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Progress in hybrid greenhouse solar dryer (HGSD): A review

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Abstract. The world population reaches to about 7.7 billion in 2018 from 6.2 billion in 2000. This much growth in population results in increased energy demand and increased food supply. As the conventional energy sources are limited. These may deplete soon if consumed at this rate. So, the world is switching towards the utilization of non-conventional sources of energy. Energy from sun is the best method as it can not only solve the energy issue but also helps in meeting food demand by conserving it. Greenhouses are made for the purpose of food conservation. Various types of solar dryers are developed by researchers till now and still the effort is being putted to make them more efficient. Hybrid greenhouse is also effort toward utilization of solar energy in more efficient way. The paper presents the heat and mass transfer analysis of hybrid greenhouse solar dryer developed by different researchers till now. The review helps the researcher in understanding the heat and mass transfer taking place inside the hybrid greenhouse and how it can be further improved.

Keywords: hybrid; greenhouse; solar dryer; dryer development; dryer

1. Introduction

Need of food is one of the basic need of human being. With the increase in population, the food requirement also increases. The food requirement can be met either by growing more food or by conserving the produced one. The edible items (fruits, vegetables, cereals etc.) mostly get spoiled due to high moisture content in them.

The effective method to preserve the crop from being deteriorated is drying them upto a safe moisture level (Koyuncu *et al.* 2007). Solar drying is considered as the efficient method of using solar insolation (Selvanayaki and Sampath Kumar 2017, Chauhan *et al.* 2015, Janjai *et al.* 2007). Solar drying of crop prevents crop deterioration and helps in storing it for longer time (Fudholi *et al.* 2016). The dried produce has various advantages like better quality, low after harvest losses and longer storage time. The energy from the sun is clean source of energy and available in ample quantity (Kumar and Tiwari 2007). In comparison to available conventional sources, the solar

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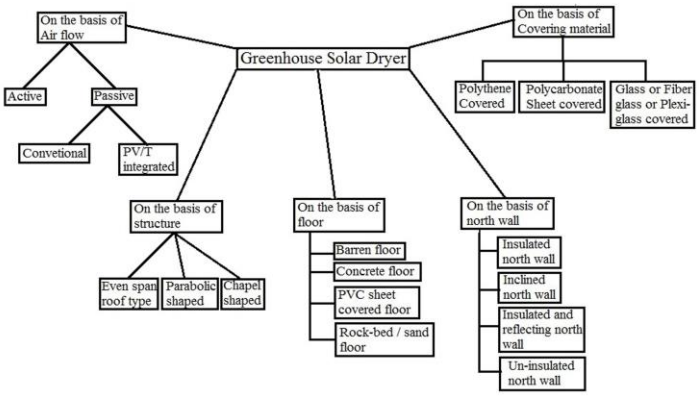


Fig. 1 Classification of greenhouse on various basis [9]

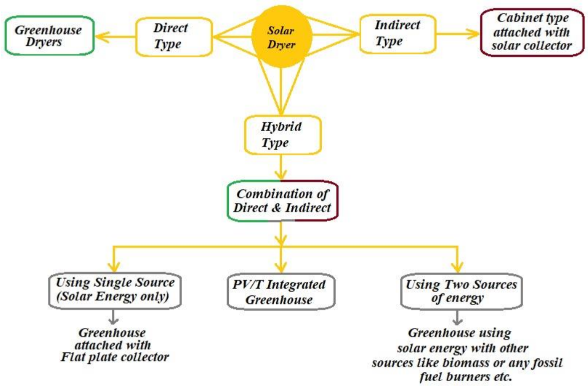


Fig. 2 Methods used for making greenhouse hybrid

systems emit low or even negligible carbon if used for space heating (Semple *et al.* 2017).

From ancient times, natural sun drying is used for drying crops and other non-agricultural produce (Vijaya Venkata Raman *et al.* (2012). The open sun drying requires less investment but the dried product contaminates easily by birds, insects, pest, dirt grit, rain etc. (ELkhadraoui *et al.*. 2015, Prakash and Kumar 2013, Kumar *et al.* 2013, Dhanore and Jibhakate 2014, Ramos Inês *et al.* 2015, Sallam *et al.* 2015). Various artificial dryers are developed providing required velocity and temperature in order to achieve good quality product in less time (Banout *et al.* 2011). But these dryers consume energy generated from conventional sources and are also not eco-friendly. Greenhouse dryers are emerges as a best way to utilize the solar energy for drying and space heating.

