# Solar Dryers: Empowering the Future of India

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**Abstract**

Solar drying is one of the most beneficial and sustainable technologies pertinent to our society, in particular to the increasing population from amongst the developing countries. Solar drying not only saves us from the ill effects of the use of an anthropogenic form of energy but also it can be faster, saving precious time. The solar dryer of higher efficiency occupies less area and is capable of providing improved product quality in terms of highly nutritious consolidated food. In this paper, a comprehensive review of various designs of natural and direct type (NCDT) of solar dryers has been brought forward for the simple reason of collating the desired and the most intriguing state of the art of practicing of solar drying technology for the benefit of one and all.

**Keywords:** Natural, Forced, Convection, Solar Conduction Dryer, Solar Grain Dryer.

## Introduction

India is often thought of as a development paradox with really high economic growth rates in the past few years, but with lower progress in areas of life expectancy, education, and standard of living. While serious inequalities in growth, development, and opportunities explain the illusion of the paradox at the country level, still, a significant proportion of the world's poor live in India, as do a significant proportion of the world's malnourished children. Reasons related to under-nutrition issues include deprivation leading to poor ability to purchase food and sustain dietary differences and food shortages over off-seasons when farm products are not available. 25 % farmers in India commit suicide because of lack of refrigeration; 20-30 % of their harvest (fruits, vegetables, and fish-meat) is spoiled, leaving them in perpetual poverty. These problems can be solved if the dried product's productivity increases to a certain level so that seasonal food products can be processed and preserved at low cost throughout the year.

On a wider scale, cold storage and dehydration are two technically possible alternatives for storing food products throughout the year. Cold storage requires high capital costs, continuous electricity supply, different storage conditions for various food products, and maintenance of food products during processing time at significantly lower temperatures. This makes cold storage highly ineffective for poor and rural areas with energy shortages, high capital costs, and skilled manpower. On the contrary, dehydration (drying) is a relatively simpler techniques that can be used under the open sky or through electrical and solar dryers. Dehydrated agricultural products can be processed and used throughout the year at room temperatures. Open sun drying cannot be achieved to dry all agricultural-animal products and suffers from problems of low nutritional product quality, loss of color-flavor, contamination of dust-insects and losses of 10-30 % during drying. Electric dryers are complex, they need electricity, and their operating costs for low-value agricultural animal products such as fruits, vegetables, and fish are prohibitively high (Rs. 10/kg). The current solar dryers are complex, require electricity, capital intensive, and their modular designs are remote. Current scenarios require low-capital, electricity-free, easy-to-use, technologically superior and price-competitive technical intervention.

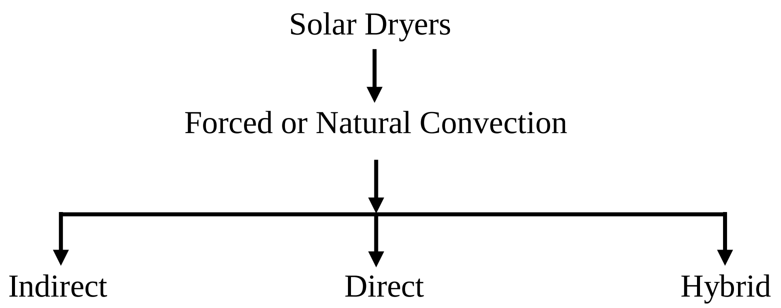

Figure 1: Classification of solar dryers

Taking the above considerations in mind, there are various types of solar dryers that have been developed. Classification of solar dryers can be done in two major groups: a) Forced convection (active solar-energy drying systems), b) Natural convection (Passive solar-energy drying systems). Three distinct sub-classes of drying systems can be identified from various sources such as patents, publications, and trademark design, namely: a) indirect type solar dryers, b) direct type solar dryers, and c) mixed-mode solar dryers, i.e. hybrid. Many solar dryers were invented by various researchers around the globe, few of them are as follows: Typical natural circulation solar-energy dryer was solar biomass dryer (Prasad et al. 2006), direct solar cabinet dryer (Murthy, 2009), cabinet dryer with chimney (Madhlopa et al. 2002), glass-roof solar energy dryer (Ekechukwe and Norton, 1999), natural circulation polythene-tent dryer (Doe, 1979), solar dome dryer (Sachithananthan, 1983), greenhouse type natural circulation solar energy dryer (Ekechukwe and Norton, 1997), solar rice dryer (Exell, 1980), solar dryer with thermal storage (Ayensu and Asiedu-Bondzie, 1986), multi-stacked mixed-mode natural circulation solar energy dryer (Mohanraj and Chandrasekar, 2009), mixed-mode wind ventilated solar dryer (Bolaji et al. 2011), tropical solar rice dryer (Ekechukwu et al. 1993), solar rice dryer (Ekechukwe and Norton, 1999), staircase solar dryer (Hallack, et al. 1996), reverse absorber cabinet dryer (Goyal and Tiwari, 1999), PV assisted solar dryer (Ruslan et al. 2003).

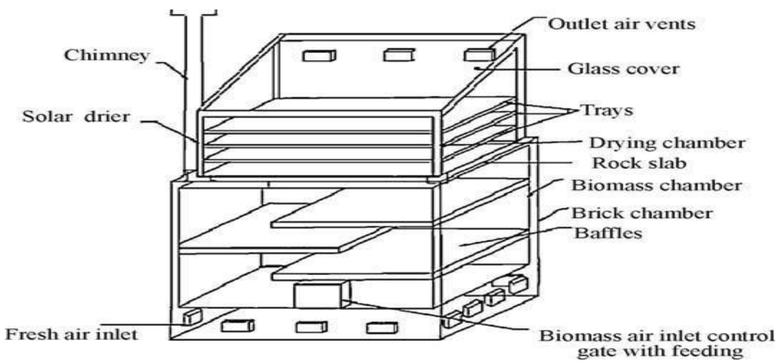


Figure 2: Solar biomass dryer (Prasad et al. 2006)

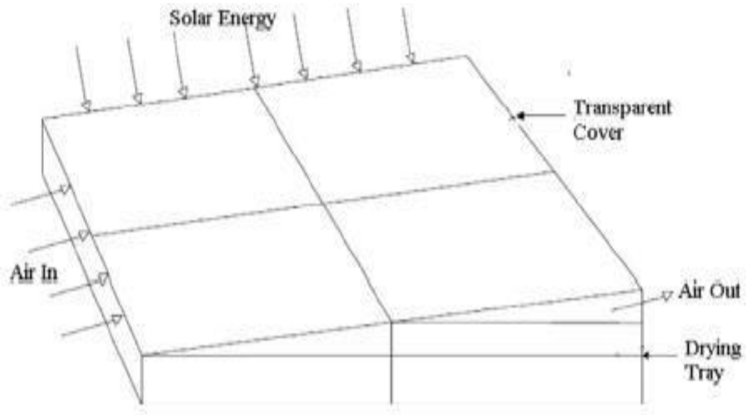


Figure 3: Direct solar cabinet dryer (Murthy, 2009)

