# Review of Hybrid Solar Dryers


## ABSTRACT

In many under developed and developing countries, agricultural products are dried in open sun and this method of drying diminishes the quality and standard of the dried products due to interference from external impurities, excessive ultra violet radiation and uneven drying rates. Diminishing fossil fuel reserves and increasing effects of anthropogenic climate change due to greenhouse gas emissions have led to an unprecedented global interest in renewable sources of energy in food processing. A leading candidate among these emerging technologies is the conversion of sunlight to electricity as a support and stability for solar drying system. This process can be achieved either directly with solar cells (using the photovoltaic effect) or indirectly by concentration of incident solar radiation to generate high-grade heat that then supports heat generation in a traditional solar dryer. Numerous types of solar dryers have been designed and developed in various parts of the world, yielding varying degrees of technical performance. Drying process is successful even under unfavorable weather conditions in the hybrid solar dryers. In this review paper, we reviewed different types of hybrid solar dryers with respect to different design modifications in order to increase their effectiveness and thermal stability.



Keywords:*Direct Solar Dryer,Drying,Hybrid Solar Dryer, Solar Radiation, Sun.*


## 1. INTRODUCTION

There is a number of traditional drying methods currently available, but it is worth consideringboth the technical and economic benefits of the possibility of solar drying, along with a substantialnumber of commercially available solar dryers in operation today. However, for some special casesindividually designed solar dryers have also been developed and used. The scope of hybrid solardrying is to produce a solid end product of a certain percentage of moisture content for immediateuse or for further long-term safe storage within a limited time[1]-[3]**.**This condition should be achieved at a moderate constant and continuous temperature level as some of the materials to be dried may be sensitive to higher and instable temperature.

Several ways can be used to evaluate the technical performance of solar dryers but economic and practical issues will often be more important in determining their acceptability[4]. Advances in design methods, absorber and glazing materials and control systems will all bring improvements in the technical performance of solar dryers and these will all contribute to the greater acceptance of a technology that can play important role in a more sustainable world, particularly the food production system.

## 2. REVIEW OF PREVIOUS HYBRID SOLAR DRYERS

## 2.1 Automated Solar Powered Hot-Air Supplemented Dryer

Inability to stabilize and regulate temperature level inside solar drying system especially during the off peak insolation period has been a major challenge in achieving uniformly dried biological material. Aduewa*et al*.designed and developed a solar powered hot-air supplemented dryer (SPHSD) with a control and data logging system [4]. The SPHSD has 3 sections which are solar collector chamber, drying chamber and hot-air supplement chamber which is powered with two 150 watt solar panel and one 200 Amps solar battery for continuous operation during bad weather. An electronic data logger and control unit was also developed for monitoring and controlling the temperature, air velocity and moisture content values [4]. Likewise the logger was used to record parameters at every level and location where different measuring sensors were position in the drying system as shown in Figures 1a, 1b and 1c. The SPHSD has a capacity of 20 kg/batch, drying efficiency of 87.020 %, effective moisture diffusivity value of 3.38 × ($10^{-10}$ $m^2/s$), specific energy consumption 4620.571 J/kg.K, solar collector efficiency of 91.29 % and thermal efficiency of 52.539 % at peak operating condition.

