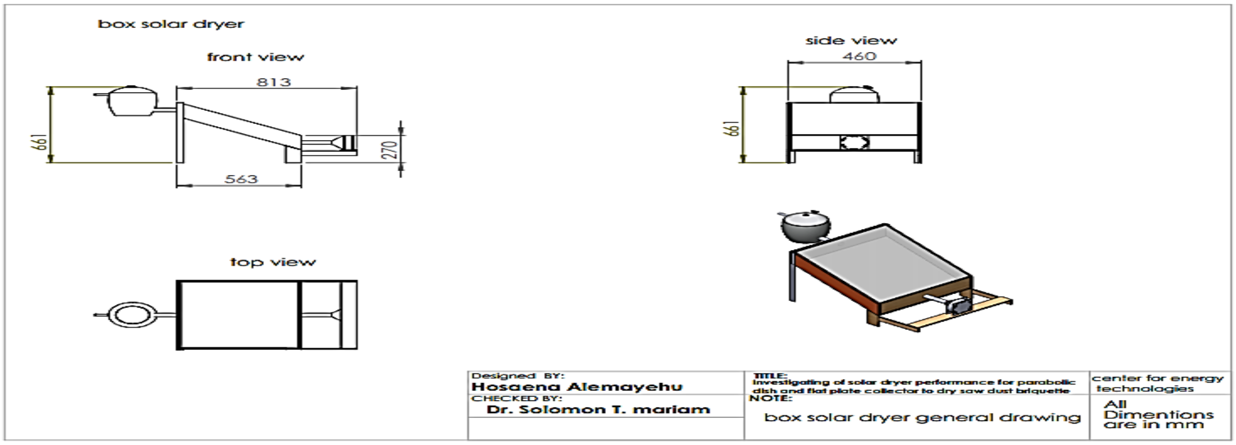


Part 5: Drying Chamber Unit **part 6: Fan unit**

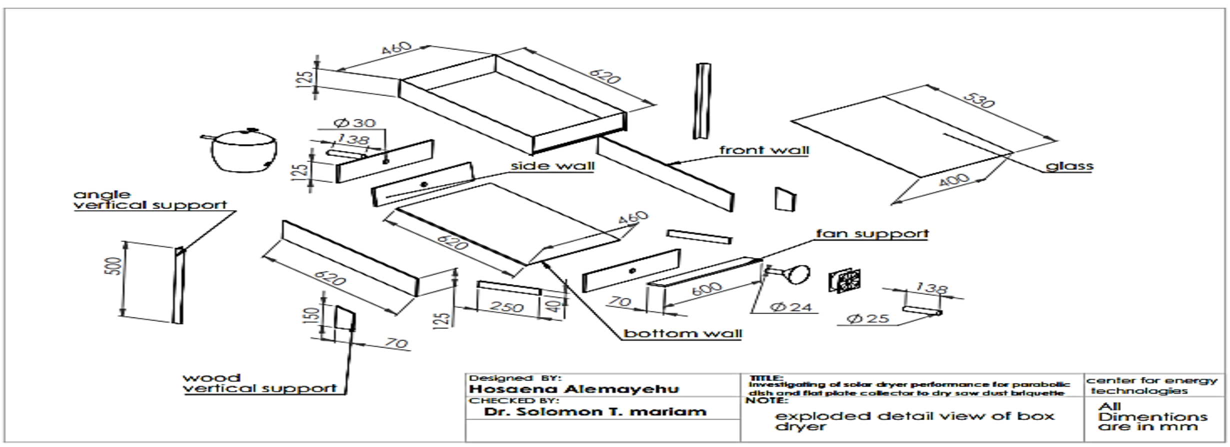




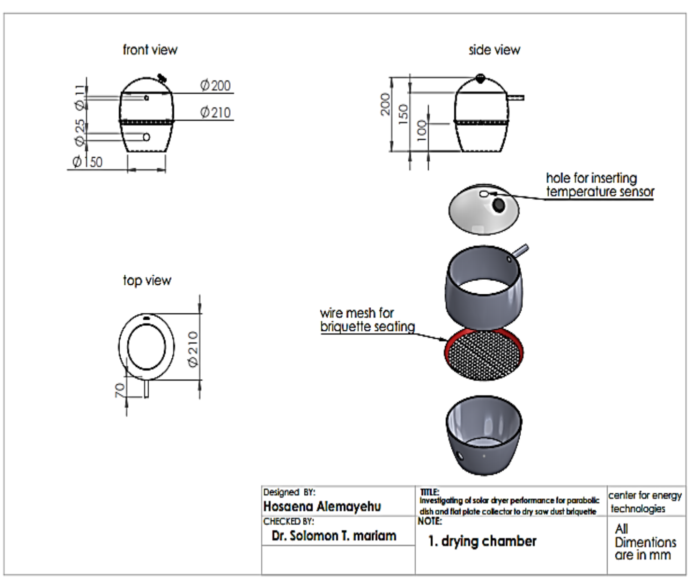
1.2 Flat Plate Drier Design

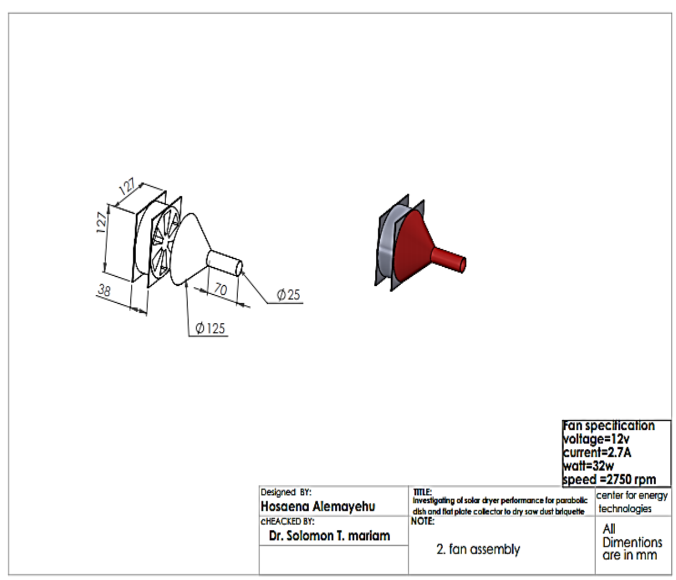


Part 1: **Flat Plate collector box** Exploded view



Part 2: Fan and Drying chamber Assembly





8.3 Appendix B: Direct measuring Data for Unloaded and Loaded briquettes

Time Interval	Solar data		PDSC			FPSC		
Day 1	I_s	T_{1amb}	$T_{abs.P}$	$T_{2.P}$	$V_{air.P}$	$T_{abs.F}$	$T_{2.F}$	$V_{air.F}$
Units	**W/m2**	**°C**	**°C**	**°C**	m/s	**°C**	**°C**	m/s
9:00 Am	394	24	80	58	1.2	46	40	0.6
10:00Am	609	26	88	60	1.3	50	44	0.7
11:00 Am	749	28	99	63	1.4	56	47	0.8
12:00 Am	765	30	108	68	1.6	60	50	0.8
1:00 pm	558	30	98	68	1.6	52	44	0.7
2:00 pm	330	25	88	72	1.7	49	41	0.7