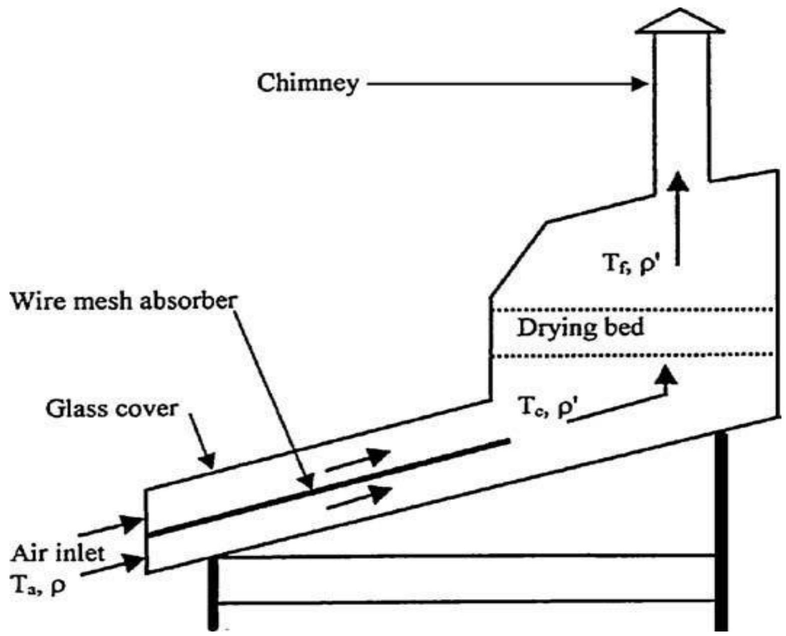


Figure 4: Cabinet dryer with chimney (Madhlopa et al. 2002)

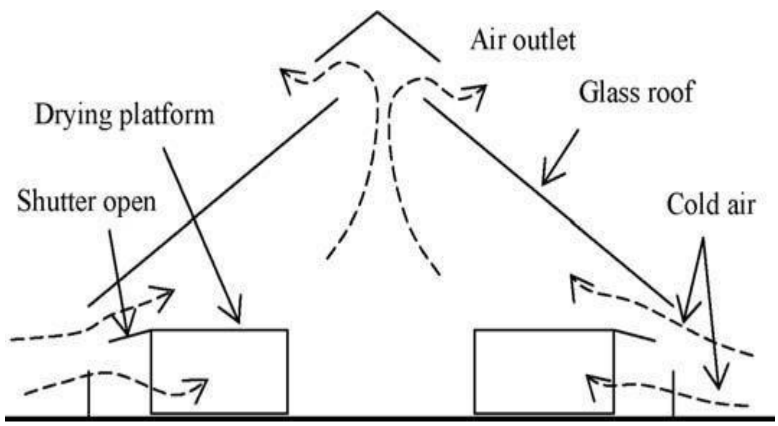


Figure 5: Glass-roof solar energy dryer (Ekechukwe and Norton, 1999)

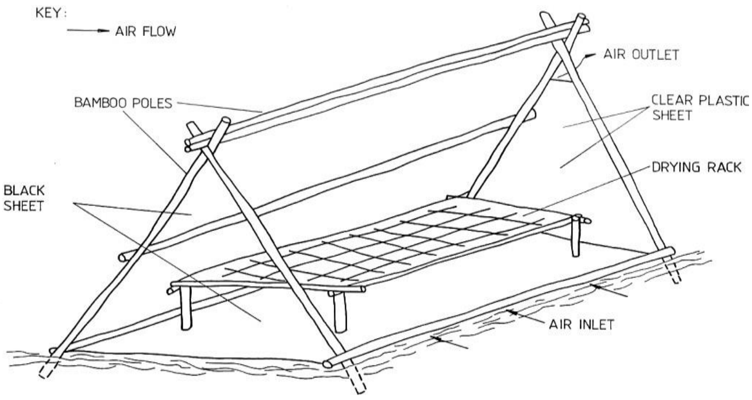


Figure 6: Natural circulation polythene tent dryer (Doe, 1979)

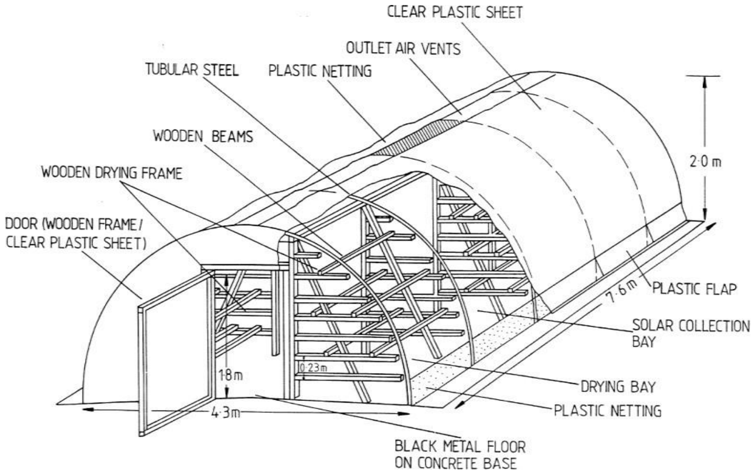


Figure 7: Natural convection solar dome dryer (Sachithananthan et al. 1983)

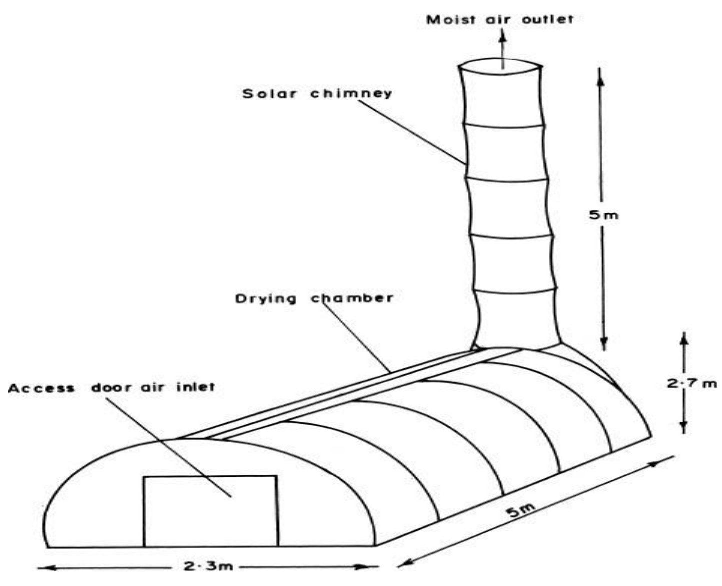


Figure 8: greenhouse type natural circulation solar energy dryer (Ekechukwe and Norton, 1997)