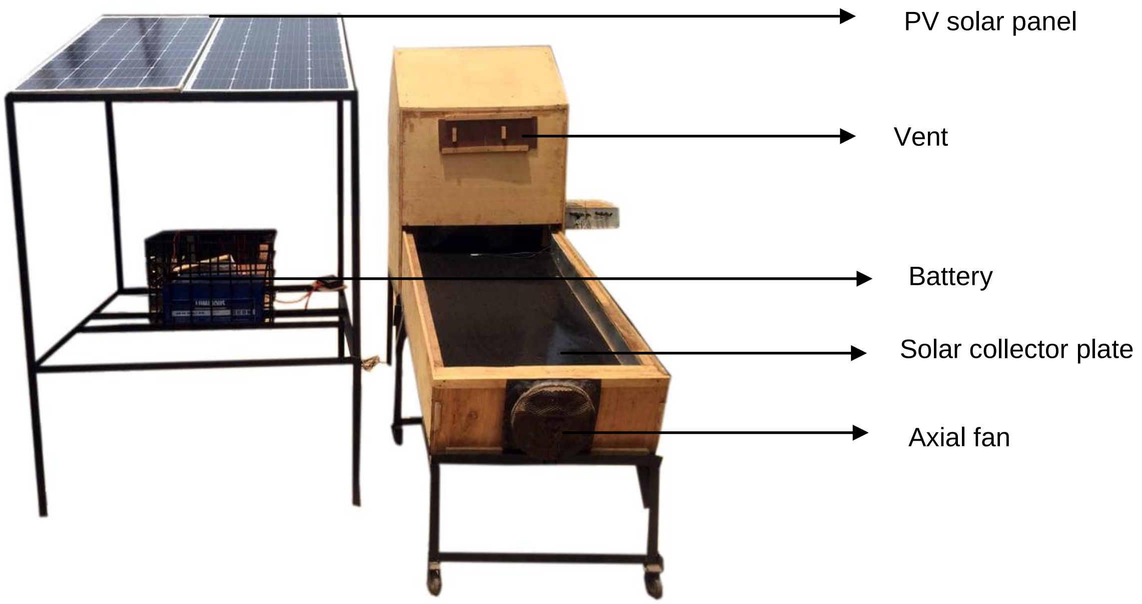


Figure 1a: Solar powered hot-air supplemented dryer

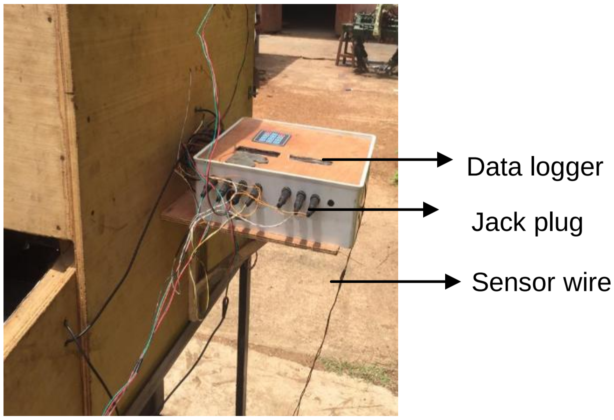


Figure 1b: Developed data logger and control

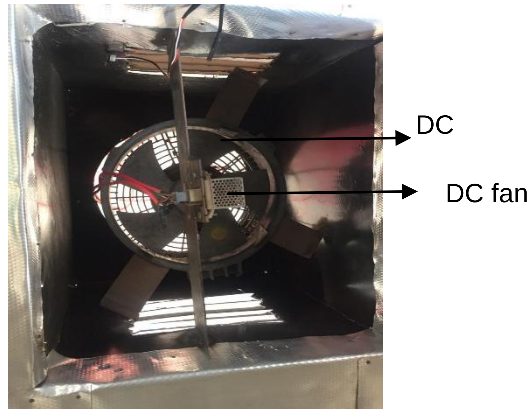


Figure 1c: Hot-air supplement section of the dryer

## 2.2 Hot-Air Supplemented Solar Dryer

Aduewa*et al*. designedand fabricated a hot-air supplemented solar dryer for drying white yam (*Dioscorearotundata*) slices [5]. The capacity of the designed hot-air supplemented solar dryer was 14 kg. The equipment was tested in Federal University of Technology Akure (FUTA) using white yam to establish the effect of incorporating the hot-air section into the solar dryer which was powered using a generator. The designed hybrid dryer consists of a drying chamber, a solar collector chamber and a mechanical heating chamber. Drying experiments were conducted using a temperature of 60°C for the hot-air supplemented solar drying process at a drying air velocity of 0.8 m/s [5]. After the experiment, it was deduced that the total drying time used to reduce the moisture in the white yam slices to safe storage moisture content (SSMC) differs for the two different drying conditions giving a total drying time of 18 hours for solar dryer and 13 hours for hot-air supplemented solar dryer [5]. The average dryer thermal efficiency for the solar dryer was 31.45 %, and the average dryer thermal efficiency is 42.10 % at solar/mechanical drying at 60 ºC, and also the solar collector highest efficiency was calculated to be 83.28 % at solar radiation intensity of 1199.46 W/m$^2$ and lowest efficiency of the solar collector was 23.89 % at solar radiation intensity of 300.40 W/m$^2$ [5].

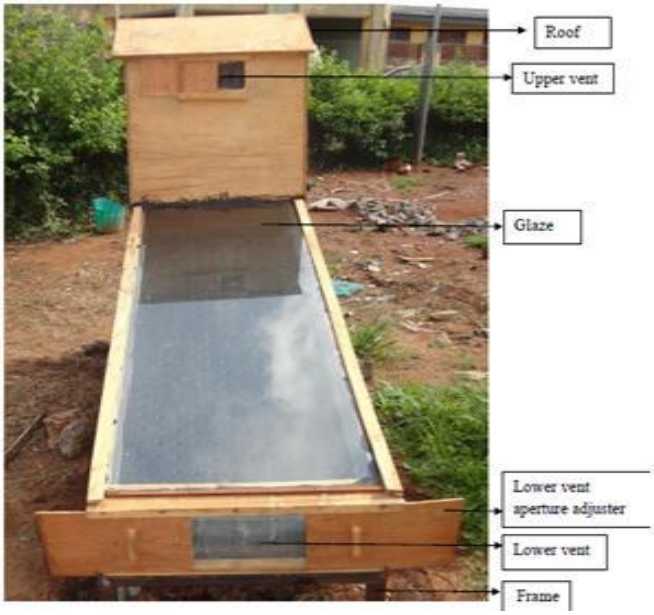

Figure 2a:Front view of the hot-air supplemented solar dryer

Figure 2b:Back view of the dryer

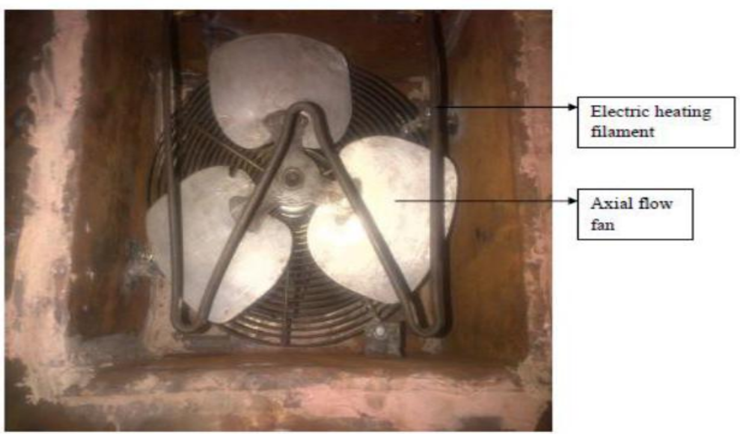

Figure 2c: Picture of the heating element and the axial fan

### 2.3 Double pass solar drier system

Banout*et al*. designed a double pass solar drier system. Figure 3 shows the detailed description of the Double pass solar drier (DPSD) [6].The dimensions of the dryer are as follows: length 5 m, width 2 m and height 0.30 m with its solar absorber made of galvanized metal sheet painted black matt to ensure good absorption of solar radiation. The heated air flows on either side of the absorber plate, thus increasing the heat transfer surface area.At the beginning of the drier there are five DC fans which provide the necessary air-flow through the absorber and drying chamber. The fans are connected directly to a photovoltaic panel by a parallel connection.

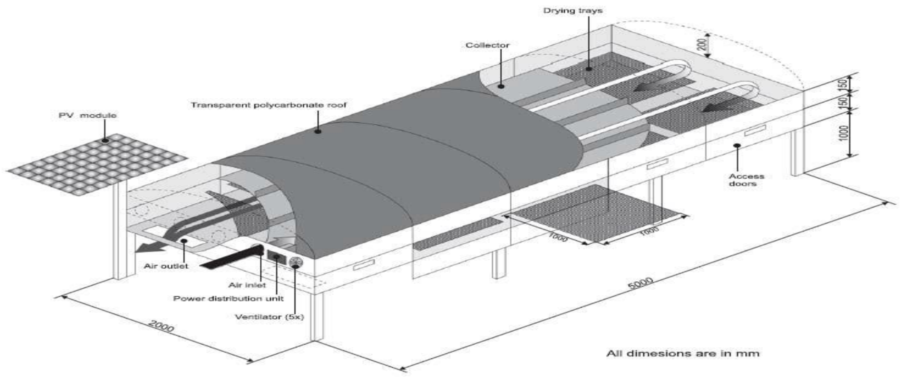


Figure 3. Description of the Double pass solar drier (DPSD)

Source: [6]

According to [6], experimental runs for drying red chilli slices were performed using DPSD and compared with typical cabinet drier (CD) and atraditional open-air sun drying.The overall drying efficiencies of DSPD and CD to reach the desired moisture content of 10% (on a wet basis) were 24.04% and 11.52% respectively while the overall drying efficiency of open-air sun drying to reach the desired moisture content of 15% (on a wet basis) was 8.03%.Further, ASTA colour value of the solar dried products from the DSPD was higher than those from CD and open-air sun drying. TheDPSD shows higher performance as well in all measuredefficiencies and the overall drying efficiency was morethan two times higher in case of DPSD compared to CD.

