TRAINING MANUAL

FOR DESIGN AND FABRICATION OF HYBRID SOLAR BIOMASS GREENHOUSE DRYER

IFT PROJECT

SCALING UP SOLAR DRYING TO REDUCE POST HARVEST LOSSES IN KENYA-OPPORTUNITIES FOR INCLUSIVE CLIMATE-ENTERPRISES PROJECT

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UN environment programme

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Preface

Preservation of agricultural produce is one of the central problems faced by developing countries due to poor post-harvest practices in farms. The use of solar dryers offers a cheaper, convenient, and environmentally friendly way to dry and reduce post-harvest losses.

The consortium of African Centre for Technology Studies (ACTS), Kenya Industrial Research and Development Institute (KIRDI) and United Nations Environment Programme (UNEP) is implementing the SCALING-UP SOLAR DRYING TO REDUCE POST-HARVEST LOSSES (PHL) IN KENYA– OPPORTUNITIES FOR INCLUSIVE CLIMATE-ACTION ENTERPRISES PROJECT (Solar Dryers Project). The project seeks to scale and commercialize the proof-of-concept of climate-action solutions of low-cost solar drying technology enterprises to cut post harvest losses (PHLs) and drive realization of multiple Sustainable Development Goals (SDGs), leveraging lessons from the UNEP Ecosystem Based Adaptation for Food Security (EBAFOSA) initiative advancing this concept. This solar dryer project has three components: Fabrication of solar dyers, Optimizing business models and Business and Knowledge hub.

The project vision is:

i) To accelerate bridging the $500 million PHLs gap in Kenya by scaling-up the solution in more locations.

ii) Scaling-up support to youth-led SMEs to deploy more affordable solar dryers. Target 500 low-cost dryers over 5 years reaching over 40,000 smallholders.

iii) Grow market for “pay as you dry” services across various Agri-value chains for optimal dehydration of healthy, safe, nutritious food products.

iv) Expand inclusive entrepreneurship and green jobs especially for youth and women in agro-processing.

About this Manual

The objective of this manual is to provide uniform, broad-based scientific and practical information on the construction of solar drying facility that would be used for safe processing of fruits and vegetable through solar drying. This manual:

(i) Provides a teaching tool to train trainers who will be conducting courses to facilitate construction and upscaling of solar dryers in different parts of the country.

(ii) Serves as a resource for trainers preparing and conducting courses to assist those in the solar dryer fabrication industry in identifying and implementing appropriate measures to ensure solar dryers are standardized and of high quality.

The material in this manual is guidance and not regulation and should be applied as appropriate and feasible to individual in solar dryer fabrication industry.

Abbreviations

ACTS – African Centre for Technology Studies

EBAFOSA - Ecosystem Based Adaptation for Food Security

GMP – Good Manufacturing Practise

HSBGD – Hybrid Solar Biomass Greenhouse Dryer

IFT – Institute of Food Technologists

KIRDI – Kenya Industrial Research and Development Institute

SDG - Sustainable Development Goals

PHL – Post Harvest Loss

PV – Photovoltaic

SME – Small and Medium Enterprises

UNEP – United Nations Environment Programme

UV – Ultraviolet

Use of this Manual

The information presented includes:

Principles (science-based) information regarding standardized high quality hybrid solar dryer.

Topics included are:

- Introduction to solar drying technology
- Hybrid solar dryer fabrication
- Requirement for installation of hybrid solar dryer
- Good manufacturing practices (GMPs)
- Maintenance of hybrid solar dryer
- Business model

Additional Resources – include relevant reference documents, videos and web information on issues addressed by this manual. This training manual provides broad, scientifically based principles. Trainers should encourage operators to use the information to help assess solar dryer technology advances that expand understanding of those factors associated with fabrication of hybrid solar dryers. Awareness of these advances will allow updating of the recommendations and information contained in this manual as appropriate to keep the content current.

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MODULE 1: Introduction to Solar Drying Technology

Learning outcomes:

Trainers should understand solar drying technology and able to differentiate various solar dryers available in Kenya

1.1 Introduction

Solar drying is a method of food preservation, which inhibits the growth of bacteria, yeasts, and molds through the removal of water. Dehydration has been widely used for this purpose since ancient times. Water is traditionally removed through evaporation (air-drying, sun drying, smoking or wind drying).

Food drying requires high-energy consumption due to the considerable latent heat of evaporation of water and the relatively low energy efficiency of the industrial dryers. The required energy for drying can take up from 7% to 15% of the corresponding total energy use. Hence, using solar energy in drying applications is a potential alternative since it decreases consumption of conventional energy by about 27% to 80%.

Farmers in developing countries cannot afford to import expensive equipment that is either electrically or diesel engine driven. In addition, the access to conventional energy remains very limited in these countries. Hence, they use direct sun drying to preserve their agricultural products. This process is affordable in terms of cost due to its inexpensive nature; using solar radiation. Even though this traditional method is cheap, it suffers from many drawbacks such as the long drying process, labor cost and deterioration of the product quality due to several factors like dust, moisture, insects and micro-organisms' attacks. Thus, farmers in developing countries face problems in drying their products fast and in suitable environmental conditions. Therefore, cost-effective and drying kinetics are the major criteria characterizing the dryer device and are the main parameters affecting the quality of the dried foods.

Unfortunately, solar dryers are limited and intermittent. Their performances depend strongly on climatic conditions (solar irradiation, ambient temperature, ambient relative humidity and natural airflow). Hence, they cannot be fully effective without the use of a secondary heating source. This can extend the drying time, can allow the control of drying parameters and can help to overcome the intermittency of solar energy.

Various types of hybrid solar dryers using electrical heaters, biomass and gas burners have been designed and developed for drying various agricultural products.

What is a Solar Dryer?

Solar dryers are devices that use solar energy to dry substances, especially food e.g. mangoes, pineapples, bananas, coffee etc. Solar dryers use the heat from sun to remove the moisture from food substances. Most of the solar dryers have three major drier components:

- A drying/food chamber in which food is dried,
- A solar collector that heats the air, and
- Some type of airflow system (forced or natural)

Air is circulated by fans powered by a solar photovoltaic system, a generator, or a central utility. Air is forced into the solar collector by the fans where it is heated by the solar energy, and then flows on to the food drying section. An advantage of the PV powered system is that, depending on the solar radiation, the air through put is automatically adjusted by the speed of the fans (Mathew *et al*., 2001)

1.2 Classification of Solar Dryers

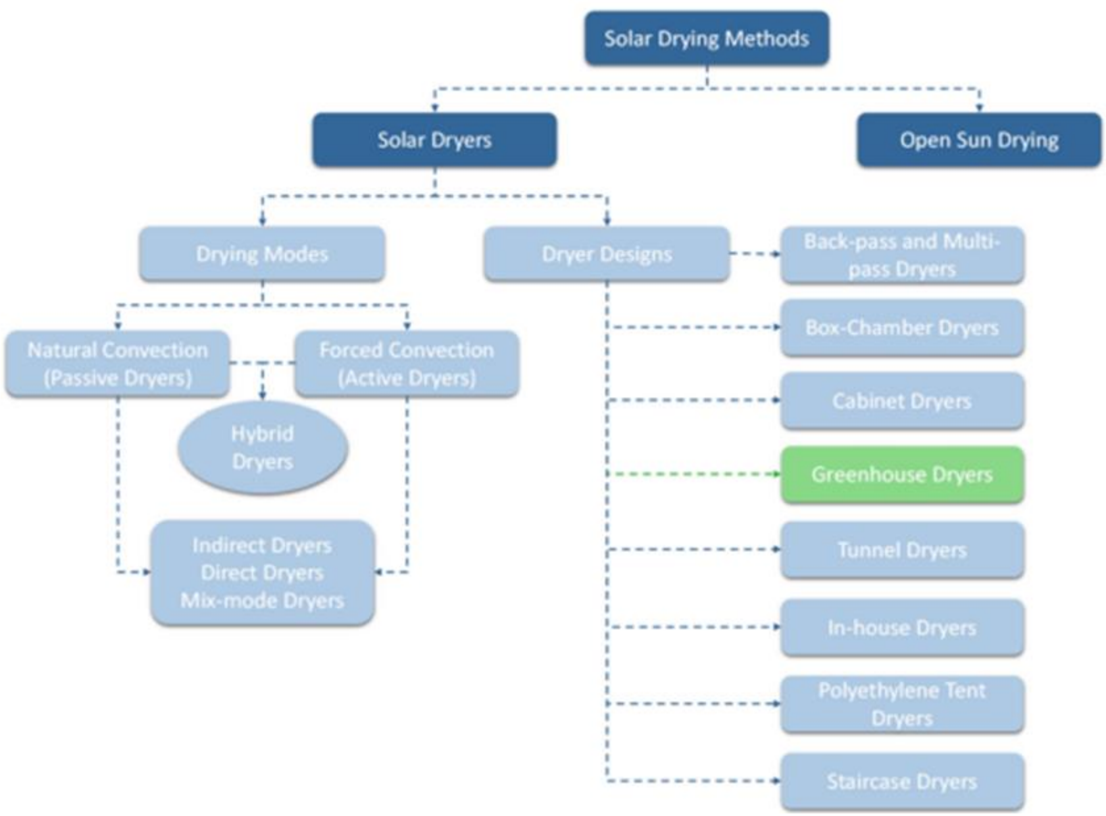


Figure 1: Classification of solar dryers

Solar dryers are available in a range of sizes and designs and are used for drying of various agricultural products. They can be classified into several categories depending on the design or working principle of the dryer, mode of drying, and type of product to be dried (Figure 1). The classification of available solar dryers for agriculture products based on the mode of air circulation e.g. natural and forced circulation; and mode of utilization of solar energy e.g. direct, indirect and mixed modes. Solar dryers can be broadly classified into either forced convection or natural convection solar dryer.

1.2.1 Forced Convection Dryer

The forced convection dryer is where hot air is forced through the product bed by means of external device such as a fan or a blower, normally referred to as active dryer.

1.2.2 Natural Convection Dryer

In the natural convection solar dryer, the heated air flows through the product naturally by thermal gradient. It is sometimes called a passive dryer because of the natural movement of heated air.

1.2.3 Direct Solar Dryer

This is the class of dryer in which the solar radiation is absorbed directly by the product intended to be dried. The material to be dried is placed in an enclosure, with transparent covers or side panels. The products are directly exposed to solar radiation through the transparent covers (Figure 2).

Advantages

- The drying rate is very high compared to natural sun drying.
- Easy to assembly using locally available materials.

