# CAI335 SOLAR AND WIND ENERGY SYSTEM

## UNIT I NOTES

## 1.4 solar dryer

**Solar dryers** are devices that use solar energy to dry substances, especially food. Solar dryers use the heat from sun to remove the moisture content of food substances. There are two general types of solar dryers: Direct and indirect.

Solar drying is a possible replacement for sun drying or for standard dehydration processes. In terms of sun drying, solar drying is competing with an approach that is deeply entrenched in the way of life for most potential users. Sun drying is by no means a perfect process with problems arising due to potential contamination of the produce, variability in drying times,rain damage and so on. However some of the reasons proposed for the lack of success in adoption of solar drying are as follows:

- Solar dryers have often been too expensive or initial investment capital or loan facilities were unavailable.
- Solar dryers have often been too complicated or poor training of local entrepreneurs and technicians was provided.
- Solar dryers have often required too big changes from traditional methods.
- Solar dryers have not been built for long term use.

### 1.4.1.Advantages of solar drying

The higher temperature, movement of the air and lower humidity, increases the rate of drying.

Food is enclosed in the dryer and therefore protected from dust, insects, birds and animals.

The higher temperature deters insects and the faster drying rate reduces the risk of spoilage by micro organisms.

The higher drying rate also gives a higher throughput of food and hence a smaller drying area (roughly 1/3).

The dryers are water proof and the food does not therefore need to be moved when it rains.

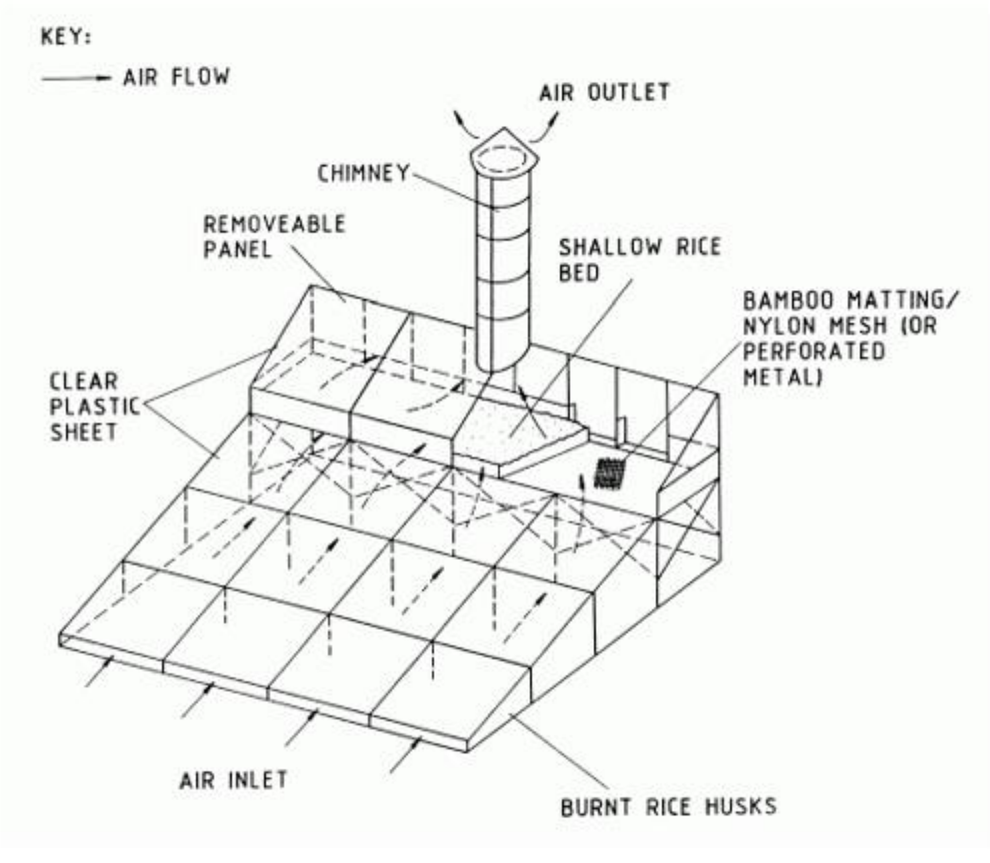
Dryers can be constructed from locally available materials and are relatively low cost.