3:00 pm	520	26	89	67	1.5	54	44	0.7
4:00 pm	218	23	76	55	1.2	47	38	0.6
Average	**517.8**	**26.5**	**90.7**	**63.8**	**1.43**	**51.75**	**43.5**	**0.70**
Maximum	765	30	108	72	1.7	60	50	0.8
Minimum	218	23	76	55	1.2	46	38	0.6

Day 2	I_s	T_{1amb}	$T_{abs.P}$	$T_{2.P}$	$V_{air.P}$	$T_{abs.F}$	$T_{2air.F}$	$V_{air.F}$
Units	**W/m2**	**°C**	**°C**	**°C**	m/s	**°C**	**°C**	m/s
9:00 Am	299	23	72.2	55	1.2	44	38	0.6
10:00Am	501	25	86.2	60	1.3	48	40	0.6
11:00 Am	671	27	95.2	64	1.4	52	44	0.7
12:00 Am	698	28	107.8	69	1.6	57	47	0.8
1:00 pm	523	29	88.2	62	1.4	52	43	0.7
2:00 pm	384	27	82.9	60	1.3	48	41	0.7
3:00 pm	404	26	78.2	58	1.2	48	41	0.7
4:00 pm	310	24	74	56	1.2	44	39	0.6
Average	**473.7**	**26.1**	**85.5**	**60.5**	**1.325**	**49.1**	**41.6**	**0.67**
Maximum	698	29	107.8	69	1.6	57	47	0.8
Minimum	299	23	299	55	1.2	44	38	0.6