Disadvantage

- The direct exposure of solar radiation may cause discoloration on the product and thus greatly reduce the quality of the dried product.

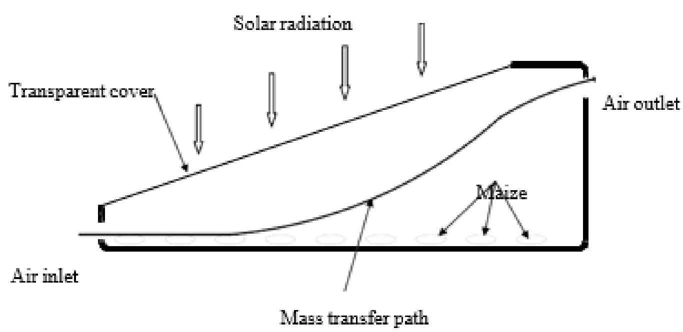


Figure 2: Simple type of direct solar dryer

1.2.4 Indirect Solar Dryer

In this type of dryer, the solar radiation gained by the system is used to heat the air, which passes through the product to be dried. The air is heated in a flat plate collector through black painted absorber plate which converts solar radiation to heat energy; the heated air is then channeled to drying chamber (Figure 3).

Advantages

- Drying rate is high compared to direct solar drying, thus improved quality of the product.
- Nutritional value of product is preserved in indirect dryers due to non-direct exposure of solar radiations to the products.

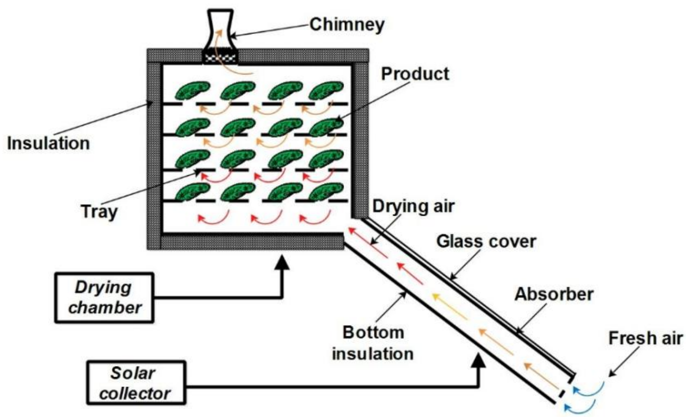


Figure 3: Indirect solar dryer

1.2.5 Mixed-Mode Solar Dryer

The mixed type dryer is a combined direct and indirect drying where the hot air from the exterior solar heater is combined with direct solar heating of the products through the transparent roof of the drying cabinet (Figure 4).

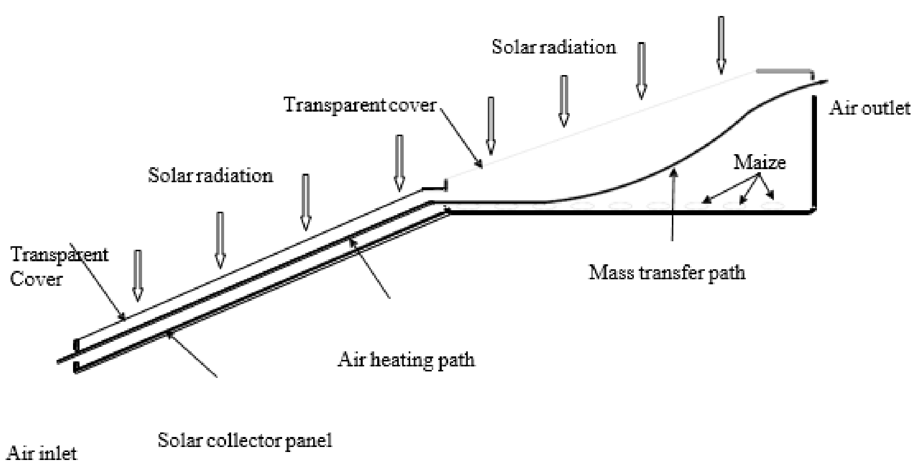


Figure 4: Simple form of mixed mode dryer

1.2.6 Hybrid Solar Dryers

In a hybrid system, a combination of solar energy with another source of energy such as fossil fuel, electricity or biomass are employed in order to have a double heating. Hybrid dryers work in two ways; the first one is when solar heating is the principal source of energy during sunny days with additional heat supplied by an auxiliary heating system during cloudy days or in some cases at night to maintain continuous drying. Secondly, when the conventional energy sources are used as the main means of heating the drying air and solar energy is used as a supplement to reduce fuel costs. Figure 5 (a) – (c).

Advantages

- Better quality dried products in comparison to the products dried in an exclusively solar dryer system.
- Besides, this dryer has lower operational costs compared to a conventional dryer in which air is heated using electricity or fossil fuels.

Figure 5: (a) and (b) Hybrid solar biomass cabinet dryer (c) Hybrid solar biomass tunnel dryer

Types of hybrid dryers

- Solar Biomass hybrid dryer
- Solar Biogas hybrid dryer
- Solar Thermal hybrid dryer
- Solar LPG hybrid dryer
- Solar Electric hybrid dryer

1.3 Greenhouse Solar Drying Technology

Greenhouse dryers are generally the direct type dryers, which are considered as the best mean to harness solar energy for space heating and drying. It works on the principle of greenhouse effect that implies that the cover of greenhouse dryer allows the short wavelength solar radiation through it while the long wavelength radiation coming from inside remains trapped inside the dryer. This rises the inside temperature of dryer which is required for drying purpose. In some cases polycarbonate cover is used for greenhouse solar drying system for construction in order to improve thermal performance.

1.3.1 Orientation and Geometry

Solar dryers are normally oriented to maximize the capture of available solar irradiation. For areas lying in latitudes lower than 40^0, like Busia, Siaya, Kakamega and Bungoma; the north-south orientation is recommended to maximize all-year sunlight irradiation into the greenhouse. However, for higher altitudes, like Mount Elgon region within Bungoma County, an east-west orientation would be the preferred option.

From literature review, two geometry configurations, Quonset and Gothic arch shapes, were considered for adoption due to their efficacy (Figure 6). A Quonset shape was applied as it provided a better configuration to support the auxiliary ventilator, chimney and axial fan mounting structures with minimal condensation of moisture on the films.

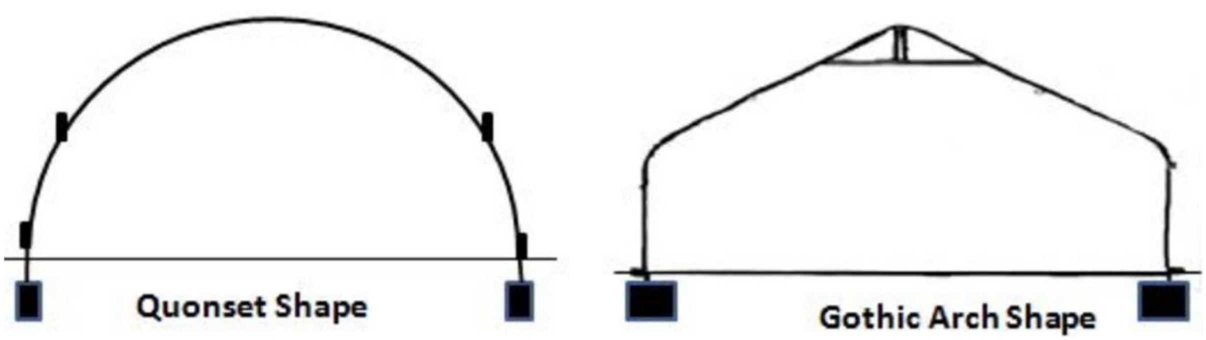


Figure 6: Adopted geometry for green-house dryers

1.3.2 Classification of Greenhouse type Solar Dryers

Greenhouse solar dryers are classified as shown in Figure 7 below.

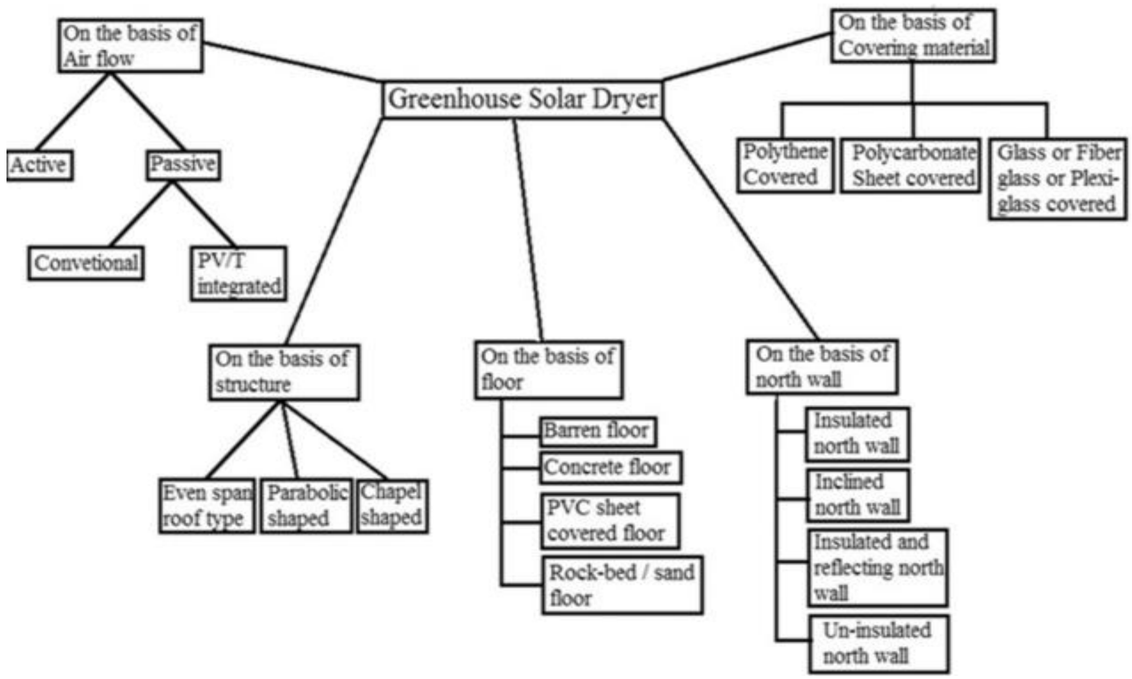


Figure 7: Classification of greenhouse dryers based on various parameters

1.3.3 Available Innovations on Hybrid Solar Greenhouse Dryer

Figure 8 shows some of the available innovations hybrid solar greenhouse dryers. Examples are shown in Figures 9, 10, 11 and 12.