The greenhouses are named so because of their working principle i.e.,, on greenhouse effect. The enclosing material like glass, polythene, polycarbonate sheets etc. allows the short wavelength radiation coming from sun through it and traps the infrared or long wavelength radiations inside it. The temperature inside the greenhouse increases due to trapped radiations (Morad *et al.* 2017). Greenhouses can be used for various purposes like drying, aqua-culture, soil solarisation, crop cultivation, space heating etc. (Chauhan *et al.* 2016, Prakash and Kumar 2014). The greenhouse dryers are mostly used for drying agricultural produce but these are also used for drying non-agricultural products like rubber, paper, surgical cotton, sludge etc. (Sevda and Rathore 2010, Panwar *et al.* 2013, Jitjack *et al.* 2016, Belloulid *et al.* 2017). The greenhouses are basically direct type or hybrid type operating in active or passive mode. The further classification of greenhouse is given in Fig. 1 (Singh *et al.* 2018).

Active greenhouses operate by air forced or induced by some external means like fans blowers etc. Thus requiring extra energy for the operation of external devices, while the passive greenhouses do not requires any such devices. Due to density difference arising due to temperature change, the air moves naturally in passive dryers (Patil *et al.* 2009). In terms of cost, the passive dryers are preferred while for faster drying active dryers are preferred (Hossain and Bala 2007).

Direct type or greenhouse dryers operating in active or passive mode give better result in terms of quality, color, drying time etc. in comparison to open sun drying (Semple *et al.* 2017, Nayak *et al.* 2013). Various researches had taken place to improve the efficiency of greenhouse dryers like insulating north wall (Rathore and Panwar 2010, Sevda and Rathore (2010), Panwar *et al.* 2013, Prakash and Kumar 2014, Chauhan and Kumar 2017), using mirrors for reflecting infrared radiations (Sethi and Arora 2009), using thermal storage material in floor (Janjai *et al.* 2007, Sevda M.S. and Rathore 2010, Belloulid *et al.* 2017, Prakash *et al.* 2016, Ayyappan *et al.* 2016), etc. The hybrid dryers are also a step towards the utilization of solar energy in more efficient manner and improving the productivity of greenhouses. Simply a word hybrid means combination of two or more than two. So hybrid greenhouses are those which utilize two sources of energy or utilize single source (solar energy) using in different ways.

The review presents the advances carried out in the field of hybrid greenhouse solar dryers. As per our literature review, the methods by which the greenhouses are converted into a hybrid greenhouse are shown by Fig. 2. As per our literature survey, the greenhouses are converted into hybrid ones by three methods given below:

i) PV/T integrated greenhouse solar dryers
ii) Greenhouse attached with solar collectors
iii) Greenhouse attached with other air heating devices like biomass or any other fossil fuel burners

2. Researches in hybrid greenhouse solar dryer

Various researches have taken place till now in the field of hybrid greenhouses. The advances in this field are listed below:

2.1 PV/T integrated HGSD

Barnwal and Tiwari (2008) developed the PV/T integrated HGSD at Indian Institute of Technology, New Delhi, India. The dryer was even span roof type having 6.5 m^2 floor area and enclosed with polyethylene sheet as shown in Fig. 3. DC fan powered by PV modules is used to force air inside the dryer. Matured (GR-II) and pre-matured (GR-I) grapes are dried in open sun and in drier and the observations were compared. The heat transfer coefficient for GR-II type is higher than GR-I type.