More complete drying allows longer storage

**1.4.2 processes during solar drying**

The objective of a dryer is to supply the product with more heat than is available under ambient conditions, thereby increasing sufficiently the vapour pressure of the moisture held within the crop and decreasing significantly the relative humidity of the drying air and thereby increasing its moisture carrying capacity and ensuring sufficiently low equilibrium moisture content.

Air is drawn through the dryer by natural convection. It is heated as it passes through the collector and then partially cooled as it picks up moisture from the rice. The rice is heated both by the air and directly by the sun.




Warm air can hold more moisture than cold air, so the amount required depends on the temperature to which it is heated in the collector as well as the amount held (absolute humidity) when it entered the collector. The way in which the moisture absorption capabilityof air is affected by its initial humidity and by the temperature to which it is subsequently heated.

The objective of most drying processes is to reduce the moisture content of the product to a specified value. Moisture content (wet basis) is expressed as the weight of water as a proportion of total weight.

The heat required to evaporate water is 2.26 kJ/kg. Hence, approximately 250 MJ (70 kWh) of energy are required to vaporise the 100 kg water. There is no fixed requirement for solar heat input to the dryer. This is because the incoming ambient air can give up some of its internal energy to vaporise the water (becoming colder in the process). Indeed, if the ambientair is dry enough, no heat input is essential.

### 1.4.3Classification of solar dryers

All drying systems can be classified primarily according to their operating temperature ranges into two main groups of high temperature dryers and low temperature dryers. However, dryers are more commonly classified broadly according to their heating sources into fossil fuel dryers (more commonly known as conventional dryers) and solar-energy dryers. Strictly, all practically-realised designs of high temperature dryers are fossil fuel powered, while the low temperature dryers are either fossil fuel or solar-energy based systems.

To classify the various types of solar dryers, it is necessary to simplify the complex constructions and various modes of operation to the basic principles. Solar dryers can be classified based on the following criteria:

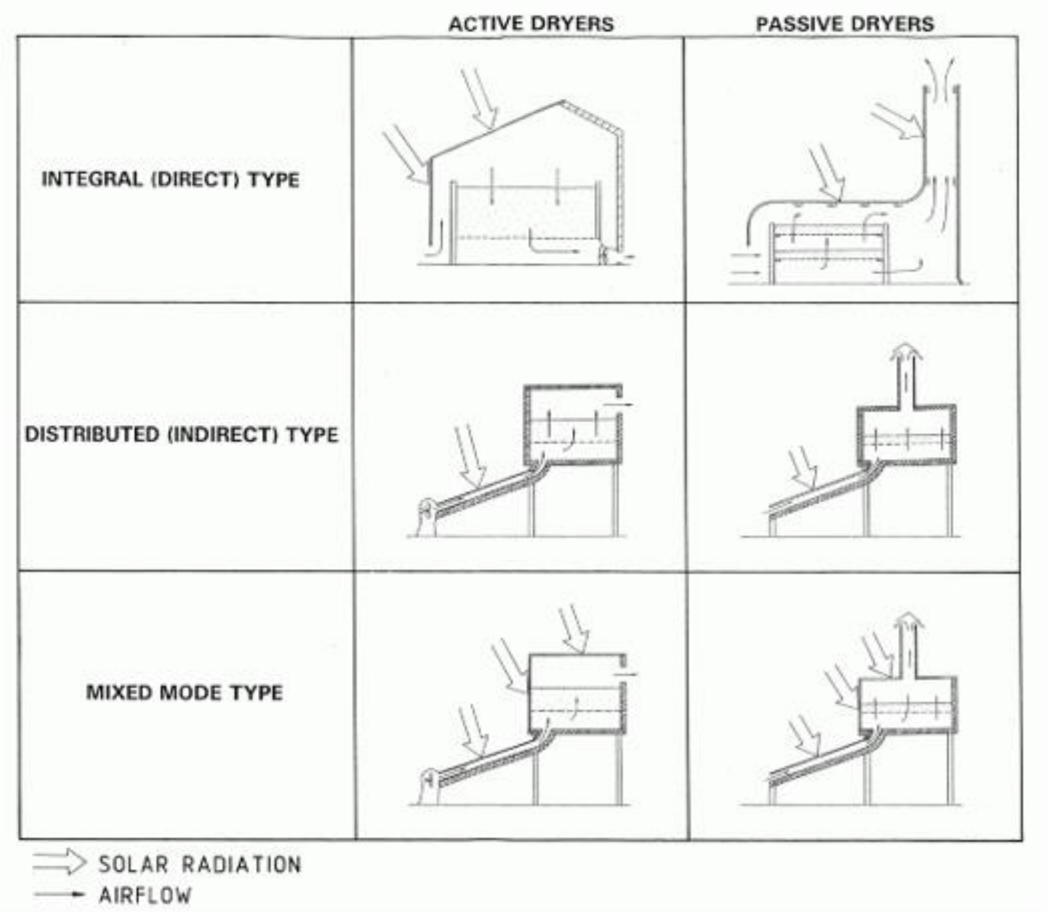
- Mode of air movement
- Exposure to insulation
- Direction of air flow
- Arrangement of the dryer
- Status of solar contribution