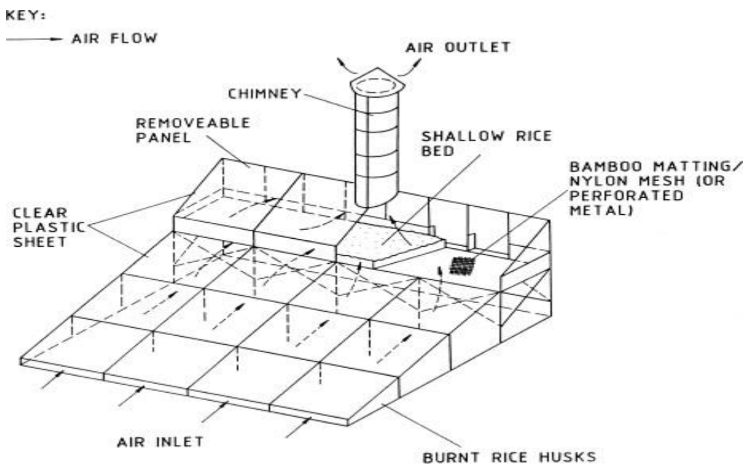


Figure 9: Mixed-mode natural convection solar rice dryer (Exell, 1980)

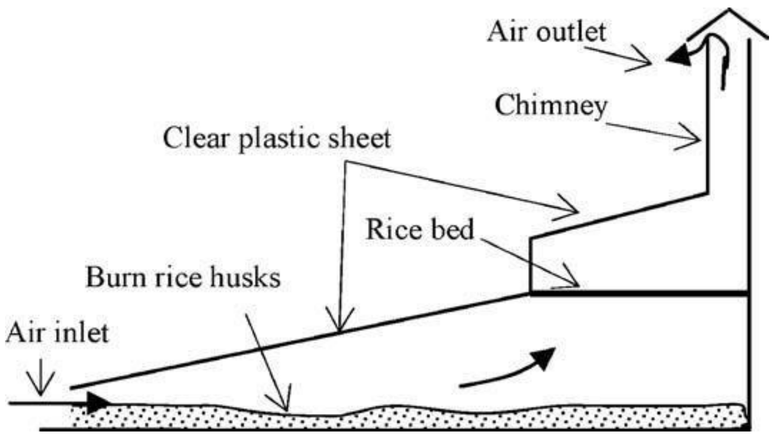


Figure 10: Solar rice dryer (Ekechukwe and Norton, 1999)

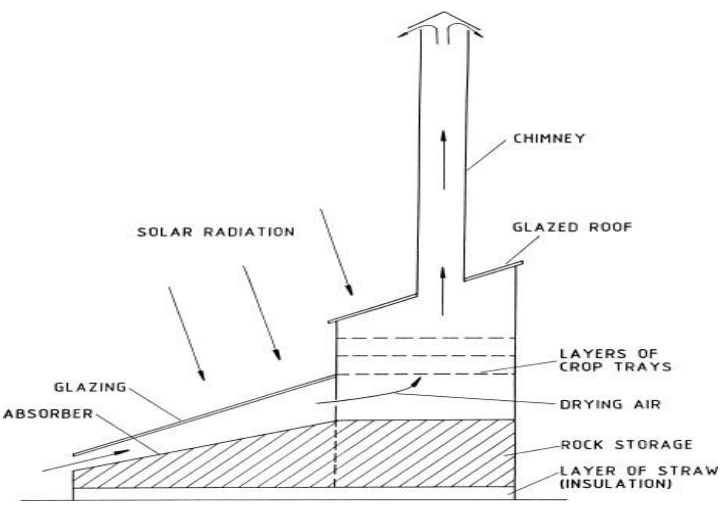


Figure 11: Mixed mode natural convection solar energy dryer with thermal storage (Ayensu and Asiedu-Bondzie, 1986)

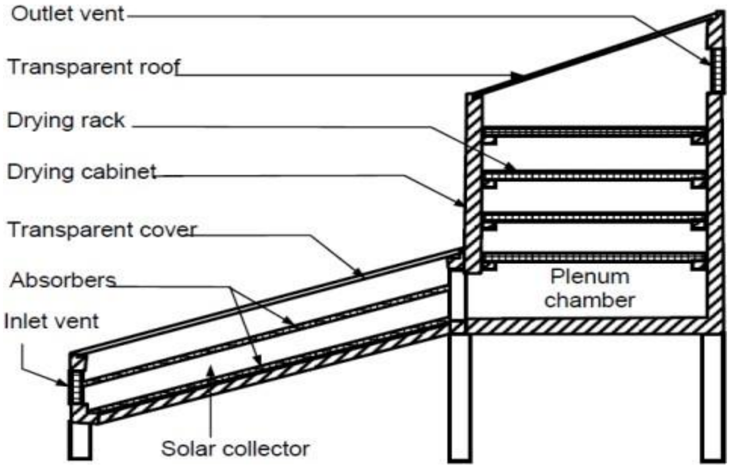


Figure 12: Multi-stacked mixed-mode natural circulation solar energy dryer (Mohanraj and Chandrasekar, 2009)

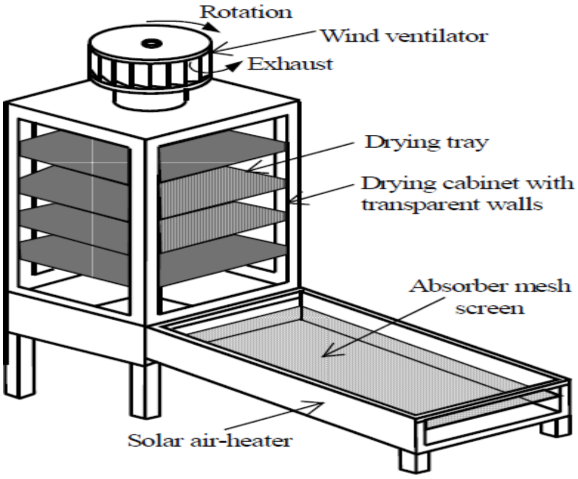


Figure 13: Mixed-mode wind ventilated solar dryer (Bolaji et al. 2011)

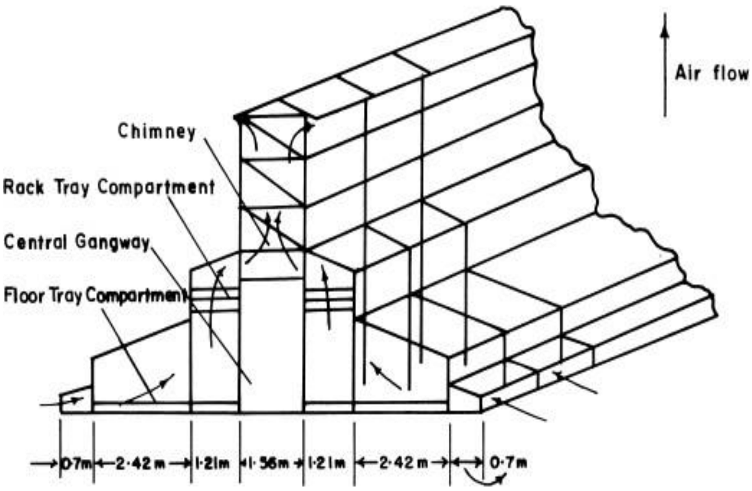


Figure 14: Mixed mode natural convection tropical solar rice dryer (Ekechukwu et al. 1993)