Day 3	I_s	T_{1amb}	$T_{abs.P}$	$T_{2.P}$	$V_{air.P}$	$T_{abs.F}$	$T_{2.F}$	$V_{air.F}$
Units	**W/m2**	**°C**	**°C**	**°C**	m/s	**°C**	**°C**	m/s
9:00 Am	161	20	70	54	1.2	42	31	0.5
10:00Am	202	22	71	56	1.2	44	34	0.5
11:00 Am	270	23	74	57	1.2	46	36	0.6
12:00 Am	387	24	80	58	1.3	48	42	0.7
1:00 pm	483	26	84	60	1.3	50	46	0.7
2:00 pm	417	25	86	62	1.4	51	47	0.8
3:00 pm	485	26	86	62	1.4	56	49	0.8
4:00 pm	347	24	75	58	1.2	51	43	0.7
Average	**344**	**23.7**	**78.25**	**58.3**	**1.27**	**48.5**	**41**	**0.66**
Maximum	485	26	86	62	1.4	56	49	0.8
Minimum	161	20	70	54	1.2	42	31	0.5

Time Interval	Solar data		PDSC			FPSC		
Day 4	I_s	T_{1amb}	$T_{abs.P}$	$T_{2.P}$	$V_{air.P}$	$T_{abs.F}$	$T_{2.F}$	$V_{air.F}$
Units	**W/m2**	**°C**	**°C**	**°C**	m/s	**°C**	**°C**	m/s
9:00 Am	241	22	70	54	1.2	44	37	0.6
10:00Am	340	23	78	58	1.3	45	40	0.7
11:00 Am	550	25	89	62	1.4	48	42	0.7
12:00 Am	564	26	92	65	1.5	51	43	0.7
1:00 pm	636	27	100	67	1.6	54	46	0.8
2:00 pm	725	28	103	68	1.6	57	47	0.8
3:00 pm	716	27	99	62	1.4	56	47	0.8
4:00 pm	545	26	90	60	1.3	54	44	0.7
Average	**539.6**	**549.7**	**90.1**	**62**	**1.41**	**51.1**	**43.25**	**0.72**
Maximum	725	725	103	68	1.6	57	47	0.8
Minimum	241	241	70	54	1.2	44	37	0.6

5th Day Direct Experimental Data records for (PDSC and FPSC)

Time Interval	Solar data and Ambient		PDSC					FPSC				
Day 5	I_s	T_{1amb}	$T_{abs.P}$	$T_{3Db.P}$	$T_{2.P}$	$V_{air.P}$	$M_{br.P}$	$T_{2.P}$	$T_{3Db.F}$	$T_{abs.P}$	$V_{air.F}$	$M_{br.F}$
Units	W/m2	**°C**	**°C**	**°C**	**°C**	m/s	**(kg)**	**°C**	**°C**	**°C°**	m/s	**kg**
9:00 Am	418	24	76	45	56	0.9	0.105	45	39	48	0.6	0.108
10:00 Am	609	26	91	54	62	1.2	x	52	41	50	0.7	x
11:00 Am	751	29	102	59	66	1.3	x	56	48	56	0.8	x
12:00 Am	833	32	112	63	70	1.4	x	58	52	62	0.9	x
1:00 pm	761	30	109	64	70	1.4	x	57	53	60	0.9	x
2:00 pm	396	26	76	53	58	1.2	x	41	39	52	0.6	x
3:00 pm	433	25	78	56	60	1.2	x	46	42	50	0.7	x
4:00 pm	279	23	70	54	55	1.2	0.066	40	35	46	0.6	0.086
Average	**560**	**26.875**	**89.25**	**56**	**62.12**	**1.225**	**0.09**	**49.375**	**43.625**	**53**	**0.725**	**0.024**
Maximum	833	32	112	64	70	1.4	0.105	58	53	62	0.9	0.108
Minimum	279	23	70	45	55	0.9	0.066	40	35	46	0.6	0.086

Appendix C: Indirect measuring and Recorded Data for Unloaded and Loaded briquettes

