



University of Southern Queensland  
Faculty of Engineering and Surveying

# **DESIGN A PROTOTYPE SOLAR DRYER FOR DRYING SEA CUCUMBER**

A dissertation by

**Seini 'Ela Uatekini Vaipulu**

In fulfilment of the requirements of  
ENG4111/4112 Research Project and Dissertation

Towards the Degree of  
**Bachelor of Agricultural Engineering**

## Certification of Dissertation

I certify that the ideas, designs and results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Seini Ela Uatekini Vaipulu

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Signature

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Date

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*Dedicated to my beloved husband Amini Vaipulu and to  
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## **Abstract**

Different drying techniques for drying agricultural products were reviewed in the study to develop a suitable dryer for drying sea cucumber as it is a high export value product gaining importance in the international markets now a days. A conceptual prototype solar dryer for drying sea cucumber was designed which has its advantages over the traditional open sun drying methods such as reducing the loss due to damage caused by insects, birds, rodents and adverse climatic conditions. The drying period using the conceptual solar dryer is 1 -2 days whereas it takes 4 -14 days in the traditional open sun drying methods.

# CHAPTER 1: INTRODUCTION.

This Chapter outlines the background, purpose and objectives of the project as well as providing an introduction into the necessity of the study.

## 1.1 Introduction.

The processing technologies of many agricultural products are often dedicated and consume a large amount of energy and fuel.

Low-cost solar dryer using renewable solar energy therefore offers the great potential for widespread adoption and application in both the developing countries and in many parts of Australia.

## 1.2 Project purpose

The present research project aims to develop a small-scale prototype solar dryer for drying and testing of high-value agricultural products, particularly sea cucumber.

This project has significant economic, environmental and social benefits, particularly given the current concern on greenhouse gas emissions of fossil fuels and climate change.

The main research tasks of this project are:

1. Project development and literature review. This chapter will produce an insight into the available solar dryers designs and their limitations.
2. Design a prototype solar dryer in consultation with the industry and other researchers. The feasibility of incorporating new and innovative design features such as a suitably-sized photovoltaic module to power the air circulation fan will be investigated.

### **1.3 Research Objectives**

The overall objective of this research project is the conceptual design of the solar dryer for drying agricultural products. In order to accomplish this very important objective there were other objectives that must also be addressed to make it possible for the solar dryer design. These other objectives are:

1. Research published literature on solar drying technology
2. Determine the availability and suitability of solar energy in Australia
3. Identify agricultural products suitable for solar dryers
4. Predict the performance of the proposed design
5. Identify and evaluate the opportunities for further improvements, if time permits.

### **1.4 Conclusion**

This project aims to develop a conceptual design of a solar dryer to be used for drying agricultural products. The study is expected to come up with some approximate calculations of the amount of energy required to dry the agricultural products to its appropriate dry state. A literature review is provided in the following chapters in order to present the research undertaken on this topic to date, and demonstrate what further research is required on this issue.

## **CHAPTER 2: LITERATURE REVIEW.**

### **2.1 Introduction**

This section comprises of the literature review on studies in the past in relation to solar dryer and present. It also discuss the different types of solar dryers, its advantages and disadvantages, comparison of using open sun drying and solar drying technology.

### **2.2 – Background**

#### **2.2.1 – Background on food drying**

Preservation of human and animal food by open-air drying in the sun was presumably one of the first conscious and purposeful technological activities undertaken by humanity (Imre, 1995). Traditional open-air, solar drying methods are based on long term experiences and continue used all over the world to dry plants, seeds, meat, fish, and other agricultural products in order to preserve them.

Over the last few decades, open-air drying has gradually become more and more limited because of the requirements for a large area, the possibilities of quality degradation, pollution from the air, infestation caused by birds and insects, and inherent difficulties in controlling the drying process (Imre, 1993).

Solar drying refers to methods of using the sun's energy for drying, but excludes open air sun drying.

A Solar dryer is an enclosed unit, to keep the food safe from damages from, birds, insects, and unexpected rainfall. The food is dried using solar thermal energy.

## **2.2.2 – Main Types of Solar dryers**

According to Baker & Christopher G.J, 1997 there are three types of solar dryers and they are classified according to the type of energy used.

- Solar natural dryers
- Semi-artificial dryers
- Solar-assisted dryers

**2.2.2.1 - Solar natural dryers.** These devices use only ambient energy and have no active elements. The air flow, if there is any, is maintained by natural convection or, in some cases, by thermosyphon effects induced by a chimney.

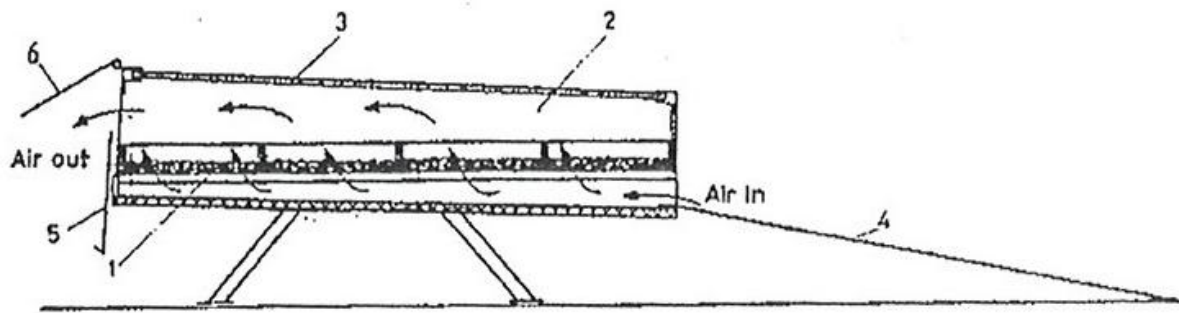
Solar natural dryers are mainly used as substitutes for traditional open-air drying methods in areas where no other source of energy is available. In contrast to these traditional methods, however, losses and damage to the product caused by rain, dust, insects, birds, and other animals, as well as the pollution from the atmosphere are avoided by the purpose built construction (i.e cabinet and tent type arrangements). Their use results in a better quality product, which should be considered as a positive cash contribution in any economic evaluation.

### **Types of Solar Natural Dryers**

#### **Cabinet type dryers**

**(a) Cabinet dryers.** These are the simplest and cheapest type of solar dryer. They are generally used for drying agricultural products, such as fruits, herbs, vegetables, and spices, in small quantities (Wibulswas and Niyomkarn, 1980, Reuss, 1993 cited in Baker & Christopher G.J, 1997).





**Figure 1** Cabinet type dryer for fruit and herbs

Simple cabinet dryers consist of a south-facing drying space covered by a transparent material (glass or foil), which also serves as a roof to protect against rain and pollutions. The material to be dried is spread in a thin layer on a tray having a perforated bottom and is directly exposed to the solar radiation. Holes are opened in the lower part of the front wall and in the upper part of the back wall of the cabinet to induce an air flow by natural convection. This carries away the water evaporated from the material and prevents its overheating.

An improved version of the simple cabinet dryer designed for household use is illustrated in Figure 1. The trays with perforated bottoms 1 are arranged under the transparent cover 3, making it possible to dry simultaneously various kinds of foodstuffs, such as fruits, herbs and vegetables. Each product, in its individual tray, may have its own specific drying time. Air, preheated by a black-painted aluminium sheet 4, is introduced into the dryer and regulated by the throttling devices 5 and 6. The open cross-sectional area of the air outlet can gradually be decreased as drying proceeds. At night time, the slide 6 should be closed and the sheet 4 should be fitted to the transparent cover of the cabinet 2.

(b) **Tent type dryers.** The drying capacity of cabinet type's dryers can be increased by enlarging the basic surface area of the dryer. Tent type dryers represent the simplest and cheapest way to achieve this goal. A schematic representation of a tent type solar dryer is shown in Figure 2. The drying space 2 is located within a tent, which may have a triangular or semi-circular cross-section. The south-facing surface of the cover 1 should be transparent; the other sides are opaque. The material to be dried (e.g. coffee beans) is spread on a perforated tray 3 or directly on a concrete floor (Sunworld, 1980).

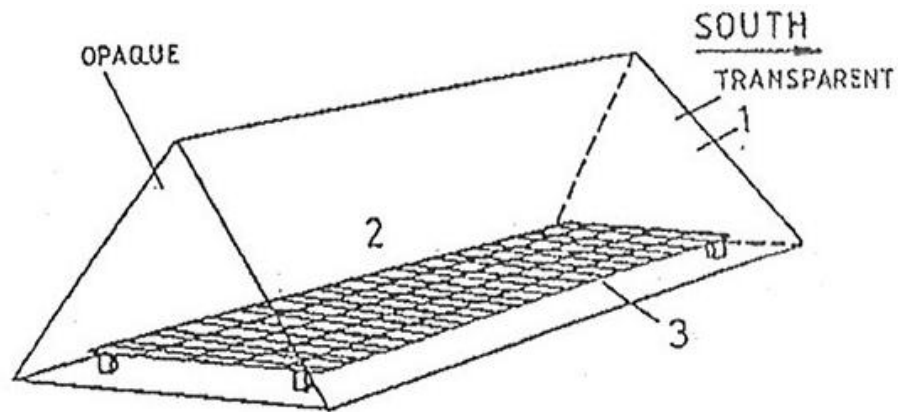


Figure 10.2 Tent type solar dryer.

**Figure 2** Tent type solar dryer

(c) **Shelf type dryers.** Another way to increase the drying capacity, without enlarging the basic surface area, is to employ several trays or shelves, one above the other. Figure 3 illustrates a schematic of a shelf type dryer (Wibulswas and Niyomkarn, 1980). Thin layers of fruit, vegetable, etc, to be dried are loaded on the perforated shelves partly shade to produce the energy required. Air flow is generated by natural convection through the collector and the material layers on the shelves; moist air leaves the dryer through the upper opening 5.

In the shelf type arrangement, the flow resistances of the separate material layers are coupled in series and the total resistances is their sum. To ensure a satisfactory air flow rate, the height of the dryer should be sufficient to produce an adequate "chimney effect".

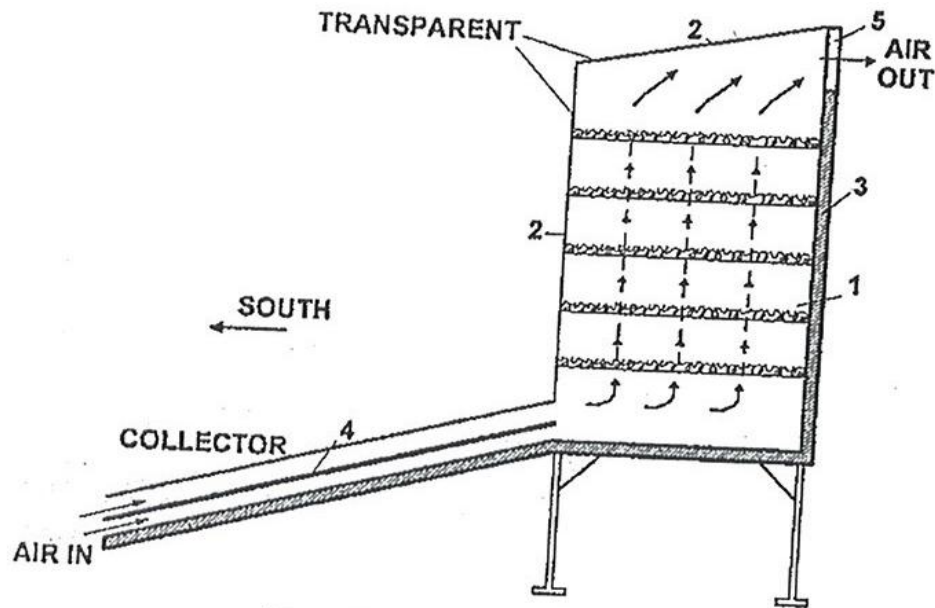


Figure3 – shelf type cabinet dryer.

### Cabinet dryers fitted with a chimney.

The thermosyphon effect required to induce an adequate flow through a solar dryer can be increased by means of a chimney. A simple version of a chimney type solar dryer is presented in Figure 4 (Sunworl, 1980 cited in Baker& Christopher G.J, 1997).

The lower part of the dryer acts as an integrated solar collector with a transparent cover 2; the bottom surface 4 functions as an absorber. Material to be dried is arranged in a static bed. Cover 3 over the bed is also transparent. Chimney 5 is connected to the upper part of the drying space. The technical specifications for a solar rice dryer have been given as (Sunworld, 1980 cited in Baker& Christopher G.J, 1997):

Mass of rice to be dried

- , 1000 kg;
- Bed thickness, 0.1 m;
- Collector surface area, 23 m<sup>2</sup>;
- Height of the chimney, 5 m;
- Drying time (at 15MJ m<sup>-2</sup> day<sup>-1</sup> mean global irradiation), 3-4 days.

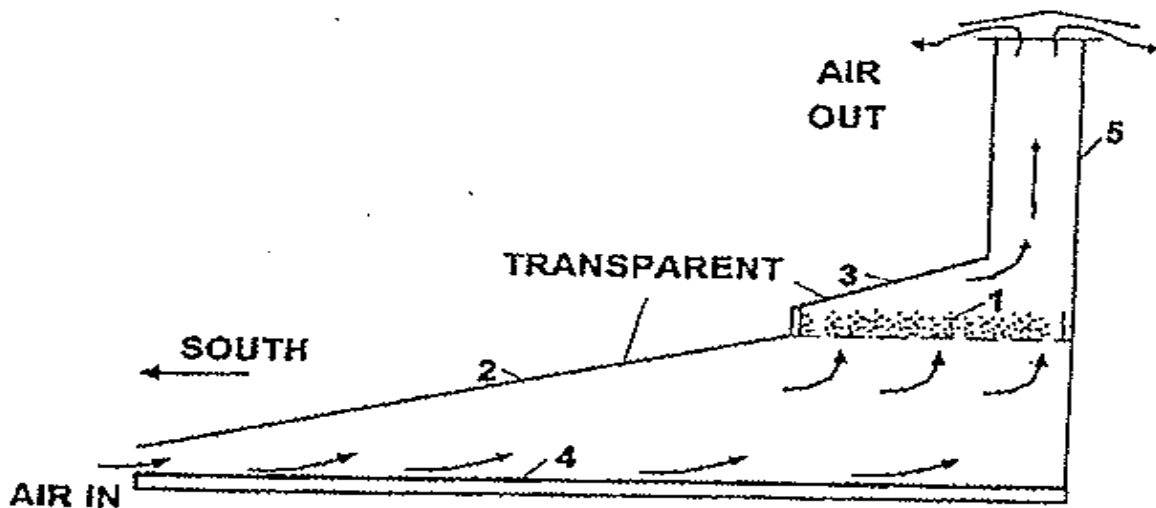


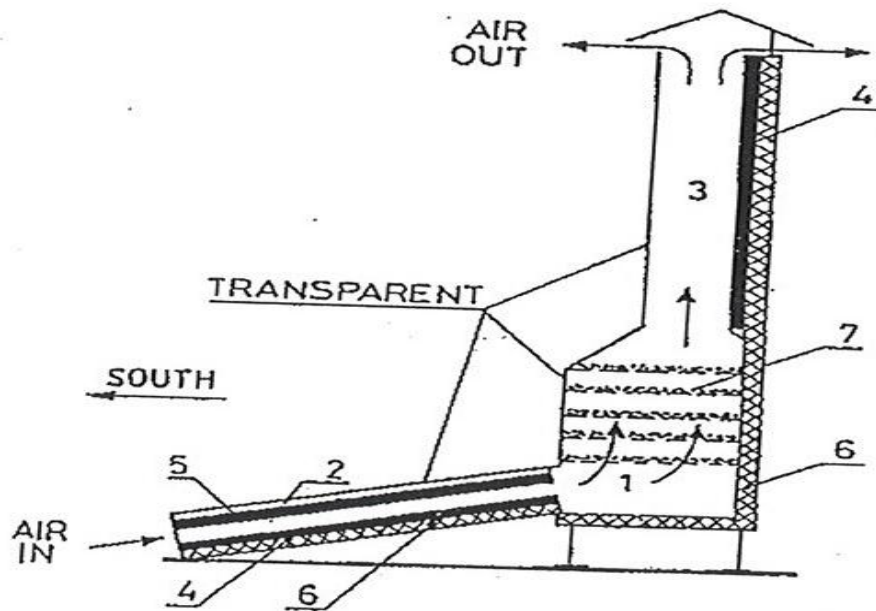
Figure 4 – cabinet dryers with chimney

### **Cabinet dryers fitted with a chimney and heat storage**

To extend the drying process into the non-sunny hours of the day, heat storage should be employed. Water vessels have been used as a relatively low cost means of heat storage (Puigalli and Lara, 1982 cited in Baker & Christopher G.J, 1997).

Sensible-heat storage capacity can be increased by using phase change materials. Figure 5 shows a simplified schematic of a chimney type cabinet dryer in which calcium chloride hexahydrate ( $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ ) is employed for this purpose (Imre, 1986b, 1989 cited in Baker & Christopher G.J, 1997). The phase change material is enclosed in plate shaped containers. The fixed latent heat storage plates 4 are arranged as the absorber of the separate collector 2, and of the northern wall of the chimney as well. The outer-wall surfaces 6 of the chimney 3 are thermally insulated. Additional heat storage plates 5 are movable and arranged below the cover of the collector. In sunny hours, these plates 5 are pulled out of the collector on both sides and are directly irradiated and charged. During night-time operation, they are pushed back below the collector covering, forming an air duct with hot upper and lower surfaces. Since the phase change process occurs at contrast temperature, a constant thermosyphon effect and a continuous air flow through the dryer will be maintained until the heat storage unit has been fully discharged. The material to be dried is spread in thin layers on trays 7 having perforated bottoms located in the drying space 1. Upper and lower

trays can be exchanged during drying to equalize differences in drying rates. The air flow rate through cabinet dryers fitted with a chimney can also be enhanced by using a wind-driven ventilator connected to the upper end of the chimney (Bansal and Geroge, 1993 cited in Baker and Christopher G J, 1997).



**Figure 5** – cabinet dryer with chimney with latent heat storage.

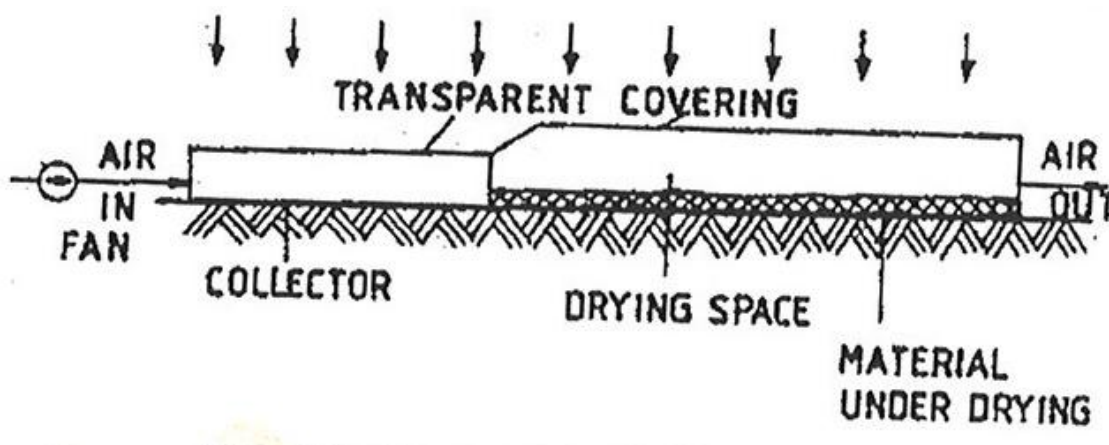
**2.2.2.2 - Semi-artificial solar dryer.** These usually feature a solar collector and a fan for maintaining a special air flow through the drying space. In the case of directly irradiated solar tunnel dryers, a section of the tunnel may be employed as a transparent plastic covered solar collector (Imre, 1989, 1995; Lutz and Muhlbauer, 1986 cited in Baker & Christopher G.J, 1997).

The use of semi-artificial solar dryers is justified by their unsophisticated and fairly cheap construction. They can be recommended for drying materials that are not sensitive to change in the drying conditions caused by the periodic character of the solar irradiation and by the changing atmosphere conditions.

## Types of Semi-artificial solar dryers

### Solar tunnel dryers

Solar tunnel dryers are frequently used for drying agricultural products (Imre, 1986a, 1995; Lutz and Muhlbauer, 1986; Esper and Muhlbauer, 1993; Bansal and George, 1993 cited in Baker & Christopher G J, 1997). Figure 6 shows a simplified arrangement of a serial solar tunnel located on the ground. The required mass flow rate of air is blown into the tunnel by means of a fan. The tunnel has a transparent covering. The first section serves as a solar collector with a black-bottomed surface for preheating the air. The connecting section of the tunnel forms the drying space. Material to be dried is spread on the bottom and is directly irradiated by the sun.



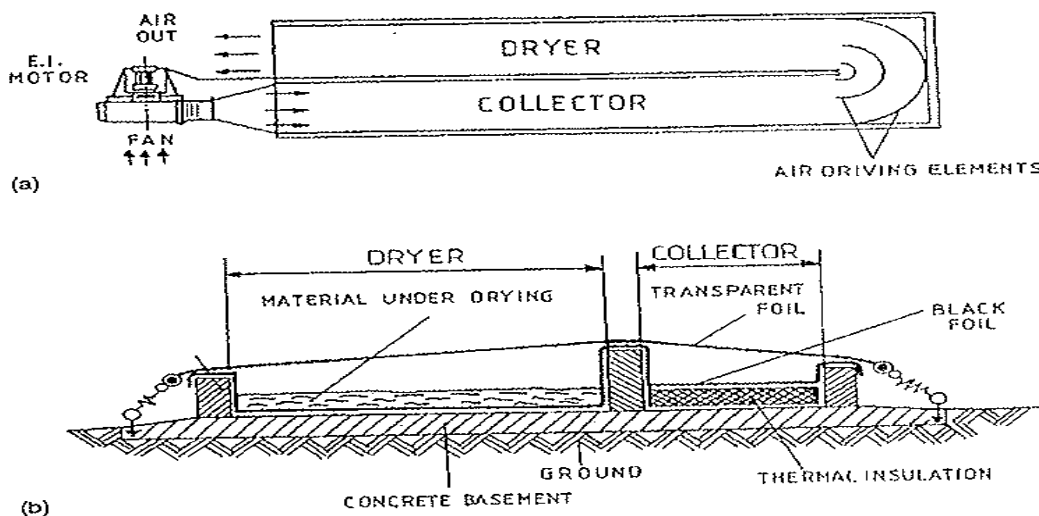
**Figure 6** – solar tunnel dryer (serial arrangement)

The length of the solar tunnel dryer can be reduced by arranging the collector and the drying section in parallel (Fig 7a). The fan is driven by an electric motor connected to the grid or fed by electricity generated by solar photovoltaic or wind-driven equipment. The cross-section of the dryer is shown in Figure 7b. A transparent-foil covering sheet is held in place by springs and black foil is used as an absorber and as the bed surface of the material to be dried. Structural elements are supported on concrete foundations.