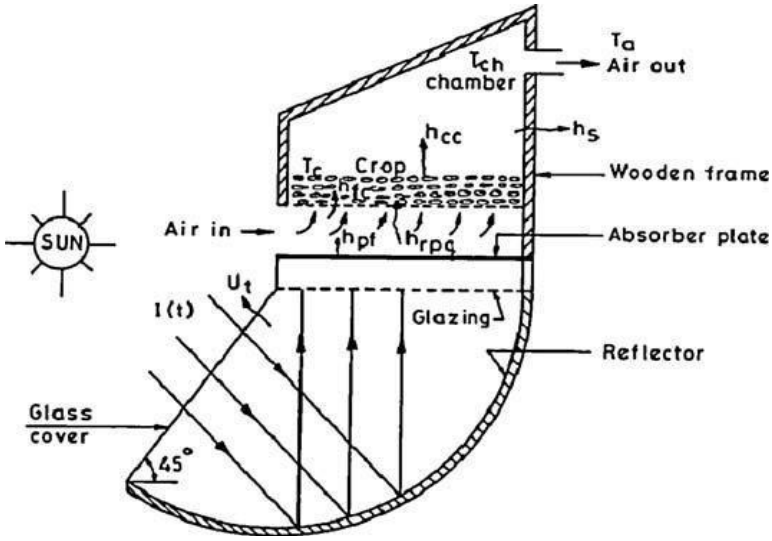


Figure 15: Reverse absorber solar energy dryer (Goyal and Tiwari, 1999)

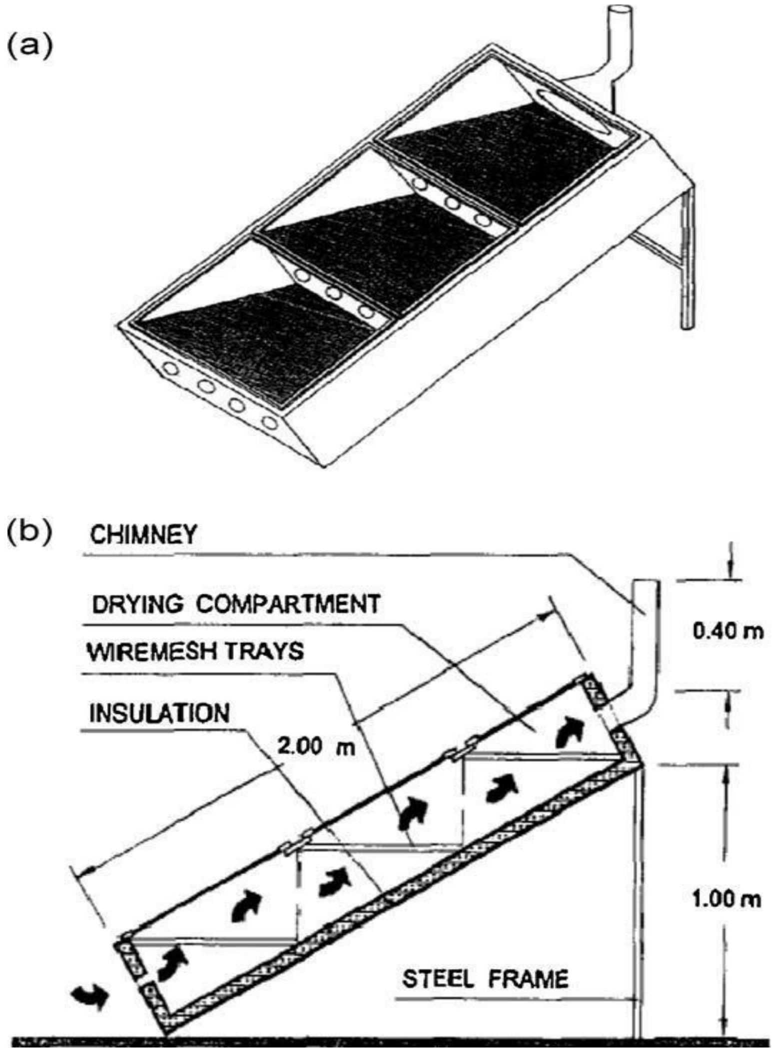


Figure 16: Staircase solar dryer (Hallack, et al. 1996)

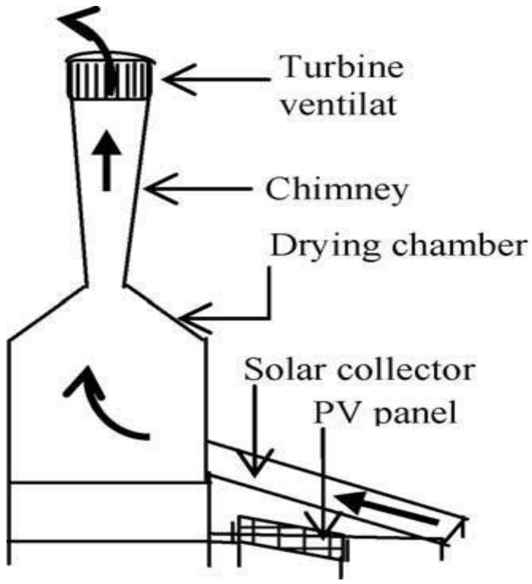


Figure 17: PV assisted solar dryer (Ruslan et al. 2003)

In the type of forced convection category, there were forced convection solar dryer (Murthy, 2009), greenhouse dryer (Soponronnarit, 1995), forced convection transparent roof solar barn (Shove et al.1981), interior drum absorber greenhouse active solar dryer (Huang and Toksoy, 1983), interior plastic absorber greenhouse active solar dryer (Trim and Ko, 1982), internal absorber greenhouse active solar timber kiln (Akachukwu, 1986), distributed type active solar dehydrator with partial air recirculation (Bolin et al. 1978), indirect solar dryer with rectangular fins (Moummi et al. 2004), forced convection solar grain dryer (Soponronnarit, 1995), solar dryers along with phase change material (PCM) (Mohanraj and Chandrasekhar, 2009), solar drying systems using various types of grooves solar collector (Sopian et al. 2001), multi-pass solar collector (Gatea, 2010), double pass solar dryer (Banout et al. 2010), solar tunnel dryer (Usub et al. 2008), solar drying system with cylindrical section (Gatea, 2010), rotary column with cylindrical dryer (Sarsilmaz et al. 2000).