Time Interval	Solar data and Ambient humidity		PDSC (wet and dry bulb temperature , Drying chamber relative humidity and humidity ratio)				FPSC (wet and dry bulb temperature , Drying chamber relative humidity and humidity ratio)			
Day 1	**I_s**	**Amb R.H**	**T_{wP}**	**T_{3dP}**	**DC R.H .P**	**H.R.P**	**T_{3wF}**	**T_{3dF}**	**DC R.H.F**	**H.R.F**
Units	(W/m^2)	(%)	°C	°C	(%)	Kg/kg	°C	°C	(%)	Kg/kg
9:00 Am	394	41	34	58	23	0.0365	26	40	36	0.023
10:00 Am	609	37	33	60	19	0.0325	26	44	27	0.0213
11:00 Am	749	33	34	63	17	0.0343	25	47	20	0.0179
12:00 Am	765	30	35	68	14	0.0354	27	50	20	0.021
1:00 pm	558	31	36	68	16	0.0389	24	44	22	0.0171
2:00 pm	330	33	40	72	17	0.0527	23	41	25	0.0164
3:00 pm	520	39	38	67	19	0.0467	26	44	27	0.0213
4:00 pm	218	42	31	55	21	0.0289	23	38	31	0.0177
Average	**517.875**	**35.75**	**35.12**	**63.875**	**18.2**	**0.038**	**25**	**43.5**	**26**	**0.0194**
Maximum	765	42	40	72	23	0.0527	27	50	36	0.023
Minimum	218	30	31	55	14	0.0289	23	38	20	0.0164
Day 2	**I_s**	**Amb R.H**	**T_{3wP}**	**T_{3dP}**	**DC R.H .P**	**H.R.P**	**T_{3wF}**	**T_{3dF}**	**DC R.H.F**	**H.R.F**
Units	(W/m^2)	(%)	°C	°C	(%)	Kg/kg	°C	°C	(%)	Kg/kg
9:00 Am	299	55	31	55	21	0.0289	24	38	35	0.0196
10:00 Am	501	46	33	60	19	0.0325	22	40	24	0.015
11:00 Am	671	41	32	64	16	0.0339	22	44	17	0.0133
12:00 Am	698	38	36	69	15	0.0384	24	47	18	0.0158
1:00 pm	523	39	30	62	12	0.0232	23	43	21	0.0156
2:00 pm	384	39	29	60	13	0.0215	22	41	22	0.0145
3:00 pm	404	44	31	58	18	0.0276	23	41	25	0.0164
4:00 pm	310	44	32	56	22	0.0313	22	39	26	0.0154
Average	**473.75**	**43.2**	**31.7**	**60.5**	**17**	**0.0296**	**22.7**	**41.625**	**23.5**	**0.0157**
Maximum	698	55	36	69	22	0.0384	24	47	35	0.0196
Minimum	299	38	29	55	12	0.0215	22	38	17	0.0133
Day 3	**I_s**	**Amb R.H**	**T_{3wP}**	**T_{3dP}**	**DC R.H .P**	**H.R.P**	**T_{3wF}**	**T_{3dF}**	**DC R.H.F**	**H.R.F**
Units	(W/m^2)	(%)	°C	°C	(%)	Kg/kg	°C	°C	(%)	Kg/kg
9:00 Am	161	64	30	54	21	0.0266	20	31	40	0.0152
10:00 Am	202	62	29	56	16	0.0232	19	34	28	0.0123
11:00 Am	270	59	27	57	12	0.018	18	36	20	0.01
12:00 Am	387	54	26	58	10	0.0154	21	42	18	0.0124
1:00 pm	483	48	28	60	11	0.0191	23	46	17	0.0143
2:00 pm	417	46	31	62	14	0.0259	24	47	18	0.0158
3:00 pm	485	42	35	62	20	0.038	26	49	19	0.0192
4:00 pm	347	42	34	58	23	0.036	25	43	27	0.019
Average	**344**	**52.12**	**30**	**58.37**	**15.8**	**0.0253**	**22**	**41**	**23.37**	**0.014**
Maximum	485	64	35	62	23	0.038	26	49	40	0.0195
Minimum	161	42	26	54	10	0.0154	18	31	17	0.01