Solar dryers can be classified primarily according to their heating modes and the manner in which the solar heat is utilised. In broad terms, they can be classified into two major groups, namely:

1. active solar-energy drying systems (most types of which are often termed hybrid solar dryers); and
2. passive solar-energy drying systems (conventionally termed natural-circulation solar drying systems).

Three distinct sub-classes of either the active or passive solar drying systems can be identified (which vary mainly in the design arrangement of system components and the modeof utilisation of the solar heat, namely

- integral-type solar dryers;
- distributed-type solar dryers; and
- mixed-mode solar dryers.



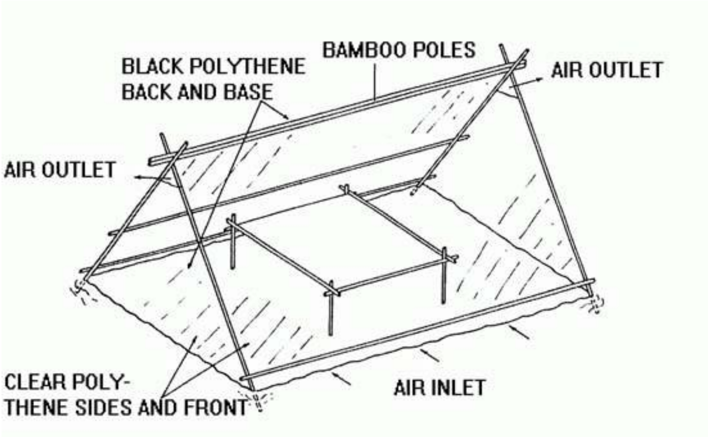

Natural convection is used on the diminution of the specific weight of the air due to heating and vapour uptake. The difference in specific weight between the drying air and the ambient air promotes a vertical air flow. Natural convection dryers therefore can be used independent from electricity supply. However, the airflow in this type of dryer is not sufficient to penetrate higher crop bulks. Furthermore the air flow comes to a standstill during night and adverse weather conditions. The risk of product deterioration due to mould attack and enzymatic reactions is high.

**Passive solar dryers**

Passive solar dryers are also called natural circulation or natural convection systems. They are generally of a size appropriate for on-farm use. They can be either direct (e.g. tent and box dryer) or indirect (e.g. cabinet dryer). Natural-circulation solar dryers depend for their operation entirely on solar-energy. In such systems, solar-heated air is circulated through thecrop by buoyancy forces or as a result of wind pressure, acting either singly or in combination.