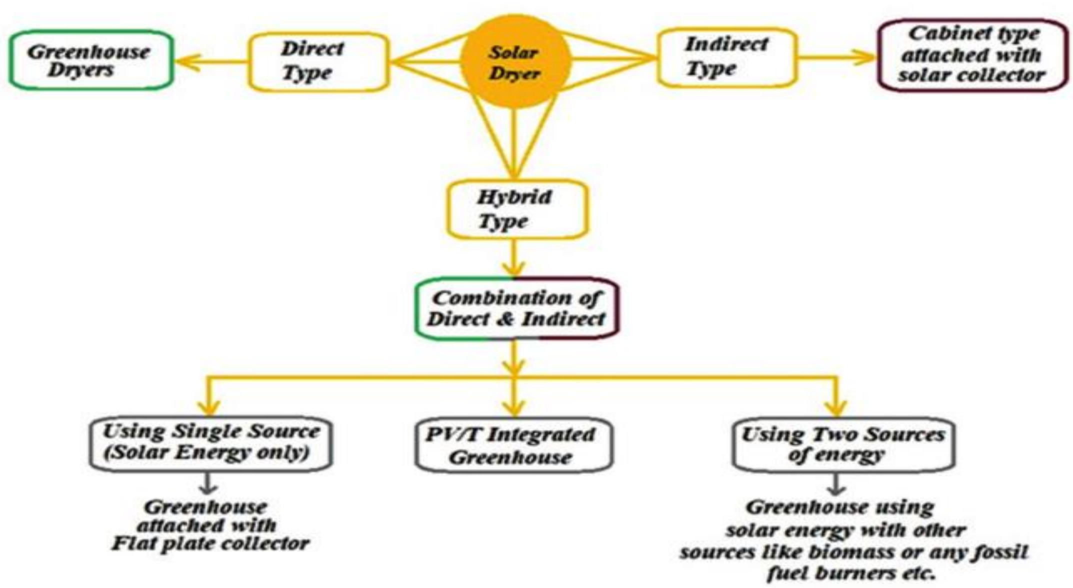


Figure 8: The various methods used for making greenhouse dryer hybrid

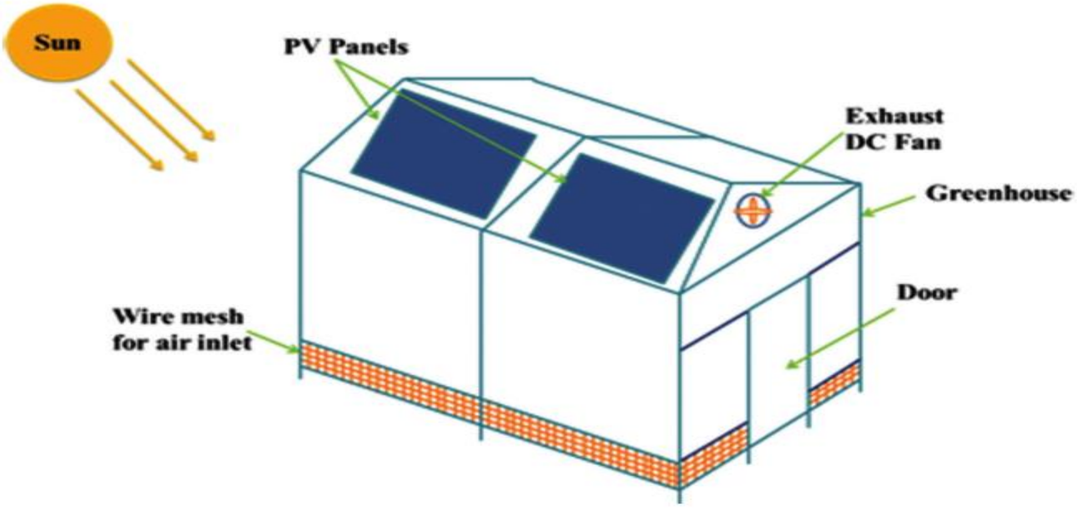


Figure 9: PV/T integrated HGHD

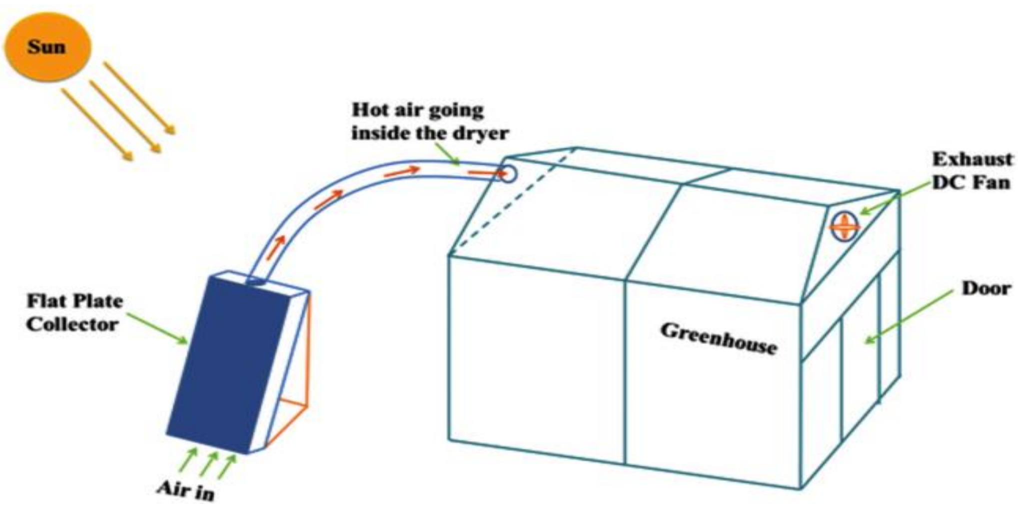


Figure 10: Greenhouse dryer integrated with a flat plate collector

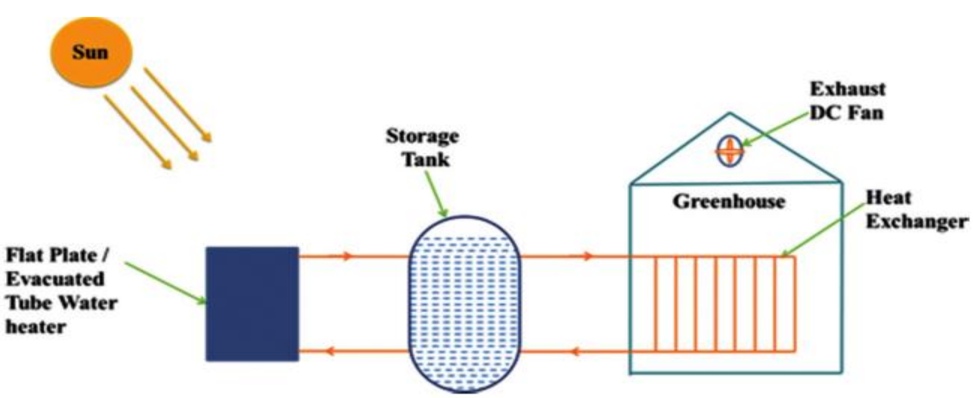


Figure 11: HGSD with solar collector and water as thermal energy storage material

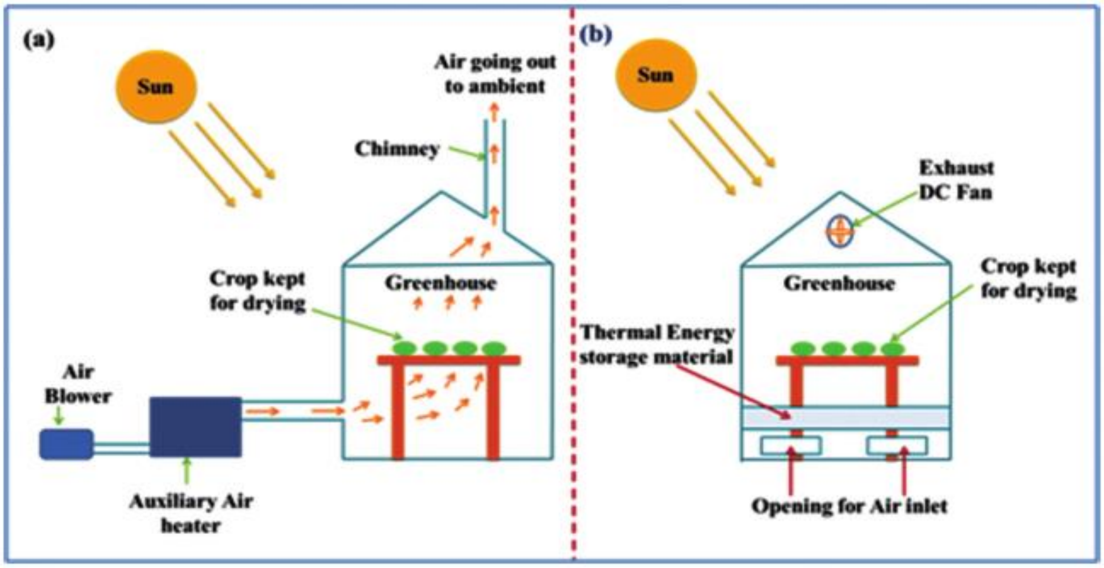


Figure 12: (a) HGSD with auxiliary air heater arrangement (b) HGSD with a layer of thermal energy storage material

MODULE 2: Design of Hybrid Solar Biomass Greenhouse Dryer

Learning outcomes:

Trainers to learn how to fabricate and manage a solar dryer construction project from onset to end.

Preparations: Videos and pictures of on-going solar dryer construction.

Benefits: Leaners will be retooled with knowledge and practical skills of making and running a functional hybrid solar dryer for various uses with special emphasis on fruits and vegetable drying.