Time Interval	Solar data and Ambient humidity		PDSC (wet and dry bulb temperature, Drying chamber relative humidity and humidity ratio)				FPSC (wet and dry bulb temperature, Drying chamber relative humidity and humidity ratio)			
Day 4	I_s	Amb R.H	T_{3wP}	T_{3dP}	DC R.H. P	H.R.P	T_{3wF}	T_{3dF}	DC R.H.F	H.R.F
Units	(W/m^2)	(%)	°C	°C	(%)	Kg/kg	°C	°C	(%)	Kg/kg
9:00 Am	241	47	30	54	21	0.0266	23	37	34	0.0181
10:00 Am	340	44	31	58	18	0.0276	22	40	24	0.015
11:00 Am	550	41	30	62	12	0.0232	21	42	18	0.0124
12:00 Am	564	39	32	65	13	0.0274	20	43	14	0.0103
1:00 pm	636	35	33	67	13	0.0295	22	46	15	0.0125
2:00 pm	725	33	33	68	12	0.0291	22	47	14	0.0121
3:00 pm	716	31	30	62	12	0.0232	23	47	16	0.0139
4:00 pm	545	31	31	60	16	0.0267	24	44	22	0.0171
Average	**539.625**	**37.625**	**31.25**	**62**	**14.625**	**0.02666**	**22.125**	**43.25**	**19.625**	**0.01393**
Maximum	725	47	33	68	21	0.0295	24	47	34	0.0181
Minimum	241	31	30	54	12	0.0232	20	37	14	0.0103

Day 5	I_s	Amb R.H	T_{3wP}	T_{3dP}	DC R.H .P	H.R.P	T_{3wF}	T_{3dF}	DC R.H.F	H.R.F
Units	(W/m^2)	(%)	°C	°C	(%)	Kg/kg	°C	°C	(%)	Kg/kg
9:00 Am	418	46	38	45	66	0.0566	31	39	59	0.0358
10:00 Am	609	42	40	54	45	0.0608	31	41	52	0.0349
11:00 Am	751	37	40	59	34	0.0586	33	48	39	0.0377
12:00 Am	833	34	41	63	30	0.0612	36	52	38	0.0459
1:00 pm	761	33	40	64	26	0.0563	37	53	39	0.0491
2:00 pm	396	35	36	53	36	0.0455	29	44	36	0.0283
3:00 pm	433	41	32	56	22	0.0313	28	42	38	0.0267
4:00 pm	279	39	30	54	21	0.0266	25	36	44	0.0225
Average	**560**	**38.3**	**37.1**	**56**	**35**	**0.04961**	**31.25**	**44.3**	**43.1**	**0.03511**
Maximum	833	46	41	64	66	0.0612	37	53	59	0.0491
Minimum	279	33	30	45	21	0.0266	25	36	36	0.0225

8.4 Appendix D: Result Analysis Table from Average data

4 days unloaded average data Analysis for Direct and Indirect measurement result

$C_{Pa.P}$ = 1.0049 kJ/kg K , $A_{c.p}$ = $A_{c.p}$ = 0.217 η$_{opt.p}$ =0.73, η$_{opt.F}$ = 0.77

Day 1-4 For PDSC Unloaded average data Analysis

Time	I_s	$C_{Pa.P}$	$A_{c.p}$	$\eta_{opt.p}$	ΔT_{air}	$\dot{m}_{air.P}$	$Q_{abs.P}$	$Q_{ua.P}$
Units	(W/m^2)	kJ/kg	m^2	℃	℃	Kg/h	Wh	j/s
9:00 AM	273.75	1.0049	0.217	0.73	50.8	1.044	43.364	30.8
10:00 AM	413	1.0049	0.217	0.73	56.8	1.116	65.423	33.8
11:00 AM	560	1.0049	0.217	0.73	63.5	1.152	88.709	36.64
12:00 AM	603.5	1.0049	0.217	0.73	69.9	1.296	95.600	43.28
1:00 PM	550	1.0049	0.217	0.73	64.5	1.26	87.125	40.6
2:00 PM	464	1.0049	0.217	0.73	63.7	1.26	73.502	44.12
3:00 PM	531.25	1.0049	0.217	0.73	61.8	1.188	84.155	37.58
4:00 PM	355	1.0049	0.217	0.73	54.5	1.08	56.235	31.09
Average	**468.81**	**1.0049**	**0.217**	**0.73**	**60.7**	**1.1745**	**74.264**	**37.25**
Maximum	603.5	1.0049	0.217	0.73	69.9	1.296	95.600	44.12
Minimum	273.75	1.0049	0.217	0.73	50.8	1.044	43.3647	30.85

$C_{Pa.P}$ = 1.0049 kJ/kg K , $A_{c.p}$ = $A_{c.p}$ = 0.217 η$_{opt.p}$ =0.73, η$_{opt.F}$ = 0.77

