

Design, Construction and Experimental Evaluation of Hybrid Solar Clothes Drying System

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ABSTRACT This paper presents a design and performance analysis of a solar driven clothes drying system. The system comprises an evacuated tube solar array and an integrated photovoltaic panel used to power the drying fans, and a drying chamber for cloth hang. In addition to the electrical power that replenishes a 12V DC battery which powers the air blowing fans, the PV panel also provides further thermal energy which is used to preheat the air entering the system. Drying performance tests of the drying system were conducted under controlled conditions using simulated solar radiation for a range of clothes samples. The test results showed the ability of the system to perform under variable solar radiation conditions.

Key words: Solar drying, Cloth drying, Hybrid solar system

1. INTRODUCTION

Solar drying is one of the oldest methods of food preservation. For several thousand years people have been preserving most of their food items e.g., dates, figs, apricots, grapes, herbs, potatoes, corn, milk, meat, and fish by drying under the sun. Until food canning was developed at the end of the 18th century, drying was virtually the only method of food preservation [1]. Drying is still the

most widely used preservation method for both domestic and industrial scales. Generally dried crops, vegetables and fruit are lighter, require less space for storage, and do not need refrigeration, compared to their state before drying. Leon et al (2002) [2] classifies solar dryers into two categories: natural convection (passive) and forced convection (active) dryers. The natural convection system operates on the principle of temperature difference and consequently the difference in the

density of the air inside and outside the drying chamber. This temperature difference provides the driving force (buoyant force) for the air to flow through the drying bed. In the forced convection the air is circulated through the drying bed using air circulating fan. Passive solar drying systems do not require any mechanical or electrical power, unlike active dryers which requires both mechanical and electrical powers to run the fan.

Different types of solar dryers have been developed as an alternative to the direct sun drying, drying in a control environment help to produce dried product that doesn't lose its constituent tastes, vitamins and colour. There are several solar dryers include direct, indirect and mix-mode dryers [3]. In all cases, effective drying process requires a minimum temperature of about 30°C in the drying chamber, and relative humidity preferably below 60 percent [4] In a passive solar drying configuration, damp air escapes through the upper outlets and the fresh air enters through the lower inlets in the dryer. The moisture content of the dry specimen decreases more quickly than in open air [4].

While a great deal of research had been reported on agricultural products drying. A limited number of studies have been reported on cloth or textile drying. There is a global-wide need for low energy consumption equipment for clothes drying in high humid climate. The use of conventional simple cloth line of course is one of the cheapest drying methods but it is not free of problems including issue of colour change dust in arid zone and inconvenient in urban areas [5].

The hybrid stand alone solar clothes drying system is a better alternative to the conventional clothes line drying, it enables clothes drying effectively without fear of dust, sudden rain showers and protects the specimen from contact with UV-radiation and has a host of other economically and environmental benefits. In line with the need of environmentally sustainable solutions, this paper presents a hybrid stand alone solar clothes dryer; designed, constructed and evaluated for this application. Such a system is environmentally friendly as it reduces reliance on the national grid power, which has negative impact on the environment.

The use of a conventional domestic electrical dryer is a practical but very expensive solution for clothes drying, as it is inherently an energy intensive process. Hence, a search for a low cost solution for drying cloth for such cases is quite relevant and more so in the context of the global concern for energy conservation and protection of the environment [6]. A number of climatic factors have emanated on the utilisation and public acceptance of sustainable solar thermal systems including: morning dews, rain showers, dusty winds and unprecedented sudden weather change. These barriers limit the utilisations of the solar drying systems in the past. The good news is that past and on going research reduce these shortcomings with help of Phase change material storage (PCM), storage batteries and state-of-art efficient solar thermal evacuated tube collector, all optimised to maximise the system efficiency.

2. SYSTEM DESCRIPTION

A hybrid active solar drying system (see Figure 1) was designed, constructed and evaluated at the Institute of Sustainable Energy Technology, School of the Built Environment, University of Nottingham UK. The

system consists of an array of evacuated tubes, a PV module and the drying chamber.