Generally, the design of any solar dryer involve the following steps:

- Understanding of the problem to be addressed by the dryer
- Review the existing dryers and related literature
- Come up with different conceptual designs
- Sizing/Designing of the system components
- Generation of drawings: orthographic, isometric and working drawings
- Fabrication of the prototype dryer
- Test Results Analysis
- Recommendations

2.1 Components of hybrid solar biomass greenhouse dryer

Hybrid solar biomass greenhouse dryer consist of the following components:

- Drying chamber
- Drying trolley and trays
- Biomass furnace/stove
- Gas to gas heat exchanger
- Air circulation system
- Solar PV system

2.2 Material for the hybrid solar biomass greenhouse dryer

Materials selection was done by considering compatibility between construction materials and working fluids, in particular with regard to corrosion and/or operation at elevated temperatures. Physical and chemical properties of the materials were also taken into account. The selected materials for the hybrid solar-biomass greenhouse dryer were:

- Galvanized iron pipes were used for the construction of dryer super structure i.e. drying chamber. It was chosen because of its toughness and ability to conduct and radiate heat.
- UV-treated sheet were chosen for glazing material because they are cheap and not prone to photo degradation.
- Aluminum channel/profile and wiggle wire was used for attaching the UV-treated sheet since it can easily be removed during maintenance or replacement of the sheet.
- Aluminum painted mild steel square tube and angle line was used for construction of drying trolley since it has great strength and can be easily welded. Wire mesh was used to construct the drying trolleys and removable trays because it resists corrosion and allows air to pass through. It was lined by plastic mesh for holding food.
- Black painted concrete slab for the dryer floor to act as collector to absorb and store solar radiation.
- Rock wool has good thermal insulation properties and was used to insulate the heat exchanger.
- Castable refractory cement was used to make the refractory lining of the biomass stove and heat exchanger because of its ability to resist high temperatures and poor conductor of heat.
- Firebricks were chosen because they are poor conductors of heat and resistant to high temperatures.
- Galvanized iron pipe were chosen for heat transfer surface (heat exchanger tubes) because of low cost and ability to conduct and radiate heat.

2.3 Design considerations of the hybrid dryer

In designing the dryer, the following design aspects need to be factored in:

- Geographical and meteorological data of the location.
- Solar radiation/insolation of the location.
- Sanitary design factor: the construction material must be non-toxic and no-corrosive.
- Time constraint.
- Drying characteristics: drying air temperature, humidity, air flow rate.
- Initial and expected final moisture content of the material to be dried.
- Other material characteristics: loading density, product size, size distribution.

- Dimension of variables: Length, Width and Height of dryer, and dryer configuration, tray area.
- Available space for dyer construction.
- Convenience: in loading, removal, cleaning etc.

Table 1: Initial and Final Moisture content of various products

Product	Moisture content	
	Initial (%)	Final (%)
Onions	85	6
Onion flakes	80	10
Onion rings	80	10
Tomatoes	95	7
Green peas	80	5
Grapes	80	15-20
Applies	82	11-14
Bananas	80	15
Cassava	62	17
Copra	30	5
Tobacco	90	10
Coffee	65	11
Garlic flakes	80	4
Chilies	80	5
Ginger	80	10
Cabbage	80	4
Tea	80	3
Pepper	71	13
Turmeric	80	10
Potato chips	75	13
Paddy, raw	22-24	11
Paddy, parboiled	30-35	13
Maize	35	15
Wheat	20	16
Millet	21	4
Corn	24	14
Cauliflower	80	6
Carrots	70	5
Green beans	70	5
Garlic	80	4
Cabbage	80	4
Sweet potato	75	7
Red lauan	90	20
Potatoes	75	13
Spinach	80	10
Prunes	85	15
Apricots	85	18
Peaches	85	18
Guavas	80	7
Mulberries	80	10
Okra	80	20
Pineapple	80	10
Yams	80	10
Nutmeg	80	20
Sorrel	80	20
Coffee beans	55	12
Cocoa beans	50	7
French bean	70	5
Groundnuts	40	9
Figs	70	20

2.4 Sizing/Designing of Hybrid Solar Biomass Dryer Components

2.4.1 Drying Chamber Design

The drying chamber is a greenhouse type with an enclosed structure which traps short wavelength solar radiation and stores long wavelength thermal radiation to create a favorable micro-climate drying. The chamber is made of galvanized pipe bent to form a dome shape. The chamber is covered with UV stabilized sheet that allows solar radiation to directly heat the product inside. UV films have infrared inhibitor that cut heat loss inside the greenhouse by up to 20% on cloudless night. The floor of the drying chamber is made of concrete slab painted black which act as solar collector since it can absorb solar radiation and then release it inform of heat to the surrounding air.

2.4.1.1 Basic design calculations

❖ **Amount of moisture or water to be removed**

Mass of water to be removed from the material to be dried is given by:

$$m_w = W_g \left[\frac{M_i - M_f}{100 - M_f} \right] \quad [1], [2]$$

Where: M_0 – initial moisture content of the material, %

M_f – Final moisture content of the material, %

W_g – Mass of material to be dried, kg

❖ **Dry weight of material to be dried**

$$W_{bd} = W_g \times \left[1 - \left(\frac{M_i}{100} \right) \right]$$

❖ **Drying rate**

The drying time, during which the drying takes place, i.e. the effective sunshine hours may be considered as 9:00 am to 5:00 pm.

$$W_{dr} = \frac{M_w}{t_d}$$

Where: t_d - Drying time, hour

- **Energy required to remove the moisture**

It considers drying as a two stage process where the first one is raising the temperature of the wet material to a desired level at which the moisture will be removed and the second stage is evaporating the moisture from the produce.

The energy required for drying was determined based on the following formula:

$$H = W_g C_p \Delta T + m_w L$$

Where: W_g – Mass of material to be dried, Kg

C_p – Specific heat capacity of the produce, (KJ/Kg^{0}C)

ΔT – Change in temperature, ^{0}C

m_w – Mass of water removed, Kg

L- Latent heat of vaporization of water, (KJ/Kg)

- **Quantity of air required to effect drying**

Consider energy balance for drying which states that energy available from the quantity and temperature of air going through the dryer should be equal to the energy needed to evaporate the amount of water to be removed from the material. Mathematically it is expressed as:

$$M_a C_p (T_d - T_i) = M_w L$$

Where: M_a = mass of dry air

C_p = Specific heat capacity of air (KJ/KgK)

T_i = Ambient temperature (°C)

T_d = Temperature of the dryer (°C)

L = Latent heat of vaporization of water from grain (KJ/kg)

M_w = Mass of water to be removed from the product (Kg)

- **Solar collector area**

The solar collect area was calculated from the following equation as given by:

$$A_c = \frac{Va \times \rho_a \times \Delta T \times C_p}{I\eta}$$

Where:

I - Total global solar radiation on the horizontal surface during the drying period.

η – The collector efficiency, 30 – 50 %

ρ_a – Density of air

V_a - Volumetric flow rate

Thumb Rule

- Collector size: 0.75 x Total tray area

2.4.1.2 Determination of Size of Drying Chamber

Assumptions:

- Loading capacity of one dryer per batch 1000kg.
- Dimensions of the tray are taken as 1500mm length, 1200mm width and 25mm high.
- Two rows of trolley each with 4 levels.

Thumb rule: Average loading density is taken as 5 kg/ m^2

- **Length of drying chamber**

Therefore, one tray which $1m^2$ can hold 5 kg of material to be dried.

Consider the total loading capacity of the dryer per batch i.e. 200kg, then the number of trays required to hold this capacity is given by:

$$\left(\frac{200}{5}\right) = 40 \text{ Trays}$$

If each trolley contains four (4) levels of tray, the total number of trolleys to hold the total capacity is given by;

$$\left(\frac{40}{4}\right) = 10 \text{ Trolleys}$$

The trolleys are arranged in two rows; therefore, each row should have five **(5) trolleys**.

If the length of each trolley is 1000mm, then the total length of 5 trolleys in a row is given by;

$$(1000 \times 5) = 5000mm$$

Considering allowance of about 1000mm for distance between each trolley and the pipe work for hot air distribution duct, then we have

$$5000 + 1000 = 6000mm$$

- **Width of the drying chamber**

The width of each trolley is given as 1000mm.

Allowance from each side of dryer to the trays is around 250mm.

Walkway within the dryer is taken to be around 1200mm to allow for the removal of trays and to enable personnel to load banana slices on both sides of the trolleys (easy access to the product)

Therefore width of the dryer is $[(2 \times 1000) + 1200 + (2 \times 300)]$ =3800mm

2.4.2 Drying trolleys and trays design

Material to be dried are placed in drying chamber on removable tray mounted on trolleys with four shelves/levels. The trolleys are made of mild steel square tube painted aluminum with the food contact surface made of plastic mesh attached to the frame using aluminum channel and wiggle wire and supported by aluminum painted weld mesh.

The drying trays are constructed in such a way that all the surfaces contacting the material to be dried can be exposed, cleaned and inspected. Easy to adjust, dismantle and couple.

Ten trolleys with four levels of trays were fabricated with each tray approximated to have a loading density of 5 Kg/m^2

2.4.3 Biomass Furnace Design

This is where briquettes are burned to produce flue gas that is used to heat air through gas to gas heat exchanger. The furnace is made of firebricks joined by castable cement to prevent heat loss during operation and also ability to withstand high temperatures emanating from burning of biomass. The furnace is provided with grate to hold the fuel and fuel loading window. The furnace is designed with two doors, one for ash pit and the other is for ignition, which also fitted with a blower to enhance turbulence and promote cleaner combustion.

The recommended fuel are: briquettes, wood logs and any other biomass.

The following were considered in designing biomass furnace/kiln:

- The supporting structure and casing shall be able to support the entire load of the furnace during operation.
- Hopper should have feeding section to convey the fuel directly to the combustion chamber.
- Efficiency of the furnace which is assumed to be 40%.
- Total energy required for drying.
- Calorific value of the fuel used.

Based on the above stated considerations, the furnace was designed to consume approximately 20 kg of fuel in one loading which can take approximately 2 hrs. The furnace is constructed on site.

Basic calculations:

The following formula can be used in designing the size of the combustion chamber:

- **Combustion chamber diameter or length of cross section**

$$D = \left(\frac{1.27 \times FCR}{SGR}\right)^{0.5}$$

Where: FCR - Fuel consumption rate (Kg/h)

SGR - Specific Gasification Rate of briquette, given in range of 100-210 or 5-130 kg/ m^2/h

- **Height of combustion chamber**

$$H = \frac{SGR \times T}{\rho}$$

Where: T- time required to completely burn briquettes

ρ – Density of the briquettes

SGR - Specific Gasification Rate of briquette, given in range of 100-210 or 5-130 kg/ m^2/h

2.4.4 Gas to Gas Cross Flow Heat Exchanger

This is used for indirect heating of air to avoid contamination by smoke, soot and ash of flue gas. In cross flow both fluids (i.e. air and flue gas) meet at right angle and the heating is through conduction and convection.