Day 1-4 For FPSC Unloaded average data Analysis

Time	$Ins\ (I_b)$	$C_{Pa.P}$	$A_{c.p}$	$\eta_{opt.F}$	ΔT_{air}	$\dot{m}_{air.F}$	$Q_{abs.F}$	$Q_{ua.F}$
Units	(W/m^2)	kJ/kg	m^2	℃	℃	Kg/s	Wh	j/s
9:00 AM	273.75	1.0049	0.217	0.77	21.7	0.54	45.740	6.78
10:00 AM	413	1.0049	0.217	0.77	22.7	0.576	69.008	7.92
11:00 AM	560	1.0049	0.217	0.77	24.7	0.684	93.570	9.45
12:00 AM	603.5	1.0049	0.217	0.77	27	0.684	100.838	11.2
1:00 PM	550	1.0049	0.217	0.77	24	0.684	91.899	9.82
2:00 PM	464	1.0049	0.217	0.77	25	0.684	77.529	10.7
3:00 PM	531.25	1.0049	0.217	0.77	27.2	0.684	88.766	11.5
4:00 PM	355	1.0049	0.217	0.77	24.7	0.612	59.316	8.91
Average	**468.813**	**1.0049**	**0.217**	**0.77**	**24.6**	**0.6435**	**78.333**	**9.55**
Maximum	603.5	1.0049	0.217	0.77	27.2	0.684	100.838	11.5
Minimum	273.75	1.0049	0.217	0.77	21.7	0.54	45.7408	6.78

Table: **5th day Loaded** average result data Analysis for Direct and Indirect measurement

$C_{Pa.P}$ = 1.0049 kJ/kg K, $A_{c.p}$ = $A_{c.p}$ = 0.217 $\eta_{opt.p}$ =0.73, $\eta_{opt.F}$ = 0.77

Day 5 **For PDSC loaded average data Analysis**

Time	I_s	$\dot{m}_{air.P}$	ΔT_{air}	$C_{Pa.P}$	$A_{c.p}$	$\eta_{opt.p}$	$Q_{abs.P}$	$Q_{ua.P}$
Units	Wh/m²	Kg/h	℃	kJ/kg	m^2		Wh	J/s
9:00 AM	418	0.792	52	1.0049	0.217	0.73	66.21	14.91
10:00 AM	609	1.044	65	1.0049	0.217	0.73	96.47	25.84
11:00 AM	751	1.116	73	1.0049	0.217	0.73	118.96	29.61
12:00 AM	833	1.188	80	1.0049	0.217	0.73	131.95	32.52
1:00 PM	761	1.188	79	1.0049	0.217	0.73	120.55	35.67
2:00 PM	396	1.044	50	1.0049	0.217	0.73	62.73	25.24
3:00 PM	433	1.044	53	1.0049	0.217	0.73	68.59	28.98
4:00 PM	279	1.044	47	1.0049	0.217	0.73	44.19	28.98
Average	**560**	1.0575	**62**	**1.0049**	**0.217**	**0.73**	**88.70**	**27.7**
Maximum	833	1.188	80	1.0049	0.217	0.73	131.95	35.67
Minimum	279	0.792	47	1.0049	0.217	0.73	44.196	14.91

$C_{Pa.P}$ = 1.0049 kJ/kg K, $A_{c.p}$ = $A_{c.p}$ = 0.217 $\eta_{opt.p}$ =0.73, $\eta_{opt.F}$ = 0.77