Solar tunnel dryers are successfully used on farms for drying fruit, crops, vegetables, herbs, coffee, beans, cocoa and coconuts can be built using materials available locally. The size of

the dryer may be adapted to the drying capacity required. For tropical use, a biomass assisted version of the solar tunnel dryer has been developed.

The cross-section of the tunnel may be triangular, semi-circular, or have a flat cover (Muhlbauer et al., 1993; Janjal and Hirunlabh, 1993 cited in Baker & Christopher G J, 1997). A curved or semi-circular shaped cross-section is generally used in the case of serial collector-dryer arrangement.



**Fig 7** Solar tunnel dryer (parallel arrangement).

### **Greenhouse-type solar dryers**

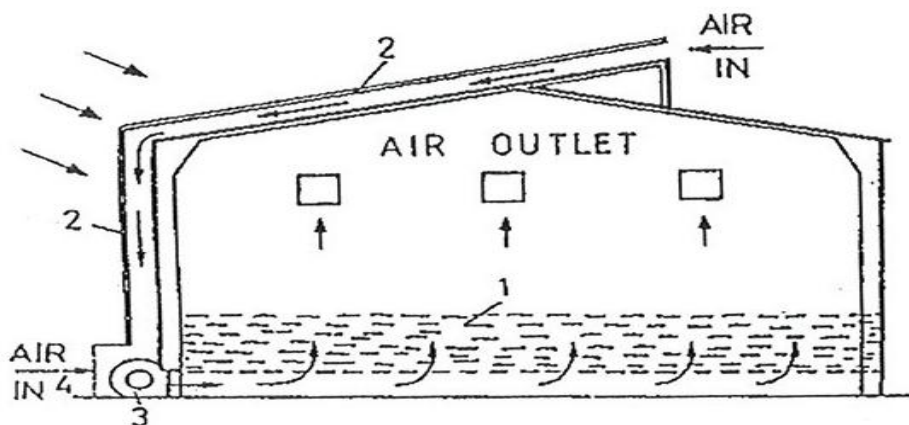
Foil-covered tunnel type greenhouses can also be used for drying agricultural products (Bansal and George, 1993; Reuss, 1993; Muhlbauer et al., 1993 cited in Baker & Christopher G J, 1997). They always incorporate a fan for maintaining a continuous flow of air, which is sometimes partially recirculated. Where sensitive materials are dried, some kind of shading is needed is moved through the drying space on a belt or a conveyor.

Greenhouse type solar dryers having titled flat-roof surfaces have been developed for drying herbs and aromatic plants. These feature roof integrated plastic collections and air recirculation.

### Solar room dryers

For drying agricultural products in larger quantities (e.g. grains, fodder), solar room dryers with a static bed are used successfully (Dernedde and Peters, 1978; Wieneke, 1980; Imre, 1995 cited in Baker & Christopher G J, 1997).

Figure 8 represents a typical solar room dryer. Air flow through the bed 1 is maintained by a fan 3 selected according to the flow resistance of the material layer. The bottom of the bed is perforated and air is blown into the distribution space beneath it. Preheating of the air occurs in the roof integrated solar collector 2, using the roof cover as heat absorber. Atmosphere air, entering through the inlet 4, can be mixed with preheated air to control the inlet air temperature if required. Moist air leaves room through the air outlets arranged on the side walls. For emergencies situations, such as bad weather conditions, a simple auxiliary gas operated air heater can be connected to the suction side 4 of the fan. Solar room dryers with roof integrated collectors have also been used successfully for drying fruits such as peanuts and bananas (Vaughan and Lambert, 1980; Bowrey et al., 1980 cited in Baker & Christopher G J, 1997).



**Figure8** – solar room dryer

**2.2.2.3 - Solar-assisted dryers.** Solar assisted dryers are conventional dryers having a solar collector. They are generally fitted with a heat storage system and are always fitted with an auxiliary energy source, such as a thermo-generator fuelled by natural gas or oil, for use in situations where the solar energy collected is insufficient for drying purposes. They are normally fitted with modern control systems.



## **Types of Solar- assisted dryers**

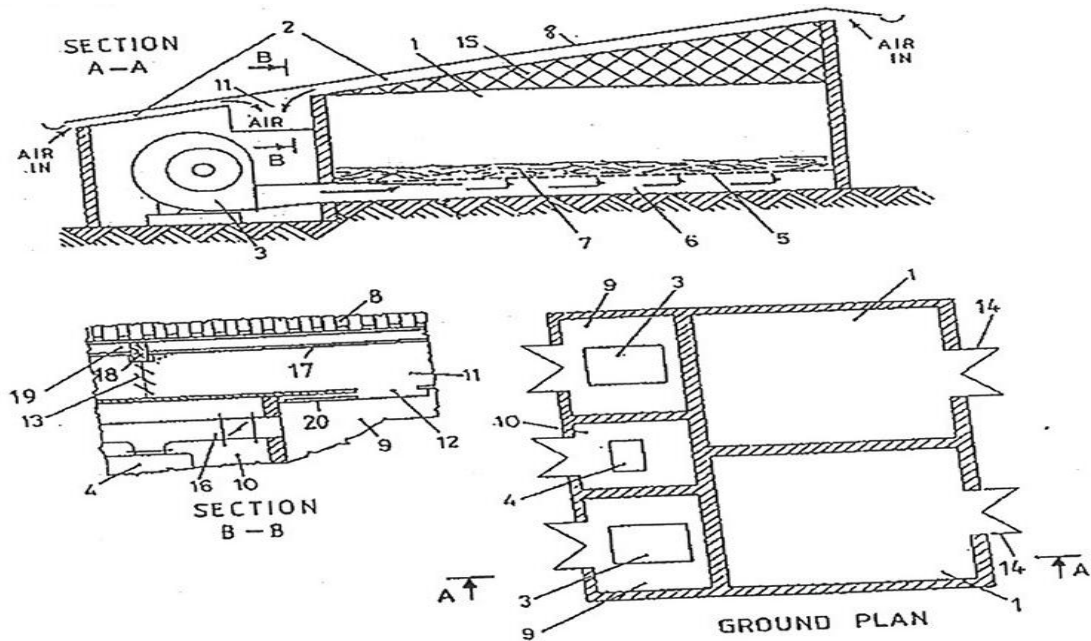
Solar-assisted dryers are conventional dryers to which supplementary equipment is added to enable a significant proportion of the thermal energy required for drying to be replaced by solar energy. In these types of dryer, a planned, and generally optimized drying process can be achieved to obtain superior product quality and good economic performance of the dryer can be eliminated by using an independent energy source, if needed, and proper control facilities.

### **Solar-assisted dryer for seeds and herbs**

In Fig 9, the ground plan and the cross-section of the dryer are presented (Imre, 1986a, 1995; Imre et al., 1986a; Catalogue, 1986). For economic reasons, the drying space is divided into two cells. Each cell has its own individual 2-speed fan 3. Fans are arranged in separate chambers 9. The conventional energy source of the dryer, a burner 4 fuelled by natural gas, is situated in chamber 10.

An uncovered air-collector 2, integrated into the roof structure, is used to convert the solar radiation into thermal energy. The conventional roof covering, made of trapezoidal galvanized steel blades 8 with black-painted surfaces, serves as heat absorber. A continuous covering of monolith plates 17, mounted at an appropriate distance beneath the absorber, forms of air ducts 19 between the rafters 18. These ducts 19 connect into a distribution channel 11 located in the ceiling sections of chambers 20. In this way, the total air flow through the collector can be shared between the fan chambers when valve 13 is open. Fans 3 blow the air into the drying cells. Thermo generator 4 moves the heated air into the fan ducts in the required ration through ducts 16, when required.

In the layer type version of the dryer, the material to be dried is loaded into the drying space 1 through entry doors 14. It is evenly spread in a bed 7 having a perforated bottom 5. Air is blown into the space 6 under the holding structure of the bed and passes through the supported solids. Moist air leaves the drying space through the openings 15 in the side walls.



**Figure.9** – solar assisted dryers for seeds and herbs

In Figure 10, a schematic diagram of the containerized version of the dryer is shown. For fragile materials that may be subject to damage during handling, the use of containers with perforated bottoms 21 is preferred. These are placed on foot stools with proper air stuffing 22 between them.

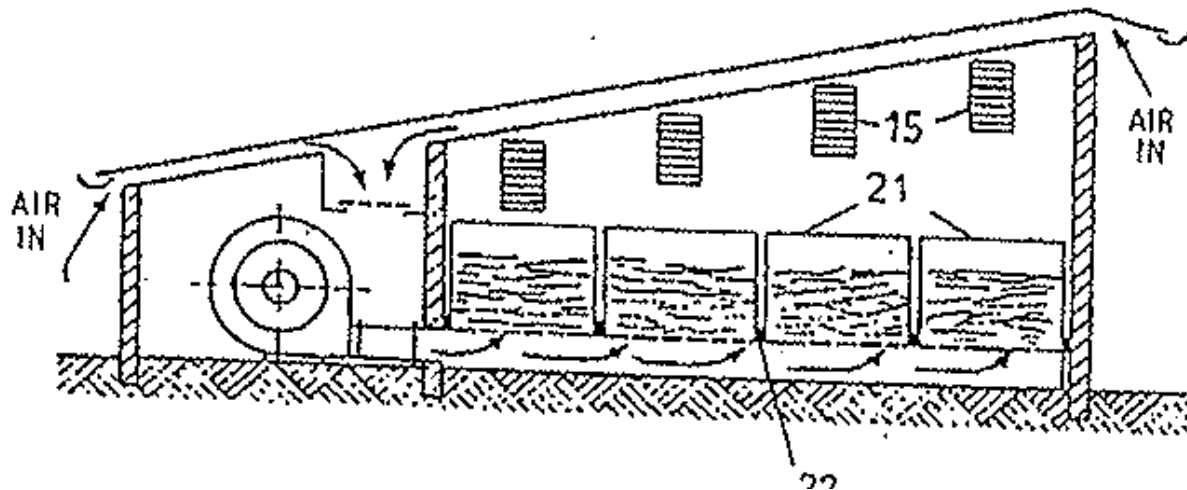
The main technical specifications for a seeds dryer are (Catalogue, 1986);

- Effective surface area of one cell, 56 m<sup>2</sup>;
- Dry mass of seed in one cell, 5600 kg;
- Mass flow rate of air (one fan),  
at 1090 rpm, 41 000 m<sup>3</sup> h<sup>-1</sup>  
at 475 rpm, 21500 m<sup>3</sup> h<sup>-1</sup>;
- Surface area of the collector field, 191 m<sup>2</sup>;
- Output of the thermogenerator, 93 kW.

The use of a two-cell arrangement by economic reasons. The in-feeding and drying process in two cells can be staggered. In this way, the average drying rate and the average energy consumption can be approximately equalized between the cells. The solar energy gained

can be distributed between the cells according to actual need and can be used more effectively in the dryer by reducing the exit losses, especially in the falling-rate drying period.

The fans are rated according to the layer thickness employed in the beds and the air inlet temperature required; the fan should be operated at the lower rpm when higher temperatures are needed.



**Figure 10** – solar assisted dryer containerized version

### **Solar-assisted dryers with heat storage**

Connecting physical heat storage equipment to solar dryers is justified by three main reasons

- The daily drying time can be extended to those hours of the day when the sun does not shine
- Overdrying can be prevented by storing the surplus solar energy collected in the peak radiation periods
- The inlet temperature of the drying air can be controlled

Natural and artificial materials can be used for heat storage. Natural materials include e.g. water, pebble beds and rock beds, which store only sensible heat. The artificial materials employed are generally salt solutions, which also store latent heat.

(a) **Solar-assisted dryers with heat storage.** Figure 11 depicts a solar-assisted dryer with water heat storage (Auer, 1980). The working fluid of the solar collector 1 is water, circulated by pump 2 along the pipe 3. The heated water flows to the heat storage tank 4. Atmosphere air is drawn by fan 7 through the water-air heat exchanger 5. The primary working heat exchange medium is the water circulated by pump 6 from the heat storage tank 4. An auxiliary air heater 8 can be used if required to maintain the prescribed inlet air temperature. Material to be dried is arranged in a static bed 9.

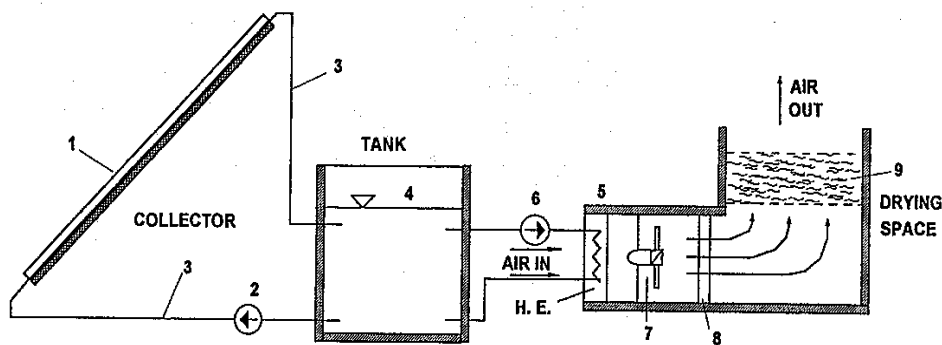


Figure 11 Solar assisted dryer with water type heat storage.

(b) **Integrated solar-assisted high performance dryers.** Preservation of agricultural products by solar drying is promising, since harvest time, on the whole, coincides with the period of highest-intensive solar irradiation. At the same time, however, seasonal variations limit the annual operating time and the solar energy utilization. In the case of high performance solar dryers with a large collector area and a high heat storage capacity, year-round operation of the collectors is essential in order to achieve an acceptable economic return. This goal can be achieved by the complex use of the solar collectors, which are capable of supplying heat, not only for drying, but also for satisfying other needs such as providing a hot supply to a farm, and heating or air conditioning of greenhouse or animal houses. For such purposes, indirect solar dryers with a water type collector come to the fore. The water tank can be used as heat storage for the solar dryer as well as for hot-water system (HWS). At

the same times, the conventional energy source of the HWS can be used as the auxiliary heater for the solar dryer.

Figure 12 illustrates a complex, integrated high performance solar dryer (Imre, 1986, 1989, 1995; Imre et al., 1986b, 1991 cited in Baker & Christopher G J, 1997). It was designed to produce dried lucerne hay for dairy farming. During idle periods, the system produces hot water for technological purposes. The drying space is arranged in a barn, which also serves for storing the dried hay. The single-glazed solar flat-plate collector is integral with the roof structure. It can be connected to the water-air heat exchanger of the dryer and to the hot water tank serving as the heat storage vessels by proper manipulating of valves 1 to 4.

The available drying space in the barn is divided into four cells (Figure 13(Imre, 1989 cited in Baker & Christopher G J, 1997)). Each cell has its own fan and water-air heat exchanger. Hot water produced by the solar collector can be distributed at will between the cells. Auxiliary energy is provided by gas operated thermo generators. For emergency situations, electrical heating is built into the tank. This can also be used as an additional auxiliary energy source. The principal system specifications are (Imre et al., 1986b cited in Baker & Christopher G J, 1997).

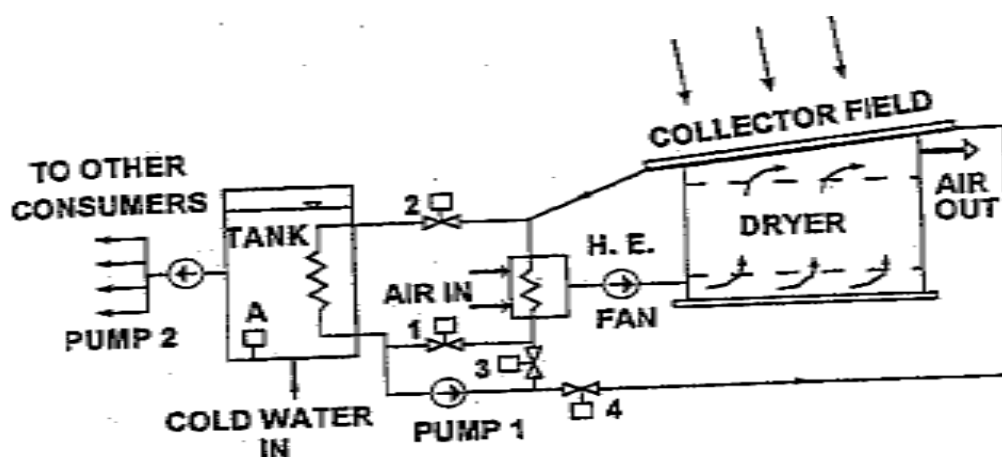


Figure 12 – simplified schematic of complex, integrated solar drying systems

### Solar flat-plate collector

Working fluid, water; surface area, 900 m<sup>2</sup>

Maximum volumetric flow rate of the working fluid,  $15.6 \text{ m}^3 \text{ h}^{-1}$

### Dryer

System, static bed dryer; area,  $800 \text{ m}^2$

Number of drying spaces (cells), four ( $200 \text{ m}^2$  each)

Total layer thickness, 6 m

Annual quantity of dried material, 1000 t

Storage capacity, 700 t

### Air System

Indirect, preheating the air by water-air exchangers

Number of fans, four (one fan per cell). Air flow rate per fan,  $106000 \text{ m}^3 \text{ h}^{-1}$

Primary auxiliary energy sources, biogas generations

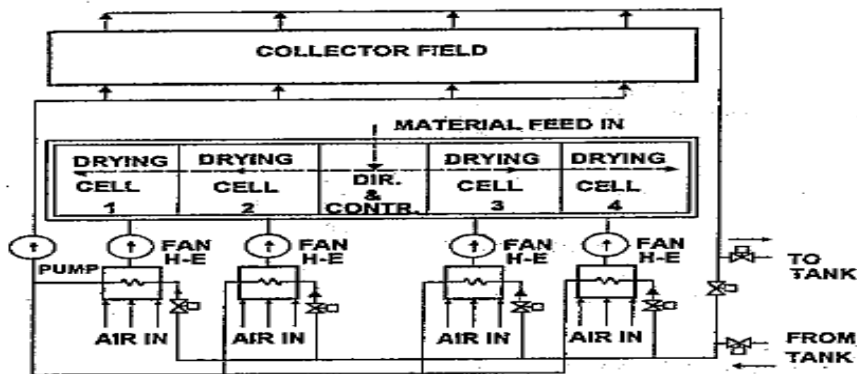
### Storage tank

Volume,  $100 \text{ m}^3$

System, stratified

Secondary auxiliary energy source in tank, electricity (400 kW) for night-time operation.

The system has several modes of operation (Imre, 1987 cited in Baker & Christopher G J, 1997). The actual mode is selected according to the technological requirements and the meteorological conditions. The four-cell arrangement offers the possibility of various drying programs. In selecting the mode of operation, a priority is assigned according to the solar energy collected: 'dryer' has the highest priority, heat storage' is second, followed by the 'hot water consumers' and 'other heat consumers'. The microprocessor based control system is described below (Imre, 1987; Imre et al., 1983a, b cited in Baker & Christopher G J, 1997).



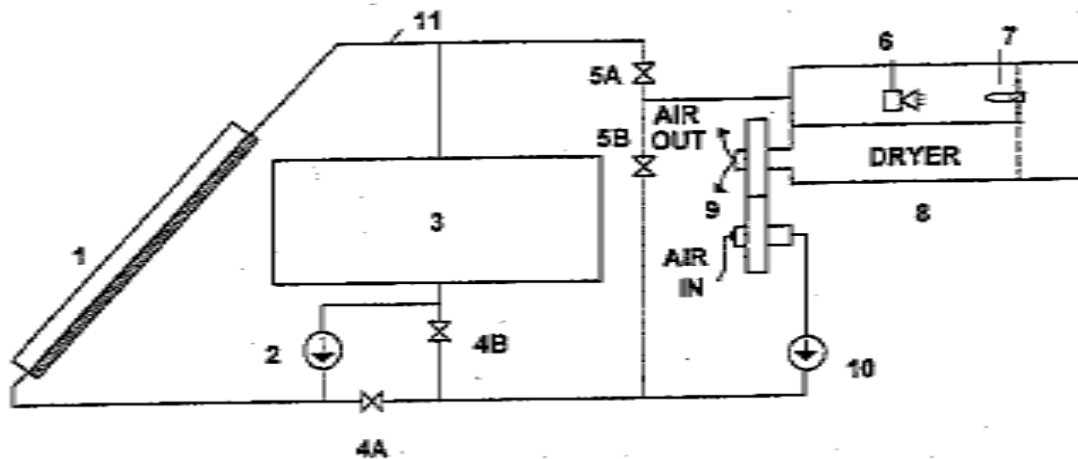
**Figure 13** – Schematic of dryers with four cells arrangement.

### **Solar-assisted dryers with rock bed heat storage**

In solar-assisted direct type dryers, rock bed, gravel bed and pebble bed heat storage systems are frequently used (Auer, 1980; Read et al., 1974; Contier and Farber, 1982; Niles et al., 1978; Choudhury et al., 1995 cited in Baker & Christopher G J, 1997).

A high performance raisin dryer featuring a gravel bed storage system is shown in Figure 14. The collector field<sup>1</sup> of 1812 m<sup>2</sup> surface area is located on the ground. Fresh air is blown through the collector loop by the fan 10 connected to a heat recovery unit 9 (dampers 4B and 5B are closed). Air, preheated in the collector, flows in the air duct 11 to the location where the gas burner 6 situated. The burner serves as auxiliary heater and operates when the temperature of the air arriving from the collector is lower than required. Warm air is transported into the drying tunnel 8 by the fan 7. Moist air leaves the dryer through the heat recovery unit 9. The rock bed heat store 3 can be charged by the collector when the fan 2 is in operation and air valves 4A and 5A are closed.

The dryer can also be operated by stored energy: dampers 4A and 5B are closed and fan 2 is switch off. Partial charging of the heat storage unit or partial use of stored energy can be achieved by the proper regulation of dampers 4A and 4B and the operation of fan 2. With this dryer, it proved possible to provide some 69% of the annual drying energy consumption by solar means.



**Figure 14** – Solar assisted main dryers with rock – bed heat storage

### **Solar-assisted dryer combined with absorbent units**

Complex and integrated solar- assisted dryers can be combined with absorbent beds, which may serve for energy storage as well as for auxiliary heating (Imre et al., 1982; Twidell et al., 1993; Imre, 1995 cited in Baker & Christopher G J, 1997). The energy storage capacity of an absorbent (e.g.zeolite or silica gel) is partly attributable to sensible heat and partly to moisture absorptions. The specific total energy capacity is about an order of magnitude than that of a physical heat store.

The dynamic adsorption capacity of the subsoilers should be exploited by regeneration at a temperature normally exceeding 150°C. However a considerable part of the energy used for regeneration can also be used for other purposes, eg. for hot water production. When solar energy is not available, the adsorption capacity can be used to operate the dryer.

Solar dryers fitted with adsorbent units have proved to be economically competitive with that incorporating rock bed energy storage. However, the economic comparison is greatly influenced by the local condition, opportunities and requirements (Imre,1974; Close and Dunkle,1977;Pinaga et al, 1981 cited in Baker & Christopher G J, 1997).