Barnwal and Tiwari (2008) carried out the test on the same dryer as shown in Fig. 3 using thermal loss efficiency factor. The dryer is tested in no-load under forced as well as natural

Fig. 3 PVT integrated HGSD

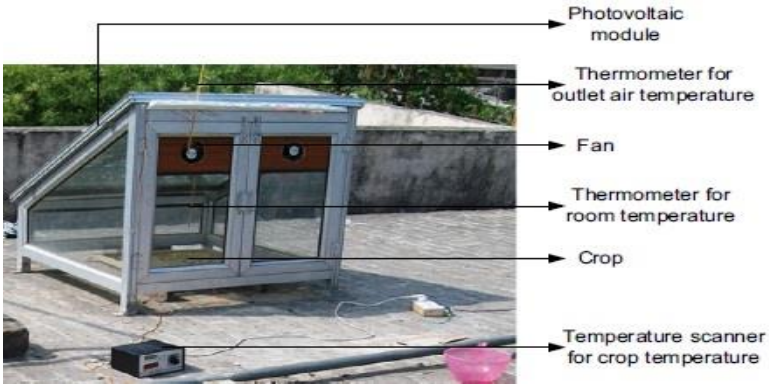
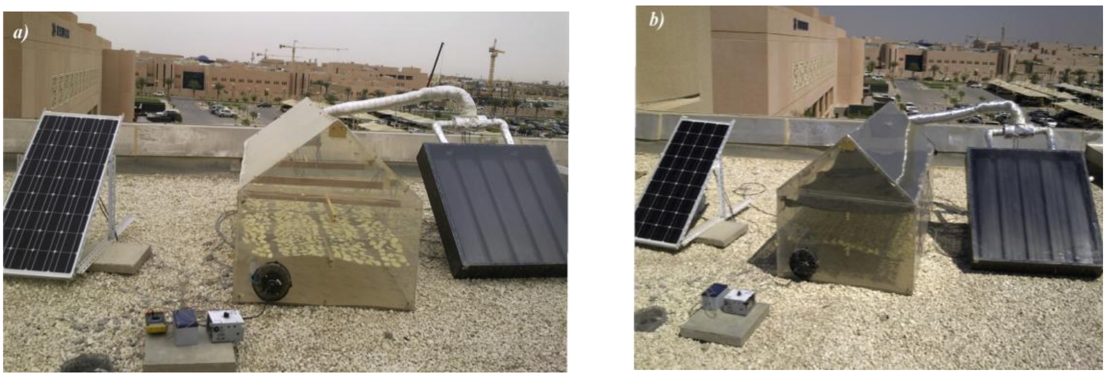


Fig. 4 The pictorial view of developed HGSD



(a) (b)

Fig. 5 Greenhouse attached with flat-plate collector and PV panel (a) without thermal curtain and (b) with thermal curtain

convection mode. The thermal loss efficiency was observed higher in forced mode.

Tiwari *et al.* (2016) developed the PV/T integrated mixed mode hybrid dryer at Indian Institute of Technology, New Delhi, India. The developed HGSD is shown in Fig. 4. The dryer had a floor

Table 1 PV/T Integrated HGSD

S. No.	Authors	Type	Crop Dried	Remarks
1	P. Barnwal and G.N. Tiwari (2008)	PV/T integrated greenhouse solar dryer	Thompson seedless grapes	Moisture evaporation in natural convection was found better than in forced convection. The convective heat transfer coefficient for GR-II (matured) type grapes was higher than GR-I type (pre-mature) and thus takes less time for drying.
2	P. Barnwal and Arvind Tiwari (2008)	PV integrated hybrid Greenhouse dryer	----	The proposed dryer has been tested in terms of thermal loss efficiency factor.
3	Sumit Tiwari, G.N. Tiwari, I.M. Al-Helal (2016)	Greenhouse mixed mode solar dryer	Grapes	Developed thermal modeling for various parameters of developed dryer and uses MATLAB 2013a for numerical computations. Thermal energy and exergy was also calculated.
4	Mohamed A. Eltawil, Mostafa M. Azam, Abdulrahman O. Alghannam (2018)	PV powered Mixed-mode solar tunnel dryer	Potato Chips	The dryer performance was evaluated under with and without load with varying airflow rate and with and without thermal curtain.
5	Sujata Nayak, Ajit Kumar, Jaya Mishra and G. N. Tiwari (2011)	PVT integrated greenhouse dryer	Mint	Dried and tested various samples of mint. Also calculated dryer efficiency, earned carbon credit and carbon mitigation.

area of 1.066 m^2 and enclosed with 3mm glass. Two DC fans operated by PV panels were provided for forced circulation of air. MATLAB 2013a was used for numerical computation of thermal models developed considering parameters like temperature of crop, greenhouse, PV module etc.