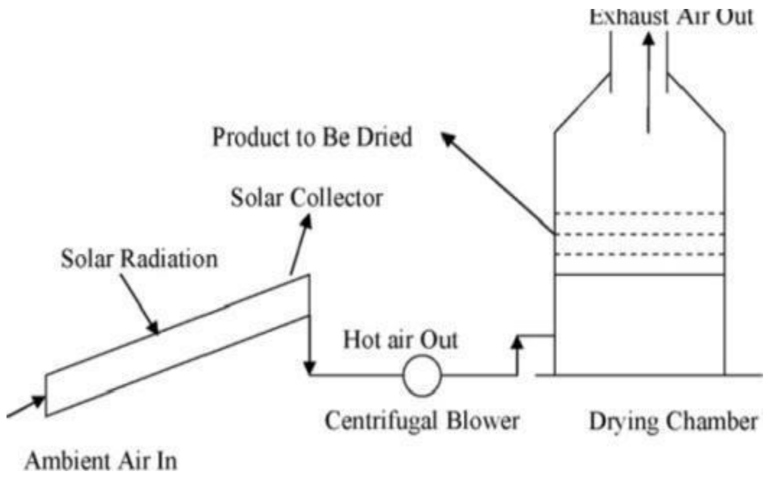


Figure 18: Forced convection solar dryer (Murthy, 2009)

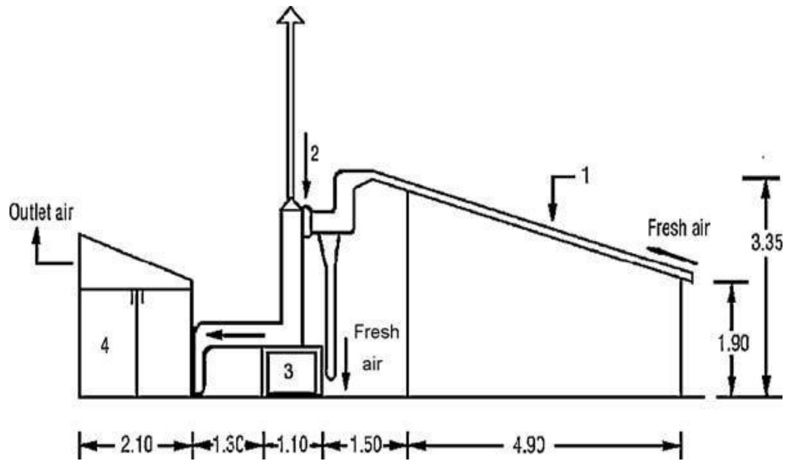


Figure 19: Forced convection solar greenhouse dryer (Soponronnarit, 1995)

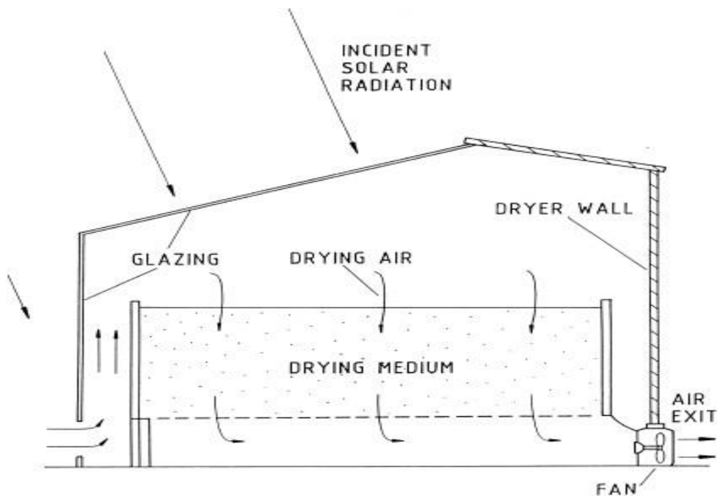


Figure 20: Forced convection transparent roof solar barn (Shove et al. 1981)

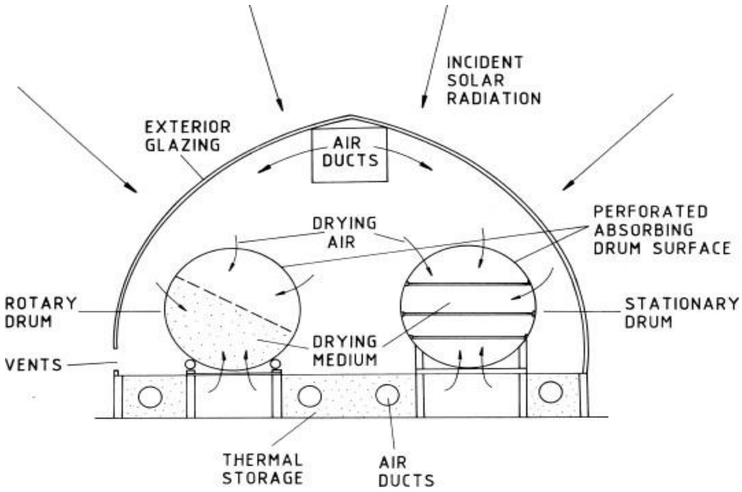


Figure 21: Interior drum absorber greenhouse active solar dryer (Huang and Toksoy, 1983)

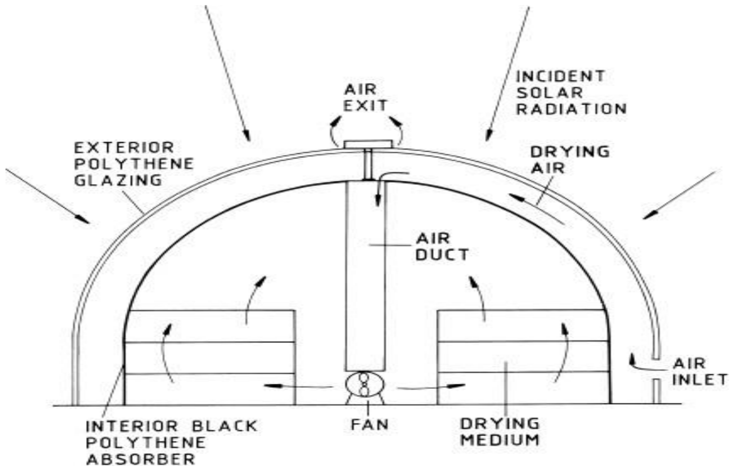


Figure 22: interior plastic absorber greenhouse active solar dryer (Trim and Ko, 1982)