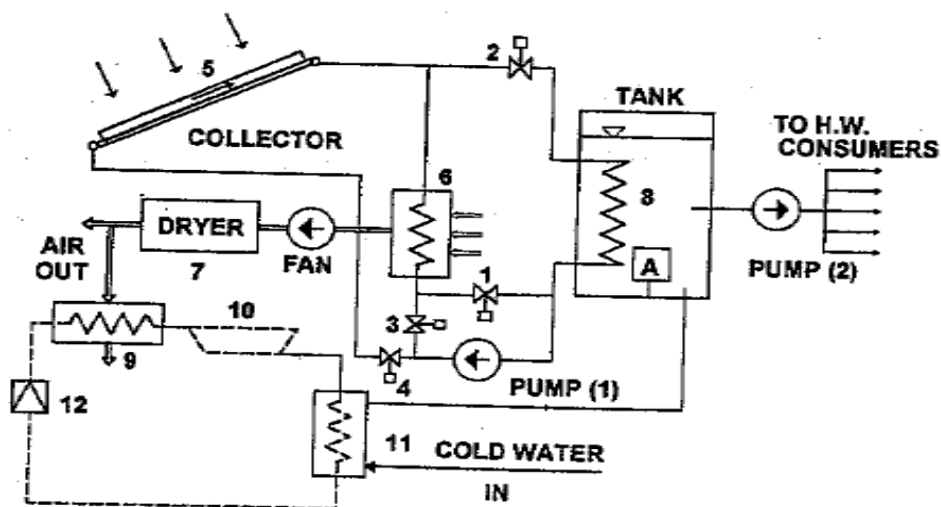
### **Solar – assisted dryers combined with heat pumps.**

Moist air leaving the drying space has almost the same enthalpy as the dry air had when it entered the dryer. A considerable part of the energy used for drying can be regained as



latent heat by cooling the air and condensing its water vapour content. This could be achieved by using a heat pump connected to the air outlet of the dryer.

Figure 15 illustrates the construction of a complex integrated solar lucerne dryer combined with a heat pump (Imre et al, 1982, Imre,1995 cited in Baker & Christopher G J, 1997). Moist air flows from the dryer 7 to the evaporator 9 of the heat pump. Here the air is cooled and moisture condenses. This provides the latent heat required to evaporate the working fluid of the heat pump, which circulates through the compressor 10, the condenser 11, the expansion valve 12, and back to the evaporator. Cold water is heated in the condenser 11 and fed the water heat storage tank and depending upon the ambient conditions, air leaving the evaporator 9 can be recirculated to the dryer heat exchanger 6. Solar assisted drying equipment combined with a heat pump and heat storage has been developed for drying peanuts (Auer, 1980 cited in Baker & Christopher G J, 1997).



**Figure 15** – Complex, intergrated solar assisted dryer combined with heat pump

### **2.2.3 – ADVANTAGES AND LIMITATIONS OF DIFFERENT TYPES OF SOLAR DRYERS.**

#### **Advantages of solar natural driers**

1. Low investments, as compared to mechanical dryers
2. Minimize the problems associated with open sun drying
3. A variety of solar natural driers are available worldwide.

#### **Limitations**

1. Due to its small capacity is use to small scale applications
2. Discoloration of crop due to direct exposure to solar radiation
3. Moisture condensation inside glass covers reducing its transitivity.
4. Sometimes the insufficient rise in crop temperature affecting moisture removes
5. Limited use of selective coatings on the absorber plate.

#### **Advantage of Semi artificial assisted driers**

1. Can be used to drying agricultural products in such as fruits, crops, vegetables , herbs, coffee, cocoa and coconuts
2. Relatively cheap in terms of construction
3. Reliable when compared with solar natural driers.

#### **Limitations**

1. Cannot be used to dry agricultural products in large quantity.

#### **Advantages of solar assisted dryer**

1. Most suitable for drying large quantity of agricultural products
2. It's designs are economical in the sense of drying space.

#### **Limitations**

1. Expensive because of the components that deals with the designs.
2. It is too complicated in terms of designs and people in developing countries or urban areas may find it hard to operate

3. Costly to use for small scale drying

## **2.3 – Design Methodology.**

The design methodology section comprises of the components of solar dryers designs and how to get the best performance from it.

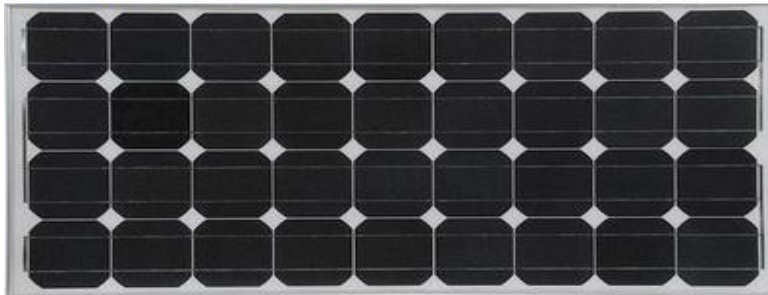
### **2.3.1 – solar dryer components**

#### **2.3.1.1 – solar collectors**

##### **Three types of solar panels**

##### **1. Monocrystalline Solar Panels**

###### **Monocrystalline Solar Panel**

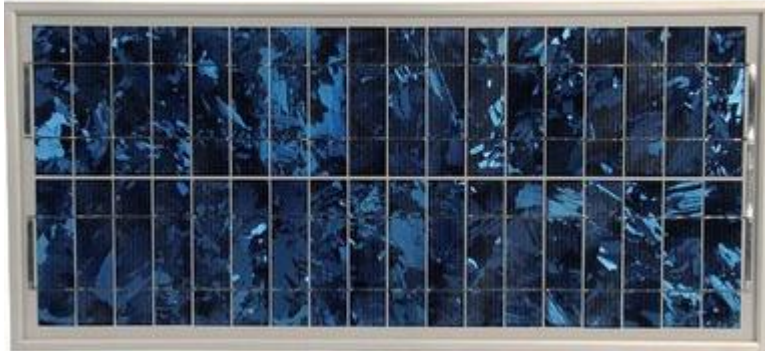


**Figure16 – Monocrystalline solar panel**

Monocrystalline solar panels are made from a large crystal of silicon. These types of solar panels are the most efficient as in absorbing sunlight and converting it into electricity; however they are the most expensive. They do somewhat better in lower light conditions than the other types of solar panels. Polycrystalline Solar Panels are the most common type of solar panels on the market today. They look a lot like shattered glass. They are slightly less efficient than the monocrystalline solar panels and less expensive to produce. Instead of one large crystal, this type of solar panel consists of multiple amounts of smaller silicon crystals.

## 2. Polycrystalline Solar Panels

### Polycrystalline Solar Panel



**Figure 17 – Polycrystalline solar panel**

Polycrystalline solar panels are the most common type of solar panels on the market today. They look a lot like shattered glass. They are slightly less efficient than the monocrystalline solar panels and less expensive to produce. Instead of one large crystal, this type of solar panel consists of multiple amounts of smaller silicon crystals.

## 3. Amorphous Solar Panels

### Amorphous Solar Panel



**Figure 18 – Amorphous solar panel**

Amorphous solar panels consist of a thin-like film made from molten silicon that is spread directly across large plates of stainless steel or similar material. These types of solar panels have lower efficiency than the other two types of solar panels, and the cheapest to produce. One advantage of amorphous solar panels over the other two is that they are shadow protected. That means that the solar panel continues to charge while part of the solar panel cells are in a shadow. These work great on boats and other types of transportation.

## **Solar Panel Efficiency**

Solar Panel efficiency is the percentage of solar energy that is captured and converted into electricity. It's difficult to give an exact number, so the numbers below are an average percentage of efficiency that the different types of solar panels output. Thin film solar panels will generally degrade approximately 1% each year, whereas crystalline panels degrade at approximately .5%. Below are the approximate percentages for each type of solarpanel

Monocrystalline-18%

Polycrystalline-15%

Amorphous (thin-film)- 10%

### **2.3.1.2 – Heating chambers**

The heating chamber can in any shape and size but it should have the following characteristic in order to increase its efficiency

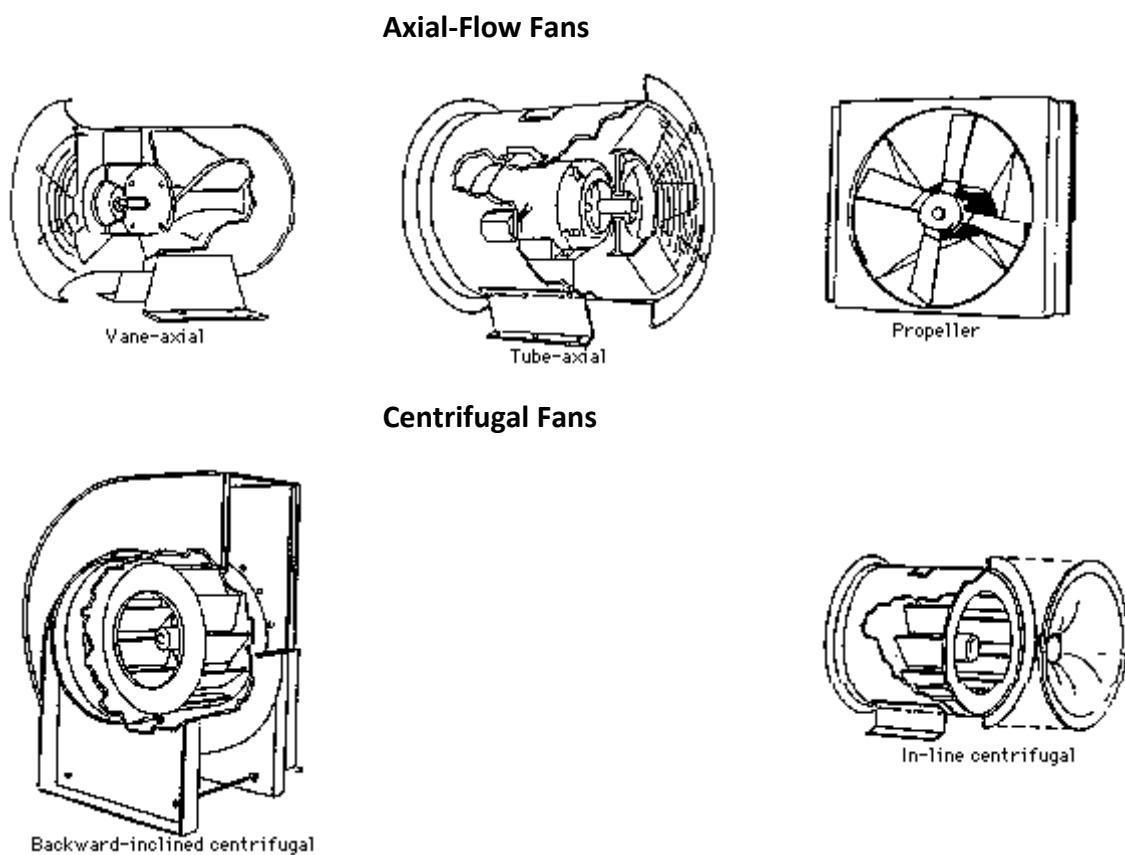
- a. Should have an appropriate size for its projected use.
- b. Should be of a convenient height.
- c. The floor and walls inside the drying chamber should be of a dark color.

### 2.3.1.3 – Fans

#### Fan Types

Most fans can be categorized as either axial-flow or centrifugal (see Figure 3). Axial-flow fans are sometimes called propeller fans, although that's really just one type of axial-flow fan. Air moves in a straight line through axial-flow fans parallel to the axis or impeller shaft. The impeller has a number of blades attached to a central hub.

**Figure 3. Types of fans used for ventilating crops.**



**Figure 19a – 19b – a. axial fan, b. centrifugal fan**

Centrifugal fans are sometimes called blowers or squirrel cage fans. The impeller is a wheel that consists of two rings with a number of blades attached between them. Air enters one

or both ends of the impeller parallel to the shaft and exits one side perpendicular to the shaft. The blades can be straight, slanted in the direction of airflow (forward-curved), or slanted opposite the airflow direction (backward-curved or backward-inclined).

### **Propeller Fans (panel fans)**

These are axial-flow type fans that have from two to about seven long blades attached to a small hub. Fan diameter is usually large relative to the fan's length or thickness. Some propeller fans are called panel fans and are designed for mounting in a wall or plenum divider. Some are belt-driven and some have the impeller hub attached directly to the motor shaft (direct-driven).

Propeller fans normally can't generate more than about 2 in. water pressure. They are most commonly used for potato ventilation, forced-air produce cooling, hay drying, exhausting air from attics or overhead spaces, or general air circulation. They are seldom used for grain drying or aeration.

### **Tube-axial, vane-axial**

These axial-flow fans have a barrel-shaped housing and an impeller that has a large hub with a number of short blades attached to it. They are generally direct-driven and the motor is cooled by the airstream. In positive pressure systems, the air stream captures the waste heat given off by the motor. Vane-axial fans have guide vanes inside the fan housing to help reduce air turbulence.

Tube-axial and vane-axial fans are the most common types used for grain drying and aeration. They are relatively inexpensive and fairly efficient when static pressure is less than about 4 in. water. The main disadvantage of these fans is that they are very noisy.

### **Centrifugal**

The centrifugal fans used for crop drying and storage generally have backward-curved or backward-inclined blades. They are expensive, but are also quiet and are usually the most

efficient type of fan when static pressure is greater than about 4 in. water. The motor on centrifugal fans is normally outside the air stream; you need to install a special housing around the motor if you want to capture the heat it gives off.

Forced-air heating and ventilating systems often use centrifugal fans that have forward-curved blades. Motors on these fans can be overloaded and burn out when the fans are operated outside certain pressure ranges. This characteristic makes them unsuitable for many crop drying and storage applications.

### **In-line centrifugal**

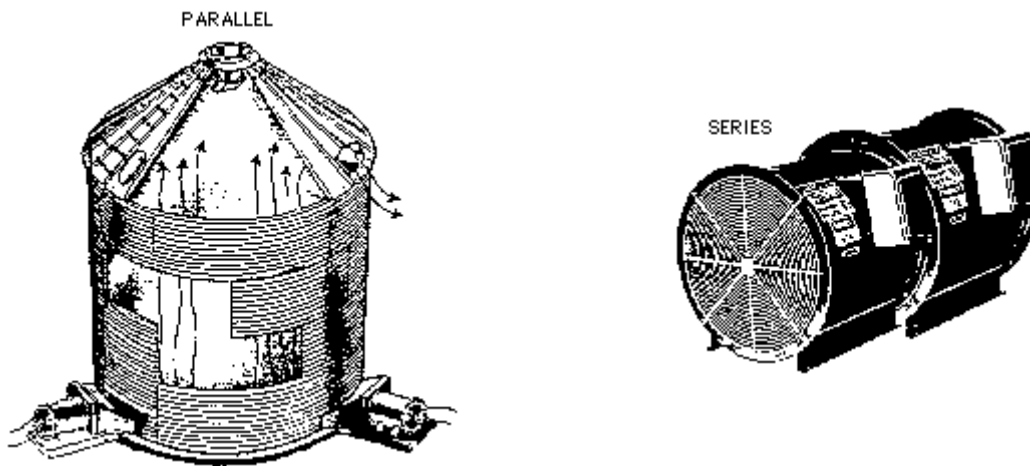
These fans have axial airflow, but use a centrifugal-type impeller. Price and operating characteristics are between those of backward-inclined centrifugal and tube-axial fans.

### **Multiple Fans**

It is sometimes necessary or desirable to install more than one fan to provide air to a common plenum or supply manifold for a duct system. Fans can be arranged in parallel or series (Figure 4). Reasons for using multiple fans include:

- Total airflow, pressure, or power requirements exceed the capabilities of the largest fan available from your dealer.
- The starting current for a single large fan motor is greater than the electrical system can handle. The maximum starting current is lower if several small fans are started one at a time.
- When multiple fans are installed, you have the option of turning some of the fans off and operating with a lower airflow when conditions allow.
- Air distribution is sometimes more uniform when several small fans are used in place of one large one.





**Figure 20 – Parallel and series**

### **Parallel**

Parallel arrangement means fans are installed side-by-side or at several points along a manifold or plenum. The most common applications are where total airflow requirement is large, but pressure is moderate. When fans are installed in parallel, they all face the same pressure. Total airflow is estimated by adding the airflow provided by each fan at the expected pressure.

### **Series**

Series arrangement, where fans are fastened in line or end-to-end, is not used very often. When it is used, it generally involves tube-axial or vane-axial fans in situations where pressure is relatively high, such as in deep grain bins. Series arrangement is seldom used with centrifugal fans and seldom are more than two axial-flow fans connected in series. When fans are arranged in series, each fan handles the same airflow. Total pressure is estimated by adding the pressure developed by each fan at the expected airflow.

### **2.3.1.4 – other components**

#### **a. Drying trays**

The drying trays should have the following characteristic

1. Make them strong enough to withstand vigorous cleaning as well as the weight of food.
2. Use a material that will allow good circulation of air through the tray.
3. Make them of a non-toxic material (don't use galvanized or aluminum tray material).
4. Design them to easily fit into the dryer.
5. Space them at least 5 cm. apart.

#### **b. Vents**

Characteristic of a good vent :

1. Maximize the difference in height between the inlet and outlet vents.
2. Maximize the width of both vents. In a cabinet dryer, make both vents 1/3 the area of the back wall.
3. Insect-proof the vent openings with screen or netting.
4. Make a door over the bottom vent that hinges from the top side.
5. Make a door over the top vent that hinges from the bottom.
6. Make both doors sealable against night air.
7. Devise a way to maintain the vent doors open at different angles.

#### **c. Access Door**

1. Should be large enough for easy access to all the trays.
2. Should hinge either from the side or bottom
3. Should be insect-proof when closed.

#### **d. Glazing**

1. Must be transparent.
2. May be two layers (with a 2-4 cm air space in between).

3. Should be considered as far as its: cost strength thickness ease of installation
4. Should have the correct compass orientation if built in place.
5. Should have the correct angle according to the time of year it will be used. (For summer: Latitude -10°; winter: Latitude +30°; spring, fall and year round: Latitude +10°.)

#### **e. Solar Preheater**

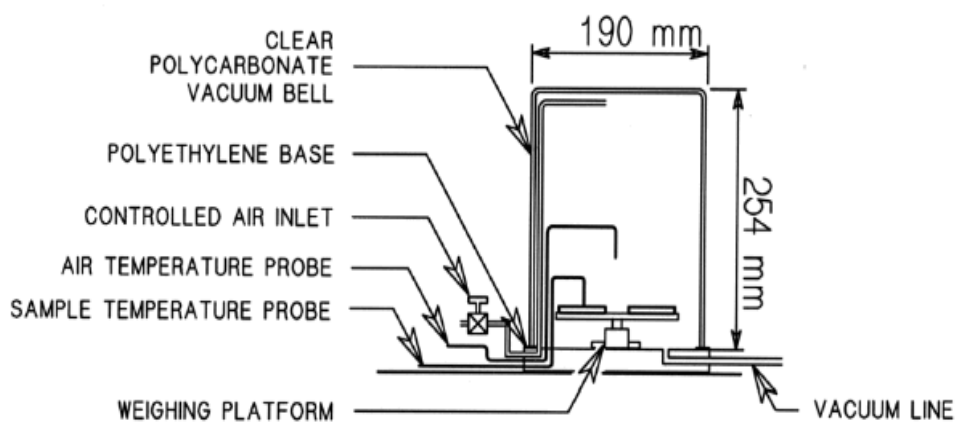
1. Inlet and outlet vents should be of the same size as the ones on the dryer.
2. Glazing angle may be different from the one on the dryer to maximize use throughout the year.
3. The absorber surface on the bottom of the preheater should be a dark color, and preferably made of metal.
4. It can be removable, but should seal well to the bottom vent of the dryer.

### **2.3.2 – EXISTING DESIGNS FOR DIFFERENT TYPES OF SOLAR DRYERS.**

This part will discuss some of the existing solar dryers designs. There are so many designs found throughout the course of this research and therefore only a few designs will be mentioned.

#### **1. Vacuum assister solar dryer**

According to (Raijkumar. P et al. 2006) this drying unit consists of a drying chamber (polycarbonate vaccum bell) measuring 25.4cm height and 19cm diameter, a circular disc fitted with weighing platform, polyethylene gasket, temperature probe and vacuum pump. The polyethylene gasket was kept in between the drying chamber and circular disc to avoid leakage of air.



**Figure 21 – Vacuum assisted solar dryer.**

#### **2. In – storage solar drying systems**

(W.Radajewski & D.Gaydon, 1990) shows designs of a in – storage drying system.

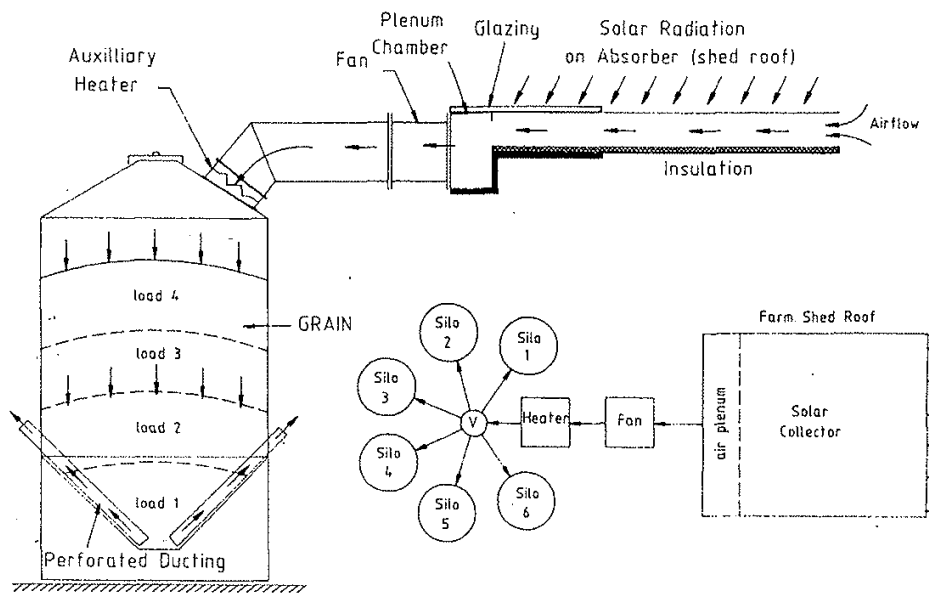


Figure 22 – Schematic diagram of in storage solar drying systems

**3. Solar – Biomass Dryer.**

The solar biomass dryer has 3 major components which are drying chamber, solar collector and a biomass furnace (Arnold R et al. 2001).