**Tent dryers**

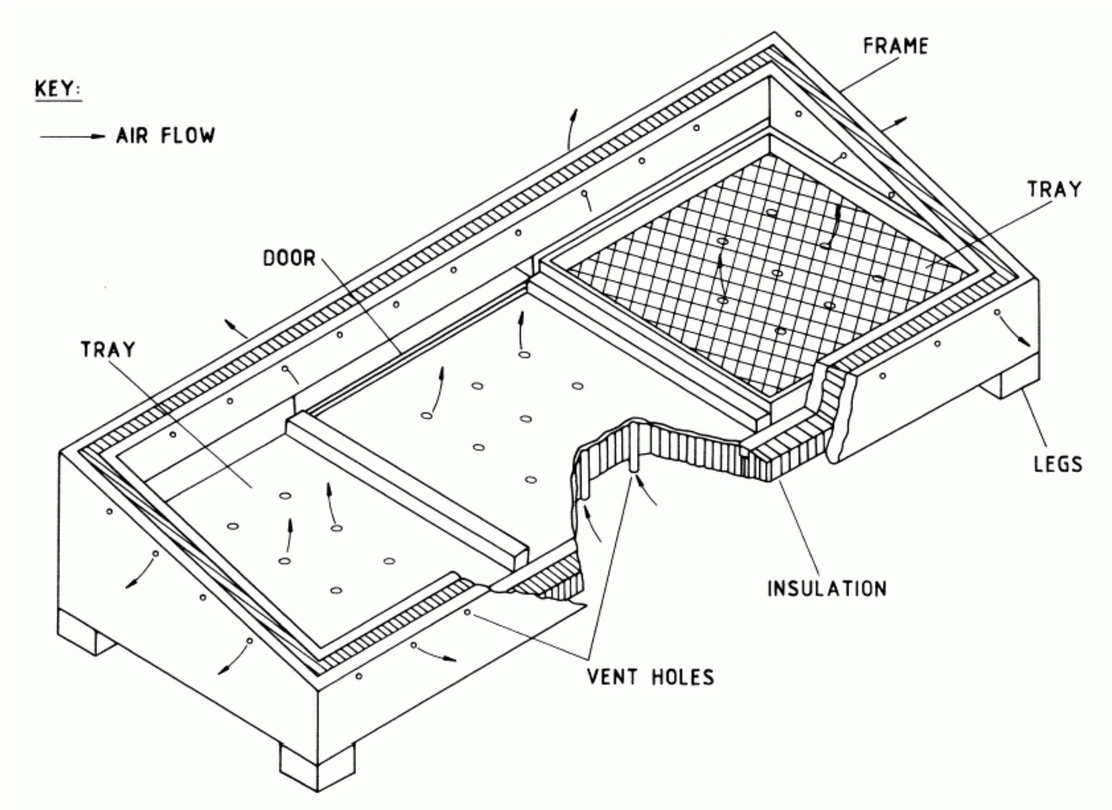
Tent solar dryers, as shown in Fig. 9, are cheap and simple to build and consist of a frame of wood poles covered with plastic sheet. Black plastic should be used on the wall facing away from the sun. The food to be dried is placed on a rack above the ground. Drying times are however not always much lower than for open-air drying (-25 %). (Probably, insufficient attention has so far been paid to utilizing natural convection.) The main purpose of the dryers may be to provide protection from dust, dirt, rain, wind or predators and they are usually used for fruit, fish, coffee or other products for which wastage is otherwise high. Tent dryers can also be taken down and stored when not in use. They have the disadvantage of being easily damaged by strong winds.




**Box dryers**

The box-type solar dryer has been widely used for small scale food drying. It consists of a wooden box with a hinged transparent lid. The inside is painted black and the food supported on a mesh tray above the dryer floor. Air flows into the chamber through holes in the front and exits from vents at the top of the back wall.

Pioneering works on solar cabinet dryers were reported by the Brace Research Institute, Canada. Fig. 10 illustrates the fundamental features of the standard Brace Institute solar cabinet dryer. Brace type dryers achieve higher temperatures, and thus shorter drying times, than tent dryers. Drying temperatures in excess of about 80 °C were reported for the dryer