The design of the biomass system was based on the following considerations:

- The heating will be indirect, i.e. flue gas from the biomass stove and the drying air would not be mixed. This will protect the product being dried from contamination by smoke, soot and ash of the flue gas.
- The temperature of air heated by the heat exchanger, entering the dryer, would be in the range of 65-70°C. This is based on the allowable maximum drying temperature for most staple food crops.
- Temperature control of the drying air would be possible, by controlling combustion in the stove through opening or closing the primary air supply gate in the stove.
- The center-to-center distance of the heat exchanger tubes installed shall be more than 1.25 times the tubes outside diameter.
- Tube pitch P_T is chosen so that the pitch ratio is $1.25 \le \frac{P_T}{d_o} \le 1.5$. When the tubes are too

close to each other ($\frac{P_T}{d_o}$ less than 1.25), the header plate (tube sheet) becomes too weak for proper rolling of the tubes and cause leaky joints.

- Tube layout for heat exchanger should be triangular patterns for efficient heat transfer also provides a more compact arrangement, usually resulting in smaller shell, and the strongest header sheet for a specified shell-side flow area (Figure 13).
- Tubes of heat exchanger shall have provision for ease of replacement.

The following assumptions were made in the design of heat exchanger:

- The heat exchanger is at steady state.
- The overall heat transfer coefficient U is constant.
- The heat exchanger is perfectly insulated (i.e. heat loss to the surroundings is negligible).
- There is no heat conduction in the direction of the metal separating the fluids or in the fluids themselves.
- There is a uniform temperature in each section of the heat exchanger and that complete mixing takes place just before the fluids exit each passage.
- The specific heat capacities are constant through the heat exchanger.

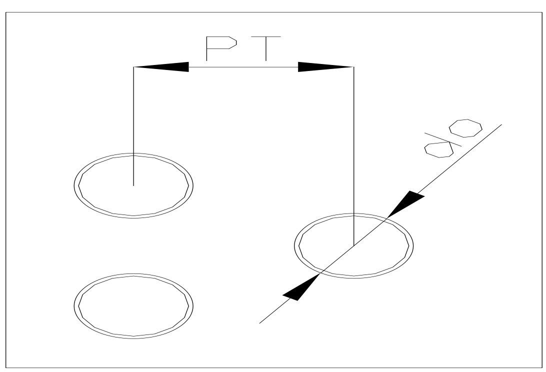


Figure 13. Staggered triangular tube arrangement

Heat transfer rate can be calculated using:

$$Q = m \times C_p \times \Delta t$$

Where:

m – Mass flow rate of air (Kg/h)

C_p – Specific heat capacity of air

Δt – Temperature

The heating surface required is given by:

$$A = \left[\frac{Q}{U \times \Delta T_m} \right]$$

Where:

$A -$ Heat transfer area (m^2)

$Q -$ Heat transfer rate (kJ/h)

$U -$ Overall heat transfer Coefficient (kJ/hm^2)

$\Delta T_m -$ Log mean temperature difference (^{0}C) which is given by:

$$\Delta T_m = \left[\frac{(T_1 - t_2) - (T_2 - t_1)}{In \frac{(T_1 - t_2)}{(T_2 - t_1)}} \right]$$

Where:

$T_1 -$ Inlet fire tube temperature (^{0}C)

$T_2 -$ Outlet fire tube temperature (^{0}C)

$t_1 -$ Inlet shell side air temperature (^{0}C)

$t_2 -$ Outlet shell side air temperature (^{0}C)

2.4.5 Air Circulation System

The dryer is fitted with hot air distribution dusting consisting of blower fan, flexible insulated aluminium duct and two rows of circular ducts with perforations to provide hot air from the biomass furnace-heat exchanger system to the drying chamber.

The dryer is also fitted with fans and wind cyclone to extract humid air from the drying chamber, the fans are meant to complement the cyclone depending on the drying conditions with the drying chamber. Size of the wind cyclone to be used is 600mm throat diameter and extractor fans of 9 inch.

Blower of size 24 inches diameter and 1400 rpm was used as the hot air supply from the heat exchanger to the drying chamber through perforated circular ducting installed below the trolleys in the drying chamber.

Rule of Thumb: Airflow rate of 0.75 cubic meters per minute per square meter of tray area was used for design.

2.4.6 Solar PV System Sizing

In designing solar PV system used to power the extractor fan and blower the following steps are followed:

Step 1. Determine the load:

Determine the energy load required in watt-hours (Wh) per day. Multiply the number of watts the load will consume by the hours per day the load will operate. Multiply your result by 1.5.

Step 2. Determine the available Sunlight Hours:

Determine the hours per day of available sunlight at the site.

Step 3. Determine the PV array size (Solar Panel size):

Determine the PV array size needed. Divide the energy needed (Step 1) by the number of available sun hours per day (Step 2). **PV array means two or more identical solar panels.**

Step 4. Determine the size of the battery bank:

Determine the size of the battery bank.

Multiply the load (Step 1) by 3 (result is watt-hours, Wh). Where 3 is the number of days without sunshine.

Then divide by the battery voltage (for example, 12 volts) to get the amp-hour (Ah) rating of the battery bank.

Step 5. Determine the size of the solar charge controller:

Solar charge controller rating is given by the total short circuit current of PV array (solar panel). The short circuit current is indicated at the back of the solar panel. Where two or more panels are used, the short circuit current rating of each will be added together to determine the size of the solar charge controller.

Step 6. Determine the size of the Inverter to be used:

The input rating of the inverter should never be lower than the total Watts of appliances.

The inverter must have the same nominal voltage as your battery. The inverter size should be 30% bigger than total Watts of appliances.

Two 250W solar panels are needed, 1,000W inverter, 30A charge controller, and 2 Deep cycle solar batteries of 200AH / 12V each.

2.5 Technical Drawings of Hybrid Solar Biomass Greenhouse Dryer

Drawings are generated using any of the computer aided design software e.g. Solid works, AutoCAD, Autodesk inventor, CATIA, Creo Parametric etc. as shown in the Figure 14.

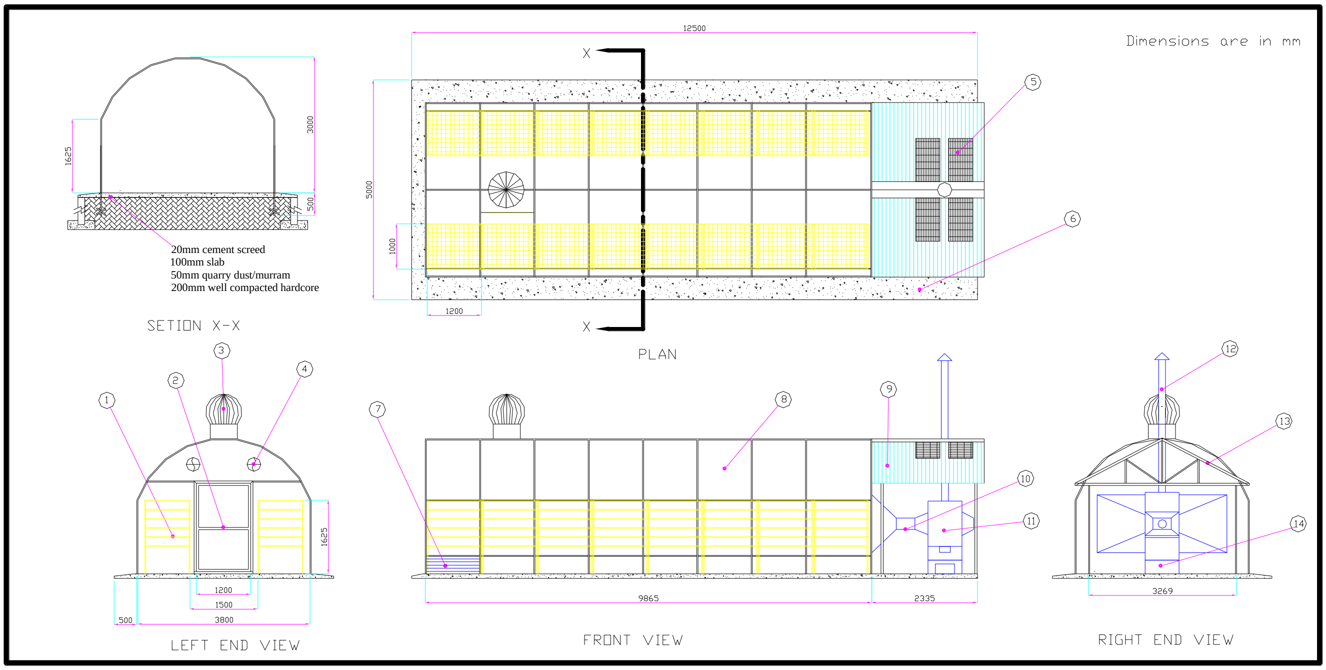


Figure 14: Hybrid Solar Biomass Greenhouse Dryer

2.6 Bill of Materials for Hybrid Solar Biomass Greenhouse Dryer

This highlights the materials required for construction and their quantities as shown in Table 2.