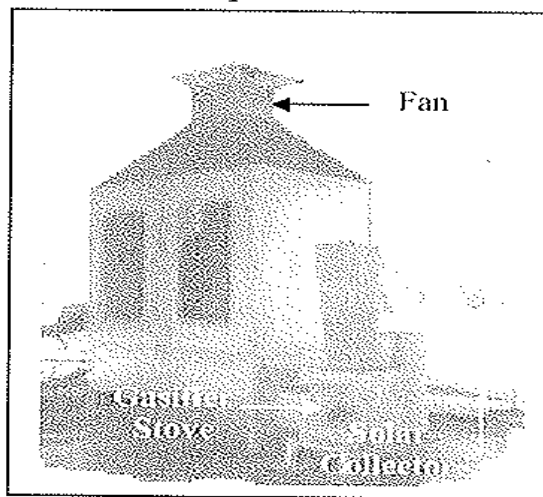


Figure 23 – solar biomass dryer.

4. Solar driers design for drying copra (M.Moharaj & P.Chadrasejkar, 2008).

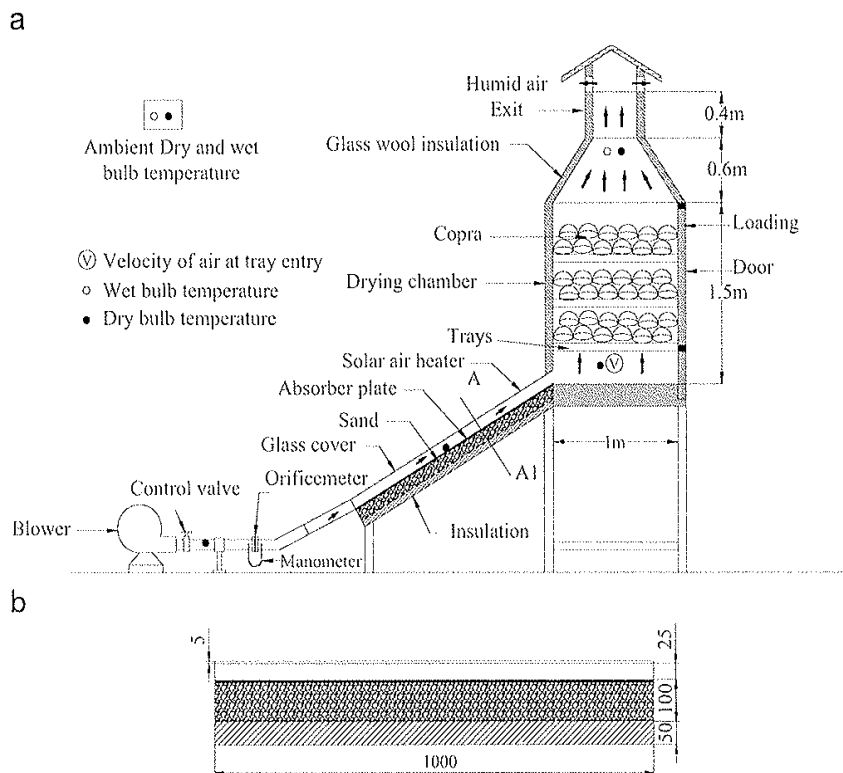
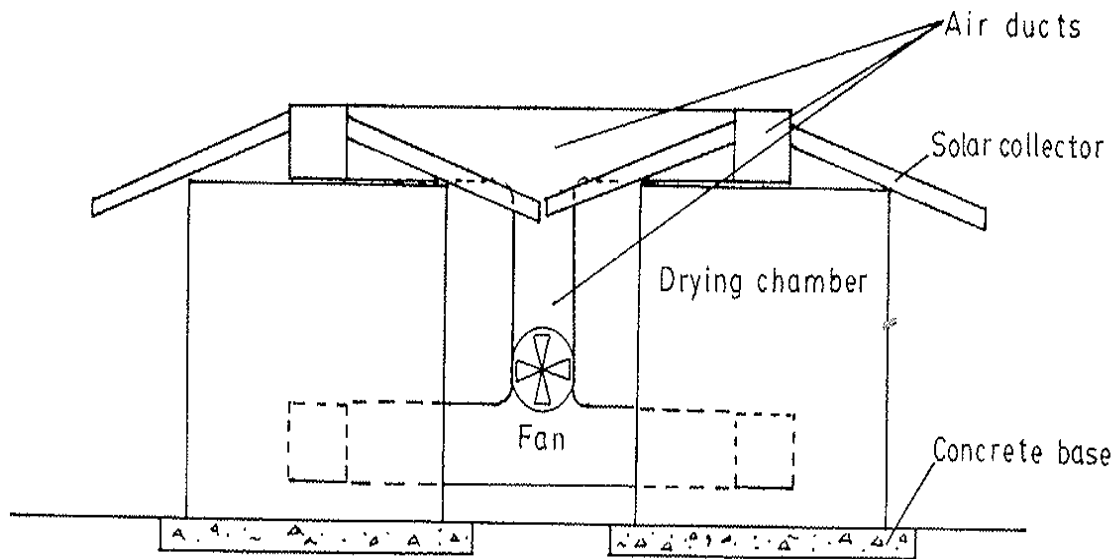


Figure 24a) – schematic view of a solar drier for copra

b) – sectional view and all dimensions are in millimetres.

### 5. Electrical Solar Dryer – AC Powered



**Figure 25** – Electrical solar dryer designed by Professor Oliver – Barbados

## 6. Solar dryer – DC powered.

The dryer consists of sun collector panel, drying chamber, fan for air circulation, moisture and temperature sensor and PV-panel for powering the fan.



Figure 26 – DC powered solar dryer designed by Giulio Pozzoli – Italy.

## 7. Natural-circulation solar maize dryer

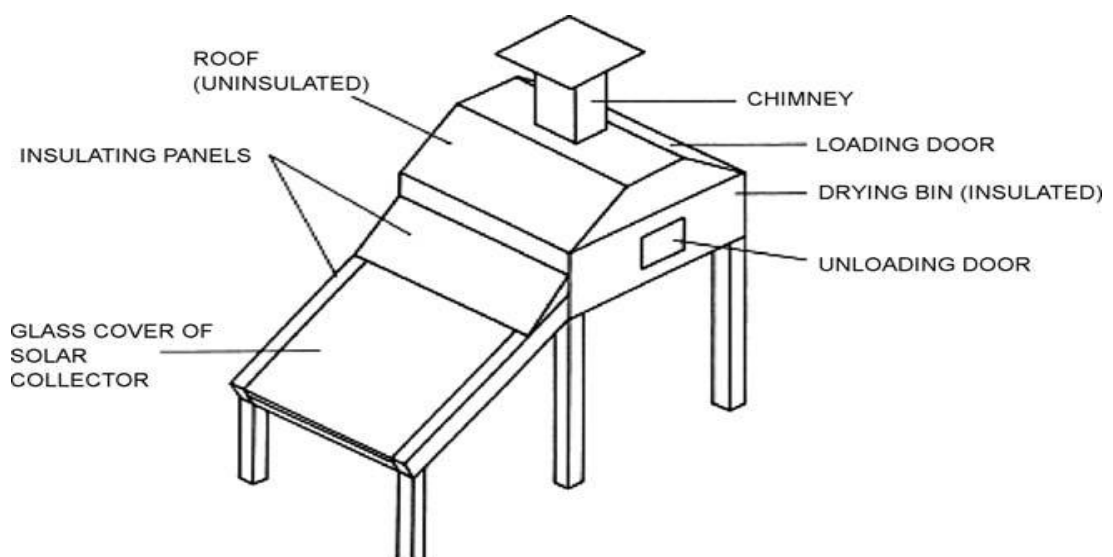




Figure 27 - A distributed – type natural-circulation solar Maize dryer designed by Othieno, Graiger and Twidell.

8. Natural –circulation solar-energy cabinet dryer with chimney.

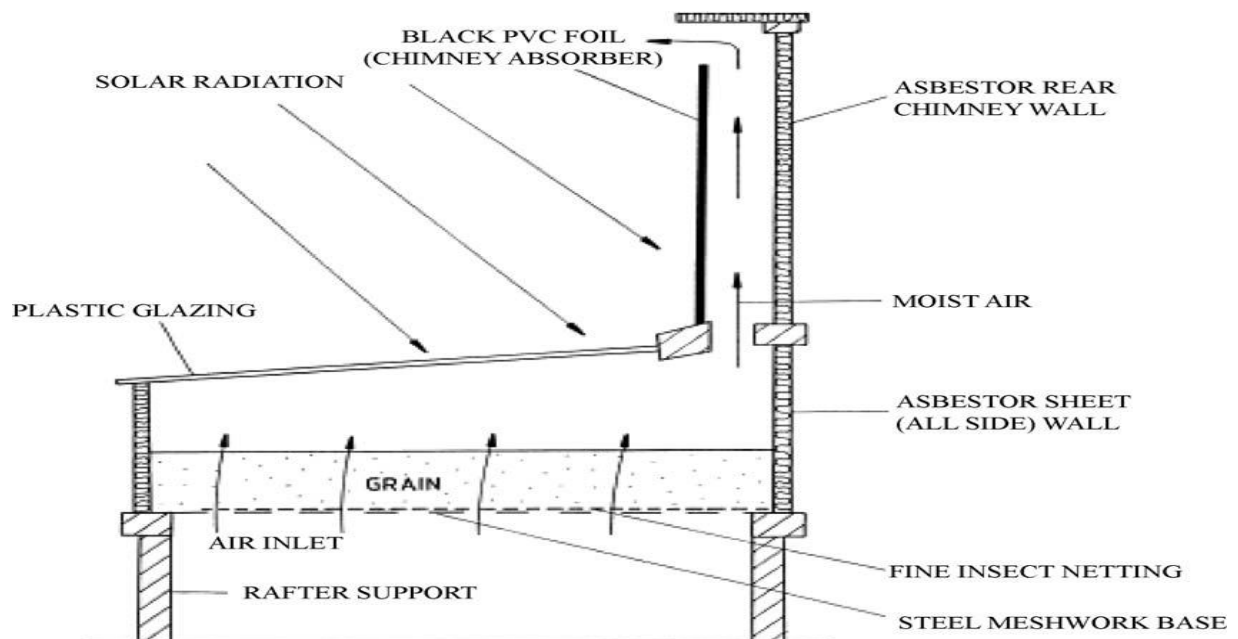


Figure 28 - A natural-circulation solar-energy cabinet dryer with chimney. Designed by Gustafson (tested a natural circulation solar-energy cabinet dryer with chimney in Nicaragua).

9. Modified natural-circulation solar-energy cabinet dryer.

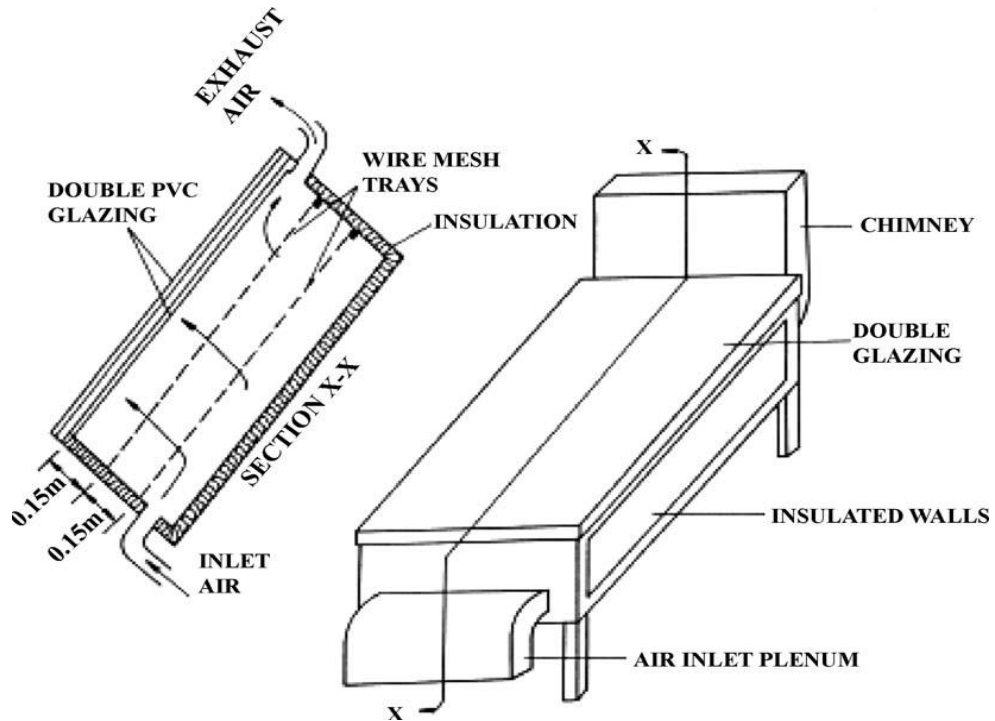


Figure 29 - Ezekwe reported a modification of the typical designed cabinet dryer.

### 10. Solar dryer cum water heater

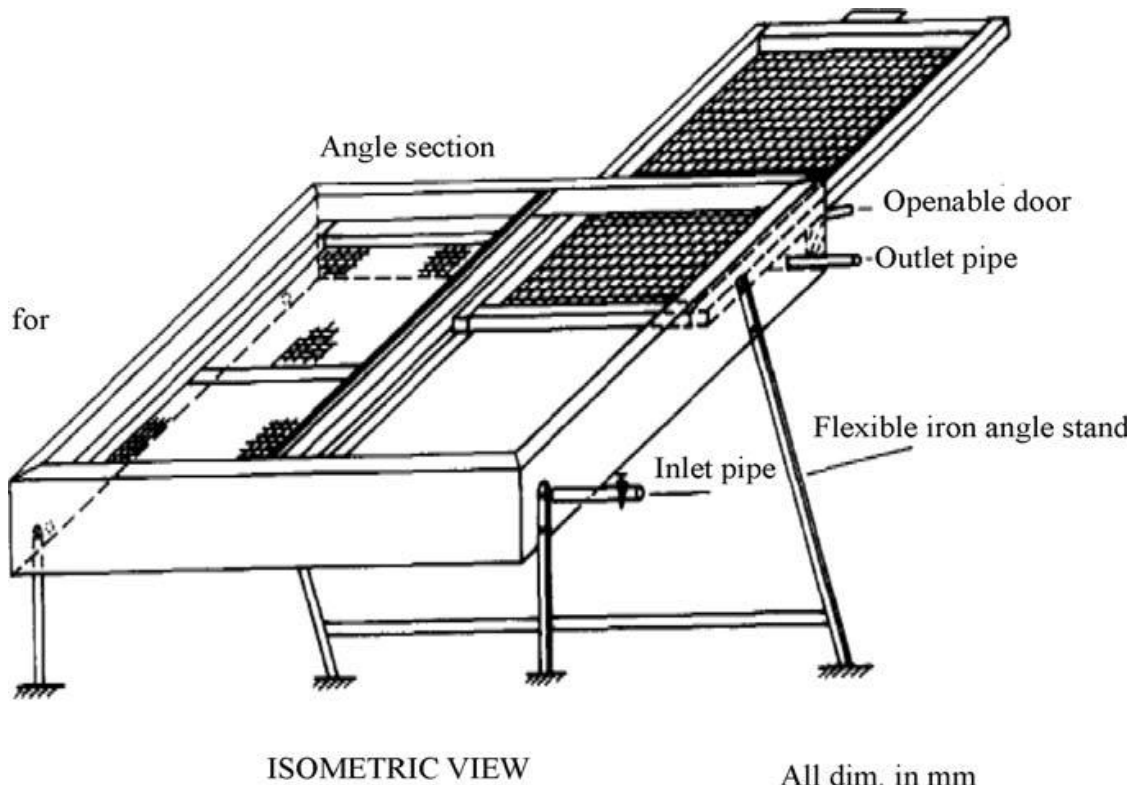


Figure 30 - Pande and Thanvi designed developed, and tested a solar cum water heater

### 11. Fixed bed solar dryer

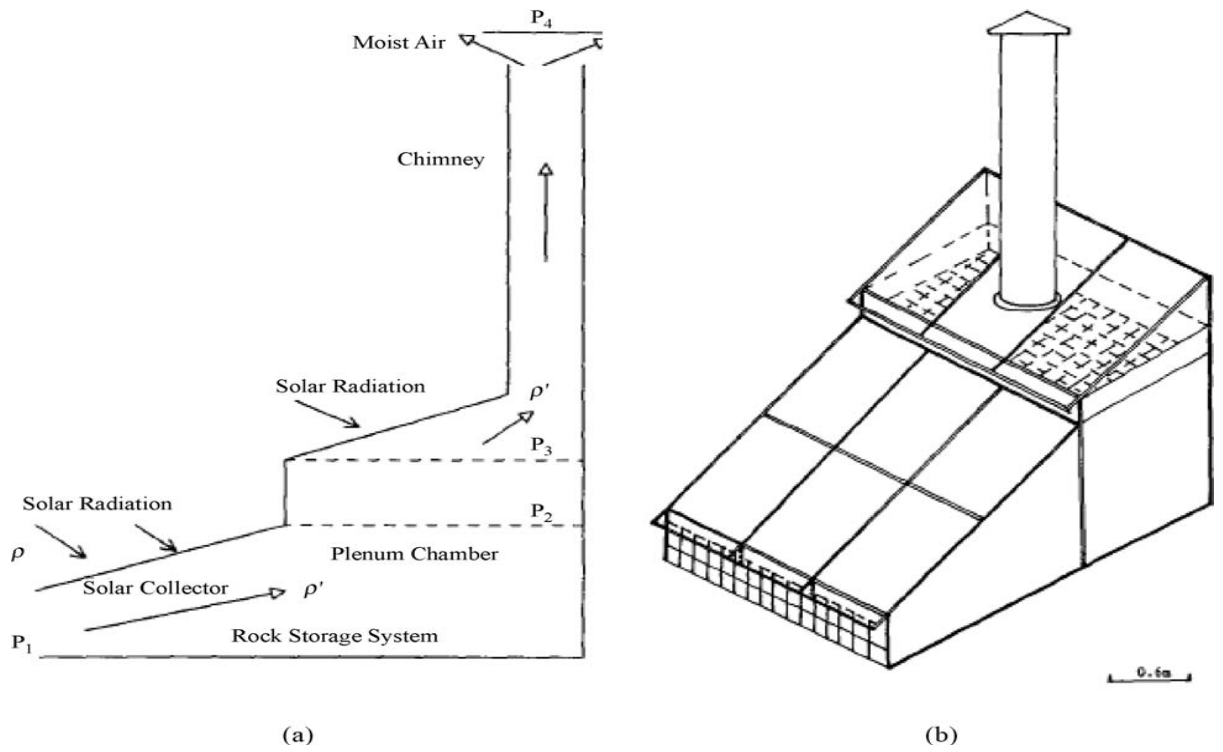


Figure 31 - Ayensu designed a low cost, low temperature and simple to operate solar dryer was constructed to dehydrate farm produce.

## 12. Indirect type natural –circulation solar-energy dryer

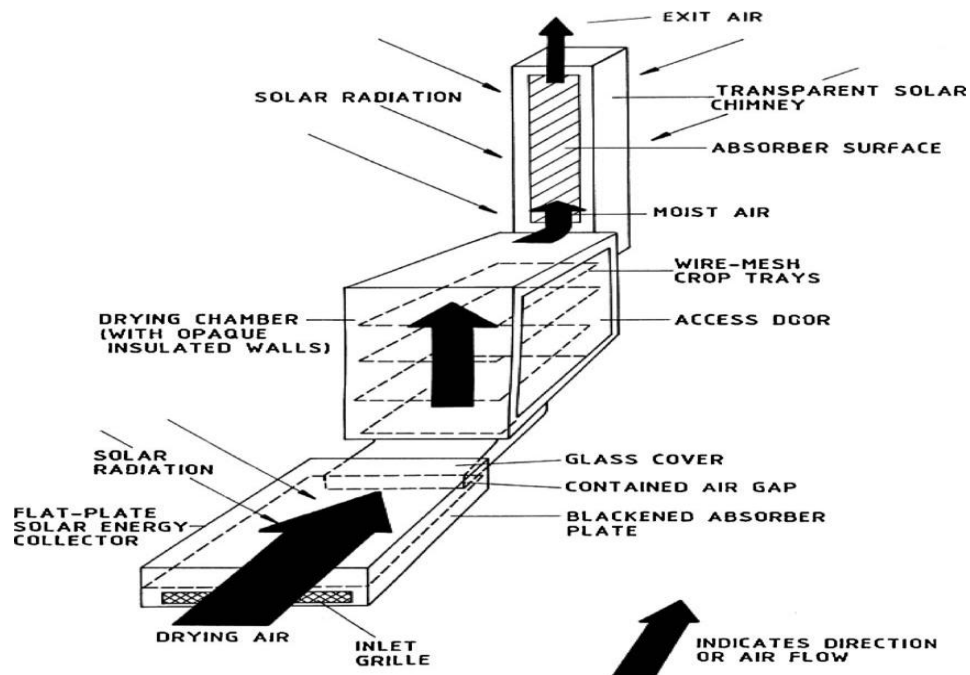


Figure 32 - Ekechukwu and Norton designed and developed a natural solar dryer which is suitable for most of the crops.

13. Solar Cabinet with open cover

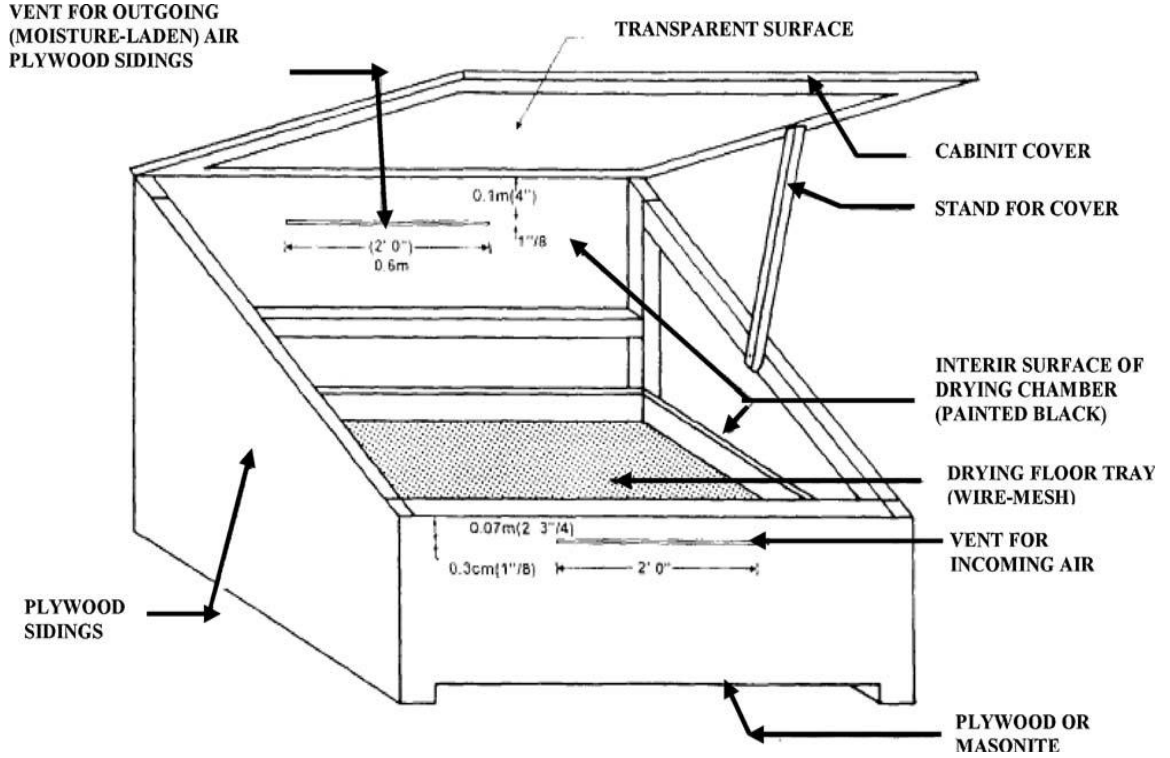


Figure 33 - Ampratevum developed a solar collector in the form of a prototype solar cabinet dryer in Oman.