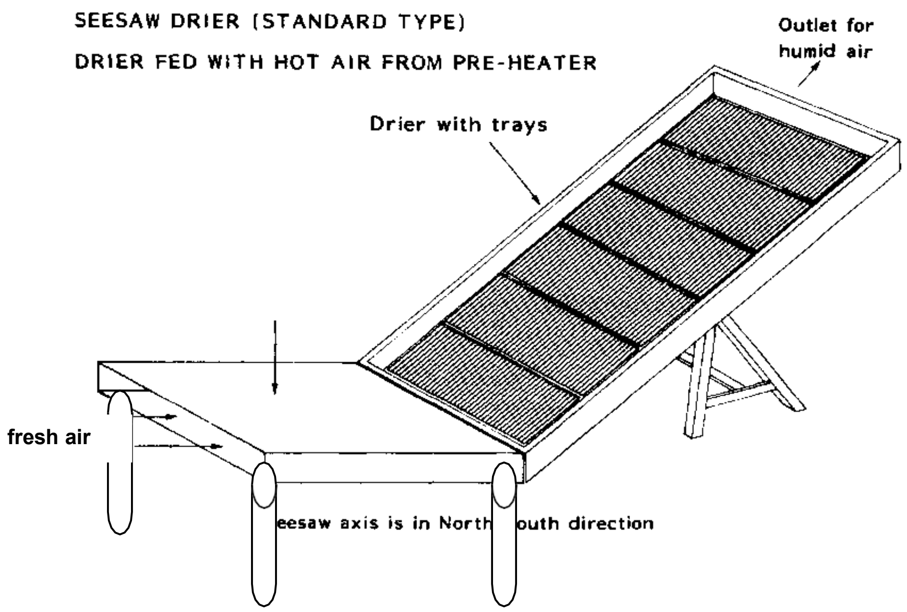

**Seesaw dryer**

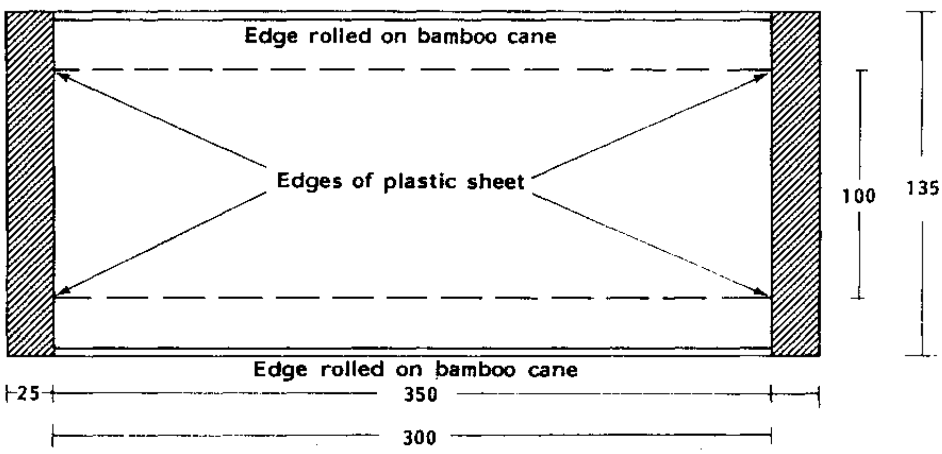
The traditional seesaw dryer has a rigid, rectangular frame, the length of which being 3 times the width' resting on a support with an axis. This support is oriented north-south and is sufficiently high to allow the frame to be tilted 30° - towards east in the morning and towards west in the afternoon.

The material for drying is placed on a number of trays, which have a wooden frame 100 x 50 cm and a mesh bottom, which can be made of a variety of materials, such as wire netting, old fishing nets, bamboo lattice or any other material that will allow vertical air circulation and maximum evaporation.

The bottom of the improved seesaw dryer is made of galvanised corrugated iron sheets reinforced crosswise by wooden planks and lengthwise by two wooden planks, about 15 cm high. The upper surface of the bottom is painted black. Good thermal insulation can be provided by attaching insulation plates made of lignified wood fibre, expanded polystyrene various layers of corrugated cardboard etc. to the underside of the bottom.

The removable trays are placed on top of the corrugated iron bottom either in a continuous row or with space between them, which will result in better heating of the air above the blackened surface of the corrugated iron bottom. In this case the edges of the trays shouldbe propped up with wooden supports.