Table 2: Example of bill of materials for hybrid solar biomass greenhouse dryer

No	Item description	Specifications	Qty	UoM
1.	Galvanized iron pipe	Dia. 25mm Class A	19	Pcs
2.	Angle lines bars	40mm x 40mm x 3mm	22	Pcs
3.	UV- stabilized polythene sheet	200 micron	115	M^2
4.	White spirit	5 liters	1	
5.	Aluminum lock channel (profile) and Plastic coated Wiggle spring wire	1 ½" wide x ½" height x 1/16" thick	53	Pcs
6.	Self-tapping screws	Dia. 6mm	1	Pkt
7.	Rectangular hollow section	50mm x 25mm x 1.5mm	5	Pcs
8.	Door Bushes	1"	2	Pcs
9.	Welding rod	3.25mm	2	Pkt
10.	Cutting disc	7" dia.	5	Pcs
11.	Grinding disc	7" dia.	2	Pc
12.	Hacksaw blades		4	Pcs
13.	Square hollow section	25mm x 25mm x 1.5mm	50	Pcs

14.	Weld Mesh (GI)	Medium gauge	16	Pcs
15.	Plastic Netting		60	M^2
16.	Aluminum paint		4	Ltrs
17.	Extractor fans	75 watts, fan size 9”	2	pcs
18.	Solar PV cells	300W	1	pc
19.	Solar battery	12V maintenance free ,250Ah	1	pc
20.	Inverter	800W	1	Pc
21.	Solar power charge controller	30A	1	pc
22.	Wind ventilator plus base plate	Dia 600mm	1	pcs
23.	Bulb holder		1	Pcs
24.	Electric cable	$2.5mm^2$ 3 core	18	m
25.	Aggregates (ballast)		1	Tonnes
26.	Cement		6	Bags
27.	Sand		1	Tons
28.	Black matte paint	4 liter tin	2	4 Ltr Tin
29.	Brush	4”	1	Pc
30.	MS plate	4mm thick	1	Pc
31.	MS Flat bar	1 ½” x 3mm	3	Pcs
32.	MS Sheet	18 gauge	2	Pc
33.	GI plain sheet	28 gauge	1	Pc
34.	Castable Refractory Cement	25Kg	4	Pcs
35.	Fiber glass		1	Roll
36.	Bolts and nuts (assorted)		50	Pcs
37.	Drill bits (HSS)	Dia. 4, 6, 8,10	8	Pcs
38.	Pop rivets	4mm	1	Pkt
39.	Blower fan	150mm	1	Pc
40.	Aluminum tape		1	Pc
41.	Flexible duct	200mm	1	Pc
42.	Fire bricks		30	Pcs
43.	Deformed steel bar	D 16	1	Pc
44.	Door bushes	1” and ¾”	6	Pcs
45.	Blower fan		1	Pc
46.	Black pipe	1 ½”	2	Pcs
47.	GI sheet hot air distribution duct	1.2mm	2	Pcs
48.	Iron sheet transparent	3m	4	Pcs
49.	MS angle line bar	50mm x 50mm x 4mm	1	Pc
50.	Galvanized iron pipe	Dia. 25mm Class A	19	Pcs

MODULE 3: Fabrication and Installation of Hybrid Solar Greenhouse Dryer

Learning outcomes:

Trainers to learn step by step procedure of fabricating and set up hybrid solar dryer.

Preparations: Videos and pictures of on-going solar dryer fabrication and installation.

Training Procedure:

- Have a hybrid lesson that combines lectures and practical lessons on selection of potential site for installation and developing the bill of quantities.

3.1 Site Selection and Preparation

The following should be considered during site selection and preparation for construction of hybrid solar greenhouse dryer.

- Preferably, the soil at the location should not be waterlogged.
- Ensure that all weeds, debris, stumps etc. are totally removed.
- The selected site should be a flat surface and in an open area preferably about 30-50 m away from shadows of trees and buildings.
- Choose a south or north (depending on location) facing area. The main element required for a greenhouse is good consistent sunlight.
- Give preference to locations that have morning sun over afternoon sun: Although all day sun is the best option, opening up the area to morning light will increase the temperatures.
- Choose a well-drained area: This is to avoid dampness that will encourage growth of molds.
- Site slope: the site for the construction has to be gently sloping to a flat surface, where the slope is very steep. Soil leveling has to be done before the actual construction is undertaken.
- Wind direction: the direction of the wind year round determines how the dryer should be oriented. The dryer should be constructed along the wind direction and not against it.

3.2 Drying Chamber:

3.2.1 Main Tools and Equipment for Construction:

- Hacksaw
- Hydraulic pipe bending machine
- Metal Cut off Machine

- Arc welding machine
- Bench Vice
- Hand drilling machine
- Hand grinder
- Bench drilling machine
- Rolling machine

3.2.2 Steps in Construction

Step1: Bending of the hoops and foundation posts

- The hoops and foundation pipe were made using galvanized pipe of 25mm diameter. 6 hoops/arches were made from full length of GI pipe by gently bending it using hydraulic bending machine to form dome shape (Figure 15).
- 12 Foundation post of length 500mm were cut from GI pipe of 25mm diameter. Wall pass was then welded on the side going in to the hole for it to hold firmly on the concrete foundation.

Figure 15: Bending of the hoops/arches using hydraulic pipe bender

Step 2: Marking out construction area

Measure and clearly mark out on the cleared ground using pegs, the specific land area for the solar dryer construction depending on the size or overall dimension of the dryer (Figure 16). In our case (3.8m wide by 6m long). The strings should be placed just above the soil surface.

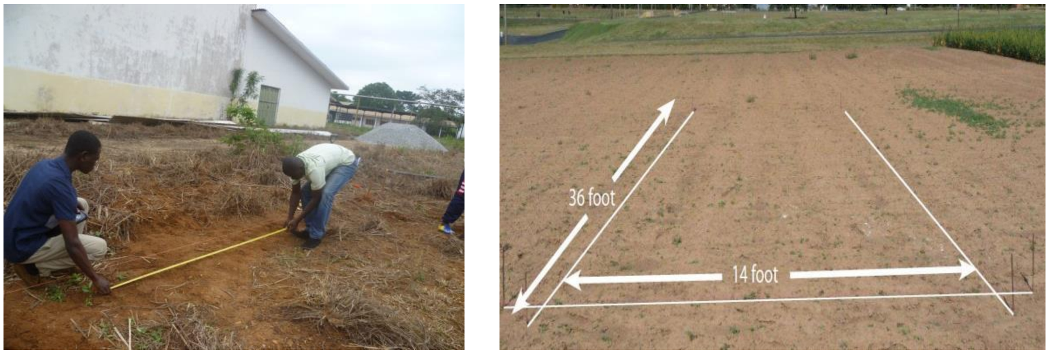


Figure 16: Measurement and marking out construction area

Step 3: Location of foundation corner posts:

Mark the location of corner posts using pegs and strings as shown in Figure 17.

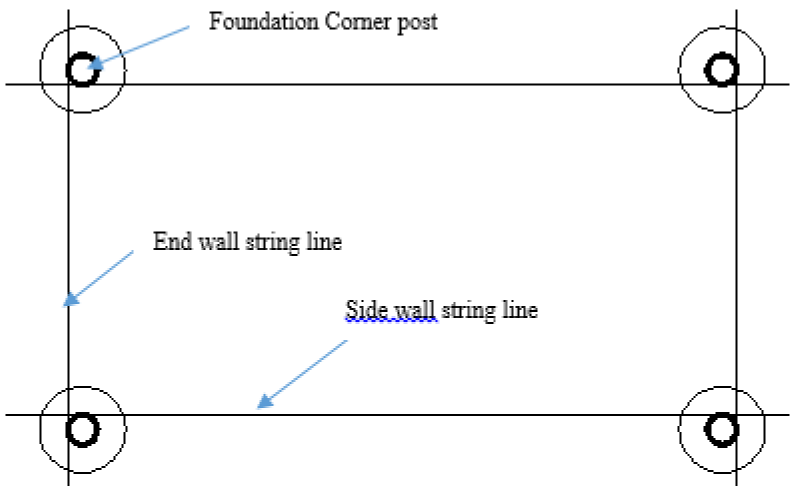


Figure 17: Location of the corner foundation pipes

Step 4: Digging corner holes and erection of the foundation corner pipes

Dig a 1-foot-deep by 1-foot-wide hole at each corner. Align with string corner as illustrated in Figure 18(a).

Mark the length of the post to be covered by the concrete floor. Then position corner posts in the base of the holes by using a large bolt or trailer ball inserted into the pipe to prevent the pipe ends from flaring when struck by a hammer, drive the posts into the soil until the marks on the posts are even with the string line (~ground level) (Figure 18(b)). Use spirit level to ensure the post is being driven vertically (Figure 18 (c)). Locate posts on the outside edge of the sidewall string line.

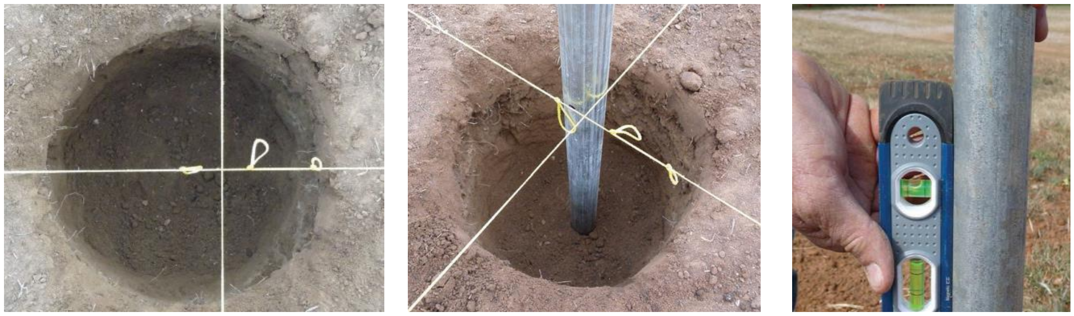


Figure 18: (a) Corner hole (b) Setting the foundation pipe in the corner holes (c) Checking level of the foundation pipe

Step 5: Cover the corner posts with concrete

Pour the concrete around the foundation corner posts until the mark made on the foundation corner pipe is reached (Figure 19).

Figure 19: Corner pipes covered with concrete

Step 6: Installation of the remaining foundation posts

The remaining foundation posts are then installed at 1500mm distance apart. While driving the posts in, stop occasionally to check the level using spirit level to ensure all are in the same level (Figure 20).

Figure 20: Installation of other foundation pipes

Step 7: Laying of foundation and platform for dryer construction

Lay blocks to set the foundation and overlay it with concrete cast to prepare a platform for the construction of the dryer (Figure 21). The edges outside drying area should be made sloping outwards to prevent runoff water during raining from entering the structure.

Figure 21: Foundation concrete slap laying

Step 8: Mounting of the hoops and support pipes

The arches or hoops were mounted and welded on the foundation pipes starting with the ones at the ends to aid in alignment of the middle ones, then attach or fit aluminum profile on the end arches using self-tapping screws. Five levels of support purlins were welded after that the hoops were mounted (Figure 22).

Figure 22: Construction of super structure

Step 9: Overlaying or cladding the drying chamber with UV transparent plastic sheet

The dryer is covered with 200 micron UV treated transparent sheet and attached to the structure using wiggle wire. The transparent plastic sheet is very delicate and should be cut with care to the required sizes to fit the roof and the sides of the drying chamber.

The sheets should be fixed to overlap at the ridge and the base of the boundary walls and attached with motor on the slab to avoid rainwater seapage into the dryer (Figure 23).

Figure 23: Cladding or covering of drying chamber

3.3 Construction Drying Trolleys

Four pieces of square tube of length 1400mm was cut and then welded together to form main structure of the drying trolleys. Eight pieces of angle line of length 1000mm were also cut and attached or welded to support the removable tray with the lower one placed at a distance of 500mm from the floor, while the rest are placed at 300mm apart.