14. Radiative-convective dryer

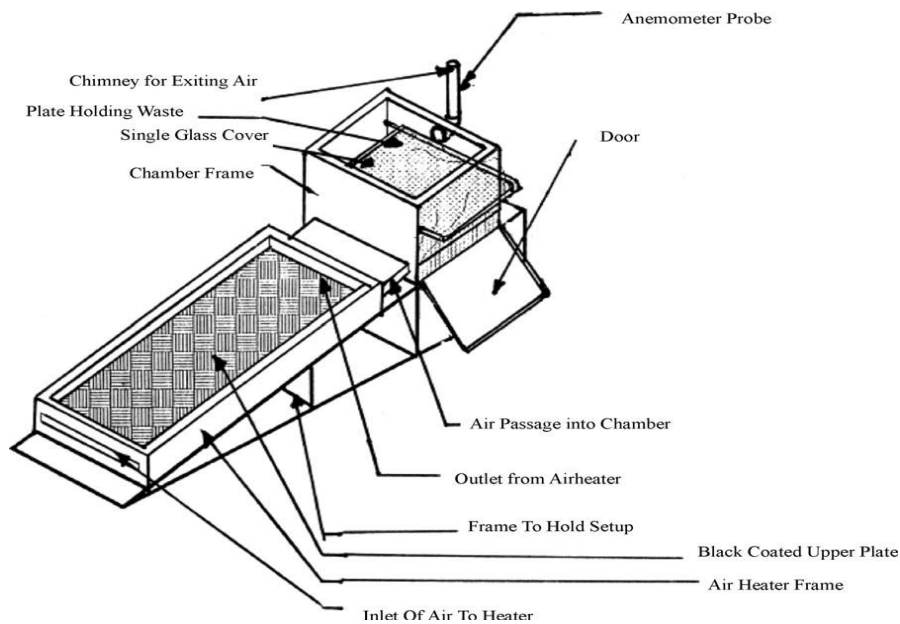


Figure 34 - Nijimeh et. Al studied the drying behaviour of food waste for utilisation of animal feeds thru the two solar dryers manufactured from locally available materials (For radiative and boiler dryer).

### 15. Boiler Solar dryer

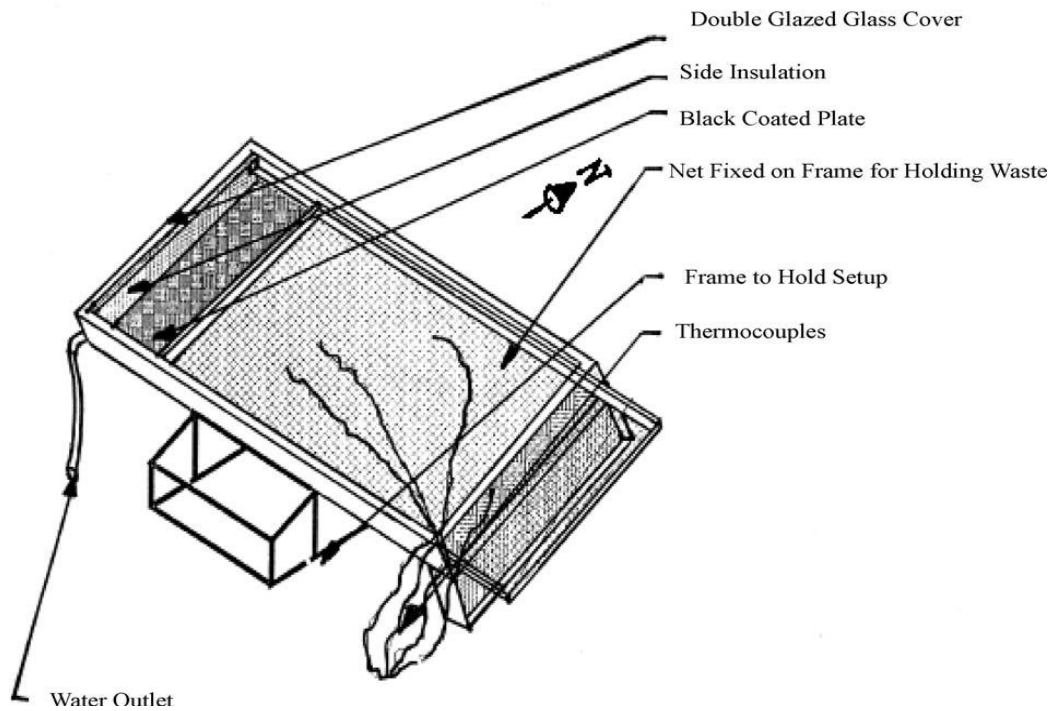


Figure 35 – Boiler solar dryer

## 16. Fruit and Vegetable solar dryer

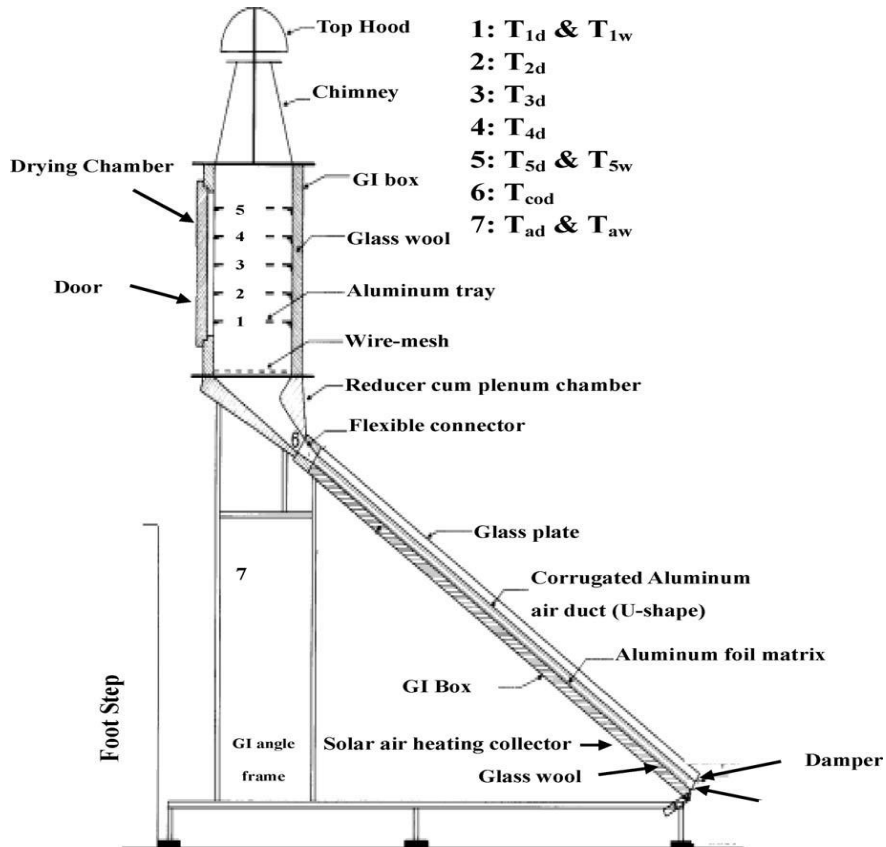


Figure 36- Pangavhane et.al developed a new natural convection solar dryer consisting of a solar air heater and a drying chamber.



### 17. Portable farm solar dryer

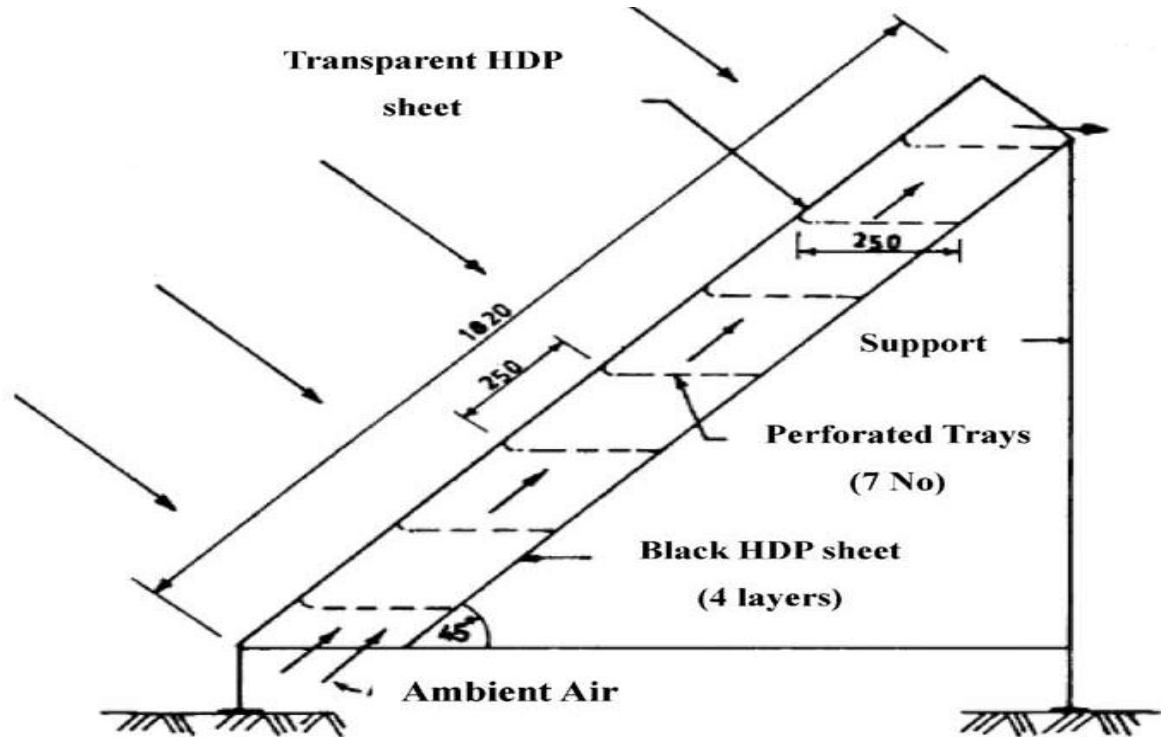


Figure 37 - Singh et.al developed a solar dryer to enable Indian farmers to add values to their produce by drying it at farm itself.

### 18. Solar dryer used in drying experiments- pictorial view and cross sectional view

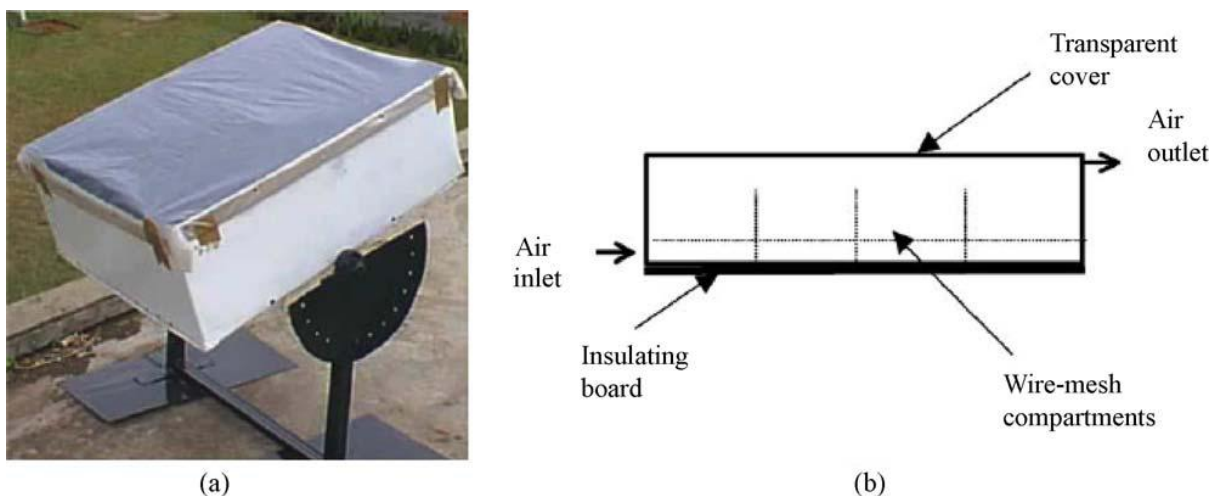


Figure 38- Mwithiga and Kigo designed and tested a small solar dryer with limited sun tracking capabilities.

### 19. Domestic solar dryer



Figure 39 - Singh et.al developed a multi- shelf domestic solar dryer for drying various products.

## 20. Simple Presentation MI

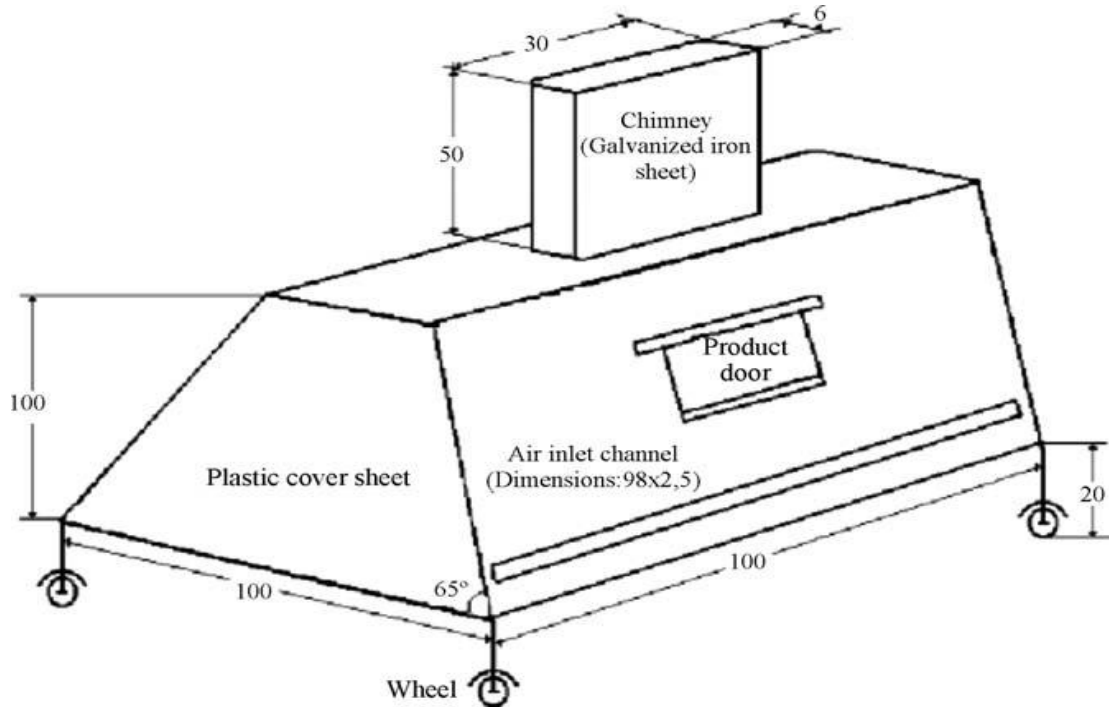


Figure 40 - Koyuncu designed, constructed and tested two different types of natural circulation greenhouse crop dryers.

## 21. Biomass solar dryer



Figure 41 – Biomass solar dryer

## 22. Solar grain dryer

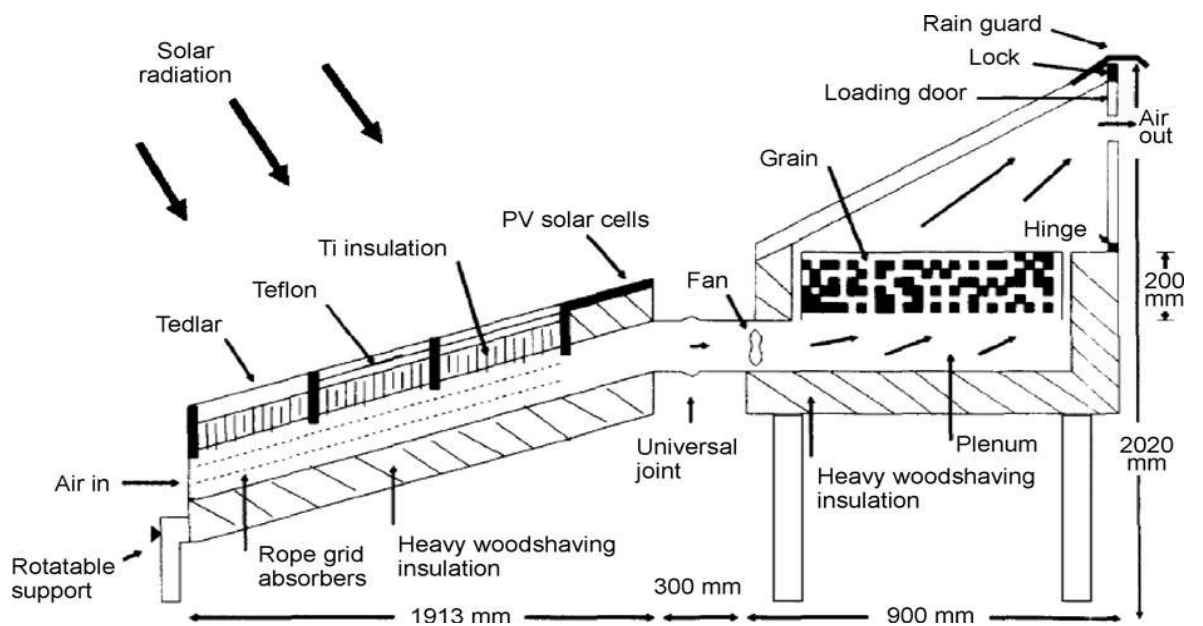


Figure 42 - Mumba designed and developed a solar grain dryer with photovoltaic powered air circulation.

### 23. Prototype solar dryer

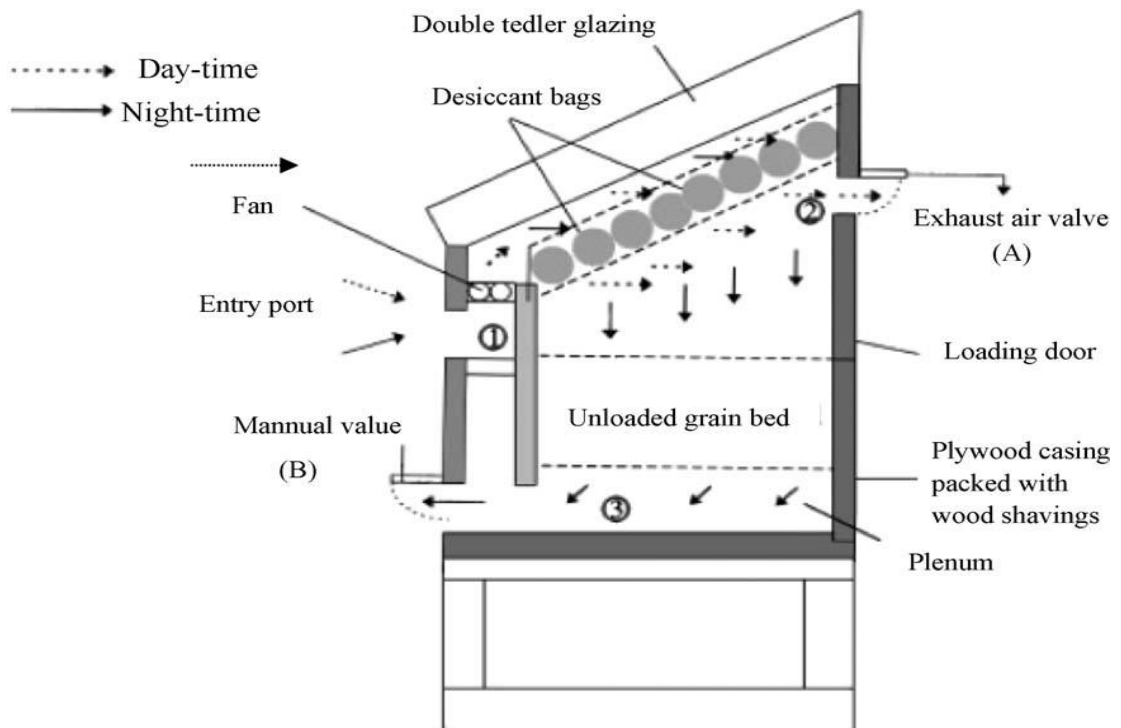


Figure 43 - Thoruwa et.al designed and developed a prototype solar crop dryer.

### 24. Complete drying system

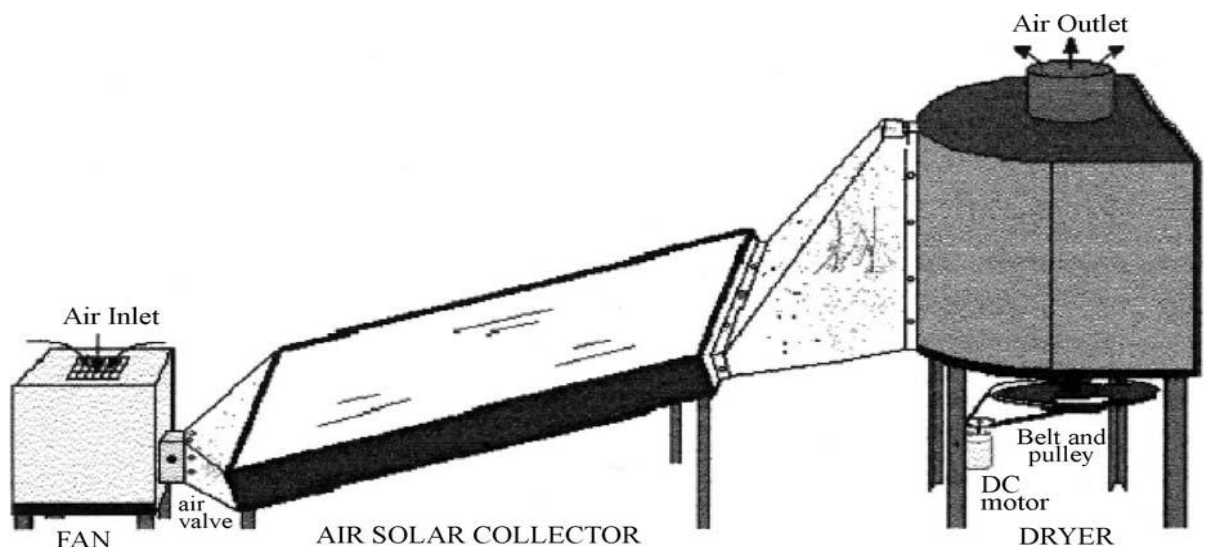


Figure 44 -Sarsilmaz et.al conducted experiments on drying of apricots in a newly developed rotary column cylindrical dryer.