### 2.3 Combined Solar and Mechanical Cabinet Dryer

Bhuiyan*et al*. also designed and fabricated a combined solar and mechanical cabinet dryer that utilizes solar and electrical energy either separately or in combination to conduct air drying [7]. Different drying conditions were applied by changing the heating source and flow of air. The highest temperature reported in the drying chamber was 55 °C and this was realized in two heating source and a fan condition. The temperature in upper shelf ranged from 47 °C to 70 °C for different heater-fan configuration. The highest temperature was achieved in the upper shelf by 2 kW heater and 1 fan (70 °C) and was successively followed by 2 kW heater and 2 fans (60 °C), 1 kW fan and 1 fan (56.7 °C) and 1kW heater and 2 fans (47 °C) [7]. The temperature in lower shelf ranged from 42 °C to 50 °C for different operational conditions and the sequence was same as the upper shelf with respect to temperature with the exception that kW fan and 1 fan and 2 kW heater and 2 fans gave similar temperature (47 °C). Bhuiyan*et al*. reported that the highest temperature (50 °C) was given by 2 kW heater and 1 fan, while the lowest temperature (42 °C) was given by 1 kW heater and 2 fans [7]. The variation in the temperature gradient gives the highest temperature at the upper chamber and the lowest at the lower chamber.

### 2.4 Indirect Active Hybrid Solar – Electrical Dryer System

Boughali*et al*. in their research developed indirect active hybrid solar–electrical dryer in the eastern Algerian Septentrional Sahara [8]. The indirect active hybrid solar–electrical dryer constructedby Boughali*et al*. consists mainly of a flat plate solar collector, drying chamber, electrical fan, resistance heater (3.75 kW: accuracy ± 2%) and a temperature controller [8]. The solar air collector has an area of 2.45 $m^2$, and was inclined at an angle of 31° (latitude of Ouargla city) with the horizontal facing south all the time and used a painted matte black metal galvanized of 0.002 m thickness to absorb most of the incident solar radiation [8]. An experimental test with and without load were performed in winter season in order to study the thermal behavior of the dryer and the effect of high air mass flow on the collector and system drying efficiency. The fraction of electrical and solar energy contribution versus air mass flow rate was investigated. It was noticed that when airflow rates of the drying air increased from 0.0405 $kg/m^2s$ (1 m/s) to 0.0810 $kg/m^2s$ (2 m/s) the percent energy contribution by the solar air heater decreased from 25.074 % to 13.22 % while that of auxiliary heater increased from 74.92 % to 86.78 % [8]. This increase in contribution of the auxiliary heater is due in fact to the collector outlet temperature of the air drying which will be decreased significantly in high airflow rates and hence the air drying will be required to be heated by the auxiliary heater by larger temperature difference. The pictorial representation is shown in Figure 4.

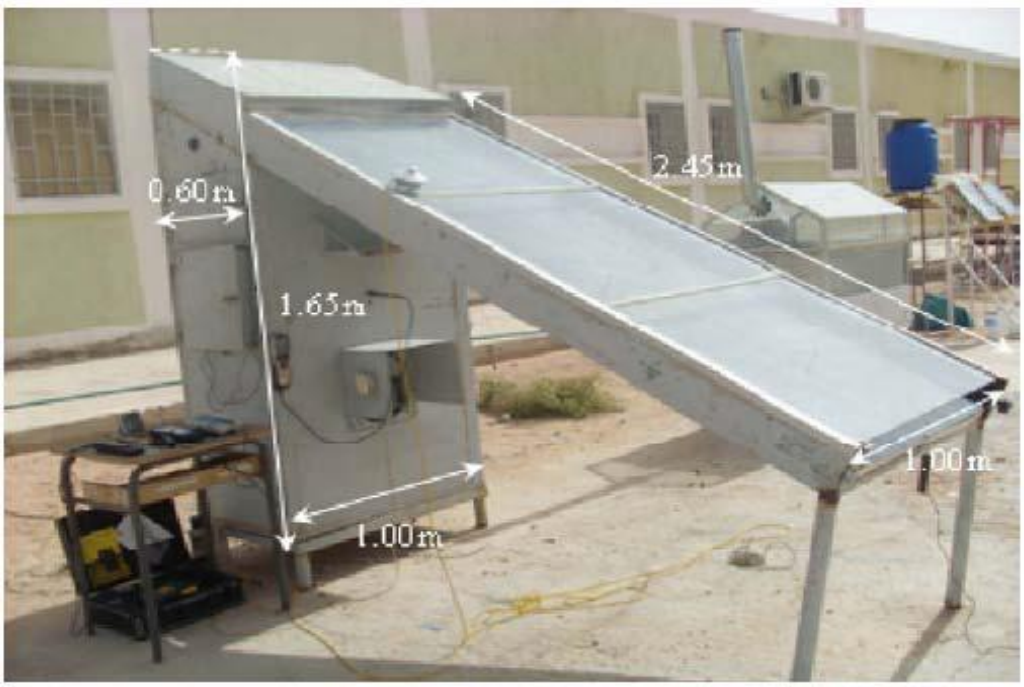


Figure 4. Photo of an indirect active hybrid solar–electrical dryer

Source: [8]

## 2.5 Solar Dryer System with Swirling Flow

Gülşahand Cengizdesigned a new solar dryer system with swirling flow for drying seeded grape [9]. A swirl element was installed by the researchers in the entrance of the chamber to give rotation effect to the air. A new type of air solar collector, having dimensions 940 × 1850 × 200 $mm^3$ was manufactured for supplying hot air necessary for drying. For the purpose of increasing the collector's efficiency, absorbing surface was manufactured in steps with 6holes of 15 mm diameter drilled on each step for increasing turbulence effect on the developed expanded surface collector [9]. In the developed system various drying air velocities were examined in terms of drying periods. Drying periods of dried grapes in the drying chamber with air solar collector and over cement ground were compared. Likewise, drying experiments were made with air directing elements installed inside the dryer and a swirl element to the entrance of drying chamber was then compared with drying in open air under natural conditions in terms of drying period. It was reported by [9] that 200 h of drying period under natural conditions decreased to 80 h with the developed dryer having swirl element with an air velocity of 1.5 m/s.