Day 5 **For FPSC loaded average data Analysis**

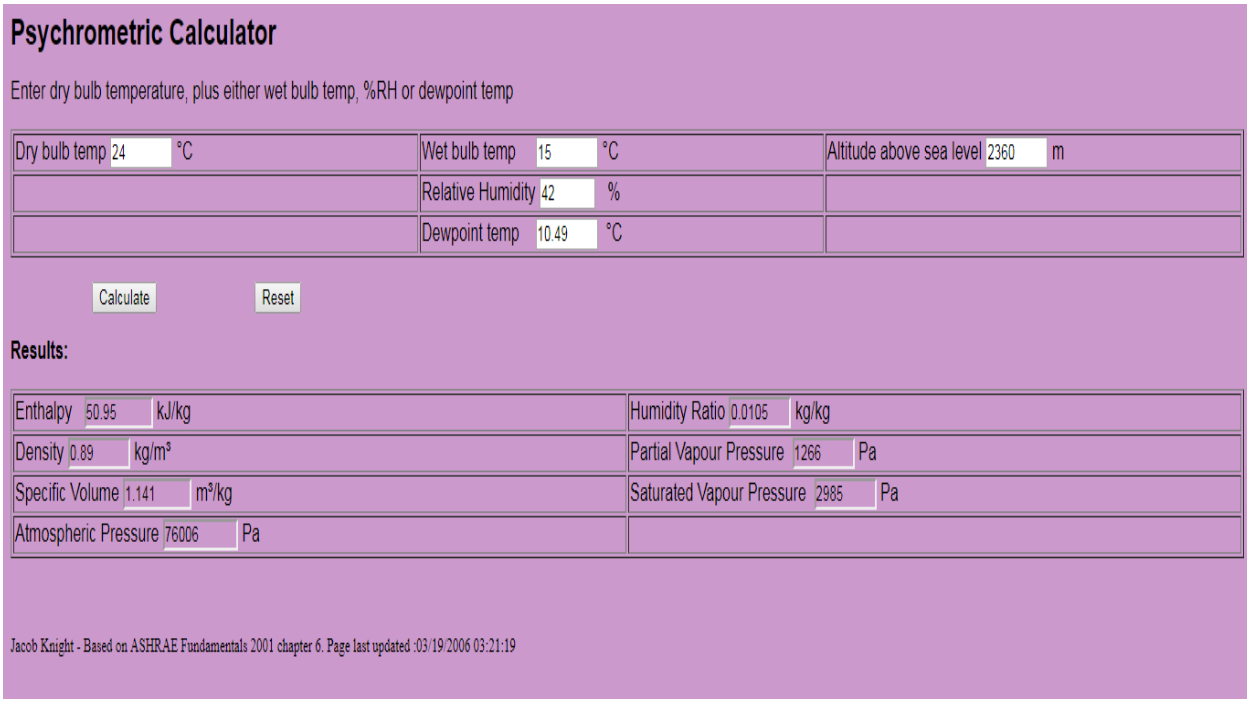
Time	I_s	$\dot{m}_{air.P}$	ΔT_{air}	$C_{Pa.P}$	$A_{c.p}$	$\eta_{opt.F}$	$Q_{abs.P}$	$Q_{ua.P}$
Units	**W/m**	Kg/s	℃	kJ/kg	m^2	℃	Wh	**j/s**
9:00 AM	418	0.54	24	1.0049	0.217	0.77	69.84	7.36
10:00 AM	609	0.64	24	1.0049	0.217	0.77	101.75	8.491
11:00 AM	751	0.72	27	1.0049	0.217	0.77	125.48	11.99
12:00 AM	833	0.72	30	1.0049	0.217	0.77	139.18	14.02
1:00 PM	761	0.79	30	1.0049	0.217	0.77	127.15	15.92
2:00 PM	396	0.54	26	1.0049	0.217	0.77	66.16	6.30
3:00 PM	433	0.64	25	1.0049	0.217	0.77	72.34	9.62
4:00 PM	279	0.57	23	1.0049	0.217	0.77	46.61	5.964
Average	**560**	**0.64**	**26**	**1.0049**	**0.217**	**0.77**	**93.57**	**9.96**
Maximum	833	0.79	30	1.0049	0.217	0.77	139.18	15.9
Minimum	279	0.54	23	1.0049	0.217	0.77	46.61	5.96

Table: Collector Thermal Efficiency result for every hour average experimental data