## 25. Intergrated solar dryer

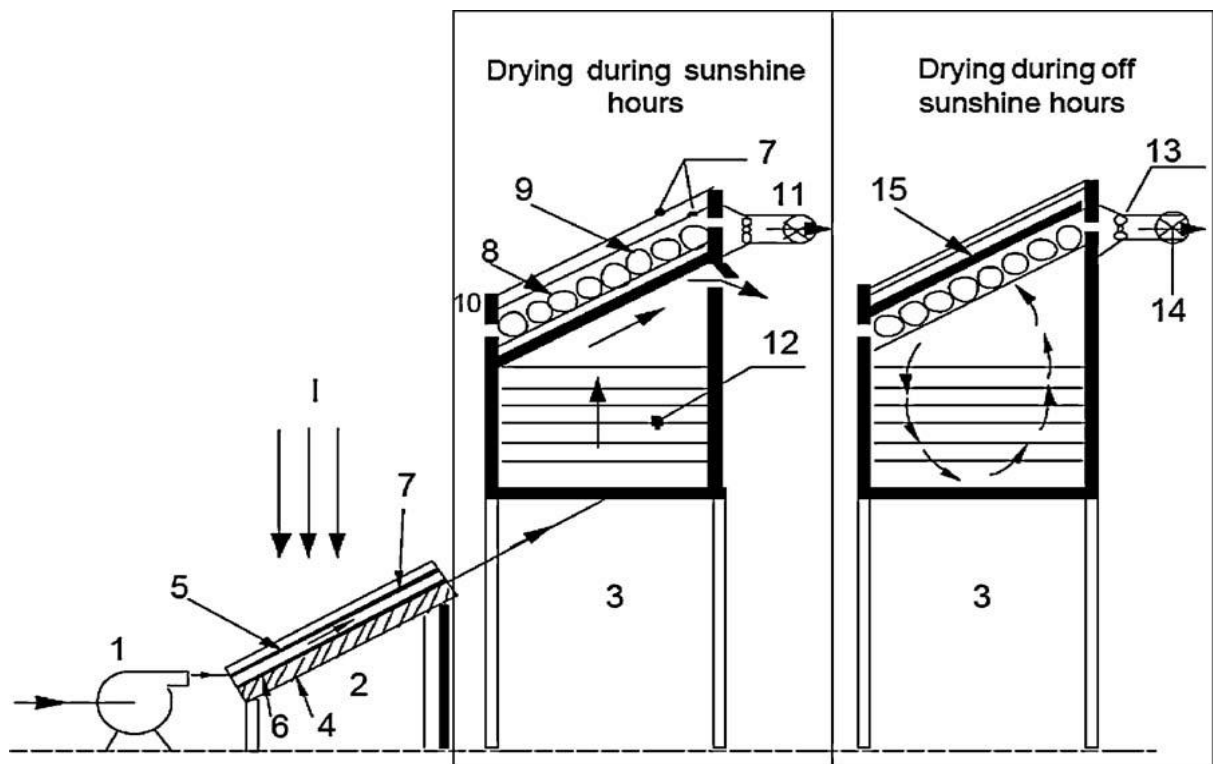


Figure 45 -Shanmugam and Natarajan designed and fabricated an indirect and desiccant intergrated solar dryer.

## 26. Force flow solar dryer



Figure 46 -Chen et.al conducted an experimental investigation to test a new forced flow solar dryer at Kun Shan University, Taiwan.

## 27. Solar-assisted forced convection



Figure 47 - Sarsavadia developed a solar assisted forced convection dryer for dehydration of onions slices for the controlled condition.



## 28. Semi-continuous active mixed – mode type drying

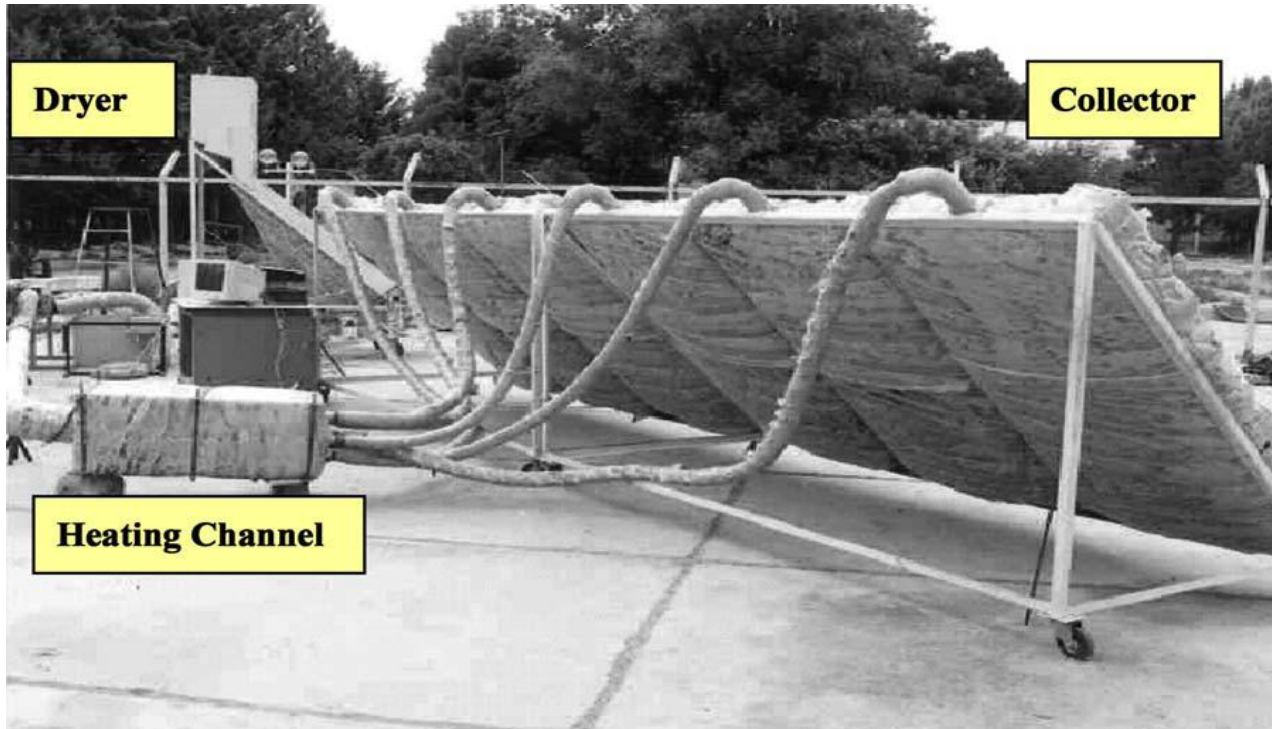


Figure 48 - Zomorodian et.al introduced a new approach for employing solar radiation as the main source of energy.

## 29. Roof – intergrated solar drying

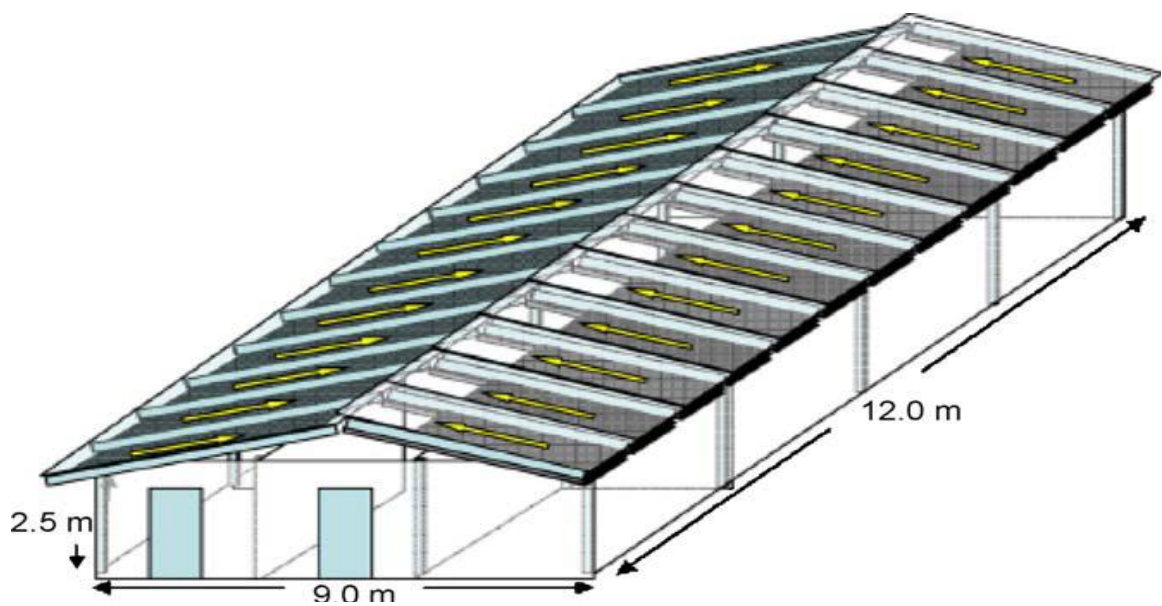


Figure 49 - Janjaia et.al presented experimental performance of solar drying of rosellaflower and Chilli using roof intergrated solar dryer.

### 30. Laboratory solar dryer



Figure 50 - The effect of air temperature and airflow rate on the drying kinetics of *Gelidium sesquipedale* was investigated by Mohamed et. al in convective solar drying.

## **Chapter 3 – Availability and suitability of solar dryers in Australia.**

### **3.1– Introduction**

This chapter will discuss the suitability of solar dryers here in Australia in terms of the solar radiation it produces per day. Not only that but it will also discuss the availability of solar dryers in terms of companies here that manufactures them. It will also include a list of agricultural products that are suitable to be dried using solar dryers.

### **3.2– Availability and suitability of solar dryers in Australia.**

#### **3.2.1 – Solar Energy.**

Solar energy is energy from the sun. This energy drives the climate and weather and supports virtually all life on Earth.

Solar energy is Australia's largest energy source. The average amount of solar energy that fall on Australia is about 15,000 times the nation's energy use. In all parts of Australia except southern Victoria and Tasman, solar resources are good to very good. Sunlight can be used to generate electricity, provide hot water and to heat, cool and light building.

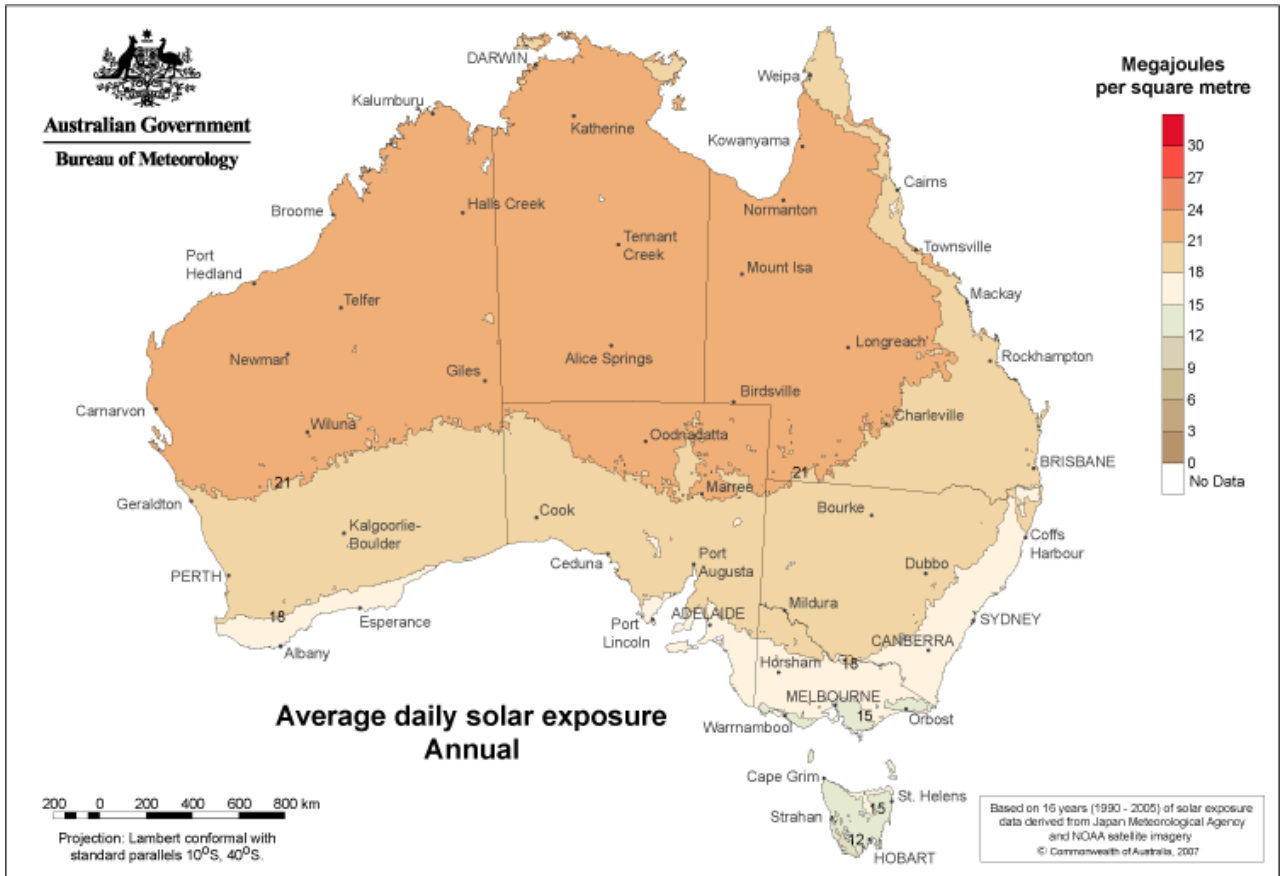
Solar energy is an intermittent and diffuse source. It is not available on cloudy days or at night, and it is not concentrated. Sunlight therefore has to be collected and or converted for use.

### **3.2.2– Australian solar radiation.**

Solar power is a clean energy source, which is very accessible in Australia, due to the amount of open plains and sunlight that the country get each day. Australia has a very suitable climate for solar energy with most of our nation desert and very arid and having 80% of the land experiencing less than 600 millimetres of rainfall per year. The land is also very flat, making Australia extremely suitable for solar power.

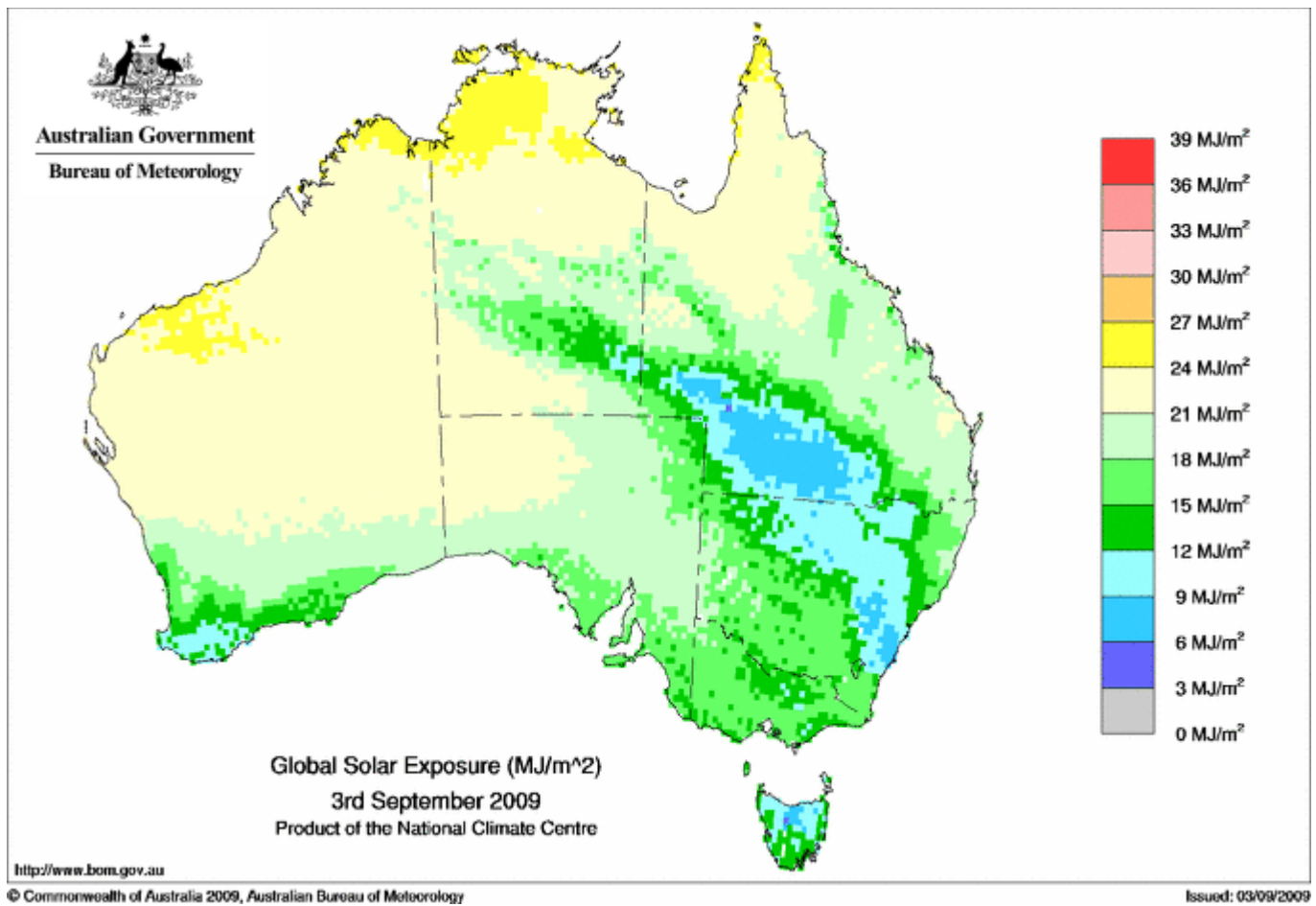
The amount of solar radiation in Mega Joules per square metre per day and annually is depicted in maps 1 and 2. The average output of energy per day for Queensland per day is approximately 6-27Megajoules per square meter and annually it is 15-24Megajoules per square meter.

It is also noted in Map 3 the amount of sunshine hours obtained, again for Queensland is between 6 to 9 hours of sunshine. Clearly there is abundance of solar energy and sunshine hours for the use of solar dryers here in Australia.



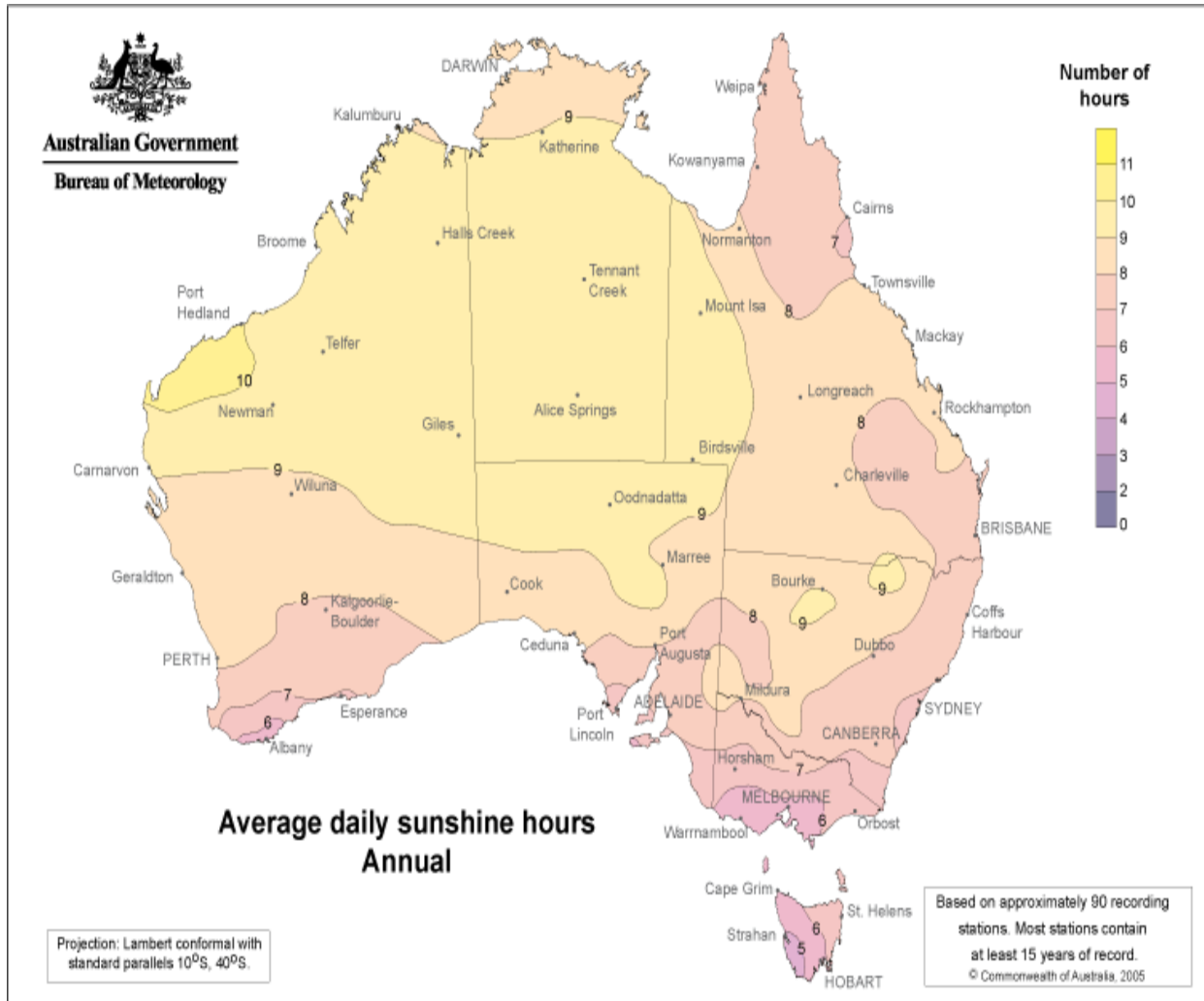
**Map 1 – Average annual solar exposure**

**Source:** Australian Bureau of Meteorology



**Map 2 – Daily solar exposure**

**Source:** Australian Bureau of Meteorology



**Map 3 – Average annual daily sunshine hours**

**Source:**

### **3.2.3– Australian solar Dryers Industries**

Throughout this research there has been one solar dryer company here in Australia that manufactures Solar Dryers. This company is called Solar Dryers Australia and it is a completely Australian owned and operated company with a major environmental focus.

The company originated as Rose Gum Timbers, a producer of hardwood furniture timber, using initially pure solar kilns for the drying process. The timber company was so successful so they started to design and manufacture solar dryers to dry timber. The standard solar kiln

sizes are 10m<sup>3</sup>, 20m<sup>3</sup>, 30m<sup>3</sup>, 50m<sup>3</sup>, 75m<sup>3</sup> and 100m<sup>3</sup> and are custom design for specific requirements.