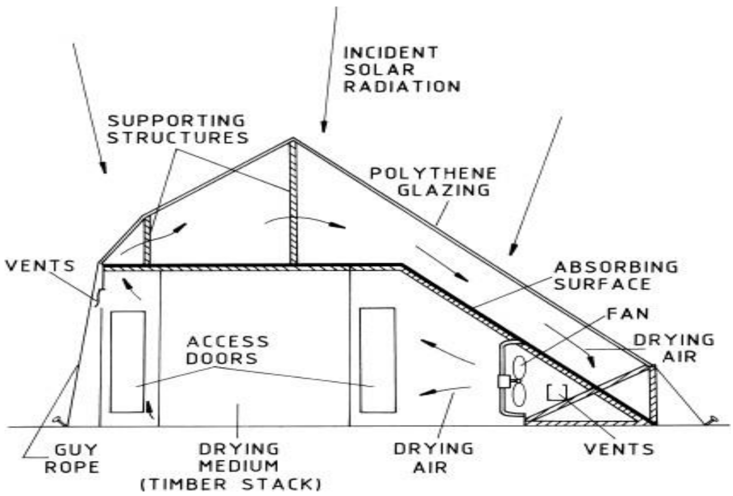


Figure 23: internal absorber greenhouse active solar timber kiln (Akachukwu, 1986)

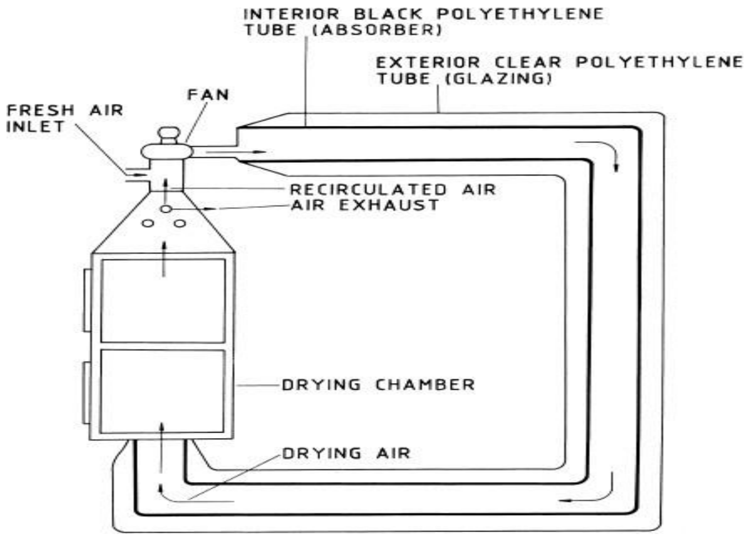


Figure 24: Distributed type active solar dehydrator with partial air recirculation (Bolin et al. 1978)

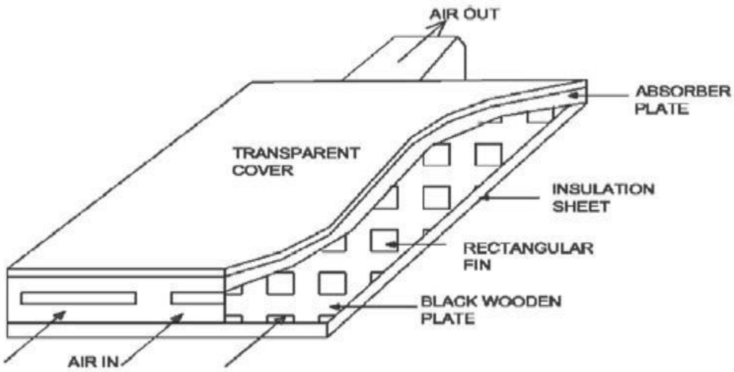


Figure 25: Indirect solar dryer with rectangular fins (Moummi et al. 2004)

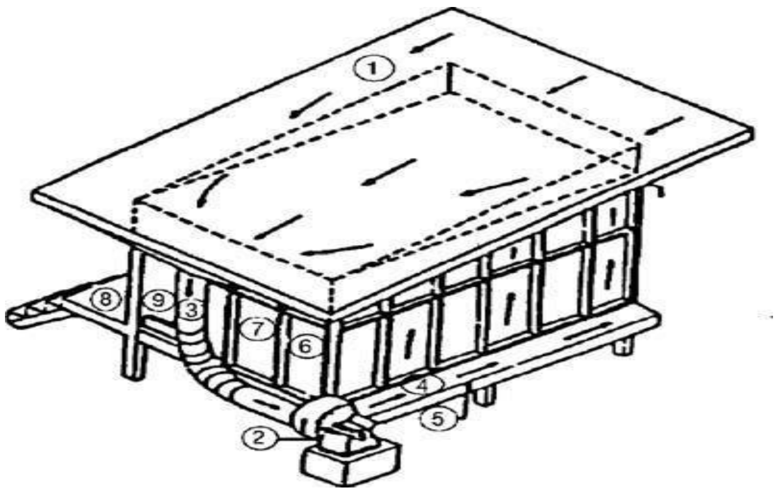


Figure 26: Forced convection solar grain dryer (Soponronnarit, 1995)

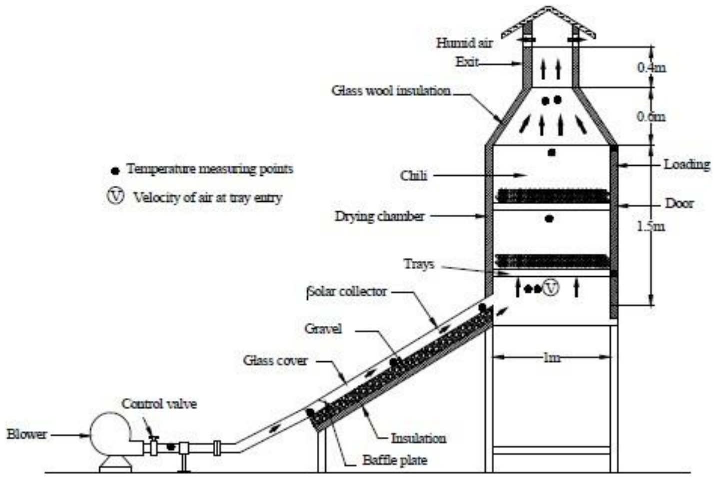


Figure 27: Forced solar convection dryer with phase change material (Mohanraj and Chandrasekhar, 2009)

