International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
www.chemijournal.com
IJCS 2021; 9(1): 1781-1785
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Received: 20-10-2020
Accepted: 30-12-2020

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Performance evaluation of hybrid photovoltaic/thermal solar system combined with greenhouse for drying of rose flower

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DOI: https://doi.org/10.22271/chemi.2021.v9.i1y.11484

Abstract
A study was conducted to evaluate the performance of Hybrid Photovoltaic/Thermal (HPV/T) solar system combined with a greenhouse dryer and air cooling arrangements. The experiments were carried out in warm and humid climatic condition of Odisha, India for the winter and summer months during the year 2020. The enhancement in the electrical efficiency of the solar panel was studied by lowering its temperature during the operating period with the help of extracting absorbed heat energy from its back surface through an air cooling arrangement. The extracted heat energy in this study, was utilized in a low thermal energy consuming application such as greenhouse heating for drying of rose flower. It was observed that the temperatures of solar panel were decreased in the range of 9-12 ˚C and its efficiencies were increased in the range of 8-14% respectively in forced air cooling system compared to without cooling in clear sunny days. The reduction in moisture contents of the rose flower compared to fresh flower was about 67-73% in HPV/T greenhouse drying, 54-61% in greenhouse drying alone and 32-41% in open sun drying in 3 days' duration of drying. The colour, appearance and texture of the flower were also maintained in HPV/T greenhouse drying for its marketability in International market.

Keywords: Solar photovoltaic system, cooling of solar photovoltaic panel, electrical efficiency of solar photovoltaic panel, greenhouse drying of rose flower

Introduction
Hybrid Photovoltaic/Thermal (HPV/T) solar system is at present gaining more importance among the researchers, users and entrepreneurs in order to enhance the electrical efficiency of the solar panel by lowering its temperature during the operating period with the help of extracting absorbed heat energy at its back surface through various cooling devices (Ali *et al.* 2017 and Ganiyu *et al.* 2020) [2, 5]. The extracted heat energy is utilized in low thermal energy consuming applications such as greenhouse heating, crop drying, water heating, thermo-electric power generation etc. This practice can easily be accomplished by the users without much cost involvement with the dual advantages of improving the electrical efficiency of the panel and to utilize the unused thermal energy in a productive and sustainable manner (Dubey *et al.* 2020 and Nayak and Tiwari 2008) [4, 7]. This type of effort is also under the control of the user. Crop drying has got more relevance through the above practice especially providing warm air produced with the help of the integrated air cooling techniques compared to water cooling arrangement, which needs more complex structure and incurs more expenditure (Gupta *et al.* 2020, Agarwal *et al.* 2018 and Barnwal and Tiwari 2008) [6, 1, 3]. Hence, attempt has been made in this study, to utilize the extracted thermal energy by air cooling device for drying of a high value crop i.e. rose flower by coupling a greenhouse with the solar PV system for rapid and efficient drying of flower when kept inside it. The (HPV/T) solar greenhouse drying system has therefore been developed and evaluated for drying, one of the most perishable horticultural produces i.e. rose flower which has got more commercial value both in the national and international markets in its dried and packaged form for earning a good income through this venture.

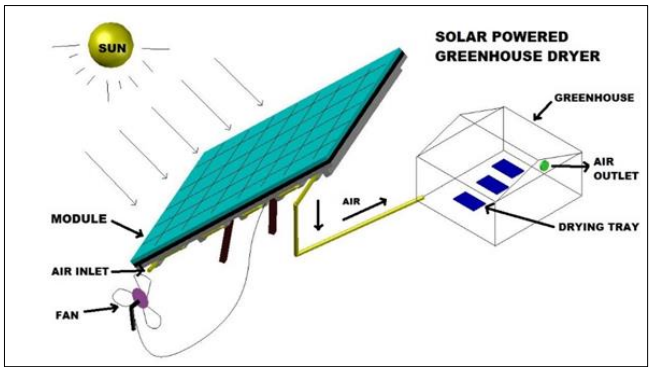
In floriculture trade, fresh flowers constitute a major part but due to their reduced shelf-life, flowers remain fresh only for a short duration. Therefore, to overcome this problem, techniques of dehydration and drying play a vital role. Dried flowers and plant parts constitute 70% of the total share of the export of the floricultural produces from India (Rani and Reddy