Figure 51 - picture of solar kiln dryer designed by Solar dryers Australia Ltd.

### **3.3– Agricultural products suitable for solar dryers**

Solar dryers are perfectly acceptable for use in the drying process. The agricultural products suitable for drying using the solar dryer are as follows:

1. Fruits
2. Vegetables
3. Crops
4. Fish
5. Sea Food
6. Grains
7. Nuts
8. Herbs n spices
9. Seeds



### **3.4- Conclusion**

To conclude this chapter it is clear from the information discussed that the solar dryers will be suitable to use here in Australia due to the favourable climate conditions. Apart from individuals constructing their own solar dryers for own purpose uses there is one leading company in Australia that manufactures solar dryers named Solar Dryers Australia. In relation to what agricultural products most acceptable for drying using the solar dryers, all agricultural products can be dried using the solar dryer according to published literature.

## Chapter 4 – Case study

### 4.1 – Introduction

This chapter comprises of information related to the product dried. Sea cucumber is the product chosen for this case study, therefore there will be background information related to its initial and final moisture content after being dried, drying methods and its density.

In this case study 1000Kg of Sea Cucumber needs to be dried using the conceptual solar dryer in half or more than half the drying time it takes using open sun drying. The traditional sun drying take up to two weeks but in this case study the drying time should only be in approximately 2 days with 8 hours sunshine hours. The other task in this chapter is to calculate the followings:

- The amount of water evaporated from the Sea Cucumber in order to get the final moisture content after drying
- Drying time required for drying using the solar dryer
- Fan air flow rate
- Fan Power
- The amount of heat required
- The amount of moisture removed per hour

This chapter is very important because the conceptual design chapter that follows will heavily depend on this chapter in terms of dimension and size for the conceptual solar dryer components due to the calculation produced.

## **4.2 – Sea cucumber**

### **4.2.1 – Background information**

Sea cucumbers (Holothurians) are echinoderms—like starfish and sea urchins. There are some 1,250 known species, and many of these animals are indeed shaped like soft-bodied cucumbers. All sea cucumbers are ocean dwellers, though some inhabit the shallows and others live in the deep ocean. They live on or near the ocean floor—sometimes partially buried beneath it.

Sea cucumbers are traditionally consumed raw, dried and boiled as food for human consumption in many tropical and sub-tropical countries. Major consuming countries are China, Hong Kong, South Korea, Singapore, and Japan. The dried product is called beche-mer in French, hai-som in Chinese, and trepan in Indonesia. (reference Effect and handling of Procedure on the chemical composition of sea cucumber, Nil Pembe Ozer, suhendan Mol and Candan Varlik.)

Economically, sea cucumbers are important in two main ways. First, some species produce toxins that are of interest to pharmaceutical firms seeking to learn their medical value. Some compounds isolated to date exhibit antimicrobial activity or act as anti-inflammatory agents and anticoagulants. Second, as a gourmet food item in the orient, they form the basis of a multimillion-dollar industry that processes the body wall for sale as beche-de-mer or trepang. However, the high value of some species, the ease with which such shallow-water forms can be collected and their top-heavy age structures all contribute to over-exploitation and collapse of the fisheries in some regions. Fishermen in the Pacific islands use the toxins, some of which act as respiratory inhibitors, to entice fish and octopus from crevices so that they may be more easily speared. Furthermore, the sticky Cuvierian tubules are placed over bleeding wounds as a bandage.



**Figure 52- Picture of different sea cucumber species**

### **4.2.2 – Moisture Contents**

The initial moisture content of fresh sea cucumber is found to be 85% and must be dried to 10% or 6.5% moisture content.

### **4.2.3 – Sea cucumber’s density.**

Broad-scale distribution and density data of sea cucumber inhabiting Ningaloo Reef, Western Australia (WA), are compared with published data from Ashmore Reef, Cartier Reef and Rowley Shoals, northern WA. Results are presented particularly of the black teatfish, *Holothuria (Microthele) nobilis*. Heavy fishing pressure has affected numbers of *H. nobilis* on both Ashmore and Cartier Reefs, where population densities of less than 1.0 in  $\text{ha}^{-1}$  have been recorded. Rowley Shoals and Ningaloo Reef, areas that are unlikely to have experienced significant fishing pressure, support black teatfish densities of 9.1 and 19.3-27.2  $\text{ind ha}^{-1}$ , respectively. Densities of black teatfish recorded at Coral Bay are approximately equal to or exceed those reported on reefs that are closed to fishing on the Great Barrier Reef.

The distribution patterns of *H. nobilis*, *H. atra* and *Stichopus chloronotus* were examined on Ningaloo Reef using a novel method integrating both Global Positioning System (GPS) and Geographic Information Software (GIS). Differences in patterns of distribution between *H. nobilis* and *S. chloronotus* were identified. *H. nobilis* preferred habitats closer to the reef crest, whilst *S. chloronotus* were distributed among coral rubble within the inner-reef

lagoon. *H. atra* showed little or no recognisable pattern of distribution. Studies utilising GIS are currently determining the relationship between species distribution and physical habitat characteristics. This process ultimately will help clarify the micro-habitat characteristics of coral reef holothurians. Methods associated with this technique are described.

Management of a potential Western Australian *H. nobilis* fishery should be approached with caution. Research investigating sources of recruitment and population recovery following fishing should be undertaken as a minimum prerequisite to the adoption of policy concerning beche-de-mer fishery management in WA.

#### **4.2.4 – Drying Sea cucumber**

##### **The Procedure**

The procedure is simple but must be carried out with care if good - quality products are to be obtained.

Boiling is the most important step in processing. Incorrect cooking can irreversibly damage the product by causing splitting of the skin or other faults that will only show up at the drying stage.

##### **1. First Boil**

Fill the container with clean sea water and bring it to the boil. It is very important to bring the water to the boil before adding the live sea cucumber to the container. Sort the sea cucumber according to size. Only boil those of similar size together, as the cooking time needed varies according to size. If the sea cucumber have been kept in seawater for some time, allow them to naturally evacuate any internal water. Gently squeezing the body to assist this process. Immediately put the animal into the boiling water one by one while stirring, making sure that each one is completely covered with water. Do not allow any to remain partly out of the water as the skin could split. To ensure uniform heating do not put too many animals into the water at once.

Stir continuously and examine frequently. Cooking time for the first boil depends on the size of the animals and may be as short as a few minutes. The best way to judge the cooking time is by inspection. If the sea cucumbers start to swell too much you will need to pierce them. This can happen quickly, so you must keep a close watch. If they are left to boil too long at this stage they will burst.

## **2. Piercing the body wall during the first boil (optional)**

The procedure releases the build-up of pressure caused by too much water and air inside the cooking animal. Make a short longitudinal slit about 4 cm long, along the center line of the back, to let the water out.

After piercing continue to boil for about another 10 -15 minutes. Continue to stir gently and frequently, to ensure uniform cooking. When the ends of the sea cucumber become rubber ball, the first boiling is complete. This will not be hard to recognise. Remove the cooked sea cucumber from the container and immerse them in fresh seawater to cool down.

## **3. Slitting and removal of the gut**

Make a straight slit down the centre line of the animal to within 3cm of each end, incorporating the cut made during the first boiling. Open up the beche-de-mer and empty out the loose gut contents. Cut out the organs that run through the centre, removing the anal teeth and any loose tissue, using the hands only. Do not remove the strips of tissue running down the length of the inner walls of the body cavity (the longitudinal muscle bands). Wash out with clean sea water.

## **4. Second boil**

Follow the same procedure as for the first boil. Cook for 15 -40 minutes, stirring continuously. Exact boiling time again depend on the size of the animal. The sea cucumber will shrink slightly and gradually become hard. This hardness is the best way to gauge cooking time, so inspect them frequently. Check the cut edge of the animal too; if it no longer feels slimy, but rather dry rubbery, the second boiling is complete. Remove the sea cucumbers quickly from the container and put them into cold seawater to cool. They are now ready for smoke-drying or sun drying.

## **5. Smoke drying**

The fire should be small, producing constant heat. If the fire is too hot, it will overcook sea cucumbers, reducing their value. The fire should therefore be tended regularly.

To prepare the sea cucumber with long body slits for smoking, open them up one at a time and place a short stick, not more than 2.5 to 4cm long, across the cut to keep the sides apart. This helps speed up the drying process. Place the cooked sea cucumber on the smoking tray with their slit side down so that the inner part of the body is exposed to the heat of the fire.

Do not turn them over during smoking – always leave a split side facing down. Place the cooked sea cucumber on the trays of small ones at the top and the larger ones at the bottom closer to the fire.

Periodically rotate the trays around in the dryer. Move the tray on the bottom rung to the top rung. This ensures uniform drying.

The sticks holding open the long slits should be removed about half-way through the drying process, when insides of the animal feel dry to the touch. The sea cucumbers can now be tied up with a string or vines to help close up the slits edges, especially if they are misshapen.

## **6. Sun curing**

Brush off any shoot, ash or dirt that has accumulated during the smoking. Place the product in the sun on a clean, dry surface. It is preferable to use drying racks for sun-curing because the product can then dry on both sides simultaneously. These are simply wood – framed tables with a fixed mesh top (chicken wire, steel mesh, plastic mesh or fishing nets). Alternatively, mesh trays similar to the ones used in the smoker, can be placed directly onto the table frame.

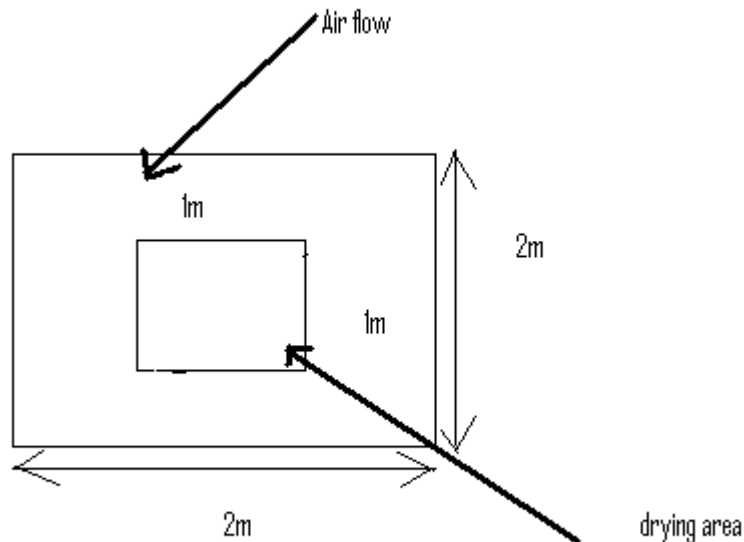
Curing can take as few as four or five days, or as long as one to two weeks, depending on the size of the species of sea cucumber, and of course, the weather. It is important to avoid exposing the product to the rain at any time – contact with fresh water is not good for it. Use plastic sheets to cover the curing product if rain threatens, or, if using trays move them indoors. When sun-curing is complete, a powdery substance will appear on the surface of the beche-de-mer.

Remove the string from the tied beche-de-mer and brush off any dirt or sand. The product should now be ready for packing and storing. If after examining the product, you find it somewhat soft and damp, you will have to repeat the smoking and sun-curing process. A properly dried and cured beche-de-mer is easy to recognise with a little experience.



### 4.3 - Calculations

#### 1. Calculating the airflow rate required for the solar dryer fan.



**Figure 53- air flow diagram**

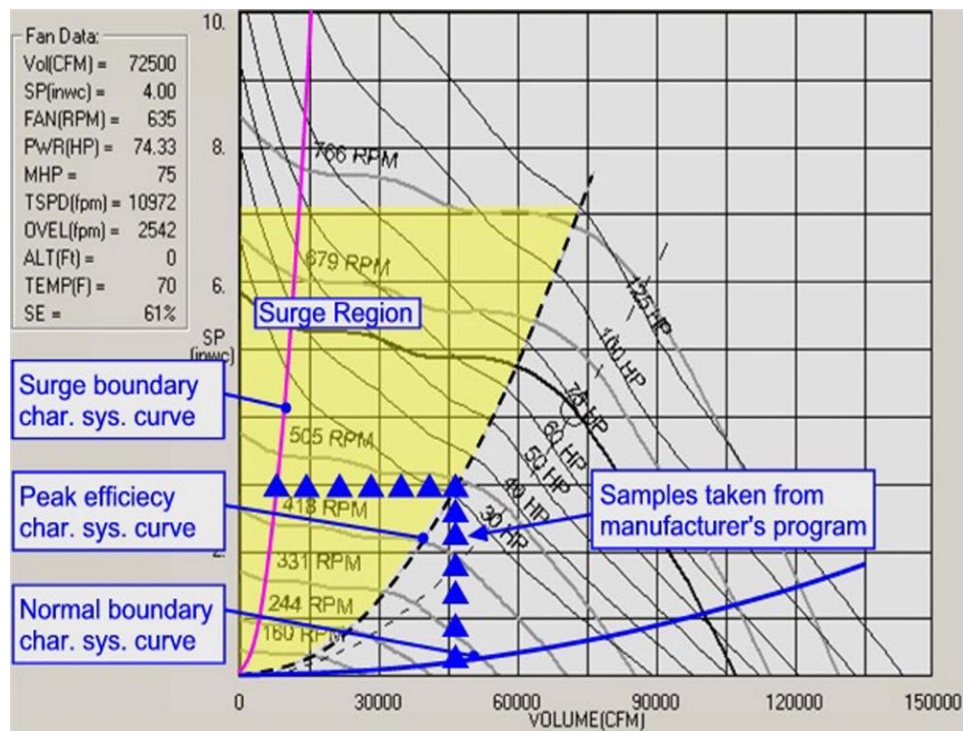
Assume that the airflow is 1m/s

Area of drying area =  $1\text{m}^2$

**Airflow rate =  $2\text{m}^2 \times 1\text{m/s}$**

=  $2\text{m}^3/\text{s}$  Or 4237.8 CFM (cubic feet per minute)

## Fan Curve



**Figure 54 – Fan curve**

The red line in the above diagram refers to measurements in this particular example.

At 350 rpm and a airflow rate of 2118.9 CFM the static pressure (in.water) = 2inches

**Fan Power = airflow rate x static pressure (in.water)/3814**

$$= 4237.8 \times 2.8(\text{in.water})$$

$$= 11865.8 / 3814$$

$$= 3 \text{ HP or 2KW}$$

## 2. Calculating the Mass of water to be lost from the product.

In this case study 1000kg of sea cucumber will be dried in one load using the conceptual solar dryer. It is important to find out the mass of the water that has to be taken out from the sea cucumber in order for the sea cucumber to reach its dried moisture content.

The equation used is

$$M_w = M_c [(W_i - W_f) / (100 - W_f)] \text{ where}$$

$M_w$  = Mass of water loss

$M_c$  = Mass of product to be dried

$W_i$  = initial moisture content

$W_f$  = final moisture content

The initial moisture content of sea cucumber is 85% but in this calculation the initial moisture content will be 35. The reason is that from after the cooking for 2 times the moisture content will decrease.

$$M_w = M_c [(W_i - W_f) / (100 - W_f)]$$

$$= 1000\text{Kg} [(45 - 5) / (100 - 5)]$$

$$= 421.05\text{Kg}$$

### 3. Calculating the mass flow rate of air.

Assumptions

- Drying temperature in the dryer = 43.3°C
- Ambient condition = 29.4°C dry bulb
- Ambient condition = 21.1°C wet bulb

Relative humidity = 85%

From the calculation in 1 we know that the airflow rate is 1m<sup>3</sup>/s or 2118.9 CFM (cubic foot per minute) or 7200m<sup>3</sup>/h.

The specific volume for this calculation is obtained from the psychometric chart attached in appendix 2. The specific volume is known to be 0.87m<sup>3</sup>/kg.

$$\begin{aligned}\text{Mass flow rate of air} &= (7200\text{m}^3/\text{hr})/0.87\text{m}^3/\text{kg} \\ &= 8275.86\text{Kg}/\text{hr}.\end{aligned}$$

### 4. Calculate the amount of heat required for heating the air provided the Enthalpy of air at point 1 and 2 is 61.5 and 76.6KJ/Kg.

$$\begin{aligned}&= (8275.86\text{kg}/\text{hr}) \times (76 - 61.5)\text{KJ}/\text{Kg} \\ &= 120,000\text{KJ}/\text{hr}.\end{aligned}$$

### 5. Calculate the amount of moisture removed per hour

Humidity ratio of the air = 0.0124kg water/dry air

Humidity ratio increase = 0.0192

$$\begin{aligned}&= (8275.86\text{Kg}/\text{hr}) \times (0.0192 - 0.0124) \\ &= 56.3\text{Kg}/\text{hr}\end{aligned}$$

6. Calculating the approximate time for the sea cucumber to be dried using the conceptual solar dryer.

The drying time is calculated using the formula

**Mass of water loss/Amount of moisture removed**

$$= 421.05\text{Kg}/56.3\text{Kg/hr}$$

$$= 7.5\text{hrs or equivalent to 1 day drying with 8 sunshine hours.}$$

## **Chapter 5 – Solar dryer conceptual design.**

### **5.1- Introduction**

This chapter will introduce the conceptual a solar dryer design specifically designed for drying Sea Cucumber but other agricultural products can also be dried using this solar dryer. The solar dryer design is named Moto solar dryer. It will also consist of the dryers' components the reason to the use of each component and the performance prediction to the conceptual solar dryer.

### **5.2– Conceptual design components.**

#### **a. Metal sheets 2x2x2**

Four iron sheets of 2m x 2m meters each will be used to construct the body of the solar dryer in a square shape. There will be one iron sheet with 3m x 2m which will be used for the floor. The 0.5 meters overlap on each side will be used support 7 x 300 Watt solar panels. The volume for this dryer as a whole is 8m<sup>3</sup>. The reason why iron material was picked for the construction was simply because iron is a good conductor of heat and the material can be easily purchased at local hardware store.

#### **b. Solar Panels**

The chosen solar panel is a monocrystalline type solar panel. From the above calculation it is know that the power required to power a 3 Horse Power fan is equal to 2KiloWatt. The solar panel produces a maximum power of 300Watt. Therefore to get the 2 Kilowatt power there will be approximately 7 x 300Watt solar panels to power the fan for this dryer.



**Figure 55 – 300 watt solar Panel**

**c. Fan**

The airflow rate that the fan must produce according to the calculations in chapter 3 is equal to  $2\text{m}^3/\text{s}$ . Therefore the fan suitable for this solar dryer must have this flow rate to ensure that the drying process is effective.

The chosen fan for this particular solar dryer is an axial flow fan. According to the calculations in chapter 4 the airflow rate is  $2\text{m}^3/\text{s}$ , the fan power is 3 HP or 2KW and the pressure in inches water was 2.8 which is equivalent to 700pa. The proper fan that satisfies these requirements is from the Aerotech Fans PTY. Ltd. From the performance curve the AF480-2P-2.20KW-85dBA is the fan to use.

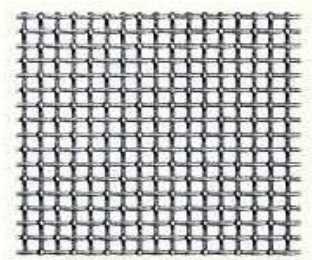


**Figure 56 – Axial fan for Moto solar dryer**

**d. Trays**

The trays for this solar dryer will consist of three trays made from wire mesh. Since most of the moisture from the sea cucumber is being removed during boiling the mesh wire will be perfect to use as trays. The solar radiation can penetrate through the 3 trays and so as the air from fan making the drying process quicker.

The size for the 3 piece of wire mesh will be 4m<sup>2</sup> and it will also have 2 pieces of metal welded on each side of the trays to hold the trays. This idea is for practical reasons in terms of loading and unloading the sea cucumbers.



**Figure 57 – Mesh wire**

**e. Black Paint**

The black paint in this solar dryer is only used to paint the inside wall of the dryer so that maximum heat can be retained in the dryer for maximum heating effect.

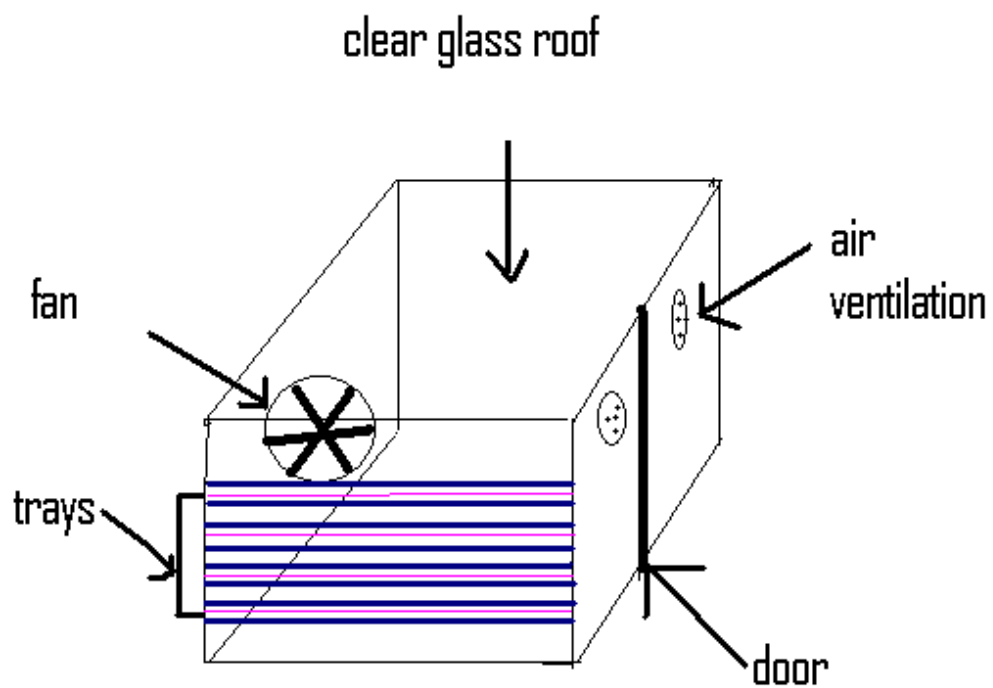
**f. Mosquito wire**

The mosquito wire will be used to cover the hole for the air ventilation so that insects cannot enter the drying chamber.



**g. Glass roof**

The glass roof is used so that in areas where solar panels are not available the solar dryer can function without the it.