The evacuated tubes solar (air) collector provides the thermal energy to the system. Conventional simple flat-plate solar collectors were suitable in sunny and warm climates. Their benefits however are greatly reduced when conditions become unfavourable during cold, cloudy and windy days. Furthermore, weathering influences such as condensation and moisture will cause early deterioration of internal materials resulting in reduced performance and system failure. In this system state of the art evacuated tube solar collectors were employed. Thermal energy is derived through capturing both direct and diffuse solar radiation by the evacuated tube solar collectors. Part of solar irradiance that passes through the insulated cellular transparent pane is also directly collected and used.

The integrated photovoltaic solar panel is installed at the top of the drying chamber. In addition to the electrical energy that provides power to the DC fans, it also replenishes DC battery power storage for system

operation beyond sunshine hours. The PV panel also provides further thermal energy which is used to preheat the air entering the condenser of the solar tubes. The panel connects with a 12V battery through a charge controller for storage of generated electrical energy for use during none sunshine. Apart from serving as a roof to the drying system, the panel also provides initial heating as inlet air passes underneath the panel removing its generated heat thereby relatively increasing its performance. The initial heat generated by the PV panel is vented by a fan installed at the top left end of the manifold in the upper compartment. The second fan blower is fixed at the at the right end of the rectangular manifold, which incorporates evacuated tube solar collector (ETC) heat pipes, condensers and conduction fins, blowing the heated air to the drying chamber compartment in a horizontal plane. The remaining 2 fans were also fixed in the centre of the drying chamber for equal distribution of the thermal heat towards the drying specimen in the drying chamber. The amalgamation of thermal heated air passes through the clothes and finally moist air gets out

through the system outlet situated at the bottom of the drying chamber.

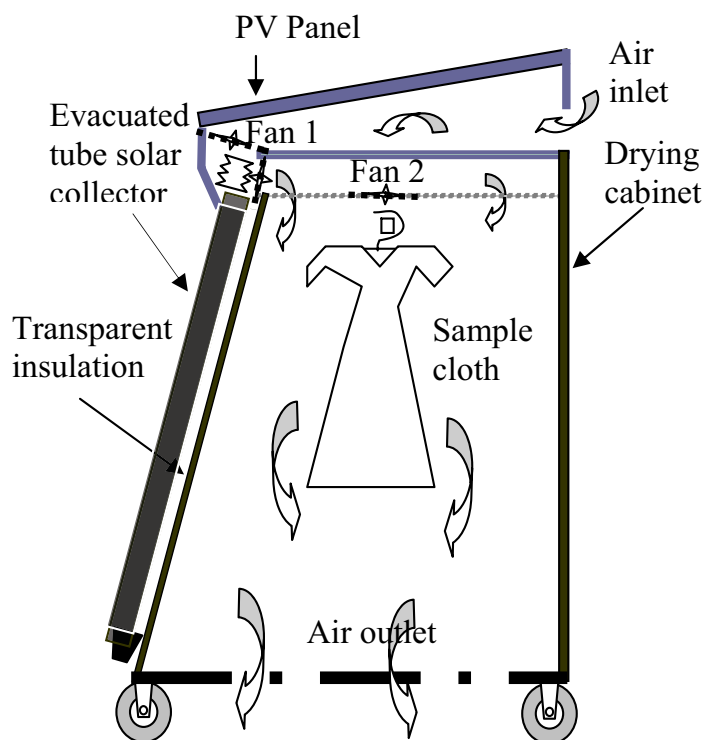


Figure 1: Schematic diagram of hybrid solar clothes dryer

The drying chamber cabinet was made of two compartments the upper compartment that comprises of i) PV panel, ii) storage battery iii) electric charge regulator and iv) blowing fans. While the lower part comprises of the drying chamber, ETC collectors, manifold and well insulated the cabinet walls fitted with two swinging opening doors for loading and unloading at the opposite side of the dryer (see Figure 1).

A Cellular transparent panel made of polythene insulation panel was fixed behind the evacuated tube solar collector, to allow the diffused light between the tubes to reach the drying chamber. This provides some day lighting into the chamber and hence improves the drying process.