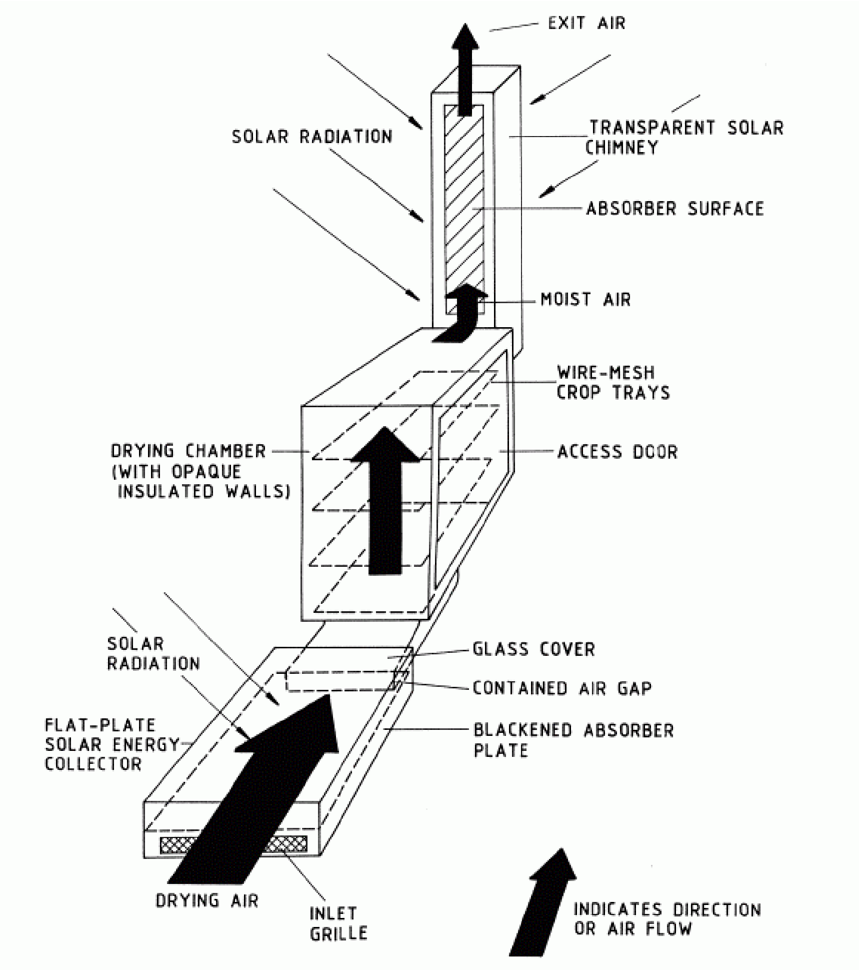

A greenhouse effect is obtained by placing a transparent plastic sheet over the filled trays. This sheet rests on the raised edges of the trays and is kept stretched by the weight of bamboo canes fixed to the sides of the plastic sheet. When not in use the sheet is rolled around the bamboo canes.

Air circulation is secured by convection, the dryer being tilted at an angle of 30°: fresh air enters at the lower end of the chamber formed by the trays and the plastic covering' escapingat the upper end. A 3 m long dryer tilted 30° has 1.40 m difference in levels of air inlet and airoutlet.

Air circulation can be improved still more by making the air outlet opening wider (28 x 50 cm) than the air inlet opening (15 x 50). In this way the room enclosed by the dryer bottom and the plastic sheet widens gradually from air inlet to air outlet. This will improve convection and prevent the formation of "hot air bubbles" inside caused by air dilatation.

**Cabinet solar dryers**

Here, the crop is located in trays or shelves inside a drying chamber. If the chamber is transparent, the dryer is termed an integral-type or direct solar dryer. If the chamber is opaque, the dryer is termed distributed-type or indirect solar dryer Fig. 13. Mixed-mode dryers combine the features of the integral (direct) type and the distributed (indirect) type solar dryers. Here the combined action of solar radiation incident directly on the product to bedried and pre-heated in a solar air heater furnishes the necessary heat required for thedrying process.