Eltawil *et al.* (2018) developed the tunnel type dryer attached with flat-plate collector and PV panels at King Faisal University, Saudi Arabia. The tunnel was even span roof type having floor area of 2 m^2 and enclosed with plexiglass of thickness 2mm. Fig. 5 shows the developed solar tunnel hybrid dryer. The dryer was tested with and without load and also with and without thermal curtain. The potato was dried inside the dryer with air flowing at different speeds. The drying efficiency reaches to maximum value of 34.29% at air flow rate of 0.0786 kg/s with thermal curtain above the potato slices.

Nayak *et al.* (2011) evaluate the performance of dryer by drying various samples of mint. In the time period of 21 hours, the mint was dried from 80% (wb) to 11% (wb) moisture content. The dryer had an efficiency of about 34.20%. The CO_2 mitigation and carbon credit earned by the dryer in its lifetime was also evaluated.

Table 1 is provided for the brief description of the PV/T integrated HGSD developed by various researches.

2.2 Greenhouse attached with solar collectors

Zaineb Azaizia *et al.* (2017) developed the hybrid greenhouse at Research and Technology Centre of Energy in North of Tunisia. The dryer had floor area of 14.8 m^2 and central height of 3 m. The plexiglass enclosed dryer was attached with solar collector having area 2 m^2. Fig. 6 shows

Fig. 6 Greenhouse dryer attached with flat plate collector

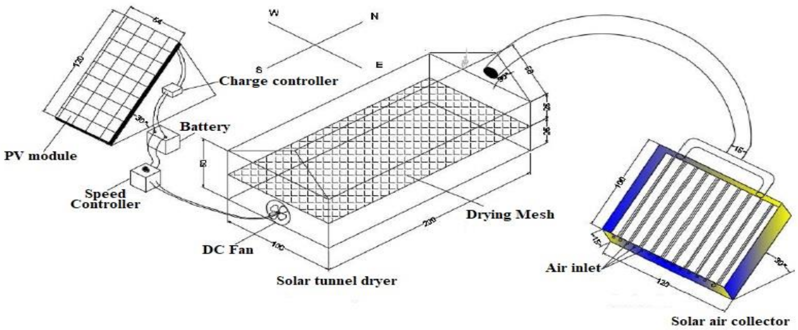


Fig. 7 Schematic diagram of greenhouse attached with solar collector and PV module

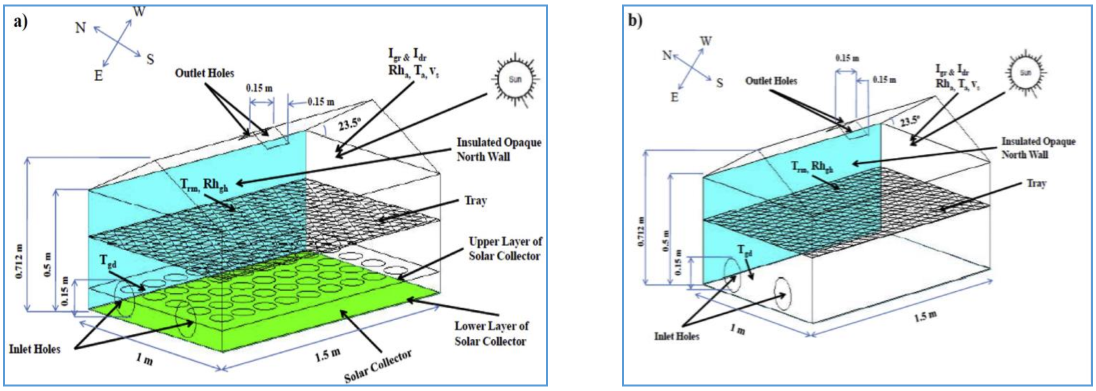
the developed HGSD with flat plate collector. TRNSYS program was used to develop the mathematical model for the proposed system. The effect of air flow rate, collector and drying area on the humidity and temperature inside the greenhouse was studied. Result shows that the optimum collector area was 2 m^2 with optimum air flow rate of 250 kg/h and optimum drying area of 40 m^2.