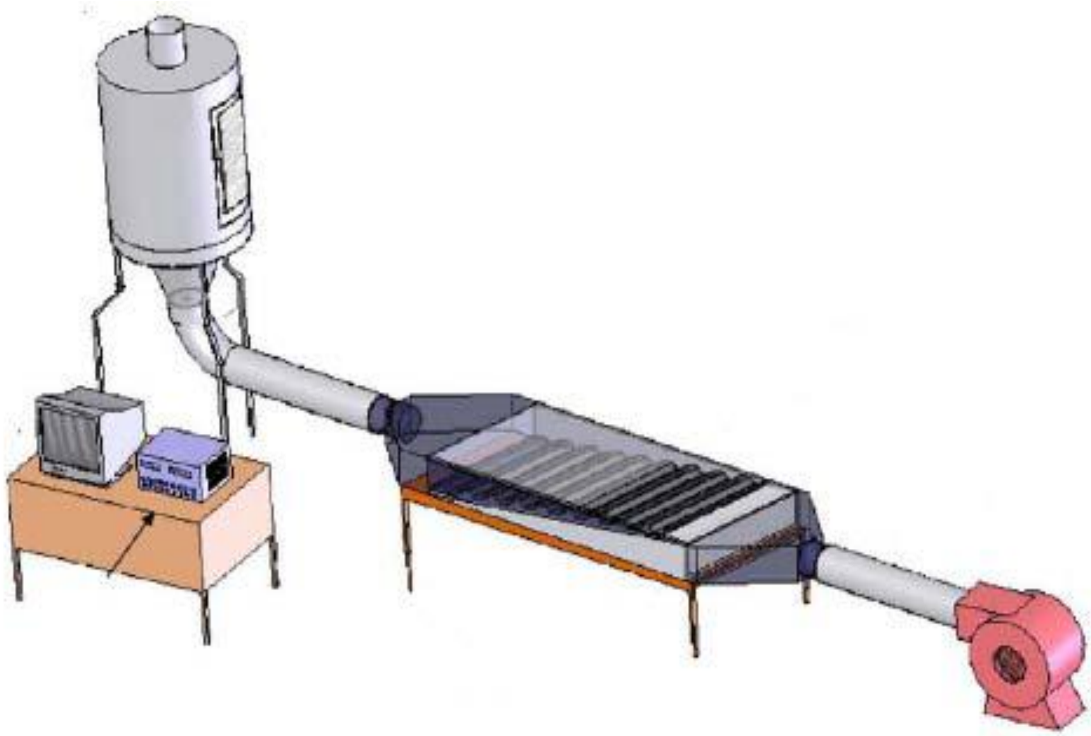

Figure 5: Schematic view of designed experiment set

Source:[9]

## 2.6 Solar Assisted Heat-pump Dryer System

Hawladerand Jahangeerbuilt a fully equipped experimental solar assisted heat pump drying system set-up for drying of green beans [10]. The experimental set-up comprised of two separate paths which are for air and refrigerant. Solar air collector, air-cooled condenser, auxiliary heater, blower, dryer unit, evaporator, and temperature and flow control devices were in the air path (see Figure 6).

Hawlader*et al*.compared the performance of an evaporator–collector and an air collector used in an integrated solar system [11]. It was found that the evaporator– collector performed better than the air collector in a solar assisted heat pump drying system [11]. The air collector efficiency was raised because of higher mass flow rates of air and using of dehumidifier in system. The range of efficiency of the air collector, with and without dehumidifier, was found to be about 0.72–0.76 and 0.42–0.48, respectively [11]. It was also revealed that the efficiency of the evaporator–collector was higher than that of the air collector and it increased with increment of refrigerant mass flow rate. A maximum evaporator–collector efficiency of 0.87 against a maximum air collector efficiency of 0.76 was obtained [11].

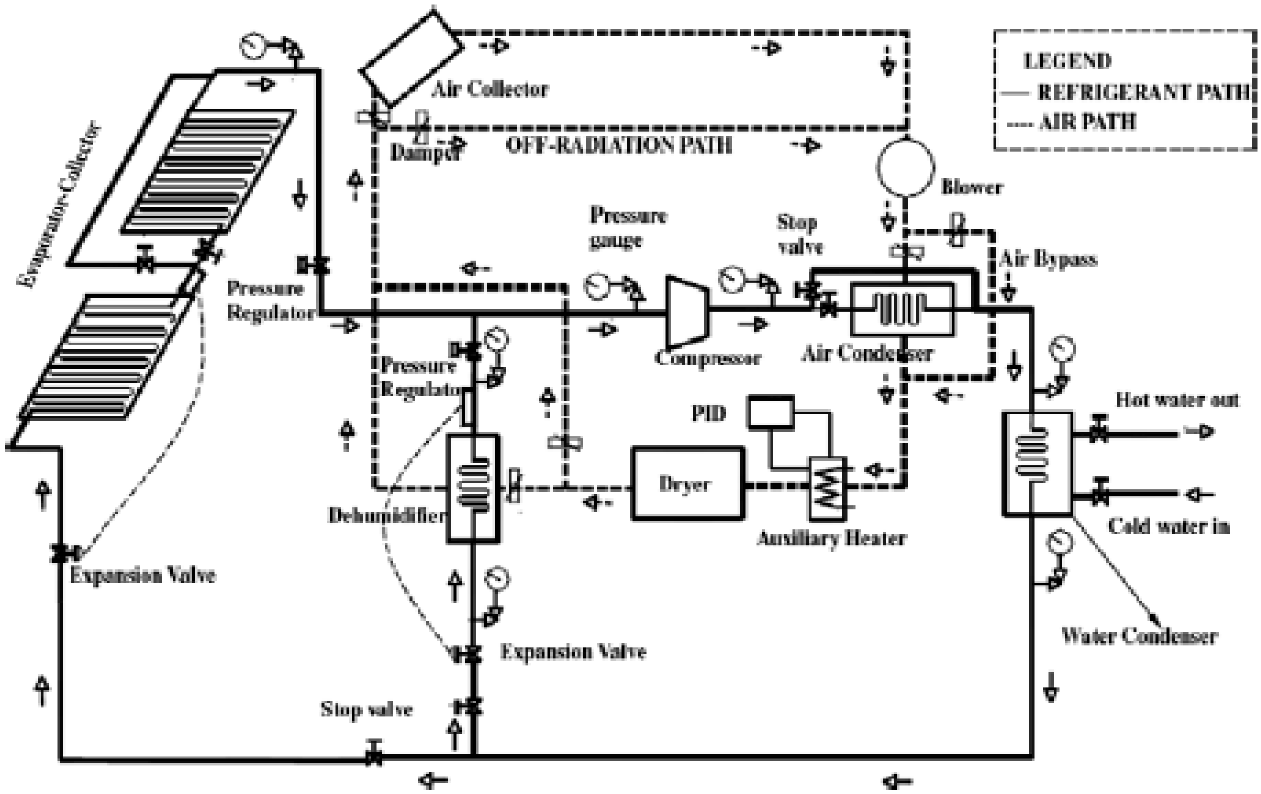


Figure 6: Component and Schematic diagram of a solar assisted heat-pump drying system
Source: [10]