3 INSTRUMENTATIONS AND MEASUREMENTS

In order to evaluate the performance of the developed hybrid solar dryer, measurement of temperatures ($^{\circ}\text{C}$), relative-humidity (%), moisture content (%), cloth specimen weight (Kg), air velocity (m/s) and global solar radiation (W/m^2) were recorded during indoor controlled performance evaluation tests. Dry bulb temperatures were measured with T-type thermocouples. Solid state hygrometers were used to measure relative-humidity at different locations of the solar dryer. Air velocities were also measured using a hot wire anemometer. The solar radiation on the plane of the array was measured using a pyranometer.

Table 1: Effect of varying solar radiation from $1000\text{W}/\text{m}^2$ to $200\text{W}/\text{m}^2$

The instantaneous values of the above measuring sensors were averaged and recorded at 30 seconds intervals by a multi channel DE 500 Data-taker Data logger which was connected to a desktop computer. An electric weighing balance with an accuracy of ($\pm 0.02 \text{ Kg}$) was employed for the measurements of wet-weight and dry-weight of the clothes specimen. A variable power supply was also used for fan speed selections.

4 EXPERIMENTAL RESULTS

The indoor performance test results (Table 1.) of the hybrid stand-alone solar dryer, show difference in temperature (ΔT) between the air inlet / ambient (T_{in}) situated at the top of the system and air outlet (T_{o}). temperature difference between the drying chamber and the ambient air of 22°C , 18°C , 17°C , 12°C , and 7°C over a period of 3.5 hours insolation has been obtained at solar radiation of $1000 \text{ W}/\text{m}^2$, $800 \text{ W}/\text{m}^2$, $600 \text{ W}/\text{m}^2$, $400 \text{ W}/\text{m}^2$ and $200 \text{ W}/\text{m}^2$ respectively. Four samples of laboratory clothes specimens were dried. The weights of the samples have decreased from 4.64 kg to 2.58 kg in a 3.5 hrs at a $1000 \text{ W}/\text{m}^2$ solar radiation.

Radiation W/m ²	RH _o %	Chamber ΔT (°C)	Moisture removed (kg)
1000	15	21	2.06
800	18	18	2.04
600	23	17	1.78
400	27	11	1.48
200	30	7	1.42

The most important parameter that dictates the system performance is the chamber temperatures (T_o) which reflect the delivered energy in to the drying system and the temperature difference. The clothe specimens were dried under various solar radiation levels. Figure 2: shows a maximum chamber temperature attained during these tests was 43°C, under an insolation of 1000W/m² with a temperature difference of 21°C. the PV thermal contribution under this radiation level was 5°C.

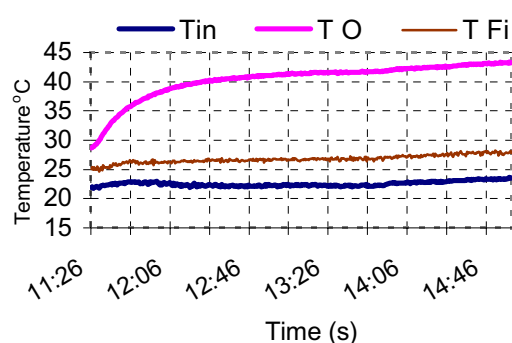


Figure 2: Chamber temperature

From the recorded chamber temperatures under varying solar insolation level from 200W/m² -

1000W/m² the minimum chamber temperature of 30°C was attained from 1000W/m² up to 400 W/m².

5 CONCLUSIONS

A stand alone hybrid PV integrated solar clothes drying system was designed, constructed and evaluated under indoor conditions. A maximum temperature difference of 11°C was attained in the drying chamber under a simulated insolation of 400W/m². Intermittent rain showers and cloud cover interruptions for the outdoor test were not favourable for comparative evaluation testing; therefore indoor steady state condition tests using simulated solar radiation was used. The solar radiation was varied from 200W/m² to 1000W/m². The results show that the developed hybrid solar dryer could effectively carryout drying under insolation level as low as 400W/m². The tests also showed that the system has reduced the phenomenon of case hardening of direct solar where the item looks dry outwards but it trapped some moisture in the clothes. The numerous advantages of the system include; the specimens are not exposed to direct UV-radiation. Though tested on cloth drying, the developed solar dryer

mechanism could be used for other domestic and industrial applications.

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