Eltawil *et al.* (2018) developed the tunnel type dryer attached with flat-plate collector and PV panels at King Faisal University, Saudi Arabia. The schematic diagram of developed hybrid dryer is shown in Fig. 7. The peppermint is dried inside the dryer in one, two and three layers for evaluating dryer performance. The maximum drying time was 360 min inside dryer while 420 min in open sun. Use of thermal curtain gives better quality mint as compared to natural sun drying. The dryer had an efficiency of 30.71% and energy payback period of 2.06 years.

ELkhadraoui *et al.* (2015) carried out the economic analysis and performance evaluation on the dryer as mentioned in Fig. 6. The dryer operates in forced convection mode and used for drying red peppers and grapes. The dryer payback time was 1.6 years. Result shows that the drying time for grapes and red pepper was 50 hours and 17 hours respectively inside the dryer while it was 67 hours and 24 hours respectively in open sun.

Pranav Mehta *et al.* (2018) constructed a hemi-cylindrical shaped greenhouse dryer attached with flat-plate collector at CSIR-Central Salt & Marine Chemicals Research Institute, Gujarat, India. The photograph of the developed HGSD is shown in Fig. 8. Fish was dried inside the dryer to test its performance. In order to predict the collector outlet temperature, mathematical model was developed and them solved by SageMath programming language. The drying time of fish was 18 hours inside the dryer while it takes 38 hours in open sun.

Fig. 8 Rack-type HGSD attached with flat-plate collector



(a) (b)

Fig. 9 Schematic representation of HGSD (a) with collector and (b) without collector

Table 2 Greenhouse attached with solar collectors

S. No.	Authors	Type	Crop Dried	Remarks
1	Zaineb Azaizia, Sami Kooli, Aymen Elkhadraoui, Ilhem Hamdi, AmenAllah Guizani (2017)	Flat plate solar air collector integrated greenhouse solar dryer	Red peppers	TRNSYS was used for simulation of solar drying system. The effect of the area of the product to be dried, airflow rate and collector area on the drying kinetics was studied.
2	Mohamed A. Eltawil, Mostafa M. Azam and Abdulrahman O. Alghannam (2018)	Flat plate solar collector integrated tunnel dryer	Peppermint	The thermal performance of developed hybrid tunnel dryer is evaluated by drying one, two and three layers of mint and compared the result obtained from open sun drying result.
3	Aymen ELkhadraoui, Sami Kooli, Ilhem Hamdi, Abdelhamid Farhat (2015)	Flat plate solar collector integrated chapel-shaped greenhouse	Red pepper and Grape	Performance evaluation of developed dryer had been and compared with open sun drying. Economic analysis of dryer had also been done.
4	Pranav Mehta, Shilpa Samaddar, Pankaj Patel, Bhupendra Markam, Subarna Maiti (2018)	Flat plate solar collector integrated greenhouse dryer	Bombay Duck Fish	Evaluated the performance of developed hybrid dryer. Aldo develops the mathematical model using SageMath programming language for calculating temperature at collector outlet and developing energy balance equation.
5	Prashant Singh Chauhan and Anil Kumar (2016)	Greenhouse integrated with solar collector at the ground	----	The proposed dryer has been tested with and without solar collector at the ground keeping north wall insulated in both cases.