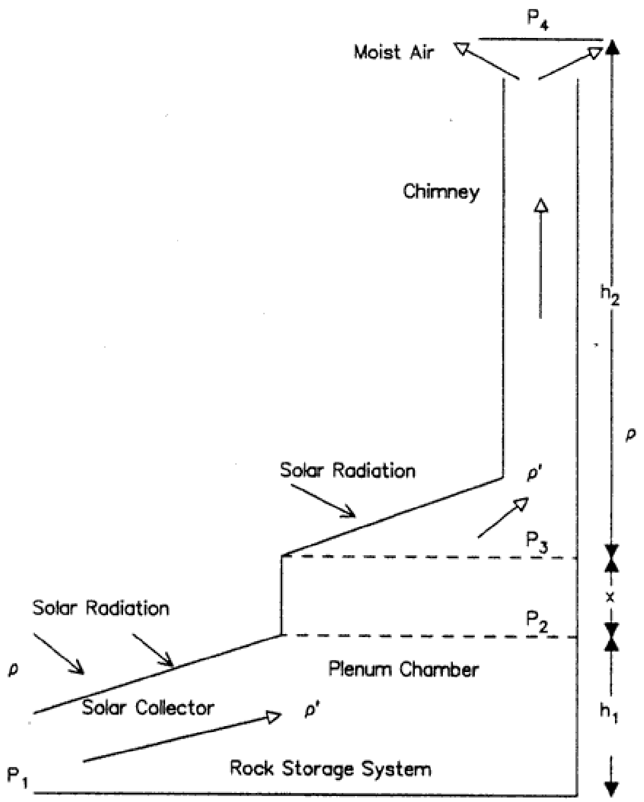

In most cases the air is warmed during its flow through a low pressure drop thermosyphonic solar collector and passes through air ducts into the drying chamber and over drying trays containing the crops. The moist air is then discharged through air vents or a chimney at the top of the chamber.

The cabinet is a large wooden or metal box. It should be insulated properly to minimise heat losses and made durable (within economically justifiable limits). Construction from metal sheets or water resistant cladding, e.g. paint or resin, is recommended.

Inside the box internal runners are fitted to support the trays of food being processed. A general rule of thumb is that one $m^2$ of tray area is needed to lay out 10 kg of fresh produce .Access to the inside of the dryer is via hinged doors at the rear of the cabinet. Thedrying trays slide on rails on the inside of the cabinet so that they can be removed from the dryer for loading, unloading and cleaning.

Heated air flows through the stack of trays until the entire product is dry. Clearly, as the hot air enters below the bottom tray, this tray will dry first. The last tray to dry is the one at the top of the chamber

Further major drawbacks for natural convection solar dryers are the poor moist air removal which reduces drying rate and the very high internal temperatures with the likelihood of over heating the product. Drying air temperatures as high as 70 °C - 100 °C may be reached with these dryers. These temperatures are excessive for most products. The most severe constraints are on beans (35°C), rice (45°C), and all grains if they are to be used for seed (45°C).




Solar cabinet dryer with natural convection

In a natural convection system, the flow of air is caused by the fact that the warm air inside the dryer is lighter than the cooler air outside. This difference in density creates a small pressure difference across the bed of grain, which forces the air through it. This effect increases the higher the height of the bed is above the inlet (h1 in Fig. 15) and the outlet above the bed (h2). The effect of an increased h2 is less than that of an increased h1 because the air is cooled as it passes through the bed.

Air density variation in a natural convection dryer (Air enters at 20°C and leaves at 80% RH)

| Initial relative humidity | Density of the air (kg/m$^3$) (Drop in density, in brackets) | | | |
|---|---|---|---|---|
| | Not heated | | Heated to | |
| | | 30 °C | 40 °C | 60 °C |
| 40% | Ambient 1.19 | 1.19 | 1.19 | 1.19 |
| | Below bed 1.19 (.00) | 1.15 (.04) | 1.12 (.07) | 1.05 (.14) |
| | Above bed 1.21 (-.02) | 1.19 (.00) | 1.17 (.02) | 1.14 (.05) |
| 60% | Ambient 1.19 | 1.19 | 1.19 | 1.19 |
| | Below bed 1.19 (.00) | 1.15 (.04) | 1.11 (.08) | 1.05 (.14) |
| | Above bed 1.20 (-.01) | 1.18 (.01) | 1.16 (.03) | 1.13 (.06) |
| 80% | Ambient 1.18 | 1.18 | .18 | 1.18 |
| | Below bed 1.18 (.00) | 1.14 (.04) | 1.11 (.07) | 1.04 (.14) |
| | Above bed 1.18 (.00) | 1.16 (.02) | 1.15 (.03) | 1.11 (.07) |

It can be seen in Table 1 that if the incoming air is heated by only 10-30°C then the presenceof a chimney on top of the dryer would make little or no difference, unless it acted efficiently as a solar collector and raised the temperature of the air significantly. So a solar chimney increases the buoyancy force imposed on the air stream and provides a higher air flow velocity and, thus, a more rapid rate of moisture removal.