	Unloaded								
Day (1-4)	**PDSC**				**FPSC**				
Time Interval	$Q_{s.P}$	$Q_{abs.P}$	$Q_{ua.P}$	$\eta_{cth.P}$	$Q_{s.F}$	$Q_{abs.F}$	$Q_{ua.F}$		$\eta_{cth.F}$
Units	W h	Wh	Wh	%	Wh	Wh	Wh	Wh	%
9:00 AM	59.4	43.364	30.85	51.9	59.4	45.74	6.787		11.4
10:00 AM	89.62	65.423	33.83	37.7	89.62	69.008	7.929		8.8
11:00 AM	121.52	88.709	36.64	30.1	121.5	93.57	9.454		7.7
12:00 AM	130.95	95.6	43.28	33	130.9	100.838	11.22		8.5
1:00 PM	119.35	87.125	40.6	34	119.3	91.899	9.82		8.2
2:00 PM	100.6	73.502	44.12	43.8	100.6	77.529	10.765		10.7
3:00 PM	115.2	84.155	37.58	32.6	115.2	88.766	11.523		10
4:00 PM	77.03	56.235	31.09	40.3	77.03	59.316	8.912		115
Average	**101.7088**	**74.264**	**37.25**	**37.9**	**101.7**	**78.333**	**9.55**		**9.6**
Maximum	130.95	95.6	44.12	51.9	130.9	100.838	11.523		11.5
Minimum	59.4	43.3647	30.85	30.1	59.4	45.7408	6.787		7.7
	Loaded								
Day (5)	**PDSC**				**FPSC**				
Time Interval	$Q_{s.P}$	$Q_{abs.P}$	$Q_{ua.P}$	$\eta_{cth.P}$	$Q_{s.F}$	$Q_{abs.F}$	$Q_{ua.F}$		$\eta_{cth.F}$
Units	W h	Wh	Wh	%	Wh	Wh	Wh	Wh	%
9:00 AM	90.7	66.21	14.91	16.4	90.7	69.84	7.367		8.1
10:00 AM	132.1	96.47	25.84	19.5	132.1	101.75	8.491		6.4
11:00 AM	162.9	118.96	29.61	18.1	162.9	125.48	11.992		7.3
12:00 AM	180.7	131.95	32.52	17.9	180.7	139.18	14.023		7.7
1:00 PM	165.1	120.55	35.67	21.6	165.1	127.15	15.923		9.6
2:00 PM	85.93	62.73	25.24	29.3	85.93	66.16	6.307		7.3
3:00 PM	93.96	68.59	28.98	30.8	93.96	72.34	9.623		10.2
4:00 PM	60.54	44.19	28.98	47.8	60.54	46.61	5.964		9.8
Average	**121.4**	**88.7**	**27.7**	**25.2**	**121.4**	**93.57**	**9.961**		**8.3**
Maximum	180.7	131.95	35.67	47.8	180.7	139.18	15.923		10.2
Minimum	60.54	44.196	14.91	16.4	60.54	46.61	5.964		6.4

8.5 Appendix E: psychometrics chart and online software tools used

Psychometric online calculator software https://www.kwangu.com/work/psychrometric.htm



Meteoblue online weather data browsing interface

8.6 Appendix F: Bill of quantity for PDSCD and FPSCD

Components	Bill of Quantity for each dryer type					
	PDSCD			FPSCD		
Item	**Specifications (Quantity × Size, type)**	**Unit price (ETB)**	**Total Price (ETB)**	**Specifications (Quantity × Size, type)**	**Unit price (ETB)**	**Total Price (ETB)**
Satellite dish	1× (0.28 m^2)	200	200	No satellite dish	0	0
Glass cover	1× (0.012 m^2)	4.97	4.97	1× (0.217 m^2)	90	90
Aluminum plate	1× (0.04 m^2)	15.50	15.50	1 × (0.224 m^2)	85	85
Body frame metals	2 × 5m,	175	875	No metal frame	0	0
Bearing & wheel	2 × (D= 0.044m)	40	80	No bearing	0	0
Wood	No wood used	0	0	3m + 0.217 m^2	16.7 +15	65
Insulation cover	1 × (0.09 m^2)	94.5	94.5	1 × (0.224 m^2)	235	235
Reflector glass mirror	218 × (3mm)	0.5	120	No reflector glass	0	0
Drying chamber	0.078 m^2, steel	135	135	0.078 m^2	135	135
Fan (Axial type)	1 × (12V,32 W)	150	150	2700 rpm, 12V, 32 W	150	150
Air passage tube	2 × (40cm) steel	40	45	2 × (10cm)	6	12
Sealing material	1	90	90	1	90	90
Bolt and nets	(2 × 6cm), + (6 × 3cm)	8+ 4	48+ 24	No bolt used	0	0
Welding lead	15	2.5	37.5	No lead used	0	0
Labor cost	-	-	1500	-	-	800
Total cost			**3,419.17 ETB**			**1,662 ETB**

8.7 Appendix G: Optical property of material with color

Absorbed Solar Radiation by Surface Color

Surface Color	Absorb Factor - Fraction of Incident Radiation Absorbed (approximated)
White smooth surfaces	0.25 - 0.40
Grey to dark grey	0.40 - 0.50
Green, red and brown	0.50 - 0.70
Dark brown to blue	0.70 - 0.80
Dark blue to black	0.80 - 0.90