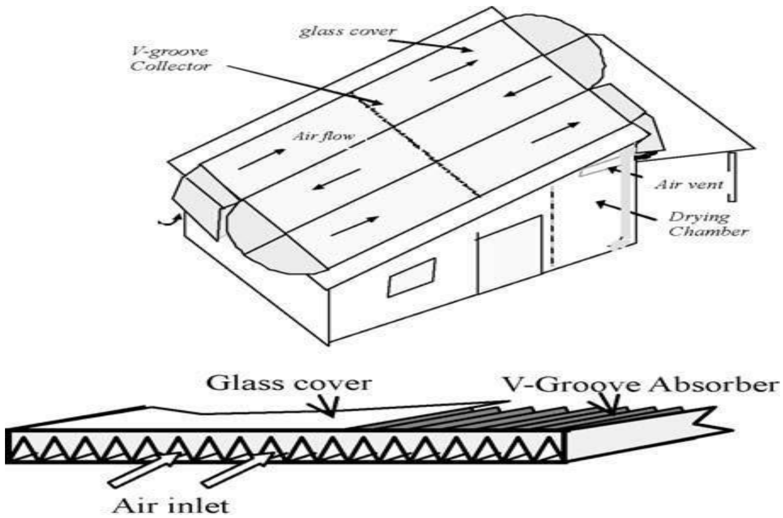


Figure 28: Solar-assisted drying system with v-groove absorber (Sopian et al. 2001)

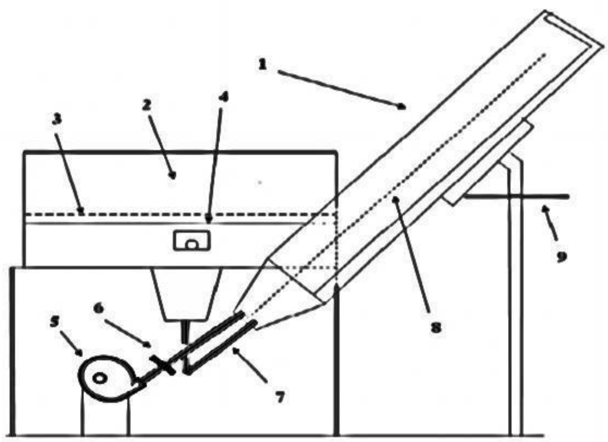


Figure 29: Multi-pass forced convection solar collector (Gatea, 2010)

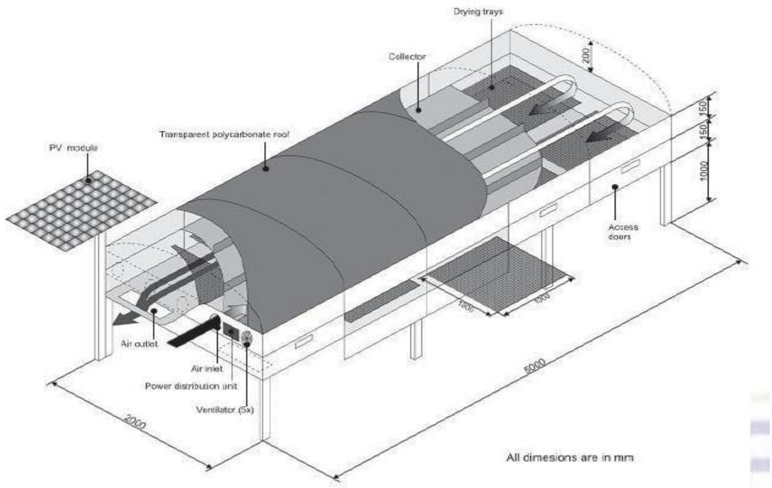


Figure 30: Double pass solar dryer (Banout et al. 2010)

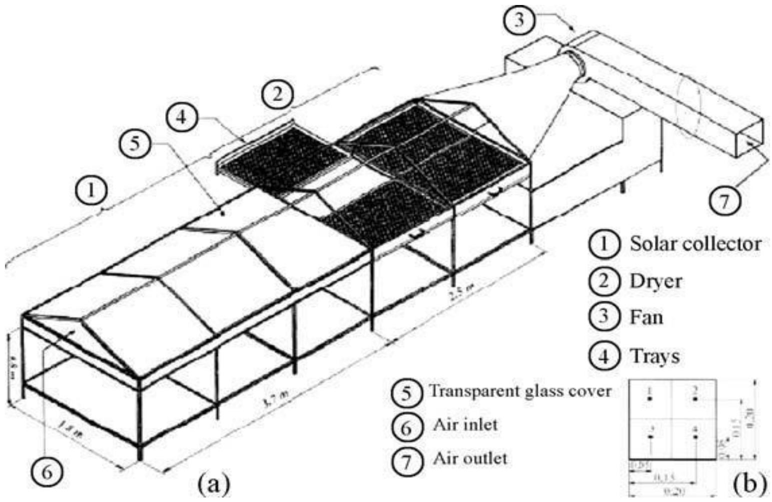


Figure 31: Solar Tunnel Dryer (Usub et al. 2008)

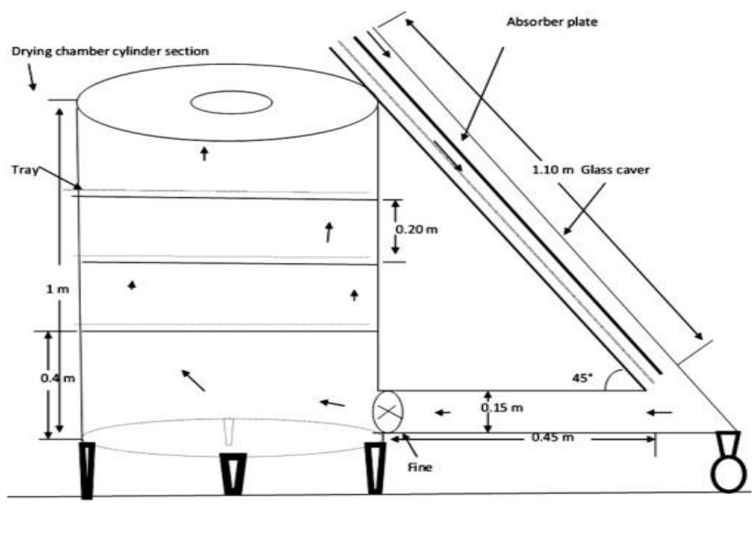


Figure 32: Solar drying system with cylindrical section (Gatea, 2010)

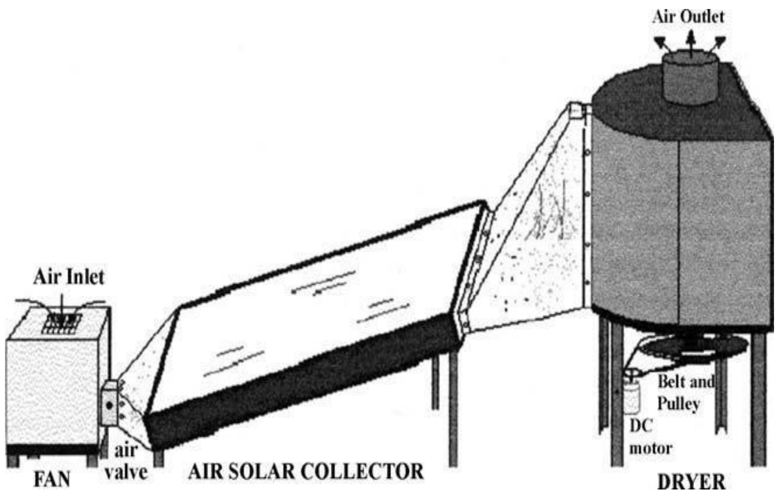


Figure 33: Rotary column with cylindrical dryer (Sarsilmaz et al. 2000)