2015, Pachpinde *et al.* 2019) [9, 8]. However, the country's share in dry flower industry is below 5% of the global market. Drying leads to reduced microbial activity and ageing effect. The dried flowers can be stored in moisture-free atmosphere for longer periods without losing their appearance and decorative value (Ugale *et al.* 2016) [10]. Thus, the availability of flowers need not be dependent on seasons. Only a few research and development works have been undertaken in the flower drying industry across the globe, in contrast to other areas of floriculture, due to the unavailability of improved dryers. The demand for dry flower and attractive plants (dried part) for floral arrangement and floral crafts has increased manifold during the last decade. The demand for dry flowers is also increasing at an impressive rate of 8–10% annually, thus offering good opportunity for Indian entrepreneurs to enter into the global floriculture trade. Dry flowers that are nearer to their natural form, dried and preserved, have a good market value that can be cherished for longer periods and require little care. Dry flower market has grown exponentially as consumers have become 'eco-conscious', and choose dried flowers because they are eco-friendly and a biodegradable alternative to fresh flowers. There is large potential to develop the dry flower industry in India and to provide employment to housewives, unemployed youths and rural women. Simplified indigenous techniques have been developed by which flowers, branches, twigs, foliage, etc. retain their freshness for several months or even years. The original shape, colour and size before dehydration are retained, thus, making them highly suitable raw materials for interior decoration. Dehydrated flowers and foliage can be used for designing artistic decorative items, e.g. greeting cards, wall plates, calendars, landscapes, etc.

The present study has therefore been focused on the development of a cost-effective and small capacity hybrid photovoltaic/thermal (HPV/T) solar greenhouse dryer for enhancing the efficiency of panel as well as drying of a high-value flower by using the extracted thermal energy from the back side of the solar panel through air cooling arrangement. The HPV/T system has been designed to improve the electrical efficiency of the panel and simultaneously providing warm air into the greenhouse for drying of rose flower in this study. The temperatures of the panel need to be reduced for enhancing its efficiency and power output. The cooling system is therefore necessary to be included in the solar PV system to tackle this issue.

Materials and Methods

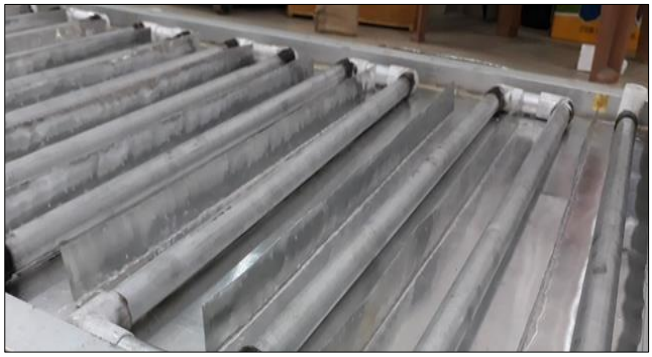
The experiments were conducted and the data were recorded in an interval of one hour from 9 am to 4 pm from December 2019 to April 2020 by installing the set up at the roof top of College of Agricultural Engineering and Technology, Bhubaneswar, Odisha (latitude 20.50˚N and longitude 85.81˚E). The place is coming under warm and humid climatic condition where the annual average rainfall is 1450 mm and average daily solar insolation is 4.8 kWh/m^2. During the course of investigation, important parameters recorded were solar radiation, ambient air temperature, wind velocity, relative humidity, voltage, current and power output from the solar panel. These parameters were recorded at an interval of 1 hour. Solar radiation was measured using solar irradiance meter. Two solar panels, each of 100 W_P were used for the study. Of the two, one panel was used without incorporating any air cooling arrangement to evaluate its electrical efficiency and to compare with the other panel with air cooling device. The air cooling arrangement consisted of four number of DC fans and an air duct system of aluminium tubes along with aluminium fins spaced in between the rows of the tubes. The power used for operating the fans was only from the same experimental panel. The cooling arrangement was fitted in the back side of the panel in order to extract the absorbed thermal energy from it and to maintain its temperatures nearing to its normal operating temperatures. The extracted thermal energy was ultimately allowed to enter into the greenhouse in which fresh rose flower was kept for drying. One fan was also fitted in the greenhouse to remove moisture from the materials kept for drying. Hence, in this study, the reduction in the temperatures of the panel, improvement in its electrical efficiency along with drying characteristics of rose flower have been studied. The performance of HPV/T solar greenhouse dryer was evaluated and compared with greenhouse system only and open sun drying method. Forced air was used in this study to extract the heat from the back surface of the solar panel. Open sun drying, in which the product is spread on the ground in open condition, is the simplest and cheapest method of drying. But there are considerable losses associated with it. So, an advanced method of drying i.e. hybrid photovoltaic thermal (HPV/T) greenhouse drying has been followed in this study for efficient drying and improving the quality of the dried product. The details of each of the component in the experimental set-up are shown below.