## 2.7 Solar Assisted Chemical Heat Pump Drying System

A chemical heat pump (CHP) proposed as one of the potentially significant technologies for effective energy utilization in drying was developed by [12].Series of experiments has been performed on the (SACHPD) system to evaluate the performance. The performance of the system has been investigated experimentally for different environment climate conditions. Two representative days for clear and cloudy conditions were presented [13]. The maximum values of the solar fraction (SF) and the coefficient of performance of chemical heat pump (COPh) of the system are 0.713 and 2 on a clear day, against the maximum values of 0.322 and 1.42 on a cloudy day. The total system energy output of 51 kWh and 25 kWh were obtained for clear and cloudy days, over 9 hours drying time. The component details is shown in Figure 7.

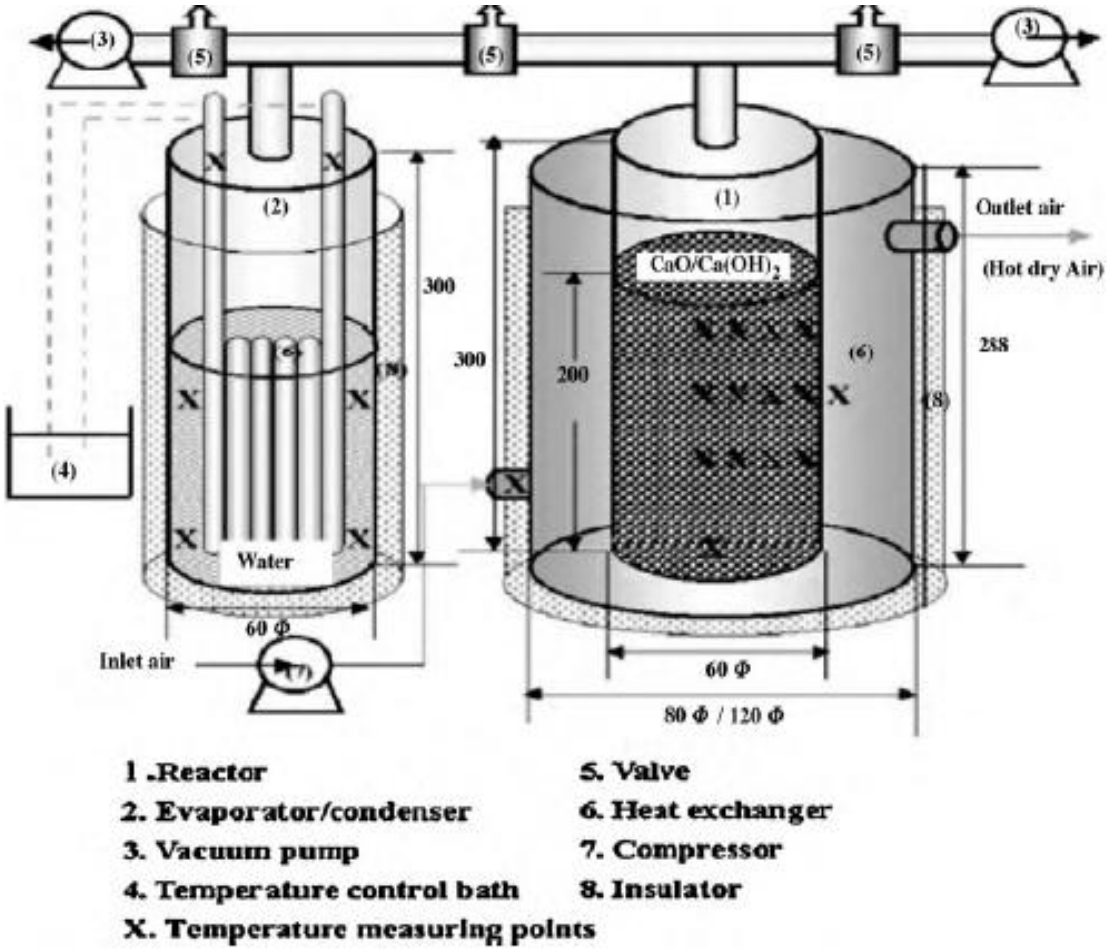


Figure 7:Standard-type CHP unit

Source: [12]

## 2.8 Solar-assisted Dehumidification System

Yahya*et al*. designed and tested a solar dehumidification system for medicinal herbs [14]. The system consisted of a solar collector, an energy storage tank, auxiliary heater and adsorbent, water to air heat exchanger, a water circulating pump, drying chamber, and other equipment as shown in Figure 8. It is made up of essentially three processes, namely regeneration, dehumidification, and batch drying. During regeneration process, the air outside the dryer is heated with the heat exchanger and is supplied to the adsorbent. The air is firstly dehumidified with the adsorbent and is supplied to the drying chamber as the dry air. The relative humidity and temperature of the drying chamber were 40 % and 35 °C respectively. The performance indices considered to calculate the performance of the drying system are: Pick up efficiency ($\eta p$), Solar Fraction (SF) and Coefficient of Performance (COP) [14]. The results indicated that the maximum values of the pickup efficiency ($\eta p$), solar fraction (SF) and coefficient of performance (COP) was found 70 %, 97 % and 0.3, respectively with initial and final wet basis moisture content of *CentellaAsiatica L* type, 88 % and 15 %, respectively at an air velocity of 3.25 m/s [14].