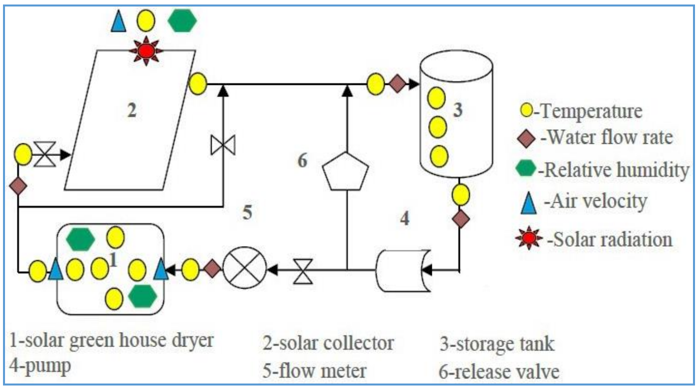


Fig. 10 Block diagram of proposed hybrid setup

Fig. 11 The fabricated HGSD attached with biomass burner

Singh Chauhan and Kumar (2016) constructed the north wall insulated greenhouse at Energy Centre, Maulana Azad National Institute of Technology, Bhopal, India. The greenhouse was tested with and without solar collector at the ground of the dryer. Fig. 9 shows the schematic diagram of the dryer with and without collector. The dryer was operated in passive mode and tested in no-load condition. The dryer performance in terms of heat utilization factor, coefficient of performance (COP), heat loss factor (HUF) etc. were calculated. The result shows that the dryer with solar collector has better HUF and COP.

Table 2 gives the brief description of the greenhouses attached with flat-plate solar collector developed by various researchers.

2.3 Greenhouse attached with other air heating devices

Deeto *et al.* (2017) developed a greenhouse attached with solar collector and heat storage unit at King Mongkut's University of Technology, Bangkok, Thailand. The floor area of the dryer was 0.3 m^2 and mounted on a black PVC sheet. The block diagram of the proposed hybrid setup is shown in Fig. 10. A water storage tank of 180 liter capacity and insulated with polyurethane foam was attached to the dryer for storing hot water. The result shows that the coffee beans were dehumidified from 55% to 12% (wb) in 12 hours. Also investigate the model suitable for coffee drying.

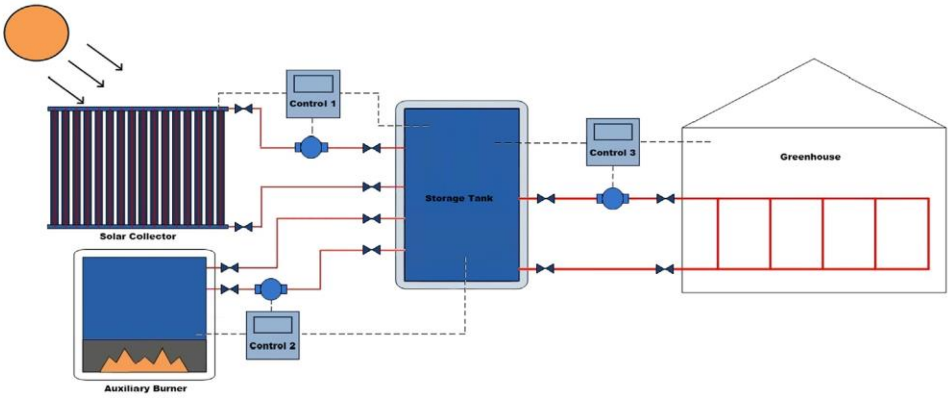


Fig. 12 The schematic diagram of proposed hybrid dryer

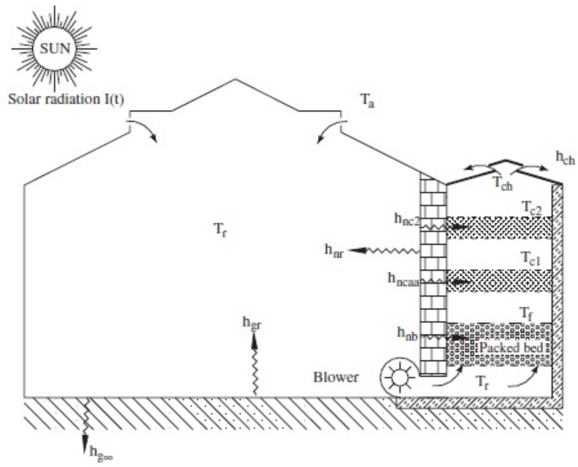


Fig. 13 The schematic view of greenhouse with separate drying chamber

Hamdani *et al.* (2018) manufactured the tunnel type greenhouse dryer attached with biomass burner at Samudra University, Aceh, Indonesia. The fabricated picture of the developed hybrid dryer is shown in Fig. 11. The drying area was 2.08 m^2 and dryer was covered with transparent plastic sheet. The Queenfish was dried for evaluating the dryer performance. Wood was used as fuel for supplying hot air during off-sunshine hours. Result shows that in 15 hours only the fish was dried to 12 % moisture level. Also economic analysis of the dryer was also carried out.