Schematic diagram of the experimental set up

Hybrid Photovoltaic/Thermal solar system

Fixing of aluminium air flow channel at back side of the PV panel



Fixing of aluminium fins

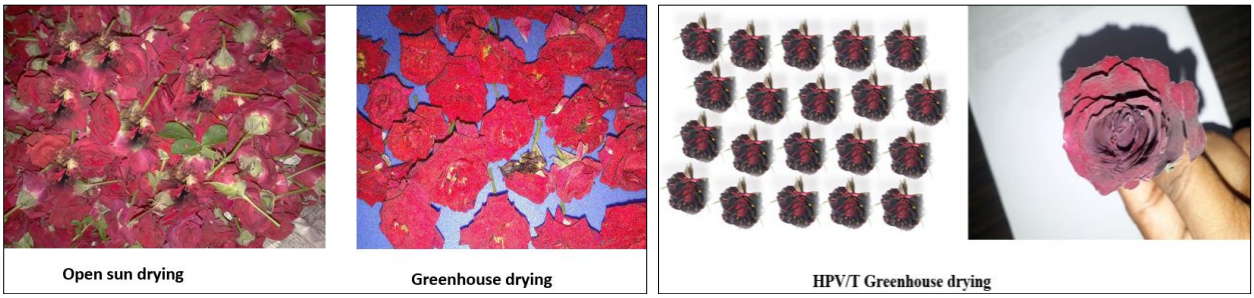


Fig 1: Components of experimental set up

Table 1: Two poly crystalline solar panels were used for the study with the following specifications

No of solar panel	2
Type of solar panel	Poly crystalline
Panel connection	series
Panel dimensions	100cm×166cm×4cm
Maximum power	100 Wp
Total power of panel	1×100 Wp = 100 Wp
Open circuit voltage	37.69V
Short circuit current	8.89A
Voltage at maximum power	30.33V
Current at maximum power	8.41A

The solar panels were installed at a height of 0.91 m from ground level and were oriented in the south direction. Two panel were installed at 10 m distance apart. Arrangement was made to vary the inclination of solar panel with respect to the horizontal plane. In order to measure different electrical parameters for the panel, a solar testing kit was used. It can wirelessly capture and record real-time solar irradiance, ambient air temperature and PV panel temperature. The drying behaviour of rose flower was recorded and compared with open sun drying, greenhouse drying and HPV/T greenhouse drying. The moisture content was calculated every day during the experiment.

Results and Discussion

The results of this study consists of three parts. In the first part, the tilt angle of the solar module was decided to fix for the study on the basis of the maximum availability of incident solar radiation on it in the experimental site from January to April (Figure-2). In the second part, all the electrical parameters such as short circuit current, maximum current, open circuit voltage, maximum voltage, fill factor of the used solar module were measured on hourly basis from 9 am to 4 pm along with the incident solar radiation on the surface of the module with the help of solar PV testing kit (Figures 3). In the third part, the drying behaviours of the rose flower were studied. The data for temperatures of panel were recorded by following air cooling method and compared these without any cooling arrangement (Figure 4). The efficiency of the solar module is calculated from the measured data and compared with those in case of without using any cooling method. Similarly, the drying behaviours of the rose flower were compared with the open sun, greenhouse and hybrid solar photovoltaic thermal drying (Figure 5 and Table-1). The method of sensory analysis was used to evaluate the quality of the dried flowers.