**Figure 58 - A schematic diagram of the- Moto Solar Dyer.**

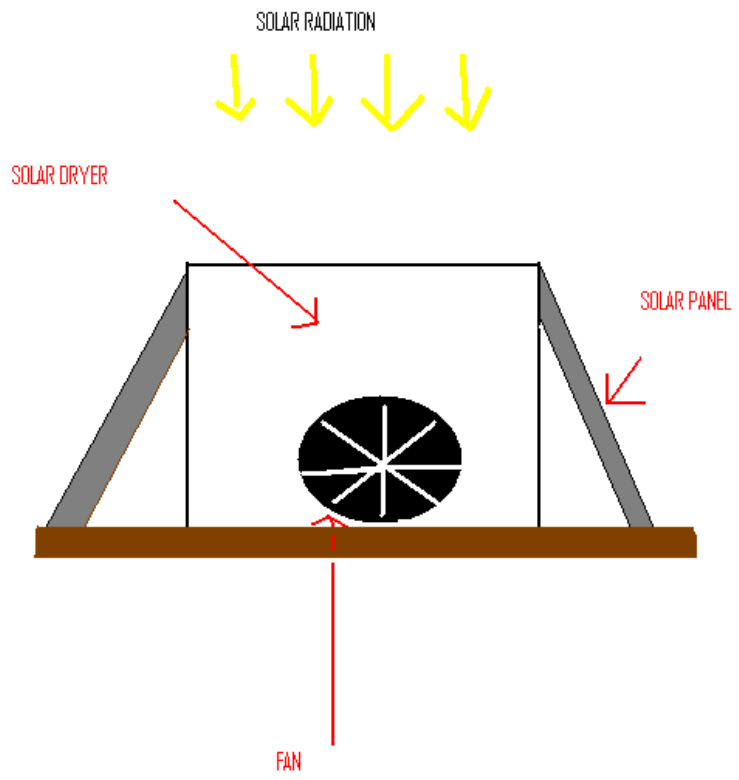


Figure 59 - The actual Moto Solar dryer design

### **5.3– Performance predictions for the conceptual solar dryer**

According to the calculations carried out in chapter 4 the drying time for drying Sea cucumber in the solar dryer was known to have decrease. In the traditional method of drying Sea Cucumber using the open sun drying time ranges from between 1 – 2weeks. The drying time given in the calculation in chapter 4 shows that using the dryer it will reduce the drying time to only day with 8 hours of sunshine.

## Chapter 6 – Cost Analysis of solar dryer

### 6.1 – Introduction

This chapter will discuss the advantages and disadvantages of solar dryers versus open sun drying in theory and also financially.

### 6.2 – Comparison of sun drying versus solar drying.

#### Open sun drying

The term open sun drying is used to denote the spreading of the commodity in the sun on a suitable surface, hanging it in eaves of building and trees, or drying on the stalk by standing stooks or bundles.

#### The working Principle of open sun drying

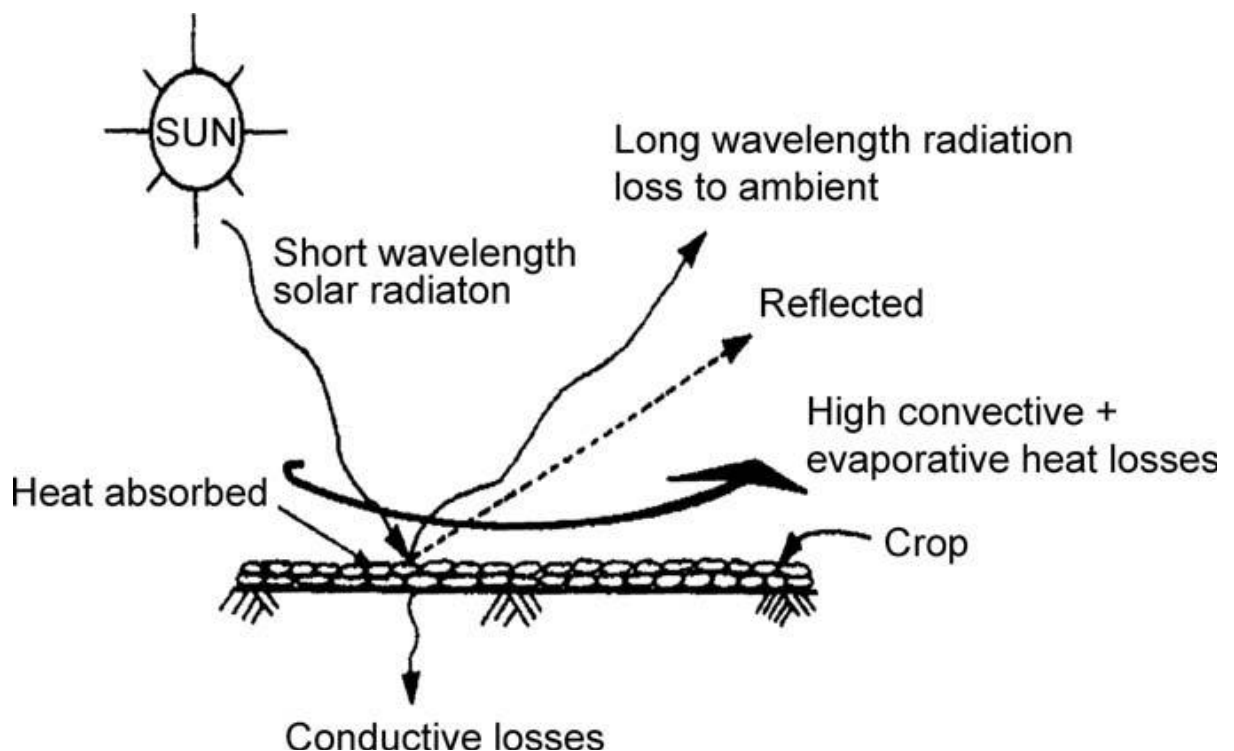


Figure 60 – Working Principle of open sun drying.

The above diagram depicted above displays the working principle of open sun drying by using solar energy. The short wavelength solar energy falls on the uneven crop surface. A part of the energy is reflected back and the remaining part is absorbed by the surface depending upon the colour of the crop. The absorbed radiation is converted into thermal energy and the temperature of the crop starts increasing. This is result in long wavelength radiation loss from the surface of the crop to ambient air through moist air.

In addition to long wavelength radiation loss there is convective heat loss due to the blowing wind through moist air over the crop surface. Evaporation of moisture takes place in the form of evaporative losses and so the crop dried. Further apart absorbed thermal energy is conducted into the interior of the product. This cause a rise in temperature and formation of the water vapour inside the crop and then diffuses towards the surface of the crop finally losses thermal energy in the form of evaporation. In the initial stages, the moisture removal is rapid since the excess moisture on the surface of the product presents a wet surface by a diffusion process depending upon the type of the product.

Solar dryer relies, as does open sun drying on the sun as its source of energy. Solar drying differs from sun drying in that a structure, often of very simple construction, is used to enhance the effect of drying.

## **Advantages of Solar dryers**

According to (Atul Sharma, C.R.Chen &Nguyen Vu Lan, 2008) the advantages of solar dryers are listed below:

1. It is faster. Foods can be dried in a shorter period of time. Solar food dryers enhance drying times in two ways. Firstly the translucent, or transparent, glazing over the collection area traps heat inside the dryer, raising the temperature of the air. Secondly, the flexibility of enlarging the solar collection area allows for greater collections of the sun's energy.
2. It is more efficient. Since foodstuffs can be dried more quickly, less will be lost to spoilage immediately after harvest. This is especially true of products that require immediate drying such as freshly harvest grain with high moisture content. In this way a large percentage of food will be available for human consumption. Also less of the harvest will be loss to marauding animals and insect since the food products are in safety enclosed compartments.
3. It is hygienic. Since foodstuffs are dried in a controlled environment, they are less likely to be contaminated by pests, and can be stored with less likelihood of the growth of toxic fungi.
4. It is healthier. Drying foods at optimum and in shorter amount of time enables them to retain more of their nutritional value. An added bonus is that foods will look and taste better, which enhances their marketability and hence provide better financial returns for the farmers.
5. It is cheap. Using freely available solar energy instead of conventional fuels to dry products, or using a cheap supplementary supply of solar heat, so reducing conventional fuel demand can result in significant cost savings.

**Disadvantage of solar dryers**

James P Armstrong, Carter.S. Hall stated that the “Solar drying is not without disadvantages. Topmost and the most important disadvantages is the heavy dependence on the weather. Drying rates vary greatly depending upon the outside temperatures and the number of hours of sunshine per day.”

### 6.3– Cost analysis of conceptual solar dryer and open sun drying.

This part is very important because the cost analysis will give an estimate of the total cost incurred for the solar dryer plant and the quantity of the dried product in a given period when compared to open sun drying.

Components	Quantity	Price (\$)
Solar Panels	7	17710
Iron sheets	5	700
Fan	1	2000
Trays	3	100
Black Paint	2	100
Mosquito wire	2	20
Glass roof	1	500
Metal rods	6	100
Nuts and bolts	18	20
Labour cost	2 x 7days	1120
<b>Total</b>		<b>22370.00</b>

**Table 1 – cost analysis of the Moto solar dryer.**

The construction cost for constructing the Moto solar dryer is equal to \$22370. To dry the 1000kg of raw sea cucumber at the end of the drying time the dried product will be roughly 350 kg. It costs \$300 for 1 Kg of dried sea cucumber. It only takes one day to dry using the Moto Solar dryer so 350 kg at a price of \$300/kg will give \$105000.000. If the dryer was going to dry sea cucumber in two months per year the total return per year will be \$6405000.00.



## Chapter 7 – Conclusion and Recommendations

### 7.1 – Introduction

The summary of all the results of the project work is discussed in this chapter. Recommendations are given for the improvement of the solar dryer.

### 7.2- Achievements of objectives

1. From the literature on research on solar drying technology it was found that solar dryers are of three types viz., solar natural dryers, semi-artificial dryers and solar assisted dryers. The solar natural dryers are used for drying small quantities of crops as they use only ambient energy and natural convection for air flow. Semi-artificial solar dryers are used for low moisture content crops. A solar collector and a fan is used for the purpose. Solar assisted dryers are used for drying large quantity of crops as they are designed with a solar collector, heat storage system and auxiliary energy source.
2. The climatic conditions and the topography of the Australian continent is extremely suitable for trapping solar energy. In the state of Queensland the average out of solar energy per day is approximately 6-27 Mega joules per square meter and 15 -24 Mega joules per square meter annually.
3. Agricultural products suitable for solar drying are fruit, vegetables, crops, fish, seafood, grains, nuts, herbs and spices and seeds.
4. A small scale prototype solar dryer named Moto Solar dryer was designed for drying sea cucumber. The dryer is square shaped with the drying chamber made of iron

sheets. The inner wall of the chamber is painted black to ensure maximum absorption of thermal energy. The clear glass roof enables to trap maximum solar radiation. The solar panels are used to power the axial flow fan. Three trays are used in layers for drying the products.

5. From the calculations done during the project period the performance of the Moto Solar Dryer has been assessed. The results for the performance of each component of the dryers calculated is as follows:

- Airflow rate for the solar dryer fan is  $2\text{m}^3/\text{s}$
- Fan power is 3 HP
- Mass of water to be evaporated from 1000kg sea cucumber is 421.05kg
- Mass flow rate of air is 8275.86kg/hr
- Heat required to heat the air provide is 120000KJ/hr
- Amount of moisture removed per hour is 56.3kg/hr
- Drying time for drying sea cucumber using the Moto Solar dryer is 7.5 sunshine hours.
- The cost of installing the Moto Solar dryer is approximately \$22400.00

The drying time for drying sea cucumber using open sun drying method is approximately 4 - 14 days depending on the size of the sea cucumber and the weather conditions. But the Moto Solar dryer dries the sea cucumber in approximately 1 – 2 days irrespective of the weather conditions.

### **7.3 – Recommendations for improving the Moto Solar Dryer.**

1. The cost of the dryer can be reduced by reducing the size of the dryer to certain extends.

### **7.4 – Conclusion**

The traditional open sun drying of sea cucumber is a long process which takes about two weeks for the product to be dried. The sea cucumber industry is gaining importance now a days due to its high export value to the Asian markets. In these circumstances it was essential to develop a drying technology which is faster than the open sun drying method. The Moto solar dryer designed for the purpose has the advantages of reducing the damages caused to the product by insect, birds, rodents, mirco-organisms and the adverse climatic conditions such as rain, storm etc. The drying time is also reduced considerably. Thus the Moto Solar dryer is an efficient dryer which can enhance the quality of the dried sea cucumber.

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## Appendices

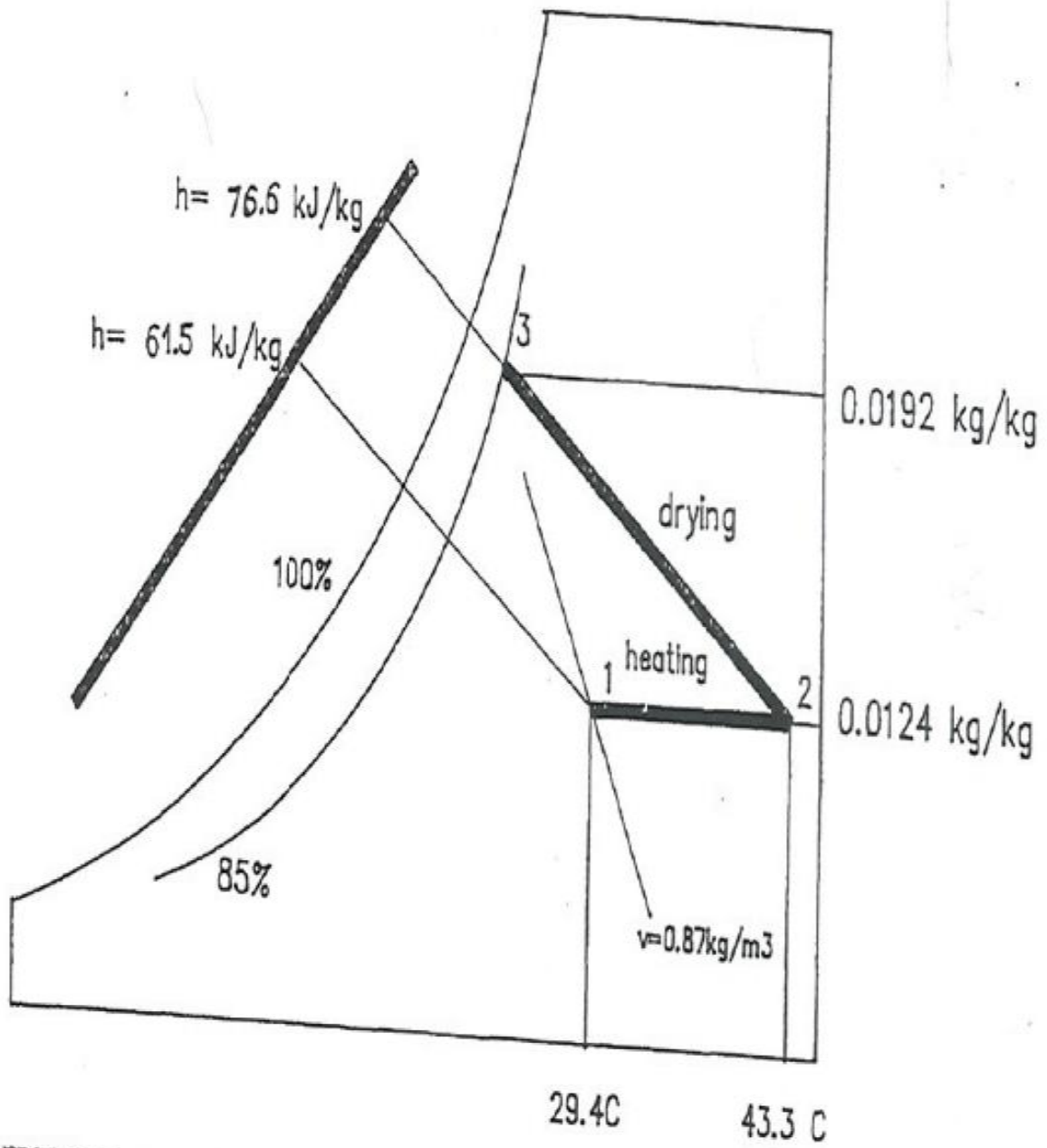
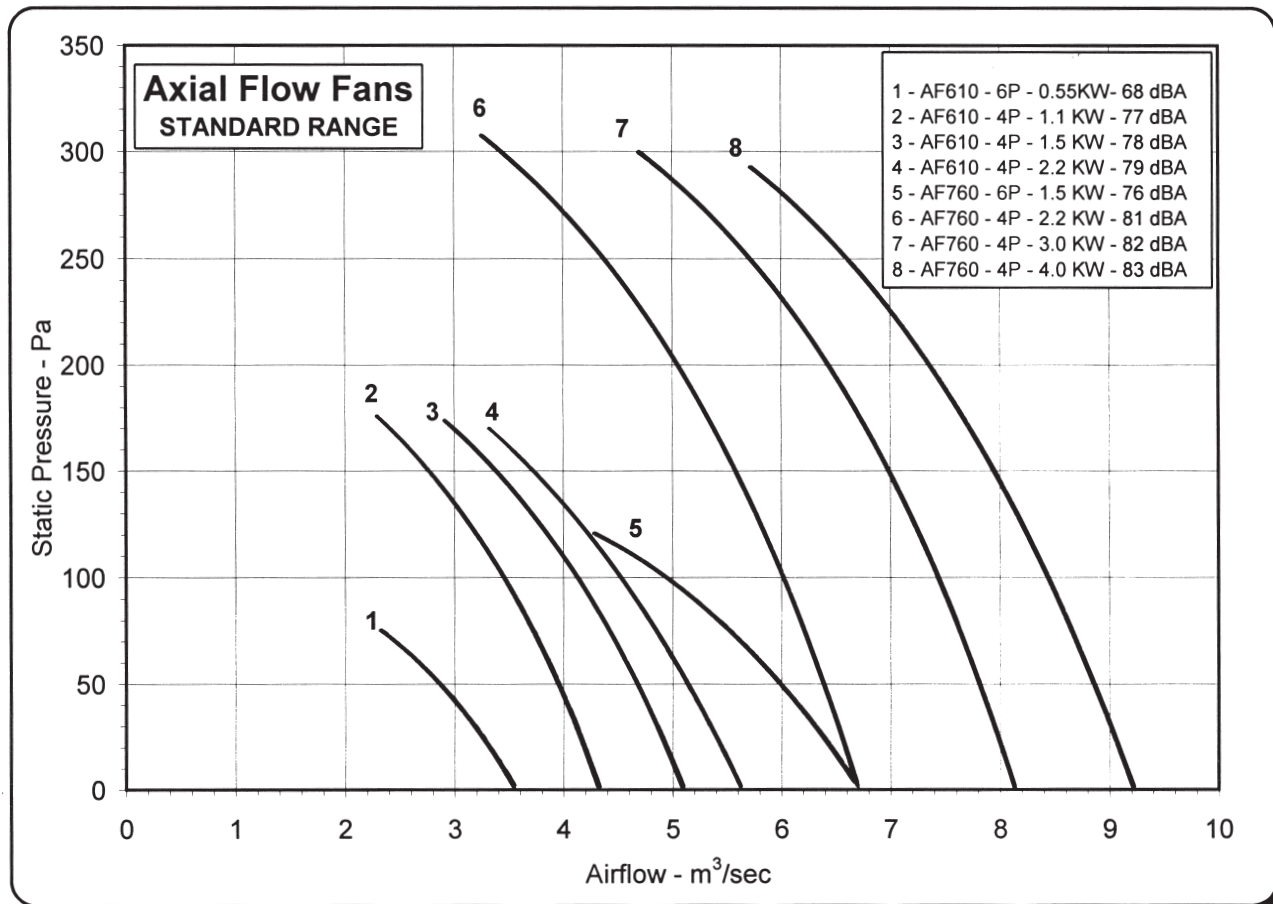
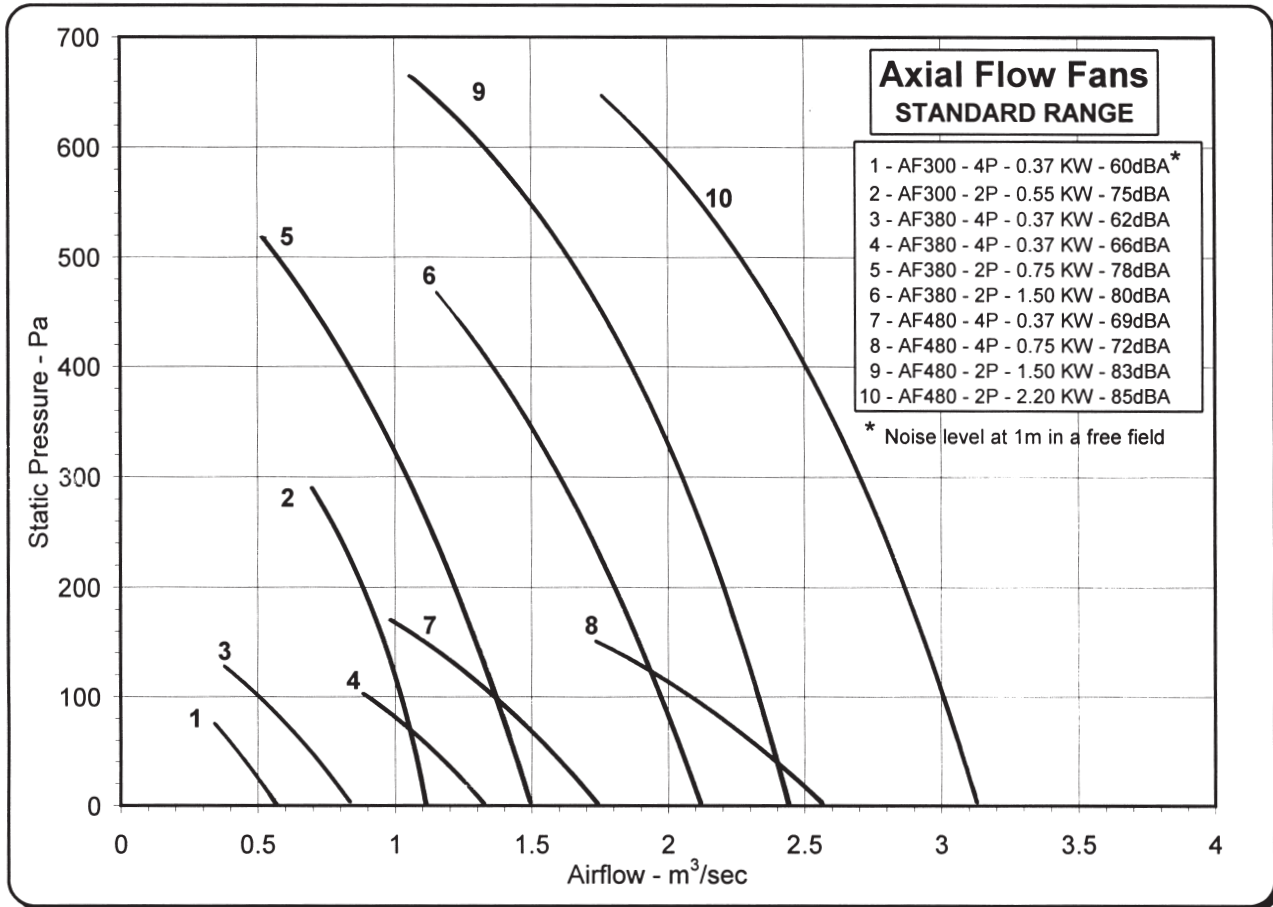


FIGURE 11.11







1000 pa = 4.0 in.wg

1m³/sec = 1000 l/s = 2118 cfm