Kıyan *et al.* (2013) proposed a hybrid setup consisting of greenhouse attached with hot water storage unit and fossil fuel heater. The schematic representation of the proposed setup is shown in the Fig. 12. The mathematical model had been developed for the proposed setup. The models are solved by simulation software MATLAB/Simulink. A case study had been done on the greenhouse at Aılım University, Ankara, Turkey to check the feasibility of the developed models.

Jain (2005) developed a hybrid solar dryer in which the tray type dryer including thermal storage material at the bottom was attached to the north wall of the greenhouse. The schematic diagram of the greenhouse attached with separate drying chamber is shown in Fig. 13. During sunshine hours, the hot air from greenhouse is supplied to the drying chamber through blower

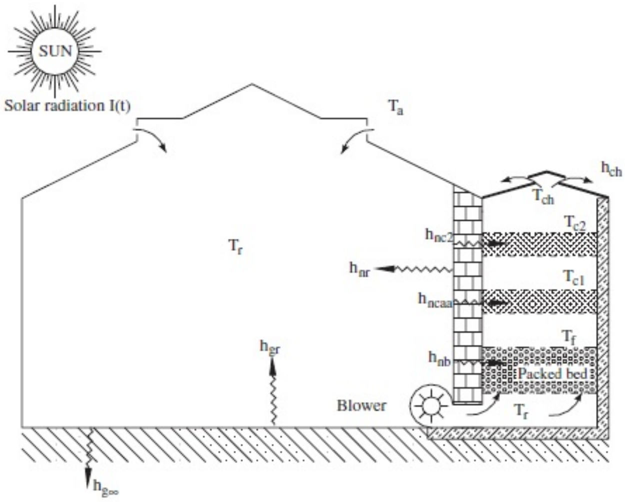


Fig. 13 The schematic view of greenhouse with separate drying chamber

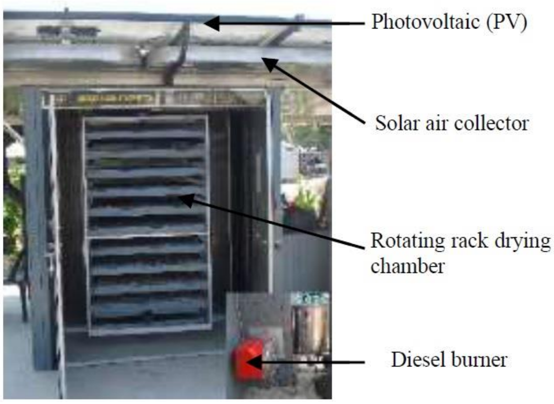


Fig. 14 Hybrid greenhouse attached with diesel burner

Fig. 15 Rack-type greenhouse attached with biomass burner

Fig. 16 Hybrid dryer integrated with LPG burner

Fig. 17 HGSD attached with blower and LPG burner

while during off sun shine hours the heat stored in the thermal storage material was used for drying. The greenhouse had floor area of 24 m^2. Thermal model was developed to study the effect of size and mass flow rate of air on the crop temperature.

Fudholi *et al.* (2016) developed the hybrid dryer incorporating solar collector, PV panels and diesel burner. The developed dryer is located at Johor, Malaysia. Fig. 14 shows the developed hybrid dryer. Silver Jewfish was dried inside the dryer in order to determine the energy and exergy of the dryer. Result shows that fish was dried from 64% to 10% (wb) in 8 hours. Also the exergy efficiency lies in the range of 17-44%.