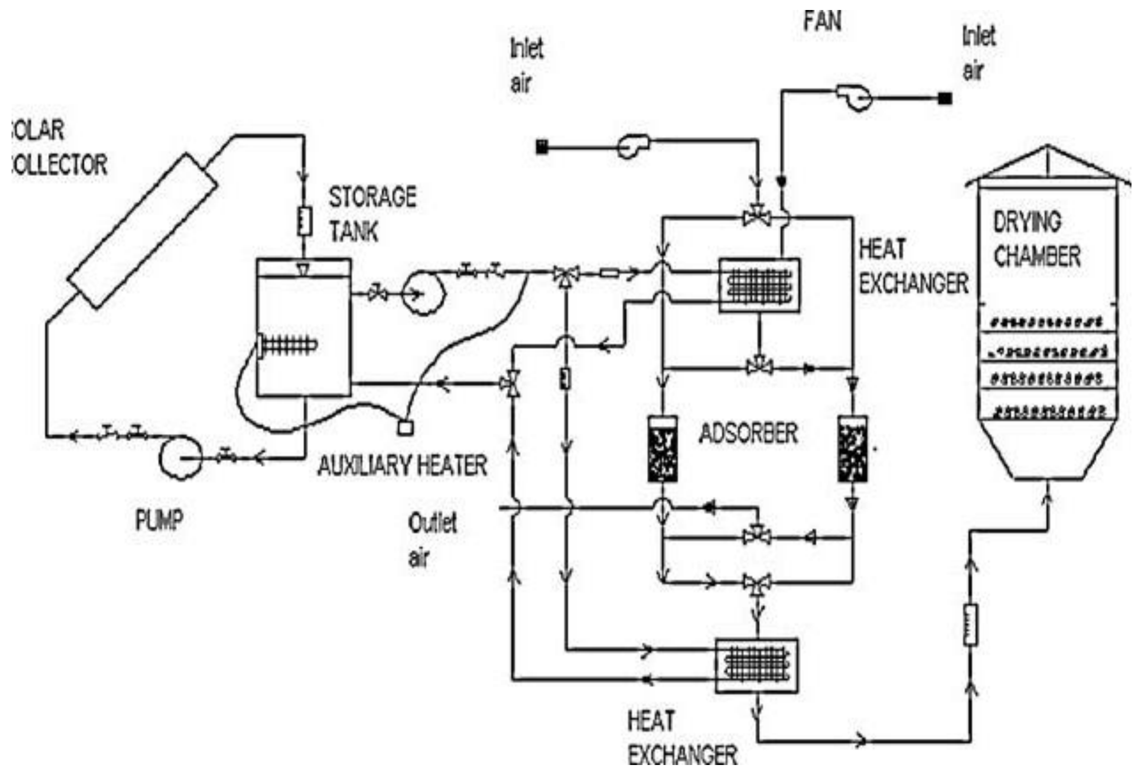


Figure 8: Schematic diagram of the solar assisted dehumidification system

Source: [14]

### 2.9 PV-Ventilated Solar Greenhouse Dryer System

Janja*et al*. reported the experimental performance of a PV-ventilated solar greenhouse dryer for drying of chilies [15]. The designed greenhouse dryer consist of a concrete floor with an area of 5.5 × 8.0 $m^2$ [15]. It is covered with transparent polycarbonate plates designed in the parabolic shape to facilitate the construction. Three fans powered by asolar cell module of 53 W were used to ventilate the dryer. The structure of the greenhouse is shown in Figure 9. To investigate its performance, [15] ensured that the dryer was used to dry 4batches of chilies with air temperature inside the dryer at range of 60-65 °C at the noon of a clear day. High drying air temperature with reasonablylow relative humidity inside the dryer during almost whole period of the day demonstrated the potentiality of solar drying inside the greenhouse dryer. The temperatures at three locations (top, middle and bottom) inside the dryer follow the similar pattern [15]. Heat stored in the concrete floor helped to reduce variation of drying air temperature due to the fluctuation of solar radiation. The use of solar cell module helps to regulate indirectly the drying air temperature. The results from the experiments demonstrate that the drying time fordrying of 100-150 kg of chilies in the dryer was significantly less than that required for natural sun drying but the drying efficiency increases with loading capacity [15].

Janjai*at al*. in their study presented the experimental and simulated performance of a PV-ventilated solar greenhouse dryer for drying of peeled longan and banana [16]. While investigating the experimental performances of the solar greenhouse dryer for drying of peeled longan and banana, 10 full scale experimental runs were conducted. Five experimental runs were conducted for drying of peeled longan and another five experimental runs were conducted for drying of banana. The drying air temperature varied from 31 °C to 58 °C during drying of peeled longan while it varied from 30 °C to 60 °C during drying of banana [16]. The drying time of peeled longan in the solar greenhouse dryer was 3 days, whereas 5–6 days are required for natural sun drying under similar conditions. The drying time of banana in the solar greenhouse dryer was 4 days, while it took 5–6 days for natural sun drying under similar conditions. The quality of solar dried products in terms of color and taste was high-quality dried products. A system of partial differential equations describing heat and moisture transfer during drying of peeled longan and banana in the solar greenhouse dryer was developed and this system of nonlinear partial differential equations was solved numerically using the finite difference method [16]. The numerical solution was programmed in Compaq Visual FORTRAN version 6.5 [16]. The simulated results reasonably agreed with the experimental data for solar drying of peeled longan and banana. The picture of the PV-ventilated solar greenhouse dryer system is as shown in Figure 9.

Figure 9:The greenhouse solar dryer.

Source: [15]

## 2.10 Photovoltaic/Thermal solar collector (PV/T) Drying System

A hybrid photovoltaic-thermal (PV/T) greenhouse dryer of 100 kg capacity was designed and constructed at Solar Energy Park, Indian Institute of Technology, New Delhi), India. The developed dryer was used to dry the Thompson seedless grapes (Mutant: Sonaka) [17]. The hybrid photovoltaic-thermal (PV/T) integrated greenhouse (roof type even span) dryer has been developed having floor area of 2.50 m × 2.60 m, 1.80 m central height and 1.05 m side walls height from ground and 30° roof slope. The greenhouse dryer has been integrated with two PV modules (glass to glass; dimensions: 1.20 m × 0.55 m × 0.01 m; 75 Wp each) on south roof of the dryer. The PV module produces DC electrical power to operate a DC fan (inner diameter = 0.080 m, outer diameter = 0.150 m) for forced mode operation and also provides thermal heating of greenhouse environment.

Various hourly experimental data namely moisture evaporated, grape surface temperatures, ambient air temperature and humidity, greenhouse air temperature and humidity, etc. were recorded to evaluate heat and mass transfer for the proposed system. It has been found that the value of the convective heat transfer coefficient for grapes (GR-I) lies between 0.26 and 0.31 $W/m^2K$ for greenhouse and 0.34–0.40 $W/m^2K$ for open conditions, respectively and that for grapes (GR II) lies between 0.45–1.21 $W/m^2K$ for greenhouse and 0.46–0.97 $W/m^2K$ for open conditions, respectively [17]. The Pictorial representation of the hybrid photovoltaic-thermal (PV/T) integrated greenhouse dryer designed by Barnwal and Tiwari is shown in Figure 10.