Four pieces of 20mm square tube of length 1000mm were also cut and welded together to form the main structure and the food contact surface made of plastic mesh attached to the frame using aluminum channel and wiggle wire and supported by aluminum painted weld mesh (Figure 24).

Figure 24: Fabrication of drying trolleys and trays

3.4 Fabrication of Gas to Gas Heat Exchanger

Two square pieces of dimension 600mm by 600mm was cut from mild steel plate of thickness 6mm and then holes for fire tubes were drilled in staggered manner as per the design to form heat exchanger header as in the Figure 25. The headers were joined together by side plates of 6mm thick as in the figure. Then all heat exchanger tubes (tube bank) were fitted through the holes and welded on the header plate as shown.

Figure 25: Heat exchanger fabrication and assembly

The body of the heat exchanger was then insulated or lagged using fiber-glass as shown in Figure 26 to prevent heat loss and to protect the use from injury due to burns from hot surface.

Figure 26: Insulation of heat exchanger

3.5 Construction of Biomass Furnace/Kiln

The biomass furnace was constructed using firebricks and castable cement as motor for joining. The plinth was first constructed around the area where the biomass furnace is to be constructed. The floor of the furnace was first constructed, then side walls as shown in the Figure 27. Biomass furnace was fitted with fuel loading window and ash pit door with provision for blower fan to aide in combustion Figure 27(a).

The stove has a grate made of mild steel round bars of diameter 15mm designed to allow ash to fall through it into the ash pit and to increase the efficiency and quality of combustion as shown in Figure 27 (b).

Figure 27: (a) Construction of biomass furnace (b) Grate design

3.6 Assembling of Hybrid Solar Biomass Greenhouse Dryer Components

The biomass furnace was supported by angle line bar at the corners and the supports were welded on the top frame. This was done to reinforce the kiln to enable it support and withstand the weight of the heat exchanger when mounted on it. Chimney attached to top part of the heat exchanger was fitted and bolted as in Figure 28.

Figure 28: Assembling of Biomass heat exchanger system

The chimney was extending to and the heat exchanger connected to blower fan through insulated aluminum flexible duct as in the figure. The blower fan was then connected to the drying chamber through circular duct as in Figure 29.

Figure 29: Connection of Biomass heat exchanger system with the hot air distribution ducting

Figure 30 shows complete assembled hybrid solar biomass greenhouse dryer ready for testing and optimization.

Figure 30: Complete assembled Hybrid solar biomass greenhouse dryer

MODULE 4: Good Manufacturing Practices (GMP)

Learning outcomes: Appreciate the working principles and how to implement effective GMP in a food processing facility and in design of equipment.

Preparations: Videos and pictures of on-going solar dryer maintenance.

Training Procedure:

- Have a hybrid lesson that combines lectures and practical lessons on good manufacturing practices

4.1 Good Manufacturing Practices (GMP)

Good manufacturing practices are the procedures that should be followed during plant construction and operation to assure food wholesomeness. GMP refers to the minimum sanitary and processing conditions required in a properly built processing plant. GMP contains cleanliness and sanitary requirements for personnel, building and facilities, equipment and utensils, in addition to food processing requirements and controls. Cleaning and sanitation is a multi-step procedure that involves first cleaning and then sanitizing in the food processing plant. Food processing refers to the actual manufacturing operations, such as shelling, sorting and packaging nuts that are applied to the food product. When implemented properly, GMP not only reduces new forms of biological, chemical and physical contamination, but eliminates existing contamination. It is critical to consider food safety and quality in solar drying design and fabrication. The first step being ensuring that the design incorporates components that ensure that air doesn't bring microbes, dust etc., in material selection food grade materials should be used in dryer construction.

Good manufacturing practices (GMPs) help to ensure the consistent quality and safety of products by focusing attention on five key elements, which are often referred to as the 5 P's of GMP—**people, premises, processes, products and procedures (or paperwork)**.

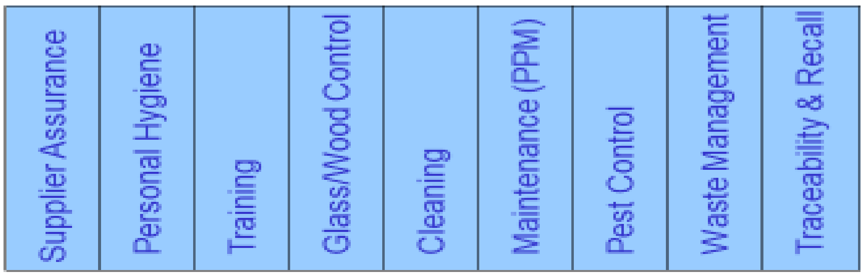
- Significant improvement in product quality (colour, texture and taste).
- No contamination by insects, microorganism and mycotoxin.
- Reduction in drying time up to 50%.
- Reduction of drying and storage losses.
- Considerable increase in shelf life of dried products.

4.1.1. GMP in Dryer Consideration

Some sources of the potential contaminants in food processing are:

- Location of processing facility.
- Plant construction materials: food grade.
- Construction of the facility: plant design, layout.

Good Manufacturing Practices Components-GMP



Training and personal hygiene

- Reporting illness
- Wear protective clothing
- Hair, jewellery
- Hand washing

Premises-interior and exterior

- Building and machinery design
- Interior: Design, Construction, Lighting, Ventilation, Waste Disposal
- Sanitation Facilities: Employee Facilities, Equipment Cleaning & Sanitizing Facilities
- Equipment design and maintenance
- Pest control
- Waste and drainage control
- Chemical hazards control
- Glass and foreign object control

Product

- Raw material control
- Product design

Process Control

- QA checks

Distribution

- Protect food from contamination
- Protect food from damage likely to make it unsafe
- Temperature control

Retailer

- Proper storage
- Product trace and recall

Consumer

MODULE 5: Maintenance of Hybrid Solar Biomass Dryer

Learning outcomes:

Trainers to learn how to maintain the hybrid solar dryer

Preparations: Videos and pictures of on-going solar dryer maintenance.

Training Procedure:

- Have a hybrid lesson that combines lectures and practical lessons on maintaining the Hybrid solar dryer
- Product information on storage and handling

5.1 Maintenance practice

- UV sheet should be cleaned with a cloth and clean water twice a week.
- Wash the trays every after drying food and make sure the trays are not washed with chemicals. NOTE: Use clean water.
- The drying area should equally be cleaned to keep it free from dust and dirt.
- Clean the drying surface to make more effective the drying of products.
- Inside dryer should be cleaned in every 3 weeks.
- Mesh (trays) should be cleaned after every use and if some products stick on mesh, place wet cloth over it for 1-2 hour(s) and then rub with scrubber.
- Wash cloth piece after every use.
- Make sure the solar dryer is not near toilet areas.

5.2 Personal & Hygienic practices to be followed while drying

- Persons involved in food processing must be healthy & free from diseases.
- Cut nails short.
- Washing hands thoroughly & wearing gloves.
- Wearing head gear / shower cap to prevent falling of hair.
- Wearing a clean apron / a coat to protect clothing.
- Avoid licking & tasting while handling & processing.

MODULE 6: Business Models for Hybrid Solar Biomass Dryer

Learning Outcome:

Upon completion of this module, trainees should be able to understand and apply key business models that they can use in their enterprises to delivery of products and services.

Training Procedure:

- Have a hybrid lesson that combines lectures and group in developing business model canvas

6.1 Introduction

A business model describes the various aspects, approaches and values that an enterprise offers to one or more segment of customers while launching or running a business; in particular focusing on the generation of profitable and sustainable revenue streams. The business models focuses on roles and linkages of actors in the food product supply chain, and is related to but are distinct from the legal structure of the business.

The development of an appropriate business model is very important as it helps the entrepreneur/s to identify the right implementation strategies to be profitable. In the absence of a business model, an entrepreneur may find that he/she is unable to take the right decision at the time of starting a business that may lead to inefficient operations and in turn a non-viable business.

6.2 Parameters of Business Model

Four key components need to be defined and developed before starting a business as outlined in the table below and explained in this section further.

Table 3: Business model format

Business Goal	Objectives the enterprise aims to achieve through its operations. Includes profit making as well as social objectives.
Product/Services	The device / equipment (or services) that will be sold by the enterprise, the uses it will fulfil. Also, the way in which the enterprise will obtain products and provide them to the customers.
Demand	Source of demand, the target segment and its characteristics geographic and socio-economic characteristics.
Delivery Model	Financing mechanism, ownership and management, delivery / implementation, sales / distribution, collaboration with other market players.

6.3 Business goal

Establishing the business goal is important. The entrepreneur(s) need to clearly lay out its objectives such as:

- Is the enterprise profit making?
- Does the enterprise serve society as well?

Once the objective is clear, the performance of the business can be measured against the goals. For profit-oriented entrepreneurs, any profits can be reinvested in growth and expansion. The goals of the enterprise also determine other aspects of the business model.

Example: Company X sells hybrid solar dryers to Agro-entrepreneurs. It is a for profit private business that has brought about social welfare as well. By keeping itself profitable, it has been able to sustain itself and also grow. Since profitability is one of the key drivers, it has developed its business model accordingly. It is also working with micro finance institutions to provide end user financing for its customers.

6.4 Products and Services

To create the business model, the food technology that will be the main product or service for business needs to be determined. It is important that the entrepreneur know the various sections within the technology supply chain. Once this is understood, the entrepreneur can determine the appropriate devices/equipment or services to start or expand a particular food business. In this process, the entrepreneur must be able to identify clearly the following:

- Product v/s service: will the entrepreneur provide only products or services related to a product or both?
- Uses: what uses will the products or services fulfil?
- Product / Service suite: will the entrepreneur further provide a wider range of related services or products that will enable the business to be more sustainable? For example, supplying complimentary products, providing repair and maintenance services, providing credits to consumers, providing training for use and maintenance and others.
- Supply chain: It is important to establish the supply chain. How will the entrepreneur obtain products and then provide them to the customers? Will the products be manufactured or assembled?
- Standardization: will the product be standardized or customized per user?
-

6.5 Demand encompasses having a good understanding of:

- End user of the product – is it an individual, a household, an organization or a community?
- The geographic coverage area and its demographics where the enterprise will operate and sell its product.
- The socio-economic strata of the society that will be the users of the organizations products / services including the income level – are they willing or capable to pay for the product or service?
- Presence of formal / informal groups and leadership structures that will impact local practices.
- The current levels of spending on food needs of the produce in the target segment.