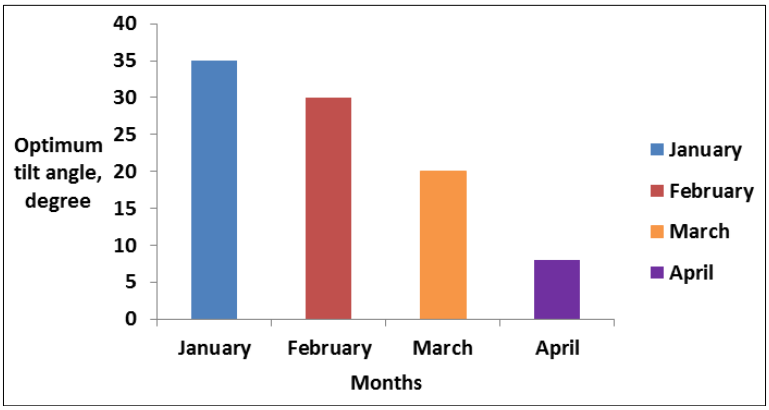


Fig 2: Fixation of Tilt Angle of Panel during January-April 2020

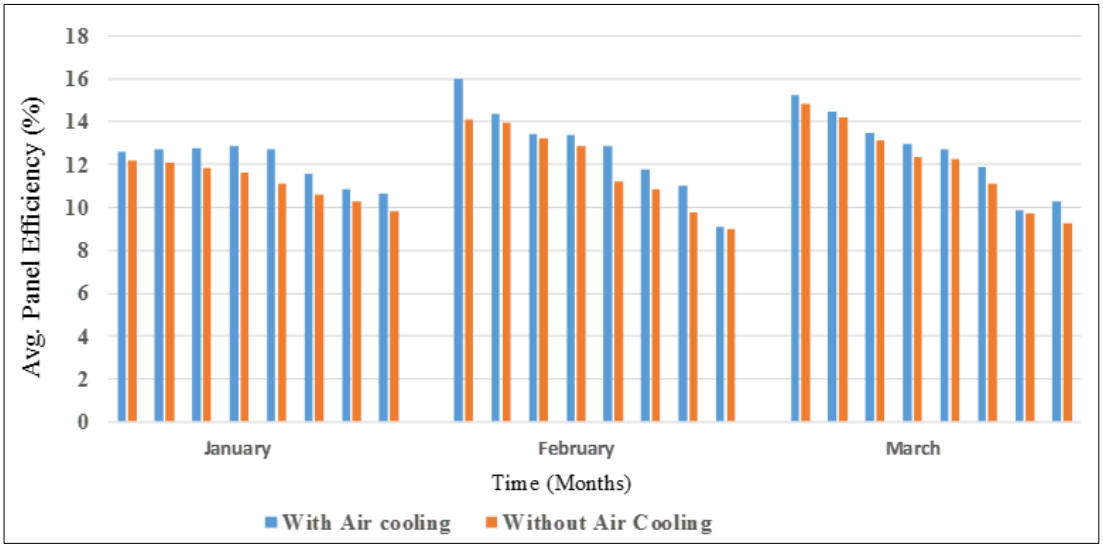


Fig 3: Average efficiency of solar panel in different months with and without air cooling