**Innovative Solar Conduction and Grain Dryer**

Researchers invented these many types of solar dryers and primarily used the mode of operation for radiation and convection heat transfer. The missing link was the judicious use of the conductive system. Solar Conduction Dryer (SCD) and Solar Grain Dryer (SGD) can enable farmers to dry the produce, saving it up to a year without relying on the unstable power grid of India. SCD (IP Status: 740/MUM/2011 and PCT/IN2012/000843) (Tidke et al. 2014) and SGD developed at the Institute of Chemical Technology (ICT) use all the three heat transfer modes and have been described as being more effective. SCD has been successfully designed and tested at the Advanced Drying Laboratory, Institute of Chemical Technology formerly UDCT, Mumbai, India, for its quality and nutrition for four years. It has recorded one of the world's highest quality that makes it more competitive and adding flexibility to the process dramatically reduces costs. SCD marketing is already underway: in nearly 10 countries, 1300 dryers with a capacity of 4000 tons per year are being installed. UNEP-Bayer Ag acknowledges SCD as the top four sustainable global developments, while the University of Texas-Dell supports the social innovation center, IIT-B, and IIM-A for its creativity in architecture. 200 rural women farmers in Aurangabad and Shahapur in Maharashtra were provided with SCD.

They were able to preserve seasonal products during the surplus season and consume them during the lean period to overcome malnutrition.

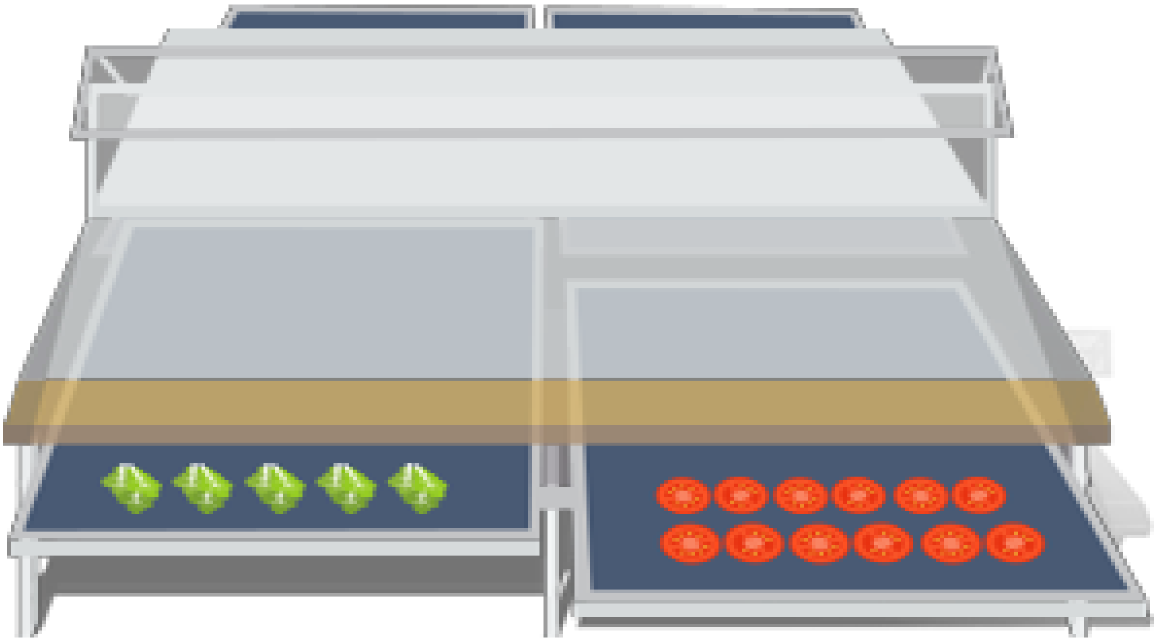

Figure 36: Solar Conduction Dryer (SCD)

Figure 37: Solar Grain Dryer (SGD)

A 36 % improvement was observed in the intervention group's dietary diversity score relative to the lean season control group. This indicated more availability of food in the lean season due to usage of SCD. Out of the 200 women of the intervention group, 105 women sold the surplus SCD dried food products. Approximately 10 tons of agricultural products, including dried ginger, onion, fenugreek, spinach, drumstick leaves, and moth beans were sold by women, with a total purchase price of more than 20 lakh INR and a gain of more than 50 %. The impact of consumption of SCD dried vegetables at Shahapur showed an increase in the mean Hb value by 0.83 g/dL (Nagwekar et al. 2017).

The basic understanding of heat and mass transfer was necessary to increase the dryer's material handling capabilities and dryer modeling. Therefore, the mathematical analysis was expected to give a comprehensive inside look of the flow area, temperature distribution, humidity and drying time by using computational fluid dynamics (CFD) modeling. CFD analysis helped us in suitable modification in the internals of SCD and SGD. With the effective use of solar energy, unique absorber plate material, and its multi-layer orientation used to fasten the material's drying. The predicted performance, which eventually increases the material handling efficiency of the internationally licensed and engineered SCD and SGD, was a superior dryer based on CFD and experimental studies (Chavan et al. 2018).

SCD and SGD are based on an ecosystem strategy to empower small farmers to make them independent of price fluctuations and seasonal availability of the highest possible dried fruit and vegetable value. These dryers are an integrated solution to cope with malnutrition, poverty, food shortage, and food losses. This strategy will enable farmers, self-help organizations, NGOs, and individuals, including housewives to save several thousand tons of agricultural products per year and turn them into value-added goods, ensuring better nutrition and health for thousands of people.

Small holding women farmers, apart from domestic consumption, can create value-added dehydrated products that typically give them 50-200 percent more income. The total market is $16 billion annually for dehydrated goods. By reducing post-harvest losses, farmers can dramatically increase their profits, and by creating new market opportunities both inside and outside the country, it will create a new opportunity for living.

## Conclusion

A comprehensive review of the design of various types of natural and forced type of solar dryers has been presented. As described above, these incumbent dryers work on the principles of one or maximum of two types of heat transfer mechanisms. Solar conduction dryer is one of the first of its kind of technology in the world that uses all the three modes of heat transfer, viz., conduction, convection, and radiation making it the most energy-efficient dryer. Also, it was found that the experimentally dried vegetables by SCD retained better microbial and biochemical quality as compared to the traditionally open sun dried ones. It was found that the SCD and SGD are based on an ecosystem strategy to empower small farmers to make them independent of price fluctuations and seasonal availability of the highest possible dried fruit and vegetable value.

## Acknowledgement

The author is thankful to Prof. B. N. Thorat for his valuable guidance.

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