Once the market, in particular the demand is understood, appropriate delivery models can be designed. This is the fourth dimension of designing an appropriate business model for the enterprise.

6.5 Delivery Model

The delivery model includes the approach that the enterprise will follow to provide products or services to the customers in a way that it fulfills its goals. Few key aspects are:

Financing mechanism: It is important to know where the finance for setting up or expanding your business is coming from. How will the business make profit? Understanding the costing and revenue model is important. Will the entrepreneur be able to provide credit to the customer or how will products or services be affordable?

Ownership and Management: One of the most important components of the business model is to determine the ownership and management structure. Is the enterprise a co-operative, private or public one? What is the right of ownership of the products/services?

Delivery: This is very important to be determined as it includes the way the product or services are made available to the customers. The delivery model is dependent on the other factors particularly demand. The delivery should look at the following in detail:

Distribution: Will the product be delivered through a decentralized mechanism or will there be centrally provided product/services where several units can use it

Sales model: The mechanism through which the product / service will be sold - lease /hire purchase/ cash / credit / (background on these expanded in this section with examples) as utility.

Sales channels: What sales channels will be used e.g. franchise

Marketing: What will be the marketing approach?

ACTIVITY

A. Think about your business, what model are you using? ---

B. From the discussion, what business model would you like to work with and why? ----------
----

6.6 Value Proposition Canvas

Describe the different types of customer value propositions (CVP) and learn how to identify your target customers.

Businesses tend to have different CVPs for each customer segment. This is to ensure they are meeting the needs of the customers within each segment. Examples of different customer segments targeted by different types of businesses include

- Niche market
- Segmented market
- Diversified market
- Multi-sided markets
- Mass Market

6.7 The Business Model Canvas

6.7.1. Components of a Business Model

An ideal business model usually conveys four key aspects of the business:

- Customers – Whom the business serves to (the target market),
- Offerings – What the business provides (the product),
- Infrastructure – How it provides the offering (the operating model),
- Financials – How the business makes money and what are the costs involved (the revenue model).

6.7.2 Identify the nine components of the business model canvas

The four core elements above of a business model can be expanded to nine business model components. Separating core elements into their respective components makes them easier to define and integrate with one another. The offering constitutes the:

<table>
<tr><td rowspan="2">KEY PARTNERS (7)</td><td>KEY ACTIVITIES (8)</td><td rowspan="2">VALUE PROPOSITION (1)</td><td>CUSTOMER RELATIONSHIPS (4)</td><td rowspan="2">CUSTOMER SEGMENTS (2)</td></tr>
<tr><td>KEY RESOURCES (6)</td><td>CHANNELS (3)</td></tr>
<tr><td colspan="3">COST STRUCTURE (9)</td><td colspan="2">REVENUE STREAMS (5)</td></tr>
</table>

Table 4: The Business Model Canvas perspective

Value proposition: A feature that makes your product attractive to your customers i.e. why does the company exist? Which can be because of problem or need you are solving or satisfying e.g. waste due to post harvest practices.

Customer segments: A specific group of consumers who would be interested in your product. Who are your target customers? Who can be described by geographical, social, and demographics e.g. Cooperative Societies, Farmers' groups and agro-based companies?

Channels: Avenues through which the customers come into contact with the business and become part of the sales cycle and how a company communicates with its customer segments and distribution channels. How products get from your company to customers i.e. distribution channels. It can be web-based.

Customer Relations: Describe how company get, keep and grow customers. Getting customers; physical, online, mobile, etc. How to keep good service, complying with their needs, etc. How to grow and how can they spend/use more of your product.

Revenue streams: Defines how companies make money from each segment or what value is the customer paying for the product. Consideration include direct sales, pricing of product, revenue models.

Key Resources: These are important assets required to make business model to work e.g. capital, physical assets, Intellectual property, vehicles, human and software.

Partners: List of other external companies/suppliers/parties needed for collaborations or partnerships etc. i.e. key partners and supplies needed to make your business model work. It can be a joint venture, strategic alliance, or suppliers and buyers.

Key Activities: What are the most important things the company must do to make the business model work?

- Production business
- Problem solving
- Supply chain management

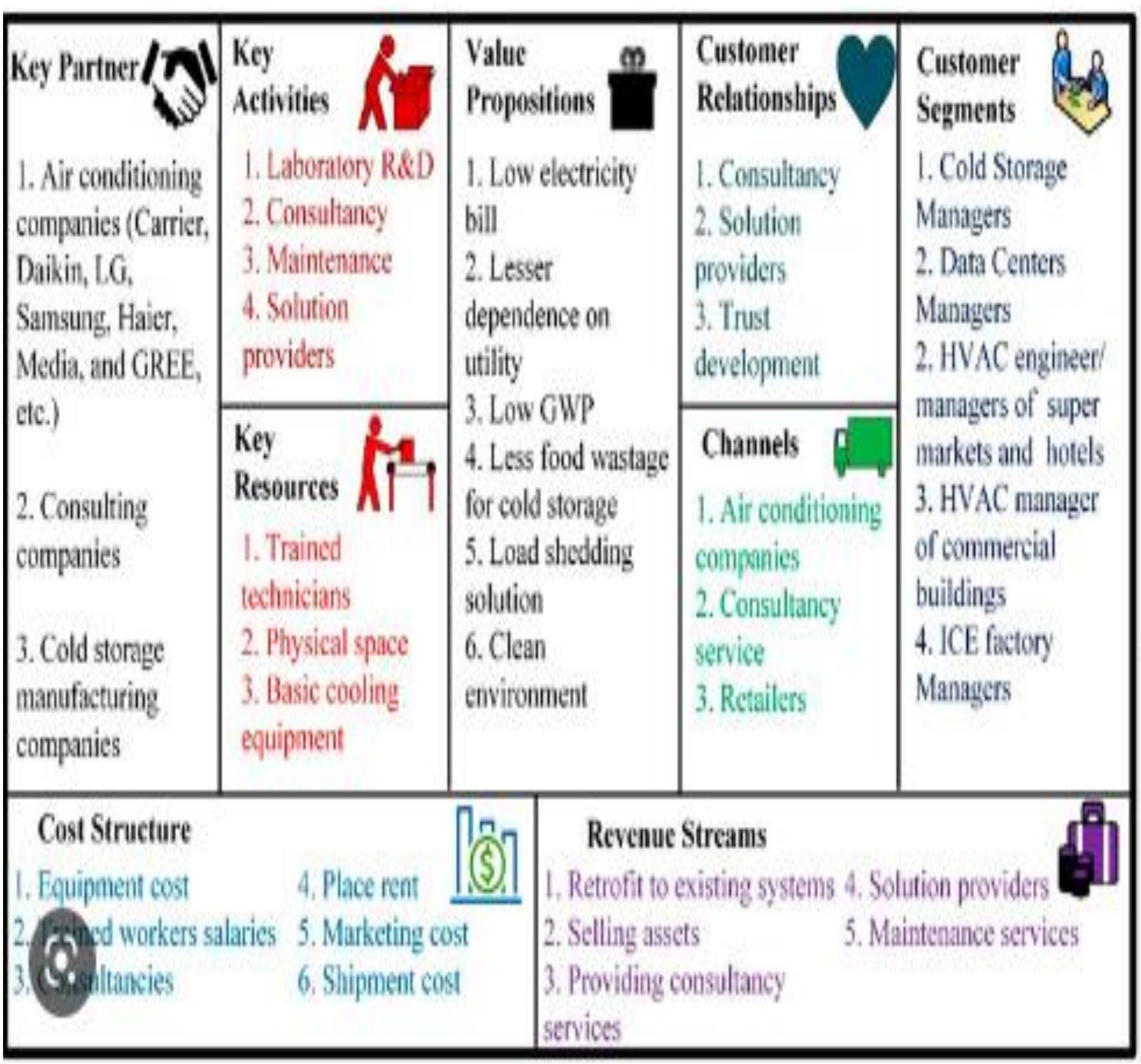
Costs: A list of the fixed and variable expenses (monetary costs) your business requires to function, and how they affect pricing; this leads to a satisfactory profit margin; the amount your revenue exceeds your business costs i.e. costs to operate a business model e.g. input costs, activity costs.

ACTIVITY

A. Develop business model canvas for your business --

B. Presentation of the model canvas to the plenary ---

Practical examples of Business Model Canvas



Lessons Learnt

The solar dryer is very simple to build and to operate. It is low-cost, it uses local or easily obtainable materials and incorporates the local knowledge of fabricators. During the process of developing the hybrid solar dryer, we discovered that alternative technologies not only have to suit the social and economic conditions, but they must also fulfill a number of other requirements: they should build on and incorporate local knowledge; they should not contaminate the environment or be harmful to people's health; they should be simple to build and use easily obtainable materials; and they should be simple to operate repairs and maintenance work should not pose a problem.

References

[1] Susan Andrew Mbacho, Development and Performance Evaluation of Solar Greenhouse Dryer with Desiccant Energy Storage System for Tomatoes, Msc. Thesis, Kenyatta University, Nairobi, Kenya, 2021

[2] K.S. Tonui, E.B.K. Mutai, D.A. Mutuli, D.O. Mbuge and K.V. Too, Design and Evaluation of Solar Grain Dryer with a Back-up Heater **,** *Research Journal of Applied Sciences, Engineering and Technology* 7(15): 3036-3043, 2014

[3] JB Hussein, MA Hassan, SA Kareem, KB Filli, Design, Construction and Testing of a Hybrid Photovoltaic (PV) Solar Dryer, *International Journal of Engineering Research & Science (IJOER)* Vol-3, Issue-5, May- 2017, ISSN: [2395-6992]

[4] Ndirangu, S. N., E. K. Ronoh, C. L. Kanali, U. N. Mutwiwa, and G. M. Kituu. 2020. Design and performance evaluation of a solar-biomass greenhouse dryer for drying of selected crops in western Kenya. Agricultural Engineering International: CIGR Journal, 22(3): 219-229.

[5] Ana Nurhasanah, Astu Unadi, Suherman Suherman and Sularno, Design and Tested A Pilot Scale of A Greenhouse Hybrid dryer for Fermented Cassava Slices, IJRDO-Journal of Agriculture and Research Volume-2 | Issue-12 | December, 2016 | Paper-3

[6] Khairul Anuar B Kamarul Baharin, Design and Fabrication of Biomass Burner for Gas-To-Gas Heat Exchanger, Universiti Teknologi Petronas, Tronoh, Perak, 2010