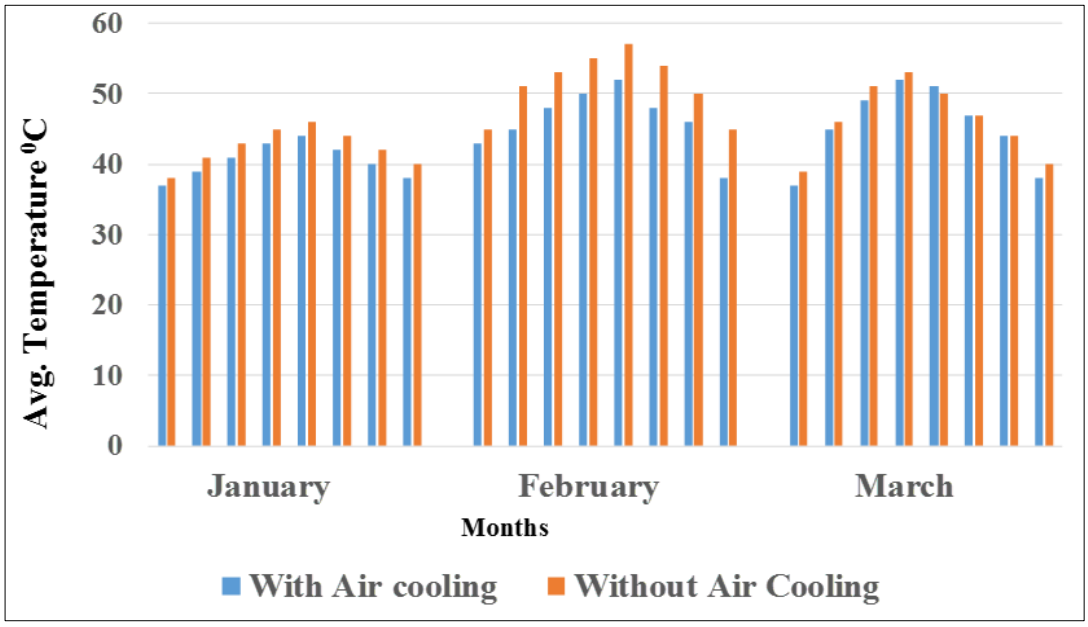


Fig 4: Average temperature of solar panel in different months with and without air cooling

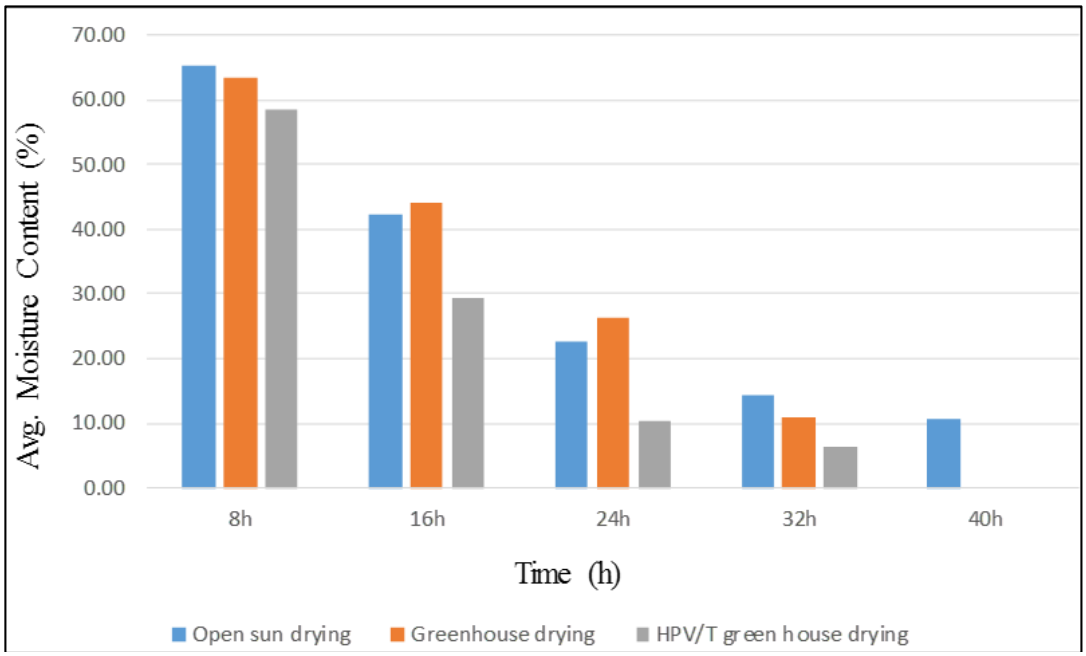


Fig 5: Variations of moisture content of rose flower for different drying systems