It should be noted that even if the difference in densities is as much as 0.5 kg/m$^3$, then the resulting pressure difference is only 0.5 Pa (5 millionths of atmospheric pressure) per metre of chimney. For comparison, forced convection systems commonly operate with pressure differences of 100-500 Pa.

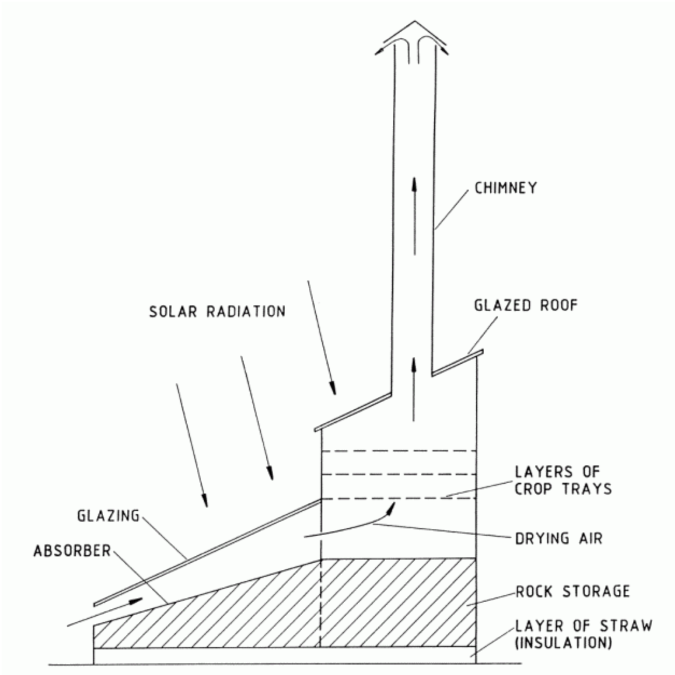
One of the earliest designs to enhance ventilation in cabinet solar dryers is the solar and wind-ventilated dryer, illustrated in Fig. 16 (left). The design uses a ventilator which depends entirely on the wind effect. Air is drawn through the dryer by wind-powered rotary vanes located on top of the dryer chimney. Temperature and air flow rates are controlled by a damper.

Passive cabinet solar dryers

The rotary wind ventilator, made of a moving corrugated vane rotor, is placed on top of a stack above the drying chamber. The stack requires an appropriate length to achieve a chimney effect and catch more wind. As the rotor spins in the wind, it expels air from the ventilator stack. The rotor is mounted on a ball bearing suspension with low friction.

Monitoring results of rotary wind ventilators installed on cabinet dryers in Zimbabwe showed low performance, because its limitation is that it can only follow the wind pattern and is essentially inoperative between wind peaks and has periods of complete inactivity during lulls. Air flows are critical factors in natural-circulation solar drying, thus they should be used especially in areas with relatively high average wind speed.

Modifications to the typical cabinet dryer designs include absorbers equipped with thermal storage, either of a rock bed or water.




Schematic diagram of fixed bed dryer with a rock storage system

**Active solar cabinet dryers**

Active solar dryers are also called forced convection or hybrid solar dryers. Optimum air flow can be provided in the dryer throughout the drying process to control temperature and moisture in wide ranges independent of the weather conditions. Furthermore the bulk depthis less restricted and the air flow rate can be controlled. Hence, the capacity and the reliability of the dryers are increased considerably compared to natural convection dryers.

It is generally agreed that well designed forced-convection distributed solar dryers are more effective and more controllable than the natural-circulation types.

The use of forced convection can reduce drying time by three times and decrease the required collector area by 50 %. Consequently, dryer using fans may achieve the same throughput as a natural convection dryer with a collector six times as large [19]. Fans may bepowered with utility electricity if it is available, or with a solar photovoltaic panel.
Almost all types of natural convection dryers can be operated by forced convection as well.

**Active ventilated cabinet solar dryers**

If utility electricity is available it is cheaper to connect the fans to the grid, compared to a connection to a PV installation. Besides the fans also an electronic controller may be connected to the grid, which is able to adjust the appropriate temperature by variable speed of the fan.