Figure 10:Hybrid photovoltaic-thermal (PV/T) integrated greenhouse dryer

Source: [17].

## 2.11 Biomass Hybrid Solar Dryer

Drying of Cashew nut to remove test is one of the most energy-intensive processes of cashew nut process industry. For this reason,Saravanan*et al*.designed and fabricated a hybrid dryer consisting of a solar flat plate collector, a biomass heater and a drying chamber as shown in Figure 11 [18]. 40 kg of Cashew nut with initial moisture of 9 % is used in the experiment. The performance test of the dryer is carried out in two modes of operation: hybrid-forced convection and hybrid-natural convection. Drying time and drying efficiency during these two modes of operation are estimated and compared with the sun drying. The system is capable of attaining drying temperature between 50º and 70ºC. In the hybrid forced drying, the required moisture content of 3% is achieved within 7 hours and the average system efficiency is estimated as 5.08%. In the hybrid natural drying, the required moisture content is obtained in 9 hours and the average system efficiency is 3.17% [18]. The fuel consumption during the drying process is 0.5 kg/hr and 0.75 kg/hr for forced mode and natural mode, respectively. The drying process in the hybrid forced mode of operation is twice faster than the sun drying. The dryer can be operated in any climatic conditions: as a solar dryer on normal sunny days, as a biomass dryer at night time and as a hybrid dryer on cloudy days. Based on the experimental study, it is concluded that the developed hybrid dryer is suitable for small scale cashew nut farmers in rural areas of developing countries.

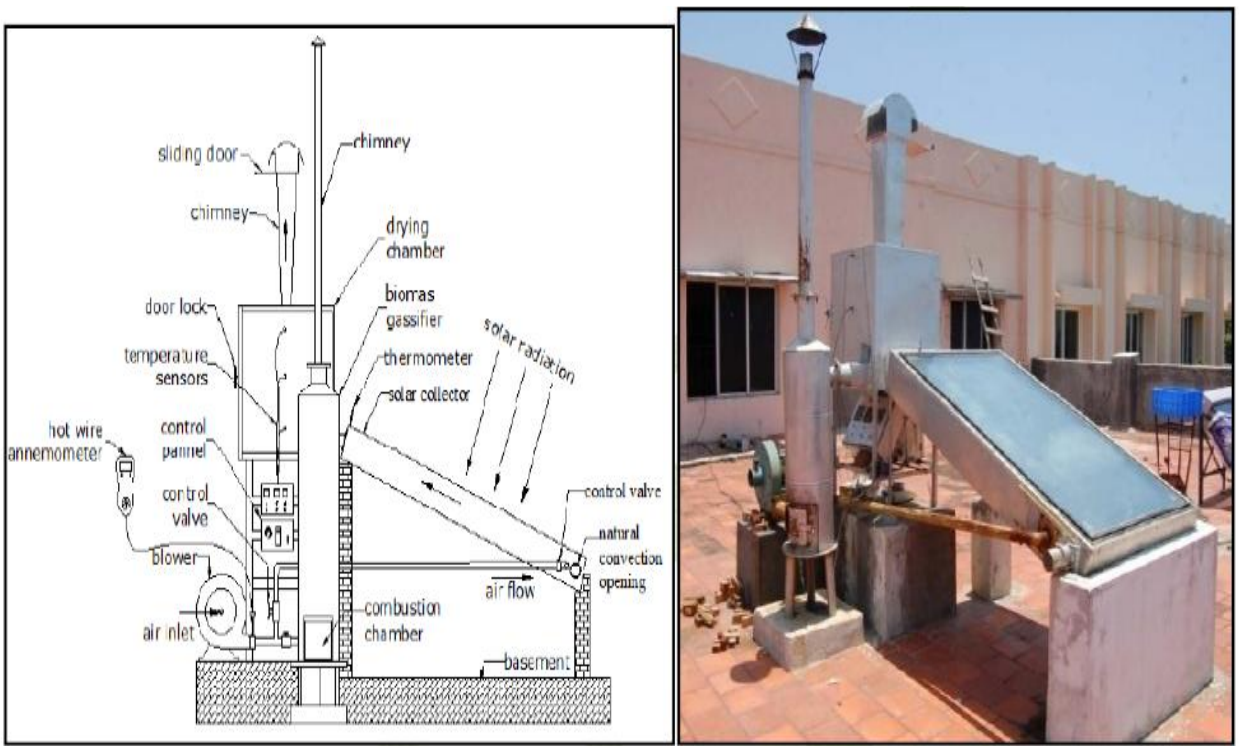


Figure 11: Biomass Hybrid Solar dryer

Source: [18].

## 2.12. Advantages of Hybrid Solar Dryers

Drying is often considered to be an energy-intensive and cost effective method to improve the storability of various types of agricultural products. In order to reduce amount moisture content in agricultural materials, likewise to prevents the risk of microorganism growth and to minimizedeteriorative reactions such as enzymatic reactions, non-enzymatic browning, and oxidation of lipids and pigments, most efficient solar drying system should be considered [17], [19]. Among numerousavailable methods, hybrid solar dyer is the most professional and economical means of drying biological materialsmostly bycommercial farmers[20], [21]. In order to derive a highly desirable dried products, several hybrid drying systems such as the greenhouse dryer [15], [22], [23], [24], [17] and the hybrid solar dryer [4], [25], [26], [5], [18]have been introduced. These systems are faster, more efficient, and more hygienic, resulting in lower crop losses relative to the traditional open-air sun drying and Indirect and direct solar drying methods [27], [28], [29],[30]. To obtain the desired quality and assure a good return for the producers, however, the systems must be properly designed and scaled to meet the requirements of specific crops and environments.

## 3. CONCLUSION

This review paperfocused on hybrid solar dryers. A comprehensive study of how hybrid solar dryers farecompared to other dryers, various design modifications and enhancement techniques applied to them is done.In this paper, various new improvements to hybrid dryers are also discussed. The Hybrid dryers are the mostcost-effective type of dryers and are mostly easy to fabricate and use. Hybrid solar dryers uses auxiliaryequipment and protects the products from external contamination and it can use in unfavorable weathercondition and also it is used in night time. These are the simplest form of dryers and are easy to fabricate, useand cost-effective.