Table 2: Mean values of different parameter of Open sun, Greenhouse and HPV/T greenhouse dried sample for rose

Parameter	Open sun drying	Greenhouse drying	HPV/T Greenhouse drying
Total drying time (h)	41	32	24
Reduction in diameter (%)	18.85	16.86	7.45
Shape	1	1.98	2.80
Colour	1.2	1.88	3.84
Intactness	81.22	89.87	100
Brittleness	3.97	3.28	1.07
Texture	1.7	2	3.86

Sensory analysis is the method which employs human senses (sight, smell, touch, taste and hearing) for evaluation of quality of dried flowers. Different properties like shape, colour, texture, intactness and brittleness were evaluated by a panel of five members. Each treatment was evaluated by the panel after drying of the produces and the respective scores were recorded. The scale used for scoring was similar to that followed by Ugaale *et al.* 2016 [10]. (Colour: 1- Not acceptable, 2- less acceptable, 3- acceptable, 4- highly acceptable. Shape: 1- Distorted, 2- maintained, 3- very well maintained. Intactness: 100% - No damage, 90%, -80% partially damage, 80%-10% damage. Texture: 1- Not acceptable, 2 - less acceptable, 3 - acceptable, 4 - highly acceptable. Brittleness: 1 - Very low, 2 - low, 3- moderate, 4 - high). As the temperature inside the HPV/T greenhouse dryer is fairly constant throughout the drying process and shields the flower from direct solar radiation, the drying rate for the flower was found to be higher than that in open sun and greenhouse dryer. Thus the drying time was reduced by 65%, when the flower was dried using the HPV/T greenhouse dryer. As the solar radiation varies throughout the day, with solar intensity reaching maximum at noon, the quality parameters like shape, texture, brittleness and colour were adversely affected and high in open sun drying and moderate in greenhouse drying.

Conclusions

Solar energy now plays a leading role in reducing the reliance on fossil fuels. Research and development is going on, to develop more efficient solar energy devices to harness and utilize solar energy in a wider scale. More attention has also been given on enhancing the efficiency of solar photovoltaic panel. One controllable approach for increasing the efficiency of solar panel is to decrease the operating temperatures of the panel to a permissible level, mostly nearer to the temperature specified as per the standard test condition. This can be achieved by incorporating various cooling devices. The use of cooling devices reduces the operating temperatures of the panel by extracting the absorbed heat energy at its back surface. The extracted heat energy by the way, is utilized for low energy consuming applications such as greenhouse heating, water heating, crop drying and thermo-electric power generation etc. Such type of system is therefore called as a hybrid system due to the dual advantages of improving electrical efficiency of the panel and utilizing unused thermal energy in a productive and sustainable manner. The present study therefore focusses on the enhancement of the efficiency of solar panel by cooling its back surface with the flow of air through forced circulation due to DC powered fan and drying of high-value horticultural produce i.e. rose flower with the entry of extracted heat energy to the greenhouse integrated with the developed hybrid system. The following conclusions were made out of the study.

- Average solar radiation in a clear day was found to be highest at tilt angle of 35˚, 30˚, 20˚, and 8˚ in month of January, February, March and April respectively.
- The temperatures of solar panel were decreased in the range of 9-12 ˚C in forced air cooling compared to without cooling in a clear day.
- The efficiencies of solar module were increased in the range of 8-14% in air cooling compared to without cooling in a clear day.
- The reduction in moisture content of the rose flower compared to fresh flower was about 67-73% in HPV/T greenhouse drying, 54-61% in greenhouse drying alone and 32-41% in open sun drying in 3 days' duration of drying. The colour, appearance and texture of the flower were also maintained in HPV/T greenhouse drying for its marketability in International market

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