Aritesty and Wulandani (2014) developed the rack-type greenhouse solar dryer attached with biomass burner at Faculty of Agricultural Technology, Bogor, Indonesia. The dryer consist of 144 trays and 3 blowers. Fig. 15 shows the developed rack-type HGSD. Wild ginger was dried to test the dryer performance. The dryer was tested in no-load and also in two load condition i.e., 21 kg and 60 kg. Result shows that drying time and drying efficiency increases with increase in load.

Janjai (2012) constructed the parabolic shaped greenhouse attached with LPG gas burner at

Table 3 Greenhouse attached with other air heating devices

S. No.	Authors	Type	Crop Dried	Remarks
1	S. Deeto, S. Thepa, V. Monyakul and R. Songprakorp (2017)	Greenhouse solar dryer attached with hot water storage system	Coffee beans	Experimental analysis was done on developed greenhouse. Hot water storage system was provided to store and supply thermal energy during off sunshine hours.
2	Hamdani, T.A. Rizal, Zulfri Muhammad (2018)	Solar-biomass hybrid dryer	Queenfish	Manufactured and tested the developed solar dryer attached with biomass fueled air heater.
3	Metin Kıyan, Ekin Bingöl, Mehmet Melikoğlu, Ayhan Albostan (2013)	Greenhouse attached with evacuated tube collector, fossil fuel heating unit and hot water storage unit	----	Mathematical modeling and simulation of proposed hybrid system has been done using MATLAB/simulink.
4	Dilip Jain (2005)	Greenhouse attached with crop dryer having packed bed thermal storage	Onion	Studied the effect of length, breadth and mass flow rate on the crop temperature.
5	Ahmad Fudholi, Rado Yendra, Dayang Fredalina Basri, Mohd Hafidz Ruslan, Kamaruzzaman Sopian (2016)	Greenhouse incorporating drying chamber with diesel burner	Salted silver Jewfish	Carried out the energy and exergy analysis of the proposed hybrid setup.
6	Elsamila Aritesty and Dyah Wulandani (2014)	Greenhouse incorporating rack type solar dryer with biomass burner	Wild Ginger	Test the performance of the proposed dryer in no-load and also tested it at two different capacities.
7	Serm Janjai (2012)	Greenhouse attached with LPG gas burner	Tomato	Carried out the performance analysis of dryer and also develops the differential equations for heat and mass transfer taking place during tomato drying.
8	Yefri Chan, Nining Dyah and Kamaruddin Abdullah (2015)	ICDC Solar dryer with LPG burner	Rough Rice	Carried out the performance analysis of proposed dryer.

Nakhon Pathom, Thailand. The dryer had floor area of 160 m^2 and enclosed with polycarbonate sheet. Nine DC fans operated by PV panels were provided to main air circulation. The HGSD integrated with LPG burner is shown in Fig. 16. Maximum temperature inside the dryer was 65 °C. Result shows that the tomatoes were dried from 54% to 17% (wb) in 4 days. Partial differential equations for the heat and mass transfer taking place inside the dryer were also developed.

Chan *et al.* (2015) developed an integrated collector drying chamber (ICDC) type solar dryer integrated with LPG burner. The developed HGSD with different component attached is shown in Fig. 17. The dryer performance was tested with two different loads i.e., 104 kg and 200 kg rough rice. Result shows that the drying time and drying efficiency increases with increase in load.

Table 3 gives the brief description of the greenhouses attached with air heating devices like biomass burner or any other fossil fuel burner in order to make it hybrid.

3. Conclusions

The entire world is focusing toward the utilization of energy given by sun i.e., solar energy. Various researchers had done a lot work in the field of harnessing the solar energy for the space heating and drying purpose. Various researches have published till now showing the advancement in greenhouses. The hybrid greenhouse is an effort toward utilization of solar energy in better way and improves the efficiency of the greenhouse. From the literature review it can be conclude that:

- Hybrid greenhouse results in faster drying rate along with maintaining the quality and nutritious value of the product.
- Among the three methods mentioned above, the greenhouse attached with auxiliary heating source gives better result as it can be used in off sunshine hours also.
- For small scale drying, solar collector integrated HGSD under natural convection are better as they give faster drying with less investment.
- The cost of greenhouse becomes higher by making it hybrid but that can be recovered by drying more quantity in lesser time.

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