**References**


[1] Tiwari, A and Jain, S. (2016). A review on Solar Drying of Agricultural Produce.*Journal of Food Processing and Technology*. 7(9):1-12.

[2] Jairaj, K.S., Singh, S.P. and Srikant, K. (2009). A review of solar dryers developed for grape drying. *Solar Energy*, 83(9):1698-1712.

[3] Ekechukwu, O.V and Norton, B. (1999). Review of solar-energy drying system II: An overview of solar drying technology. *Energy Conversion and Management*.40: 615-655.

[4] Aduewa, T.O., Oyerinde, A.S. and Olalusi, A.P. (2019). Development of an Automated Solar Powered Hot-air Supplemented Dryer. *Asian Journal of Advances in Agricultural Research*. 11(3):1-14.

[5] Aduewa, T.O., Ogunlowo, A.S. andOjo, S.T. (2014). Development of Hot-Air Supplemented Solar Dryer for White Yam (*DioscoreaRotundata*) Slices. *IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)* 7(12) II: 114-123.

[6] Banout, J., Ehl, P., Havlik J., Lojka, B., Polesny, Z. and Verner, V. (2011). Design and performance evaluation of a double-pass solar drier for drying of red chilli (*Capsicum annuum L*.). *Solar Energy* 85:506–525.

[7] Bhuiyan, M.H.R., Alam M.M. and Islam M.N. (2011). The construction and testing of a combined solar and mechanical cabinet dryer,*Journal of Environment Science and Natural Resources*.4(2): 35-40.

[8] Boughali, S. and Bouchekima, B., Mennouche, D., Bouguettaia, H., Bechki, D. and Moussa, H. (2009). Crop drying by indirect active hybrid solar - Electrical dryer in the Eastern Algerian Septentrional Sahara. *Solar Energy.* 83(12):57-62.

[9] Gülşah, Ç. and Cengiz, Y. (2009). Design of a new solar dryer system with swirling flow for drying seeded grape*. International Communications in Heat and Mass Transfer*.36:984-990.

[10] Hawlader, M. and Jahangeer, K.A. (2006). Solar heat pump drying and water heating in the tropics. *Solar Energy.* 80. 492-499.

[11] Hawlader, M., Rahman, S. andJahangeer, K.A. (2008). Performance of evaporator-collector and air collector in solar assisted heat pump dryer. *Energy Conversion and Management*. 49. 1612-1619.

[12] Ogura, H. and Mujumdar, A. (2000). Proposal for a novel chemical heat pump dryer. *Drying Technology*. 18:(4-5).

[13] Ibrahim, M., Sopian, K., Daud, W.R.W. and Alghou, M.A. (2009). An experimental analysis of solar-assisted chemical heat pump dryer. *International Journal of Low-Carbon Technologies*, 4, 78–83.

[14] Yahya, M., Sopian, K., Wan Daud, W., Othman, M. and Yatim, B. (2009). Performance of a solar assisted dehumidification system for *CentellaAsiatica L*. *Proceedings of the 8th WSEAS International Conference on Power Systems.* 23-25.

[15] Janjai, S., Khamvongsa, V. and Bala, B.K. (2007). Development, design, and performance of a PV-Ventilated greenhouse dryer. *International Energy Journal.* 8. 249-258.

[16] Janjai, S.,Lamlert, N.,Intawee, P.,Mahayothee, B.,Bala, B.K., Nagle M. and Müller, J. (2009). Experimental and simulated performance of a PV-ventilated solar greenhouse dryer for drying of peeled longan and banana. *Solar Energy*. 83(9):1550-1565.

[17] Barnwal, P. and Tiwari, A. (2008). Design, construction and testing of hybrid photovoltaic integrated greenhouse dryer. *International Journal of Agricultural. Resources.*3 (2):110-120.

[18] Saravanan, D., Wilson, V. and Kumarasamy, S. (2014). Design and thermal performance of the solar biomass hybrid dryer for cashew drying. *Factauniversitatis - series Mechanical Engineering*. 12(3): 277-288.

[19] Kumar, A. and Tiwari, G.N.(2007). Effect of mass on convective mass transfer coefficient during open sun and greenhouse drying of onion flakes. *Journal of Food Engineering*. 79: 1337–1350.

[20] El Hage, H., Herez, A., Ramadan, M., Brazzi, H. and Khaled, M.(2018). An investigation on solar drying: a review with economic and environmental assessment. *Alternate Energy*. 157:815–829.

[21] Singh, P., Shrivastava, V. and Kumar, A.(2018). Recent developments in greenhouse solar drying: a review. *Renewable and Sustainable Energy Review*. 82(3): 3250–3262.

[22] Azaizia, Z., Kooli, S., Elkhadraoui, A., Hamdi, I. andGuizani, A.(2017). Investigation of a new solar greenhouse drying system for peppers. *International Journal of Hydrogen Energy*. 42(13):8816–8826.

[23] Hamdi, I., Kooli, S., Elkhadraoui, A., Azaizia, Z., Abdelhamid, F. and Guizani, A.(2018). Experimental study and numerical modeling for drying grapes under solar greenhouse. *Renewable Energy*. 127: 936–946.

[24] Iskandar, A.N., Ya'acob, M.E. and Anuar, M.S.(2017). Tropical field performance of dual-pass PV tray dryer. 3rdelectronic and green materials international conference. *AIP Conference Proceedings* 1885 (1), 020016.

[25] Amer, B.M.A., Gottschalk, K. and Hossain, M.A. (2018). Integrated hybrid solar drying system and its drying kinetics of chamomile. *Renewable Energy*.121: 539–547.

[26] Eltawil, M.A., Azam, M.M. and Alghannam, A.O. (2018). Energy analysis of hybrid solar tunnel dryer with PV system and solar collector for drying mint (*MenthaViridis*). *Journal of Cleaner Production*. 181, 352364.

[27] Muehlbauer, W. (1986). Present status of solar crop drying. *Energy in Agriculture* 5: 121–137.

[28] Chua, K.J. and Chou, S.K.(2003). Low-cost drying methods for developing countries. *Trends in Food Science Technology*. 14: 519–528.

[29] Karim, M.A. and Hawlader, M.N.A.(2004). Development of solar air collectors for dryingapplications. *Energy Conversion Management*. 45: 329–344.

[30] Tomar, V., Tiwari, G.N. and Norton, B.(2017). Solar dryers for tropical food preservation: Thermophysics of crops, systems and components. *Solar Energy*. 154: 2–13.